Power Generation using Piezoelectric Sensor

Project Report submitted in partial fulfillment of the requirement for the degree of

Bachelor of Technology

in

Electronics and Communication Engineering

By

Aakash Rana – 061003
Abhishek Sharma – 061008
Jagatjeet Singh – 061055
Charan Kamal Singh – 061060

under the Supervision of

Dr. Vivek Sehgal

Jaypee University of Information Technology
Waknaghat, Solan - 173 234, Himachal Pradesh

Certificate

This is to certify that the project report entitled "Electric power generation using Piezoelectric Sensors", submitted by Aakash Rana, Abhishek Sharma , Jagatjit Singh,Charan kamal Singh,in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

Signature

Vivek Sehgal

Date :

(Dr.Vivek Sehgal)

(Lecturer)

Certified that this work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma

Signature

(Aakash Rana)

061003

Abhi

Signature

(Abhishek Sharma)

061008

Jagatjit Singh

Signature

(Jagatjeet Singh)

061055

Signature

(Charan Kamal Singh)

061060

Acknowledgement

It has been a wonderful and intellectually stimulating experience working on "**Electric Power generation using piezoelectric sensors**" which is in itself a new and innovative idea in the field of Power Harvesting.

We gratefully acknowledge the Management and Administration of Jaypee University of Information Technology for providing us the opportunity and hence the environment to initiate and complete our project.

For providing with the finest suggestions for the project, we are greatly thankful to our project guide **Mr. Vivek Sehgal**. He has provided us the way to get the job done, not only providing the exact way to do it, but the concept behind the complexities so that we can make better use of existing knowledge and build up higher skills to meet the industry needs. His methodology of making the system strong from inside has taught us that output is not end of project

Date:

Aakash Rana
Abhishek Sharma
Jagatjit Singh
CharanKamal Singh

Table Of Contents

ABSTRACT

The process of acquiring the energy surrounding a system and converting it into usable electrical energy is termed power harvesting. In the last few years, there has been a surge of research in the area of power harvesting. This increase in research has been brought on by the modern advances in low power electronics. The advances have allowed numerous doors to open for power harvesting systems in practical real world applications. The use of piezoelectric materials to capitalize on the ambient vibrations surrounding a system is one method that has seen a dramatic rise in use for power harvesting. Piezoelectric materials have a crystalline structure that provides them with the ability to transform mechanical strain energy into electrical charge and vice versa convert an applied electrical potential into mechanical strain. This property provides these materials with the ability to absorb mechanical energy from their surroundings, usually ambient vibration, and transform it into electrical energy that can be used to power other devices. While piezoelectric materials are the major method of harvesting energy other methods do exist, for example one of the conventional methods is the use of electromagnetic devices. This paper will discuss some of the research that has been performed in the area of power harvesting and the future goals that must be achieved for power harvesting systems to find their way into everyday use.

CHAPTER 1

System Model

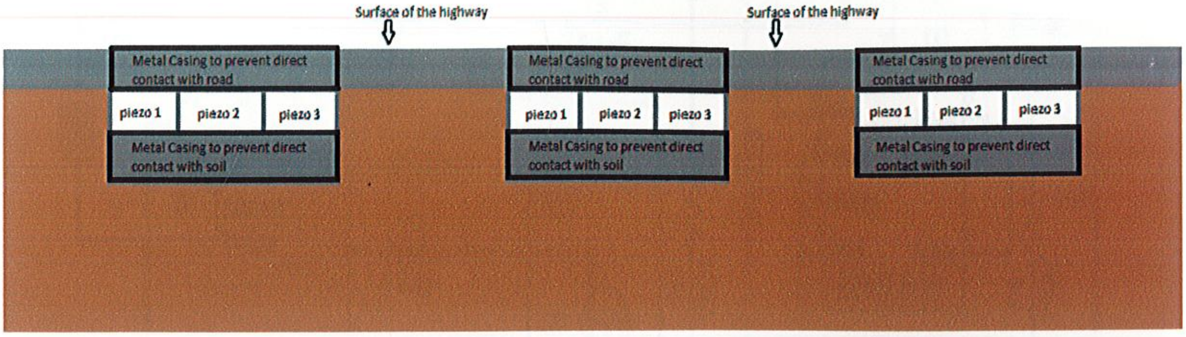
1.1 Introduction:

Power scavenging is the technique that will utilize the electricity produced by the piezoelectric sensors system, mounted beneath the road surface, to glow the side lane lights. The piezoelectric sensors mounted beneath the road surface protected from the direct contact with the road by a metallic layer, will be compressed by the vehicles passing over the system. The compression of the piezoelectric material will lead to the generation of electric charge. The power produced in the form of random fluctuations due to compression by vehicles of different weight. Proper rectification and voltage regulation techniques are being used to compensate the effect of these fluctuations and to charge the Ni-Metal-hydride battery ultimately. This charged battery can be used to energize the electric side lane lights of the road.

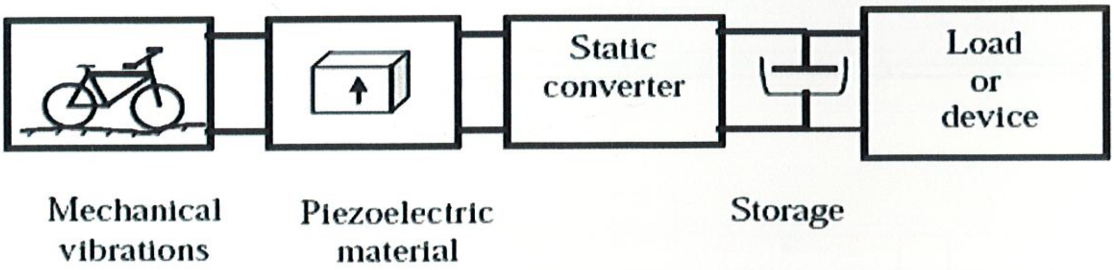
Hence large scale implementation of this system can save the electricity being used every day to glow these side lane road lights.

1.2 Pictorial diagram to illustrate the way by which system will be implanted beneath the road:

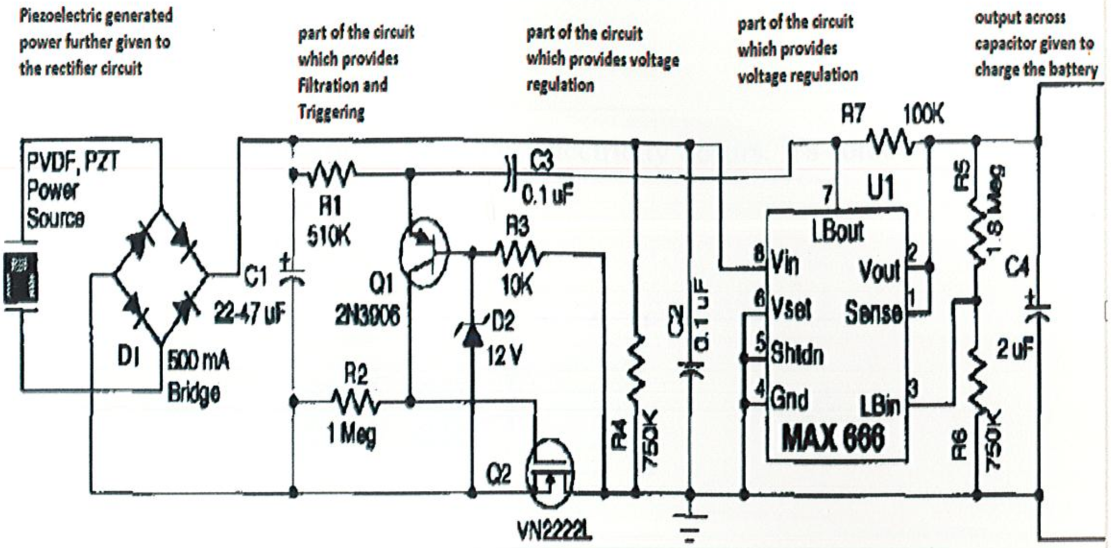
(Side View)

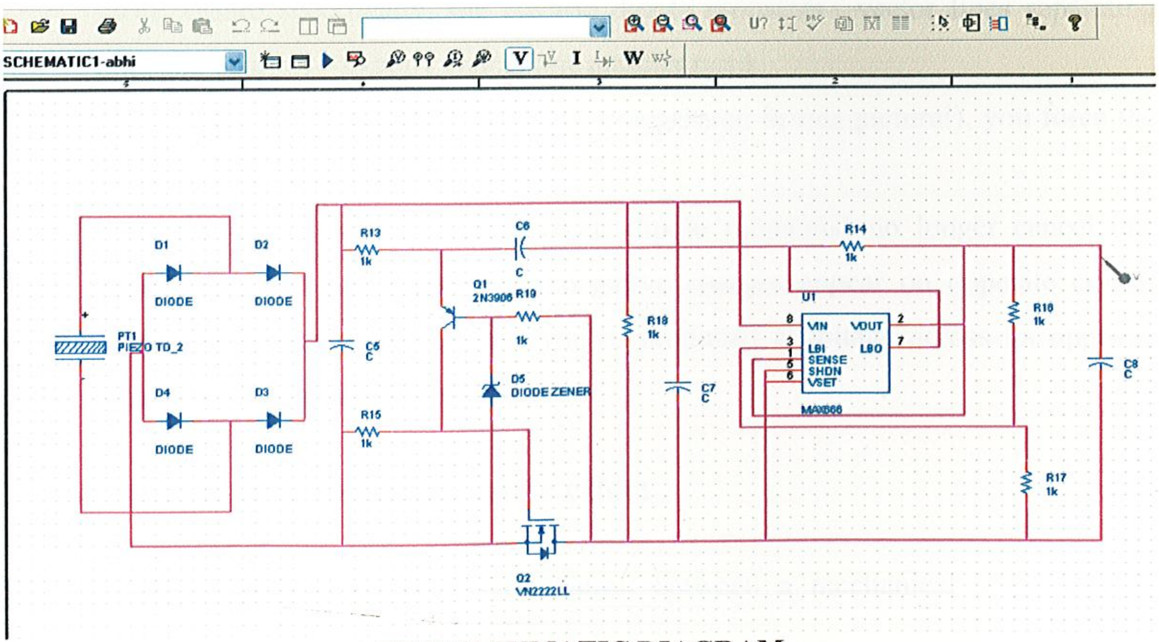


Block Diagram:



1.3 Circuit Diagram:



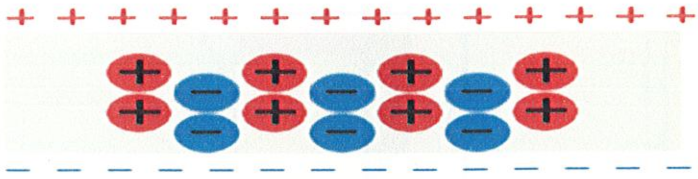


ORCAD SYMATIC DIAGRAM

CHAPTER 2

BASICS OF PIEZO ELECTRICITY

Here's a quick animation showing how piezoelectricity occurs. It's somewhat simplified, but it gives us the basic idea:



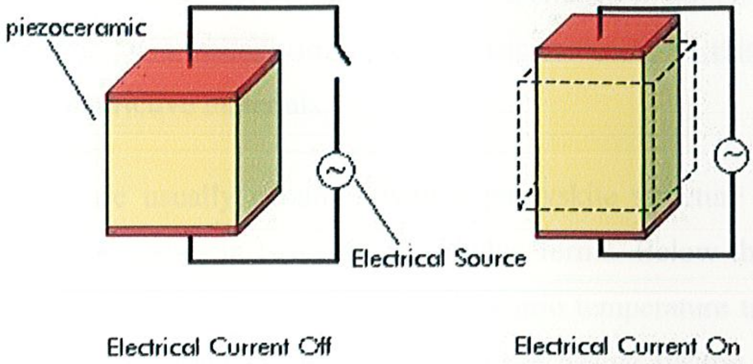
1. Normally, the charges in a piezoelectric crystal are exactly balanced, even if they're not symmetrically arranged.
2. The effects of the charges exactly cancel out, leaving no net charge on the crystal faces. (More specifically, the electric dipole moments—vector lines separating opposite charges—exactly cancel one another out.)
3. If you squeeze the crystal (massively exaggerated in this picture!), you force the charges out of balance.
4. Now the effects of the charges (their dipole moments) no longer cancel one another out and net positive and negative charges appear on opposite crystal faces. By squeezing the crystal, you've produced a voltage across its opposite faces—and that's piezoelectricity!

2.1 Introduction: The piezoelectric effect

The piezoelectric effect describes the relation between a mechanical stress and an electrical voltage in solids.

It is reversible: an applied mechanical stress will generate a voltage and an applied voltage will change the shape of the solid by a small amount (up to a 4% change in volume).

