A WEARABLE SYSTEM OF MICRO MACHINED PIEZO ELECTRIC CANTILEVERS FOR ON-BODY ENERGY HARVESTING

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this project report **"A WEARABLE SYSTEM OF MICRO MACHINED PIEZO ELECTRIC CANTILEVERS FOR ON-BODY ENERGY HARVESTING"** is the Bonafide work of **"MANOJ KUMAR S 111518106082, SAAI RAGAUVENDRA S 111518106128, SANTHOSH V 111518106133** who carried out the project work under my supervision.

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The Viva Voice Examination for the Students who have submitted this project work is held on ….21-08-2022….

INTERNAL EXAMINER **EXTERNAL EXAMINER**

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The satisfactions that accompany the successful completion of any task would be incomplete without mentioning the people who made it possible by their constant guidance and encouragement crowned our efforts with success.

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ABSTRACT

In this paper, we present a compact, wearable piezoelectric on-body harvesting system that uses a small eccentric mass from a common watch movement to mechanically deflect a set of micro machined piezoelectric cantilevers when excited by the low frequency movements of the human body. The piezoelectric cantilevers are directly coupled to the rotating mass via a set of pins located near its rotational center. The energy produced by each pluck of a single cantilever is the periodic rest of typical human motion, the average output power over a full day cycle will be considerably less.

KEYWORDS: Piezoelectric, Cantilever.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Electric current usage has been increased so much if a person needs to charge his mobile but he is not in the house he can use the piezoelectric on-body sensor to charge his device .

1.2 SCOPE OF THE PROJECT

Generation of electric current from the pressure given on the piezoelectric sensor Connected to the microprocessor embedded with C& keil software.If the pressure given is high there is an increase in electric current generation.

1.3 EXISTING SYSTEM

- The Existing System is Energy harvesting sources, including solar, wind and thermal each with a different optimal size.
- They either waste much available energy due to impedance mismatch, or they require active digital control that incurs overhead, or they work with only one specific type of source.
- Using solar energy can have a positive, indirect effect on the environment when solar energy replaces or reduces the use of other energy sources that have larger effects on the environment.

1.3.1 EXISTING SYSTEM DISADVANTAGES

- High initial costs for material and installation.
- No solar power at night so there is a need for a large battery bank
- Devices that run on DC power directly are more expensive
- Depending on geographical location, the size of the solar panels vary for the same power generation. Cloudy days do not produce much energy.

1.4 LITERATURE SURVEY

TITLE 1: Modeling of electric energy harvesting using piezoelectric windmill

AUTHOR: S. Priya

YEAR: **2005**

DESCRIPTION:

This gives a theoretical model for determination of generate electric power from piezoelectric bimorph transducers in low frequency range far from the piezoelectric resonance.

The model is divided into two parts. In the first part the open circuit voltage response of the transducer under the ac stress is computed based on the bending beam theory for bimorph.

In the second part, this open circuit voltage acts as the input to the equivalent circuit of the capacitor connected across a pure resistive load.

The results of the theoretical model were verified by comparing it with the measured response of a prototype windmill.

The prototype piezoelectric windmill consisting of ten piezoelectric bimorph transducers was operated in the wind speed of 1–12 mph.

A power of 7.5 mW at the wind speed of 10 mph was measured across a matching load of 6.7kΩ.

The theoretical model was found to give very accurate prediction of the generated power and matching load and an excellent matching was found with the experimental results.

TITLE 2: Plucked piezoelectric bimorphs for knee-joint energy harvesting: modelling and experimental validation

AUTHOR: M. Pozzi and M. Zhu

YEAR:2011

DESCRIPTION:

The modern drive towards mobility and wireless devices is motivating intensive research in energy harvesting technologies. To reduce the battery burden on people, we propose the adoption of a frequency up-conversion strategy for a new piezoelectric wearable energy harvester.

Frequency up-conversion increases efficiency because the piezoelectric devices are permitted to vibrate at resonance even if the input excitation occurs at much lower frequency.

Mechanical plucking-based frequency up- conversion is obtained by deflecting the piezoelectric bimorph via a plectrum, then rapidly releasing it so that it can vibrate unhindered; during the following oscillatory cycles, part of the mechanical energy is converted into electrical energy.

In order to guide the design of such a harvester, we have modelled with finite element methods the response and power generation of a piezoelectric bimorph while it is plucked.

The model permits the analysis of the effects of the speed of deflection as well as the prediction of the energy produced and its dependence on the electrical load.
An experimental rig has been set up to observe the response of the bimorph in the harvester.

A PZT-5H bimorph was used for the experiments. Measurements of tip velocity,voltage output and energy dissipated across a resistor are reported.
Comparisons of the experimental results with the model predictions are very successful and prove the validity of the model.

TITLE 3: Awearable piezoelectric rotational energy harvester

AUTHOR: P.Pillatsch, E.M. Yeatman, A.S. Holmes

YEAR: **2013**

DESCRIPTION:

This paper discusses the operating principle of a rotational energy harvester for body motion with an eccentric proof mass.

A mathematical analysis for the rotor motion under different excitations is performed and the gravitational and inertial operation explained.

The transducing mechanism works on the principle of frequency up-conversion that is now widely used to harvest low frequency vibration more efficiently, and uses a piezoelectric beam and magnetic coupling.

A miniaturized device with an overall size similar to that of a wristwatch is introduced.

The fabrication is entirely done using standard milling and turning processes.

Experimental results for this device show significant improvement in the attachment of the piezoelectric beamcompared to a previous prototype.

Furthermore, there is a good match between the magnetic forces and the proof mass for the tested excitations.

A disadvantage of the miniaturized prototype is the higher stiffness of the piezo beam, preventing free oscillation after actuation.

Modifications to counteract this problem are provided and experimentally validated

TITLE 4: On the experimental determination of the efficiency of piezoelectric impact-type energy harvesters using a rotational flywheel

AUTHOR: P. Janphuang, R. Lockhart, S. Henein, D. Briand, and N.F. de Rooij
YEAR: 2013

DESCRIPTION:

This paper demonstrates a novel methodology using a rotational flywheel to determine the energy conversion efficiency of the impact based piezoelectric energy harvesters.

The influence of the impact speed and additional proof mass on the efficiency is presented here.

In order to convert low frequency mechanical oscillations into usable electrical energy, a piezoelectric harvester is coupled to a rotating gear wheel driven by flywheel.

The efficiency is determined from the ratio of the electrical energy generated by the harvester to the mechanical energy dissipated by the flywheel.

The experimental results reveal that free vibrations of the harvester after plucking contribute significantly to the efficiency.

The efficiency and output energy can be greatly improved by adding a proof mass to the harvester.

Under certain conditions, the piezoelectric harvesters have an impact energy conversion efficiency of 1.2%.

TITLE 5: On the optimization and performances of a compact piezoelectric impact MEMS energy harvester

AUTHOR: P. Janphuang, R. Lockhart, D. Briand and N.F. de Rooij

YEAR: 2014

DESCRIPTION:

This paper presents the development of a compact energy harvesting configuration to convert low frequency, mechanical oscillations into usable electrical energy using AFM-like MEMS piezoelectric cantilevers coupled to a rotating gear.

In this approach, one or several piezoelectric harvesters can be positioned above a rotating gear driven by an oscillating mass.

In order to analyze the motion and the electrical power output from the harvester, analytical and finite element models have been developed. The harvester, with an active device volume of

3.5 mm 3 (3×5×0.23 mm 3), is able to produce an average output power of 12 µW measured across an optimal resistive load of 4.7kΩ at a rotational speed of 19rps, demonstrating the potential of the compact MEMS piezoelectric micro-power generator.

1.5 PROPOSED SYSTEM

- In our Proposed System, the energy harvester consists of an epoxy cantilever sandwiched between electrodes that are used to collect the generated power.

- When we touch on the structure creates an impulsive force that brings the internal lattice structure of element to deform, causing the loss of symmetry, and therefore the generation of small dipoles, which global effect is an impulsive voltage on the electrodes.

- Mechanical vibrations follow the impact, stress is induced within the material, thus giving rise to an electrical source.

- The generated electrical energy are viewed on the LCD. The produced DC energyis fed to the ultra low power convertor.

- The ultra low power capacitor reduces the discharging time, hence the battery time is longer.

- The output of the Ultra Low Power Convertor is given to a DC Power Bank.The stored DC energy is converted to AC voltage and used for home application.

1.5.1 PROPOSED SYSTEM ADVANTAGES

- Good Output Power.
- Easy Method.
- Portable Technology
- Boost Level Increased.
- Trust-able One.

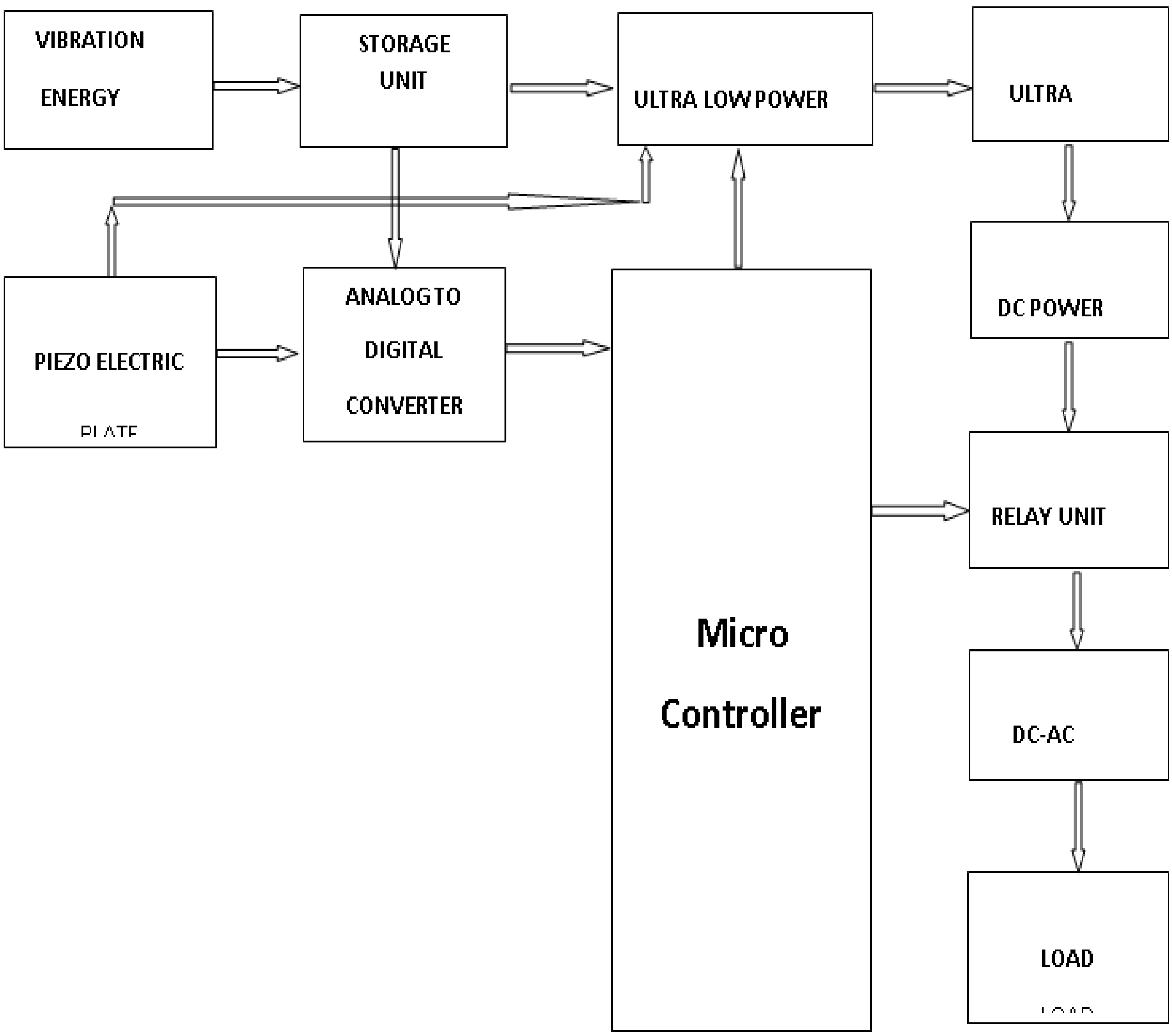
CHAPTER 2

PROJECT DESCRIPTION

2.1 GENERAL

We present a compact, wearable piezoelectric on-body harvesting system that uses a small eccentric mass from a common watch movement to mechanically deflect a set of micro machined piezoelectric cantilevers when excited by the low frequency movements of the human body. The piezoelectric cantilevers are directly coupled to the rotating mass via a set of pins located near its rotational center. The energy produced by each pluck of a single cantilever is the periodic rest of typical human motion, the average output power over a full day cycle will be considerably less.

2.2 BLOCK DIAGRAM



HARDWARE AND SOFTWARE DESCRIPTION

3.1 HARDWARE DESCRIPTION:

a) ANALOG TO DIGITAL CONVERTER

An **analog-to-digital converter** (abbreviated **ADC**, **A/D** or **A to D**) is an electronic integrated circuit, which converts continuous signals to discrete digital numbers. The reverse operation is performed bya digital-to-analog converter (**DAC**).

Successive-Approximation ADC

A **successive-approximation ADC** uses a comparator to reject ranges of voltages, eventually settling on a final voltage range. Successive approximation works by constantly comparing the input voltage to the output of an internal digital to analog converter (DAC, fed by the current value of the approximation) until the best approximation is achieved. At each step in this process, a binary value of the approximation is stored in a successive approximation register (SAR). The SAR uses a reference voltage (which is the largest signal the ADC is to convert) for comparisons. For example if the input voltage is 60 V and the reference voltage is 100 V, in the 1st clock cycle, 60 V is compared to 50 V (the reference, divided by two. This is the voltage at the output of the internal DAC when the input is a '1' followed by zeros), and the voltage from the comparator is positive (or '1') (because 60 V is greater than 50 V). At this point the first binary digit (MSB) is set to a '1'. In the 2nd clock cycle the input voltage is compared to 75 V (being halfway between 100 and 50 V: This is the output of the internal DAC when its input is '11'followedby zeros) because 60 V is less than 75 V, the comparator output is now negative (or'0'). The second binary digit is therefore set to a '0'. In the 3rd clock cycle, the input voltage is compared with 62.5 V (halfway between 50 V and 75 V:

This is the output of the internal DAC when its input is '101' followed by zeros). The output of the comparator is negative or '0' (because 60 V is less than 62.5 V) so the third binary digit is set to a 0. The fourth clock cycle similarly results in the fourth digit being a '1' (60 V is greater than 56.25 V, the DAC output for '1001' followed by zeros). The result of this would be in the binary form 1001. This is also called *bit-weighting conversion*, and is similar to a binary search. The analogue value is rounded to the nearest binary value below, meaning this converter type is mid-rise (see above). Because the approximations are successive (not simultaneous), the conversion takes one clock-cycle for each bit of resolution desired. The clock frequency must be equal to the sampling frequency multiplied by the number of bits of resolution desired. For example, to sample audio at 44.1 kHz with 32 bit resolution, a clock frequency of over 1.4 MHz would be required. ADCs of this type have good resolutions and quite wide ranges. They are more complex than some other designs. Many PIC's have the ability to perform analogue to digital conversions, PIC16F87XA doesn't take any extra components, although a pull down resistor is always good to keep the conversions as accurate as possible,though not needed in some cases.

