Palestine Polytechnic University

College of Engineering and Technology

Electrical and Computer Engineering Department

Introduction Project

Design and Implementation of a Single Channel Transcutaneous Electrical Nerve Stimulator

Project Team

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Abstract

Transcutaneous Electrical Nerve Stimulation is a treatment procedure that uses Electric pulses to alleviate pain. Two pads are hooked up to the TENS machine and are placed on the skin in strategic paths to intersect the nerves that are causing the pain. As the Electric currents enter the body they cause the muscles to contract . This process will help to alleviate the injury. The frequency and intensity of the low voltage electric wavelengths that enter the body can vary depending on the severity of the injury and the pain of the patient. The electric pulses that are sent through the pads do not cause excessive pain because the machine can block the pain signals or cause the body to produce natural pain killers. This treatment is mostly used for pain that occurs in the nerves, but is also commonly used to relieve muscle, bone, and joint problems as well.

ملخص المشروع

وهو عبارة عن استعمال تيار كهربائي منخفض التوتر من أجل تسكين الألم، ويوجد عدد من أشكال و تواترات التيارات الكهربائية المستعملة في أجهزة العلاج الفيزيائي من أجل التسكين، إلا أن الشكل الذي ثبتت فاعليته و فائدته بشكل واضح من خلال الدراسات المجراة عليه حتى الآن دون أن يكون له تأثيرات جانبية هامة هو التنبيه الكهربائي العصبي عبر الجلد و له عدد من الأشكال ذلك حسب التواتر و عرض وسعة الموجة و هذا يختلف من جهاز إلى آخر، إلا أنه بشكل عام يقسم إلى شكلين أساسيين عالي التردد ويعتقد بأنه يحدث تأثيرا مسكناً سريعا" و آنيا بتأثيره على مبدأ Gate Control Theory في تمرير السيالات العصبية إلى الدماغ، وشكل منخفض التردد يعطي تأثيرا مسكناً متأخر و يدوم لفترة أطول يستعمل TENS عادة في العديد من الحالات فهو منصوح به في الألم الناجم عن الإصابات العصبية و كل أشكال الألم الناجم عن الجهاز العضلي الهيكلي و تقريباً يمكن استخدامه في كل الحالات المؤلمة بغض النظر عن العامل المسبب.لعلاج الام أسفل الظهر.لعلاج آلام الرقبة.مدة الاستخدام 15 - 10 د. مع العلم بأنه أصبح متوفراً أجهزة TENS للاستعمال الشخصي يمكن للمريض أن يمتلكها لكي يستخدمها عند حدوث ألم أو بشكل منتظم يومياً في المنزل و ذلك في الحالات المزمنة المعندة على العلاج.

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Chapter One

Introduction

1.1 Overview

Transcutaneous electrical nerve stimulation (TENS) is a therapeutic modality that used to reduce pain perception by physiotherapists. Since the early 1970s, TENS has come into wide use as a non-invasive alternative for managing both acute and chronic pain. Electric current use to control and treat pain has existed for many years, but a new Era of electrical nerve stimulation began in the mid 1960s when the "gate control theory" of pain control was developed (Melzack & Wall, 1965; Kahn, 1994) . According to this theory, selective stimulation of certain nerve fibres could block (or close the gate on) signals carrying the pain impulse to the brain.

TENS units usually have a single channel (with two electrodes) or dual channels (With four electrodes).An electronic stimulus generator transmits pulses to the electrodes which are placed directly on the skin. The pulse forms can be exclusively Positive or Negative and are of various shapes. The number of impulses transmitted to the skin can be controlled generally in TENS therapy, frequencies in the 80 to 120 cycles per second range are Considered "high" and usually applied for acute pain. Frequencies of 1 to 20 cycles per second are considered "low" and used in treating chronic pain. Pulse width or duration, measured in microseconds, is the time the current acts on the patient during each pulse, and is usually between 50 and 400 microseconds. The final variable is intensity or amplitude of the current; TENS units range from 1 to 100 mA. And we can change the the pulse width from 40-200µs,pulse rate from 2-200Hz.

1.2 Objective:

The project objectives are:

- To design and implement a transcutaneous electrical nerve stimulator. That can be used in clinical and hospital physiotherapy units and by individual people.

1.3 Literature Review

Graduation projects could be used as previous studies for this project "Design & Implementing of a Single channel Transcutaneous Electrical Nerve Stimulation" (Transcutaneous Electrical Nerve Stimulation Device And Method For Using Same) By Ronald E.Kendall.

Also I used the theoretical background from Design and Implementation of a Functional Electrical Stimulator.

1.4 Scheduling Task

The time management will divide the system hierarchy according to the actions as follows:

T1: *Preparing of the project*: this stage of the project primarily aims at identifying the contents of it, discussing the initial information, and evaluating the project tasks and levels.

T2: *The project analysis*: the analysis process includes extensive study for all possible design options of the project.

T3: *The project requirements analysis*: tasks have to be implemented, equipments will be needed to be provided, and data should be processed.

T4: *Conceptual Design:* project objectives, design block diagram will be done with representing how the system works.

T5: *Studying project component and schematic analysis*: it is necessary to study the datasheet of the chipsets to ensure that it will meet the requirements of the project.

T6: *Writing the documentation*: the writing began from the first phase to the last one in parallel.

Table (1.1): The Task Duration

Task	Duration(weeks)	Dependencies
T1	3	-----
T2	3	-----
T3	4	T1,T2
T4	5	T3
T5	2	T3
T6	15	T4, T5

Table (1.2): Time work plan

Task / Week (1st semester)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Preparing to the project	▨	▨	▨													
Project analysis				▨	▨	▨										
Project requirement analysis						▨	▨	▨	▨							
Conceptual design										▨	▨	▨	▨	▨		
Studding project component and schematic analysis														▨	▨	
Writing documentation	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
Task / Week (2nd semester)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Buying components	▨	▨	▨	▨	▨	▨										
Implementation					▨	▨	▨	▨	▨							
testing					▨	▨	▨	▨	▨	▨						
Writing documentation					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		

1.5 Project Cost

This section lists the overall cost of the components that is considered in implementing the system. According to the Hardware Components, there are many electrical Chips and equipments shown in the table below:

Table (1.3): Hardware Costs

Component	Cost ($)
MC34063	50.00
Step-up transformer	70.00
IR2155	50.00

Resistors and Capacitors	25.00
switch	5.00
LM334z	20.00
Diode's	15.00
Electronic board	5.00
Total Sum	**240 $**

1.6 Project Risk Management

There is no risk in this project because we applied an a acceptable value about 30 voltage on the skin and the current isn't high.

1.6.1 Hardware Risks:

The most important hardware parts in the project are the IR2155 oscillator and step up transformer. The predicted risks are:

- The IR2155 timer does not generate pulses.
- One of the transistors or MOSFET may be damaged.

1.6.2 Group Risks:

- Sickness.

1.6.3 Project Risks:

- Inaccurate schedule.
- Insufficient budget.
- Delay of devices arrival.

1.6.4 Risk Avoidance Methodology:

- Demand device at earlier time.
- Start working on the implementation earlier.
- Use alternative devices with the same functionality and less cost.

1.7 Human Development Resources

The team is composed entirely of one Biomedical Engineering undergraduate student who is interested in physiotherapy field.

The project Team: Andria Bannourah.

Supervisor : Dr. Abdallah Arman.

1.8 Report Road-Map:

The documentation of this project is divided into five chapters. The following explains briefly the contents of each chapter:

Chapter 1: Introduction

This chapter presents overview, literature review, project scheduling, estimated costs, project risks and human development resources.

Chapter 2: Theoretical Background

This chapter discusses the Nervous systems anatomy, theory of the project (main idea), hardware related to the project components.

Chapter 3: Project Conceptual Design

This chapter explains the project objectives, project design block diagram, how the system works and contraindications

Chapter 4: Detailed Technical Project Design

This chapter includes project phases, subsystem detailed design. And the testing of the design which has been done in this semester.

Chapter 5: System Implementation and Test

This chapter includes testing of the design which has been done .

Chapter 6: Conclusion and Future Work

This chapter includes results of the intended design which has been achieved .And future work and development on the project.

2

Theoretical Background

Chapter Two

Theoretical Background

2.1 The Nervous System Physiological Anatomy:

In this section, the physiological structure of the nervous system will be discussed, mentioning the categories of neurons, nerve impulse propagation, the resting membrane potential and the action potential of nerves will be explained.

2.1.1 The Nervous System Structure:

The nervous system is a network of specialized cells that communicate information about human's surroundings and themselves. It processes this information and causes reactions in other parts of the body.

The nervous system is divided broadly into two categories; the Peripheral Nervous System (PNS) and the Central Nervous System (CNS). Neurons generate and conduct impulses between the two systems.

PNS is composed of sensory neurons and the neurons that connect them to CNS which composed from the spinal cord and brain. In response to stimuli, sensory neurons generate and propagate signals to the CNS which then processes and conducts signals back to the muscles and glands through the motor neurons as shown in fig (2.1).

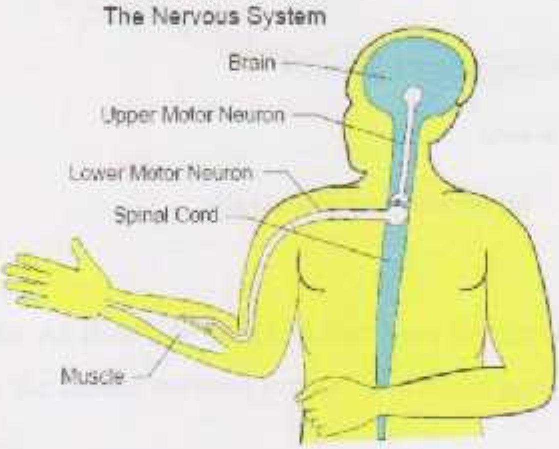


Fig (2.1): The Nervous System [a]

The neurons of the nervous systems of humans are interconnected in complex arrangements and use electrochemical signals and neurotransmitters to transmit impulses from one neuron to the next.

2.1.2 Neurons Categories:

There are three types of neurons in the body:

1. ***Sensory neurons:*** As shown in fig (2.2) have long axons and transmit nerve impulses from sensory receptors overall the body to the central nervous system.

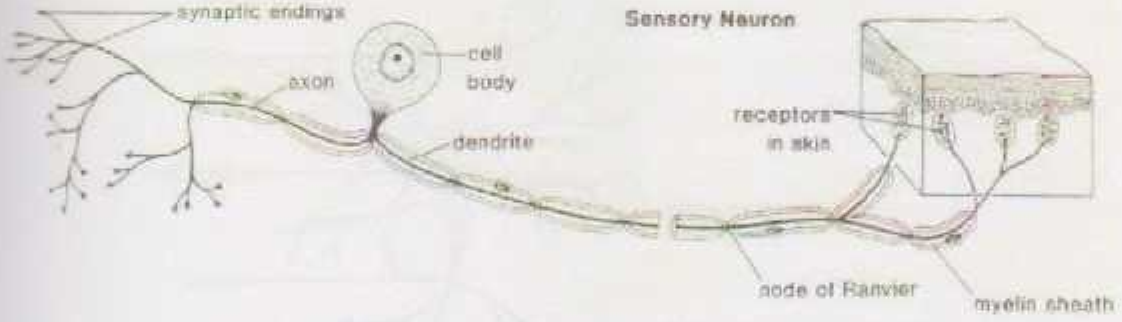


Fig (2.2): Sensory neuron [b]

2. ***Motor neurons***: As shown in fig (2.3) also have long axons and transmit nerve impulses from the central nervous system to affected parts (muscles and glands) overall the body.

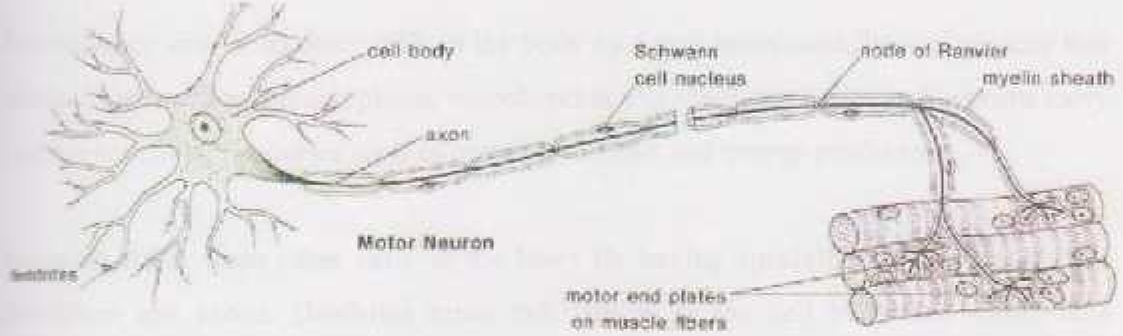


Fig (2.3): Motor neurons.[c]

3. ***Inter-neurons***: (also called connector neurons or relay neurons) are usually much smaller cells, with many interconnections as shown in fig (2.4).

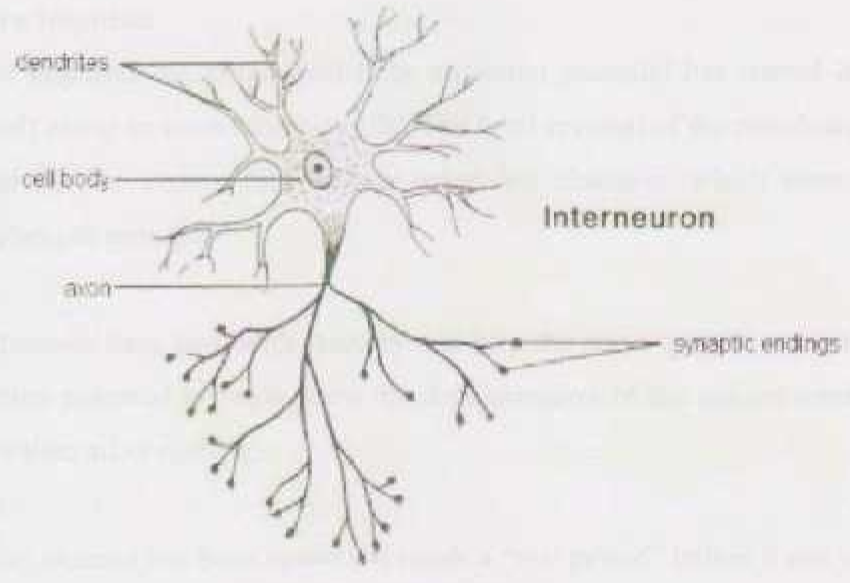


Fig (2.4): Inter-neuron [d]

Neurons are similar to other cells in the body by a cell membrane, have a nucleus that contains genes, contain cytoplasm, mitochondria and other organelles and neurons carry out basic cellular processes such as protein synthesis and energy production.

Neurons differ from other cells in the body by having specialized extensions called dendrites and axons. Dendrites bring information to the cell body and axons take information away from the cell body, neurons communicate with each other through an electrochemical process, neurons contain some specialized structures (for example, synapses) and chemicals (for example, neurotransmitters).

2.1.3 Nerve Impulse:

Nerve impulses are propagated once an action potential has started it is moved (propagated) along an axon automatically. The local reversal of the membrane potential is detected by the surrounding voltage-gated ion channels, which open when the potential changes enough.

The ion channels have two other features that help the nerve impulse work effectively. For an action potential to begin, then the depolarization of the neuron must reach the threshold value; all or nothing.

After an ion channel has been opened, it needs a "rest period" before it can open again. This is called the refractory period, and lasts for about two ms; this means that, although the action potential affects all other ion channels nearby, the upstream ion channels cannot open again since they are in their refractory period, so only the downstream channels open, causing the action potential to move one-way along the axon as shown in fig (2.5).

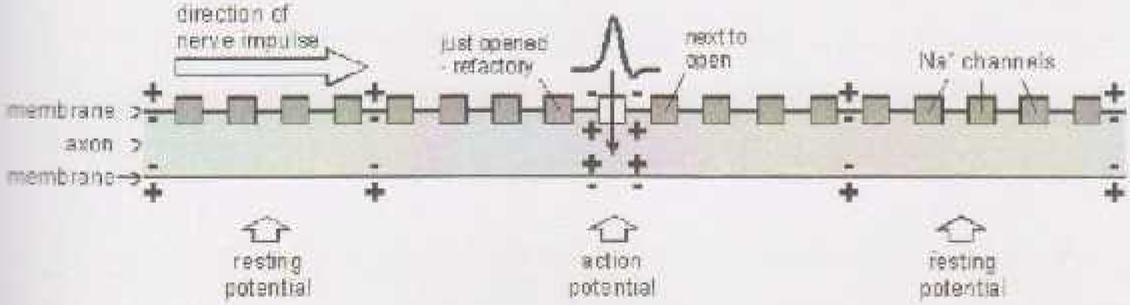


Fig (2.5): Direction of nerve impulse[e]

The refractory period is necessary as it allows the proteins of voltage sensitive ion channels to restore to their original polarity.

The absolute refractory period means that during the action potential, a second stimulus will not cause a new action potential.

There is an interval in which a second action potential can be produced but only if the stimulus is considerably greater than the threshold, which means that the relative refractory period can limit the number of action potentials in a given time; with an average of about 100 action potentials per second.

2.1.4 The Resting Membrane Potential:

When a neuron is not sending a signal, it is at 'rest', the membrane is responsible for the different events that occur in a neuron. The membrane contains a protein pump called the sodium-potassium pump (Na + K + ATP) as shown in fig (2.6). This uses the energy from ATP splitting to simultaneously pump three sodium ions out of the cell and two potassium ions in.

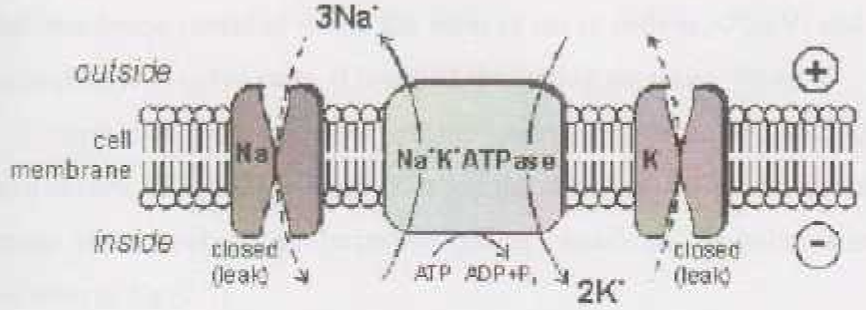


Fig (2.6): The Resting Membrane Potential

The combination of the Na +K + ATP pump and the leak channels cause a stable imbalance of Na+ and K+ ions across the membrane. This imbalance of ions causes a potential difference (or voltage) between the inside of the neuron and its surroundings, called the resting membrane potential. The membrane potential is always negative inside the cell which equals -70mV. The Na +K + ATP is thought to have evolved as an Osmo-regulator to keep the internal water potential high and so stop water entering human cells and bursting them.

2.1.5 The Action Potential:

The resting potential tells us about what happens when a neuron is at rest. An action potential occurs when a neuron sends information down an axon. When the nerve and muscle cells resting membrane potential changes this causes an explosion of electrical activity.

In nerve and muscle cells the membranes are electrically excitable, this means they can change their membrane potential, and this is the basis of the nerve impulse. The sodium and potassium channels in these cells are voltage-gated, which means that they can open and close depending on the voltage across the membrane.

The normal membrane potential inside the axon of nerve cells is –70mV, and since this potential can change in nerve cells, it is called the resting potential. When a stimulus is applied a brief reversal of the membrane potential, lasting about a millisecond, occurs. This brief reversal is called the action potential. An action potential has two main phases called depolarization (rising phase) and re-polarization (falling phase) as shown in fig (2.7).

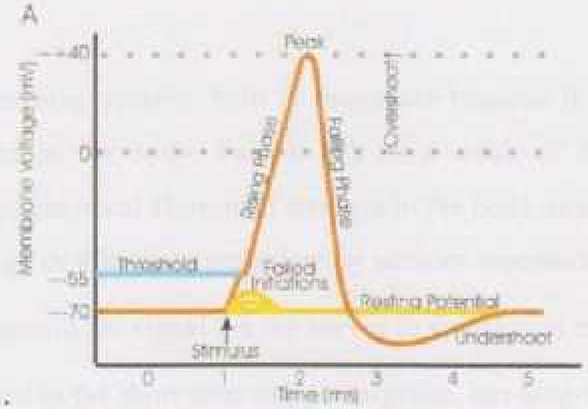


Fig (2.7): phases of Action Potential[g]

2.1.5.1 Depolarization:

When stimulated past threshold (about –30mV in humans), sodium channels open and sodium rush into the axon causing a region of positive charge within the axon.

2.1.5.2 Re-polarization:

The region of positive charge causes nearby voltage gated sodium channels to close. Just after the sodium channels close, the potassium channels open wide, and potassium exits the axon, so the charge across the membrane is brought back to its resting potential.

2.2 Project Theory

When an electrical current is applied to a painful area, transmission of the Perception of pain (via small diameter fibers) to the brain in inhibited by the activity of the large diameter. fast-conducting highly myelinated , proprioceptive sensory nerve fibers closing the gate to the pain perception to the brain.

2.2.1 Pain:

Pain is body's warning system. Pain is important because it signals an unusual condition happened in the body. Pain is felt as a result of the brain's response to electrical neural and chemical Hormonal changes in the body as a result of damage.

Signals from damage or injury are picked up by sensory receptors in nerve endings.

The nerves then transmit the signal via the nerves to spinal cord and brain.

Pain can be managed in the short term using analgesics. but long-term use can be detrimental to the patient's health.

Side effects of the long use of analgesics may affect on liver, kidney or stomach.

In many cases where pain is constant, a medical practitioner or physiotherapist may recommend the use of a TENS unit.

2.2.2 Main Idea:

Rubbing and massage are often used to relieve pain. Transcutaneous Nerve Stimulation or TENS involves passing a mild electrical current across skin between two electrodes, and has been described as "electrically rubbing the pain better".

This is called the gate control theory of pain. Pain messages travel through the nervous system to the spinal cord and then to the brain.

Not all messages get through to the brain. Basically, the gate control theory says that a gate exists in the spinal cord which can open to allow pain to flow through to the Brain or close to block it off. In addition to this, the nerve fibres which transmit messages to the brain are not all the same. There are thick ones (A beta fiber's) which carry sensation or touch messages and respond quickly to stimulation, and thin ones A delta and C fibers which carry pain signals. The gate can be closed, blocking off Pain, by stimulating the thick beta fibers. This is why rubbing it better works, the Rubbing sensation blocks off the pain. This is also how TENS works. Electrical impulses travel along nerve path way preventing pain impulse 's from getting through the gate so essentially the TENS machine is overriding the pain sensations

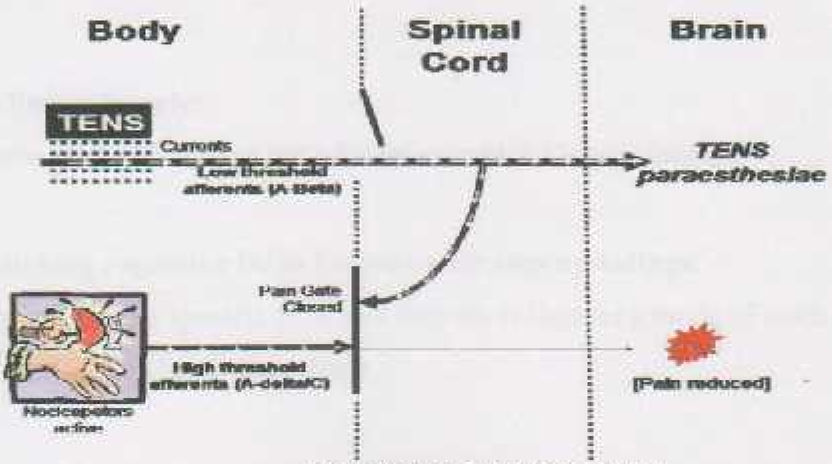


Fig (2.8): the project theory. [h]

Centre for Pain Research, Faculty of Health, Leeds Metropolitan University, UK, Leeds Pallium Research Group

2.3 Project Components:

Here in this section, provided the theoretical background of each component of project.

The design consists of the following components:

- Power supply and here it's a 9 Volt TNT battery.
- Switching regulator and here it is used to Step up the voltage and here i will use IC called Dc to Dc converter MC34063.
- Current limited circuit.
- Inductor.
- Switching oscillator (Self oscillating half bridge driver).
- Lead and Electrode.

2.3.1 The Power Supply:

It's a Dc power supply and we put a batteries with 9 Dc volt for that.

2.3.2 Switching regulator Dc to Dc converter step up voltage:

We can use here a specific IC with a step up voltage as a mode of work and this can give us a specific step up in the voltage .

