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**FEASIBILITY STUDY AND DESIGN OF ENERGY
HARVESTING PIEZOELECTRIC DISC MAT
FOR PALAWAN STATE UNIVERSITY**

by

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ABSTRACT

Energy sources can be renewable or non-renewable energy. These energies can be converted into secondary energy sources such as electricity. Non-renewable energies can be acquired from coal, petroleum, natural gas and uranium while renewable energies can be acquired from wind, solar, geothermal, hydro, biomass, marine, and many more. Due to rapid growth of the country's industry, more energy is needed as most of the technologies need more power to operate causing non-renewable sources to be endangered as it was only derived from the remains of ancient sea-plants and animals million years ago. The researchers built an optimum device that is capable of gathering energy from footsteps. They made use of Piezoelectric disc and Steel Plane as a casing for the durability of the device and then layered it with a PVC mat. However, the main drawback of their design is that they used the piezoelectric disc instead of other piezoelectric transducers that are designed for energy harvesting. Despite the lacking, the researchers were able to satisfy their objectives since the piezoelectric disc is still capable of gathering the desired outputs. They recommended to improve the device and use other Piezoelectric Disc that are capable of harvesting massive energy.

Keywords: piezoelectric disc, human footstep, mat.

Chapter I

INTRODUCTION

Energy sources can be renewable or non-renewable energy. These energies can be converted into secondary energy sources such as electricity. Non-renewable energies can be acquired from coal, petroleum, natural gas and uranium while renewable energies can be acquired from wind, solar, geothermal, hydro, biomass, marine, and many more. Due to rapid growth of the country's industry, more energies are needed as most of the technologies need more power to operate causing non-renewable sources to be endangered as it was only derived from the remains of ancient sea-plants, planktons and animals million years ago. Though renewable energies are present, we still cannot solely rely on it even though it is unlimited and natural. Still, there are some factors needed to consider in implementing on any of the renewable energy sources like windmills that must be built near the coastal area for better operation, geothermal that must be located somewhere near a volcano and same for the other sources.

According to Farouk and Gawad (2015) of Zagazig University in Egypt, "it is vital to search for other sources of energy because of the rapid depletion of the main fossil source of energy". They said that one sustainable and green source of energy is the power generation from the human footsteps. In everyday life, millions of people walk and losses energy in the road surface in the form of impact, vibration, sound, etc.

Palawan State University-Main Campus is the university in Palawan with the highest population of approximately fifteen thousand (15000) students as of SY: 2016-2017. This corresponds to a massive energy lost on a count that walking and running is part of the human's daily routine since it produces kinetic energy as the foot lands on the surface. To solve this problem, the researchers pondered the idea by creating a device that could harvest these energies.

This study aims to determine the optimum design, efficiency, and feasibility for a device that could generate power out of vibration produced by footsteps with the use of Piezoelectric Transducer Disc. The sub-objective of this study is to charge a 12-volt battery so that it can be stepped-up to 220 volts AC with the aid of inverter.

The significance of this study is to determine the capability of the optimum device to harvest more vibration energy from human footsteps using piezoelectric transducer disc. To withstand enough forces applied to the mat. To capture these energies and convert it into AC power is the significant advancement towards greater efficiency, availability, cleaner and pollution-free energy production. Areas where constantly susceptible in walking can become a productive area and it does not require too much effort when collecting energy.

The scope of this study is the design and construction of the device and the factors needed to consider in conducting the project. The inverter's construction will be included but is only limited to 30 Watts based on the circuit. The possible conduction of this study will be at the entrance gate of the Palawan State University, the area where the students are constantly walking, by counting the volume of people entering the gate at certain period of time.

Chapter 2

REVIEW OF RELATED LITERATURE

Status of Renewable Energy in the Philippines

According to S.P. Brahim (2014), "the Philippine is inevitably vulnerable to oil supply disruptions, oil price fluctuations, and geopolitical dynamics shaping the energy exporting countries". The continuous use of fossil fuel highlights the issue of energy security and also the equally important issue of sustainability. Energy insecurity and increasing CO₂ emissions are among the major issues affecting the country and with these, it seeks to harness and utilize viable alternative energy sources. The main driver for the increase in domestic energy demand is the sustained economic growth, coupled with growing population with improved living standards. She also said that propagating renewable energy sources in the Philippines is capable of reducing the heavy dependency on imported fossil fuels and led the government to research further for the development of the renewable energy sector.

Piezoelectric Material

K. Bobby, et al. (2014) stated that piezoelectricity refers to the ability of some materials to generate an electric potential in response to applied pressure. Harvesting energy which means energy is already available, but is going to be wasted if not utilized. Embedded piezoelectric material can provide the magic of converting pressure exerted by the moving people into electric current.

Nayan HR (2015) said that with the increase in energy consumption, the concept of harvesting alternative renewable energy in human surroundings arise a new interest among us. One way to produce energy is by developing a piezoelectric generator in which

the energy obtained are from vibration and pressure available on some term (like people walking).

According to S. D. Siddesh and A.A. Shaikh (2016), human-powered transport has been in existence since time immemorial in the form of walking, running and swimming. These energies can be tapped and converted in the usable form such as in electrical form. In order to develop a technique to harness footstep energy, they develop a foot step electricity generating device using piezoelectric sensor. They said that electricity produced due to pressing the piezo material is enough to make the L.E.D. glow. Based on the results gathered in their investigation, the final prototype design did fulfill the engineering goal of generating electricity sufficient to power common electrical devices such as mobile phones.