In physics, the piezoelectric effect can be described as the the link between electrostatics and mechanics.



2.1.1 History:

The piezoelectric effect was discovered in 1880 by the Jacques and Pierre Curie brothers. They found out that when a mechanical stress was applied on crystals such as tourmaline, tourmaline, topaz, quartz, Rochelle salt and cane sugar, electrical charges appeared, and this voltage was proportional to the stress.

First applications were piezoelectric ultrasonic transducers and soon swinging quartz for standards of frequency (quartz clocks).

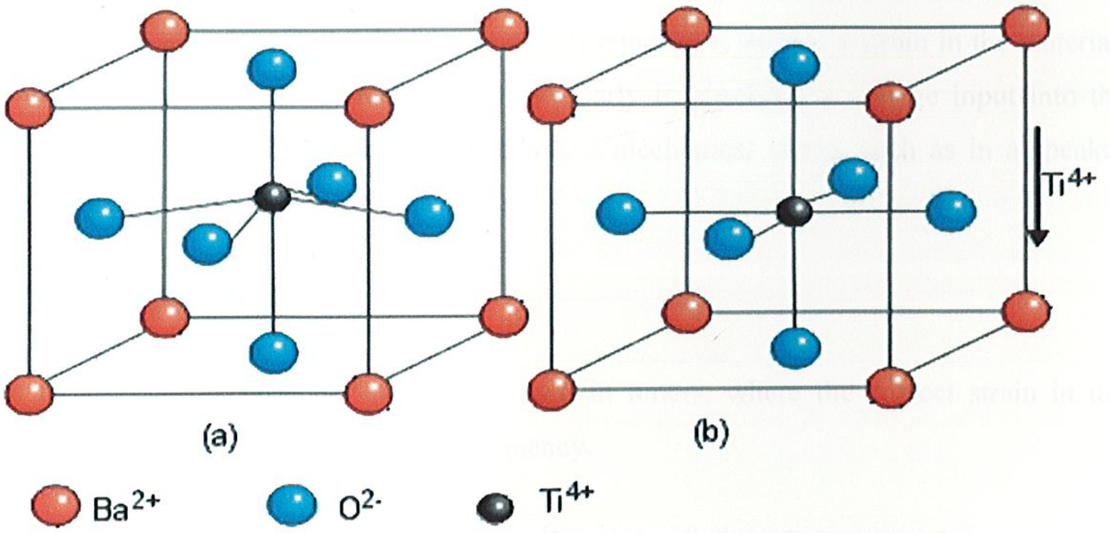
An everyday life application example is your car's airbag sensor. The material detects the intensity of the shock and sends an electrical signal which triggers the airbag.

2.2 Piezoelectric Materials:

The piezoelectric effect occurs only in non conductive materials. Piezoelectric materials can be divided in 2 main groups: crystals and ceramiics. The most well-known piezoelectric material is quartz (SiO2).

Simply stated, piezoelectric materials produce a voltage in response to an applied force, usually a uni-axial compressive force. Similarly, a change in dimensions can be induced by the application of a voltage to a piezoelectric material. In this way they are very similar to electro-strictive materials.

These materials are usually ceramics with a perovskite structure (see figure 1). The perovskite structure exists in two crystallographic forms. Below the Curie temperature they have a tetragonal structure and above the Curie temperature they transform into a cubic structure. In the tetragonal state, each unit cell has an electric dipole, i.e. there is a small charge differential between each end of the unit cell.



Shows the (a) tetragonal perovskite structure below the Curie temperature and the (b) cubic structure above the Curie temperature. A mechanical deformation (such as a compressive force) can decrease the separation between the cations and anions which produces an internal field or voltage.

Some examples of piezoelectric materials are given in table

Material	Piezoelectric Constant ($\times 10^{12}$ m/V)
Quartz	2.3
Barium titanate	100-149
Lead niobate	80-85
Lead zirconate titanate	250-365

The ability to produce a voltage output in response to an applied stress. The ability to produce a strain output (or deformation) in response to an applied voltage.

2.2.1 Applications:

Transducers

Piezoelectric materials are used in electromechanical devices. In the case of a microphone transducer, sound of a particular frequency results in a strain in the material, which in turn induces an electric field. Similarly in speakers, a voltage input into the piezoelectric material can be converted into a mechanical strain, such as in a speaker transducer.

Other Applications:

In radios, piezoelectric devices can be used in tuners, where the correct strain in the crystal will amplify only the desired frequency.

They are also employed in fine watch circuits, ones with "quartz movements".

Piezoelectric Crystals:

Piezoelectric crystals are one of many small scale energy sources. Whenever piezoelectric crystals are mechanically deformed or subject to vibration they generate a small voltage, commonly know as piezoelectricity. This form of renewable energy is not ideally suited to an industrial situation.

The ability of certain crystals to generate Piezoelectricity in response to applied mechanical stress is reversible in that piezoelectric crystals, when subjected to an externally applied voltage, can change shape by a small amount. This deformation, though only nanometers, has useful applications such as the production and detection of sound.

Probably the best-known use of piezoelectric crystals is in the electric cigarette lighter. Here, pressing the button causes a spring-loaded hammer to hit a piezoelectric crystal, the high voltage produced by this ignites the gas as the current jumps over a small spark gap. This technique also applies to some gas lighters used on gas grills or stoves.

Another common usage of a piezoelectric crystal energy source is that of creating a small motor; such as that used in a reflex camera to operate the auto focus system. These motors operate by vibration. The two surfaces are forced to vibrate at a phase shift of 90 degrees by a sine wave that has been generated at the motors resonant frequency. This forces a frictional force where the two surfaces meet and as one of the surfaces is fixed the other is forced to move. It has been found that piezoelectric crystals that have been embedded in the sole of a shoe can yield a small amount of energy with each step. This could be applied in a way that the power for instruments such as torches, cell phones or other entertainment devices can be sourced from the movement of the operator.

2.2.2 Types of Piezoelectric materials:

Three types of piezoelectric materials such as lead zirconium titanate (PZT) ceramic, macro fiber composite (MFC) and poly(vinylidene fluoride) (PVDF) polymer to investigate the capability of converting mechanical vibration into electricity under larger vibration amplitudes or accelerations conditions ($\geq 1g$, gravitational acceleration). All prototypes based on a bimorph cantilever structure with a proof mass were aimed to operate at a vibration frequency of 100 Hz. PZT-based device was optimized and fabricated by considering the resonant frequency, the output power density, and the maximum operating acceleration or safety factor. PVDF- and MFC-prototypes were designed to have same resonant frequency as well as same volume of the piezoelectric materials as the PZT prototype. All three devices were measured to determine if they could generate enough power density to provide electric energy to power a wireless sensor or a micro electromechanical systems (MEMS) device without device failure.

PZT and MFC Configuration

An aluminum shim with a PSI-5H4E piezoceramic (PZT) from Piezo Systems Inc. bonded to its surface was used to absorb the vibration energy and convert it to usable electricity. The aluminum plate was constructed as shown in Figure 1. The thickness of the aluminum plate and the PZT were 0.0025 and 0.0105 inches respectively. The MFC was bonded using double sided tape to a similar aluminum shim. It must be noted that due to the bonding of the MFC using double sided tape the damping of the plate was increased and the full mechanical energy was not transmitted.

2.2.3 Smart Piezoelectric materials:

Piezoelectric Effect Decreases with Thickness:

As active materials become increasingly smaller for the next generation of smart materials systems, the need to understand and predict material response becomes critical.

At the University of Illinois, an experimental investigation into how the properties and responses of smart materials -- such as piezoelectric ceramics -- change as a function of size has yielded a few surprises.

"Both the piezoelectric properties and the dielectric constants of smart materials cast as thin films were found to be strongly dependent on thickness," said Nancy Sottos, a professor of theoretical and applied mechanics. "As the films became thinner, the desired responses became smaller."

Piezoelectric ceramics are commonly used in pressure sensors, microphones and accelerometers. Deposited as thin films, the material can serve as tiny sensors and actuators in micro electromechanical (MEMS) devices, as elements in ultrasonic motors and as switching capacitors for integrated circuitry.

While thin films have much better mechanical properties than the bulk ceramics -- for example, films are far less brittle -- other physical and electrical properties may change in undesirable ways.

"The properties of piezoelectric films are critical to the quality and the reliability of MEMS devices," Sottos said. "To optimize the performance of thin-film structures, we must first understand the factors that influence those properties."

For their experiments, Sottos and graduate research assistant Lei Lian obtained a number of lead-zirconate-titanate thin films that ranged in thickness from 0.5 to 2.0 microns (a micron is one millionth of a meter).

To record the films' tiny displacements (on the order of trillionths of a meter), Sottos and Lian developed a high-resolution, laser Doppler heterodyne interferometric technique.

The measurement scheme is based on the Doppler shift.

First, the beam from an argon laser strikes a 40 MHz acousto-optic modulator, which produces two beams and sends them along different arms of the interferometer. One beam then bounces off the sample, while the other beam serves as a reference.

When the two beams are recombined, the researchers can very accurately extract the displacement signal from the Doppler shift riding on top of the 40 MHz carrier.

"It's clear from our experiments that as the films become thinner and thinner, there is an undesirable decrease in both piezoelectric response and dielectric constant," said Sottos, who published the results in the April 15 issue of the *Journal of Applied Physics*. "Fortunately, however, it may be possible to avoid these effects by controlling the residual stress in the material."

Significant stresses build up in piezoelectric thin-film structures during the fabrication process, Sottos said. "Changes in the residual stress state might be one major cause for the change in properties with film thickness that we observed. By applying a mechanical stress -- to relieve some of the residual stress -- the response of the film can be greatly enhanced."

Piezo materials have the property of developing an electric charge on their surface when mechanical stress is exerted on them. An applied electric field produces in these materials a linearly proportional strain. The electrical response to mechanical stimulation is called the direct piezoelectric effect and the mechanical response to electrical simulation is called the converse piezoelectric effect.

2.2.4 Properties of Soft and Hard Doped Piezoelectric Ceramic Materials:

The properties of the materials are specified according to the EN 50324 European Standard. On an international basis, it is usual to divide piezo ceramics into two groups. The antonyms "soft" and "hard" doped piezoelectric ceramics refer to the ferroelectric properties, i.e. the mobility of the dipoles or domains and hence also to the polarization / depolarization behavior.

"Soft" doped piezo ceramics are characterized by a comparatively high domain mobility and a resulting "ferroelectrically soft" behavior, i.e. relatively easy polarization. In contrast, ferroelectrically "hard" doped PZT materials can be subjected to high electrical and mechanical stresses. The stability of their properties destines them for high-power applications.

Structure of Piezoelectric Crystals:

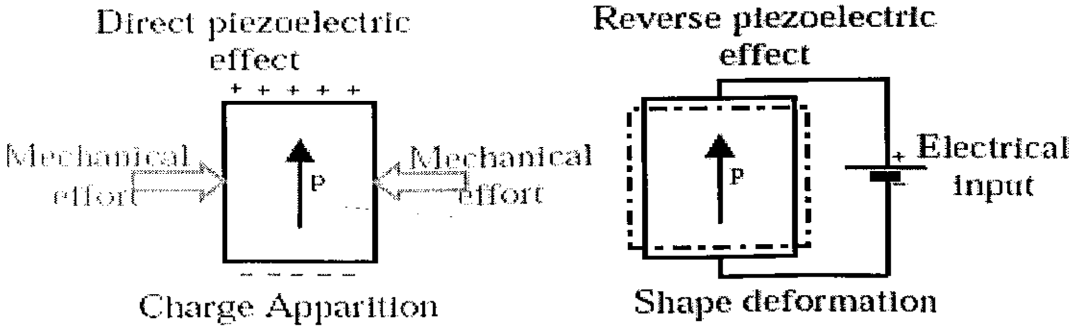
Piezoelectricity is the property of nearly all materials that have a non- centre symmetric crystal structure. Some naturally occurring crystalline materials possessing these properties are quartz and tourmaline. Some artificially produced piezoelectric crystals are Rochelle salt, ammonium dihydrogen phosphate and lithium sulphate. Another class of materials possessing these properties is polarized piezoelectric ceramic. In contrast to the naturally occurring piezoelectric crystals, piezoelectric ceramics are of a "polycrystalline" structure.

Examples of Piezoelectric Ceramics:

The most commonly produced piezoelectric ceramics are lead zirconate titanate (PZT), barium titanate and lead titanate. Ceramic materials have several advantages over single crystal, especially the ease of fabrication into a variety of shapes and sizes. In contrast, single crystals must be cut along certain crystallographic directions, limiting the possible geometric shapes.