2.3.3 Current limiting circuit:

Here we use this circuit because the oscillator we use need Vcc as a power supply for it to work and by this circuit we can limit the value from the circuit before to get this value which it's about 16 volt.

2.3.4 Switching oscillator:

Here, in this circuit we deliver the steped up voltage output from the MC34063 to the MOSFET then to the lead .This circuit give's oscillaction to the value of the voltage At frequency 2-200Hz and pulse width from 40-200 μs

2.3.5 Leads and Electrodes:

Electrodes are connected to a stimulator by insulated wires called leads. The stimulator sends electrical pulses through the leads and to the electrodes where the electrical charge is delivered to the nerve.

Two types of electrodes are used; Implemented electrodes are located inside the body and avoid the need for daily application. They provide selective stimulation of particular muscles with lower current levels. But, a drawback is the need for surgery to place the electrodes or replace them if necessary, Surface electrodes have some drawbacks. Because they are separated by skin and fat from the underlying muscles and nerves, surface electrodes can't make individual muscles active.

3

Project Conceptual Design

Chapter Three
Project Conceptual Design

In this chapter, the main objectives of the project, the general block diagram and how the overall system works are to be explained.

3.1 Project Objectives:

The project contains and implements many ideas and objectives that can be summarized in the following points:

1. To design and implement a transcutaneous electrical Nerve Stimulator.
2. To simulate the same idea of a treanscutaneous electrical nerve stimulator device.
3. To be applicable for applications in studying as a model.
4. Can be used in clinical and hospital physiotherapy units and by individual person's.
5. To design a device that can relief pain.

3.2 General Block Diagram :

The following figure shows the block diagram of the project.

Fig (3.1): General block diagram

It is clear here that each individual block has its own function, and by summing those functions, and integrating with each other; the transcutanues electrical nerve stimulator system will be accomplished.

3.2.1 DC Power Supply(Battery):

We use here a battery with 9 volt with about 5mA current as a power supply for the system , in this stage we don't need anything else ,just be sure that the system can get a Dc power supply to drive the circuit to drive the system .

3.2.2 Switching regulator :

This stage mainly consists of DC to DC converter IC, in this stage we need to step up the voltage driven from the battery to 30 volt, MC34063 which it's a step up DC-DC converter can step up the voltage from this battery to this desired value, this IC can give voltage bigger than the input voltage.

3.2.3 Switching oscillator:

In this block it convert the dc output from the first step to asymmetrical monophasic pulse signal using the switched oscillator, and here also this stage we set the frequency and pulse width of the signal .We used also two power MOSFET to driven the electrode from the SELF OSCILLATING HALF –BRIDGE DRIVER IR2155 .
IR2155 is a high voltage, high speed, self –oscillating power MOSFET driver with both high and low side referenced output channel. It is similar to the 555 timer.

3.2.4 Current limiting circuit:

We use this IC which it is LM334z because the IC2 IR2155 need a constant value of current to power on . So we can use this IC to limit the current to supply IR2155 with a constant value of voltage which it is about 16 volt to switch on .Also the IR2155 have internal regulation to work on a value of 15.6 volt .
30 volt apply on the Drain of the MOSFET.

3.2.5 Leads and Electrodes:

There are two main types of electrodes, implemented and surface electrodes. In this project, the second type was used.

The electrodes are usually supplied with an adhesive back that allows them to be easily attached to the skin. If the adhesive dries out, a smear of personal lubricant will be helpful.

The electrodes can then be attached to the skin using any of the variety of tapes or bandages used to secure wound dressings. Attach the electrodes in position on either side of the pain source or possibly on the back for pains in the leg / foot – to confuse the nerves.

3.3 How the System Works:

The volt supply from the battery is stepped up in the first stage by MC34063. This providing dc output can be adjustable from 12 - 30 volt using potentiometer.

The resulting dc voltage is converted to a pulsed signal using the switchmode oscillator. There is also two potentiometer set the frequency and the pulse width on pin 2and 3of the IC IR2155.

Then the two MOSFET drive the signal to the electrode's which it's applied on the body.

3.4 Mode of work:

There is just one mode for this system in this project and it is continuous mode. We can add another mode which it's intermittent mode by adding timer 555 to the circuit .

3.5 Risks:

Risks of electrical stimulation may be summarized as circumstances in which:

4

Detailed Technical Project Design

4.1 Detailed Description of the Project Phases

4.2 Overall System Design

4.3 Total Practical Circuit to be implemented

Chapter Four

Detailed Technical Project Design

The necessity of this chapter takes a place in order to explain the detailed design for each unit in this project. Also to clarify the main characteristics that will make this project to operate as planned, after viewing the theoretical background, and the general block diagram that explain how the system works in the previous chapters.

4.1 Detailed Description of the Project Phases

The project is divided mainly into the following phases:

- Step up the voltage from the battery up to 30 volt use the switching regulator IC MC34063 which we use it here to step up the voltage.

- Current limiting because we need to limit the voltage to get the desired supply voltage for the oscillator. And because we need constant current to power the oscillator and LM334z gives constant current source.

- Switching the MOSFET by the oscillator and set the frequency and the width for the output pulse.

4.2 Overall System Design

Here the project aim is to particularize the characteristics, and specifications for each circuit, also to view the schematics, and features of those subsystems.

4.2.1 Battery

Power from the 9 volt is switched to the circuit via S1 and the 0.1nf capacitor decouples the supply. And here we can connect a led after the power switch, and the led can light when we switch on the power of the device. Current for this power supply is 5mA.

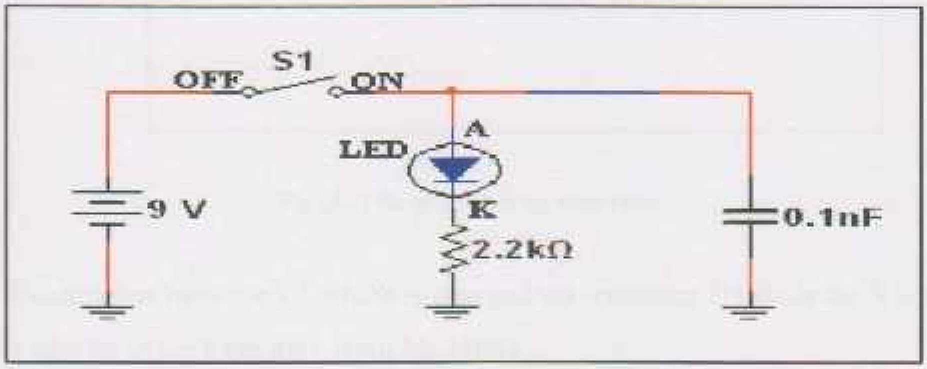


Fig (4.1) Battery

4.2.2 Switching regulator system

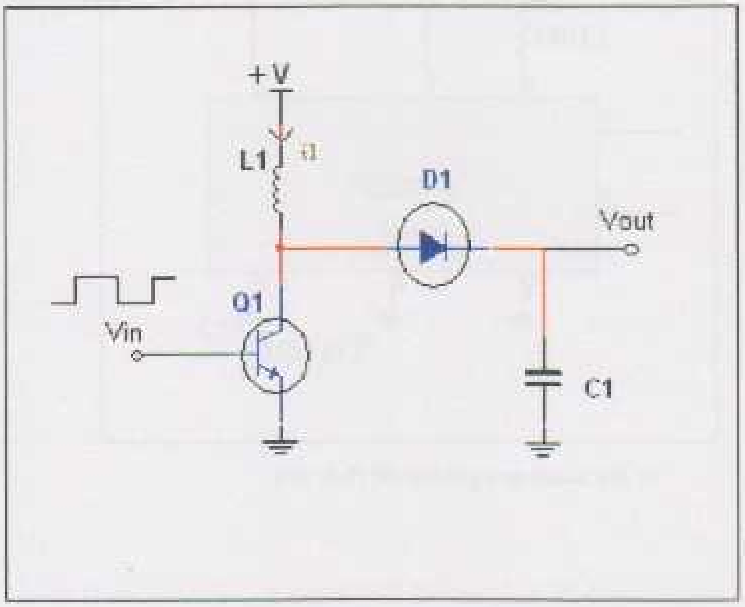


Fig (4.2) Basic of step up converter

It comprises inductor L1 which is charged via transistor Q1 from the V+ supplies which it take its value from pin1 from Mc34063.

Vin it's comparator inverting input and it's pin5 in the Mc34063.and it's work here to make transistor on or off.

The charging current is shown as i1. When the transistor is switched off the stored energy in L1 is dumped through diode D1 into capacitor C1.

The actual voltage across C1 is dependent upon the amount of charge in L1 and the load current between Vout and the ground supply. We can maintain a constant voltage for a variety of loads by controlling the amount of time Q1 is switched on.

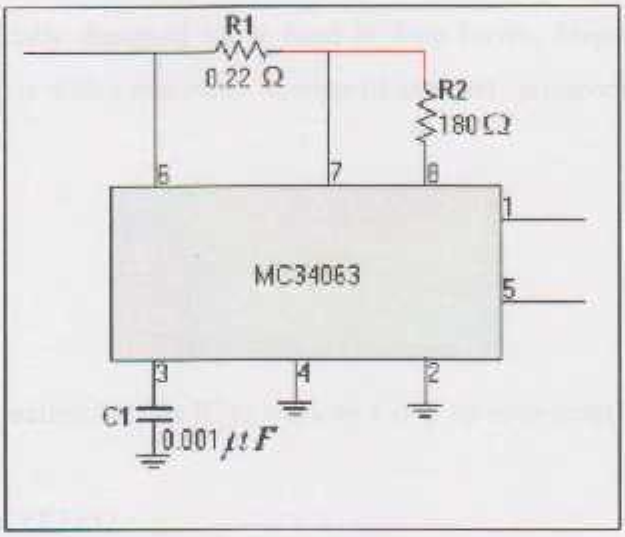


Fig (4.3) Switching regulator (IC1)

MC34063 is the switchmode controller. It has a switching transistor at pin 1 and a feedback input at pin 5.

The frequency of oscillation rate is set by the 1nf capacitor at pin 3 and the current flow through it is limited by the 0.22 Ω resistor pins6 and 7. 0.22 Ω called R sense and its between pin6,7. Typical value from data sheet to step up the voltage .

Ipeak=330mV/R sense .

The voltage induced in the inductor and charges two 0.47 µf capacitors via diode D1. Voltage feedback from VR1 and the 150kΩ resistor into pin 5 and VR2 set the output voltage. VR2 is adjusted to give 12-30 Volt when VR1 is at its maximum resistance.

The IC MC34063 is a monolithic switching regulator control circuit containing the primary functions required for DC-DC converters. This device consists of internal temperature compensated reference, voltage comparator, controlled duty cycle oscillator with active current limit circuit, driver and high current output switch. This device was specifically designed to be used in Step-Down, Step-Up and Voltage-Inverting applications with a minimum number of external components

R1=0.22Ω
C1=0.001μf
R2=180 Ω

This is a basic connection for this IC to work as a step up converter(Data Sheet)

Vout =1.25(VR2)\(VR1+1)

Maximum output from this circuit to the MOSFET is 30 Volt so the value of VR2 will be 50k Ω and here we choice wild potentiometer range to not vary the value of voltage for big value's. And VR1 1M Ω.

4.2.3 Switching oscillator system

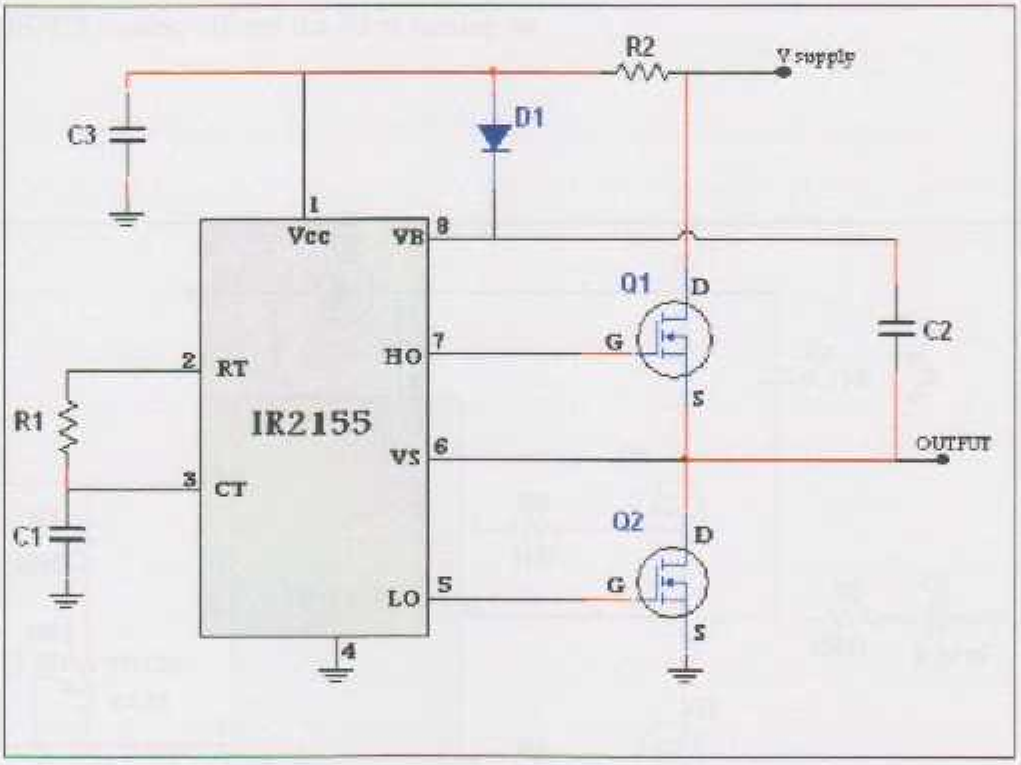


Fig (4.5) Switching Oscillator Basic connection (IC2)

Circuit configuration of the switching oscillator which modulates the output voltage of the step-up converter. Heart of the circuit is IR2155. It is described as (high side self-oscillating power MOSFET/IGBT gate driver)

It's the ideal device where MOSFET need to be driven in a variety of configurations. R1 and C1 at pin 2 and 3 set the oscillator frequency and the result is that the MOSFET Q1 and Q2 are turned on and off alternately , with a typical dead time of 1.2 µs between one MOSFET turning off and the other turning on .

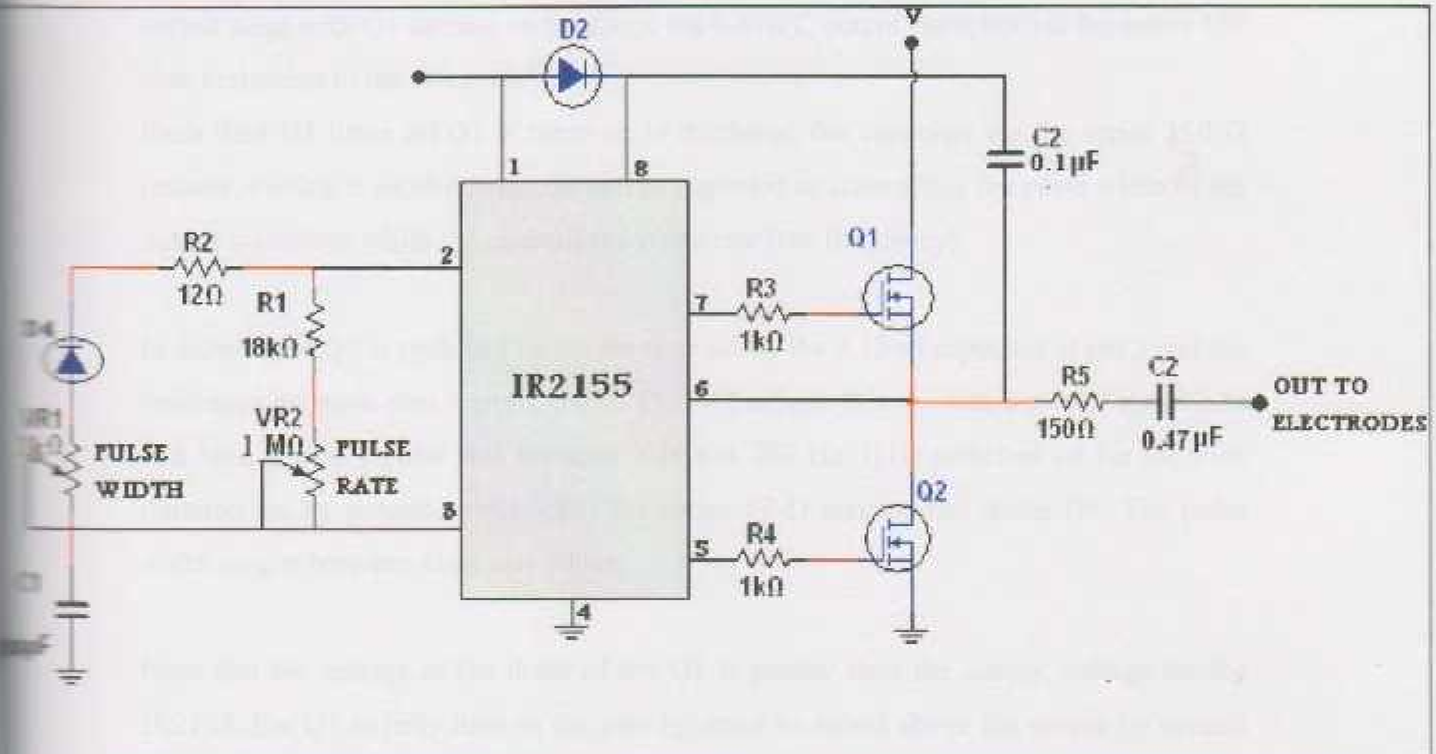


Fig (4.6) switching oscillator

The IR2155 is a high voltage, high speed, self- oscillating power MOSFET and IGBT driver with both high and low side referenced output channels. The front end features a programmable oscillator which is similar to the 555 timer. The output drivers feature a high pulse current buffer stage and an internal dead time designed for minimum driver cross- conduction. Propagation delays for the two channels are matched to simplify use in 50% duty cycle applications. The floating channel can be used to drive an N-channel power MOSFET.

Q1 and Q2 are N-channel power MOSFET which switch the voltage from the two 0.47 µf capacitor to produce the desired output pulses on the electrodes. Q1 &Q2 constitute output stage with Q1 turning on to charge the 0.47µ C output capacitor via the series 150 ohm resistance to the electrode's.

Each time Q1 turns off.Q2 is turns on to discharge the capacitor via the series 150 Ω resistor. Putting it another way .Q1 can be regarded as controlling the pulse width of the output waveform while Q2 controls the pulse rate (the frequency).

In more detail,Q2 is switched on for the time set by the 0.33 µf capacitor at pin 3 and the resistance between pins 3 and 2 (of IC 2). VR2 adjusts this on-time between about 0.5s and 5ms, giving a pulse rate between 2Hz and 200 Hz. Q1is switched on for the time duration set by potentiometer VR1, the series 12 Ω resistor and diode D4. The pulse width ranges between 40µs and 200µs.

Note that the voltage at the drain of the Q1 is greater than the supply voltage for the IR2155. For Q1 to fully turn on the gate (g) must be raised above the source by several volts. This is achieved using a diode pump consisting of diode D2 and capacitor C2(0.1µf).

Initially the Vcc supply voltage for the IC is set at 15.6 volt due to an internal regulator. In addition, MOSFET Q2 is switched on via a 15.6 volt signal at pin 5 driving gate. Capacitor C2 (0.1µf) now charges to the 15.6 supply via D2 and the switched on Q2. When pin 5, goes low, Q2 is turned off and pin 7 is connected internally to pin 8 to switch on Q1. Q1 pulls pin 6 up to the V supply and pin 8 is shifted to V supply plus the 15.6V across C2.

So the circuit changes its value up to whatever the MOSFET driving voltage need to be. Pins 6, 7 and 5 of the IR 2155 are floating outputs which can be shifted to 600 volt above the pin 4 grounds. In our case we are only using the circuit to switch up to 30 volt.

$$F = \frac{1}{1.4x(R_1+150\Omega)xC_1}$$

C1 & R1 shown in Fig(4.5)

Pulse rate will be 2HZ when the value of R1 and VR2 in series Will be 1M Ω.

For pulse rate 20 HZ R1 will be 108 K Ω.

At 100Hz R1 will be 21.5 K Ω.

$$F(HZ) = \frac{1}{T(S)}$$

At 40 μs R1 will be 63.4 Ω which it's in the pulse width include R2 and VR1

At 200 μs R1 will be 283 Ω

4.2.4 Current limiting circuit

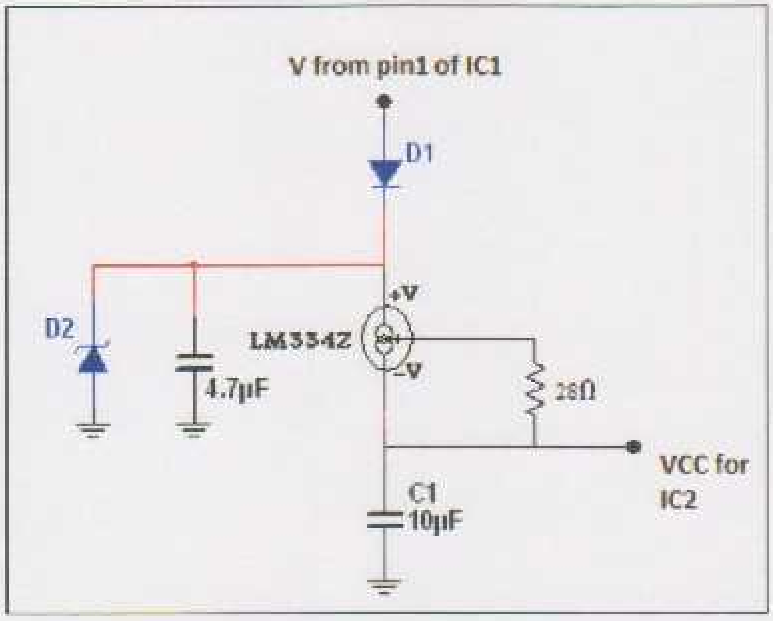


Fig (4.7) Current limiting circuit (IC3)

Voltage from upper circuit passes through D1 and charges the associated 4.7 μf capacitor and the voltage across it is limited to +39 by zener diode ZD1.

This mechanism also limit the maximum voltage at pin1 of ic1 to a diode drop above 39v due to D3 , 39.6 plus or minus the Zener diode tolerance.

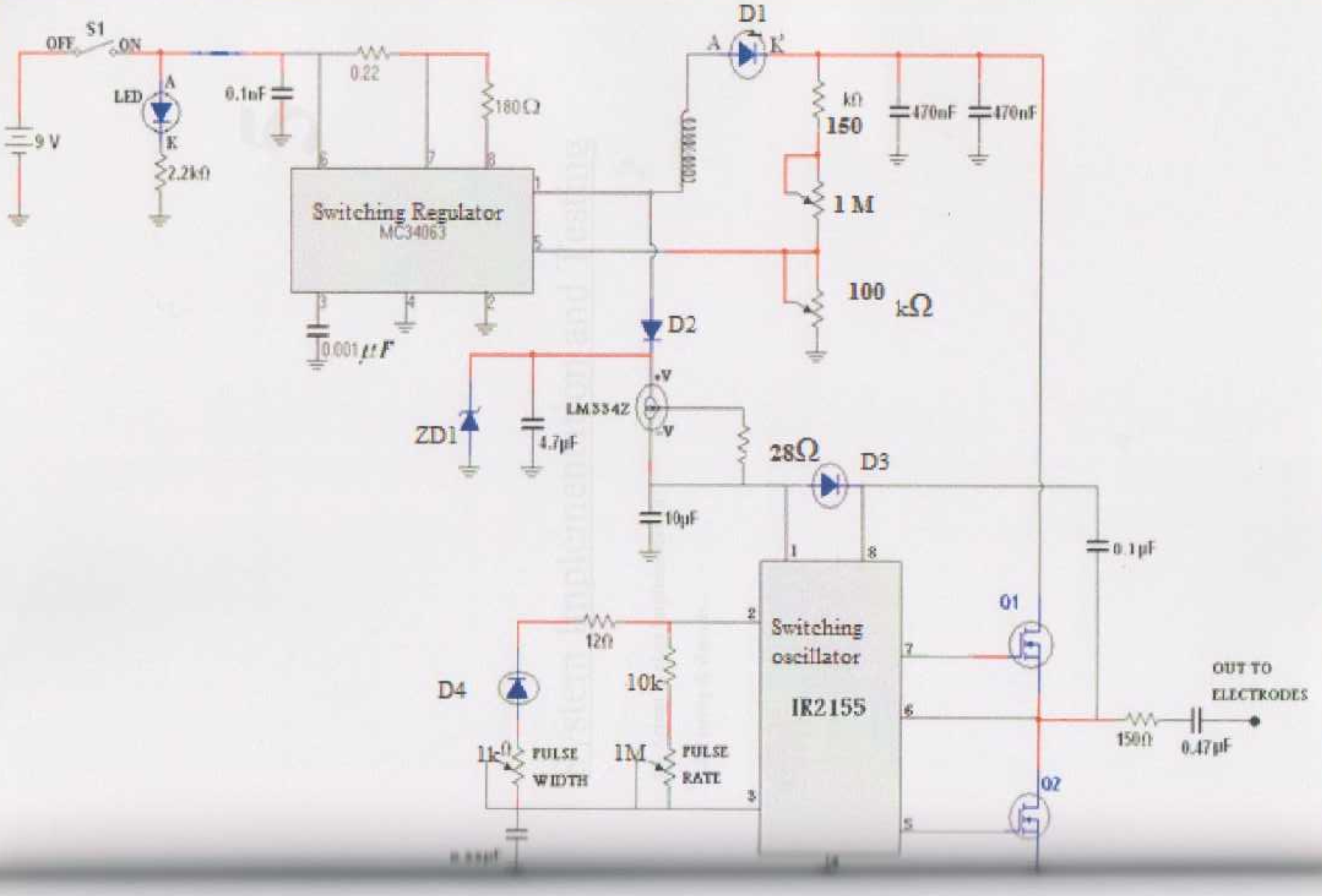
IC'2 power is supplied via an LM334Z constant current source,IC3.