Harvesting of Energy in Piezoelectric Transducers

K. Boby, et al. (2014) stated that the produced voltage of a piezoelectric transducers is in AC. As the piezoelectric transducer is pressed, the voltage is produced from the Positive terminal and changes its polarity as the pressure is released. They also studied the kind of connection that gives appreciable voltage and current. Piezoelectric transducers are connected in series, parallel and in series-parallel. According to them, series connections is good but the current obtained is poor, whereas the current from a parallel connection is good but the voltage is poor. A series-parallel connection gives a good voltage as well as current can be obtained.

A. Masroof (2016) said that a Bridge-Type Rectifier must be connected to stabilize and convert the produced AC Voltage of the piezoelectric transducer to DC Voltage to be able to store in the Lead-Acid Battery and to be converted back again to 220V AC for AC loads usage.

Efficiency of Energy Conversion for a Piezoelectric Power Harvesting System

Y.V. Shu and I.C. Lien (2006) studied the energy conversion efficiency for a rectified piezoelectric power harvester. They proposed an analytical model and an expression of efficiency derived under steady-state operation. Addition to it is the relationship among the conversion efficiency, electrically induced damping and AC-DC power output is established explicitly. It is shown that the optimization criteria are different depending on the relative strength of the coupling. For the weak electromechanical coupling system, the optimal power transfer is attained when the efficiency and induced damping achieve their maximum values. This result is consistent with that observed in the recent literature. However, a new finding shows that they are not simultaneously maximized in the strongly coupled electromechanical system.

Advantage of Using Piezoelectric Material for Generating Power

According to J. Borah (2016) on her research entitled “Generation of Electricity by Means of Footstep: A Review”, harvesting energies using piezoelectric materials has a great advantage. These advantages are cost effectiveness, super safe, no fuel or any chemical source needed, nonconventional, is reliable and the energy can be stored in the capacitors and can improve the generation of power using the heat produced by Peltier Effect. Therefore, designing a system for various applications through AC output is feasible.

Nayan HR, American International University, Dhaka, Bangladesh (2015) on their research entitled “Power Generation Using Piezoelectric Material”, states that piezoelectric materials are being more and more studied as they turn out to be very unusual materials with very specific and interesting properties. They also stated that piezoelectric materials have two properties that are define as direct and converse effect. Advantages indicated on

this research are very high frequency response, no need of external source, simple, and Barium Titanate and Quartz can be made in any desired shape and form.

V. Jamadar and P. Pingle (2017) revealed on their research journal "Analysis of Vibration Energy Harvesting from Power Consuming Devices" the benefits of vibration energy harvesting. It has long lasting operability, no chemical disposal, cost saving, safe with no maintenance and provides sufficient power when needed.

Similar Research Approach but Different in Mechanism

D.G. Kotche, et al. (2001) on their research entitled "Footstep Power Generation", they use a foot pumps as their model to generate electricity at an estimated bar pressure of 0.7. The model consists of a setup mechanism to compress an air in foot pumps through force exerted by human footsteps, the kinetic energy release is converted into compressed air which stored in the air tank of sufficient pressure, and then the accrued compressed air gets impacted on the propeller coupled with DC generator.

T. Krupin and J.A. Taylor (2011) on their article entitled "Reverse Electro Wetting as a New Approach to High Energy Harvesting", proposed a technique called reverse electro - wetting in which the vibration on the upper plate due to human footsteps results to the interaction of arrays of moving microscopic liquid droplets which novel nanometer - thick multilayer dielectric films which can generate energy. The motion of conductive liquid on dielectric coated conductive substrate tends to create electrical energy.

Tom Jose V, et al. (2013) proposed model on their research entitled "Electricity Generation from Footsteps: A Regenerative Energy Resource "is by using rick and pinion gears system with dynamo fitting with its gear mechanism. When the force is occurred to its upper plate, the gears that are connected to the dynamo start to rotate that result to the rotation of the dynamo shaft that generates electrical power.

Similar Material Research with Computation

According to A. Ledoux (2011) on his research with the title “Theory of Piezoelectric Materials and their Application in Civil Engineering”, a piezoelectric material develops an internal electric field when strained. To avoid any complicated calculations in dealing with piezoelectric materials, one can consider materials which produce electric field in only one direction, either parallel or perpendicular to the strain that is applied to it. Equations thus become:

$$\vec{D} = d_1 \vec{T} + e^T \vec{E}$$

$$\vec{S} = s^E \vec{T} + d_2 \vec{E}$$

This equation shows the relationship between the mechanical and electrical behaviors of those materials. The mechanical strain applied to the material is converted into electrical field has this equation:

$$k^2 = \frac{d^2}{s^E e^T}$$

Where:

$\vec{D}$: electric displacement

d_1 and d_2 : piezoelectric charge coefficients, respectively for the direct piezoelectric effect and the converse piezoelectric effect

$\vec{T}$: mechanical stress

e^T : permittivity at constant stress

$\vec{E}$: electric field

$\vec{S}$: mechanical strain

s^E : mechanical compliance

Conclusion from Similar Researches

The researchers' previous study mentioned above has a similar concept which is harvesting energy thru human footstep with DC power as an output but different in mechanisms, harvesting devices that is heavy, consumes more space, expensive and inconvenient. Other uses spring as their major components and air pumps on the other. Piezoelectric transducer is said to be cost-effective, safe, no fuel or any chemical source needed and nonconventional. We proposed to design and perceive an optimum device that will harness vibration energies caused by human footsteps and convert it into AC electrical output using piezoelectric transducers.

Chapter 3

METHODOLOGY

This chapter discusses the methodology used in the study. It explains each section of the design considerations and hardware specifications of the prototype. The samples are also explained in this chapter. Furthermore, this chapter shows the ideal set-up and construction of the Piezoelectric Transducer Mat. Succeeding section explains the conducted procedure and analysis to examine the appropriate output energy. This study also illustrates particular diagrams to expound how the output energy will be attained and of which design will be the optimum as those are the main objective of this project.