2.2.5 Fundamentals of piezoelectric material:

The conversion of mechanical energy into electrical one is generally achieved by converters alternator type or commonly known dynamo. But there are other physical phenomena including piezoelectricity that can also convert mechanical movements into electricity. The piezoelectric effect exists in two domains, the first is the direct piezoelectric effect that describes the material's ability to transform mechanical strain into electrical charge, the second form is the converse effect, which is the ability to convert an applied electrical potential into mechanical strain energy figure.



Electromechanical conversion via piezoelectricity phenomenon.

The direct piezoelectric effect is responsible for the materials ability to function as a sensor and the converse piezoelectric effect is accountable for its ability to function as an actuator. A material is deemed piezoelectric when it has this ability to transform electrical energy into mechanical strain energy, and the likewise transform mechanical strain energy into electrical charge. The piezoelectric materials that exist naturally as quartz were not interesting properties for the production of electricity, however artificial piezoelectric materials such as PZT (Lead Zirconate Titanate) present advantageous characteristics.

Piezoelectric materials belong to a larger class of materials called ferroelectrics. One of the defining traits of a ferroelectric material is that the molecular structure is oriented such that the material exhibits a local charge separation, known as an electric dipole. Throughout the artificial piezoelectric material composition the electric dipoles are orientated randomly, but when a very strong electric field is applied, the electric dipoles reorient themselves relative to the electric field; this process is termed poling. Once the electric field is extinguished, the dipoles maintain their orientation and the material is then said to be poled. After the poling process is completed,the material will exhibit the piezoelectric effect. The mechanical and electrical behaviour of a piezoelectric material can be modelled by two linearized constitutive equations. These equations contain two mechanical and two electrical variables. The direct effect and the
converse effect may be modelled by the following matrix.

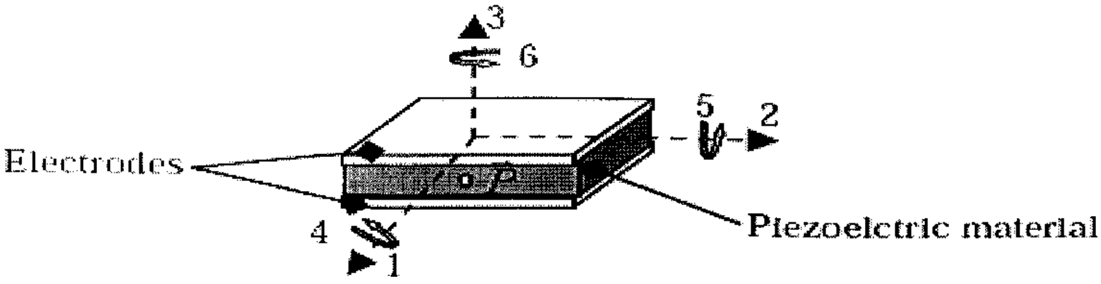
Equations:

Direct Piezoelectric Effect: $D = d\ .\ T + \varepsilon T\ .\ E$ (1)

Converse Piezoelectric Effect: $S = sE\ .\ T + dt\ .\ E$ (2)

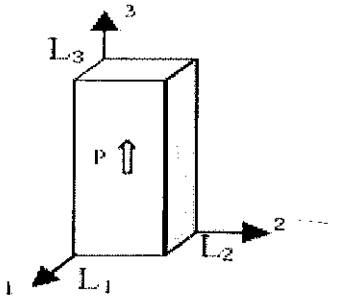
Where D is the electric displacement vector, T is the stress vector, εT is the dielectric permittivity matrix at constant mechanical stress, sE is the matrix of compliance coefficients at constant electric field strength, S is the strain vector, d is the piezoelectric constant matrix, and E is the electric field vector. The subscript t stands for transposition of a matrix. When the material is deformed or stressed an electric voltage can be recovered along any surface of the material (via electrodes). Therefore, the piezoelectric properties must contain a sign convention to facilitate this ability to recover electric potential in three directions. For the sake of keeping this discussion simple, the piezoelectric material can be generalized for two cases. The first is the stack configuration that operates in the 33 mode and the second is the bender, which operates in the 13 mode. The sign convention assumes that the poling direction is always in the "3" direction; with this point the two modes of operation can be understood .

Figure:

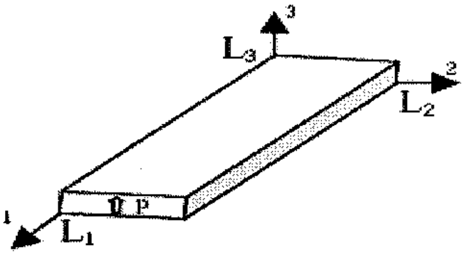


Defining the lines of a piezoelectric material

In the -33 mode, the electric voltage is recovered in the "3" direction and the material is strained in the poling or "3 direction, in the -31 mode (Figure 3b), the electric voltage is measured in the "3" direction and the material is strained in the "1" direction or perpendicular to the poling direction. These two modes of operation are particularly important when defining the electromechanical coupling coefficient such as d. Thus *d13* refers to the sensing coefficient for a bending element poled in the "3" direction and strained along "1" .



33 mode



31 mode

The coefficients d33 of a piezoelectric bar, (C / N) shown in Table I, link the amount of electrical charge (Coulomb), appearing on an electrode perpendicular to the axis 3, to the strain (Newton) applied on both ends.

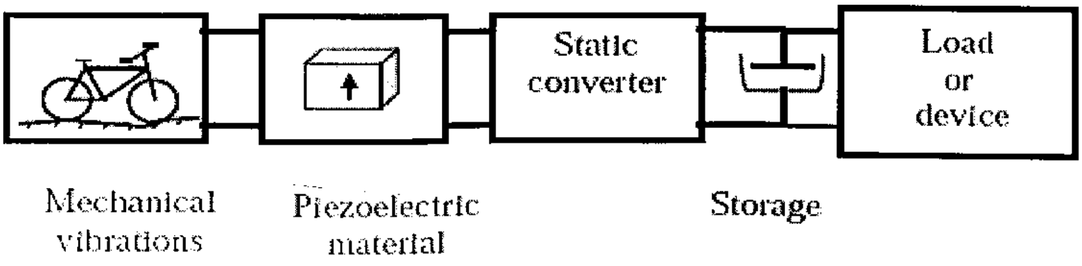
Typical piezoelectric materials coefficients

Material	$d_{33}(10^{-12}$ C/N)
Quartz	2.3
$BaTiO_3$	90
$PbTiO_3$	120
PZT	560
PZN-9PT	2500

For the PZT, d_{33} = 560 (10-12 C / N) means that 1 N applied strain produces 560 10-12 C electrical charge.

2.3 Piezoelectric Generator Principle:

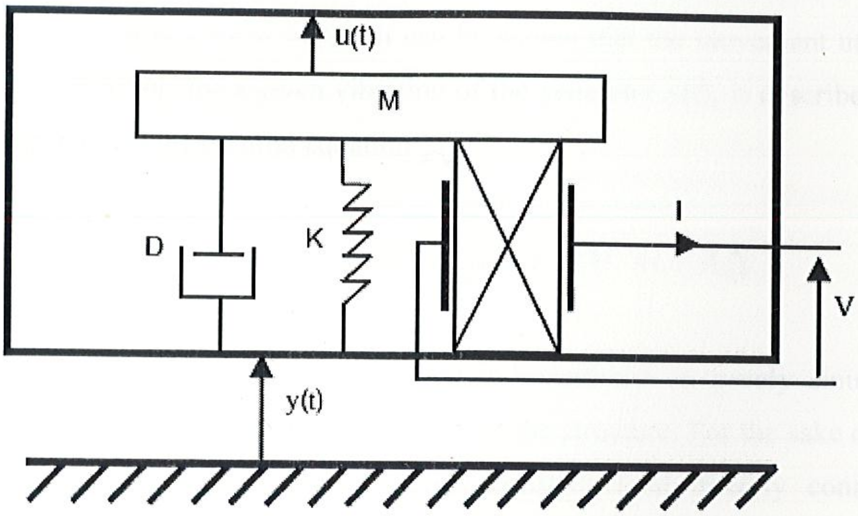
The vibrations energy harvesting principle using piezoelectric materials [4] is illustrated in figure . The conversion chain starts with a mechanical energy source: bike. Bike vibrations are converted into electicity via piezoelectric element. The electricity produced is thereafter formated by a static converter before supplying a storage system or the load (electrical device).



General diagram of generator based vibrations energy harvesting using piezoelectric material:

2.3.1 Piezoelectric beam modeling:

The electrical behavior of a vibrating piezoelectric transducer can be modeled. If the considered generator is excited around its resonance frequency and in the case of a little displacement for witch the movement remains linear, the structure with piezoelectric elements can be modeled by a mass + piezo + spring + damper as the one shown in figure.



Equivalent model of a vibrating piezoelectric structure

In this study, before developing bike piezoelectric generator, it was essential to begin with a mechanical vibrations sources identification that means carrying out vibrations accelerations and frequencies measurement and analysis. So we have carried out measurement at different locations of an experimental bicycle (Figure 5) to identify the place where harvesting more energy is possible. We could then develop a piezoelectric generator adapted to the identified natural mode of vibration of the bicycle. In a simplified approach, the considered structure is a rigid mass M bonded on a spring K corresponding to the stiffness of the mechanical structure, on a damper D corresponding to the mechanical losses of the structure, and on a piezoelectric disk corresponding to the bonded piezoelectric elements. The mass displacement is u, I and V are the outgoing current and the voltage on the piezoelectric layer that is connected on the energy harvesting device. The piezoelectric equations link the mechanical variable (u, FP) and the electric ones (I,V) is given by the simplified set of relations

$$F_P = K_P u + \alpha V$$

$$I = \alpha \dot{u} - C\dot{V}$$

Kp is the stiffness of the piezoelectric layer when it is short-circuited; C is its clamped capacitance and α is a force factor. It can be shown that the movement u(t) of the mass within the generator, for a given vibration of the generator y(t), is described by the well-known mechanical differential equation:

$$M\ddot{u} + D\dot{u} + Ku + K_P u + \alpha V = -M\ddot{y}$$

The external excitation displacement y(t) is considered as purely sinusoidal with a frequency closed to the resonance frequency of the structure. For the sake of keeping this discussion simple, we consider a purely resistive load directly connected to the piezoelectric element. In this case, the voltage at the load R is alternative. Considering the second piezoelectric equation and the resistance load, the voltage on the piezoelectric element can be expressed in the frequency domain as a function of the displacement , where ω is the angular frequency.

$$V = \frac{\alpha R}{1 + jRC\omega} j\omega u$$

Expression linking voltage V and displacement y is obtained using written in the frequency domain,

$$\frac{V}{y} = \frac{jM\alpha R\omega^3}{(-M\omega^2 + jD\omega + K + K_P)(1 + jRC\omega) + j\alpha^2 R\omega}$$

At the resonance of the structures with low viscous losses, the expression can be simplified and leads to

$$\frac{V}{y} = \frac{M\alpha R\omega^2}{\alpha^2 R + D + jRCD\omega}$$

The harvested power can be expressed as a function of displacement y and load resistance R,

$$P = \frac{VV^*}{2R} = \frac{y^2}{2}\frac{M^2\alpha^2 R\omega^4}{\left(\left(\alpha^2 R + D\right)^2 + \left(RCD\omega\right)^2\right)}$$

For weakly electromechanically coupled structure, the variable α is close to zero, which leads to a simplified expression of harvested power (8). In this case the harvested power reaches a maximum Pmax for an optimal load Ropt.

$$P = \frac{y^2}{2}\frac{M^2\alpha^2 R\omega^4}{\left(1 + \left(RC\omega\right)^2\right)D^2}$$

$$R_{opt} = \frac{1}{C\omega}\, and\, P_{\max} = \frac{y^2 M^2 \omega^2 \alpha^2}{4D^2 C}$$

In the case of a transducer vibrating out of its own mechanical resonance, the maximum harvested power is also obtained for the same optimal load Ropt. We can considered that the applied force at the centre of the diaphragm is:

$$F = My\omega^2 .$$

At the resonance of the structures with low viscous losses, the expression can be simplified and leads to

$$\frac{V}{y}=\frac{M\alpha R\omega^{2}}{\alpha^{2}R+D+jRCD\omega}$$

The harvested power can be expressed as a function of displacement y and load resistance R,

$$P=\frac{VV^{*}}{2R}=\frac{y^{2}}{2}\frac{M^{2}\alpha^{2}R\omega^{4}}{\left(\left(\alpha^{2}R+D\right)^{2}+\left(RCD\omega\right)^{2}\right)}$$

For weakly electromechanically coupled structure, the variable α is close to zero, which leads to a simplified expression of harvested power (8). In this case the harvested power reaches a maximum Pmax for an optimal load Ropt.

$$P=\frac{y^{2}}{2}\frac{M^{2}\alpha^{2}R\omega^{4}}{\left(1+\left(RC\omega\right)^{2}\right)D^{2}}$$

$$R_{opt}=\frac{1}{C\omega}\ and\ P_{\max}=\frac{y^{2}M^{2}\omega^{2}\alpha^{2}}{4D^{2}C}$$

In the case of a transducer vibrating out of its own mechanical resonance, the maximum harvested power is also obtained for the same optimal load Ropt. We can considered that the applied force at the centre of the diaphragm is:

$$F=My\omega^{2}\ .$$

. Expression can be rewritten:

$$P=\frac{F^2}{2}\frac{\alpha^2 R}{\left(1+(RC\omega)^2\right)D^2}$$

CHAPTER 3

RECTIFICATION

A rectifier is an electrical device that converts alternating current (AC) to direct current (DC), a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.