The 27 Ω resistor between the R and V pins of the IC3 sets the constant current to 2.5mA .

Iset=67.7mV\(Rset).........[Data sheet]

4.3 Total Practical Circuit :

FIG(4.8)Total circuit implemented


S1
OFF
ON
9 V
LED
A
K
2.2kΩ
0.1nF
0.22
180Ω
6
7
8
1
5
3
4
2
Switching Regulator
MC34063
0.001µF
D1
A
K
kΩ
150
470nF
470nF
1 M
100 kΩ
D2
LM334Z
+V
-V
ZD1
4.7µF
28Ω
D3
10µF
0.1µF
1
8
2
3
7
6
5
Switching oscillator
IR2155
Q1
Q2
OUT TO ELECTRODES
150Ω
0.47µF
12Ω
10k
D4
1kΩ
PULSE WIDTH
1M
PULSE RATE

5

System Implementation and Testing

5.1 Actual Project Implementation

5.2 Testing & Results

Chapter Five

System Implementation and Testing

5.1 Actual Project Implementation

Practical implementation of the project have been done in the second semester, and this implementation started by implementing each individual subsystem and after completing this implementation, the individual subsystems are connected together to accomplish the project as one unit.

5.1.1 Switching regulator system

The Switching regulator Step up converter circuit connected as it was shown in Fig (4.3),(4.2) has been connected as the first component in the project, shown as implemented practically in its final state.

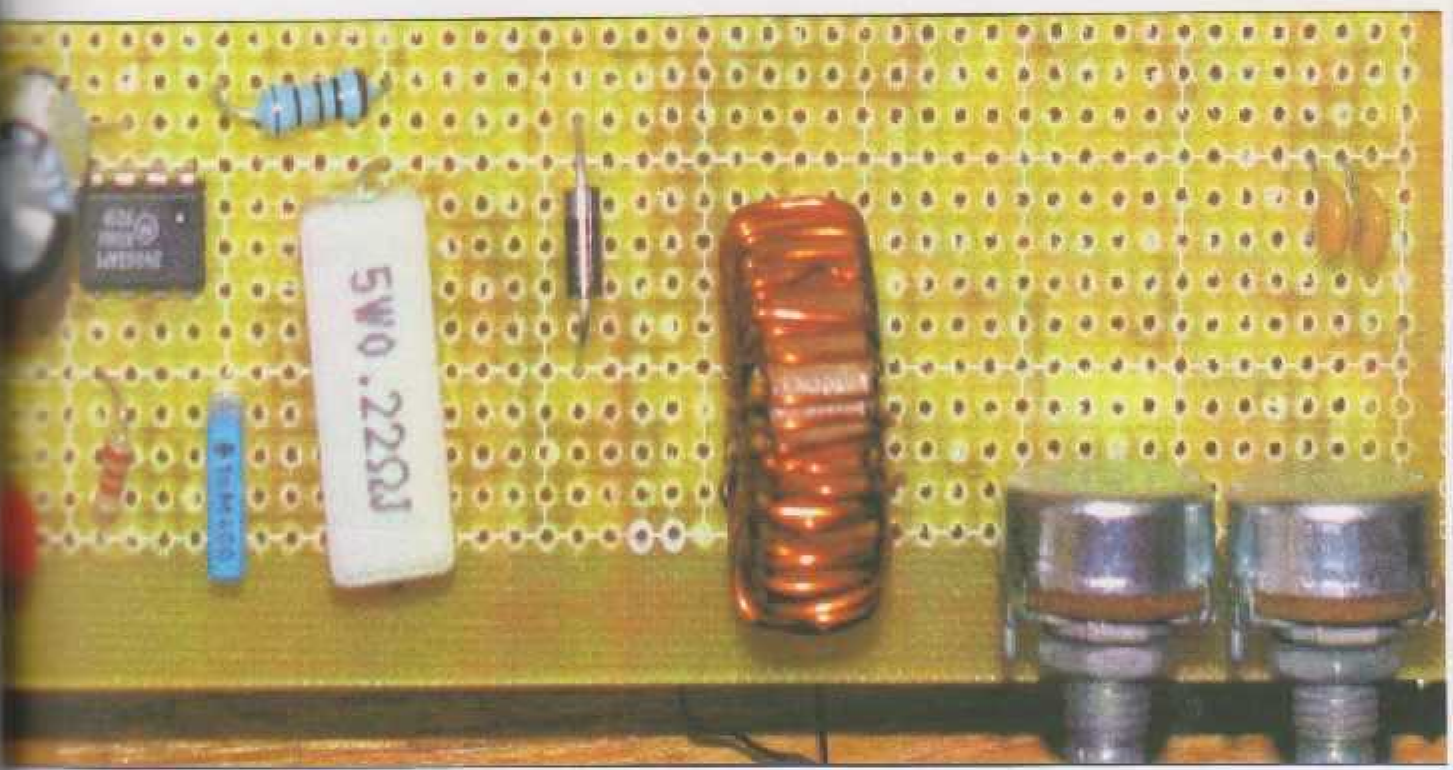


Fig (5.1): Switching regulator (Step up converter)

Inductor used instead of a Transformer ,it was because i didn't find a Transformer with the desired value I need , also I try to to turn a Manuel one but my try didn't succeed .So I couldn't reached the voltage am looking for .

Here also the the Mc34063 works on a fixed frequency so i fix (T on) to 25μs by putting capacitor with 0.1nF at pin 3 of the Ic .And I can change the value of the Capacitor to change the (T on) By the Equation :

Ct=4.0 *10^-5(T on). [Data Sheet]

The Output voltage for this stage can be changed by the variable resistance by the following Equation:

$Vout=1.25(VR2)\backslash(VR1+1)$..

Here the Vout will be about 30 Volt and VR2=50k,VR1=1M.

And it can change by changing the value of resistance.

5.1.2 Current Limiting Circuit

The Current Limiting Circuit had been connected as the second component in the project which takes it input signal from pin 1 from the first IC .

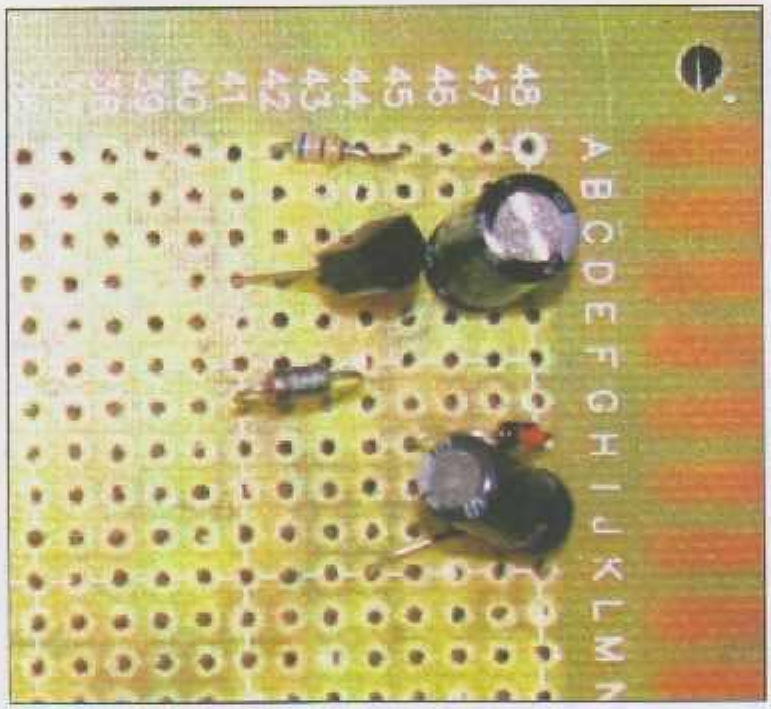


Fig (5.2): Current Limiting Circuit

Here we get the same signal from IC1 ,and we used the stage to get constat current for the next stage .

5.1.3 Switching oscillator

The Switching oscillator circuit had been connected as the third component in the project which takes it input signal from the current limiting circuit.

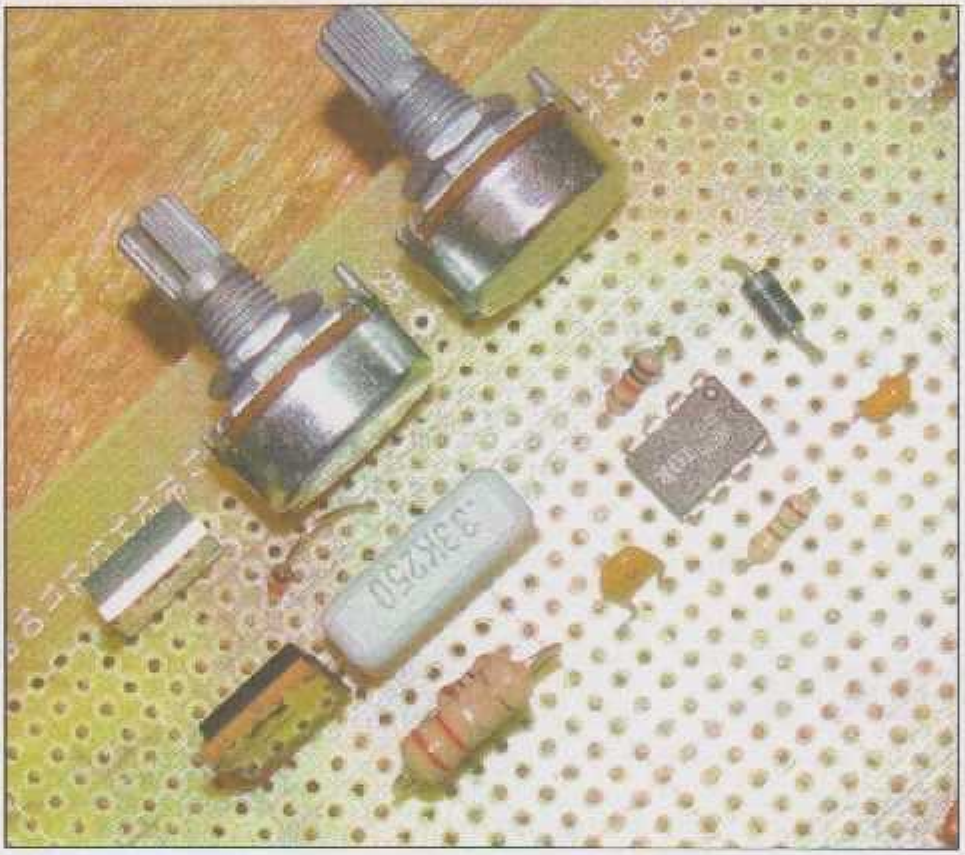
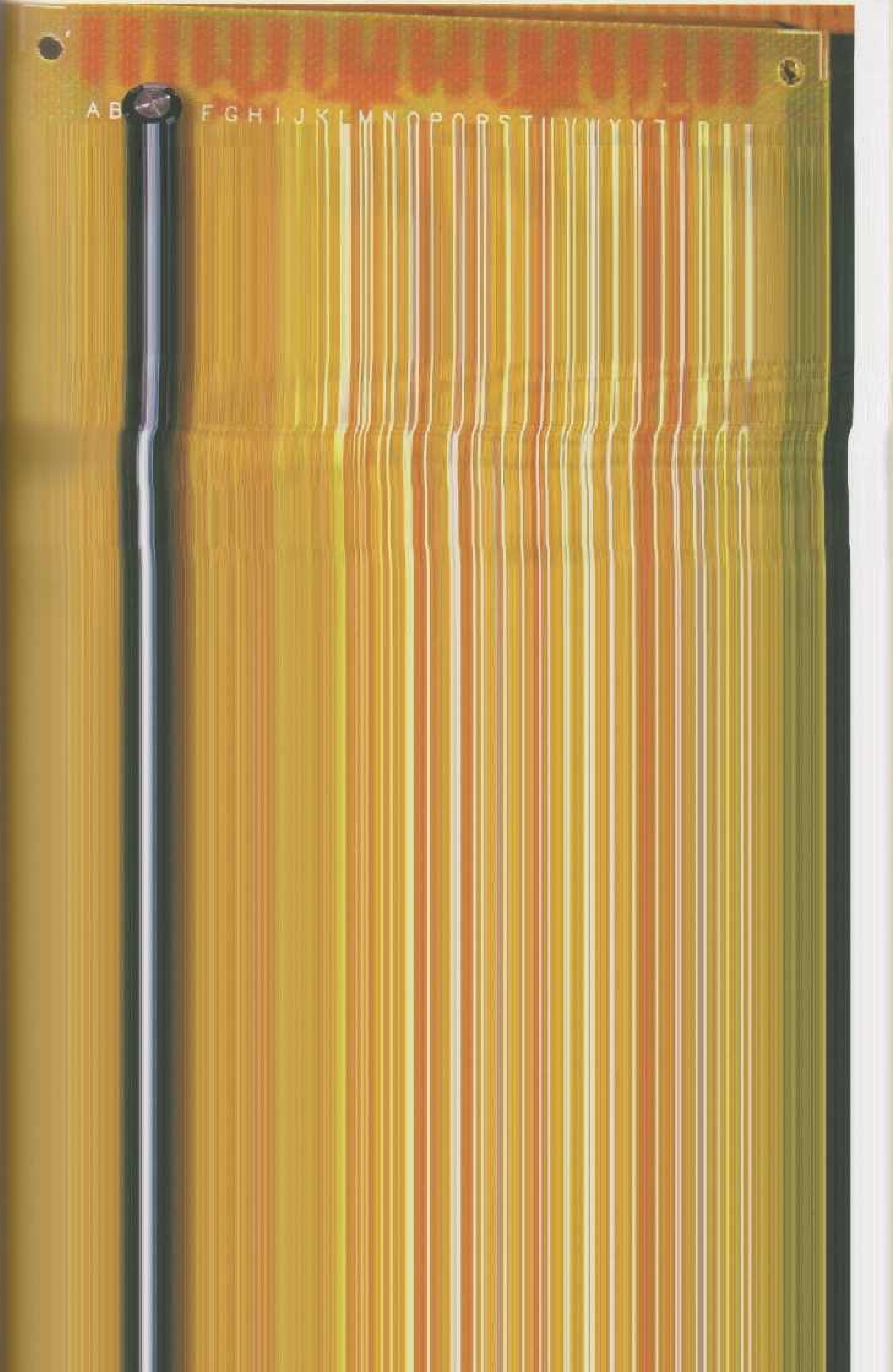


Fig (5.3): Switching oscillator

$F=1/1.4(R1+150).C1$………. R1 is the resistance on Pin3 of the IC,C1 on Pin2 The frequency can changed from 2-200Hz by changing the value of pulse rate potentiometer .And the Time width can change by changing the value of the Pulse Width potentiometer .Pulse width between 40-200 µs.


A B
F G H I J K L M N O P Q R S T U V W X Y Z

The shown pulses signal taken randomly for the circuit that follow the equation . The signal is Dc pulsed signal and it's amplitude is about 20volt from this stage

5.2.2 Switching oscillator Circuit

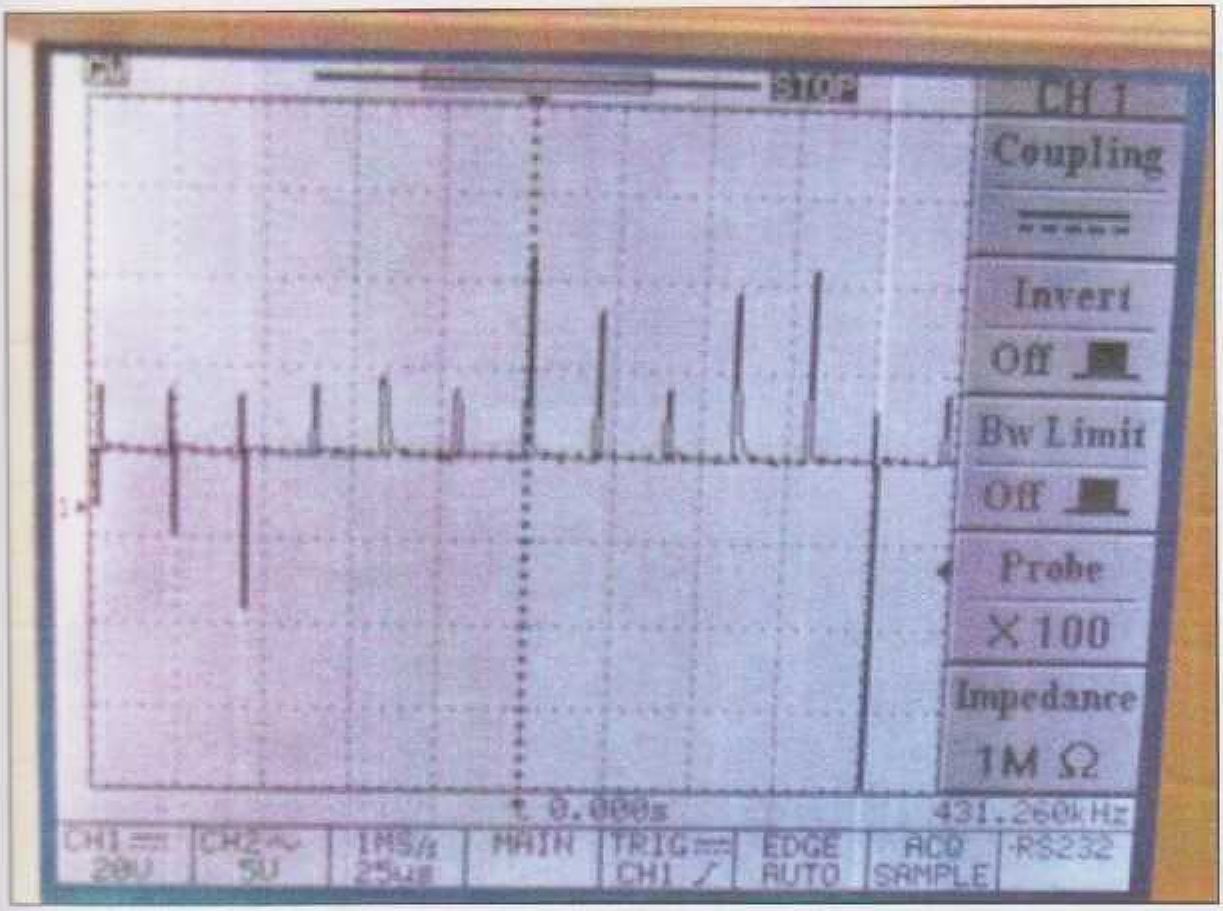


Fig (5.8): Switching Oscillator Circuit signal (Signal view Electrode's)

In this signal time varies as the pulse width and the pulse ratio potentiometer changed .The signal is a continuous Asymmetrical Monophasic pulse with about 20Volt Amplitude peak.

Chapter Six

Conclusions and Future Work

Chapter Six

Conclusion and Future Work

6.1 Conclusion

In this project thanks to God, there had been accomplished a design and implementation of an Transutanuos Electrical nerve Stimulation Device (TENs), which is used to block for Nerves Signal when it suffers from pain. to relief pain using special electrodes that is fastened on the patient skin.

The project gives the capability of adjustment between frequency, electrical voltage and the type of electrical stimulation, and the time for treatment, and it is usually used in the cases of Physiotherapy in clinics and hospitals.

This documentation includes the detailed design of the project and the stages which were followed in order to reach to the desired goals of the project, those are represented as designing and studying each partial stage of whole project's stages each one aside, then to collect or assemble these stages as a one integrated unit.

Output Level 12-30Volt.

Output Pulse Width 40-200 µs.

Frequency 2-200Hz.

Its better to let the system work on 220AC voltage and step down the voltage to the desired value we need .But we have to let in mind that we don't need high current value. Cant use Transformer to step up the voltage because the signal is not pure AC .

The project contains several results, namely:

1- The project shows that TENS gives signal that can be used to relief pain from the damaged muscle sand cells, and this idea is very useful in the physiotherapy.

2- TENS signal changed in its values (voltage and time width) according to sensitivity that depends on the type and the place of the pain.

3- TENS signal is a very critical signal in amplitude and frequency, so we must be very accurate when dealing with this signal, because it needs very high safety system of correct and safe values of voltage.

4- We could reach our goals to make a medical device that relief chronic and acute pains started with studying the electrophysiological parameters, then studying design stages of the circuit which gives these parameters as output. After that we applied the project to the practical work.

5- During all stages of the project we had to solve some problems which we got by applying the designed circuit onto circuit board, we corrected it to get the expected results. Finally, we tested the output of the circuit by applying the output directly to patient.

6.2 Future Work

The project main idea is a very interesting one, and also opens many doors in the medical field even it is not a new idea. The researches about this idea must be developed, to get more opportunities about the ways of controlling and many other things depending on this idea.

The project can be developed in the future to be digital, by taking its setting values and converting it to digital values.

Due to the small size and light weight of the TENS device, we think we can integrate it with other medical devices like therapeutic ultrasound which is used sometimes to reduce joints stiffness.

This device might be used to treat the face muscles. (Bell's Palsy disease), this is often due to the partial facial paralysis that occurs on one side of the face. In this case the face muscle is small compared to other muscles, so we need small electrodes to capture the effected muscles. In this device there are only two electrodes, so we think it will be a good idea to double the electrodes to cover more muscles.

Placing the electrodes was a little problem for us because the adhesive substance is not effective for long time, so we had an idea to implant the electrodes inside sock to be worn during the therapy, also make gloves for hand's muscles.

REFERECES

Web sites:

1. *http://en.wikipedia.org/wiki/Nervous_system*
2. *http://www.biologymad.com/NervousSystem/nerveimpulses.htm#restingpotential*
3. *http://www.biologymad.com/NervousSystem/nerveimpulses.htm#propagation*
4. *http://en.wikipedia.org/wiki/Image:Action_potential_vert.png*
5. *http://www.sld.cu/galerias/pdf/sitios/rehabilitacion-fis/capitulo_tens.pdf MARK JOHNSON Chapter 17*
6. *http://www.physiomontreal.com/TENS.pdf*
7. *http://www.electrotherapy.com*
8. *http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3066716/*
9. *http://www.aemed.com/assets/applets/StimPad_Stimulation_Induced_Analgesia_INBODY_compiled.pdf*
10. *http://www.datasheetcatalog.com*
11. *http://en.wikipedia.org/wiki/Electric_shock*

APPENDECIES

Appendix A (Definitions)

Term	*Meaning or Definition*
Transcutaneous Electrical Nerve Stimulation (TENS)	**Technique of generating electrical pulses,that can relief pain from the nerve system ,through the skin.**
Paralysis	**Partially or completely nerve damage**

Appendix B (Used Programs)

1. Microsoft Word: this program was used for writing the documentation of our project. It is a very easy program to deal with; also gives many opportunities for controlling the options of writing.

2. Microsoft Project: this program was used for generating the scheduling table, and also producing the timing plan. It is an important program and every body must have even little information about this program.

3. Microsoft Visio: this program was used for generating the block diagrams implemented inside this project. This program gives also excellent choices to draw and generate block diagrams.