Analog to digital converter in PIC Microcontroller

The Analog-to-Digital (A/D) Converter module has five inputs for the 28-pin devices and eight for the 40/44-pin devices. The conversion of an analog input signal results in a corresponding 10-bit digital number. The A/D module has high and low-voltage reference input that is software selectable to some combination of VDD, VSS, RA2 or RA3. The A/D converter has a unique feature of being able to operate while the device is in Sleep mode. To operate in Sleep, the A/D clock must be derived from the A/D’s internal RC oscillator.

The A/D module has four registers. These registers are:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register 0 (ADCON0)
- A/D Control Register 1 (ADCON1)

The ADCON0 register controls the operation of the A/D module. The ADCON1register configures the functions of the port pins. The port pins can be configured as analog inputs (RA3 can also be the voltage reference) or as digital I/O.

ADCON0 REGISTER

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0
ADCS1	ADCS0	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	—	ADON
bit 7							bit 0

ADCON1 REGISTER

R/W-0	R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	ADCS2	—	—	PCFG3	PCFG2	PCFG1	PCFG0
bit 7							bit 0

The ADRESH: ADRESL registers contain the 10-bit result of the A/D conversion. When the A/D conversion is complete, the result is loaded into this A/D Result register pair, the GO/DONE bit (ADCON0<2>) is cleared and the A/D interrupt flag bit ADIF is set.

After the A/D module has been configured as desired, the selected channel must be acquired before the conversion is started.The analog input channels must have their corresponding TRIS bits selected as inputs.

Acquisition Requirements.

After this acquisition time has elapsed, the A/D conversion can be started.To do an A/D Conversion, follow these steps:

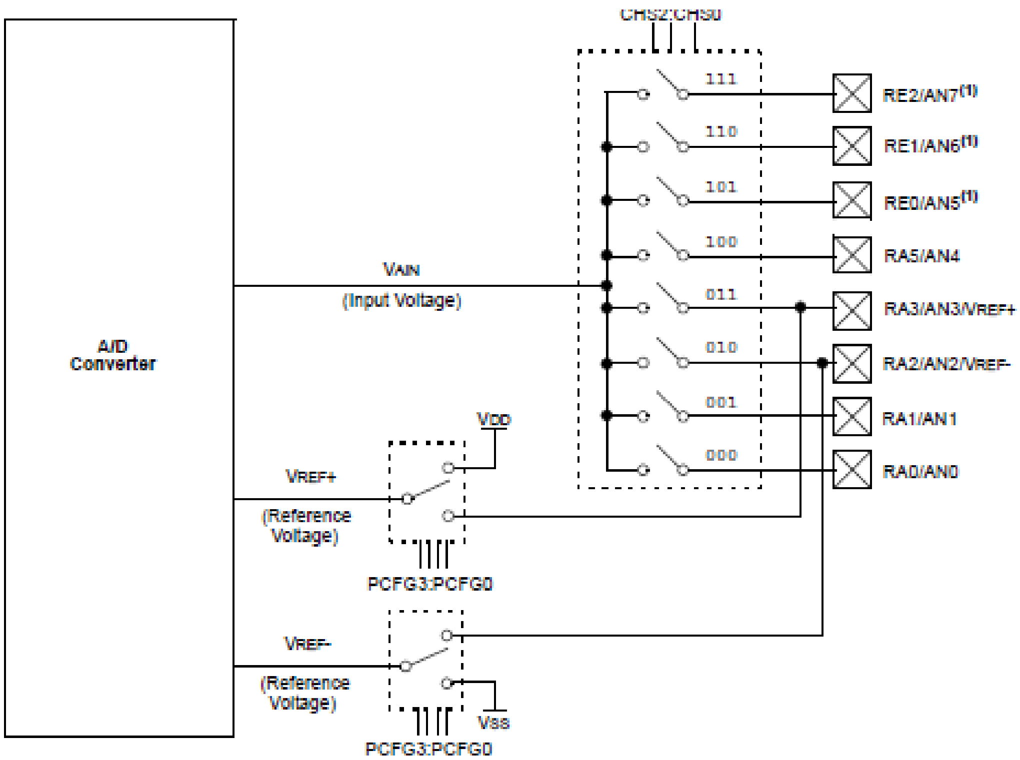
1. Configure the A/D module:

   ❖ Configure analog pins/voltage reference and digital I/O (ADCON1)

- ❖ Select A/D input channel (ADCON0)
- ❖ Select A/D conversion clock (ADCON0)
- ❖ Turn on A/D module (ADCON0)

2. Configure A/D interrupt (if desired):
   - ❖ Clear ADIF bit
   - ❖ Set ADIE bit
   - ❖ Set PEIE bit
   - ❖ Set GIE bit
3. Wait the required acquisition time.
4. Start conversion:
   - ❖ Set GO/DONE bit (ADCON0)
5. Wait for A/D conversion to complete by either:
   - ❖ Polling for the GO/DONE bit to be cleared (interrupts disabled); OR
   - ❖ Waiting for the A/D interrupt
6. Read A/D Result register pair(ADRESH:ADRESL), clear bit ADIF if required.
7. For the next conversion, go to step 1 or step 2 as required. The A/D conversion time per bit is

defined as TAD.



Selecting the A/D Conversion Clock

The A/D conversion time per bit is defined as TAD. The A/D conversion requires a minimum 12 TAD per 10-bit conversion. The source of the A/D conversion clock is software selected. The seven possible options for TAD are:

- 2 TOSC
- 4 TOSC
- 8 TOSC
- 16 TOSC
- 32 TOSC

- 64 TOSC
- Internal A/D module RC oscillator (2-6 μs)

For correct A/D conversions, the A/D conversion clock (TAD) must be selected to ensure a minimum TAD time of
1.6 μs.

Configuring Analog Port Pins

The ADCON1 and TRIS registers control the operation of the A/D port pins. The port pins that are desired as analog inputs must have their corresponding TRIS bits set (input). If the TRIS bit is cleared (output),the digital output level(VOH or VOL) will be converted. The A/D operation is independent of the state of the CHS2:CHS0 bits and the TRIS bits.

A/D Conversions

Clearing the GO/DONE bit during a conversion will abort the current conversion. The A/D Result register pair will NOT be updated with the partially completed A/D conversion sample. That is, the ADRESH: ADRESL registers will continue to contain the value of the last completed conversion (or the last value written to the ADRESH: ADRESL registers). After the A/D conversion

A/D RESULT REGISTERS

The ADRESH: ADRESL register pair is the location where the 10-bit

A/D result is loaded at the completion of the A/D conversion. This register pair is 16 bits wide.

The A/D module gives the flexibility to left or right justify the 10-bitresult in the 16-bit result register.

The A/D is aborted; the next acquisition on the selected channel is automatically started.

The GO/DONE bit can then be set to start the conversion.

After the GO bit is set, the first time segment has a minimum of TCY and a maximum of TAD.

Format Select bit (ADFM) controls this justification.

The extra bits are loaded with ‘0’s. When an A/D result will not overwrite these locations (A/D disable), these registers may be used as two general purpose 8-bit registers.

b) Battery

An electric **battery** is a device consisting of two or more electrochemical cells that convert stored chemical energy into electrical energy. Each cell has a positive terminal, or cathode, and a negative terminal, or anode. The terminal marked positive is at a higher electrical potential energy than is the terminal marked negative. The terminal marked positive is the source of electrons that when connected to an external circuit will flow and deliver energy to an external device.When a battery is connected to an external circuit, Electrolytes are able to move as ions within, allowing the chemical reactions to be completed at the separate terminals and so deliver energy to the external circuit. It is the movement of those ions within the battery which allows current to flow out of the battery to perform work.[1] Although the term *battery* technically means a device with multiple cells, single cells are also popularly called batteries.

Principle of operation

Batteries convert chemical energy directly to electrical energy. A battery consists of some number of voltaic cells. Each cell consists of two half-cells connected in series by a conductive electrolyte containing anions and cations. migrate. Redox reactions power the battery. Cations are reduced (electrons are added) at the cathode during charging, while anions are oxidized (electrons are removed) at the anode during charging.[12] During discharge, the process is reversed. The electrodes do not touch each other, but are electrically connected by the electrolyte. Some cells use different electrolytes for each half-cell.

A separator allows ions to flow between half-cells, but prevents mixing of the electrolytes.The electrical driving force or across the terminals of a cell is known as the *terminal voltage (difference)* and is measured in volts.[15] The terminal voltage of a cell that is neither charging nor discharging is called the open-circuit voltage and equals the emf of the cell.

An ideal cell has negligible internal resistance, so it would maintain a constant terminal voltage of until exhausted, then dropping to zero. If such a cell maintained 1.5 volts and stored a charge of one coulomb then on complete discharge it would perform 1.5 joules of work shape of the curve varies according to the chemistry and internal arrangement employed.

The voltage developed across a cell's terminals depends on the energy release of the chemical reactions of its electrodes and electrolyte. Alkaline and zinc–carbon cells have different chemistries.The high electrochemical potential changes in the reactions of lithium compounds give lithium cells emfs of 3 volts or more.

c) Buck boost converter:

Two different topologies are called **buck–boost converter**. Both of them can produce an output voltage much larger (in absolute magnitude) than the input voltage. Both of them can produce a wide range of output voltage from that maximum output voltage to almost zero.

- The inverting topology – The output voltage is of the opposite polarity asthe input
- A buck (step-down) converter followed by a boost (step-up) converter – The output voltage is of the same polarity as the input, and can be lower or higher than the input. Such a non-inverting buck-boost converter may use a single inductor that is used as both the buck inductor and the boost inductor.

  This page describes the inverting topology.

The **buck–boost converter** is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is a switch mode power supply with a similar circuit topology to the boost converter and the buck converter. The output voltage is adjustable based on the duty cycle of the switching transistor. One possible drawback of this converter is that the switch does not have a terminal at ground; this complicates the driving circuitry. Also, the polarity of the output voltage is opposite the input voltage.

Neither drawback is of any consequence if the power supply is isolated from the load circuit (if, for example, the supply is a battery) as the supply and diode polarity can simply be reversed. The switch can be on either the ground side or the supply side.

Principle of operation

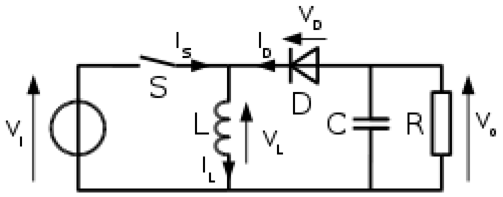


Fig. 1: Schematic of a buck–boost converter.

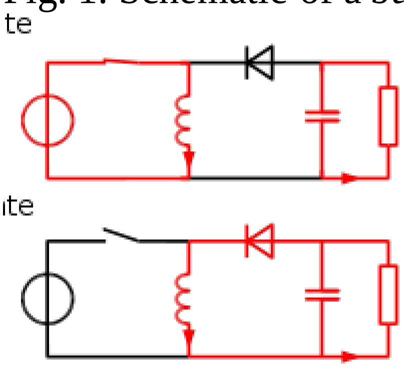


Fig. 2: The two operating states of a buck–boost converter: When the switch is turned-on, the input voltage source supplies current to the inductor and the capacitor supplies current to the resistor (output load). When the switch is opened(providing energy is stored into the inductor), the inductor supplies current to the load via the diode D.

The basic principle of the buck–boost converter is fairly simple (see figure 2):

- while in the On-state, the input voltage source is directly connected to the inductor (L). This results in accumulating energy in L. In this stage, the capacitor supplies energy to the output load.
- while in the Off-state, the inductor is connected to the output load and capacitor,so energy is transferred from L to C and R.

Compared to the buck and boost converters, the characteristics of the buck–boost converter are mainly:

- polarity of the output voltage is opposite to that of the input;
- the output voltage can vary continuously from 0 to $-\infty$ (for an ideal converter). The output voltage ranges for a buck and a boost converter are respectively0 to V_i and V_i to ∞.

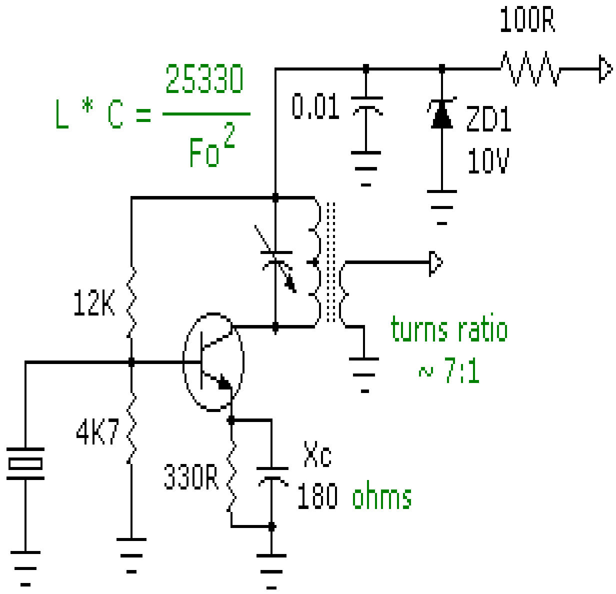
d) Crystal oscillator

- A crystal oscillator is an electronic circuit that uses the mechanical resonance of a vibrating crystal of piezoelectric material to create an electrical signal with a very precise frequency. This frequency is commonly used to keep track of time (as in quartz wristwatches), to provide a stable clock signal for digital integrated circuits, and to stabilize frequencies for radio transmitters/receivers

THE DESIGN PRINCIPLES OF CRYSTAL OSCILLATORS

- Crystal Oscillators are usually, fixed frequency oscillators where stability and accuracy are the primary considerations. For example it is almost impossible to design a stable and accurate LC oscillator for the upper HF and higher frequencies without resorting to some sort of crystal control. Hence the reason for crystal oscillators.