Block Diagram

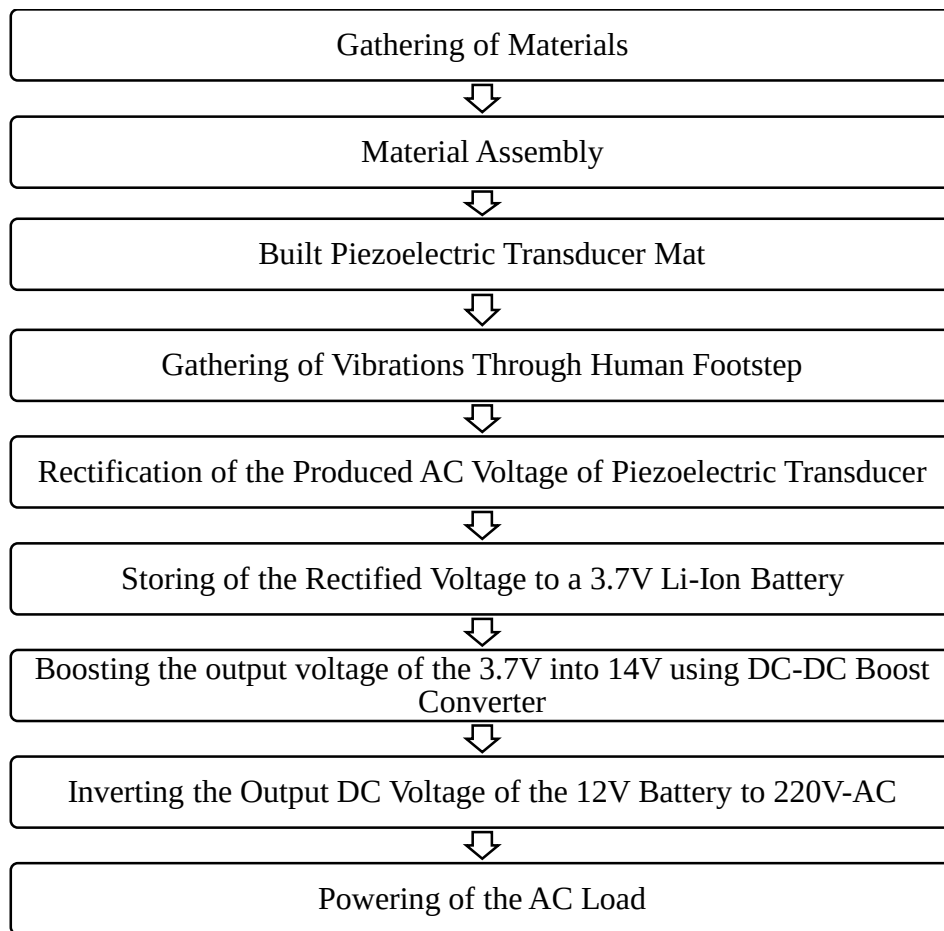


Figure 3.1. Block Diagram

Description

This figure shows the block diagram of the system. The researchers gathered and assembled the materials needed and built the device. Then, the human's footsteps are applied to the surface of the piezoelectric mat that causes vibrations. These vibrations were then converted into AC Voltage. The output AC voltage was converted to DC voltage using a Full-Wave Bridge Rectifier and then stored in a 3.7V Lithium Ion Battery. Using a DC-DC Boost Converter, the DC stored energy was stepped-up to 14VDC – 15VDC to be able to charge the 12V Lead Acid Battery. Lastly, the Lead Acid battery is connected in a 30W Homemade Power Inverter to step-up the 12VDC into 220VAC and used it to light up an LED Bulb.

Gathering of Materials

The researchers gathered all the materials needed to construct the device. Below are the lists of the materials and their functions in the construction of the device.

1. **Piezoelectric disc.** A 20 mm diameter acoustic type piezoelectric material that generates an electric potential when physically bent or a pressure is applied unto it. This should be as many as possible for quicker voltage generation.



Figure 3.2. Piezoelectric Disc

2. **Bridge-type rectifier.** A bridge rectifier is an arrangement of four or more diodes in a bridge circuit configuration which provides the same output polarity for either input polarity. It is used to convert the produced AC voltage of the Piezoelectric Disc into a DC voltage to be able to store it in a battery.

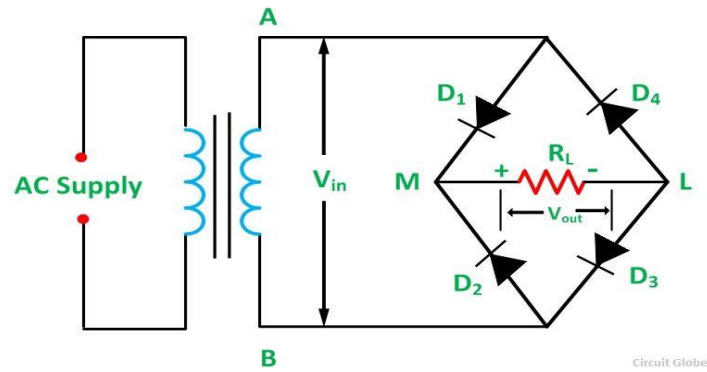


Figure 3.3. Bridge-type Rectifier

3. **3.7V Li-Ion battery.** A type of battery composed of Lithium Ion is used to store the rectified voltage produce by the piezoelectric disc.