4. Multi Sym: this program was use for drawing the schematic diagrams of the subsystems in our design

5. Math Type: is an intelligent mathematical equation editor designed for personal computers running Microsoft Windows.

Appendix C (Data Sheets)

MC34063A, MC33063A, SC34063A, SC33063A, NCV33063A

1.5 A, Step-Up/Down/ Inverting Switching Regulators

ON Semiconductor®

http://onsemi.com

The MC34063A Series is a monolithic control circuit containing the

MARKING

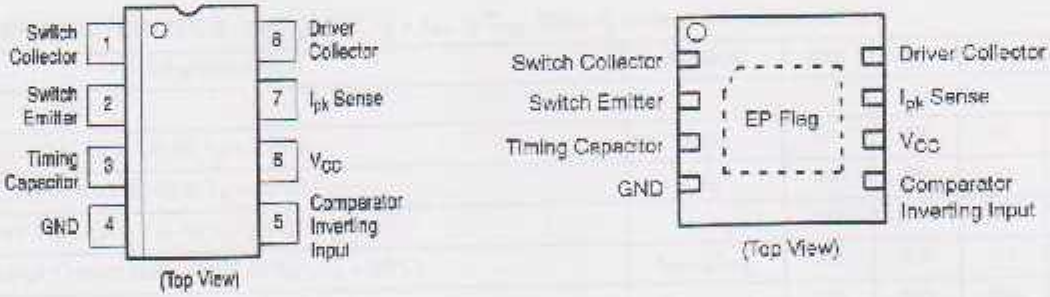


Figure 2. Pin Connections

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Power Supply Voltage	V_{CC}	40	Vdc
Comparator Input Voltage Range	V_{IR}	−0.3 to +40	Vdc
Switch Collector Voltage	$V_{C(switch)}$	40	Vdc
Switch Emitter Voltage ($V_{Pin\ 1}$ = 40 V)	$V_{E(switch)}$	40	Vdc
Switch Collector to Emitter Voltage	$V_{CE(switch)}$	40	Vdc
Driver Collector Voltage	$V_{C(driver)}$	40	Vdc
Driver Collector Current (Note 1)	$I_{C(driver)}$	100	mA
Switch Current	I_{SW}	1.5	A
Power Dissipation and Thermal Characteristics			
Plastic Package, P, P1 Suffix			
T_A = 25°C	P_D	1.25	W
Thermal Resistance	$R_{\theta JA}$	115	°C/W
SOIC Package, D Suffix			
T_A = 25°C	P_D	625	mW
Thermal Resistance	$R_{\theta JA}$	160	°C/W
DFN Package			
T_A = 25°C	P_D	1.25	mW
Thermal Resistance	$R_{\theta JA}$	80	°C/W
Operating Junction Temperature	T_J	+150	°C
Operating Ambient Temperature Range	T_A		°C
MC34063A, SC34063A		0 to +70	
MC33063AV, NCV33063A		−40 to +125	
MC33063A, SC33063A		−40 to +85	
Storage Temperature Range	T_{stg}	−65 to +150	°C

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

1. Maximum package power dissipation limits must be observed.
2. This device series contains ESD protection and exceeds the following tests: Human Body Model 4000 V per MIL−STD−883, Method 3015. Machine Model Method 400 V.
3. NCV prefix is for automotive and other applications requiring site and change control.

ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 V, T_A = T_{low} to T_{high} [Note 4], unless otherwise specified.)

Characteristics	Symbol	Min	Typ	Max	Unit
OSCILLATOR					
Frequency ($V_{Pin 5}$ = 0 V, C_T = 1.0 nF, T_A = 25°C)	f_{osc}	24	33	42	kHz
Charge Current (V_{CC} = 5.0 V to 40 V, T_A = 25°C)	I_{chg}	24	35	42	μA
Discharge Current (V_{CC} = 5.0 V to 40 V, T_A = 25°C)	I_{dischg}	140	220	260	μA
Discharge to Charge Current Ratio (Pin 7 to V_{CC}, T_A = 25°C)	I_{dischg}/I_{chg}	5.2	6.5	7.5	–
Current Limit Sense Voltage (I_{chg} = I_{dischg}, T_A = 25°C)	$V_{ipk(sense)}$	250	300	350	mV
OUTPUT SWITCH (Note 5)					
Saturation Voltage, Darlington Connection (I_{SW} = 1.0 A, Pins 1, 8 connected)	$V_{CE(sat)}$	–	1.0	1.3	V
Saturation Voltage (Note 6) (I_{SW} = 1.0 A, $R_{Pin 8}$ = 82 Ω to V_{CC}, Forced β ≃ 20)	$V_{CE(sat)}$	–	0.45	0.7	V
DC Current Gain (I_{SW} = 1.0 A, V_{CE} = 5.0 V, T_A = 25°C)	h_{FE}	50	75	–	–
Collector Off–State Current (V_{CE} = 40 V)	$I_{C(off)}$	–	0.01	100	μA
COMPARATOR					
Threshold Voltage T_A = 25°C T_A = T_{low} to T_{high}	V_{th}	 1.225 1.21	 1.25 –	 1.275 1.29	V
Threshold Voltage Line Regulation (V_{CC} = 3.0 V to 40 V) MC33063, MC34063 MC33063V, NCV33063	Reg_{line}	 – –	 1.4 1.4	 5.0 6.0	mV
Input Bias Current (V_{in} = 0 V)	I_{IB}	–	-20	-400	nA
TOTAL DEVICE					
Supply Current (V_{CC} = 5.0 V to 40 V, C_T = 1.0 nF, Pin 7 = V_{CC}, $V_{Pin 5}$ > V_{th}, Pin 2 = GND, remaining pins open)	I_{CC}	–	–	4.0	mA

T_{low} = 0°C for MC34063, SC34063; – 40°C for MC33063, SC33063, MC33063V, NCV33063
T_{high} = +70°C for MC34063, SC34063; +85°C for MC33063, SC33063; +125°C for MC33063V, NCV33063

Low duty cycle pulse techniques are used during test to maintain junction temperature as close to ambient temperature as possible.

The output switch is driven into hard saturation (non–Darlington configuration) at low switch currents (≤ 300 mA) and high driver currents (≥ 30 mA), it may take up to 2.0 μs for it to come out of saturation. This condition will shorten the off time at frequencies ≥ 30 kHz, and is magnified at high temperatures. This condition does not occur with a Darlington configuration, since the output switch cannot saturate. If a non–Darlington configuration is used, the following output drive condition is recommended:

$$\text{Forced } \beta \text{ of output switch : } \frac{I_C \text{ output}}{I_C \text{ driver} - 7.0 \text{ mA}^*} \geq 10$$

*The 100 Ω resistor in the emitter of the driver device requires about 7.0 mA before the output switch conducts.

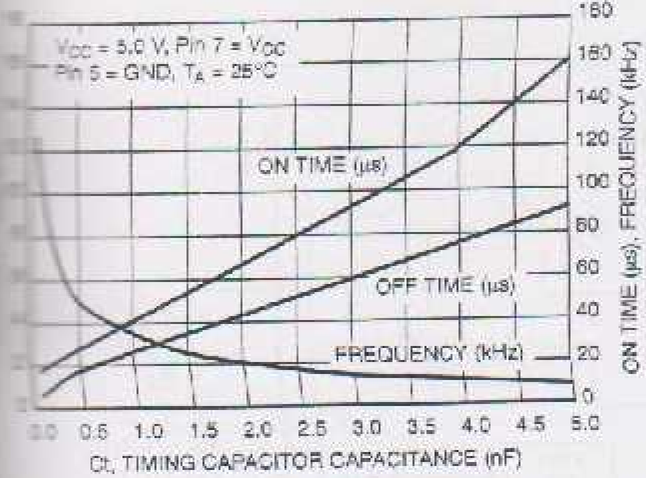


Figure 3. Oscillator Frequency

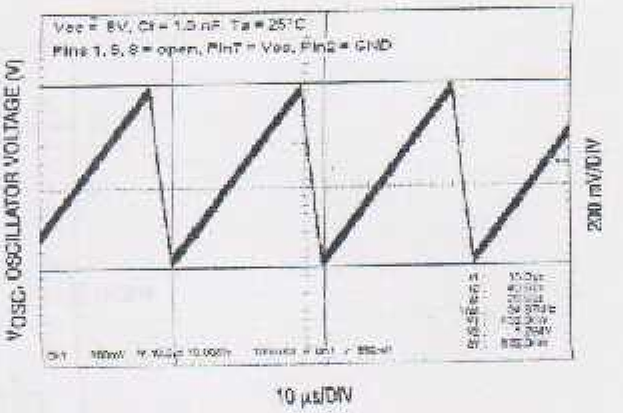


Figure 4. Timing Capacitor Waveform

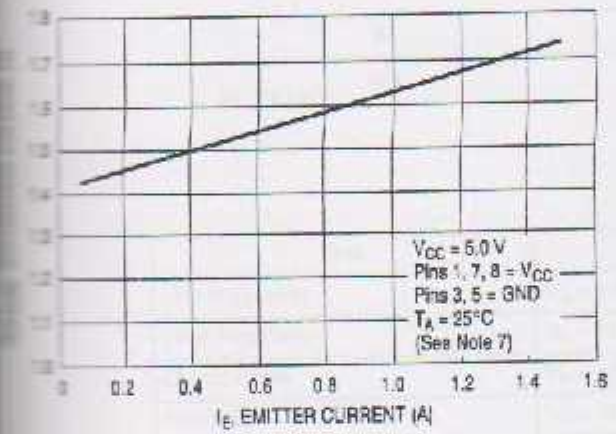


Figure 5. Emitter Follower Configuration Output Saturation Voltage versus Emitter Current

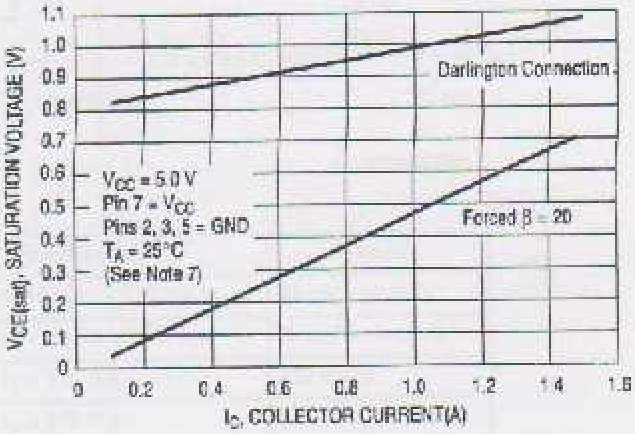


Figure 6. Common Emitter Configuration Output Switch Saturation Voltage versus Collector Current

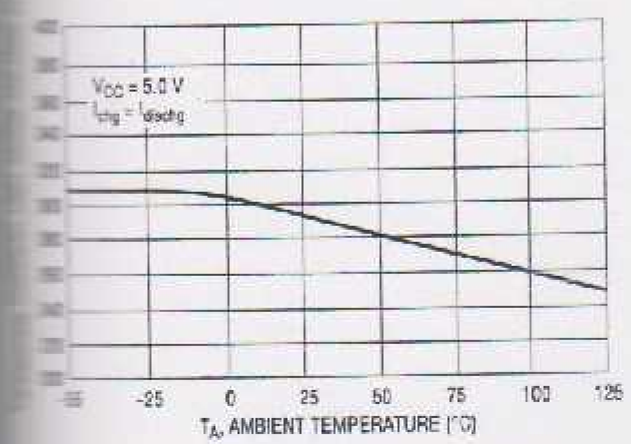


Figure 7. Current Limit Sense Voltage versus Temperature

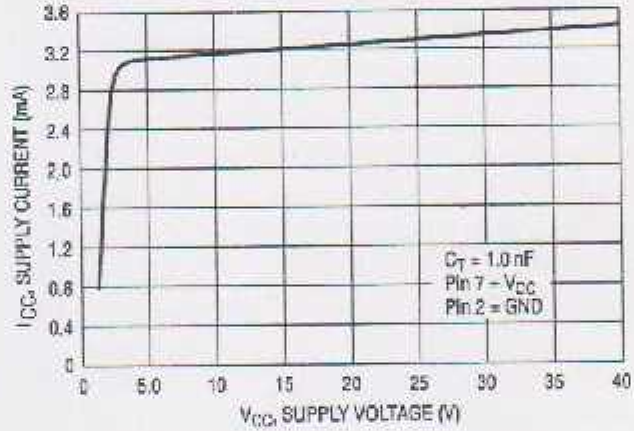


Figure 8. Standby Supply Current versus Supply Voltage

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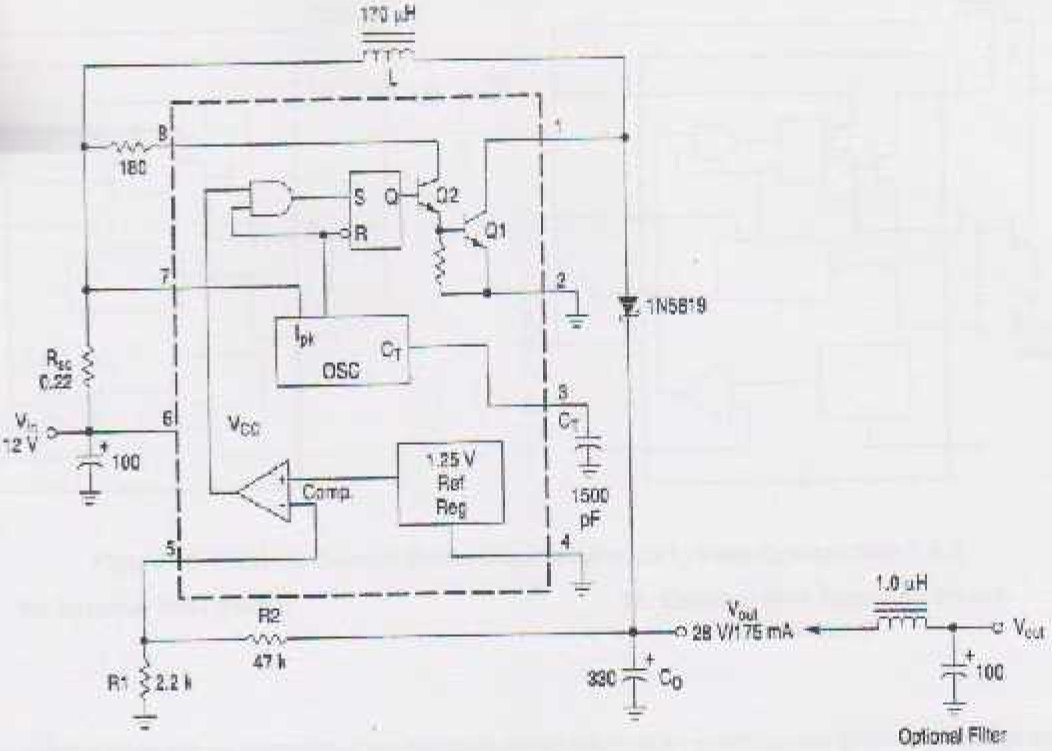
ow duty cycle pulse techniques are used during test to maintain junction temperature as close to ambient temperature as possible.



Test	Conditions	Results
Line Regulation	V_{in} = 8.0 V to 16 V, I_O = 175 mA	30 mV = ±0.05%
Load Regulation	V_{in} = 12 V, I_O = 75 mA to 175 mA	10 mV = ±0.017%
Output Ripple	V_{in} = 12 V, I_O = 175 mA	400 mVpp
Efficiency	V_{in} = 12 V, I_O = 175 mA	87.7%
Output Ripple With Optional Filter	V_{in} = 12 V, I_O = 175 mA	40 mVpp

Figure 9. Step−Up Converter

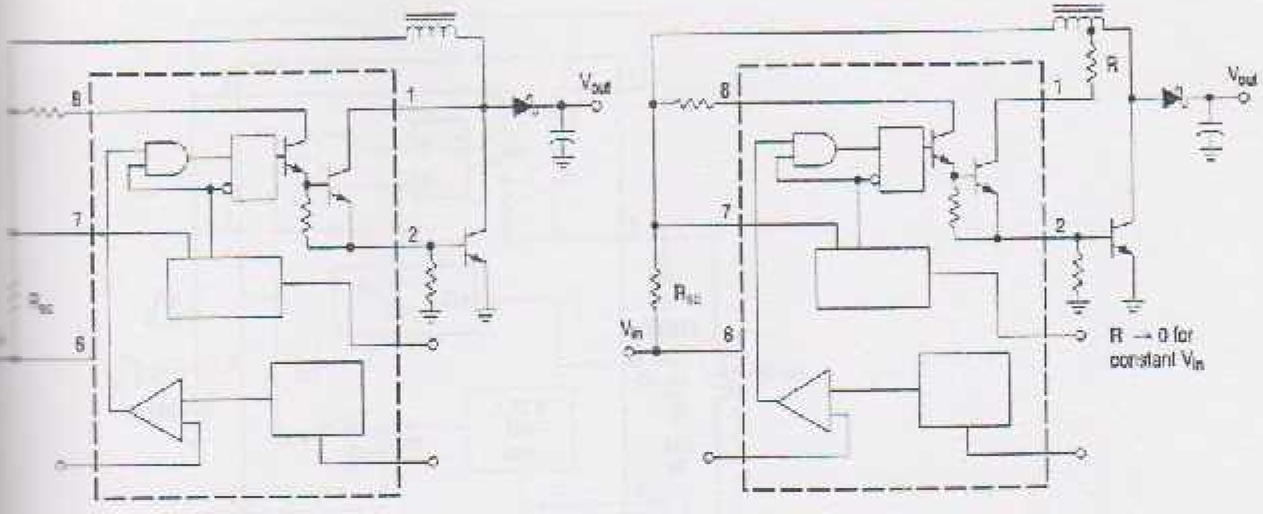
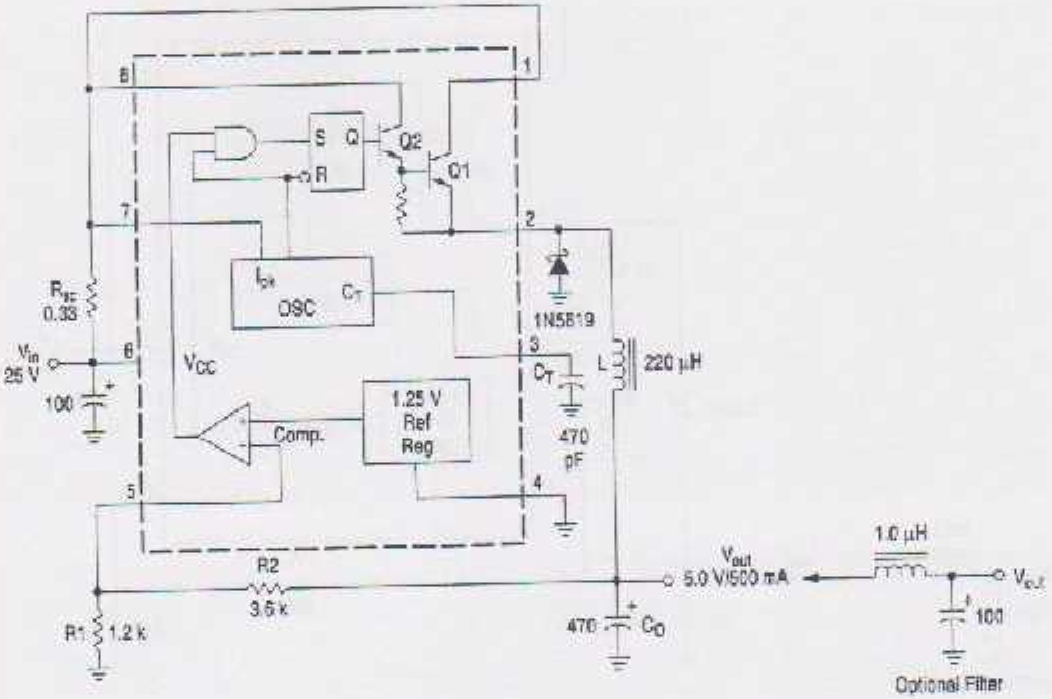


Figure 10. External Current Boost Connections for I_C Peak Greater than 1.5 A

9a. External NPN Switch

9b. External NPN Saturated Switch
(See Note 8)



Test	Conditions	Results
Line Regulation	V_{in} = 15 V to 25 V, I_O = 500 mA	12 mV = ±0.12%
Load Regulation	V_{in} = 25 V, I_O = 50 mA to 500 mA	3.0 mV = ±0.03%
Output Ripple	V_{in} = 25 V, I_O = 500 mA	120 mVpp
Short Circuit Current	V_{in} = 25 V, R_L = 0.1 Ω	1.1 A
Efficiency	V_{in} = 25 V, I_O = 500 mA	83.7%
Output Ripple With Optional Filter	V_{in} = 25 V, I_O = 500 mA	40 mVpp

Figure 11. Step–Down Converter

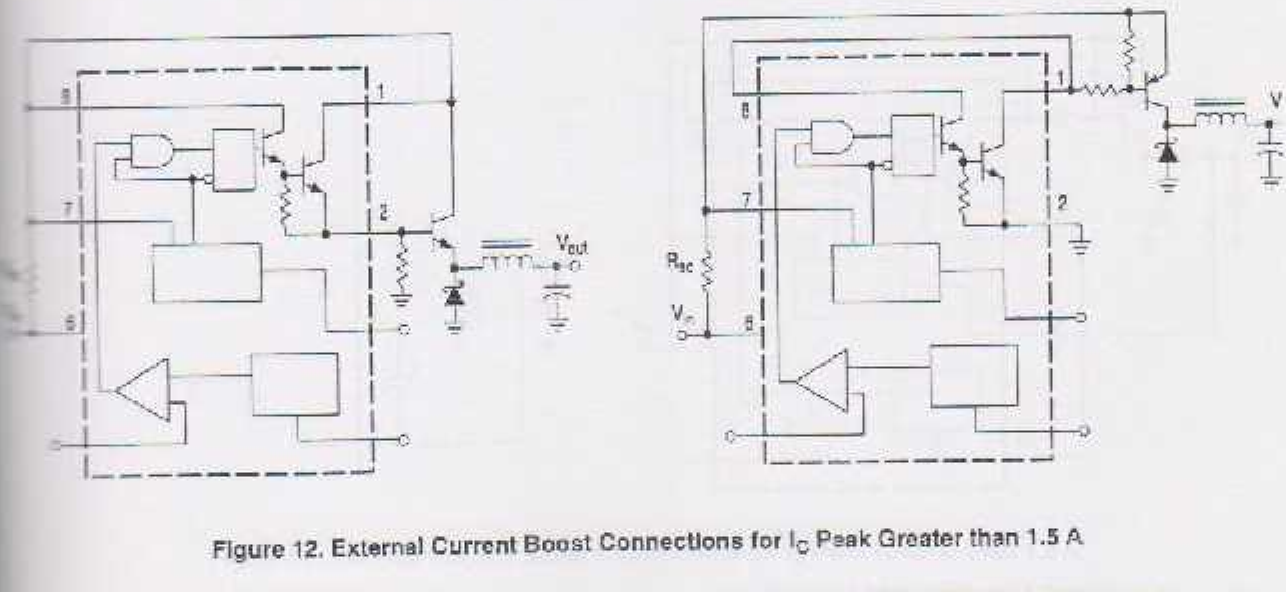
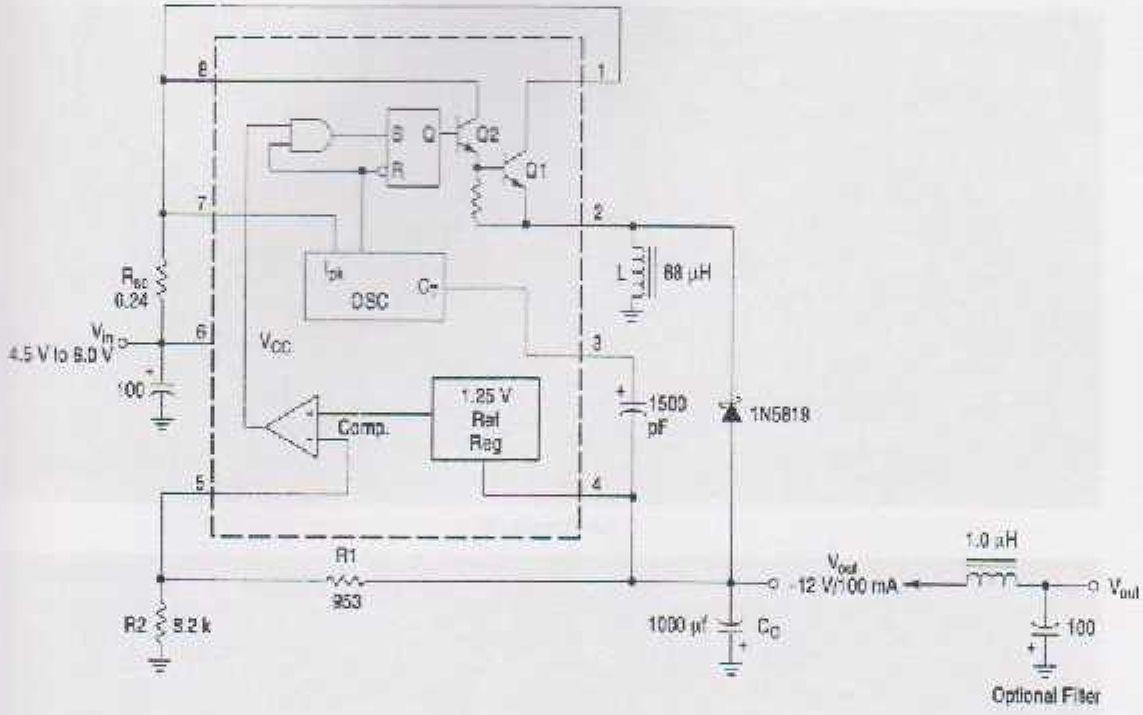