A PRACTICAL EXAMPLE OF A CRYSTAL OSCILLATOR



- This is a typical example of the type of crystal oscillators which may be used for say converters. Some points of interest on crystal oscillators. **OSCILLATOR TYPES**
- The PIC16F87XA can be operated in four different oscillator modes. The user can program two configuration bits (FOSC1 and FOSC0) to select one of these four modes:
  - LP Low-Power Crystal
  - XT Crystal/Resonator
  - HS High-Speed Crystal/Resonator
  - RC Resistor/Capacitor

CRYSTAL OSCILLATOR/CERAMIC RESONATORS

EXTERNAL CLOCK INPUT OPERATION (HS, XT OR LP OSC CONFIGURATION)

CERAMIC RESONATORS

Ranges Tested:			
Mode	Freq.	OSC1	OSC2
XT	455 kHz 2.0 MHz 4.0 MHz	68-100 pF 15-68 pF 15-68 pF	68-100 pF 15-68 pF 15-68 pF
HS	8.0 MHz 16.0 MHz	10-68 pF 10-22 pF	10-68 pF 10-22 pF
These values are for design guidance only. See notes following Table 14-2.			
Resonators Used:			
2.0 MHz	Murata Erie CSA2.00MG	± 0.5%	
4.0 MHz	Murata Erie CSA4.00MG	± 0.5%	
8.0 MHz	Murata Erie CSA8.00MT	± 0.5%	
16.0 MHz	Murata Erie CSA16.00MX	± 0.5%	
All resonators used did not have built-in capacitors.			

CAPACITOR SELECTION FOR CRYSTAL OSCILLATOR

Osc Type	Crystal Freq.	Cap. Range C1	Cap. Range C2
LP	32 kHz	33 pF	33 pF
	200 kHz	15 pF	15 pF
XT	200 kHz	47-68 pF	47-68 pF
	1 MHz	15 pF	15 pF
	4 MHz	15 pF	15 pF
HS	4 MHz	15 pF	15 pF
	8 MHz	15-33 pF	15-33 pF
	20 MHz	15-33 pF	15-33 pF

Crystals Used		
32 kHz	Epson C-001R32.768K-A	± 20 PPM
200 kHz	STD XTL 200.000KHz	± 20 PPM
1 MHz	ECS ECS-10-13-1	± 50 PPM
4 MHz	ECS ECS-40-20-1	± 50 PPM
8 MHz	EPSON CA-301 8.000M-C	± 30 PPM
20 MHz	EPSON CA-301 20.000M-C	± 30 PPM

RC OSCILLATOR

For timing insensitive applications, the “RC” device option offers additional cost savings. The RC oscillator frequency is a function of the supply voltage, the resistor (REXT) and capacitor (CEXT) values and the operating temperature. In addition to this, the oscillator frequency will vary from unit to unit due to normal process parameter variation. Furthermore, the difference in lead frame capacitance between package types will also affect the oscillation frequency, especially for low CEXT values. The user also needs to take into account variation due to tolerance of external R and C components used. Figure shows how the R/C combination is connected to the Microcontroller.

Notes:

1: Higher capacitance increases the stability of oscillator but also increases the start-up time.

2: Since each resonator/crystal has its own characteristics, the user should consult the resonator/crystal manufacturer for appropriate values of external components.

3: *Rs* may be required in HS mode, as well as XT mode, to avoid overdriving crystals with low drive level specification.

4: When migrating from other microcontroller devices, oscillator performance should be verified.

e) Inductor

An inductor, also called a coil or reactor, is a passive two-terminal electrical component which resists changes in electric current passing through it. It consists of a conductor such as a wire, usually wound into a coil. Energy is stored in a magnetic field in the coil as long as current flows. When the current flowing through an inductor changes, the time-varying magnetic field induces a voltage in the conductor, according to Faraday’s law of electromagnetic induction. According to Lenz's law the direction of induced electromotive force (or "e.m.f.") is always such that it opposes the change in current that created it. As a result, inductors always oppose a change in current, in the same way that a flywheel opposes a change in rotational velocity. Care should be taken not to confuse this with the resistance provided bya resistor.

An inductor is characterized by its *inductance*, the ratio of the voltage to the rate of change of current, which has units of henries (H). Inductors have values that typically range from 1 µH (10^{-6}H) to 1 H. Many inductors have a magnetic core made of iron or ferrite inside the coil, which serves to increase the magnetic field and thus the inductance. Along with capacitors and resistors, inductors are one of the three passive linear circuit elements that make up electric circuits. Inductors are widely used in alternating current (AC) electronic equipment, particularly in radio equipment. They are used to block AC while allowing DC to pass; inductors designed for this purpose are called chokes. They are also used in electronic filtersto separate signals of different frequencies, and in combination with capacitors to make tuned circuits, used to tune radio and TV receivers.

Applications

Inductors are used extensively in analog circuits and signal processing. Applications range from the use of large inductors in power supplies, which in conjunction with filter capacitors remove residual hums known as the mains humor other fluctuations from the direct current output, to the small inductance of the ferrite bead or torus installed around a cable to preventradio frequency interference from being transmitted down the wire. Inductors are used as theenergy storage device in many switched-mode power supplies to produce DC current. The inductor supplies energy to the circuit to keep current flowing during the "off" switching periods.

An inductor connected to a capacitor forms a tuned circuit, which acts as a resonator for oscillating current. Tuned circuits are widely used in radio frequency equipment such as radio transmitters and receivers, as narrow band pass filters to select a single frequency from a composite signal, and in electronic oscillators to generate sinusoidal signals.

Two (or more) inductors in proximity that have coupled magnetic flux (mutual inductance) form a transformer, which is a fundamental component of every electric utility power grid. The efficiency of a transformer may decrease as the frequency increases due to eddy currents in the core material and skin effect on the windings. The size of the core can be decreased at higher frequencies. For this reason, aircraft use 400 hertz alternating current rather than the usual 50 or 60 hertz, allowing a great saving in weight from the use of smaller transformers.[5]

Inductors are also employed in electrical transmission systems, where they are used to limit switching currents and fault currents. In this field, they are more commonly referred to as reactors.

Because inductors have complicated side effects (detailed below) which cause them to depart from ideal behavior, because they can radiate electromagnetic interference (EMI), and most of all because of their bulk which prevents them from being integrated on semiconductor chips, the use of inductors is declining in modern electronic devices, particularly compact portable devices. Real inductors are increasingly being replaced by active circuits such as the gyrator which can synthesize inductance using capacitors.

f) Inverter

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.

There are two main types of inverter. The output of a modified sine wave inverter is similar to a square wave output except that the output goes to zero volts for a time before switching positive or negative. It is simple and low cost (~$0.10USD/Watt)and is compatible with most electronic devices, except for sensitive or specialized equipment, for example certain laser printers. A pure sine wave inverter produces a nearly perfect sine wave output (<3% total harmonic distortion) that is essentially the same as utility-supplied grid power. Thus it is compatible with all AC electronic devices. This is the type used in grid-tie inverters. Its design is more complex, and costs 5 or 10 times more per unit power (~$0.50 to $1.00USD/Watt). [1] The electrical inverter is a high-power electronic oscillator. Itis so named because early mechanical AC to DC converters were made to work in reverse, and thus were "inverted", to convert DC to AC.

The inverter performs the opposite function of a rectifier.

An inverter converts the DC electricity from sources such as batteries, solar panels,or fuel cells to AC electricity. The electricity can be at any required voltage;

Uninterruptible power supplies

An uninterruptible power supply (UPS) uses batteries and an inverter to supply AC power when main power is not available. When main power is restored, a rectifier supplies DC power to recharge the batteries.

Induction heating

Inverters convert low frequency main AC power to a higher frequency for use in induction heating. To do this, AC power is first rectified to provide DC power. The inverter then changes the DC power to high frequency AC power.

HVDC power transmission

With HVDC power transmission, AC power is rectified and high voltage DC power is transmitted to another location. At the receiving location, an inverter in a static inverter plant converts the power back to AC.

Variable-frequency drives

Main article: variable-frequency drive

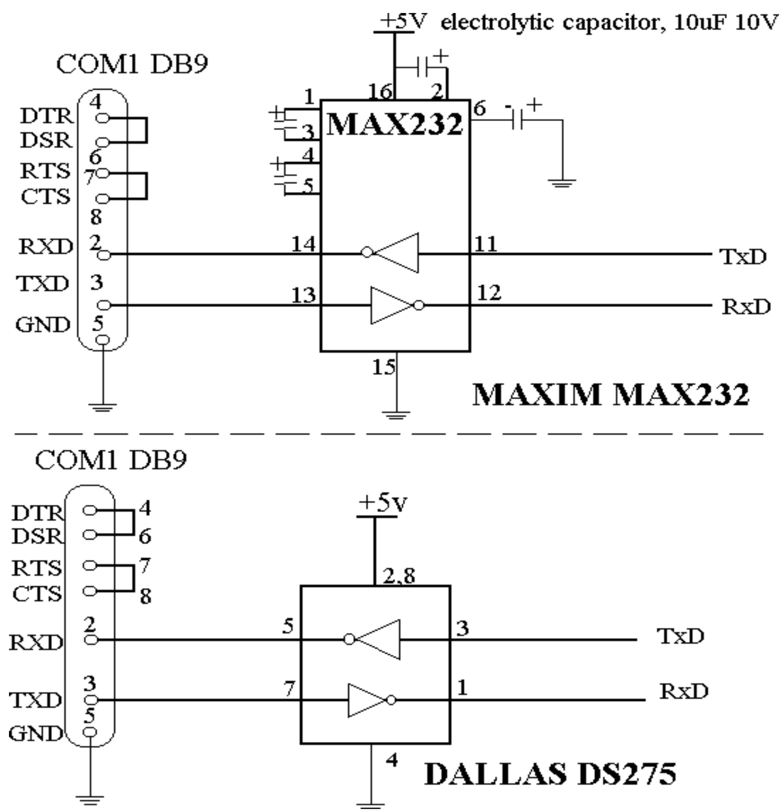
A variable-frequency drive controls the operating speed of an AC motor by controlling the frequency and voltage of the power supplied to the motor. An inverter provides the controlled power. In most cases, the variable-frequency drive includes a rectifier so that DC power for the inverter can be provided from main AC power. Since an inverter is the key component, variable-frequency drives are sometimes called inverter drives or just inverters.

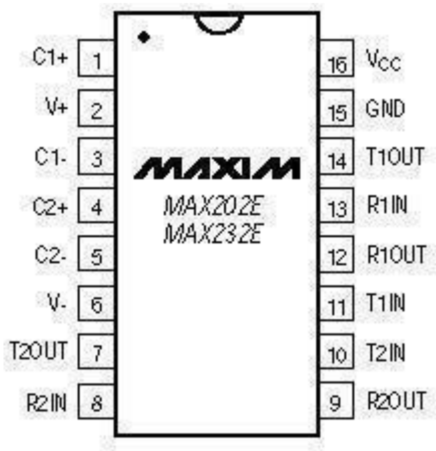
Electric vehicle drives Adjustable speed motor control inverters are currently used to power the traction motors in some electric and diesel-electric rail vehicles as well as some battery electric vehicles and hybrid electric highway vehicles such as the Toyota Prius. Various improvements in inverter technology are being developed specifically for electric vehicle applications.[3] In vehicles with regenerative braking, the inverter also takes power from the motor (now acting as a generator) and stores it in the batteries.

g) MAX232 IC

Now that we have the 8 bit value in the 16F877A , we want to send that value to the PC. The 16F877A has a built in serial port that makes it very easy to communicate with the PC's serial port but the 16F877A outputs are 0 and 5 volts and we need +10 and -10 volts to meet the RS232 serial port standard. The easiest way to get these values is to use the MAX232. The MAX232 acts as a buffer driver for the processor. It accepts the standard digital logic values of 0 and 5 volts and converts them to the RS232 standard of +10 and -10 volts. It also helps protect the processor from possible damage from static that may come from people handling the serial port connectors.

The MAX232 requires 5 external 1uF capacitors. These are used by the internal





For the first capacitor, the negative leg goes to ground and the positive leg goes to pin 16. For the second capacitor, the negative leg goes to 5 volts and the positive leg goes to pin 2.For the third capacitor, the negative leg goes to pin 3 and the positive leg goes to pin 1.

For the fourth capacitor, the negative leg goes to pin 5 and the positive leg goes to pin 4.

For the fifth capacitor, the negative leg goes to pin 6 and the positive leg goes to ground.

The MAX232 includes 2 receivers and 2 transmitters so two serial ports can be used with a single chip. We will only use one Transmitter for this project. The only connection that must be made to the 2051 is one jumper from pin 3 of the 2051 to pin 11 of the MAX232.

To power the MAX232,

Connect pin 16 to 5 volts.

Connect pin 15 to ground.

For more information one the MAX232 chip click here to get the data sheet for it. The only thing left is that we need some sort of connector to connect to the serial port.

h) MOSFET

MOSFET stands for Metal Oxide Semiconductor Field Effect Transistor. The mosfet is a capacitor operated transistor device. The capacitor plays an essential role for operating a MOSFET. We also call the device as Insulated Gate Field Effect Transistor (IGFET) or Metal Insulator Field Effect Transistor (MIFET). Why we call so we will understand when we look into the constructional features of this transistor device. We must take a look into the construction of MOSFET while going through the working principle of mosfet. Construction wise we can categorise the device into four types**.**

P – Channel Enhancement MOSFET

N – Channel Enhancement MOSFET

P – Channel Depletion MOSFET

N – Channel Depletion MOSFET

P – Channel Enhancement MOSFET

We also call the p channel MOSFET as PMOS. Here, a substrate of lightly doped n-type semiconductor forms the main body of the device. We usually use silicon or gallium arsenide semiconductor material for this purpose. Two heavily doped p- type regions are there in the body separated by a certain distance L. We refer this distance L as channel length and it is in order of 1 µm.Now there is a thin layer of silicon dioxide (SiO2) on the top of the substrate. We may also use Al2O3 for the purpose but SiO2 is most common. This layer on the substrate behaves as a dielectric. There is an aluminum plate fitted on the top of this SiO2 dielectric layer.

Now the aluminum plate, dielectric and semiconductor substrate form a capacitor on the device.

The terminals connected to two p-type regions are the source (S) and drain (D) of the device respectively. The terminal projected from the aluminum plate of the capacitor is gate (G) of the device.

We also connect the source and body of the mosfet to earth to facilitate the supply and withdrawal of free electrons as per requirement during operation of the MOSFET. P - Channel Enhancement MOSFET Now let us apply a negative voltage at gate (G). This will create negative static potential at the aluminum plate of the capacitor. Due to capacitive action, positive charge gets accumulated just below the dielectric layer.