When only one diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term diode and the term rectifier is merely one of usage, i.e., the term rectifier describes a diode that is being used to convert AC to DC. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with only one diode. Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper(I) oxide or selenium rectifier stacks were used.

3.1 RECTIFIER CIRCUITS :

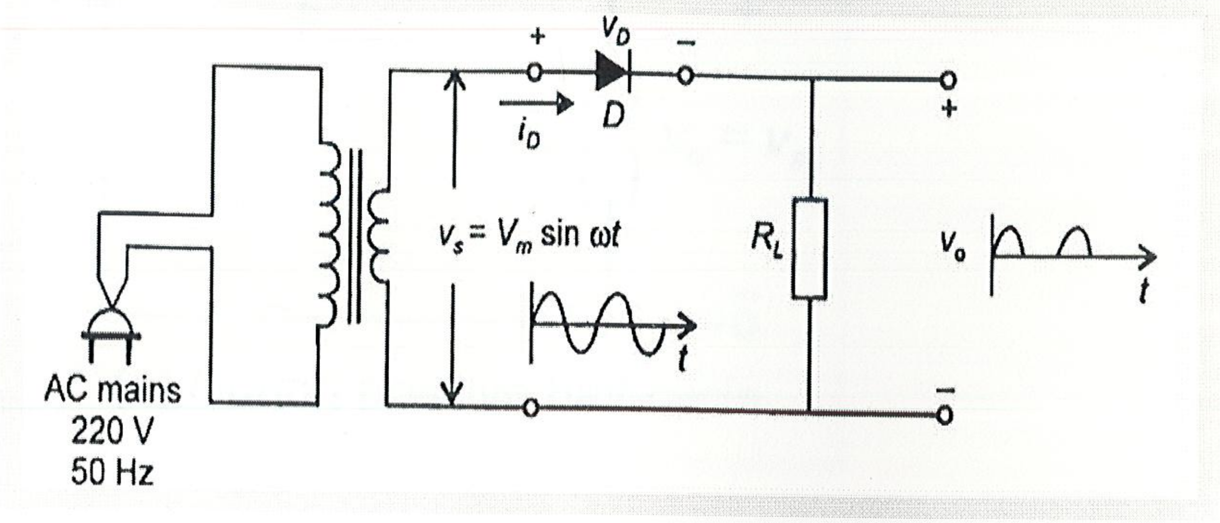
A basic rectifier converts an ac voltage to a pulsating dc voltage.

- A filter then eliminates ac components of the waveform to produce a nearly constant dc voltage output.
- Rectifier circuits are used in virtually all electronic devices to convert the 120-V 60-Hz ac power line source to the dc voltages required for operation of electronic devices.
- In rectifier circuits, the diode state changes with time and a given piecewise linear model is valid only for a certain time interval.

3.2 Types of Rectification

3.2.1 Half Wave Rectification :

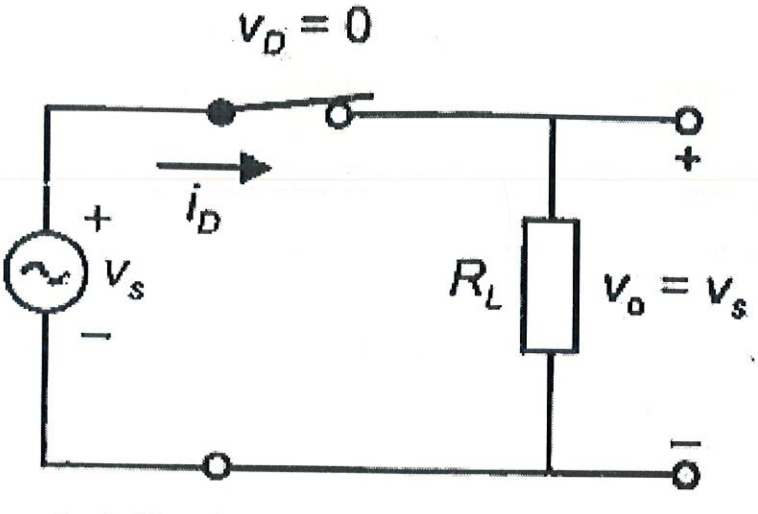
The Half wave rectifier is a circuit, which converts an ac voltage to dc voltage.



In the Half wave rectifier circuit shown the transformer serves two purposes.

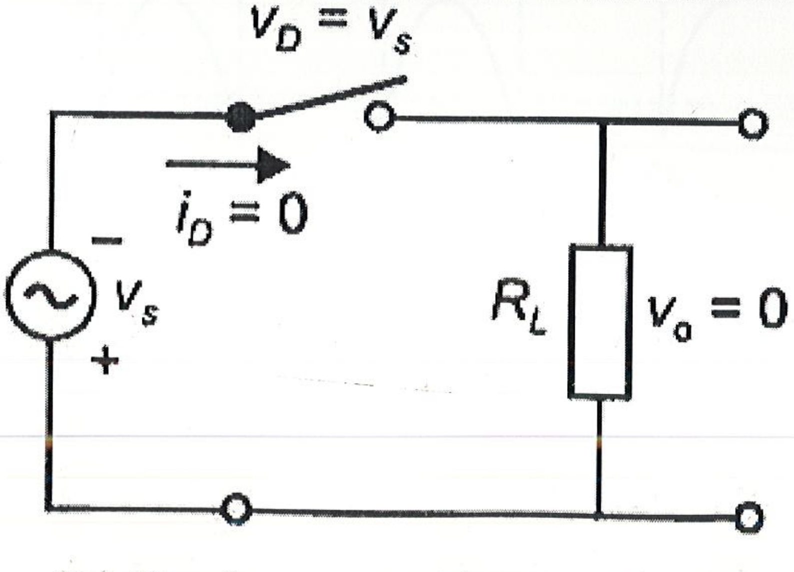
1. It can be used to obtain the desired level of dc voltage (using step up or step down transformers).
2. It provides isolation from the power line.

The primary of the transformer is connected to ac supply. This induces an ac voltage across the secondary of the transformer.



(*a*) During positive half-cycle

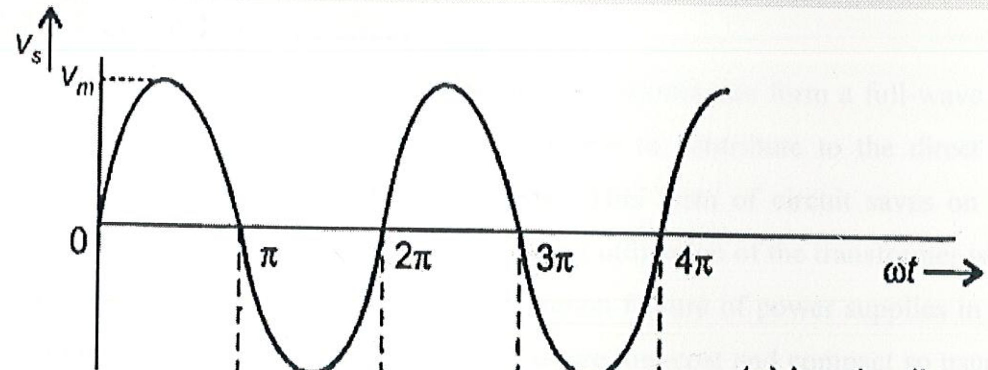
During the positive half cycle of the input voltage the polarity of the voltage across the secondary forward biases the diode. As a result a current IL flows through the load resistor, RL. The forward biased diode offers a very low resistance and hence the voltage drop across it is very small. Thus the voltage appearing across the load is practically the same as the input voltage at every instant.



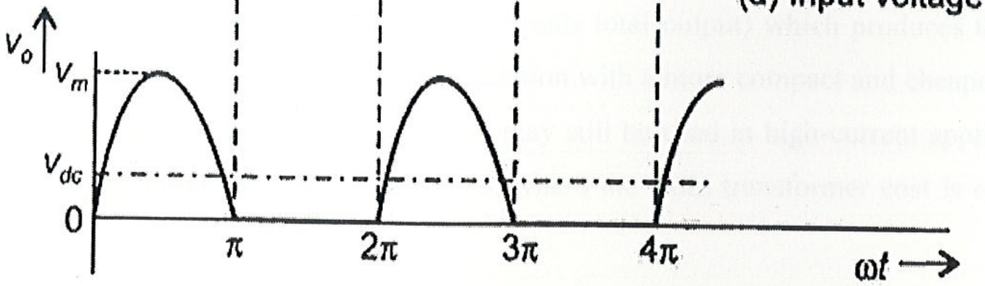
(*b*) During negative half-cycle

During the negative half cycle of the input voltage the polarity of the secondary voltage gets reversed. As a result, the diode is reverse biased. Practically no current flows through the circuit and almost no voltage is developed across the resistor. All input voltage appears across the diode itself.

Hence we conclude that when the input voltage is going through its positive half cycle, output voltage is almost the same as the input voltage and during the negative half cycle no voltage is available across the load. This explains the unidirectional pulsating dc waveform obtained as output. The process of removing one half the input signal to establish a dc level is aptly called half wave rectification.



(*a*) Input voltage waveform



(*b*) Output voltage waveform

3.2.2 Full Wave Rectification

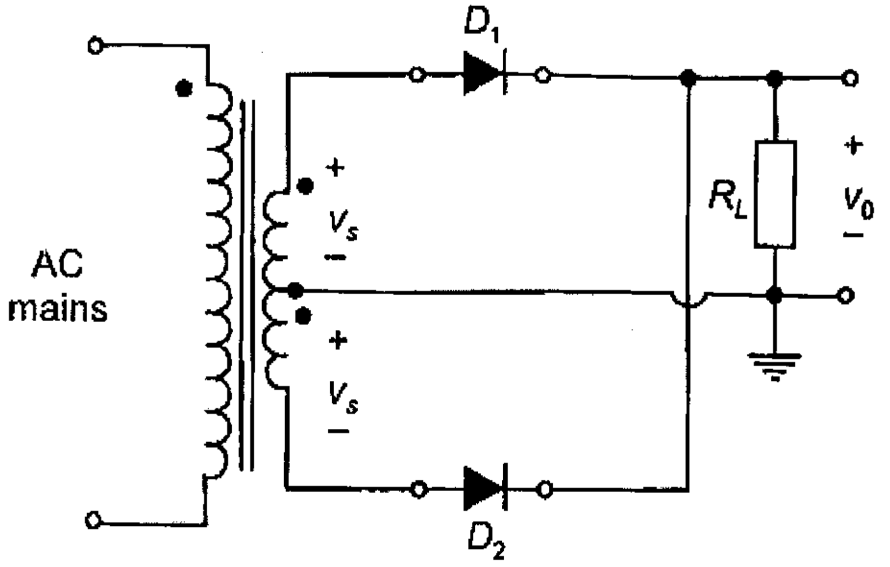
A Full Wave Rectifier is a circuit, which converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage. It uses two diodes of which one conducts during one half cycle while the other conducts during the other half cycle of the applied ac voltage.