Figure 12. External Current Boost Connections for I_C Peak Greater than 1.5 A

11a. External NPN Switch

11b. External PNP Saturated Switch



Test	Conditions	Results
Line Regulation	V_{in} = 4.5 V to 6.0 V, I_O = 100 mA	3.0 mV = ±0.012%
Load Regulation	V_{in} = 5.0 V, I_O = 10 mA to 100 mA	0.022 V = ±0.09%
Output Ripple	V_{in} = 5.0 V, I_O = 100 mA	500 mVpp
Short Circuit Current	V_{in} = 5.0 V, R_L = 0.1 Ω	910 mA
Efficiency	V_{in} = 5.0 V, I_O = 100 mA	62.2%
Output Ripple With Optional Filter	V_{in} = 5.0 V, I_O = 100 mA	70 mVpp

Figure 13. Voltage Inverting Converter

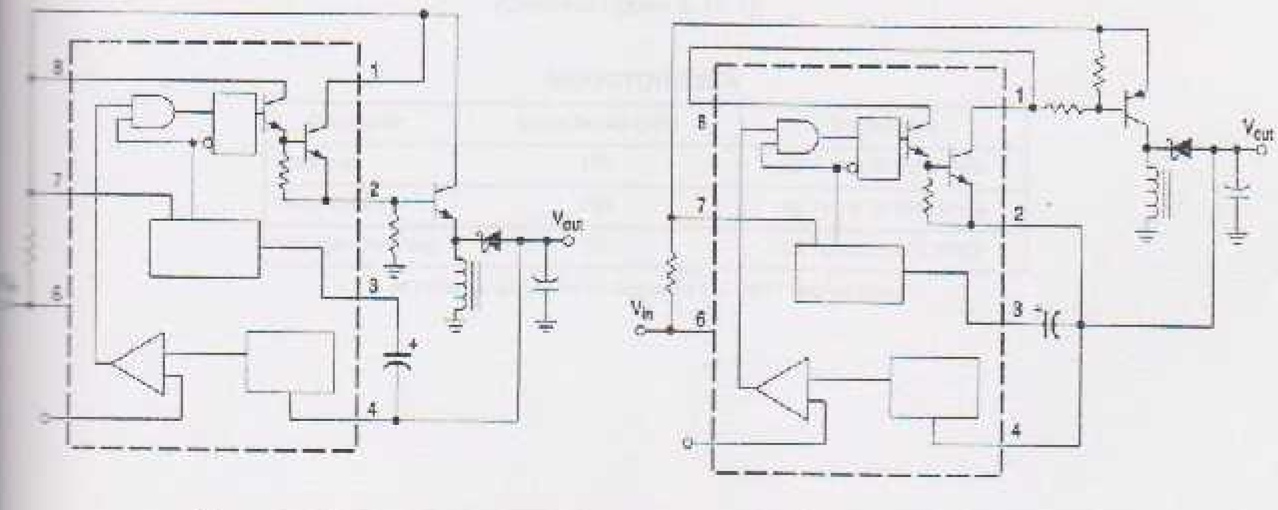
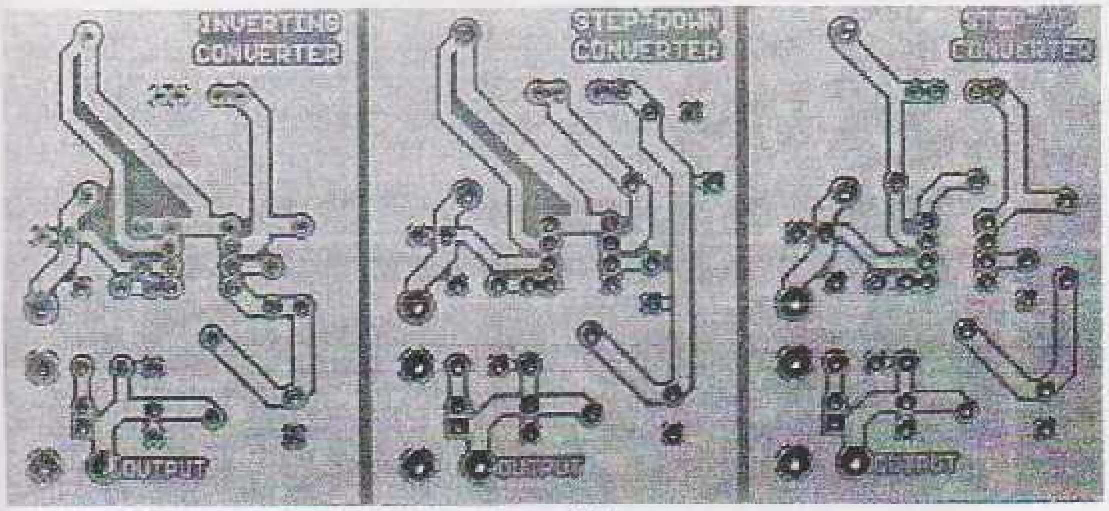


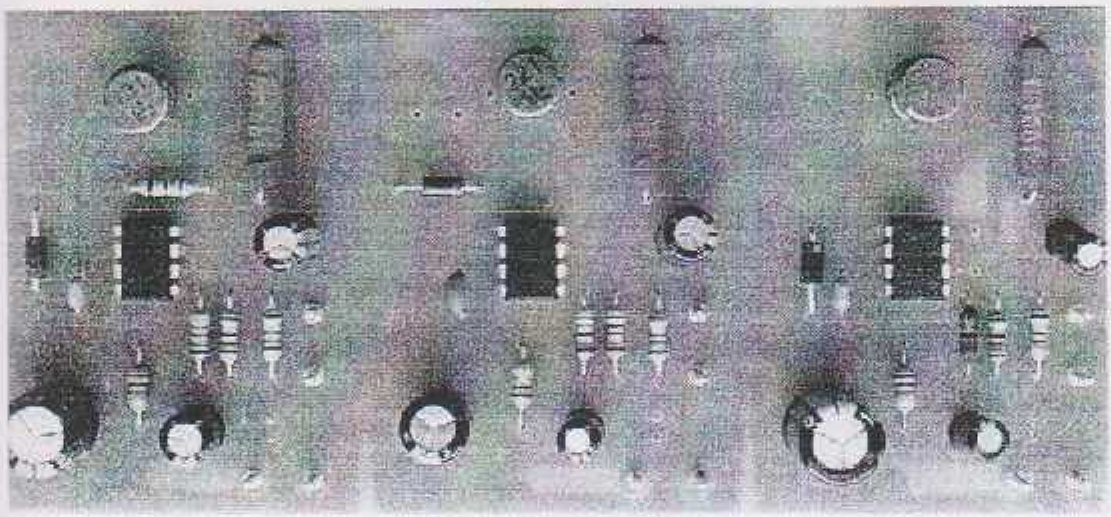
Figure 14. External Current Boost Connections for I_C Peak Greater than 1.5 A

13a. External NPN Switch

13b. External PNP Saturated Switch



(Bottom Side)



(Top View, Component Side)

Figure 15. Printed Circuit Board and Component Layout
(Circuits of Figures 9, 11, 13)

INDUCTOR DATA

Converter	Inductance (μH)	Turns/Wire
Step-Up	170	38 Turns of #22 AWG
Step-Down	220	48 Turns of #22 AWG
Voltage-Inverting	88	28 Turns of #22 AWG

All inductors are wound on Magnetics Inc. 55117 toroidal core.

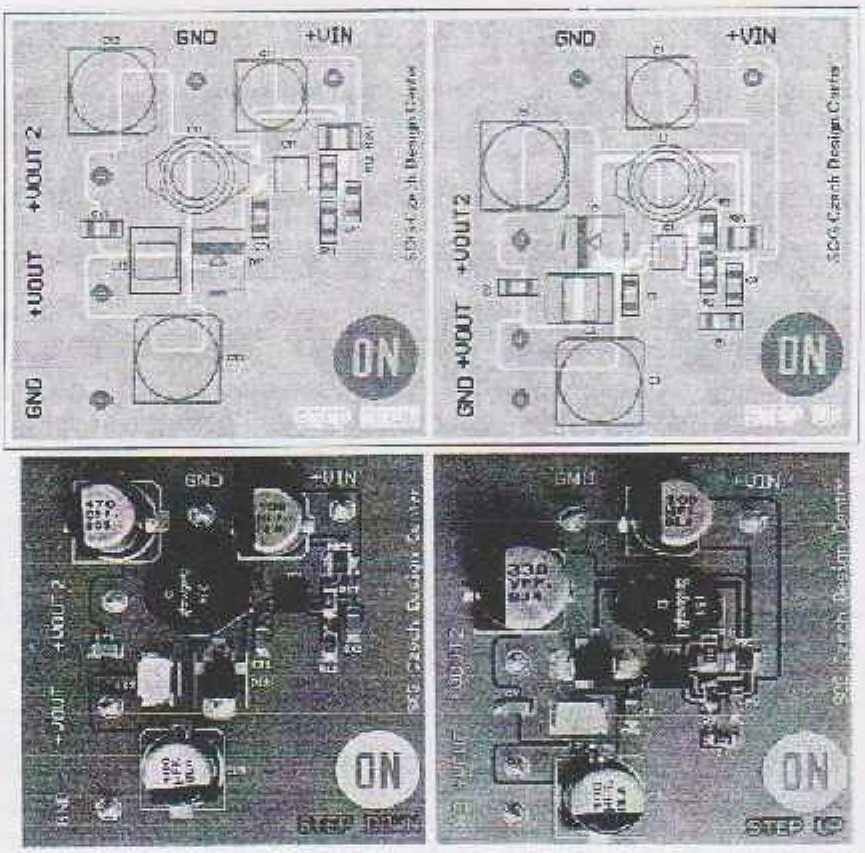


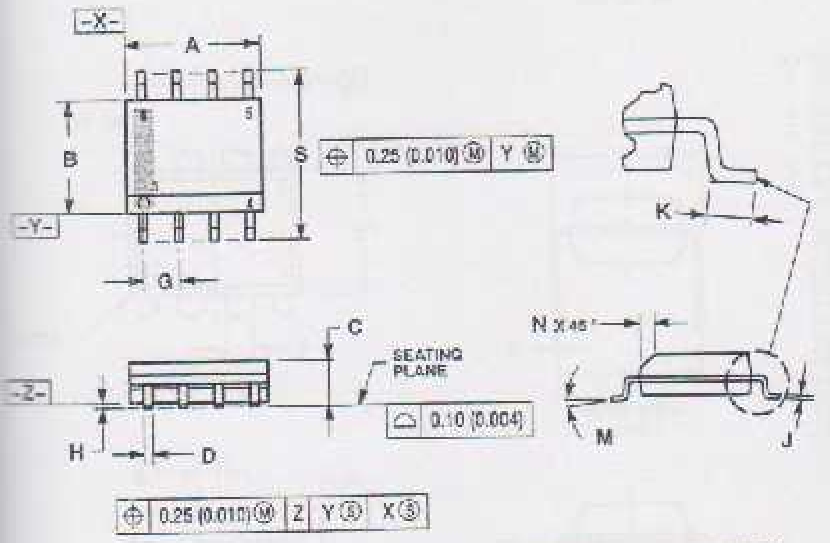
Figure 16. Printed Circuit Board for DFN Device

DERING INFORMATION

Device	Package	Shipping†
C33063AD	SOIC-8	98 Units / Rail
C33063ADG	SOIC-8 (Pb-Free)	98 Units / Rail
C33063ADR2	SOIC-8	2500 Units / Tape & Reel
C33063ADR2G	SOIC-8 (Pb-Free)	2500 Units / Tape & Reel
C33063ADR2G	SOIC-8 (Pb-Free)	2500 Units / Tape & Reel
C33063AP1	PDIP-8	50 Units / Rail
[illegible]	PDIP-8	50 Units / Rail

PACKAGE DIMENSIONS

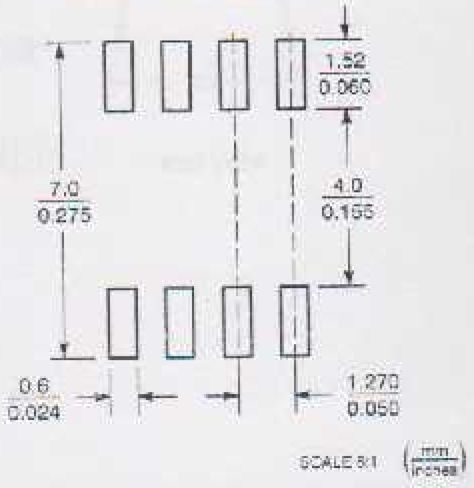
SOIC–8 NB
CASE 751–07
ISSUE AJ



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBA PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTA IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.
6. 751–01 THRU 751–06 ARE OBSOLETE. NEW STANDARD IS 751–07.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	4.80	5.00	0.189	0.197
B	3.80	4.00	0.150	0.157
C	1.35	1.75	0.053	0.069
D	0.33	0.51	0.013	0.020
G	1.27 BSC		0.050 BSC	
H	0.10	0.25	0.004	0.010
J	0.19	0.25	0.007	0.010
K	0.40	1.27	0.016	0.050
M	0 °	8 °	0 °	8 °
N	0.25	0.50	0.010	0.020
S	5.80	6.20	0.228	0.244

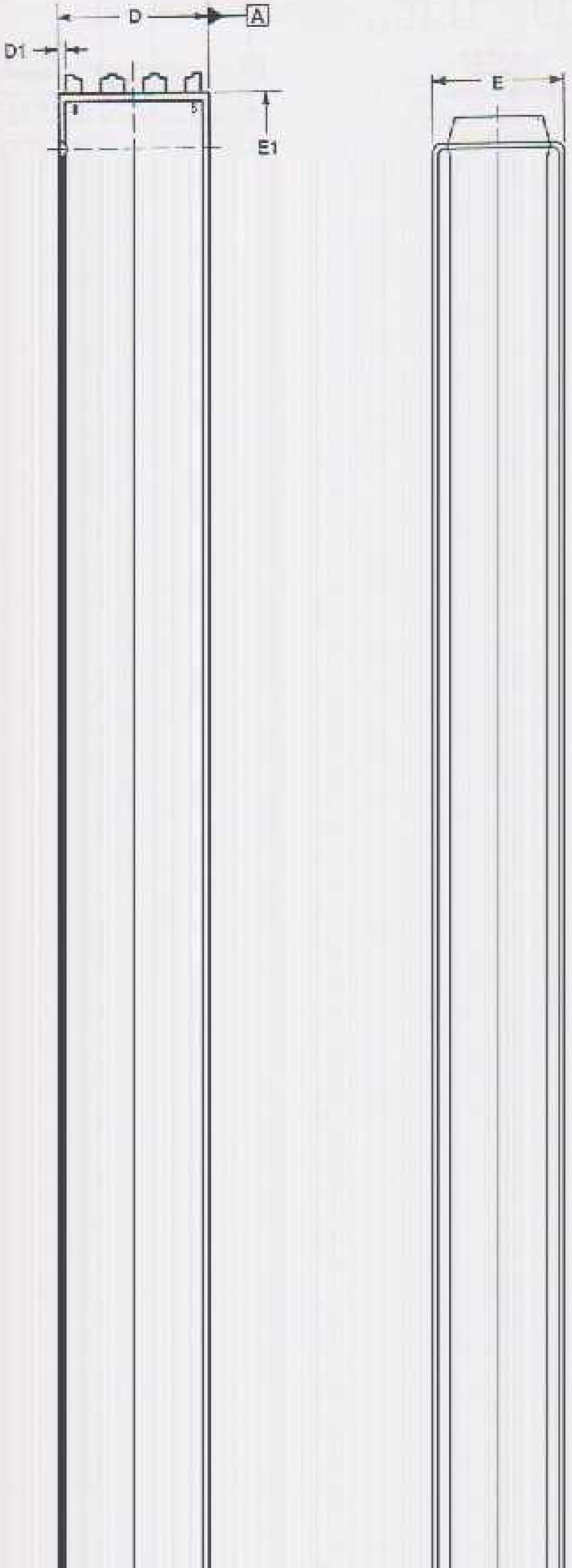
SOLDERING FOOTPRINT*



*For additional information on our Pb–Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

PACKAGE DIMENSIONS

PDIP–8
P, P1 SUFFIX
CASE 626–05
ISSUE M

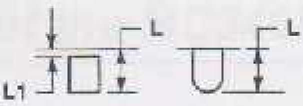


NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCHES.
3. DIMENSION E IS MEASURED WITH THE LEADS RESTRAINED PARALLEL AT WIDTH E2.
4. DIMENSION E1 DOES NOT INCLUDE MOLD FLASH.
5. ROUNDED CORNERS OPTIONAL.

	INCHES			MILLIMETERS		
DIM	MIN	NOM	MAX	MIN	NOM	MAX

PACKAGE DIMENSIONS

DFN8, 4x4
CASE 488AF−01
ISSUE C



DETAIL A
OPTIONAL CONSTRUCTIONS

NOTES:
1. DIMENSIONS AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: MILLIMETERS.
3. DIMENSION b APPLIES TO PLATED TERMINAL AND IS MEASURED BETWEEN 0.15 AND 0.30MM FROM TERMINAL TIP.
4. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS THE TERMINALS.
5. DETAILS A AND B SHOW OPTIONAL CONSTRUCTIONS FOR TERMINALS.

	MILLIMETERS	
DIM	MIN	MAX

TEXAS
INSTRUMENTS

Application Report
SLVA252B–September 2006–Revised November 2007

Application of the MC34063 Switching Regulator

Sekander and Mahmoud Harmouch

SLL Linear

MC34063 Description

The MC34063 is a monolithic control circuit containing all the active functions required for switching dc-to-dc converters (see Figure 1). The MC34063 includes the following components:

- Temperature-compensated reference voltage
- Oscillator
- Active peak-current limit
- Output switch
- Output voltage-sense comparator

The MC34063 was designed to be incorporated in buck, boost, or voltage-inverter converter applications. All these functions are contained in an 8-pin DIP or SOIC package.

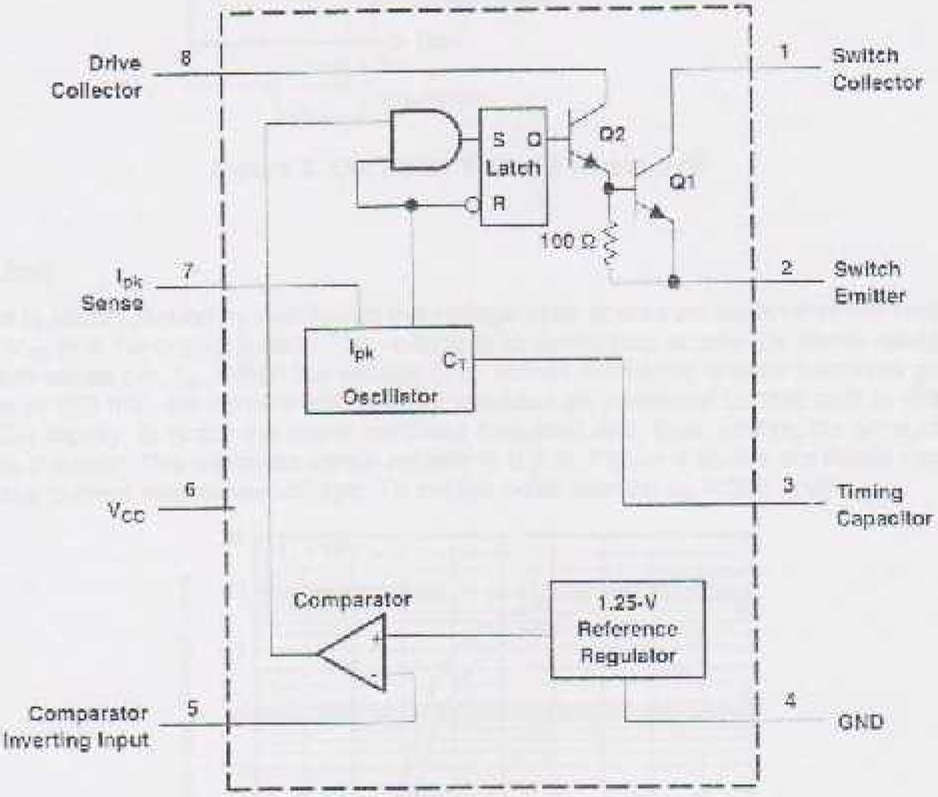


Figure 1. Functional Block Diagram

Reference Voltage

The reference voltage is set at 1.25 V and is used to set the output voltage of the converter.

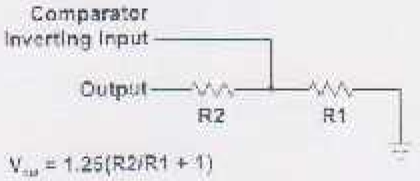


Figure 2. Reference Voltage Circuit

Oscillator

The oscillator is composed of a current source and a current sink that charge and discharge the external timing capacitor (C_T) between an upper and lower preset threshold. The typical charge current is 35 µA, and the typical discharge current is 200 µA, yielding approximately a 6:1 ratio. Thus, the ramp-up period is six times longer than that of the ramp-down period (see Figure 3).

The upper threshold is 1.25 V, which is same as the internal reference voltage, and the lower threshold is 0.75 V. The oscillator runs constantly, at a pace controlled by the value of C_T.

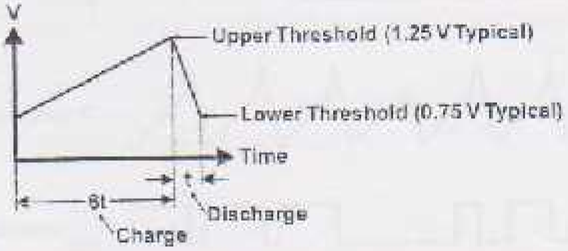


Figure 3. Oscillator Voltage Thresholds

Current Limit

Current limit is accomplished by monitoring the voltage drop across an external sense resistor located in series with V_{CC} and the output switch. The voltage drop developed across the sense resistor is monitored by the current-sense pin, I_{pk}. When the voltage drop across the sense resistor becomes greater than the preset value of 330 mV, the current-limit circuitry provides an additional current path to charge the timing capacitor (C_T) rapidly, to reach the upper oscillator threshold and, thus, limiting the amount of energy stored in the inductor. The minimum sense resistor is 0.2 Ω. Figure 4 shows the timing capacitor charge current versus current-limit sense voltage. To set the peak current, I_{pk} = 330 mV/R_{sense}.

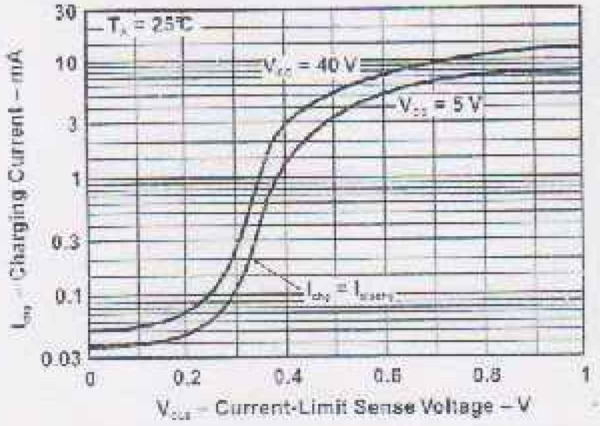


Figure 4. Timing Capacitor Charge Current vs Current-Limit Sense Voltage

Output Switch

The output switch is an NPN Darlington transistor. The collector of the output transistor is tied to pin 1, and the emitter is tied to pin 2. This allows the designer to use the MC34063 in buck, boost, or inverter configurations. The maximum collector-emitter saturation voltage at 1.5 A (peak) is 1.3 V, and the maximum peak current of the output switch is 1.5 A. For higher peak output current, an external transistor can be used. Figure 5 shows the typical operation waveforms.