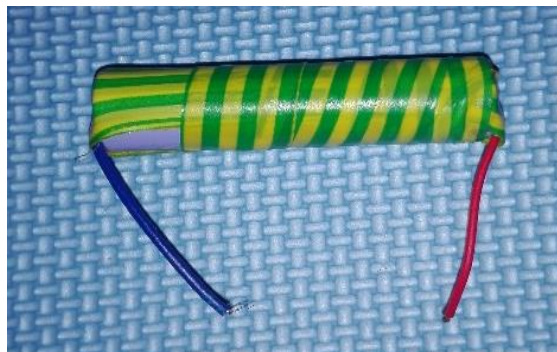


Figure 3.4. 3.7 Li-ion Battery

4. **DC boost converter.** A circuit module that steps up a low voltage DC to a higher volts DC. It is used to step up the 3.7V Li-Ion battery to 14VDC in order to charge the 12V Lead acid battery.

Specification:

- Input voltage: 3V-34V

- Output voltage: 4-35V
- Input current: 3A (max)
- Output current: 2.5A (max)
- Maximum power dissipation: 10W
- Module size: 50mm x 25mm



Figure 3.5. DC Boost Converter

5. **12V Lead-Acid battery.** A type of battery that is used for storing the boosted rectified voltage produced by the piezoelectric.



Figure 3.6. 12V Lead-acid Battery

6. **30W, 12V/220V inverter.** Homemade circuit used for stepping up 12VDC to 220VAC.

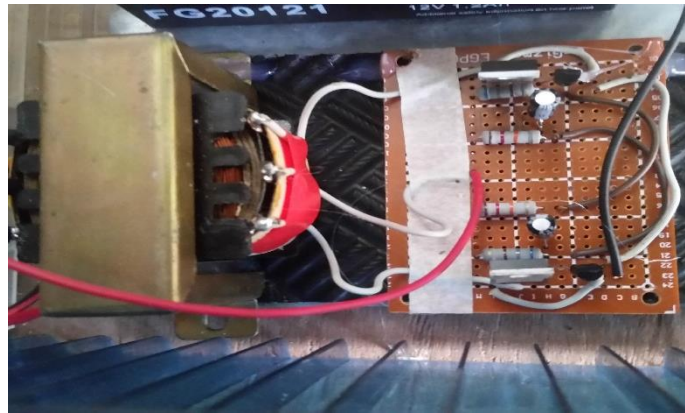


Figure 3.7. 30W, 12V/220V Inverter

7. **AC loads** – like light bulbs or anything that is supplied by a 220V input. Wattage must not exceed the rating of the homemade inverter.



Figure 3.8. AC Load

8. **PVC mat.** A mat made of Polyvinyl Chloride. It is the main protection of the design 1 and also used as another layer of protection for design 2.



Figure 3.9. Polyvinyl Chloride Mat

- 9. Gauge 16 steel plane.** A robust and durable protection that can withstand higher pressure than the PVC Mat. It is the main protection of the design 2.



Figure 3.10. Gauge 16 Steel Plane

- 10. Rubber piece.** A piece of rubber placed under and above each piezoelectric disc that serves as a cushion and pusher to concentrate the pressure in the center of piezoelectric disc which will result to more bending of the piezoelectric disc.



Figure 3.11. Rubber Piece

11. Springs. Compression type springs placed between the two steel planes to maintain its gap after stepping on the mat.



Figure 3.12. Springs

Cost of Materials

Table 3.1. List of Materials and Its Costs

Name of Materials	Quantity	Unit Price (PHP)	Total (PHP)
Piezoelectric disc	80 pcs	20.00	1,600.00
PVC mat	5 pcs	82.00	410.00
Gauge 16 steel plane(labor included)	8 pcs	450.00	3,600.00
Asstd. Adhesive		200.00	200.00
12V Lead Acid battery	1 pc	800.00	800.00
3.7V Lithium-Ion battery	3pcs	315.00	945.00
Wires	50 meters	10.00	500.00
LED bulb 3V	1 set (50 pcs)	165.00	165.00
LED bulb 3W	1 pc	365.00	365.00
Transformer (12-0-12)	1 pc	250.00	250.00
Inverter circuit components	1 pc	410.00	410.00
DC-DC boost converter	1 pc	240.00	240.00
TOTAL			9,485.00

The table shows the list of materials and its cost necessary in the assembly of the device. The prices are rounded to the nearest whole number. Most of the materials and components are ordered online due to their unavailability in the local market.

Material Assembly

After the materials are gathered, the researchers started to assemble the device in two different model with same arrays of piezoelectric discs to determine the optimum design.

1. Piezoelectric disc array and connection

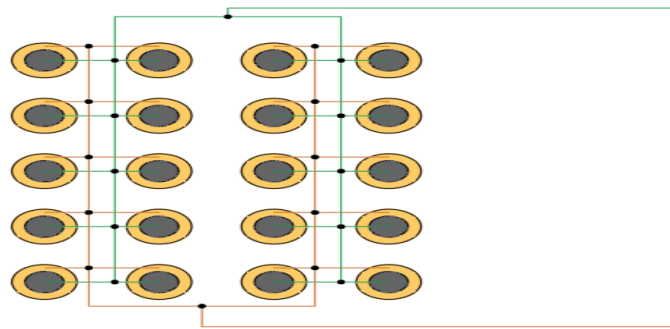


Figure 3.13. Piezoelectric Disc Array and Connection

Each mat contains twenty (20) piezoelectric disc and is arranged in a 5 by 4 manner. Piezoelectric discs are all connected in parallel in order to produce higher current since the voltage produced by each piezoelectric disc is already enough that it can reach-up up to 20 volts when normal pressure is applied.