Basically, the free electrons of that portion of the n-type substrate get shifted away due to the repulsion of negative gate plate and consequently layers of uncovered positive ions appear here. Now if we further increase the negative voltage at the gate terminal, after a certain voltage called threshold voltage, due to the electrostatic force, covalent bonds of the crystal just below the SiO2 layer start breaking. Consequently, electron-hole pairs get generated there. The holes get attracted and free electrons get repealed due to the negativity of the gate. In this way, the concentration of holes increases there and create a channel of holes from source to drain region. Holes also come from both heavily doped p-type source and drain region. Due to the concentration of holes in that channel the channel becomes conductive in nature through which electric current can pass. Now let us apply a negative voltage at drain terminal. The negative voltage in the drain region reduces the voltage difference between gate and drain reduces, as a result, the width of the conductive channel get reduced toward the drain region as shown below. At the same time, current flows from source to drain shown by arrow head.

N – Channel Enhancement MOSFET

Working of N – Channel Enhancement MOSFET is similar to that of P – Channel Enhancement MOSFET but only operationally and constructionally these two are different from each other. In N Channel Enhancement MOSFET a lightly doped p-type substrate forms the body of the device and source and drain regions are heavily doped with n-type impurities. Here also we connect the body and source commonly to the ground potential. Now, we apply a positive voltage to the gate terminal.

Due to positivity of the gate and corresponding capacitive effect, free electrons i.e. minority carriers of the p-type substrate get attracted towards the gate and form a layer of negative uncovered ions there just below the dielectric layer by recombining these free electrons with holes. If we continually increase the positive gate voltage, after the threshold voltage level, the recombinations process gets saturated and then free electrons start to accumulate at the place to form a conductive channel of free electrons. The free electrons also come from the heavily doped source and drain n-type region. Now if we apply a positive voltage at the drain, current start flowing through the channel. The resistance of the channel depends on the number of free electrons in the channel and the number of free

electrons in the channel again depends on the gate potential of the device. As the concentration of free electrons forms the channel, and the current through the channel gets enhanced due to increase in gate voltage, we name the MOSFET as N

– Channel Enhancement MOSFET. N - Channel Enhancement MOSFET

N – Channel Depletion MOSFET

The working principle of depletion MOSFET is a little bit different fromthat of enhancement MOSFET. N – Channel Depletion MOSFET the substrate (body) is of p-type semiconductor. The source and drain regions are of the heavily doped n- type semiconductor. The space between source and drain regions is diffused by n- type impurities. Now if we apply a potential difference between source and drain,a current starts flowing through the entire n region of the substrate. Now, let us apply a negative voltage at the gate terminal. Due to the capacitive effect, the free electrons get repealed and shifted downward in the n region just below the SiO2 dielectric layer. As a result, there will be layers of positive uncovered ions below the SiO2 dielectric layer.

In this way, there will be a depletion of charge carriers occurred in the channel and hence the overall conductivity of the channel gets reduced. In this situation, for the same applied voltage at the drain, the drain current gets reduced. Here we have seen that we can control the drain current by varying depletion of charge carriers in the channel and hence we call it as depletion MOSFET. Here, the drain is in a positive potential, the gate is in a negative potential and the source is at zero potential. So the voltage difference between drain to gate is more than that of source to gate, hence the width of the depletion layer is more towards drain than that towards the source. N - Channel Depletion MOSFET.

P – Channel Depletion MOSFET

Construction wise a p channel depletion MOSFET is just reverse of the n channel depletion MOSFET. Here the prebuild channel is made of p – type impurities in between heavily doped p – type source and drain region. When we apply a positive voltage at the gate terminal, due to electrostatic action, minority carriers i.e. free electrons of the p-type region get attracted and form static negative impurity ions there. Hence a depletion region gets formed in the channel and consequently, the conductivity of the channel gets reduced. In this way, by applying the positive voltage at gate we can control the drain current.

i) OPTOCOUPLER

What is MOSFET driver?

MOSFET driver is main component of power electronics circuits. MOSFET drivers are dedicated integrated circuits which are used to drive MOSFETS in low side and high side configuration. To know more about gate driver check following article:

Isolated MOSFET driver TLP250 working

In this article I will discuss isolated Mosfet driver TLP250. Mosfet driver TL250 like other MOSFET drivers have input stage and output stage.

It also have power supply configuration.

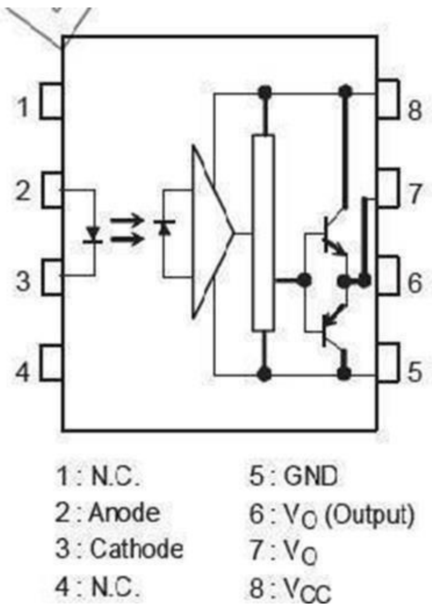
TLP250 is more suitable for MOSFET and IGBT.

The main difference between TLP250 and other MOSFET drivers is that TLP250 MOSFET driver is optically isolated.

Its mean input and output of TLP250 mosfet driver is isolated from each other. Its works likea optocoupler.

Input stage have a light emitting diode and output stage have photo diode. Whenever input stage LED light falls on output stage photo detector diode, output becomes high.

Pin configuration isolated mosfet driver TL



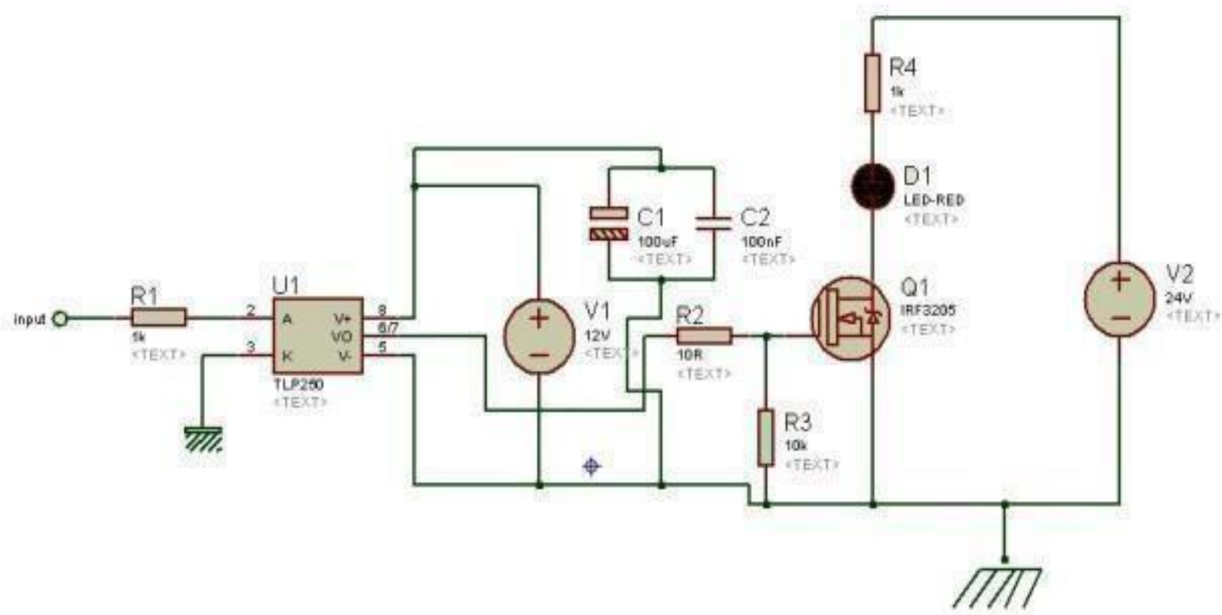
Pin layout of TLP250 is given below. It is clearly shown in figure that led at input stage and photo detector diode at output stage is used to provide isolation between input and ouput. Pin number 1 and 4 are not connected to any point. Hence they are not in use. Pin 2 is anode point of input stage light emitting diode and pin 3 is cathode point of input stage. Input is provided to pin number 2 and 3. Pin number 8 is for supply connection. Pin number 5 is for ground of power s Pin number one and four is not connected to any point physically. Therefore they are not in use.

Pin number 8 is use to provide power supply to TLP250 and pin number 5 is ground pin which provides return path to power supply ground. Maximum power supply voltage between 15-30 volt dc can be given to TLP250. But it also depends on temperature of environment in which you are using TLP250.

Pin number 2 and 3 are anode and cathode points of input stage LED. It works likea normal light emitting diode. It has similar characteristics of forward voltage and input current. Maximum input current is in the range of 7-10mA and forward voltage drop is about 0.8 volt. TLP250 provides output from low to high with minimum threshold current of 1.2mA and above.

TLP250 as a low side MOSFET driver

Circuit diagram of low side mosfet driver using tlp250 is shown below. In this circuit diagram, tlp250 is used as non inverting low side mosfet driver. you should connect an electrolytic capacitor of value 0.47uf between power supply. It provide protection to tlp250 by providing stabilize voltage to IC.

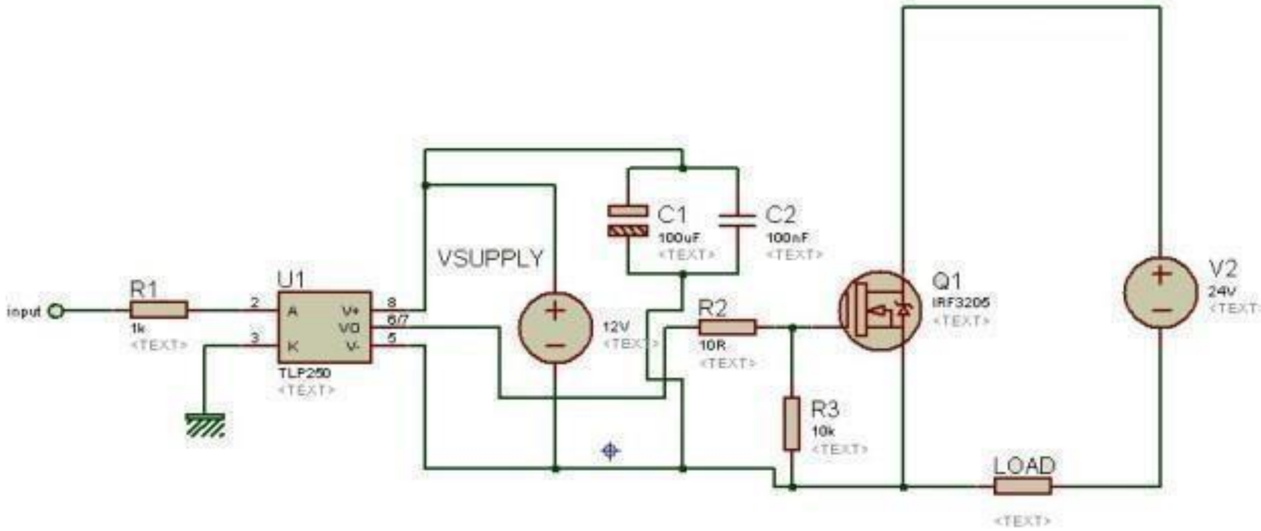


As shown in figure above input is drive signal that drives the output. Vin is according to signal ground. It should not be connected with supply ground and output ground. It is clearly shown in above figure TLP250 and load ground is referenced to the power ground and it is isolated from input signal reference ground. When input is high, MOSFET Q1 get high signal from TLP250 and it is driven by power supply and current flows through the load. When input is low, MOSFET Q1 get low signal from TLP250 output pin and mosfet Q1 remains off and there is no current flow to load. Value of supply voltage ranges between 10-15 volt. Input resistor at gate of MOSFET is used depend on amplitude of input signal. Usually input signal is provided through microcontroller and microcontroller input signal.

level is in the order of 5 volt. Capacitor C1 is used as decoupling capacitor.

TLP250 as a high side MOSFET driver

Circuit diagram of MOSFT driver tlp250 used as high side driver is shown below. It is used as non inverting high side mosfet driver. Because input signal ground is connected to cathode of input stage light emitting diode. Therefore it is used as a non inverting high side mosfet driver.



In high side configuration there are three grounds as shown in figure above. Ground of input signal, ground of supply voltage and ground of power supply voltage. Remember that while using TLP250 as high side MOSFET driver, all grounds should be isolated fromeach other.

j) PIC MICROCONTROLLER

Circumstances that we find ourselves in today in the field of microcontrollers had their beginnings in the development of technology of integrated circuits. This development has made it possible to store hundreds of thousands of transistors into one chip. That was a prerequisite for production of microprocessors, and the first computers were made by adding external peripherals such as memory, input-output lines, timers and other. Further increasing of the volume of the package resulted in creation of integrated circuits. These integrated circuits contained both processor and peripherals. That is how the first chip containing a microcomputer, or what would later be known as a microcontroller came about.

MEMORY UNIT

Memory is part of the microcontroller whose function is to store data. For a certain input we getthe contents of a certain addressed memory location and that's all. Two new concepts are brought to us: addressing and memory location. Memory consists of all memory locations, and addressing is nothing but selecting one of them. This means that we need to select the desired memory location on one hand, and on the other hand we need to wait for the contents of that location. Besides reading from a memory location, memory must also provide for writing onto it. This is done by supplying an additional line called control line. We will designate this line as R/W(read/write). Control line is used in the following way: if r/w=1, reading is done, and if opposite is true then writing is done on the memory location.

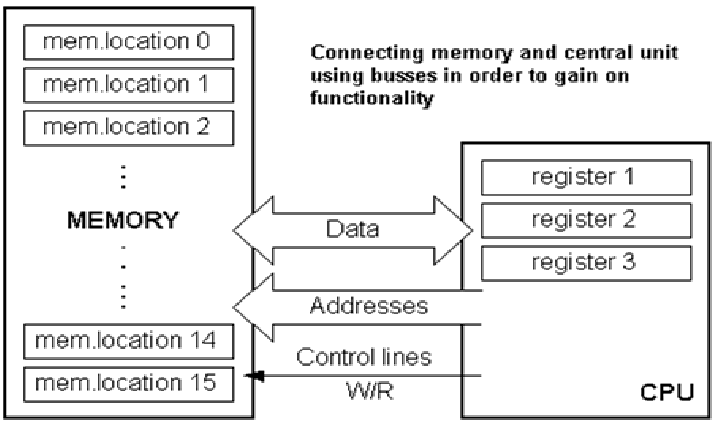
CENTRAL PROCESSING UNIT

Let add 3 more memory locations to a specific block that will have a built in capability to multiply, divide, subtract, and move its contents from one memory location onto another. The part we just added in is called "central processing unit"(CPU). Its memory locations are called registers.

Registers are therefore memory locations whose role is to help with performing various mathematical operations or any other operations with data wherever data can be found. Look at the current situation. We have two independent entities (memory and CPU) which are interconnected, and thus any exchange of data is hindered, as well as its functionality.