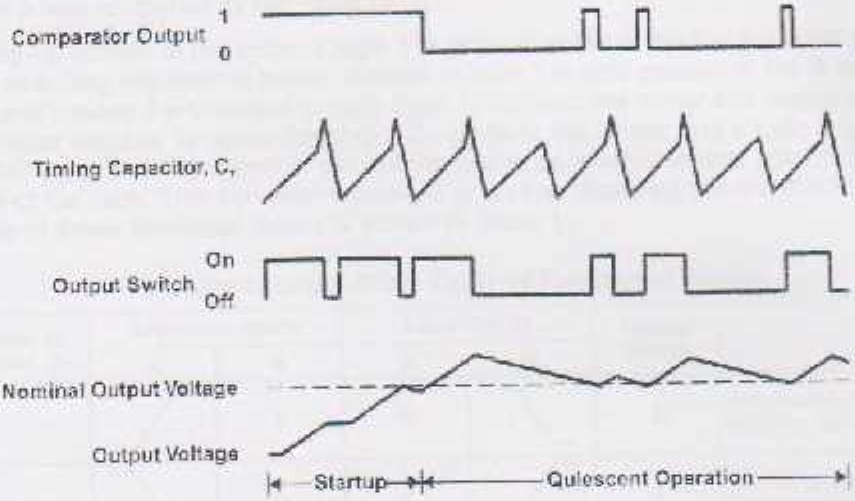


Figure 5. Typical Operation Waveforms

Functional Description

The oscillator is composed of a current source and sink, which charge and discharge the external timing capacitor (C_T) between an upper and lower preset threshold. The typical charge and discharge currents are 35 mA and 200 mA, respectively, yielding approximately a 6:1 ratio. Thus, the ramp-up period is six times longer than that of the ramp-down period (see Figure 3). The upper threshold is equal to internal reference voltage of 1.25 V, and the lower threshold is approximately equal to 0.75 V. The oscillator runs continuously at a rate controlled by the value of C_T.

During the ramp-up portion of the cycle, a logic 1 is present at the A input of the AND gate. If the output voltage of the switching regulator is below nominal, a logic 1 is also present at the B input. This condition sets the latch and causes the Q output to be a logic 1, enabling the driver and output switch to conduct. When the oscillator reaches its upper threshold, C_T starts to discharge, and a logic 0 is present at the A input of the AND gate. This logic level is also connected to an inverter whose output presents a logic 1 to the reset input of the latch. This condition causes Q to go low, disabling the driver and output switch. A logic truth table of these functional blocks is shown in Table 1.

Table 1. Logic Truth Table of Functional Blocks

Active Condition of Timing Capacitor, C_T	AND Gate Inputs		Latch Inputs		Output Switch	Comments
	A	B	S	R		
Begin ramp up	╱	0	0	╲	0	Regulator output is greater than or equal to nominal (B = 0).
Begin ramp down	╲	0	0	╱	0	No change, because B was 0 before C_T ramp down.
Ramping down	0	╱	0	1	0	No change even though regulator output less than nominal. Output switch cannot be initiated during R_T ramp down.
Ramping down	0	╲	0	1	0	No change, because output switch condition was terminated when A = 0.
Ramping up	1	╱	╱	0	╱	Regulator output became less than nominal during C_T ramp up (when B changed to 1). Partial on cycle for output switch.
Ramping up	1	╲	╲	0	1	Regulator output became greater than or equal to nominal (B changed to 0) during ramp up of C_T. No change, because B cannot reset the latch.
Begin ramp up	╱	1	╱	╲	╱	Complete on cycle, because B = 1 before C_T ramp up started.
Begin ramp down	╲	1	╲	╱	╲	Output switch conduction is always terminated when C_T is ramping down.

The output of the comparator can set the latch only during the ramp up of C_T and can initiate a partial or full on cycle of output switch conduction. Once the comparator has set the latch, it cannot reset it. The latch remains set until C_T begins ramping down. Thus, the comparator can initiate output switch conduction but cannot terminate it, and the latch is always reset when C_T begins ramping down. The comparator's output is at a logic 0 when the output voltage of the switching regulator is above nominal. Under these conditions, the comparator's output can inhibit a portion of the output switch on cycle, a complete cycle, a complete cycle plus a portion of one cycle, multiple cycle, or multiple cycles plus a portion of one cycle.

Buck Regulator

Figure 6 shows the basic buck switching regulator. Q1 interrupts the input voltage and provides a variable duty-cycle square wave to an LC filter. The filter averages the square wave and produces a dc output voltage that can be set to any level less than the input by controlling the percent conduction time of Q1 to that of the total switching cycle time.

$V_{out} = V_{in}(\%t_{on})$

or

$V_{out} = V_{in}(t_{on}/(t_{on} + t_{off}))$

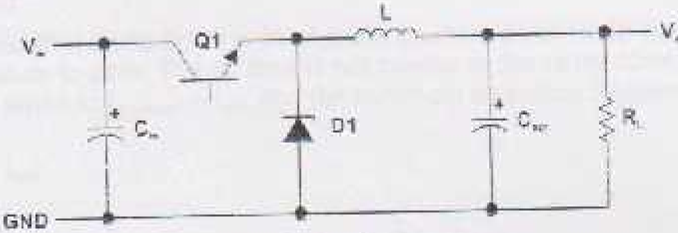


Figure 6. Buck Regulator

Buck Converter Operation

As an example, suppose that the transistor Q1 is off, the inductor current (I_L) is zero, and the output voltage is at its nominal value. The output voltage across capacitor C_{out} will ultimately decay below the nominal output level, because it is the only source of supply current to load R_L. This voltage deficiency is sensed by the switching control circuit and causes Q1 to turn on. The inductor current starts to flow from V_{in} through Q1 and C_{out} in parallel with R_L, and it rises at a rate of $\Delta I/\Delta t = V/L$. The voltage across the inductor is equal to $V_{in} - V_{sat} - V_{out}$, and the inductor peak current at any instant is calculated as shown here:

$I_L = ((V_{in} - V_{sat} - V_{out})/L)t$

At the end of the on period, Q1 is turned off. As the magnetic field in the inductor starts to collapse, it generates a reverse voltage that forward biases D1, and the peak current decays at a rate of $\Delta I/\Delta t = V/L$ as energy is supplied to C_{out} and R_L. The voltage across the inductor during this period is equal to $V_{out} + V_F$ of D1. The current as a function of time is calculated as shown here:

$I_L = I_{L(pk)} - ((V_{out} + V_F)/L)t$

Where V_F is the forward voltage of D1.

Time-On and Time-Off Calculation

As an example, suppose that during quiescent operation, the average output voltage is constant, and the system is operating in the discontinuous mode. Then $I_{L(pk)}$ attained during t_{on} must decay to zero during t_{off}, and a ratio of t_{on} to t_{off} can be determined.

$((V_{in} - V_{sat} - V_{out})/L)t_{on} = ((V_{out} + V_F)/L)t_{off}$

$\therefore t_{on}/t_{off} = (V_{out} + V_F)/(V_{in} - V_{sat} - V_{out})$

Switch Peak Current Calculation

The volt-time product of t_{on} must be equal to that of t_{off}, and the inductance value is not a factor when determining their ratio. If the output voltage inside a switching period is to remain constant, the average current into the inductor must be equal to the output current for a complete cycle. The peak inductor current with respect to output current is:

$(I_{L(pk)}/2)t_{on} + (I_{L(pk)}/2)t_{off} = I_{out}t_{on} + I_{out}t_{off}$

$\therefore I_{L(pk)} = 2I_{out}$

Timing Capacitor Calculation

The peak inductor current is also equal to the peak switch current, since the two are in series. The on time (t_{on}) is the maximum possible switch conduction time. It is equal to the time required for C_T to ramp up from its lower to upper threshold. The required value for C_T can be determined by using the minimum oscillator charging current and the typical value for the peak-to-peak oscillator voltage swing, both taken from the data sheet:

$C_T = I_{chg(min)}(\Delta t/\Delta V)$
$C_T = 20 \times 10^{-6}(t_{on}/0.5)$
$C_T = 4.0 \times 10^{-5}(t_{on})$

The off time is the time that diode D1 is in conduction and it is determined by the time required for the inductor current to return to zero. The off time is not related to the ramp-down time of CT. The cycle time of the LC network is equal to $t_{on(max)} + t_{off}$, and the minimum operation frequency is calculated as shown here:

$f_{min} = 1/(t_{on(max)} + t_{off})$

Inductance Calculation

The minimum value of inductance (L) can now be calculated. The V-known quantities are the voltage across the inductor and the required peak current for the selected switch conduction time:

$L_{min} = ((V_{in} - V_{sat} - V_{out})/I_{pk(switch)})t_{on}$

The minimum value of inductance is calculated assuming the onset of continuous conduction operation with a fixed input voltage, maximum output current, and a minimum charge-current oscillator.

The net charge per cycle delivered to output filter capacitor (C_{out}) must be zero (Q+ = Q–) if the output voltage is to remain constant.

Output Voltage Ripple

The ripple voltage can be calculated from the known values of on time, off time, peak inductor current, and output capacitor value:

During t_{on}

$ic(t) = I_{pk}/t_{on} \times t$, positive slope

$V(t) = 1/C_{out} \int I_{pk}/t_{on} \times t\,dt$

$= I_{pk}/(C_{out} \times t_{on}) \times t^2/2 + \text{constant}$

The axis of the parabola pass was chosen by its minimum, so constant = 0.

$= I_{pk}/(C_{out} \times t_{on}) \times t^2/2$

$V(t_{on}/2) = I_{pk}/(C_{out} \times t_{on}) \times (t_{on}/2)^2/2$

$= I_{pk}/C_{out} \times t_{on}/8$

During t_{off}

$ic(t) = -I_{pk}/t_{off} \times t$, negative slope

$V(t) = -1/C_{out} \int I_{pk}/t_{off} \times t\,dt$

$= -I_{pk}/(C_{out} \times t_{off}) \times t^2/2 + \text{constant}$

The axis of the parabola pass was chosen by its minimum, so constant = 0.

$= -I_{pk}/(C_{out} \times t_{off}) \times t^2/2$

$V(t_{off}/2) = -I_{pk}/(C_{out} \times t_{off}) \times (t_{off}/2)^2/2$

$= -I_{pk}/C_{out} \times t_{off}/8$

$V_{ripple(C)} = |V(t_{on}/2)| + |V(t_{off}/2)|$

$= (I_{pk}/C_{out}) \times (t_{on}/8) + (I_{pk}/C_{out}) \times (t_{off}/8)$

$$V_{ripple(C)} = (I_{pk}/C_{out}) \times (t_{on} + t_{off})/8$$
$$V_{ripple(ESR)} = I_{pk} \times ESR$$
$$V_{ripple(p-p)} = I_{pk}/C_{out} \times (t_{on} + t_{off}) + I_{pk} \times ESR$$
$$V_{ripple(p-p)} = I_{pk} \times [(1/8C) \times (t_{on} + t_{off}) + ESR]$$

Figure 7 shows a graphical derivation of the peak-to-peak ripple voltage that was obtained from the capacitor current and voltage waveforms.

The calculations shown above account for the ripple voltage contributed by the ripple current into an ideal capacitor.

In practice, the calculated value should be increased due to the internal equivalent series resistance (ESR) of the capacitor. The additional ripple voltage is equal to $I_{pk(ESR)}$. Increasing the value of the filter capacitor reduces the output ripple voltage. However, a point of diminishing return is reached, because the comparator requires a finite voltage difference across its inputs to control the latch. The voltage difference required to completely change the latch states is about 1.5 mV, and the minimum achievable ripple at the output is the feedback divider ratio multiplied by 1.5 mV:

$$V_{ripple(p-p)}(min) = (V_{out}/V_{ref})(1.5 \times 10^{-3})$$

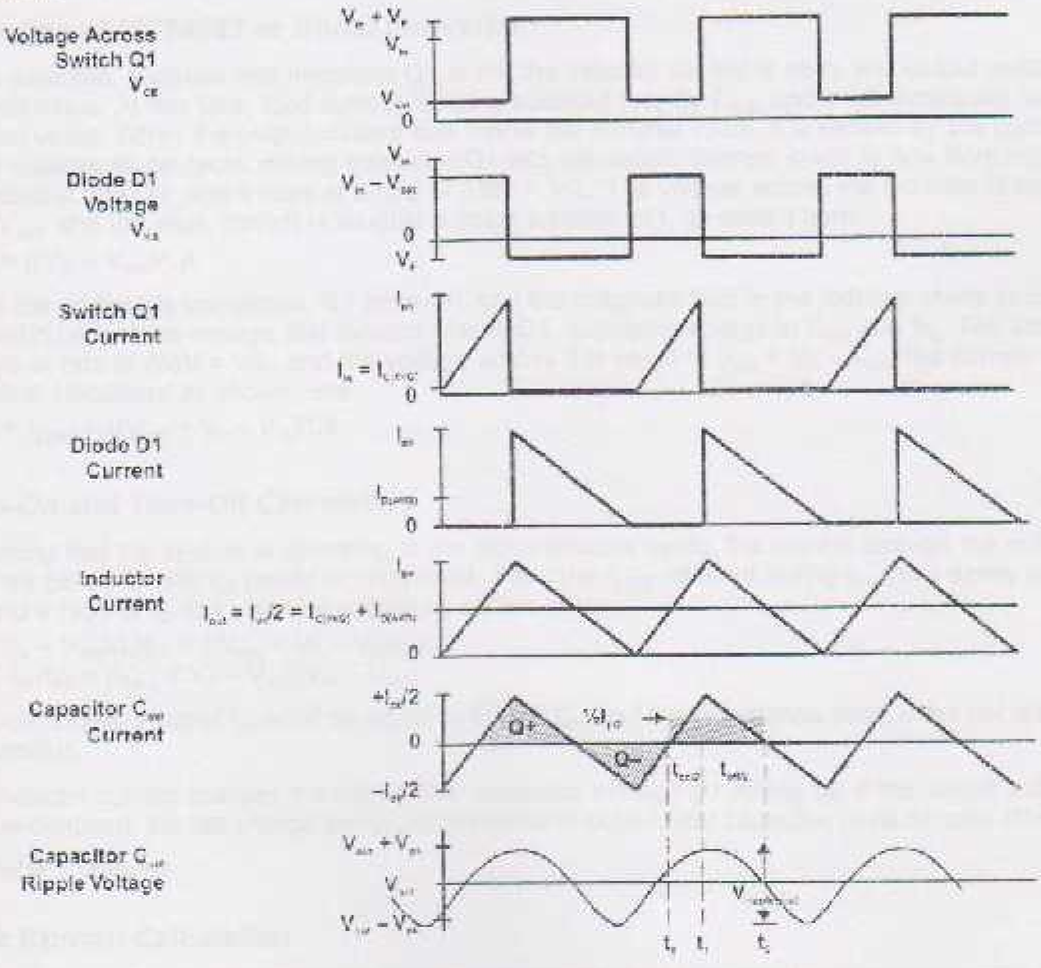


Figure 7. Buck Switching Regulator Waveforms

Boost Switching Regulator

Figure 8 shows a basic switching regulator. Energy is stored in the inductor during the time that transistor Q1 is in the ON state. When transistor Q1 is turned off, the energy is transferred in series with V_{in} to the output filter capacitor (C_{out}) and load (R_L). This configuration allows the output voltage to be set to any value greater than that of input. The following equations can be used to calculate the output voltage:

$V_{out} = V_{in}(t_{on}/t_{off}) + V_{in}$
or
$V_{out} = V_{in}((t_{on}/t_{off}) + 1)$

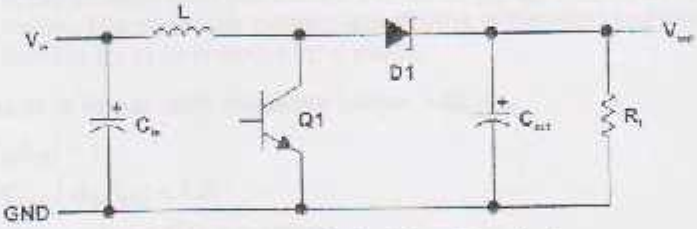


Figure 8. Boost Switching Regulator

Operation of MC34063 as Boost Converter

As an example, suppose that transistor Q1 is off, the inductor current is zero, and output voltage is at its nominal value. At this time, load current is being supplied only by C_{out}, and it will eventually fall below nominal value. When the output voltage falls below the nominal value, it is sensed by the control circuit, which initiates an on cycle, driving transistor Q1 into saturation. Current starts to flow from input through the inductor and Q1, and it rises at a rate of $\Delta I/\Delta t = V/L$. The voltage across the inductor is equal to $V_{in} - V_{sat}$, and the peak current is roughly a linear function of t, as shown here:

$I_L = ((V_{in} - V_{sat})/L)t$

When the on-time is completed, Q1 turns off, and the magnetic field in the inductor starts to collapse, generating a reverse voltage that forward biases D1, supplying energy to C_{out} and R_L. The inductor curren decays at rate of $\Delta I/\Delta t = V/L$, and the voltage across it is equal to $V_{out} + V_F - V_{in}$. The current at any instant is calculated as shown here:

$I_L = I_{L(pk)} - ((V_{out} + V_F - V_{in})/L)t$

Time-On and Time-Off Calculation

Assuming that the system is operating in the discontinuous mode, the current through the inductor reaches zero after the t_{off} period is completed. Then the $I_{L(pk)}$ attained during t_{on} must decay to zero durin t_{off}, and a ratio of t_{on} to t_{off} can be written as shown here:

$((V_{in} - V_{sat})/L)t_{on} = ((V_{out} + V_F - V_{in})/L)t_{off}$
$\therefore t_{on}/t_{off} = (V_{out} + V_F - V_{in})/(V_{in} - V_{sat})$

The volt-time product of t_{on} must be equal to that of t_{off}, and the inductance value does not affect this relationship.

The inductor current charges the output filter capacitor through D1 during t_{off}. If the output voltage is to remain constant, the net charge per cycle delivered to output filter capacitor must be zero (Q+ = Q–).

$I_{chg}t_{off} = I_{dischg}t_{on}$

Peak Current Calculation

Figure 9 shows the boost switching regulator waveforms. By observing the capacitor current and makin some substitution in the previous equation, a formula for peak inductor current can be obtained.

$(I_{L(pk)}/2)t_{off} = I_{out}(t_{on} + t_{off})$
$\therefore I_{L(pk)} = 2I_{out}(t_{on}/t_{off} + 1)$

Inductance Calculation

The peak inductor current is also equal to the peak switch current, since the two are in series. By knowing the voltage across the inductor during t_{on} and the required peak current for the selected switch conduction time, a minimum inductance value can be determined:

$$L_{min} = ((V_{in} - V_{sat})/I_{pk(switch)})t_{on(max)}$$

Output Voltage Ripple

Calculate the output ripple voltage from the known values of t_{on}, t_{off}, peak inductor current, output current, and output capacitor value. The capacitor current waveforms is depicted in Figure 9, t1 being the discharging interval. Solving for t1 in known terms yields:

[illegible] linear with negative slope [illegible]

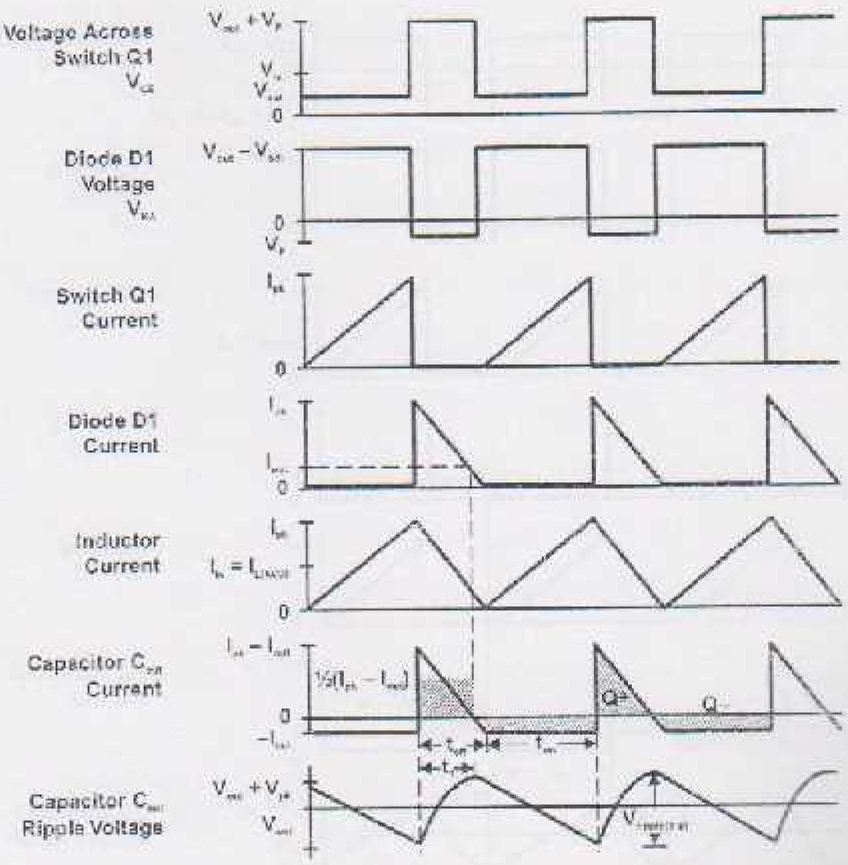


Figure 9. Boost Switching Regulator Waveforms

Inverting Switching Regulator

A basic voltage-inverting switching regulator is shown in Figure 10. The energy is stored in the inductor during the conduction time of Q1. Upon the Q1 turn off, the energy is transferred to the output filter capacitor and load. In this configuration, the output voltage is derived only from the inductor. This allows the magnitude of the output to be set to any value. It may be less than, equal to, or greater than that of input and is set by the following

$V_{out} = V_{in}(t_{on}/t_{off})$

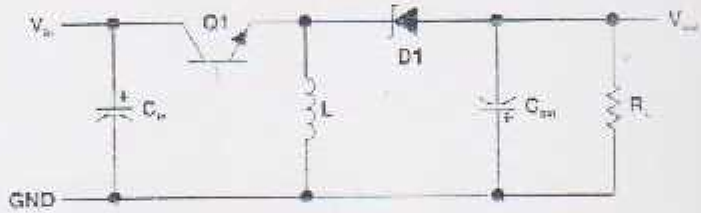


Figure 10. Switching Inverter Regulator

The inverter converter operates identically to that of the boost converter. The voltage across the inductor during t_{on} is $V_{in} - V_{sat}$ but, during t_{off}, the voltage is equal to the negative magnitude of $V_{out} + V_F$. The VLT time-product of t_{on} must be equal to that of t_{off}, a ratio of t_{on} to t_{off} can be determined:

$(V_{in} - V_{sat})t_{on} = (|V_{out}| + V_F)t_{off}$

$\therefore t_{on}/t_{off} = (|V_{out}| + V_F)/(V_{in} - V_{sat})$

The derivations and the formulas for $I_{pk(switch)}$, $L_{(min)}$, and C_{out} are the same as that of the boost converter. Figure 11 shows the voltage-inverter switching regulator waveforms.

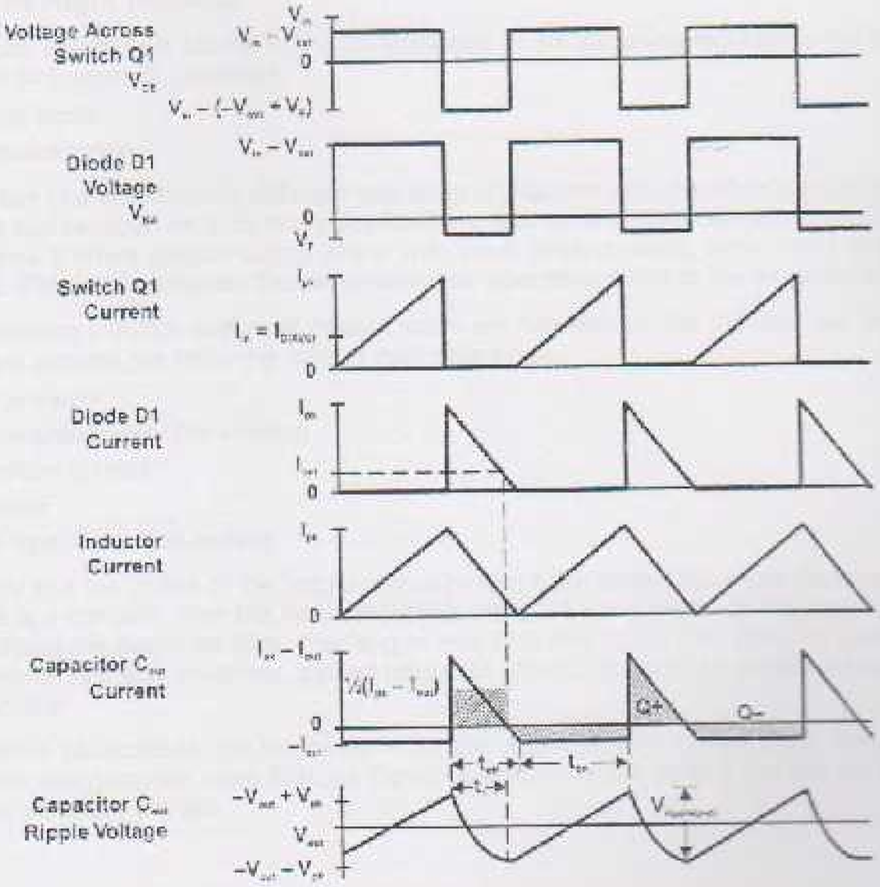


Figure 11. Inverter Switching Regulator Waveforms

Selecting the Right Inductor

Proper inductor selection is crucial to the performance of the switching regulator's design. The switchin regulator has two mode of operation:

- Continuous mode
- Discontinuous mode

Each mode has characteristically different operating characters and, therefore, can affect the regulator performance and requirements. In many applications, the continuous mode is the preferred mode of operation, since it offers greater output power with lower peak currents, wider input range, and lower output ripple. These advantages of continuous-mode operation come at the expense of a larger induct

Once the minimum inductor and peak current value are determined, the inductor can be selected. Mos manufacturers provide the following data in their data book:

- Inductance value
- DCR (dc resistance) of the winding
- DC saturation current
- RMS current
- Package type, size, and pattern

The geometry and the shape of the inductor chosen can have advantages and disadvantages. If high performance is a concern, then the toroid inductors are the best choices, as the magnetic flux is conta completely within the magnetic core, resulting in less EMI and noise. The EMI and noise can affect ne sensitive circuits. In these situations, closed magnetic structures, such as toroid, pot core, or E-core, a more appropriate.