2. Design 1

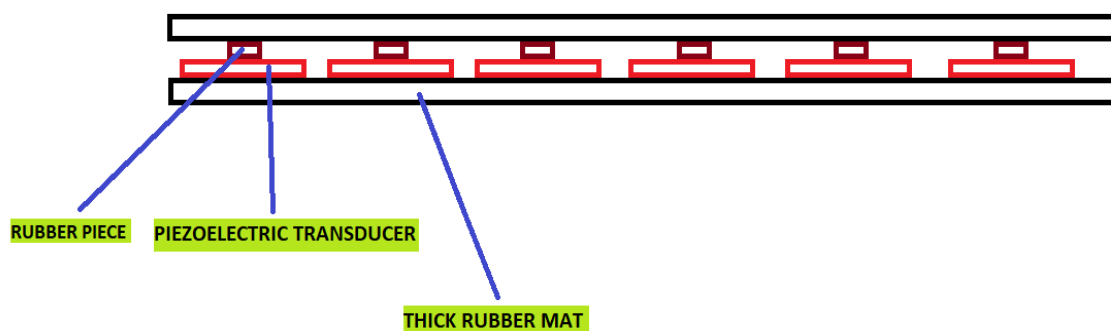


Figure 3.14. Mat-mat Design

Piezoelectric transducers were placed between the two rubber mats that serves as the outer layer and the main protection of the circuit inside. The rubber pieces were placed in the center of the piezoelectric discs so that the pressure applied by the footsteps will be

focused on the center part of the piezo-transducers which results to a greater voltage production.

Materials

- PVC mat
- Rubber Pieces
- Piezoelectric Disc

Assembly of design 1

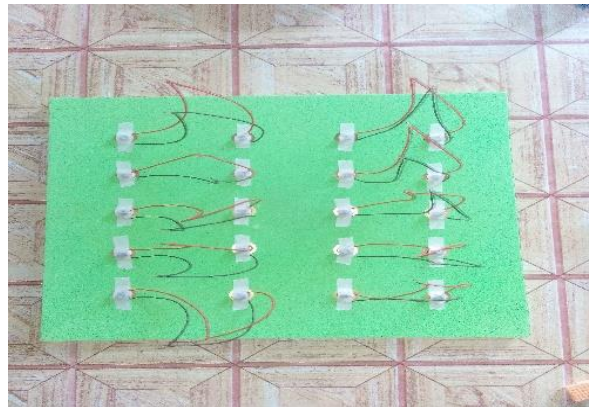


Figure 3.15. Array of Piezoelectric Disc

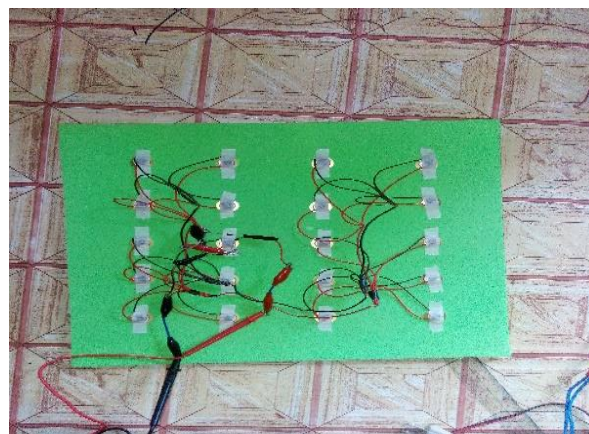


Figure 3.16. Assembled Piezoelectric Disc in Parallel Connection

3. Design 2

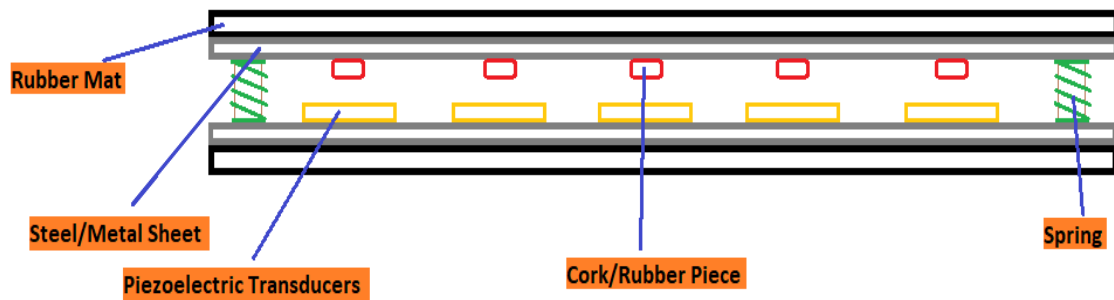


Figure 3.17. Steel-steel Plane Design

This design is more likely the upgraded version of the first design. Only that few materials are added to make it more durable but it is quite complicated and expensive compared to the first design. It is also divided into four equal squares.

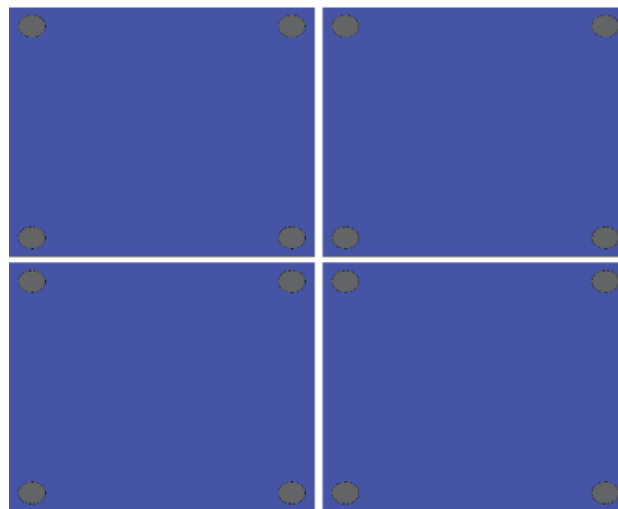


Figure 3.18. Division of the Design Into Four Equal Squares

The mechanism is still the same with the first design but this time, the researchers use springs and metal sheets in between the two rubber mats to make it more durable. The design is capable of accommodating at least two steps per person based on the length of the mat.