Bus

That "way" is called "bus". Physically, it represents a group of 8, 16, or more wires.There are two types of buses: address and data bus. The first one consists of as many lines as the amount of memory we wish to address and the other one is as wide as data, in our case 8 bits or the connection line. First one serves to transmit address from CPU memory, and the second to connect all blocks inside the microcontroller



Representation of Bus

INPUT-OUTPUT UNIT

Those locations we've just added are called "ports". There are several types of ports: input, output or bidirectional ports. When working with ports, first of all it is necessary to choose which port we need to work with, and then to send data to,or take it from the port. When working with it the port acts like a memory location. Something is simply being written into or read from it, and it could be noticed on the pins of the microcontroller.

SERIAL COMMUNICATION

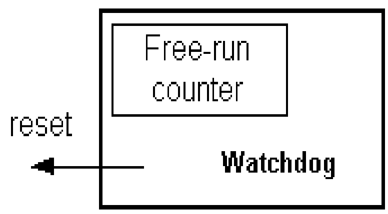
As we have separate lines for receiving and sending, it is possible to receive and send data (info.) at the same time. So called full-duplex mode block which enables this way of communication is called a serial communication block. Unlike the parallel transmission, data moves here bit by bit, or in a series of bits what defines the term serial communication comes from. After the reception of data we need to read it from the receiving location and store it in memory as opposed to sending where the process is reversed. In order for this to work, we need to set the rules of exchange of data. These rules are called protocol. Data goes from memory through the bus to the sending location, and then to the receiving unit according to the protocol.

TIMER UNIT

The timer block this can give us information about time, duration, protocol etc. The basic unit of the timer is a free-run counter which is in fact a register whose numeric value increments by one in even intervals, so that by taking its value during periods T1 and T2 and on the basis of their difference we can determine how much time has elapsed. This is a very important part of the microcontroller whose understanding requires most of our time.

WATCHDOG

One more thing is requiring our attention is a flawless functioning of the microcontroller during its run-time.

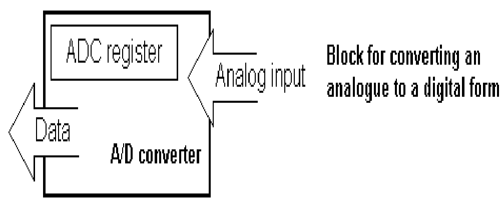


Watch dog time

Suppose that as a result of some interference (which often does occur in industry) our microcontroller stops executing the program, or worse, it starts working incorrectly. Of course, when this happens with a computer, we simply reset it and it will keep working. However, there is no reset button we can push on the microcontroller and thus solve our problem. To overcome this obstacle, we need to introduce one more block called watchdog. This block is in fact another free- run counter where our program needs to write a zero in every time it executes correctly. In case that program gets "stuck", zero will not be written in, and counter alone will reset the microcontroller upon achieving its maximum value. This will result in executing the program again, and correctly this time around.

ANALOG TO DIGITAL CONVERTER

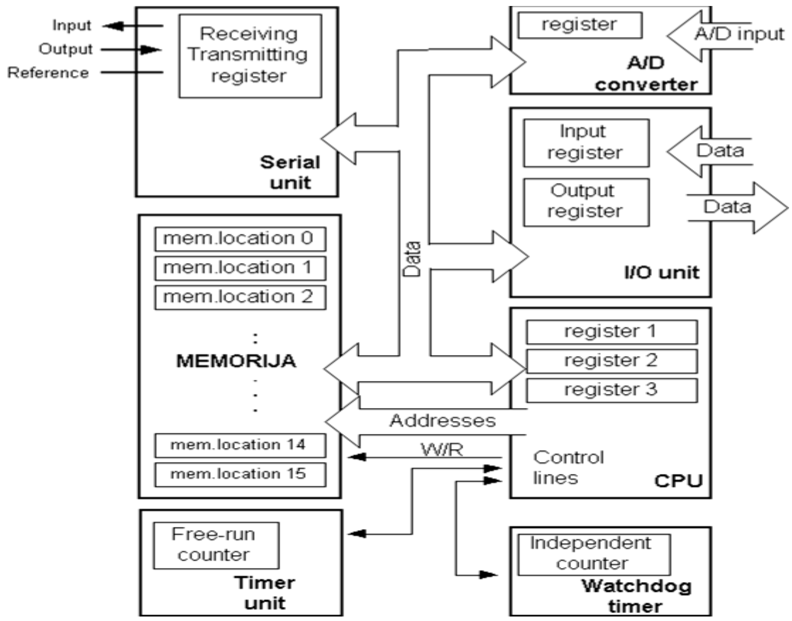
As the peripheral signals usually are substantially different from the ones that microcontroller can understand (zero and one), they have to be converted into a pattern which can be comprehended bya microcontroller.



Analog to Digital converter

his task is performed by a block for analog to digital conversion or by an ADC. This block is responsible for converting an information about some analog value to a binary number and for follow it through to a CPU block so that CPU block can further process it.

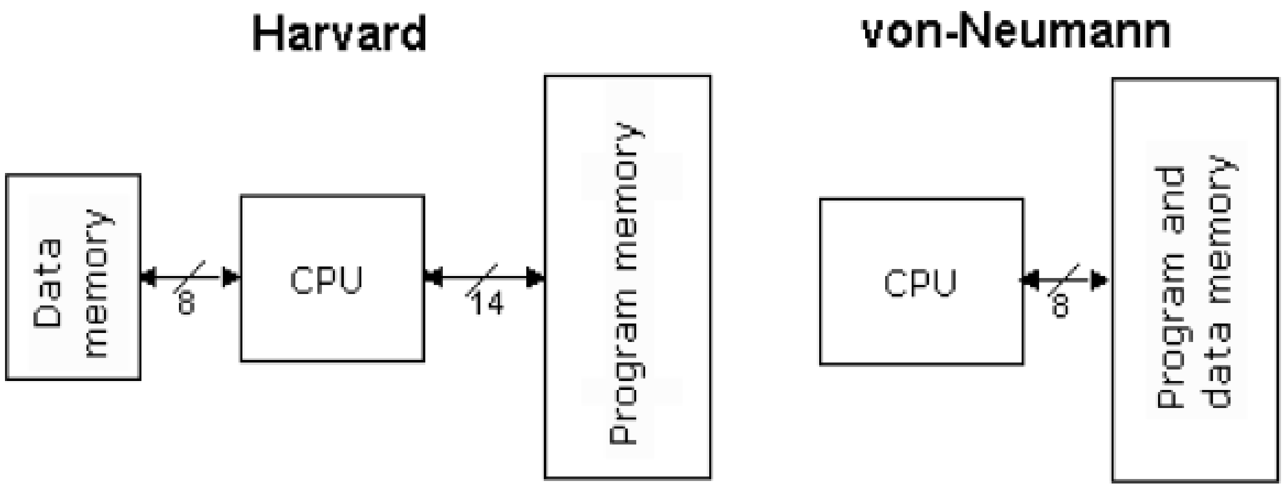
MICROCONTROLLER WITH ITSBASICELEMENTS AND INTERNAL CONNECTIONS



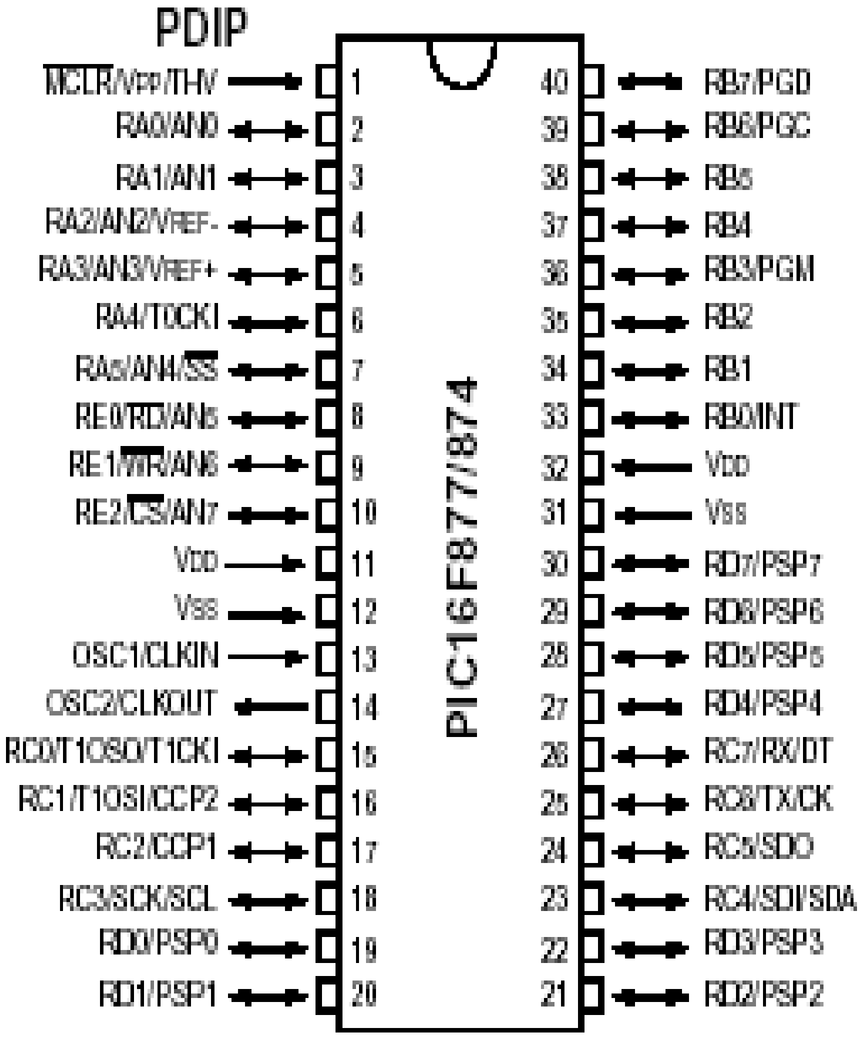
Block representation of themicrocontroller

CISC and RISC

Harvard architecture is a newer concept than Von-Neumann's. It rose out of the need to speed up the work of a microcontroller. In Harvard architecture, data bus and address bus are separate.

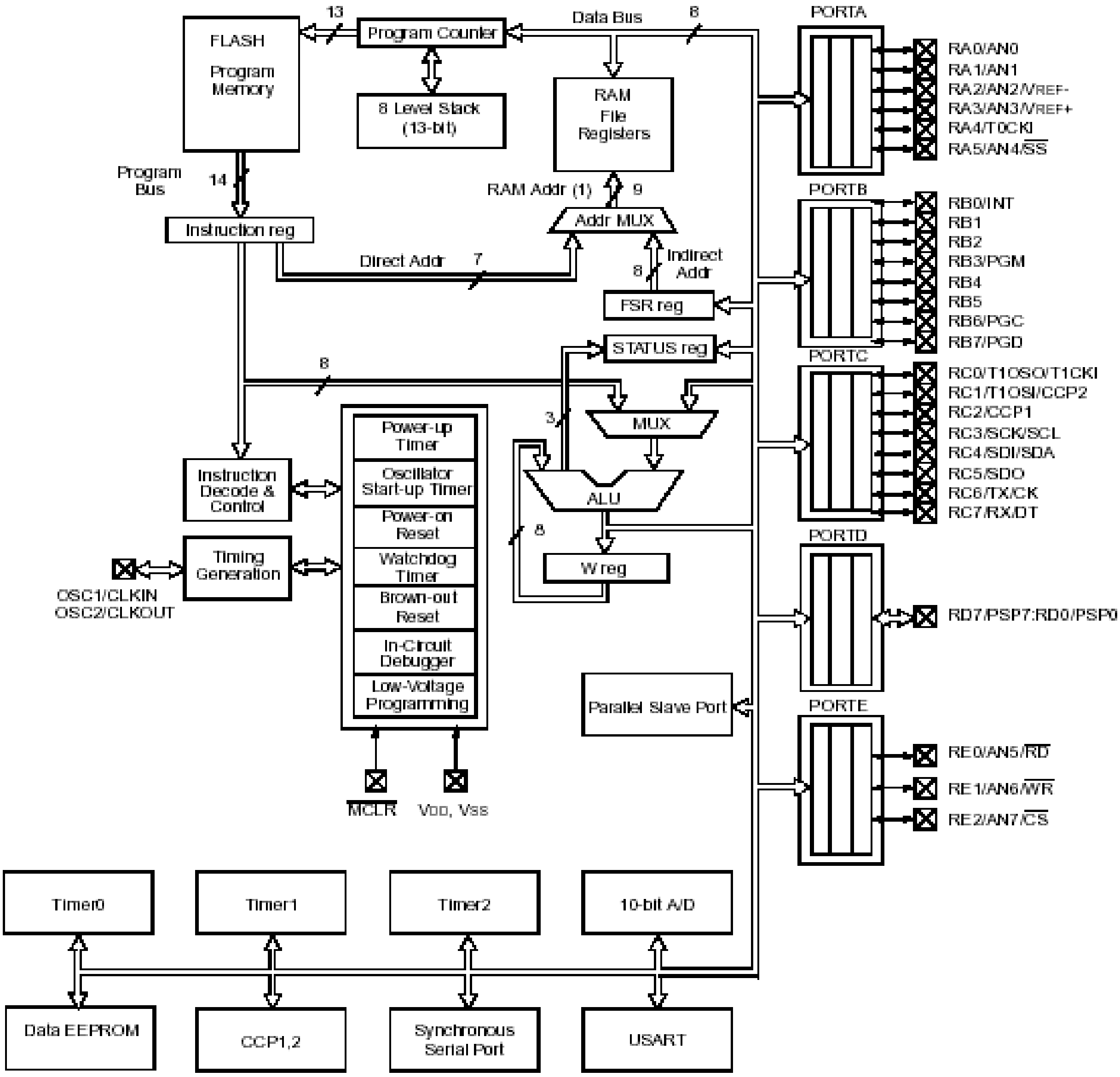


PIN LAYOUT OF PIC16F877A



PIC 16F877A

Device	Program FLASH	Data Memory	Data EEPROM
PIC16F874	4K	192 Bytes	128 Bytes
PIC16F877	8K	368 Bytes	256 Bytes



Note 1: Higher order bits are from the STATUS register.