During the positive half cycle of the input voltage, diode TWO becomes forward biased and REST becomes reverse biased. Hence forward biased diode conducts and rest remains OFF. Vice versa in case of negative half cycle

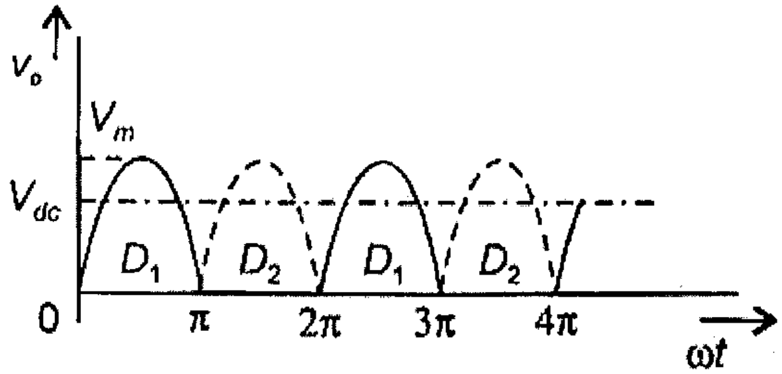
Types of full wave rectifiers:

3.2.2.1 Centre Tap Rectifier:

In a rectifier, a center-tapped transformer and two diodes can form a full-wave rectifier that allows both half-cycles of the AC waveform to contribute to the direct current, making it smoother than a half-wave rectifier. This form of circuit saves on rectifier diodes compared to a diode bridge, but has poorer utilization of the transformer windings. Center-tapped two-diode rectifiers were a common feature of power supplies in vacuum tube equipment. Modern semiconductor diodes are low-cost and compact so usually a 4-diode bridge is used (up to a few hundred watts total output) which produces the same quality of DC as the center-tapped configuration with a more compact and cheaper power transformer. Center-tapped configurations may still be used in high-current applications, such as large automotive battery chargers, where the extra transformer cost is offset by less costly rectifiers

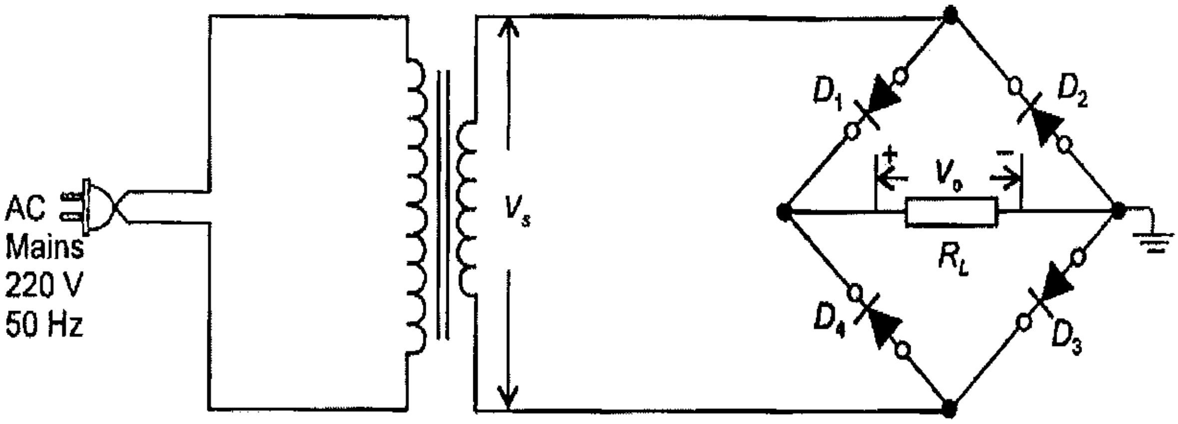


Output of the central tap rectifier



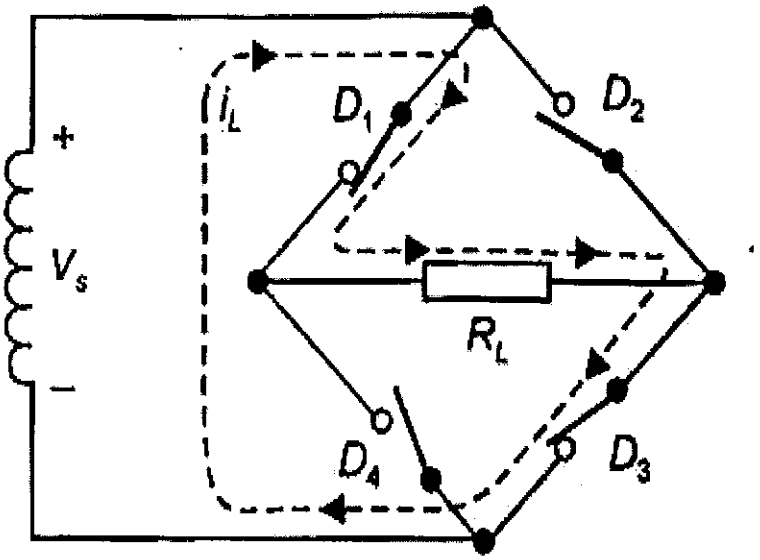
3.2.2.2 BRIDGE RECTIFIER :

A diode bridge is an arrangement of four diodes in a bridge configuration that provides the same polarity of output for either polarity of input. When used in its most common application, for conversion of an alternating current (AC) input into direct current a (DC) output, it is known as a bridge rectifier. A bridge rectifier provides full-wave rectification from a two-wire AC input, resulting in lower cost and weight as compared to a rectifier with a 3-wire input from a transformer with a center-tapped secondary winding.



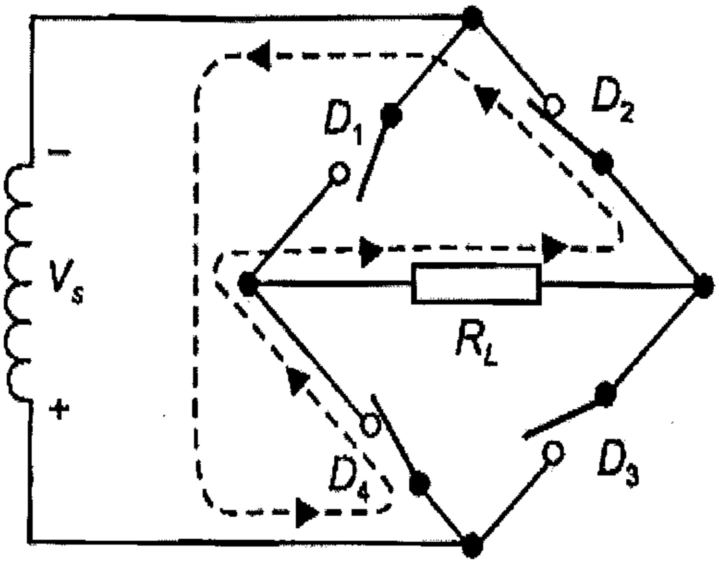
Basic operation

During the positive half cycle of the input voltage, diode D1, D3 becomes forward biased and D2, D4 becomes reverse biased. Hence D1 and D3 conducts and D2 and D4 remains OFF.



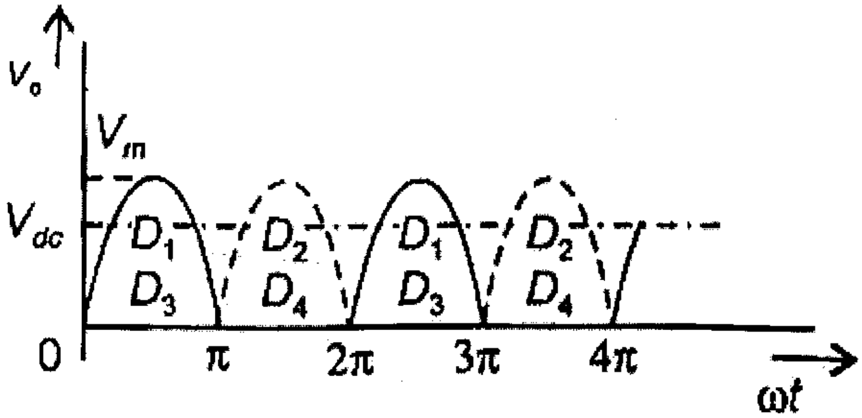
(a) During positive half-cycles

During the negative half cycle of the input voltage, diode D1, D3 becomes reverse biased and D2,D4 becomes forward biased. Hence D1, D3 remains OFF and D2,D4 conducts..



(*b*) During negative half-cycles

Hence the net output from the full wave rectifier is shown as below in diagram



(*c*) Output voltage waveform

Diode Ratings:

Peak Inverse Voltage (PIV): It is the largest reverse voltage that is expected to appear across the diode. Usually, diodes are selected which have VZ at least 50 % greater than PIV. Peak inverse voltage (PIV) or peak reverse voltage (PRV) is the maximum value of reverse voltage which occurs at the peak of the input cycle when the diode is reverse-biased. The portion of the sinusoidal waveform which repeats or duplicate itself is known as the cycle. The part of the cycle above the horizontal axis is called the positive half-cycle, or alternation; the part of the cycle below the horizontal axis is called the negative alternation. With reference to the amplitude of the cycle, the peak inverse voltage is specified as the maximum negative value of the sine-wave within a cycle's negative alternation.

Rectification Efficiency:

Half wave rectifier:

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{I_{dc}^2 \, R_L}{I_{rms}^2 \, (R_L + r_f)} = \left(\frac{I_{dc}}{I_{rms}}\right)^2 \frac{R_L}{R_L + r_f}$$

$$= \left(\frac{I_m/\pi}{I_m/2}\right)^2 \frac{R_L}{R_L + r_f} = 0.406 \frac{R_L}{R_L + r_f}$$

Full wave rectifier :

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_L + r_f)} = \left(\frac{2I_m/\pi}{I_m/\sqrt{2}} \right)^2 \frac{R_L}{R_L + r_f}$$

$$\eta = 0.812 \frac{R_L}{R_L + r_f} = \frac{\mathbf{81.2}}{1 + r_f/R_L} \%$$

THE EFFICIENCY OF FULL WAVE RECTIFIER IS ALMOST DOUBLE THAN HALF WAVE RECTIFIER HENCE WE PREFER FULL WAVE RECTIFIER.

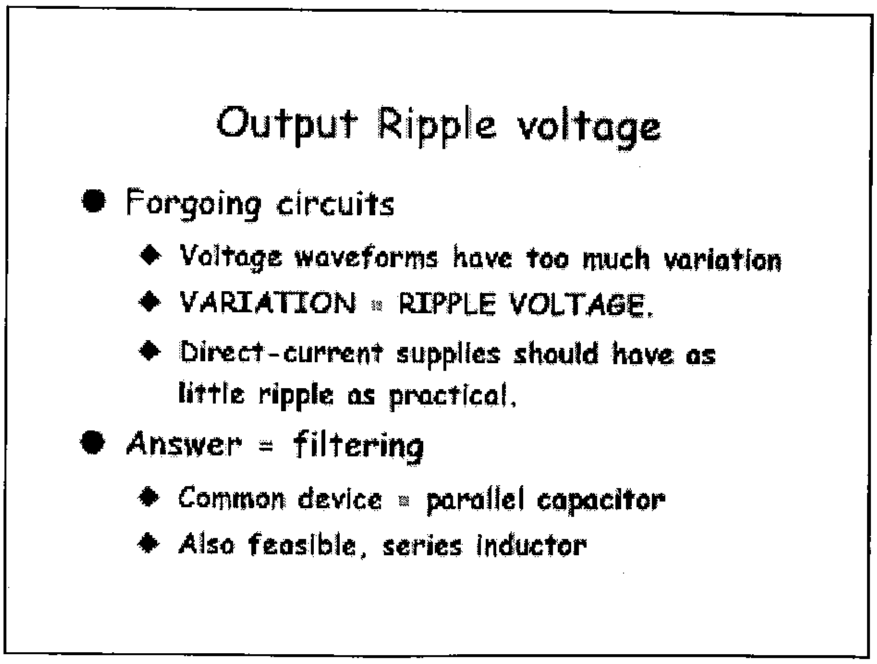
3.3 Rectifier Topology Comparison

Filter capacitors are a major factor in determining cost, size and weight in design of rectifiers.

For a given ripple voltage, a full-wave rectifier requires half the filter capacitance as that in a half wave rectifier. Reduced peak current can reduce heat dissipation in diodes. Benefits of full-wave rectification outweigh increased expenses and circuit complexity

(an extra diode and center-tapped transformer).

The bridge rectifier eliminates the center-tapped transformer, and the PIV rating of the diodes is reduced. Cost of extra diodes is negligible.



Output Ripple voltage

- Forgoing circuits
  - Voltage waveforms have too much variation
  - VARIATION = RIPPLE VOLTAGE.
  - Direct-current supplies should have as little ripple as practical.
- Answer = filtering
  - Common device = parallel capacitor
  - Also feasible, series inductor

CHAPTER 4

FILTRATION

4.1 Capacitor as a Filter:

While the output of a rectifier is a pulsating dc, most electronic circuits require a substantially pure dc for proper operation. This type of output is provided by single or multi section filter circuits placed between the output of the rectifier and the load.

Filtering is accomplished by the use of capacitors, inductors, and/or resistors in various combinations. Inductors are used as series impedances to oppose the flow of alternating (pulsating dc) current. Capacitors are used as shunt elements to bypass the alternating components of the signal around the load (to ground). Resistors are used in place of inductors in low current applications.