Materials

- Gauge 20 steel plate
- PVC Mat
- Bolts and Nuts
- Springs
- Rubber piece

Assembly of design 2



Figure 3.19. Mounting of Rubber Pieces and Piezoelectric Discs



Figure 3.20. Assembled Arrays of Piezoelectric Discs

4. Built piezoelectric transducer mat



Figure 3.21. Design 1



Figure 3.22. Design 2

Design Description

In this study, the researchers created two devices with different designs. The design 1 is mainly composed of three materials that is simple and inexpensive. While the design 2, despite having almost the same mechanism, have springs and metal sheets added in between the two rubber mats to make it more durable. Both designs have the height of about 25mm. They are made as thin as possible and with enough distance so that it will not affect the performance, durability, and efficiency of the project and will not cause tripping for the people who'll step on it.

Different arrays of piezoelectric discs do not affect the generation of power as the researchers cannot predict the area where the person will land his foot. The best way is to fill the mat or steel plane enough number and fairly distanced piezoelectric disc. The arrays of piezoelectric disc must be connected in a parallel manner only as the high voltage output is not needed. The main target of the researchers is to produce high current for as much as possible for faster charging of the battery.

Rubber or cork piece are placed on each piezoelectric disc because when a person steps on the board with no rubber or cork piece, the pressure applied gets equally distributed which will result to a larger area of pressure distribution and hence, produces less shearing. However, if a person steps on the board with a rubber or cork piece, the pressure applied gets concentrated on the piezoelectric discs that causes maximum shearing and potential difference.

According to the Mechanics of Deformable Bodies;

$$\text{Pressure} = \text{Force} / \text{Area}$$

$$\text{Stress} = \text{Force} / \text{Area}$$

$$P = F / A$$

$$P \propto 1/A$$

In other words, mass is directly proportional to the voltage and current. Therefore, the heavier the person is, the greater the power generated.