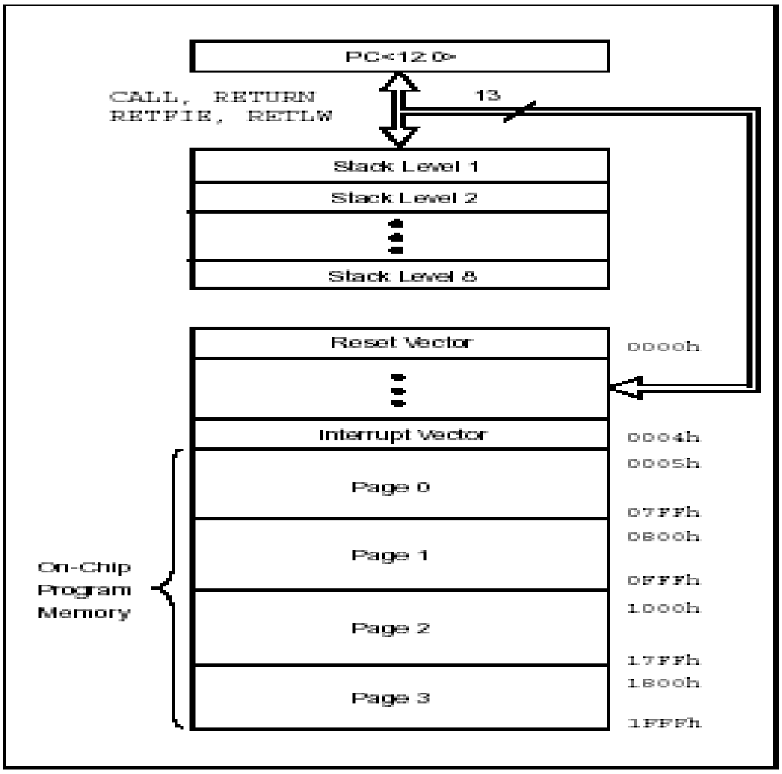
Architecture of PIC16F877A

MEMORY ORGANIZATION

There are three memory blocks in each of these PIC micro MCUs. The Program Memory and Data Memory have separate buses so that concurrent access can occur.

PROGRAM MEMORY ORGANIZATION

The PIC16F87X devices have a 13-bit program counter capable of addressing an 8K x 14 program memory space. The PIC16F877/876 devices have 8K x 14 words of FLASH program memory and the PIC16F873/874 devices have4K x 14. Accessing a location above the physically implemented address will cause a wraparound. The reset vector is at 0000h and the interrupt vector is at 0004h.



Program memory and Stack memory

The data memory is partitioned into multiple banks which contain the General Purpose Registers and the Special Function Registers. Bits RP1(STATUS<6>) andRP0 (STATUS<5>) are the bank select bits.

RP1:RP0	Bank
00	0
01	1
10	2
11	3

55

Table Register bank selection

Each bank extends up to 7Fh (128 bytes). The lower locations of each bank are reservedfor the Special Function Registers. Above the Special Function Registers are General Purpose Registers, implemented as static RAM.

GENERAL PURPOSE REGISTER FILE

The register file can be accessed either directly or indirectly through the File Select Register FSR.

SPECIAL FUNCTION REGISTERS

The Special Function Registers are registers used by the CPU and peripheral modules for controlling the desired operation of the device. These registers are implemented as static RAM. The Special Function Registers can be classified into two sets; core (CPU) and peripheral.

STATUS REGISTER

The STATUS register contains the arithmetic status of the ALU, the RESET status and the bank select bits for data memory. The STATUS register can be the destination for any instruction, as with any other register. If the STATUS register is the destination for an instruction that affects the Z, DC or C bits, then the write to these three bits is disabled. These bits are set or cleared according to the device logic. The TO and PD bits are not writable, therefore, the result of an instruction with the STATUS register as destination may be different than intended.

OPTION_REG REGISTER

The OPTION_REG Register is a readable and writable register, which contains various control bits to configure the TMR0 prescaler/WDT postscaler (single as signable register known also as the prescaler), the External INT Interrupt, TMR0 and the weak pull-ups on PORT B.

INTCON REGISTER

The INTCON Register is a readable and writable register, which contains various enable and flag bits for the TMR0 register overflow, RB Port change and External RB0/INT pin interrupts.

PIE1 REGISTER

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

PIR1 REGISTER

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

PIE2 REGISTER

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

PIR2 REGISTER

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

PCON REGISTER

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

I/O PORTS

Some pins for these I/O ports are multiplexed with an alternate function for the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general purpose I/O pin.

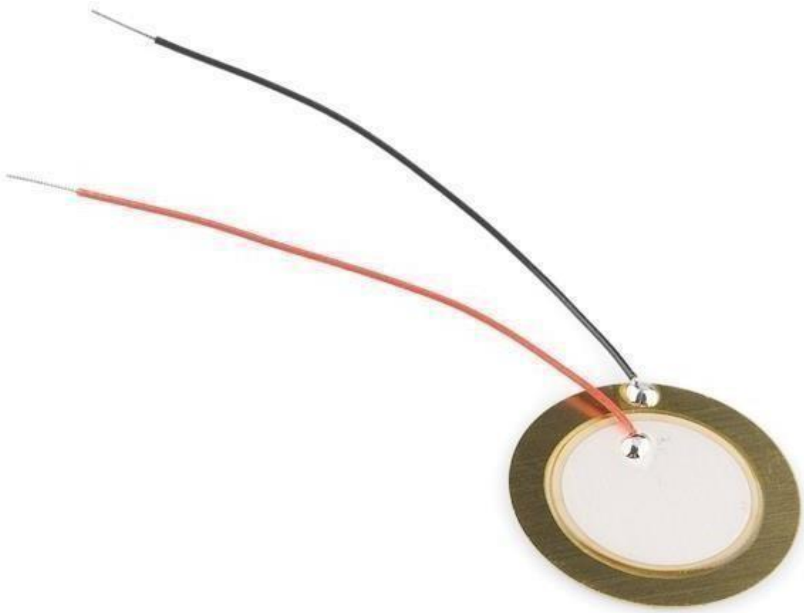
PORTA AND THE TRISA REGISTER

PORTA is a 6-bit wide bi-directional port. The corresponding data direction register is TRISA. Setting a TRISA bit (=1) will make the corresponding PORTA pin an input (i.e., put the corresponding output driver in a hi-impedance mode). Clearing a TRISA bit (=0) will make the corresponding PORTA pin an output (i.e., put the contents of the output latch on the selected pin). Reading the PORTA register reads the status of the pins, whereas writing to it will write to the port latch. Pin RA4 is multiplexed with the Timer0 module clock input to become the RA4/T0CKI pin. The RA4/T0CKI pin is a Schmitt Trigger input and an open drain output. All other PORTA pins have TTL input levels and full CMOS output drivers. Other PORTA pins are multiplexed with analog inputs and analog VREF input. The operation of each pin is selected by clearing/setting the control bits in the ADCON1 register (A/D Control Register1).

PORTB AND THE TRISB REGISTER

PORTB is an 8-bit wide, bi-directional port. The corresponding data direction register is TRISB. Setting a TRISB bit (=1) will make the corresponding PORTB pin an input. Clearing a TRISB bit (=0) will make the corresponding PORTB pin an output. Three pins of PORTB are multiplexed with the Low Voltage Programming function; RB3/PGM, RB6/PGC and RB7/PGD. Each of the PORTB pins has a weak internal pull-up. A single control bit can turn on all the pull-ups. This is performed by clearing bit RBPU (OPTION_REG<7>). The weak pull-up is automatically turned off when the port pin is configured as an output. The pull-

k) PIEZOELECTRIC SENSOR



A **piezoelectric sensor** is a device that uses the piezoelectric effect, to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge. The prefix *piezo*- is Greek for 'press' or 'squeeze'.

APPLICATIONS:

Piezoelectric sensors are versatile tools for the measurement of various processes. They are used for quality assurance, process control, and for research and development in many industries. Pierre Curie discovered the piezoelectric effect in 1880, but only in the 1950s did manufacturers begin to use the piezoelectric effect in industrial sensing applications. Since then, this measuring principle has been increasingly used, and has become a mature technology with excellent inherent reliability.

They have been successfully used in various applications, such as in medical, aerospace, nuclear instrumentation, and as a tilt sensor in consumer electronics or a pressure sensor in the touch pads of mobile phones. In the automotive industry, piezoelectric elements are used to monitor combustion when developing internal combustion engines. The sensors are either directly mounted into additional holes into the cylinder head or the spark/glow plug is equipped with a built-in miniature piezoelectric sensor

The rise of piezoelectric technology is directly related to a set of inherent advantages.
The high modulus of elasticity of many piezoelectric materials is comparable to that of many metals and goes up to 106 N/m² Even though piezoelectric sensors are electromechanical systems that react to compression, the sensing elements show almost zero deflection.

This gives piezoelectric sensors ruggedness, an extremely high natural frequency and an excellent linearity over a wide amplitude range.

Additionally, piezoelectric technology is insensitive to electromagnetic fields and radiation, enabling measurements under harsh conditions.

Some materials used (especially galliumphosphate or tourmaline) are extremely stable at high temperatures, enabling sensors to have a working range of up to 1000 °C. Tourmaline shows pyroelectricity in addition to the piezoelectric effect; this is the ability to generate an electrical signal when the temperature of the crystal changes.

This effect is also common to piezoceramic materials. Gautschi in Piezoelectric Sensorics (2002) offers this comparison table of characteristics of piezo sensor materials vs other types.

l) POWER SUPPLY:

WORKING:

power supply section consists of a transformer, a bridge circuit, a filter and a regulator. The step down transformer is used to convert 230v ac to 12v ac.

The bridge circuit converts ac to dc. The filter is used to remove the ripples in the supply.

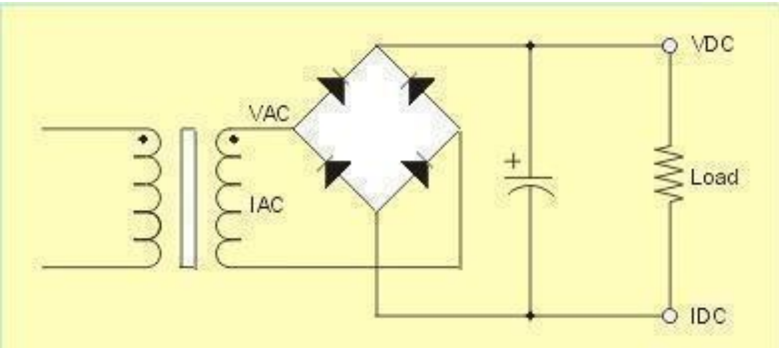
The regulator makes the supply The voltage constant.

Transformer:

Usually, DC voltages are required to operate various electronic equipment and these voltages are 5V, 9V or 12V. But these voltages cannot be obtained directly. Thus the a.c input available at the mains supply i.e., 230Vis to be brought down to the required voltage level. This is done by a transformer. Thus, a step down transformer is employed to decrease the voltage to a required level.

Rectifier:

The output from the transformer is fed to the rectifier. It converts A.C. into pulsating D.C. The rectifier may be a half wave or a full wave rectifier. In this project, a bridge rectifieris used because of its merits like good stability and full wave rectification.



The Bridge rectifier is a circuit, which converts an ac voltage to dc voltage using both half cycles of the input ac voltage. The Bridge rectifier circuit is shown in the figure. The circuit has four diodes connected to form a bridge. The ac input voltage is applied to the diagonally opposite ends of the bridge. The load resistance is connected between the other two ends of the bridge.

For the positive half cycle of the input ac voltage, diodes D1 and D3 conduct, whereas diodes D2 and D4 remain in the OFF state. The conducting diodes will be in series with the load resistance R_L and hence the load current flows through R_L.

For the negative half cycle of the input ac voltage, diodes D2 and D4 conduct whereas, D1 and D3 remain OFF.

The conducting diodes D2 and D4 will be in series

with the load resistance R_L and hence the current flows through R_L in the same direction as in the previous halfcycle. Thus a bi-directional wave is converted into a unidirectional wave.

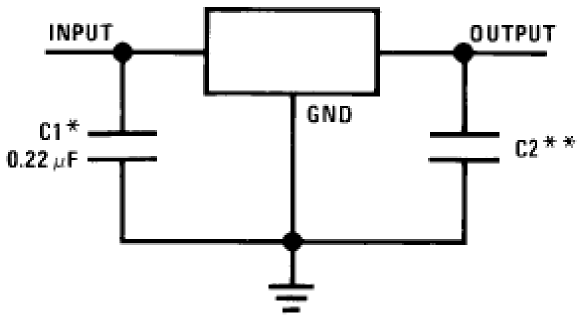
Filter: Capacitive filter is used in this project. It removes the ripples from the output of rectifier and smoothens the

D.C. Output received from this filter is constant until the mains voltage and load is maintained constant.

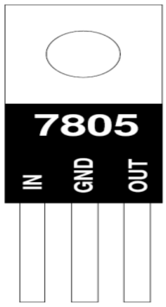
However, if either of the two is varied, D.C. voltage received at this point changes. Therefore a regulator is applied at the output stage.

Voltage regulator:

As the name itself implies, it regulates the input applied to it. A voltage regulator is an electrical regulator designed to automatically maintain a constant voltage level. In this project, power supply of 5V and 12V are required. In order to obtain these voltage levels, 7805 and 7812 voltage regulators are to be used.



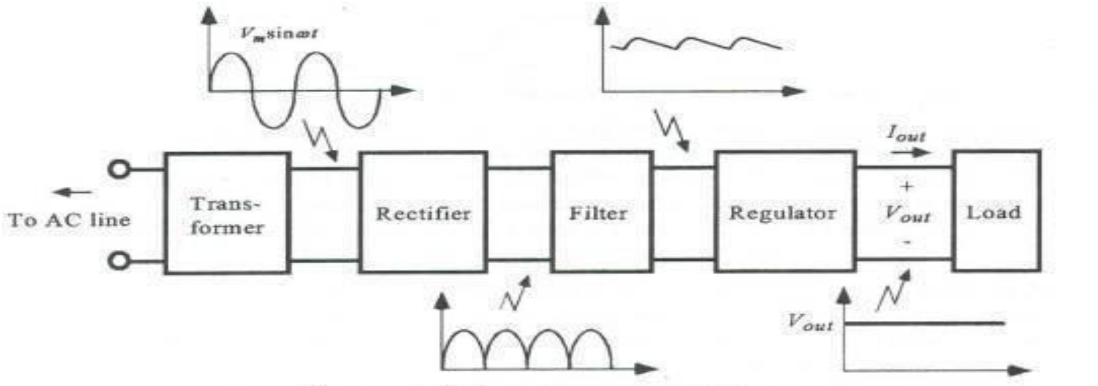
positive supply and the numbers 05, 12 represent the required output voltage levels. The L78xx series of three-terminal positive regulators is available in TO-220, TO-220FP, TO-3, D2PAK and DPAK packages and several fixed output voltages, making it useful in a wide range of applications. These regulators can provide local on-card regulation, eliminating the distribution problems associated with single point regulation. Each type employs internal current limiting, thermal shut-down and safe area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1 A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltage and currents.