In cost-sensitive applications, the inexpensive bobbin core inductors can be used. However, the bobbi core inductors can generate more EMI, as the open core does not confine the flux within the core and affect nearby sensitive circuits.

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Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
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International
IOR Rectifier

Data Sheet No. PD60029 revJ

IR2155&(PbF)

(NOTE: For new designs, we recommend IR's new products IR2153 and IR21531)

SELF-OSCILLATING HALF-BRIDGE DRIVER

Features

- Floating channel designed for bootstrap operation
  Fully operational to +600V
  Tolerant to negative transient voltage
  dV/dt immune
- Undervoltage lockout
- Programmable oscillator frequency

$$f = \frac{1}{1.4 \times (R_T + 150\Omega) \times C_T}$$

- Matched propagation delay for both channels
- Micropower supply startup current of 125 A typ.
- Low side output in phase with R_T
- Available in Lead-Free

Description

The IR2155 is a high voltage, high speed, self-oscillating power MOSFET and IGBT driver with both high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. The front end features a programmable oscillator which is similar to the 555 timer. The output drivers feature a high pulse current buffer stage and an internal deadtime designed for minimum driver cross-conduction. Propagation delays for the two channels are matched to simplify use in 50% duty cycle applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration that operates off a high voltage rail up to 600 volts.

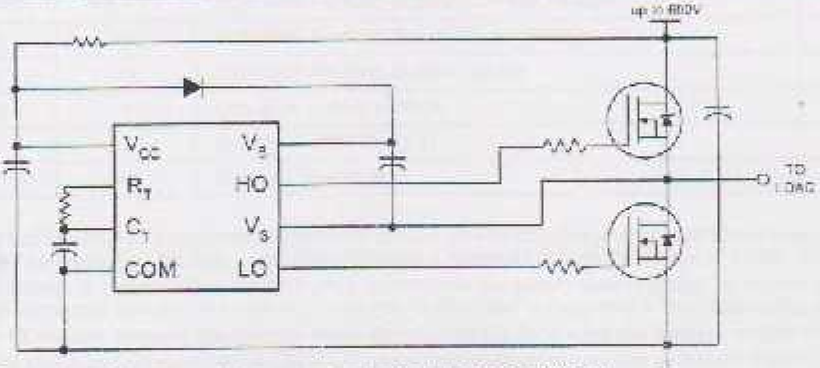
Product Summary

V_{OFFSET}	600V max.
Duty Cycle	50%
I_O+/-	210 mA / 420 mA
V_{OUT}	10 - 20V
Deadtime (typ.)	1.2 s

Package

8 Lead PDIP

Typical Connection



(Refer to Lead Assignment diagram for correct pin configuration)

Absolute Maximum Ratings

Absolute Maximum Ratings indicate sustained limits beyond which damage to the device may occur. All voltage parameters are absolute voltages referenced to COM. The Thermal Resistance and Power Dissipation ratings are measured under board mounted and still air conditions.

Units	Value		Parameter	
	Max.	Min.	Definition	Symbol
V	625	-0.3	High Side Floating Supply Voltage	V_B
	V_B + 0.3	V_B - 25	High Side Floating Supply Offset Voltage	V_S
	V_B + 0.3	V_S - 0.3	High Side Floating Output Voltage	V_{HO}
	V_{CC} + 0.3	-0.3	Low Side Output Voltage	V_{LO}
	V_{CC} + 0.3	-0.3	R_T Voltage	V_{RT}
	V_{CC} + 0.3	-0.3	C_T Voltage	V_{CT}
mA	25	—	Supply Current (Note 1)	I_{CC}
	5	-5	R_T Output Current	I_{RT}
V/ns	50	—	Allowable Offset Supply Voltage Transient	dV_s/dt
W	1.0	—	Package Power Dissipation @ T_A = +25 C (8 Lead DIP)	P_D
	0.625	—	(8 Lead SOIC)	
C/W	125	—	Thermal Resistance, Junction to Ambient (8 Lead DIP)	$R_{\theta JA}$
	200	—	(8 Lead SOIC)	
C	150	—	Junction Temperature	T_J
	150	-55	Storage Temperature	T_S
	300	—	Lead Temperature (Soldering, 10 seconds)	T_L

Recommended Operating Conditions

The Input/Output logic timing diagram is shown in Figure 1. For proper operation the device should be used within the recommended conditions. The V_S offset rating is tested with all supplies biased at 15V differential.

Units	Value		Parameter	
	Max.	Min.	Definition	Symbol
V	V_S + 20	V_S + 10	High Side Floating Supply Absolute Voltage	V_B
	600	—	High Side Floating Supply Offset Voltage	V_S
	V_B	V_S	High Side Floating Output Voltage	V_{HO}
	V_{CC}	0	Low Side Output Voltage	V_{LO}
mA	5	—	Supply Current (Note 1)	I_{CC}
C	125	-40	Ambient Temperature	T_A

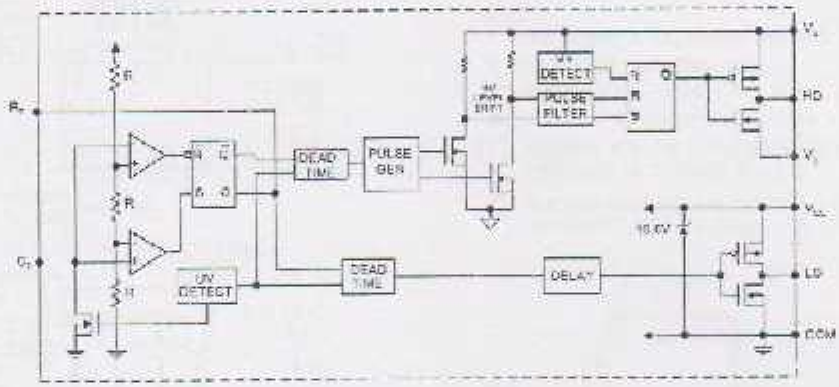
Note 1. Because of the IR2155's application specificity toward off-line supply systems, this IC contains a zener clamp structure between the chip V_{CC} and COM which has a nominal breakdown voltage of 15.6V. Therefore, the IC supply voltage is normally derived by forcing current into the supply lead (typically by means of a high value resistor connected between the chip V_{CC} and the rectified line voltage and a local decoupling capacitor from V_{CC} to COM) and allowing the internal zener clamp circuit to determine the nominal supply voltage. Therefore, this circuit should not be driven by a DC, low impedance power source of greater than V_{CLAMP}.

Dynamic Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}) = 12V, C_L = 1000 pF and T_A = 25 C unless otherwise specified.

Test Conditions	Units	Value			Parameter	
		Max.	Typ.	Min.	Definition	Symbol
		120	80	—	Turn-On Rise Time	t_r

Functional Block Diagram



Lead Definitions

Lead Description	Symbol
Oscillator timing resistor input.in phase with LO for normal IC operation	R_T
Oscillator timing capacitor input, the oscillator frequency according to the following equation: $f = \frac{1}{1.4 \times (R_T + 150\Omega) \times C_T}$ where 150Ω is the effective impedance of the R_T output stage	C_T
High side floating supply	V_B
High side gate drive output	HO
High side floating supply return	V_S
Low side and logic fixed supply	V_{CC}
Low side gate drive output	LO
Low side return	COM

Lead Assignments

8 Lead DIP

IR2155

NOTES:

1. DIMENSIONING & TOLERANCING PER ANSI Y14.5M-1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSIONS ARE SHOWN IN MILLIMETERS [INCHES].

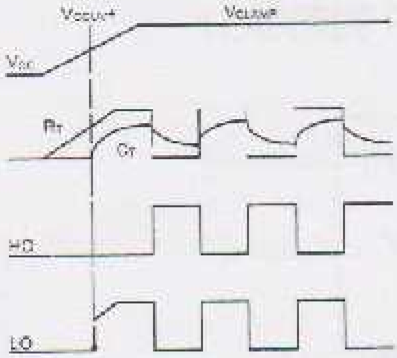


Figure 1. Input/Output Timing Diagram

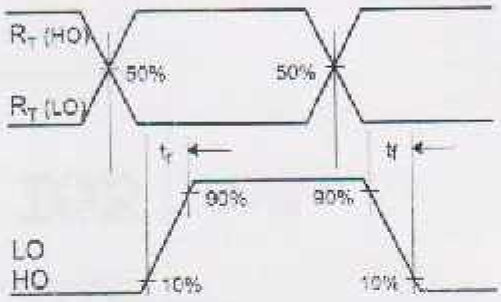


Figure 2. Switching Time Waveform Definitions

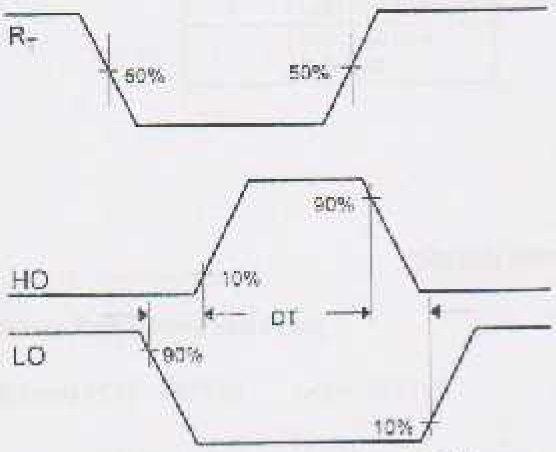


Figure 3. Deadtime Waveform Definitions

LEADFREE PART MARKING INFORMATION

March 2005

National Semiconductor

LM134/LM234/LM334
3-Terminal Adjustable Current Sources

General Description

The LM134/LM234/LM334 are 3-terminal adjustable current sources featuring 10,000:1 range in operating current, excellent current regulation and a wide dynamic voltage range of 1V to 40V. Current is established with one external resistor and no other parts are required. Initial current accuracy is ±3%. The LM134/LM234/LM334 are true floating current sources with no separate power supply connections. In addition, reverse applied voltages of up to 20V will draw only a few dozen microamperes of current, allowing the devices to act as both a rectifier and current source in AC applications.

The sense voltage used to establish operating current in the LM134 is 64mV at 25°C and is directly proportional to absolute temperature (°K). The simplest one external resistor connection, then, generates a current with ≈ +0.33%/°C temperature dependence. Zero drift operation can be obtained by adding one extra resistor and a diode.

Applications for the current sources include bias networks, surge protection, low power reference, ramp generation, LED driver, and temperature sensing. The LM234-3 and LM234-6 are specified as true temperature sensors with guaranteed initial accuracy of ±3°C and ±6°C, respectively. These devices are ideal in remote sense applications because series resistance in long wire runs does not affect accuracy. In addition, only 2 wires are required.

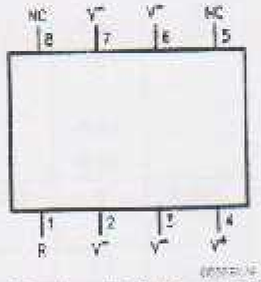
The LM134 is guaranteed over a temperature range of -55°C to +125°C, the LM234 from -25°C to +100°C and the LM334 from 0°C to +70°C. These devices are available in TO-46 hermetic, TO-92 and SO-8 plastic packages.

Features

- Operates from 1V to 40V
- 0.02%/V current regulation
- Programmable from 1µA to 10mA
- True 2-terminal operation
- Available as fully specified temperature sensor
- ±3% initial accuracy

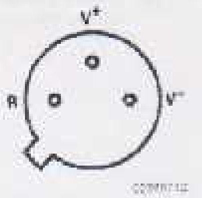
Connection Diagrams

SO-8
Surface Mount Package



Order Number LM334M or LM334MX
See NS Package Number M08A

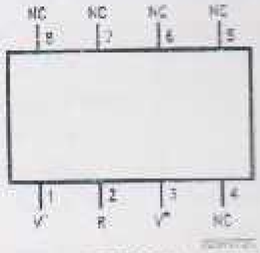
TO-46
Metal Can Package



V⁻ Pin is electrically connected to case.

Bottom View
Order Number LM134H,
LM234H or LM334H See
NS Package Number
H03H

SO-8 Alternative Pinout
Surface Mount Package



Order Number LM334SM or LM334SMX
See NS Package Number M08A

TO-92 Plastic Package

Bottom View
Order Number LM334Z, LM234Z-3 or LM234Z-6
See NS Package Number Z03A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

V^+ to V^- Forward Voltage	
LM134/LM234/LM334	40V
LM234-3/LM234-6	30V
V^+ to V^- Reverse Voltage	20V
R Pin to V^- Voltage	5V
Set Current	10 mA
Power Dissipation	400 mW
ESD Susceptibility (Note 5)	2000V
Operating Temperature Range (Note 5)	
LM134	−55°C to +125°C
LM234/LM234-3/LM234-6	−25°C to +100°C
LM334	0°C to +70°C
Soldering Information	
TO-92 Package (10 sec.)	260°C
TO-46 Package (10 sec.)	300°C
SO Package	
Vapor Phase (60 sec.)	215°C
Infrared (15 sec.)	220°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" (Appendix D) for other methods of soldering surface mount devices.

Electrical Characteristics (Note 2)

Units	LM334			LM134/LM234			Conditions	Parameter
	Max	Typ	Min	Max	Typ	Min		
%	6			3			$10\mu A \le I_{SET} \le 1mA$	Set Current Error, V^+=2.5V, (Note 3)
%	8			5			$1mA < I_{SET} \le 5mA$	
%	12			8			$2\mu A \le I_{SET} < 10\mu A$	
	26	18	14	23	18	14	$100\mu A \le I_{SET} \le 1mA$	Ratio of Set Current to Bias Current
		14			14		$1mA \le I_{SET} \le 5mA$	
	26	18		23	18		$2\mu A \le I_{SET} \le 100\mu A$	
V		0.8			0.8		$2\mu A \le I_{SET} \le 100\mu A$	Minimum Operating Voltage
V		0.9			0.9		$100\mu A < I_{SET} \le 1mA$	
V		1.0			1.0		$1mA < I_{SET} \le 5mA$	
							$2\mu A \le I_{SET} \le 1mA$	Average Change in Set Current with Input Voltage
%/V	0.1	0.02		0.05	0.02		$1.5 \le V^+ \le 5V$	
%/V	0.05	0.01		0.03	0.01		$5V \le V^+ \le 40V$	
							$1mA < I_{SET} \le 5mA$	
%/V		0.03			0.03		$1.5V \le V \le 5V$	
%/V		0.02			0.02		$5V \le V \le 40V$	
	1.04T	T	0.96T	1.04T	T	0.96T	$25\mu A \le I_{SET} \le 1mA$	Temperature Dependence of Set Current (Note 4)
pF		15			15			Effective Shunt Capacitance

Note 1: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

Note 2: Unless otherwise specified, tests are performed at $T_j = 25°C$ with pulse testing so that junction temperature does not change during test.

Note 3: Set current is the current flowing into the V^+ pin. For the Basic 2-Terminal Current Source circuit shown on the first page of this data sheet, I_{SET} is determined by the following formula: $I_{SET} = 67.7\ mV/R_{SET}$ (@ 25°C). Set current error is expressed as a percent deviation from this amount. I_{SET} increases at 0.336%/°C @ $T_j = 25°C$ (227 μV/°C).

ectrical Characteristics (Note 2) (Continued)

4: I_{SET} is directly proportional to absolute temperature (°K). I_{SET} at any temperature can be calculated from: $I_{SET} = I_o (T/T_o)$ where I_o is I_{SET} measured at T_o

5: For elevated temperature operation, T_J max is:

LM134	150°C
LM234	125°C
LM334	100°C

SO-8	TO-46	TO-92	Thermal Resistance
165°C/W	440°C/W	180°C/W (0.4" leads) 160°C/W (0.125" leads)	θ_{JA} (Junction to Ambient)
80°C/W	32°C/W	N/A	θ_{JC} (Junction to Case)

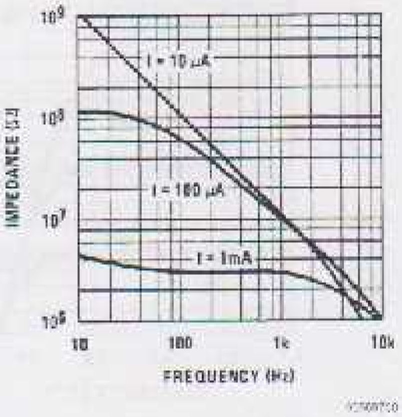
6: Human body model, 100pF discharged through a 1.5kΩ resistor.

lectrical Characteristics (Note 2)

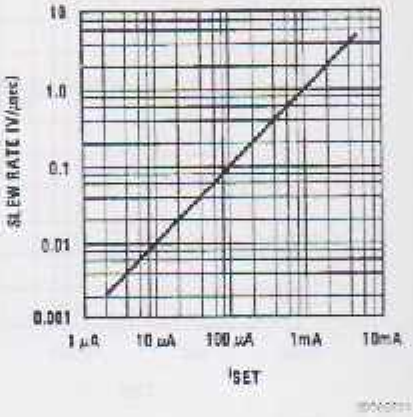
its	LM234-6			LM234-3			Conditions	Parameter
	Max	Typ	Min	Max	Typ	Min		
%	±2			±1			100µA ≤ I_{SET} ≤ 1mA T_J = 25°	Set Current Error, V^+=2.5V, (Note 3)
C	±6			±3				Equivalent Temperature Error
	26	18	14	26	18	14	100µA ≤ I_{SET} ≤ 1mA	Ratio of Set Current to Bias Current
V		0.9			0.9		100µA I_{SET} ≤ 1mA	Minimum Operating Voltage
							100µA ≤ I_{SET} ≤ 1mA	Average Change in Set Current with Input Voltage
/V	0.03	0.02		0.05	0.02		1.5 ≤ V^+ ≤ 5V	
/V	0.05	0.01		0.03	0.01		5V ≤ V^+ ≤ 30V	
	1.03T	T	0.97T	1.02T	T	0.98T	100µA ≤ I_{SET} ≤ 1mA	Temperature Dependence of Set Current (Note 4) and
%	±3			±2				Equivalent Slope Error
F		15			15			Effective Shunt Capacitance

Typical Performance Characteristics

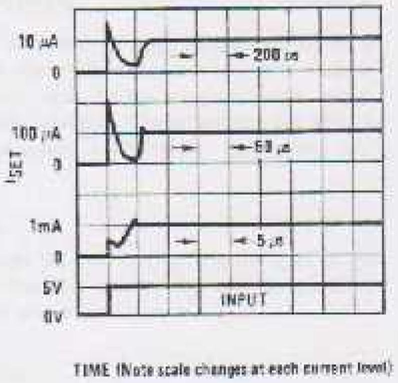
Output Impedance



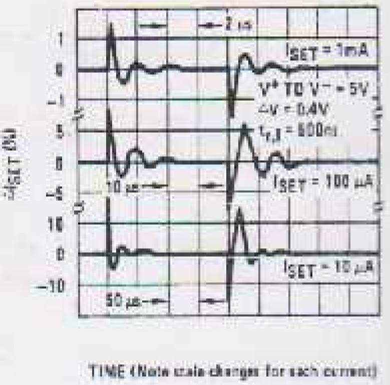
Maximum Slew Rate
Linear Operation



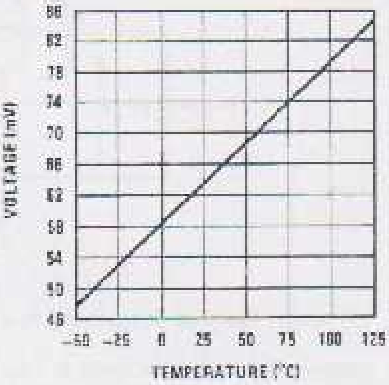
Start-Up



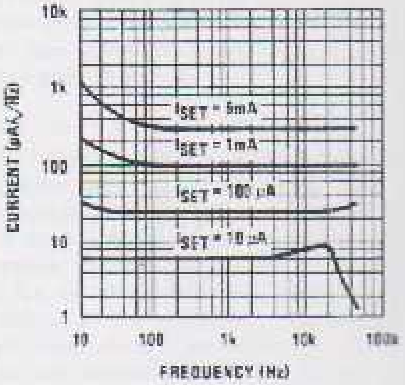
Transient Response



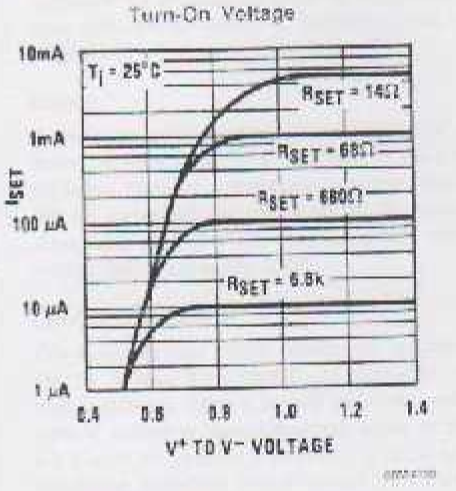
Voltage Across R_{SET} (V_R)

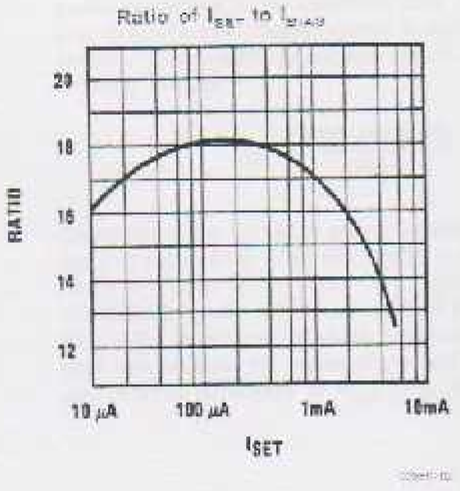


Current Noise



ypical Performance Characteristics (Continued)





Application Hints

he LM134 has been designed for ease of application, but a eneral discussion of design features is presented here to amiliarize the designer with device characteristics which ay not be immediately obvious. These include the effects f slewing, power dissipation, capacitance, noise, and conact resistance.

ALCULATING R_{SET}

he total current through the LM134 (I_{SET}) is the sum of the urrent going through the SET resistor (I_R) and the LM134's ias current (I_{BIAS}), as shown in *Figure 1*.

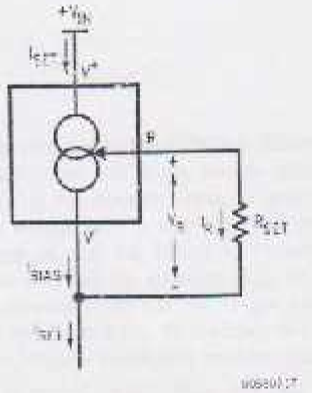


FIGURE 1. Basic Current Source

graph showing the ratio of these two currents is supplied nder Ratio of I_{SET} to I_{BIAS} in the Typical Performance haracteristics section. The current flowing through R_{SET} is etermined by V_R, which is approximately 214µV/°K (64 mV/298°K = 214µV/°K).

$$I_{SET} = I_R + I_{BIAS} = \frac{V_R}{R_{SET}} + I_{BIAS}$$

ince (for a given set current) I_{BIAS} is simply a percentage of SET, the equation can be rewritten

$$I_{SET} = \left(\frac{V_R}{R_{SET}}\right)\left(\frac{n}{n-1}\right)$$

where n is the ratio of I_{SET} to I_{BIAS} as specified in the Electrical Characteristics Section and shown in the graph. Since n is typically 18 for 2µA ≤ I_{SET} ≤ 1mA, the equation can be further simplified to

$$I_{SET} = \left(\frac{V_R}{R_{SET}}\right)(1.059) = \frac{227\ \mu V/°K}{R_{SET}}$$

for most set currents.