$$\text{Power} = (\text{Voltage})(\text{Current})$$

Gathering of Vibrations Through Human Footstep



Figure 3.23. Harvesting Human Footstep Energy

Rectification of the Produced AC Voltage of Piezoelectric Transducer



Figure 3.24. Measuring the Rectified Voltage of the Piezoelectric Disc

Storing of the Rectified Voltage to a 3.7V Li-Ion Battery



Figure 3.25. A Single Li-ion Battery Connected to the Mat

Boosting the charged Li-Ion Battery into 14VDC to charge up the 12V SLA Battery



Figure 3.26. Reading of the Output of the DC-DC Booster

Inverting the 12VDC of SLA battery using the homemade 30W inverter

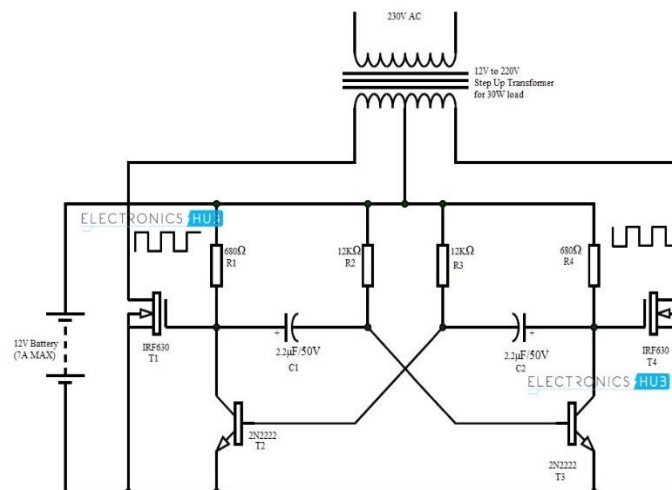


Figure 3.27. 30W Inverter Circuit

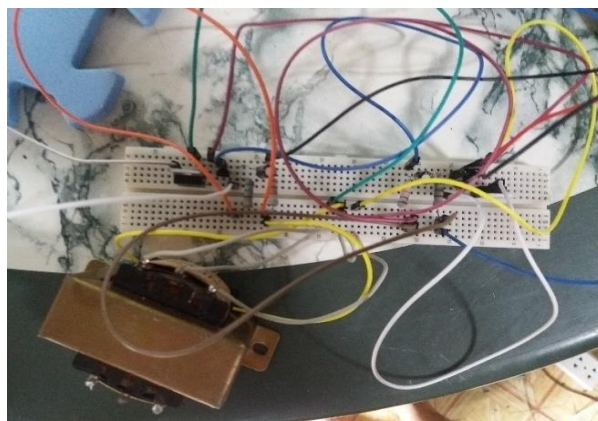


Figure 3.28. Circuit Trial in Breadboard

Powering a 9W LED Bulb using the inverted voltage from the 12V Lead Acid Battery

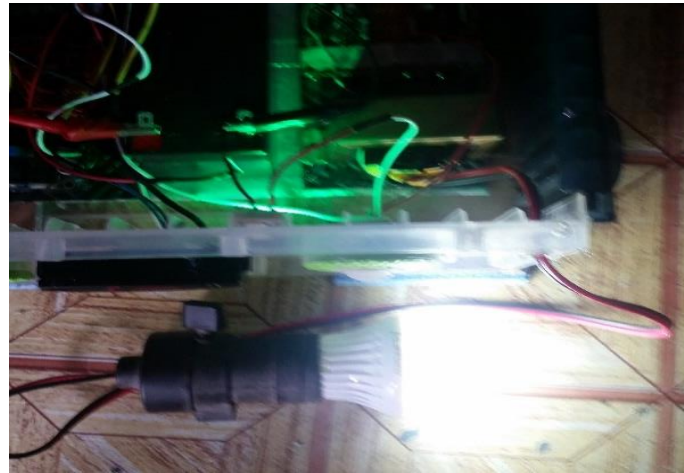


Figure 3.29. Inverter Circuit Soldered in a PCB
Testing Using a 9W bulb

Flow Chart of Process

Description

Figure 3.30 shows the system flowchart of the system. The system will start when the footsteps have made contact to the surface of the Piezoelectric Disc Mat. The system will ask if there is a contact between the human footsteps and the Piezoelectric Disc Mat's surface. If the answer is NO, it will return to the input until answered with a YES. If someone have already stepped on the mat, there will be vibrations produced and these vibrations will be converted to AC voltage with the use of piezoelectric transducer. With the use of a rectifier, the AC output voltage from the piezoelectric circuit will be converted into a DC voltage and it will be stored in a 3.7V Li-Ion Battery and will be boosted up to 14V and charge the 12V Lead-Acid battery for later use. The stored DC voltage will then be converted into AC voltage by the use of an inverter. The system will then ask if there is a load connected to the circuit. If there is a load, the load will consume the output AC electrical energy.

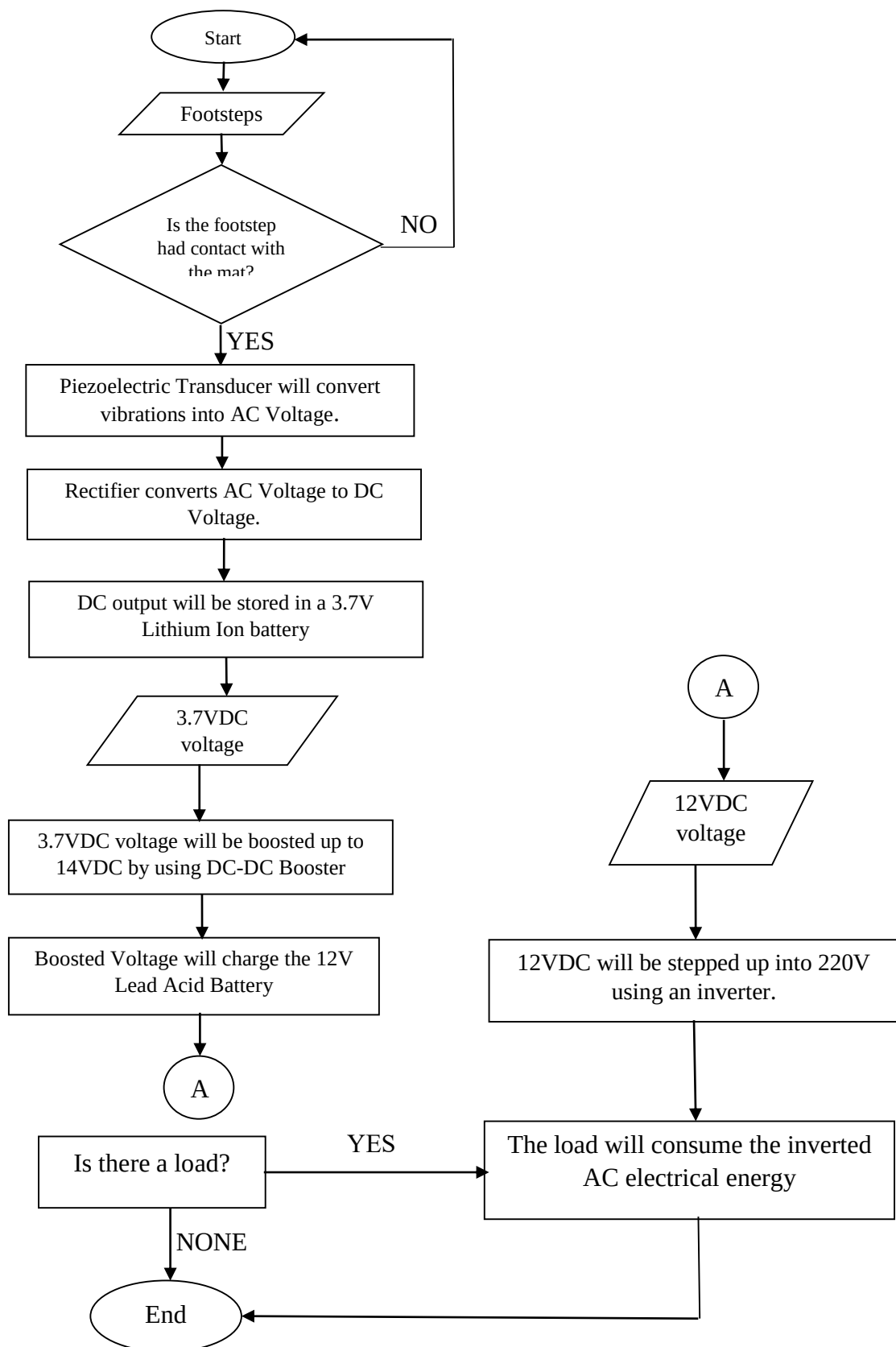


Figure 3.30. System Flowchart

Testing Procedure of Piezoelectric Disc:

1. Connect the piezoelectric disc in series.
2. Measure the voltage and current using multi-tester.
3. Connect the piezoelectric disc in parallel.
4. Measure the voltage and current using multi-tester.

Testing Procedure of the Optimum Design Piezoelectric Disc Mat

1. Assemble the Piezoelectric Mat.
2. Step onto the piezoelectric disc mat and measure the generated voltages and currents.
3. Connect a discharged 3.7V Li-Ion Battery and connect it on the device and start stepping.
4. Measure the battery if it is charged at some point.

RESULTS AND DISCUSSION

This chapter discusses the results of the tests and experiments done in the previous chapter. It explains each sections that will compensate the tests and experiments.