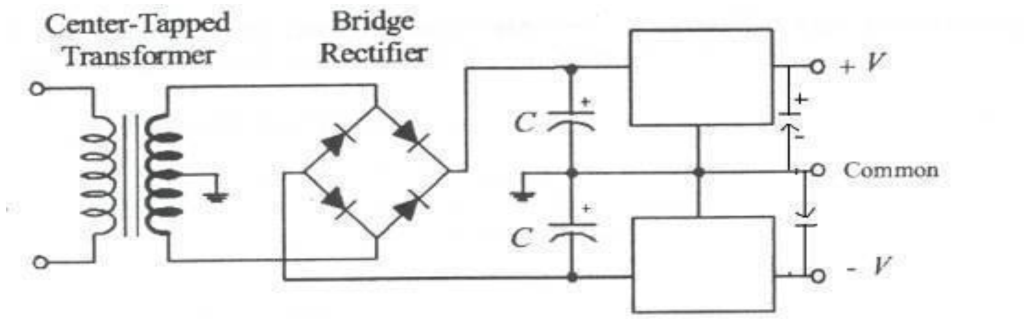
Power supply

A power supply provides a constant output regardless of voltage variations."Fixed" three-terminal linear regulators are commonly available to generate fixed voltages of plus 3 V, and plus or minus 5 V, 9 V, 12 V, or 15 V when the load is less than about 7 amperes. The "78xx" series (7805, 7812, etc.) regulate positive voltages while the "79xx" series (7905, 7912, etc.) regulate negative voltages.

Often, the last two digits of the device number are the output voltage; eg, a 7805 is a +5 V regulator, while a 7915 is a -15 V regulator. The 78xx series ICs can supply up to 1.5 Amperes depending on the model.

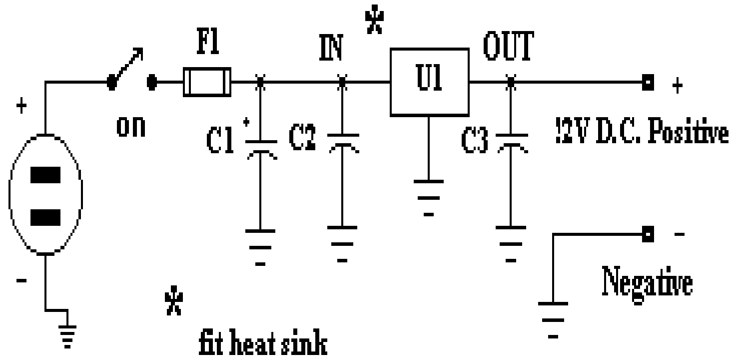


Components of a typical linear power supply



Thebasic power supplyschematic

In a typical linear power supply, AC line voltage is first down-converted to a smaller peak voltage using a transformer which is then rectified using a full wave bridge rectifier circuit. A capacitor filter is then used to smoothen the obtained sinusoidal signal. The residual periodic variation or ripple in this filtered signal is eliminated using an active regulator. To obtain a DC power supply with both positive and negative output voltages, a center-tapped transformer is used, where a third wire is attached to the middle of the secondary winding and it is taken as the common ground point. Then voltages from the opposite ends of the winding will be positive or negative with respect to this point.



Summary of circuit features

Brief description of operation: Gives out well regulated +5V output, output current capability of 100 mA Circuit protection: Built-in overheating protection shuts down output when regulator IC gets too hot

Circuit complexity: Very simple and easy to build

Circuit performance: Very stable +5V output voltage, reliable operation Availability of components: Easy to get, uses only very common basic components

Design testing: Based on datasheet example circuit, I have used this circuit successfully as part of many electronics projects

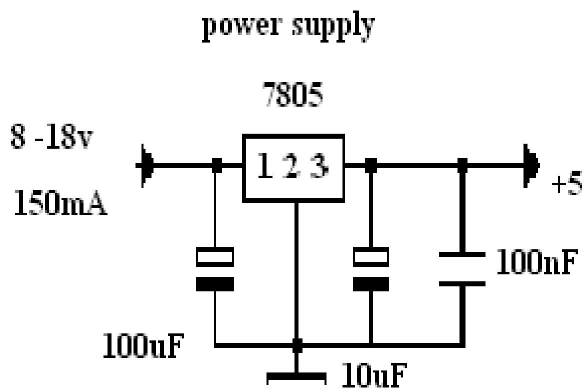
Applications: Part of electronics devices, small laboratory power supply Power supply voltage: Unreglated DC8-18V power supply

Power supply current: Needed output current + 5 mA

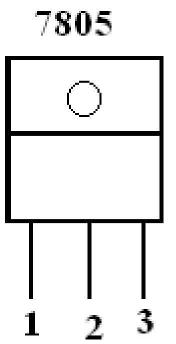
Component costs: Few dollars for the electronics components + the input transformer cost

Circuit description

This circuit is a small +5V power supply, which is useful when experimenting with digital electronics. Small inexpensive wall transformers with variable output voltage are available from any electronics shop and supermarket. Those transformers are easily available, but usually their voltage regulation is very poor, which makes then not very usable for digital circuit experimenter unless a better regulation can be achieved in some way. The following circuit is the answer to the problem. This circuit can give +5V output at about 150 mA current, but it can be increased to 1 A when good cooling is added to 7805 regulator chip. The circuit has over overload and therminal protection.



Circuit diagram of the power supply.



The capacitors must have enough high voltage rating to safely handle the input voltage feed to circuit. The circuit is very easy to build for example into a piece of vero board.

Pinout of the 7805 regulator IC.

1. Unregulated voltage in
2. Ground
3. Regulated voltage out

Component list

7805 regulator IC

m) UART (Universal Asynchronous Receiver Transmitter)

```
 start|< five to eight  data bits >|stop bit(s)
0    ---- - - - - - - - - - - -              Space(logic low)
   |   |   |   |   |   |   |   |   |   |   |   |
   | S | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | S | S |
   |   |   |   |   |   |   |   |   |   |   |   |

  1.................................................Mark (logic high)
```

Asynchronous Code Format.

The right-most bit is always transmitted first. If parity is present, the parity bit comes after the data bits but before the stop bit(s).

UART stands for the Universal Asynchronous Receiver/Transmitter. In asynchronous transmitting, teletype- style UARTs send a "start" bit, five to eight data bits, least-significant-bit first, an optional "parity" bit, and then one, one and a half, or two "stop" bits. The start bitis the opposite polarity of the data-line's idle state. The stop bit is the data-line's idle state, and provides a delay before the next character can start. (This is called asynchronous start- stop transmission). In mechanical teletypes, the "stop" bit was often stretched to two bit times to give the mechanism more time to finish printing a character. A stretched "stop" bit also helps resynchronization. The parity bit can either make the number of "one" bits between any start/stop pair odd, or even, or it can be omitted. Odd parity is more reliable because it assures that there will always be at least one data transition, and this permits many UARTs to resynchronize.

In synchronous transmission, the clock data is recovered separately from the data stream and no start/stop bits are used. This improves the efficiency of transmission on suitable channels since more of the bits sent are usable data and not character framing. An asynchronous transmission sends nothing over the interconnection when the transmitting device has nothing to send; but a synchronous interface must send "pad" characters to maintain synchronism between the receiver and transmitter. The usual filler is the ASCII "SYN" character.

This may be done automatically by the transmitting device. USART chips have both synchronous and asynchronous modes.

Transmitter (USART)

The Universal Synchronous Asynchronous Receiver Transmitter (USART) module is one of the two serial I/O modules. (USART is also known as a Serial Communications Interface or SCI). The USART can be configured in the following modes:

• Asynchronous (full duplex)

• Synchronous – Master (half duplex)

• Synchronous – Slave (half duplex) USART Baud Rate Generator (BRG)

The BRG supports both the asynchronous and synchronous modes of the USART. It is a dedicated 8-bit baud rate generator. The SPBRG register controls the period of a free running8-bit timer. In asynchronous mode, bit BRGH (TXSTA<2>) also controls the baud rate. In synchronous mode, bit BRGH is ignored. Table shows the formula for computation of the baud rate for different USART modes

Table Baud Rate Formula

USART Asynchronous Mode

In this mode, the USART uses standard non-return-to zero (NRZ) format (one start bit, eight or nine data bits,and one stop bit). The most common data format is 8 bits. An on-chip, dedicated, 8-bit baud rate generator can be used to derive standard baud rate frequencies from the oscillator. The USART transmits and receives the LSB first. The USART's transmitter and receiver are functionally independent, but use the same data format and baud rate.

The baud rate generator produces a clock either x16 or x64 of the bit shift rate, depending on bit BRGH (TXSTA<2>). Parity is not supported by the hardware, but can be implemented in software (and stored as the ninth data bit). Asynchronous mode is stopped during SLEEP. Asynchronous mode is selected by clearing bit SYNC (TXSTA<4>). The USART Asynchronous module consists of the following important elements:

- Baud Rate Generator
- Sampling Circuit
- Asynchronous Transmitter
- Asynchronous Receiver

USART Asynchronous Transmitter

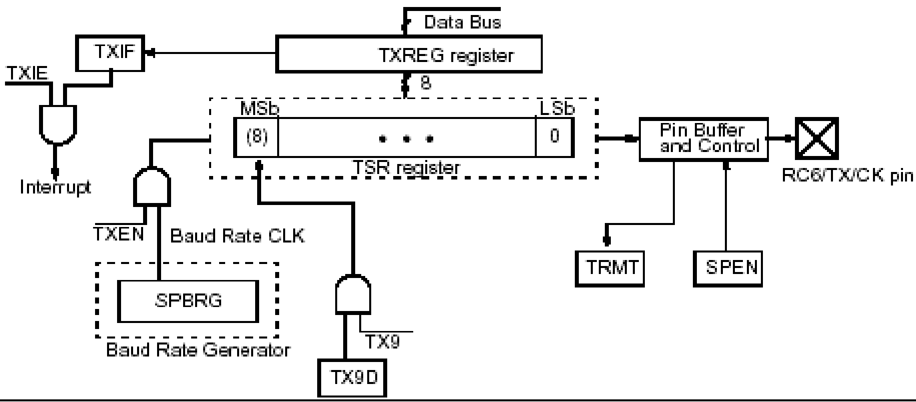
The USART transmitter block diagramis shown in fig. The heart of the transmitter is the transmit (serial)shift register (TSR). The shift register obtains its data from the read/write transmit buffer, TXREG.

The TXREG register is loaded with data in software. The TSR register is not loaded until the STOP bit has been transmitted fromthe previous load.

As soon as the STOP bit is transmitted, the TSR is loaded with new data from the TXREG register (if available).

Once the TXREG register transfers the data to the TSR register (occurs in oneTCY), the TXREG register is empty and flag bit TXIF (PIR1<4>) is set. This interrupt can be enabled/disabled bysetting/clearing enable bit TXIE.

USART transmission bockdiagram



Steps to follow when setting up an Asynchronous Transmission:

Initialize the SPBRG register for the appropriate baud rate. If a high speed baud rate is desired, set bit BRGH.

1. Enable the asynchronous serial port by clearing bit SYNC and setting bit SPEN.
2. If interrupts are desired, then set enable bit TXIE.
3. If 9-bit transmission is desired, then set transmit bit TX9.
4. Enable the transmission by setting bit TXEN, which will also set bit TXIF.
5. If 9-bit transmission is selected; the ninth bit should be loaded in bit TX9D.
6. Load data to the TXREG register (starts transmission).

USART Asynchronous Receiver

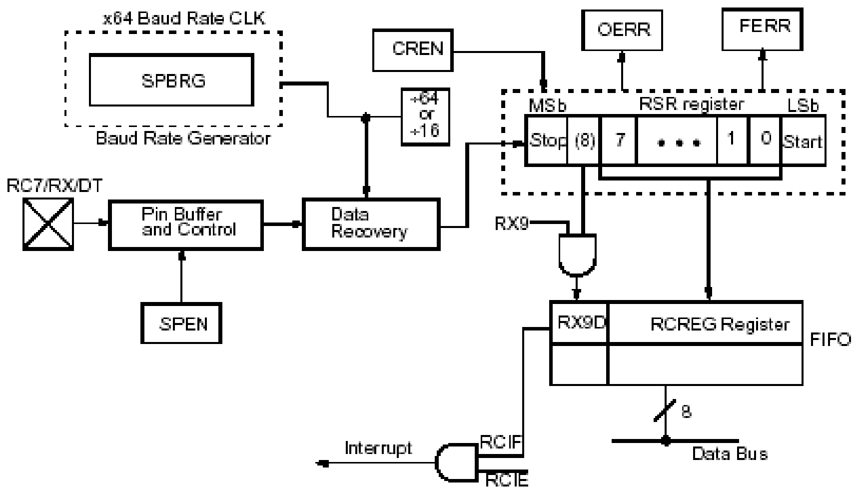
The receiver block diagram is shown in Fig. The data is received on the RC7/RX/DT pin and drives the data recovery block.

The data recovery block is actually a high speed shifter operating at x16 times the baud rate, whereas the main receive serial shifter operates at the bit rate or at FOSC.

The heart of the receiver is the receive (serial) shift register (RSR). After sampling the STOP bit, the received data in the RSR is transferred to the RCREG register (if it is empty).

If the transfer is complete, flag bit RCIF (PIR1<5>) is set. The actual interrupt can be enabled/ disabled by setting/clearing enable bit RCIE (PIE1<5>).

USART Receive block diagram



Steps to follow when setting up an Asynchronous Reception:

1. Initialize the SPBRG register for the appropriate baud rate. If a high speedbaud rate is desired, set bit BRGH.
2. Enable the asynchronous serial port by clearing bit SYNC and setting bit SPEN.
3. If interrupts are desired, then set enable bit RCIE.

4. If 9-bit reception is desired, then set bit RX9.

5. Enable the reception by setting bit CREN.

6. Flag bit RCIF will be set when reception is complete and an interrupt will be generated if enable bit RCIE is set.
7. Read the RCSTA register to get the ninth bit (if enabled) and determine if any error occurred during reception.
8. Read the 8-bit received data by reading the RCREG register.
9. If any error occurred, clear the error by clearing enable bit CREN.

USART Synchronous Master Mode

In Synchronous Master mode, the data is transmitted in a half-duplex manner (i.e., transmission and reception do not occur at the same time). When transmitting data, the reception is inhibited and vice versa.

Synchronous mode is entered by setting bit SYNC (TXSTA<4>). In addition, enable bit SPEN (RCSTA<7>)is set in order to configure the RC6/TX/CK and RC7/RX/DT I/O pins to CK (clock) and DT (data) lines respectively. The Master mode indicates that the process or transmits the master clock on the CK line. The Master mode is entered by setting bit CSRC (TXSTA<7>).