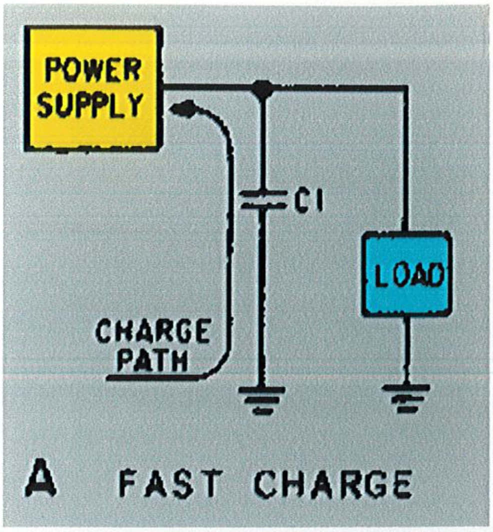
Let's briefly review the properties of a capacitor. First, a capacitor opposes any change in voltage. The opposition to a change in current is called capacitive reactance (XC) and is measured in ohms. The capacitive reactance is determined by the frequency (f) of the applied voltage and the capacitance (C) of the capacitor.

$$X_C = \frac{1}{2\pi fC} \text{ or } \frac{.159}{fC}$$

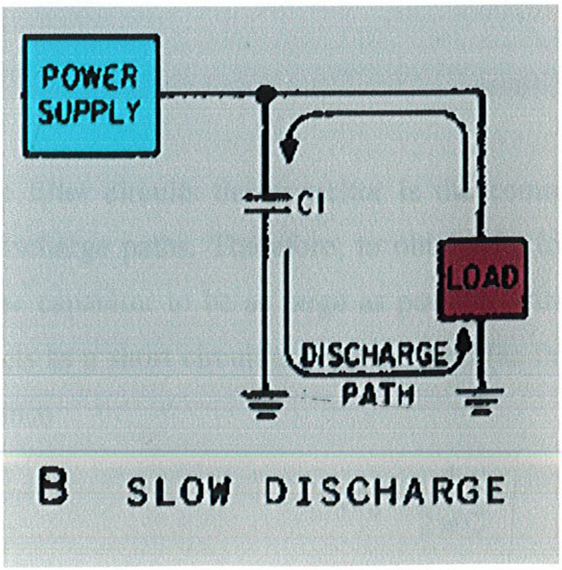
From the formula, you can see that if frequency or capacitance is increased, the XC decreases. Since filter capacitors are placed in parallel with the load, a low XC will provide better filtering than a high XC. For this to be accomplished, a better shunting effect of the ac around the load is provided

To obtain a steady dc output, the capacitor must charge almost instantaneously to the value of applied voltage. Once charged, the capacitor must retain the charge as long as possible. The capacitor must have a short charge time constant (view A). This can be accomplished by keeping the internal resistance of the power supply as small as possible (fast charge time) and the resistance of the load as large as possible.

4.2.1 Capacitor filter – (Fast charge)

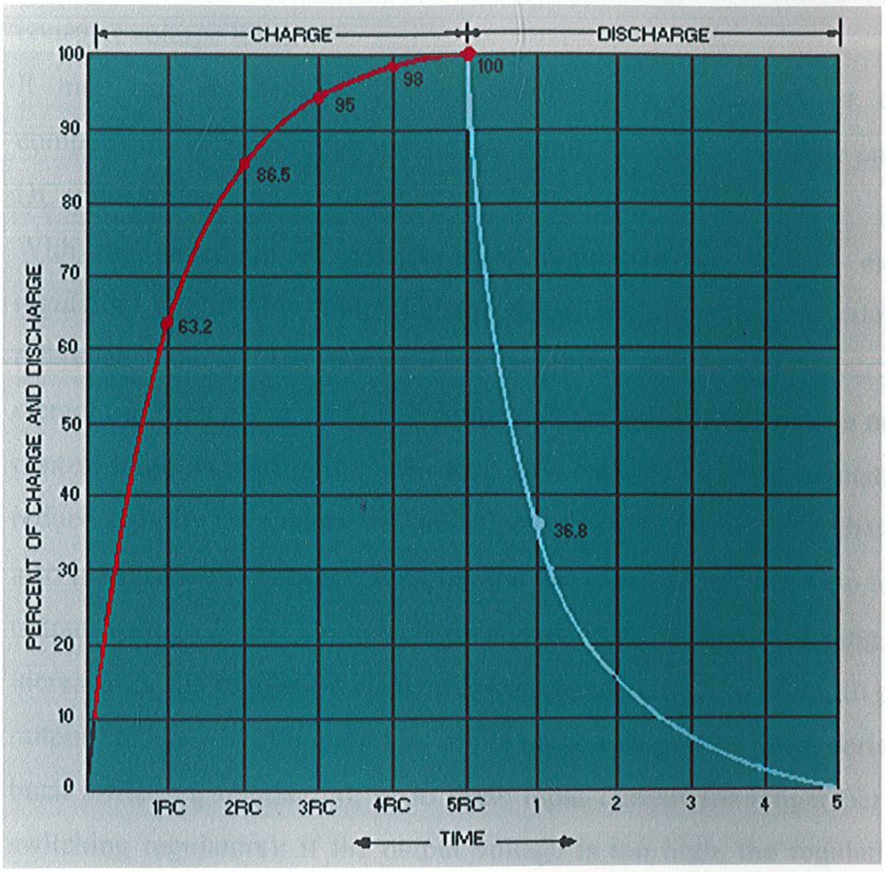


4.2.2 Capacitor filter- (Slow discharge)



A capacitor is considered fully charged after five RC time constants. Refer to . WE can see that a steady dc output voltage is obtained when the capacitor charges rapidly and discharges as slowly as possible.

RC time constant.



In filter circuits the capacitor is the common element to both the charge and the discharge paths. Therefore, to obtain the longest possible discharge time, you want the capacitor to be as large as possible. Another way to look at it is: The capacitor acts as a short circuit around the load (as far as the ac component is concerned), and since

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

the larger the value of the capacitor (C), the smaller the opposition (XC) or reactance to ac.

CHAPTER 5

VOLTAGE REGULATION

A voltage regulator is an electrical regulator designed to automatically maintain a constant voltage level.

It may use an electromechanical mechanism, or passive or active electronic components. Depending on the design, it may be used to regulate one or more AC or DC voltages.

With the exception of passive shunt regulators, all modern electronic voltage regulators operate by comparing the actual output voltage to some internal fixed reference voltage. Any difference is amplified and used to control the regulation element in such a way as to reduce the voltage error. This forms a negative feedback control loop; increasing the open-loop gain tends to increase regulation accuracy but reduce stability (avoidance of oscillation, or ringing during step changes). There will also be a trade-off between stability and the speed of the response to changes. If the output voltage is too low (perhaps due to input voltage reducing or load current increasing), the regulation element is commanded, up to a point, to produce a higher output voltage - by dropping less of the input voltage (for linear series regulators and buck switching regulators), or to draw input current for longer periods (boost-type switching regulators); if the output voltage is too high, the regulation element will normally be commanded to produce a lower voltage. However, many regulators have over-current protection, so that they will entirely stop sourcing current (or limit the current in some way) if the output current is too high, and some regulators may also shut down if the input voltage is outside a given range

COMPONENTS USED IN VOLTAGE REGULATION

1 Zener Diode

2 BJT

3 MOSFET

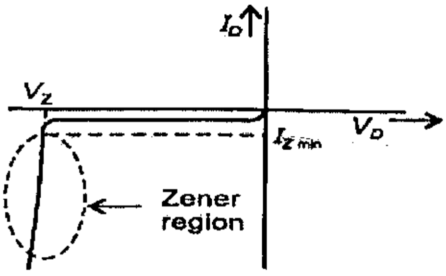
4 MAX 666

5.1 ZENER DIODE:

A Zener diode is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener knee voltage" or "Zener voltage". The device was named after Clarence Zener, who discovered this electrical property.

A conventional solid-state diode will not allow significant current if it is reverse-biased below its reverse breakdown voltage. When the reverse bias breakdown voltage is exceeded, a conventional diode is subject to high current due to avalanche breakdown. Unless this current is limited by circuitry, the diode will be permanently damaged. In case of large forward bias (current in the direction of the arrow), the diode exhibits a voltage drop due to its junction built-in voltage and internal resistance. The amount of the voltage drop depends on the semiconductor material and the doping concentrations.

A Zener diode exhibits almost the same properties, except the device is specially designed so as to have a greatly reduced breakdown voltage, the so-called Zener voltage. By contrast with the conventional device, a reverse-biased Zener diode will exhibit a controlled breakdown and allow the current to keep the voltage across the Zener diode at the Zener voltage. For example, a diode with a Zener breakdown voltage of 3.2 V will exhibit a voltage drop of 3.2 V if reverse bias voltage applied across it is more than its Zener voltage. The Zener diode is therefore ideal for applications such as the generation of a reference voltage (e.g. for an amplifier stage), or as a voltage stabilizer for low-current application.

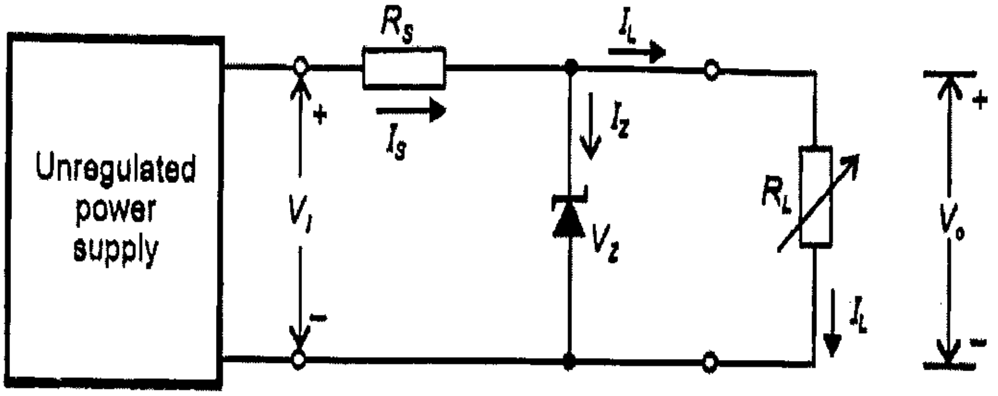


(a) V-I characteristic

(b) Symbol

5.1.1 Use of zener diode in voltage regulation.

Zener diodes are widely used as voltage references and as shunt regulators to regulate the voltage across small circuits. When connected in parallel with a variable voltage source so that it is reverse biased, a Zener diode conducts when the voltage reaches the diode's reverse breakdown voltage. From that point on, the relatively low impedance of the diode keeps the voltage across the diode at that value.



In this circuit, a typical voltage reference or regulator, an input voltage, VIN, is regulated down to a stable output voltage UOUT. The intrinsic voltage drop of diode D is stable over a wide current range and holds UOUT relatively constant even though the input voltage may fluctuate over a fairly wide range. Because of the low impedance of the diode when operated like this, Resistor R is used to limit current through the circuit.

In the case of this simple reference, the current flowing in the diode is determined using Ohms law and the known voltage drop across the resistor R. IDiode = (UIN - UOUT) / RΩ

The value of R must satisfy two conditions:

1. R must be small enough that the current through D keeps D in reverse breakdown. The value of this current is given in the data sheet for D. For example, the common BZX79C5V6[2] device, a 5.6 V 0.5 W Zener diode, has a recommended reverse current of 5 mA. If insufficient current exists through D, then UOUT will be

unregulated, and less than the nominal breakdown voltage (this differs to voltage regulator tubes where the output voltage will be higher than nominal and could rise as high as UIN). When calculating R, allowance must be made for any current through the external load, not shown in this diagram, connected across UOUT.

2. R must be large enough so that the current through D does not destroy the device. If the current through D is ID, its breakdown voltage VB and its maximum power dissipation PMAX, then IDVB < PMAX.

A load may be placed across the diode in this reference circuit, and as long as the zener stays in reverse breakdown, the diode will provide a stable voltage source to the load.

A Zener diode used in this way is known as a shunt voltage regulator (shunt, in this context, meaning connected in parallel, and voltage regulator being a class of circuit that produces a stable voltage across any load). In a sense, a portion of the current through the resistor is shunted through the Zener diode, and the rest is through the load. Thus the voltage that the load sees is controlled by causing some fraction of the current from the power source to bypass it—hence the name, by analogy with locomotive switching points.

Shunt regulators are simple, but the requirements that the ballast resistor be small enough to avoid excessive voltage drop during worst-case operation (low input voltage concurrent with high load current) tends to leave a lot of current flowing in the diode much of the time, making for a fairly wasteful regulator with high quiescent power dissipation, only suitable for smaller loads.