SLEW RATE

At slew rates above a given threshold (see curve), the LM134 may exhibit non-linear current shifts. The slewing rate at which this occurs is directly proportional to I_{SET}. At I_{SET} = 10µA, maximum dV/dt is 0.01V/µs; at I_{SET} = 1mA, the limit is 1V/µs. Slew rates above the limit do not harm the LM134, or cause large currents to flow.

THERMAL EFFECTS

Internal heating can have a significant effect on current regulation for I_{SET} greater than 100µA. For example, each 1V increase across the LM134 at I_{SET} = 1 mA will increase junction temperature by ≈0.4°C in still air. Output current (I_{SET}) has a temperature coefficient of ≈0.33%/°C, so the change in current due to temperature rise will be (0.4) (0.33) = 0.132%. This is a 10:1 degradation in regulation compared to true electrical effects. Thermal effects, therefore, must be taken into account when DC regulation is critical and I_{SET} exceeds 100µA. Heat sinking of the TO-46 package or the TO-92 leads can reduce this effect by more than 3:1.

SHUNT CAPACITANCE

In certain applications, the 15 pF shunt capacitance of the LM134 may have to be reduced, either because of loading problems or because it limits the AC output impedance of the current source. This can be easily accomplished by buffering the LM134 with an FET as shown in the applications. This can reduce capacitance to less than 3 pF and improve

Application Hints (Continued)

regulation by at least an order of magnitude. DC characteristics (with the exception of minimum input voltage), are not affected.

NOISE

Current noise generated by the LM134 is approximately 4 times the shot noise of a transistor. If the LM134 is used as an active load for a transistor amplifier, input referred noise will be increased by about 12dB. In many cases, this is acceptable and a single stage amplifier can be built with a voltage gain exceeding 2000.

LEAD RESISTANCE

The sense voltage which determines operating current of the LM134 is less than 100mV. At this level, thermocouple or lead resistance effects should be minimized by locating the current setting resistor physically close to the device. Sockets should be avoided if possible. It takes only 0.7Ω contact resistance to reduce output current by 1% at the 1 mA level.

SENSING TEMPERATURE

The LM134 makes an ideal remote temperature sensor because its current mode operation does not lose accuracy over long wire runs. Output current is directly proportional to absolute temperature in degrees Kelvin, according to the following formula:

$$I_{SET} = \frac{(227\ \mu V/°K)\ (T)}{R_{SET}}$$

Calibration of the LM134 is greatly simplified because of the fact that most of the initial inaccuracy is due to a gain term (slope error) and not an offset. This means that a calibration consisting of a gain adjustment only will trim both slope and zero at the same time. In addition, gain adjustment is a one point trim because the output of the LM134 extrapolates to zero at 0°K, independent of R_{SET} or any initial inaccuracy.

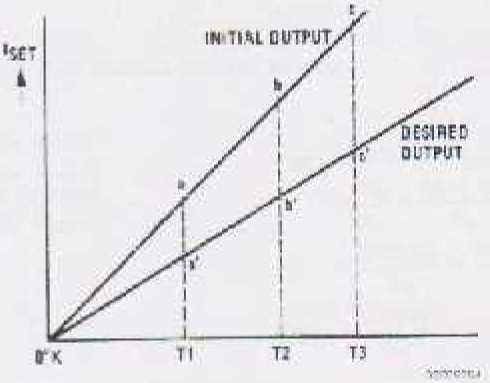


FIGURE 2. Gain Adjustment

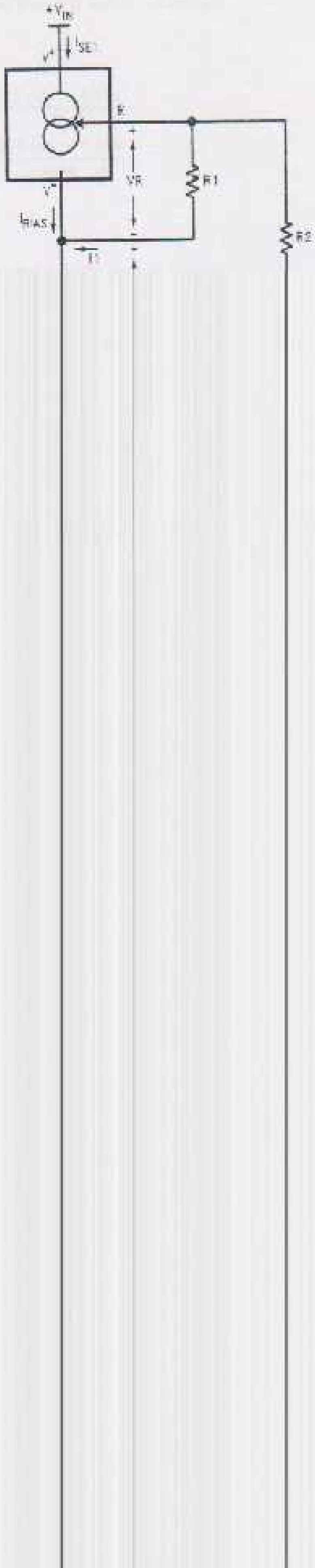
This property of the LM134 is illustrated in the accompanying graph. Line abc is the sensor current before trimming. Line a'b'c' is the desired output. A gain trim done at T2 will move the output from b to b' and will simultaneously correct the slope so that the output at T1 and T3 will be correct. This gain trim can be done on R_{SET} or on the load resistor used to terminate the LM134. Slope error after trim will normally be less than ±1%. To maintain this accuracy, however, a low temperature coefficient resistor must be used for R_{SET}.

A 33 ppm/°C drift of R_{SET} will give a 1% slope error because the resistor will normally see about the same temperature variations as the LM134. Separating R_{SET} from the LM134 requires 3 wires and has lead resistance problems, so is not normally recommended. Metal film resistors with less than 20 ppm/°C drift are readily available. Wire wound resistors may also be used where best stability is required.

APPLICATION AS A ZERO TEMPERATURE COEFFICENT CURRENT SOURCE

Adding a diode and a resistor to the standard LM134 configuration can cancel the temperature-dependent characteristic of the LM134. The circuit shown in Figure 3 balances the positive tempco of the LM134 (about +0.23 mV/°C) with the negative tempco of a forward-biased silicon diode (about −2.5 mV/°C).

Application Hints (Continued)



Application Hints (Continued)

If the forward voltage drop of the diode was 0.65V instead of the estimate of 0.6V (an error of 8%), the actual set current will be

$$I_{SET} = \frac{67.7\text{ mV}}{R_1} + \frac{67.7\text{ mV} + 0.65\text{V}}{R_2}$$
$$= \frac{67.7\text{ mV}}{133} + \frac{67.7\text{ mV} + 0.65\text{V}}{1330}$$
$$= 1.049\text{ mA}$$

an error of less than 5%.

If the estimate for the tempco of the diode's forward voltage drop was off, the tempco cancellation is still reasonably effective. Assume the tempco of the diode is 2.6mV/°C instead of 2.5mV/°C (an error of 4%). The tempco of the circuit is now:

$$\frac{dI_{SET}}{dT} = \frac{dI_1}{dT} + \frac{dI_2}{dT}$$
$$= \frac{227\ \mu\text{V/°C}}{133\Omega} + \frac{227\ \mu\text{V/°C} - 2.6\text{ mV/°C}}{1330\Omega}$$
$$= -77\text{ nA/°C}$$

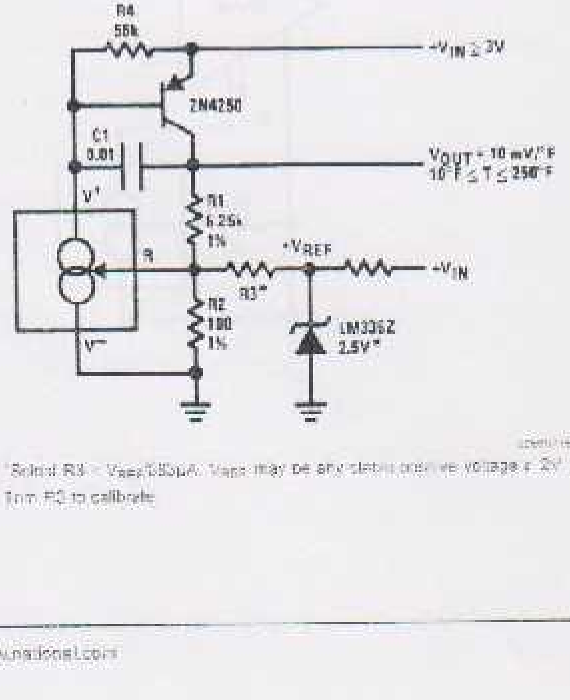
A 1mA LM134 current source with no temperature compensation would have a set resistor of 68Ω and a resulting tempco of

$$\frac{227\ \mu\text{V/°C}}{68\Omega} = 3.3\ \mu\text{A/°C}$$

So even if the diode's tempco varies as much as ±4% from its estimated value, the circuit still eliminates 98% of the LM134's inherent tempco.

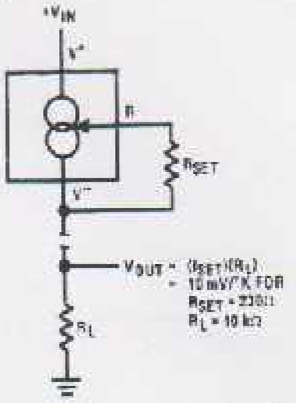
Typical Applications

Ground Referred Fahrenheit Thermometer

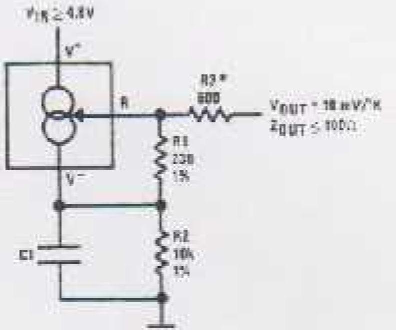


*Select R3 = V_REF/583µA. V_REF may be any stable positive voltage ≥ 2V. Trim R3 to calibrate.

Terminating Remote Sensor for Voltage Output



Low Output Impedance Thermometer

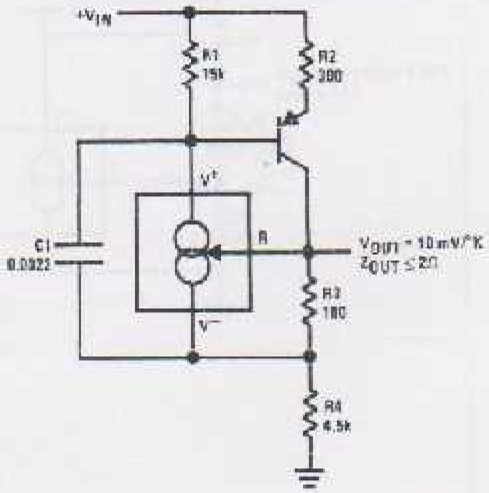


*Output impedance of the LM134 at the "R" pin is approximately

$$\frac{-R_2}{16}$$

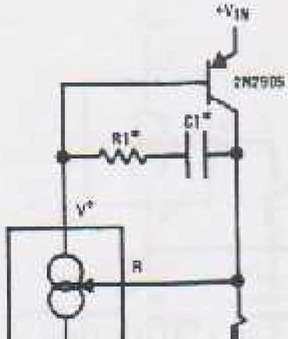
where R_2 is the equivalent external resistance connected from the V− pin to ground. This negative resistance can be reduced by a factor of 5 or more by inserting an equivalent resistor $R_3 = (R_2/16)$ in series with the output.

Low Output Impedance Thermometer



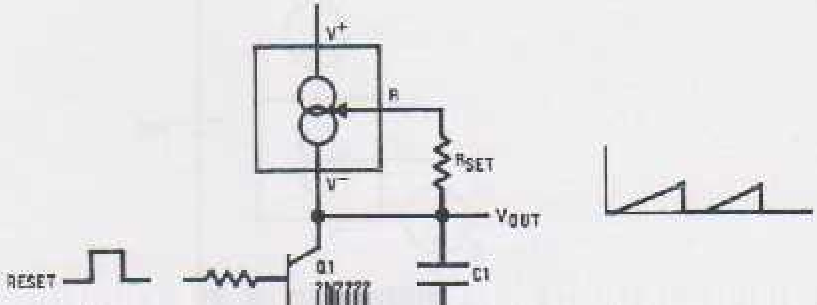
Typical Applications (Continued)

Higher Output Current



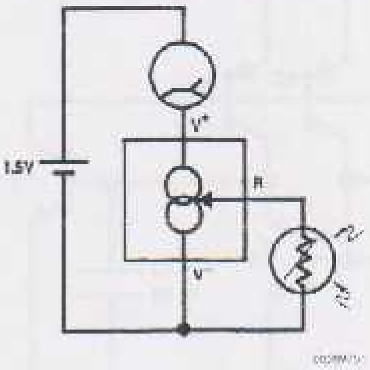
Typical Applications (Continued)

Ramp Generator

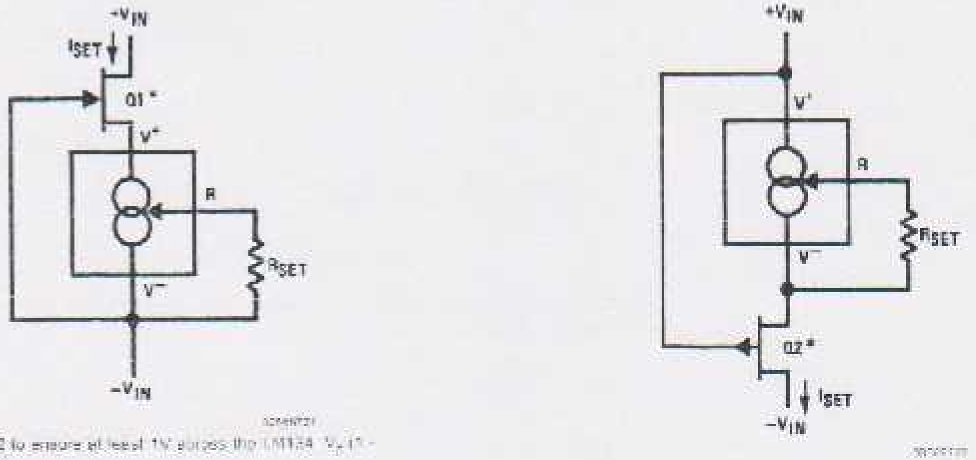


Typical Applications (Continued)

Buffer for Photoconductive Cell



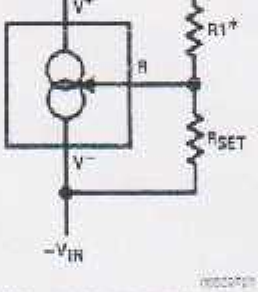
FET Cascoding for Low Capacitance and/or Ultra High Output Impedance



*Select Q1 or Q2 to ensure at least 1V across the LM134. $V_P(1 - I_{SET}/I_{DSS}) \geq 1.2V$

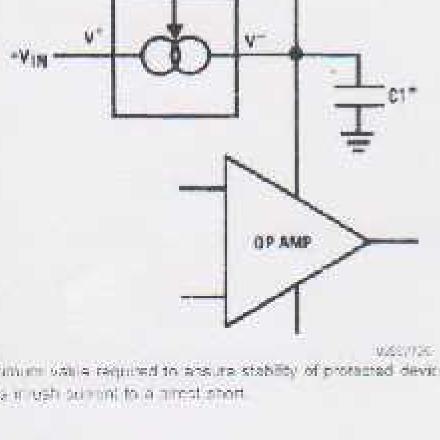
FIGURE 4.

Generating Negative Output Impedance



*$Z_{OUT} \approx -16 \cdot R1$ ($R1/V_{IN}$ must not [illegible] less)

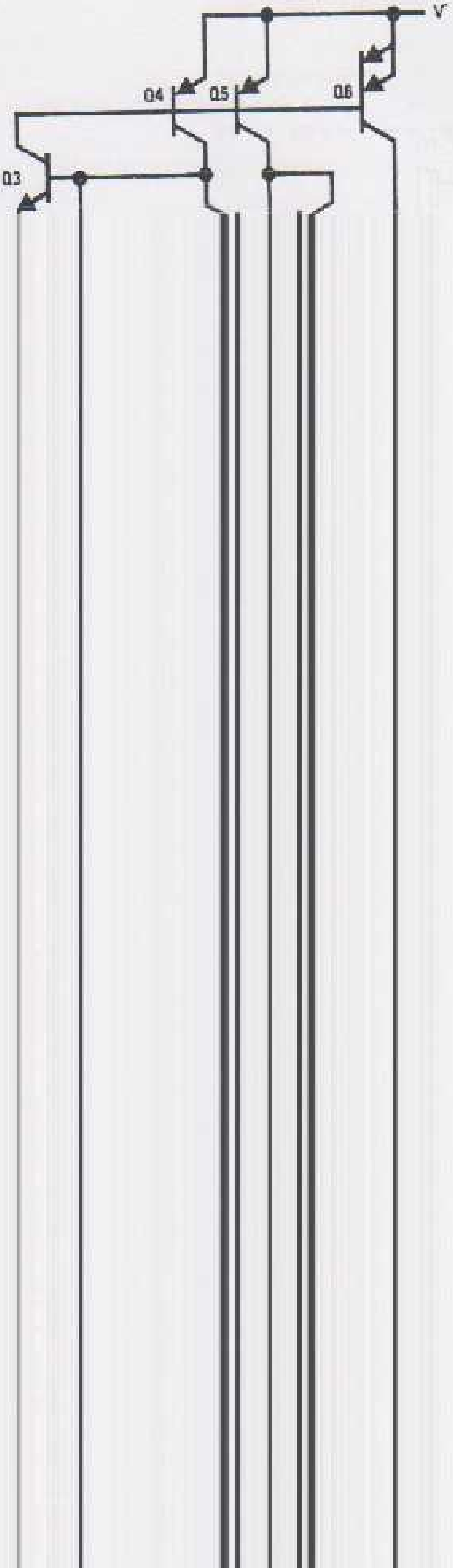
In-Line Current Limiter



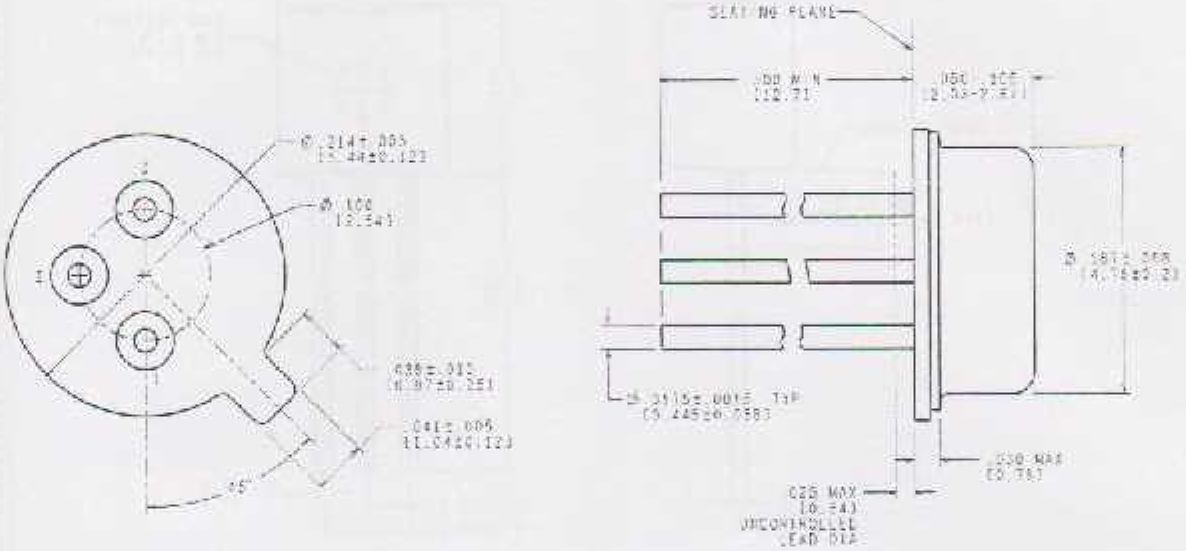
*Use minimum value required to ensure stability of protected device. This minimizes inrush current to a direct short.

Schematic Diagram

Schematic Diagram (Continued)



Physical Dimensions inches (millimeters) unless otherwise noted



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H03H (Rev F)

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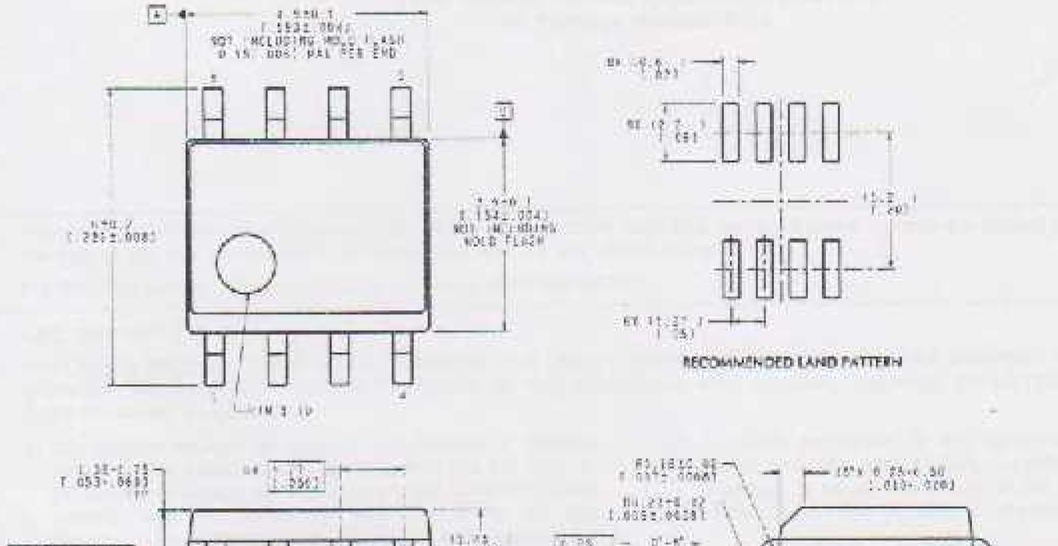
NS Package Number H03H



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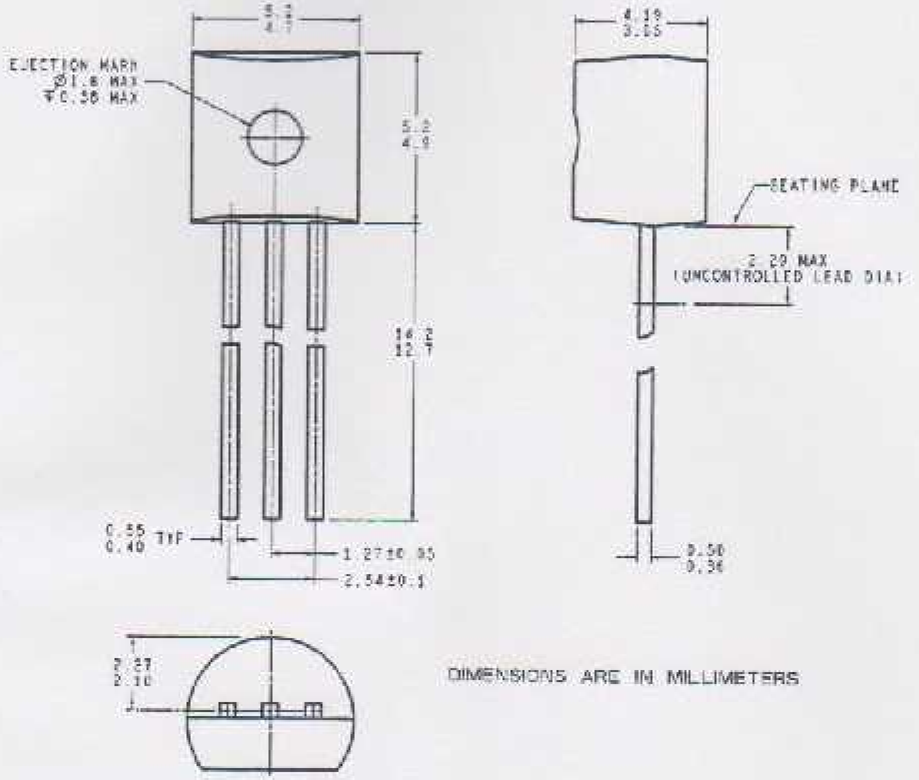
LM334SM or LM334SMX
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



DIMENSIONS ARE IN MILLIMETERS

Z03A (Rev G)

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NS Package Number Z03A

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