USART Synchronous Master Transmission

The USART transmitter block diagram is shown in 3.2.12. The heart of the transmitter is the transmit m(serial) shift register (TSR). The shift register obtains its data from the read/write transmit buffer register TXREG. The TXREG register is loaded with data in software. The TSR register is not loaded until the last bit has been transmitted from the previous load.

As soon as the last bit is transmitted, the TSR is loaded with new data from the TXREG (if available). Once the TXREG register transfers the data to the TSR register (occurs in oneTcycle), the TXREG is empty and interrupt bit TXIF (PIR1<4>) is set. The interrupt can be enabled/disabled by setting/clearing enable bit TXIE (PIE1<4>).

Steps to follow when setting up a Synchronous Master Transmission:

1. Initialize the SPBRG register for the appropriate baud rate.
2. Enable the synchronous master serial port by setting bits SYNC, SPEN and CSRC.
3. If interrupts are desired, set enable bit TXIE.
4. If 9-bit transmission is desired, set bit TX9.
5. Enable the transmission by setting bit TXEN.
6. If 9-bit transmission is selected, the ninth bit should be loaded in bit TX9D.
7. Start transmission by loading data to the TXREG register

USART Synchronous Master Reception

Once synchronous mode is selected, reception is enabled by setting either enable bit SREN (RCSTA<5>) or enable bit CREN (RCSTA<4>). Data is sampled on the RC7/RX/DT pin on the falling edge of the clock. If enable bit SREN is set, then only a single word is received. If enable bit CREN is set, the reception is continuous until CREN is cleared. If both bits are set, CREN takes precedence.

After clocking the last bit, the received data in the Receive Shift Register (RSR) is transferred to the RCREG register (if it is empty). When the transfer is complete, interrupt flag bit RCIF (PIR1<5>) is set. The actual interrupt can be enabled/ disabled by setting/clearing enable bit RCIE (PIE1<5>).

Steps to follow when setting up a Synchronous Master Reception:

1. Initialize the SPBRG register for the appropriate baud rate.
2. Enable the synchronous master serial port by setting bits SYNC, SPEN and CSRC.
3. Ensure bits CREN and SREN are clear.

4. If interrupts are desired, then set enable bit RCIE.
5. If 9-bit reception is desired, then set bit RX9.
6. If a single reception is required, set bit SREN. For continuous reception set bit CREN.
7. Interrupt flag bit RCIF will be set when reception is complete and an interrupt will be generated if enable bit RCIE was set.
8. Read the RCSTA register to get the ninth bit (if enabled) and determine if any error occurred during reception.
9. Read the 8-bit received data by reading the RCREG register.
10. If any error occurred, clear the error by clearing bit CREN

USART Synchronous Slave Mode

Synchronous slave mode differs from the Master mode in the fact that the shift clock is supplied externally at the RC6/TX/CK pin (instead of being supplied internally in master mode). This allows the device to transfer or receive data while in SLEEP mode. Slave mode is entered by clearing bit CSRC (TXSTA<7>).

USART Synchronous Slave Transmission

The operation of the synchronous master and slave modes are identical except in the case of the SLEEP mode.

Steps to follow when setting up a Synchronous Slave Transmission:

1. Enable the synchronous slave serial port by setting bits SYNC and SPEN and clearing bit CSRC.
2. Clear bits CREN and SREN.
3. If interrupts are desired, then set enable bit TXIE.
4. If 9-bit transmission is desired, then set bit TX9.
5. Enable the transmission by setting enable bit TXEN.

6. If 9-bit transmission is selected; the ninth bit should be loaded in bit TX9D.

7. Start transmission by loading data to the TXREG register.

USART Synchronous Slave Reception

The operation of the synchronous master and slave modes is identical, except in the case of the SLEEP mode. Bit SREN is a “don't care” in slave mode. If receive is enabled by setting bit CREN prior to the SLEEP instruction, then a word may be received during SLEEP.

On completely receiving the word, the RSR register will transfer the data to the RCREG register and if enable bit RCIE bit is set, the interrupt generated will wake the chip fromSLEEP. If the global interrupt is enabled, the program will branch to the interrupt vector(0004h).

Steps to follow when setting up a Synchronous Slave Reception:

1. Enable the synchronous master serial port by setting bits SYNCand SPEN and clearing bit CSRC.
2. If interrupts are desired, set enable bit RCIE.
3. If 9-bit reception is desired, set bit RX9.
4. To enable reception, set enable bit CREN.
5. Flag bit RCIF will be set when reception is complete and anInterrupt will be generated, if enable bit RCIE was set.
6. Read the RCSTA register to get the ninth bit (if enabled) and determine if any error occurred during reception.
7. Read the 8-bit received data by reading the RCREG register.
8. If any error occurred, clear the error by clearing bit CREN.

3.2 SOFTWARE REQUIREMENTS:

a) EMBEDDED C

Embedded C is the most popular programming language in the software field for developing electronic gadgets. Each processor used in electronic systems is associated with embedded software.

Embedded C programming plays a key role in performing specific functions by the processor.

In day-to-day life we use many electronic devices such as mobile phones, washing machines, digital cameras, etc. These all devices working are based on microcontrollers that are programmed by embedded C.

The Embedded C code written in above block diagram is used for blinking the LED connected with Port0of the microcontroller.

In embedded system programming C code is preferred over other languages. Due to the following reasons:

- Easy to understand
- High Reliability
- Portability
- Scalability

b) KEIL

One of the important part in making an embedded system is loading the software/program we develop into the microcontroller. Usually it is called "***burning software***" into the controller.

Before "burning a program" into a controller, we must do certain prerequisite operations with the program.

This includes writing the program in assembly language or C language in a text editor like notepad, compiling the program in a compiler and finally generating the hex code from the compiled program.

Earlier people used different softwares/applications for all these 3 tasks. Writing was done in a text editor like notepad/wordpad, compiling was done using a separate software (probably a dedicated compiler for a particular controller like 8051), converting the assembly code to hex code was done using another software etc.

It takes lot of time and work to do all these separately, especially when the task involves lots of error debugging and reworking on the source code.

- Writing programs in C/C++ or Assembly language
- Compiling and Assembling Programs
- Debugging program
- Creating Hex and Axf file
- Testing your program without Available real Hardware (Simulator Mode)

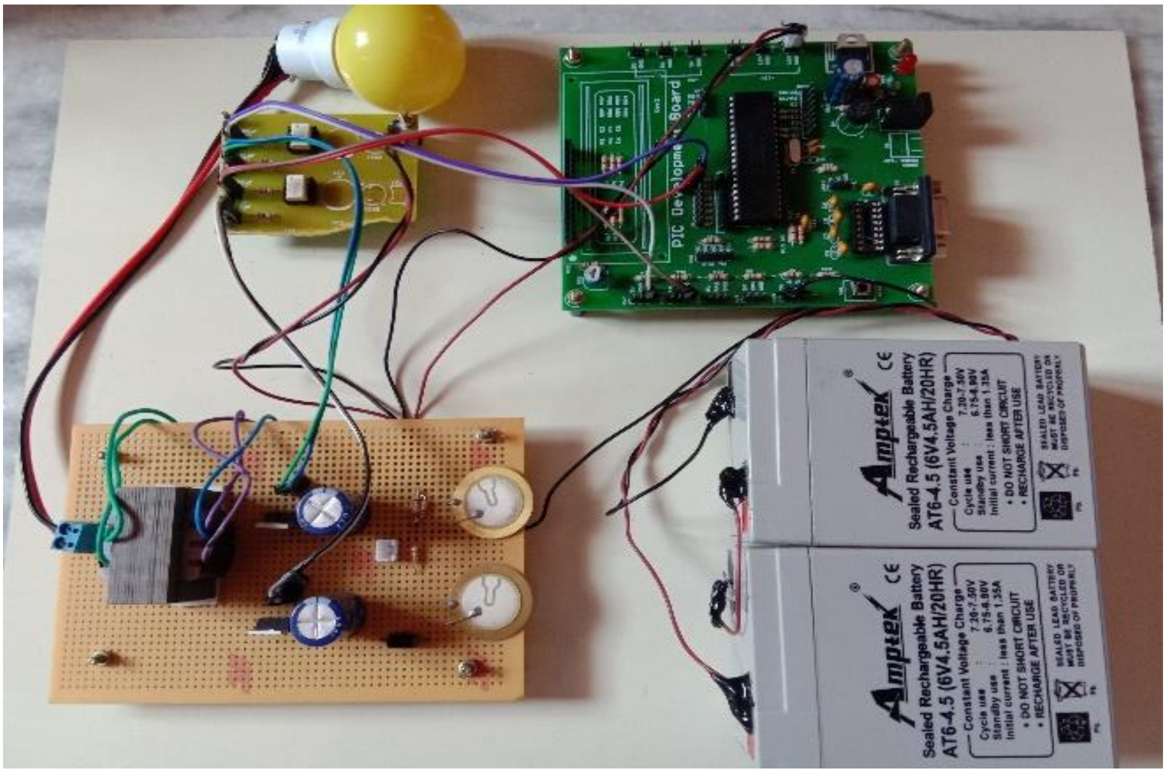
CHAPTER: 4 – RESULT & CONCLUSION

4.1 INTRODUCTION

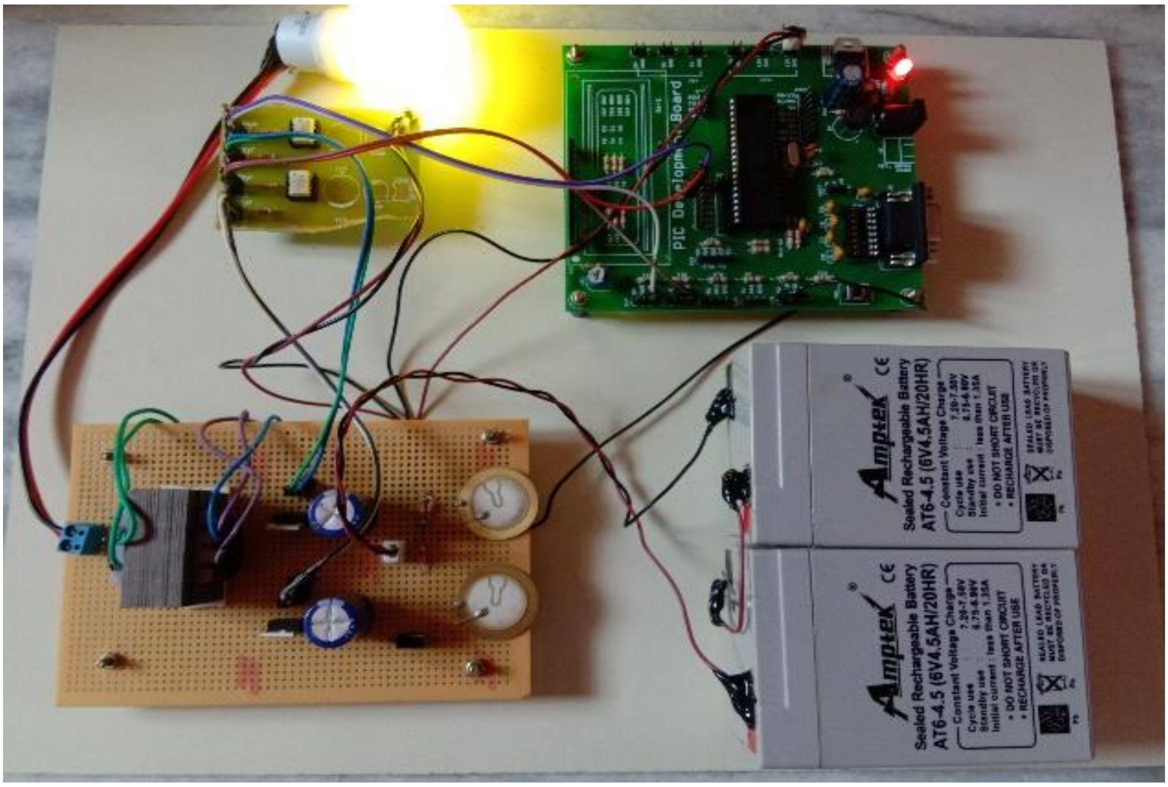
This chapter holds the photographic images of the working of the wearable piezoelectric on-body energy harvesting cantilever and also the conversion of mechanical stress into electric current**.**

4.2 OUTPUT:

Before giving vibration to piezoelectric sensor, the battery doesn’t get charged and hence the light is not lit on.



After giving vibration to Piezoelectric sensor, the charge gets stored to battery and hence the light is lit on



CHAPTER: 5 -FUTURE ENHANCEMENT

5.1 APPLICATIONS

- Energy Consume Systems
- Aeronautics Applications
- Energy Harvesting

5.2 FUTURE ENHANCEMENT:

- The piezoelectric cantilever can be used to charge the electrically operating Devices in the near future.

5.3 ADVANTAGES:

- Good Output Power.
- Easy Method.
- Portable Technology
- Boost Level Increased.
- Trust-able One.

5.4 CONCLUSION:

We have implemented a wearable system of micro machined piezoelectric cantilevers For on-body energy Harvesting.It can be used for small amount of electric current Production.The mechanical stress given on the piezoelectric sensor is converted into Electric current with the help of the microcontroller connected to it.

5.5 REFERENCES:

[1] S. Priya, "Modeling of electric energy harvesting using piezoelectric windmill," Applied Physics Letters, vol. 87, pp. 184101, 2005.

[2] M. Pozzi and M. Zhu, "Plucked piezoelectric bimorphs for knee-joint energy harvesting: modelling and experimental validation," Smart Materials and Structures, vol. 20, no. 5, pp. 055007, 2011.

[3] P. Pillatsch, E.M. Yeatman, A.S. Holmes, "A wearable piezoelectric rotational energy harvester," Body Sensor Networks (BSN), 2013 IEEE International Conference on, pp.1-6, 6-9 May, 2013.

[4] P. Janphuang, R. Lockhart, S. Henein, D. Briand, and N.F. de Rooij, “On the experimental determination of the efficiency of piezoelectric impact-type energy harvesters using a rotational flywheel,” Tech paper PowerMEMS Conference, London, UK, December 3-6, 2013.

[5] P. Janphuang, R. Lockhart, D. Briand and N.F. de Rooij, "On the optimization and performances of a compact piezoelectric impact MEMS energy harvester", Proc. IEEE 27th Int. Conf. MEMS, 2014.

[6] C. Mo, S. Kim, W. W. Clark, “Theoretical analysis of energy harvesting performance for unimorph piezoelectric benders with interdigitated electrodes,” Smart Materials and Structures, vol. 18, no. 5, pp. 055017, 2009.

[7] P. Janphuang, R. Lockhart, D. Briand and N. F. de Rooij, “Wafer Level Fabrication of Vibrational Energy Harvesters using Bulk PZT Sheets”, 26th European Conference on Solid-State Transducer.