5.2 Bipolar junction transistor

A bipolar (junction) transistor (BJT) is a three-terminal electronic device constructed of doped semiconductor material and may be used in amplifying or switching applications. Bipolar transistors are so named because their operation involves both electrons and holes. Charge flow in a BJT is due to bidirectional diffusion of charge carriers across a junction between two regions of different charge concentrations. This mode of operation is contrasted with uni polar transistors, such as field-effect transistors, in which only one carrier type is involved in charge flow due to drift. By design, most of the BJT collector current is due to the flow of charges injected from a high-concentration emitter into the base where they are minority carriers that diffuse toward the collector, and so BJTs are classified as minority-carrier devices.

TYPES OF BJT:

5.2.1 NPN

NPN is one of the two types of bipolar transistors, in which the letters "N" and "P" refer to the majority charge carriers inside the different regions of the transistor. Most bipolar transistors used today are NPN, because electron mobility is higher than hole mobility in semiconductors, allowing greater currents and faster operation.

NPN transistors consist of a layer of P-doped semiconductor (the "base") between two N-doped layers. A small current entering the base in common-emitter mode is amplified in the collector output. In other terms, an NPN transistor is "on" when its base is pulled high relative to the emitter.

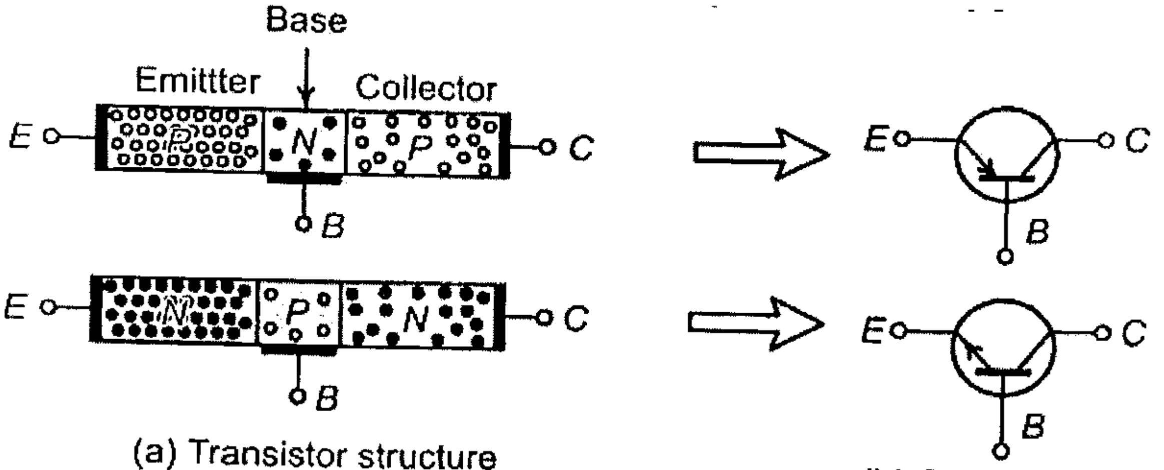
The arrow in the NPN transistor symbol is on the emitter leg and points in the direction of the conventional current flow when the device is in forward active mode.

5.2.2 PNP

The other type of BJT is the PNP with the letters "P" and "N" referring to the majority charge carriers inside the different regions of the transistor.

The symbol of a PNP Bipolar Junction Transistor.

PNP transistors consist of a layer of N-doped semiconductor between two layers of P-doped material. A small current leaving the base in common-emitter mode is amplified in the collector output. In other terms, a PNP transistor is "on" when its base is pulled low relative to the emitter. The arrow in the PNP transistor symbol is on the emitter leg and points in the direction of the conventional current flow when the device is in forward active mode.



(a) Transistor structure

(b) Circuit symbol

a) PNP

b) NPN

Regions of operation:

Bipolar transistors have five distinct regions of operation, defined mostly by applied bias:

Forward-active (or simply, active): The base–emitter junction is forward biased and the base–collector junction is reverse biased. Most bipolar transistors are designed to afford the greatest common-emitter current gain, βF, in forward-active mode. If this is the case, the collector–emitter current is approximately proportional to the base current, but many times larger, for small base current variations.

Reverse-active (or inverse-active or inverted): By reversing the biasing conditions of the forward-active region, a bipolar transistor goes into reverse-active mode. In this mode, the emitter and collector regions switch roles. Because most BJTs are designed to maximize current gain in forward-active mode, the βF in inverted mode is several (2–3 for the ordinary germanium transistor) times smaller. This transistor mode is seldom used, usually being considered only for failsafe conditions and some types of bipolar logic. The reverse bias breakdown voltage to the base may be an order of magnitude lower in this region.

Saturation: With both junctions forward-biased, a BJT is in saturation mode and facilitates high current conduction from the emitter to the collector. This mode corresponds to a logical "on", or a closed switch.

Cutoff: In cutoff, biasing conditions opposite of saturation (both junctions reverse biased) are present. There is very little current flow, which corresponds to a logical "off", or an open switch.

Avalanche breakdown region

BIASING CONDITION

Table 4.1 Four possible biasing conditions of a transistor

No.	*Emitter-base junction*	*Collector-base junction*	*Region of operation*	*Uses*
I	FB	RB	Active	Amplifiers
II	FB	FB	Saturation	Switching circuits
III	RB	RB	Cut-off	
IV	RB	FB	Inverse	Hardly used

5.2.3 USE OF BJT IN VOLTAGE REGULATION

We use PNP common Base (CB). When zener diode is forward biased then we will receive an output. Even a small voltage from zener diode can bias a transistor that is it acts as a close circuit .But when no output from zener diode is received the transistor will not get biased hence it will act as a open circuit

Thus the role of BJT over here is as a switch.

5.3 MOSFET

The metal–oxide–semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET) is a device used for amplifying or switching electronic signals. The basic principle of the device was first proposed by Julius Edgar Lilienfeld in 1925. In MOSFETs, a voltage on the oxide-insulated gate electrode can induce a conducting channel between the two other contacts called source and drain. The channel can be of n-type or p-type (see article on semiconductor devices), and is accordingly called an n MOSFET or a p MOSFET (also commonly NMOS, PMOS). It is by far the most common transistor in both digital and analog circuits, though the bipolar junction transistor was at one time much more common.

5.3.1 MOSFET operation

MOSFET structure and channel formation:

A metal–oxide–semiconductor field-effect transistor (MOSFET) is based on the modulation of charge concentration by a MOS capacitance between a body electrode and a gate electrode located above the body and insulated from all other device regions by a gate dielectric layer which in the case of a MOSFET is an oxide, such as silicon dioxide. If dielectrics other than an oxide such as silicon dioxide (often referred to as oxide) are employed the device may be referred to as a metal–insulator–semiconductor FET (MISFET). Compared to the MOS capacitor, the MOSFET includes two additional terminals (source and drain), each connected to individual highly doped regions that are separated by the body region. These regions can be either p or n type, but they must both be of the same type, and of opposite type to the body region. The source and drain (unlike the body) are highly doped as signified by a '+' sign after the type of doping.

If the MOSFET is an n-channel or NMOS FET, then the source and drain are 'n+' regions and the body is a 'p' region. As described above, with sufficient gate voltage, above a threshold voltage value, electrons from the source (and possibly[citation needed] also the drain) enter the inversion layer or n-channel at the interface between the p region and the oxide. This conducting channel extends between the source and the drain, and current is conducted through it when a voltage is applied between source and drain.

For gate voltages below the threshold value, the channel is lightly populated, and only a very small sub threshold leakage current can flow between the source and the drain.

If the MOSFET is a p-channel or PMOS FET, then the source and drain are 'p+' regions and the body is a 'n' region. When a negative gate-source voltage (positive source-gate) is applied, it creates a p-channel at the surface of the n region, analogous to the n-channel case, but with opposite polarities of charges and voltages. When a voltage less negative than the threshold value (a negative voltage for p-channel) is applied between gate and source, the channel disappears and only a very small sub threshold current can flow between the source and the drain. The source is so named because it is the source of the charge carriers (electrons for n-channel, holes for p-channel) that flow through the channel; similarly, the drain is where the charge carriers leave the channel.

The device may comprise a Silicon On Insulator (SOI) device in which a Buried oxide (BOX) is formed below a thin semiconductor layer. If the channel region between the gate dielectric and a Buried Oxide (BOX) region is very thin, the very thin channel region is referred to as an Ultra Thin Channel (UTC) region with the source and drain regions formed on either side thereof in and/or above the thin semiconductor layer. Alternatively, the device may comprise a semiconductor On Insulator (SEMOI) device in which semiconductors other than silicon are employed. Many alternative semiconductor materials may be employed. When the source and drain regions are formed above the channel in whole or in part, they are referred to as Raised Source/Drain (RSD) regions.

5.3.2 DEPLITION TYPE OF MOSFET

we note that the main ingredient of the channel is silicon. It can be a p-type or n-type channel; it is still mostly silicon. Next, we take note that silicon dioxide is simply glass, which is a good insulator. So we can form a thin layer of silicon dioxide along one surface of the channel, and then lay our metal gate region down over the glass. The result is shown to the left.

This device is sometimes known as an insulated-gate field effect transistor, or IGFET. More commonly, noting the construction of the gate, it is called a metal-oxide-semiconductor FET, or MOSFET.

With no voltage applied to the gate (G) electrode, the channel really is just a semiconductor resistance, and will conduct current according to the voltage applied between source (S) and rain (D). There is no pn junction, so there is no depletion region.

N-Channel depletion-mode MOSFET with normal (reverse) bias.

With an appropriate voltage applied between source and drain, current will flow through the channel, as a semiconductor resistance. However, if we now apply a negative voltage to the gate, as shown to the right, it will amount to a small negative static charge on the gate. This negative voltage will repel electrons, with their negative charge, away from the gate. But free electrons are the majority current carriers in the n-type silicon channel. By repelling them away from the gate region, the applied gate voltage creates a depletion region around the gate area, thus restricting the usable width of the channel just as the pn junction did.

Because this type of FET operates by creating a depletion region within an existing channel, it is called a depletion-mode MOSFET.

5.3.3 USE OF MOSFET IN VOLTAGE REGULATION

The output of the BJT is connected to the gate supply of N MOSFET even the small voltage from the BJT will trigger the MOSFET and hence MOSFET will be in on condition then the output from MOSFET will be continued to the MAX 666

CHAPTER 6

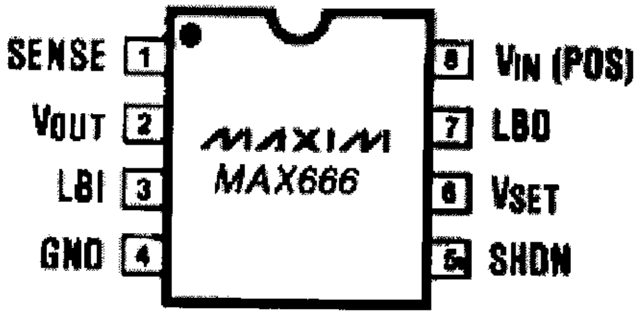
MAX666 IC

Introduction:

There is no dearth of micro power voltage regulators in the market.

The MAX666 CMOS voltage regulators have a maximum quiescent current of 12 micro amperes. They can be used either as 5volt, fixed output regulators with no additional components or can be adjusted from 1.3 volt to 16 volt using two external resistances. Fixed or adjustable operation is automatically selected via the Vset input. The MAX666 series, ideally suited for battery powered systems has an input voltage range of 2 to 16.5 volts, an output current capability of 40mA and can operate with low input/output differentials. Other features include current limiting and low power shut down. The MAX666 has a positive output and includes on-chip low-battery detection circuitry.

6.1 Pin Diagram:



Pin Description:

NAME	FUNCTION (See text for details)
$V_{OUT(1)(2)}$	Regulator Output(s)
V_{IN}	Regulator Input
SENSE	Current limit sense input
LBI	Low battery detection Input
LBO	Low battery detection output
SHUTDOWN	Disables output for minimum power consumption
V_{SET}	Ground this pin for 5V output or Connect to external resistive divider for adjustable output
V_{TC}	Temperature-proportional voltage for negative TC output

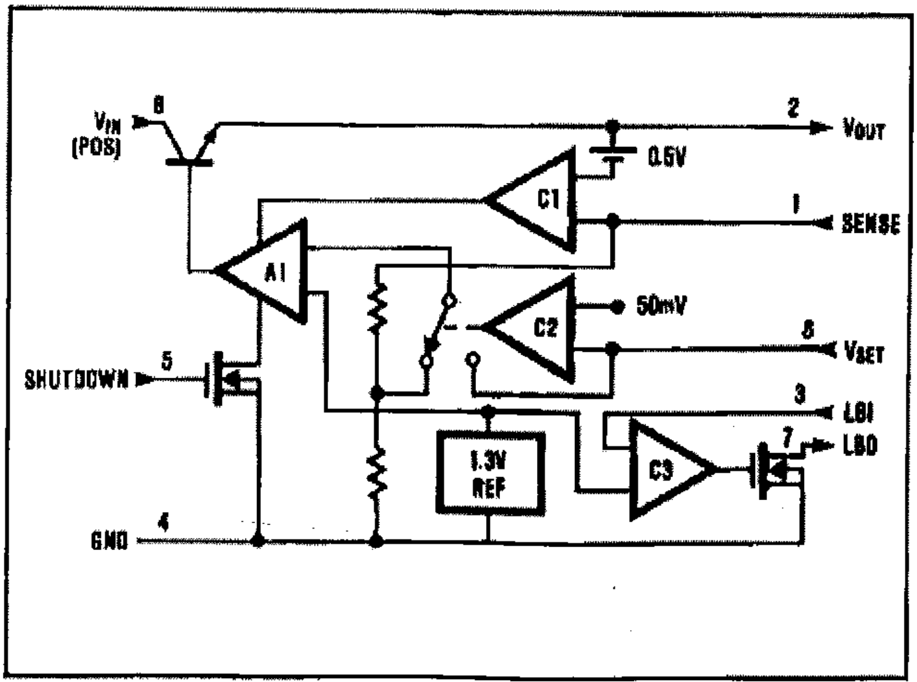
6.2 Electrical characterstics of MAX666:

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Input Voltage	V_{IN}	Over Temperature (C) Over Temperature (E, M)	2.0 2.2		16.5	V
Quiescent Current	I_Q	No Load, V_{IN} = +16.5V T_A = +25°C Over Temperature (C) Over Temperature (E, M)		6	12 15 20	μA
Output Voltage	V_{OUT}	V_{SET} = GND Over Temperature (C, E) Over Temperature (M)	4.75 4.5	5.0 5.0	5.25 5.5	V
Line Regulation	$\Delta V_{OUT}/\Delta V_{IN}$	$+2V \le V_{IN} \le +15V$, $V_{OUT} = V_{REF}$		0.03	0.35	%/V
Load Regulation	$\Delta V_{OUT}/\Delta I_{OUT}$	MAX663: $1mA \le I_{OUT2} \le 20mA$ MAX663: $50\mu A \le I_{OUT1} \le 5mA$ MAX666: $1mA \le I_{OUT} \le 20mA$		3.0 1.0 3.0	7.0 5.0 7.0	Ω
Reference Voltage	V_{SET}	$V_{OUT} = V_{SET}$	1.27		1.33	V
Reference Tempco.	$\Delta V_{SET}/\Delta T$	Over Temperature		±100		ppm/°C
V_{SET} Internal Threshold for Fixed +5V or Adjustable Output	$V_{F/A}$	$V_{SET} < V_{F/A}$ for +5V Out $V_{SET} > V_{F/A}$ for Adjustable Out		50		mV
V_{SET} Input Current	I_{SET}	Over Temperature (C, E) Over Temperature (M)		±0.01	±10 ±25	nA
Shutdown Input Voltage	V_{SHDN}	V_{SHDN} HI = Output Off V_{SHDN} LO = Output On	1.4		0.3	V
Shutdown Input Current	I_{SHDN}			±0.01	±10	nA
SENSE Input Threshold	$V_{OUT} - V_{SENSE}$	Current Limit Threshold		0.5		V
SENSE Input Resistance	R_{SENSE}			3		MΩ
Input-Output Saturation Resistance, MAX663 - V_{OUT1}	R_{SAT}	V_{IN} = +2V, I_{OUT} = 1mA V_{IN} = +9V, I_{OUT} = 2mA V_{IN} = +15V, I_{OUT} = 5mA		200 70 50	500 150 150	Ω
Output Current, V_{OUT2} (V_{OUT} on MAX666)	I_{OUT}	$+3V \le V_{IN} \le +16.5V$ $V_{IN} - V_{OUT}$ = +1.5V	40			mA
Minimum Load Current	$I_{L(MIN)}$	T_A = +25°C Over Temperature (C, E) Over Temperature (M)			1.0 5.0 10.0	μA

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
LBI Input Threshold	V_{LBI}	MAX666	1.21	1.28	1.37	V
LBI Input Current	I_{LBI}	MAX666		±0.01	±10	nA
LBO Output Saturation Resistance	R_{SAT}	MAX666, I_{SAT} = 2mA		35	100	Ω
LBO Output Leakage Current		MAX666, LBI = +1.4V		10		nA
V_{TC} Open-Circuit Voltage (Note 1)	V_{TC}	MAX663		0.9		V
V_{TC} Sink Current (Note 1)	I_{TC}	MAX663		8.0	2.0	mA
V_{TC} Temperature Coefficient (Note 1)		MAX663		+2.5		mV/°C

Detailed Description:

As shown in the block diagrams for each device the main elements of the MAX666 family of regulators are a micro power band gap reference,an error amplifier and one or two series pass output devices.One NPN transistor is used in MAX666. It also contains two comparators,one for current limiting and another which selects fixed 5 Volts or adjustable output operation.



The band gap reference, which is trimmed to 1.30V±30mV,is internally connected to one input of error amplifier,A1.the feedback signal from the regulator output is supplird to the A1's other input by either an on-chip voltage divider or by two external resistors.when Vset is grounded the internal divider provides the error amplifiers feedback signal for a fixed 5V output. when Vset is more than 50mV above ground the error amplifier's input is switched directly to the Vset pin and external resistors set output voltage.

Comparator C1 monitors the output current via the SENSE input and shuts down the regulator's output by disabling A1. An external current sense resistor Rcl sets the limit value. The MAX666 current-limit when the voltage on Rcl exceeds 0.5V,the MAX666 has a third comparator C3 which compares the LBI input to the to the internal 1.30V reference. The low battery output LBO is an open drain FET connected to ground. The low battery threshold can also be set with a voltage divider at LBI.

Basic circuit operation:

figureA shows the connections for fixed 5V output positive and negative regulators. The Vset input is grounded and low external resistors are required

figureB shows adjustable output operations with current limiting. The output voltage is set by R1 and R2 and current limit threshold is set by Rcl. Vout should be connected to SENSE if current limiting is not used and SHUTDOWN should be grounded if not used.

6.3 Output Voltage Selection:

If Vset is connected to ground , the output voltage is set by the equation :

$$V_{OUT} = V_{SET} \times \frac{R1 + R2}{R1}$$

Where Vset =1.30 V

Since the input bias current at V set has the max value of 10nA , relatively larger values can be used for R1 and R2 with no loss of accuracy . 1 M ohm is the typical value of R1

CURRENT LIMITING

Internal current limiting is activated on all MAX 666 devices when the voltage difference between Vout and SENCE input exceeds an internal threshold given by

$$R_{CL} = \frac{V_{CL}}{I_{CL}} \quad \begin{array}{l} V_{CL} = 0.5V \text{ for MAX663 and MAX666} \\ V_{CL} = -0.6V \text{ for MAX664} \\ (V_{CL} = V_{OUT} - V_{SENSE}) \end{array}$$

Where Rcl is current limit sense resistor and Icl is the maximum output current specification nor the maximum power dissipation is exceeded .

SHUT DOWN INPUT

The SHUTDOWN input allows the regulator to be turned off with logic level signal . since the current drain in shutdown is limited the regulators quiescent current this is sometimes desirable in applications where low power consumption is needed. The SHUTDOWN input should be driven with CMOS logic level since input threshold is only 0.3 V

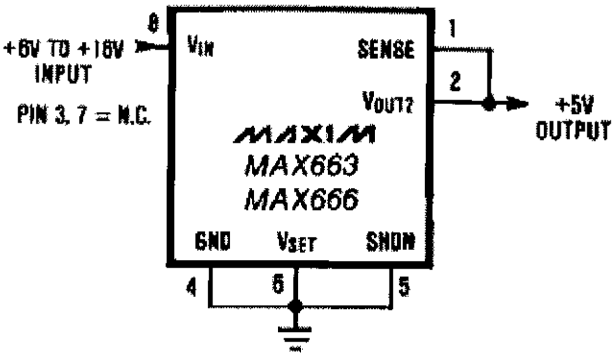
LOW BATTERY DETECTION

The MAX666 contains on chip circuitry for low battery or low power supply detection. If the voltage at LBI falls below regulators internal reference then LBO an open drain output, goes low this threshold can be set any value given by

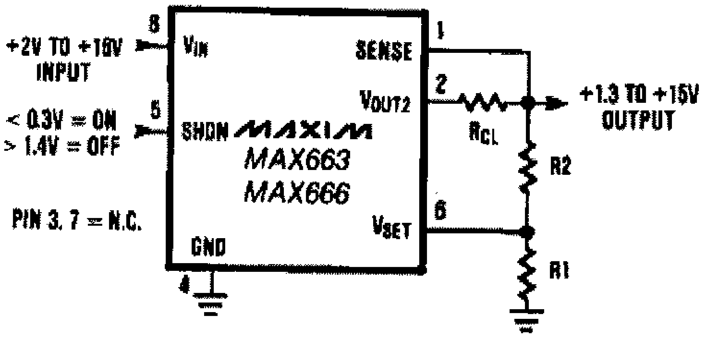
$$R3 = R4 \times \left(\frac{V_{BATT}}{1.30V} - 1\right)$$

Where Vbatt is the desired threshold of the low battery detector and R3 and R4 are the LBI input divider registers .

Since LBI'S current is no more than 10 n ampere then R3 and R4 can have high values to minimize loading. When mega ohms register values are chosen , special attention should be paid to PC board leakage which can introduce an error at LBI input.



Connections for fixed 5V output



Connections for adjustable output

CHAPTER -7

CONCLUSION

We have effectively produce power from the piezoelectric sensors. The future prospective of this power generation through piezoelectric sensors are explained below.

We can implant these array of piezoelectric sensors on the highways , due to the pressure generated by the moving vehicles on the array of sensors implanted under the road tar layer , ac fluctuations will be produced and from these random fluctuation we can produce a dc which will be stored in batteries , which will be used in lighting up the street lights .

These array of sensors can also be Implanted on the dance floor of the clubs , pubs . when people dances on the floor pressure will be applied on the dance floor due to which random fluctuations will be produced after converting these fluctuations to dc , we lit up whole club .

Similarly these array of sensors can be implanted on railway tracks , on airport's runway. By using array of sensors we can generate efficient and pollution free electricity , just investing once on implanting the sensors we can have a free power generation source . Hence saving some amount of electricity which was earlier imported from the government .

The simple sensors available in the market is not suitable for more efficient output , hence in order to have high efficient output we need to do multi layering of the piezoelectric sensors.

The efficiency can also be increased by using better voltage regulation circuit .

BIBLIOGRAPHY

1. Umeda, M., Nakamura, K. amd Ueha, S., 1996, "Analysis of Transformation of Mechanical Impact Energy to Electrical Energy Using a Piezoelectric Vibrator", Japanese Journal of Applied Physics, Vol. 35, Part1, No. 5B, May, pp. 3267-3273.

2. Starner, T., 1996, "Human-Powered Wearable Computing," IBM Systems Journal, Vol. 35, pp. 618.

3. Kymissis, J., Kendall, C., Paradiso, J., Gershenfeld, N., 1998, "Parasitic Power Harvesting in Shoes," Second IEEE International Conference on Wearable Computing, pp. 132-139.

4 Kimura, M, 1998,"Piezoelectric Generation Device", US Patent Number 5,801,475.

5. Goldfarb, M. and Jones, L. D., 1999. "On the Efficiency of Electric Power Generation With Piezoelectric Ceramic." Journal of Dynamic Systems, Measurement, and Control, Vol. 121, pp 566-571.

6. Clark, W. and Ramsay, M. J., 2000. "Smart Material Transducers as Power Sources for MEMS Devices," International Symposium on Smart Structures and Microsystems, Hong Kong.

7. Elvin, N.G., Elvin, A.A., and Spector, M., 2001, "A self-Powered Mechanical Strain Energy Sensor," Smart Materials and Structures, Vol. 10, pp. 293-299.

8. Elvin, N.G., Elvin, A.A., and Spector, M., 2000, "Implantable bone strain telemetry system and method," US Patent Specification 6034296.

9 Kasyap, A., Lim, J., Johnson, D., Horowitz, S., Nishida, T., Ngo, K., Sheplak, M., Cattafesta, L., 2002. "Energy Reclamation from a Vibrating Piezoceramic Composite Beam," Proceedings of 9th International Congress on Sound and Vibration, Orlando, FL.

10 Gonzalez, J.L., Moll, F., Rubio, A. "A prospect on the use of Piezoelectric Effect to Supply Power to Wearable Electronic Devices," ICMR 2001, Akita, Japan, October 2001, pp. Vol1,202-207.