Testing of Piezoelectric Disc

The first test conducted was the piezoelectric disc's generated voltage and current. This test was conducted by rectifying the piezoelectric discs and pressing the piezoelectric disc that is placed above a flexible surface, like PVC mat, and is connected in series and parallel manner.

Table 3.2. Testing of Piezoelectric Disc

No. of Discs	Series		Parallel	
	V	C(μ A)	V	C(μ A)
1	10.56	8.4		
2	11.84	4.8	11.74	13.7
3	7.84	8.1	11.29	19.4
4	7.44	4.3	12.89	23.7
5	5.28	4.0	14.8	29.3

Based on the data gathered, connecting piezoelectric disc in series resulted to a low voltage and current generation because the produced voltage of the piezoelectric discs is in AC, so cancellation of voltages between each discs will occur. However, in parallel connection, the voltage produced is high as well as the current.

Objective 1: Optimum Design

Design 1: Mat – Mat Model

The arrays of the piezoelectric disc connected in parallel is built and then placed on the first proposed design.

Table 3.3. Current and Voltage Reading Using Design 1

Steps	Readings		Steps	Readings		Steps	Readings	
	Voltage (V)	Current (μ A)		Voltage (V)	Current (μ A)		Voltage (V)	Current (μ A)
1	2.16	5.2	36	2.1	3.21	71	0.64	2.21
2	0.74	7.8	37	2.5	2.6	72	0.12	5.25
3	0.68	3.2	38	1.52	3.5	73	0.16	2.25
4	1.44	5.9	39	1.32	2.21	74	0.91	6.12
5	2.16	1.3	40	0.52	5.25	75	1.55	5.24
6	0.74	4.2	41	0.62	2.25	76	1.22	3.21
7	0.68	4.8	42	0.64	6.12	77	2.16	1.3
8	1.44	2.3	43	0.12	5.24	78	0.74	4.2
9	1.02	4	44	0.16	3.21	79	0.68	4.8
10	1.52	3.8	45	0.91	1.3	80	1.44	3.21
11	1.4	6.1	46	1.55	4.2	81	1.02	5.2
12	2.1	2.6	47	1.22	4.8	82	1.52	7.8
13	2.5	3.5	48	3.24.	6.1	83	1.4	3.2
14	1.52	2.21	49	0.74	2.6	84	2.1	5.9
15	1.32	5.25	50	0.68	3.5	85	2.5	1.3
16	0.52	2.25	51	1.44	2.21	86	1.52	4.2
17	0.62	6.12	52	1.02	5.25	87	1.32	4.8
18	0.64	5.24	53	1.52	2.25	88	0.52	2.3
19	0.12	3.21	54	1.4	6.12	89	0.62	4
20	0.16	2.6	55	2.1	5.24	90	0.64	3.8
21	0.91	3.5	56	2.5	3.21	91	0.12	4.1
22	1.55	2.21	57	1.52	2.6	92	0.16	6.1
23	1.22	5.25	58	1.32	3.5	93	0.91	2.6
24	3.24.	2.25	59	0.52	2.21	94	1.55	3.5
25	2.16	6.12	60	0.62	5.25	95	1.22	2.21
26	0.74	5.24	61	0.64	2.25	96	3.24.	5.25
27	0.68	3.21	62	0.12	6.12	97	0.91	2.25
28	1.44	1.3	63	0.16	5.24	98	1.55	6.12
29	2.16	4.2	64	0.91	3.21	99	1.22	5.24
30	0.74	4.8	65	1.55	1.3	100	3.24.	3.21
31	0.68	2.21	66	1.22	4.2	AVE	1.12821	3.9196
32	1.44	5.25	67	3.24.	4.8	MAX	2.5	7.8
33	1.02	2.25	68	1.32	3.21	MIN	0.12	1.3
34	1.52	6.12	69	0.52	2.6			
35	1.4	5.24	70	0.62	3.5			

The table shows the data gathered by the researchers using the mat-mat design. It shows that in every step, there is a corresponding value of current and voltage. The value of the current and voltage depends on the pressure applied. The greater the pressure, the

higher the value. Also, the table shows the average, maximum and minimum value of the current and voltage for every one hundred (100) steps.

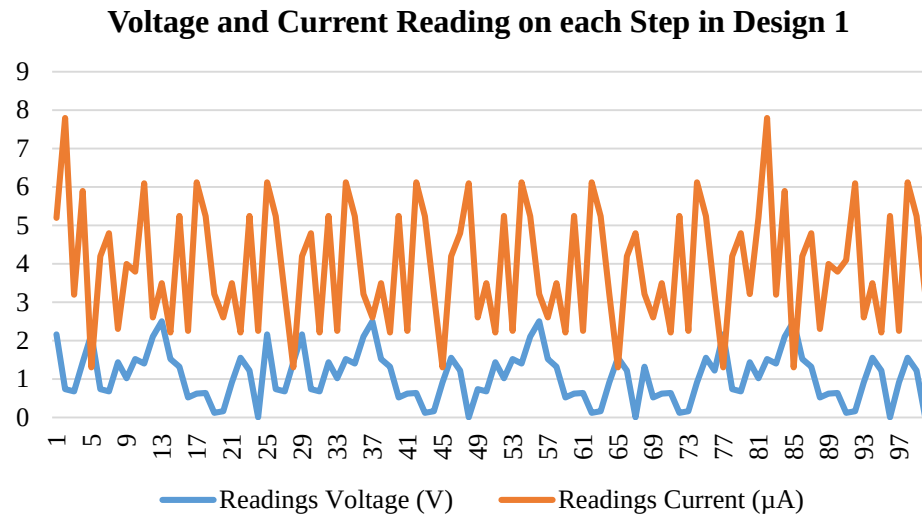


Figure 3.31. Graphical Representation of the Data of Table 3

Based on the gathered data, the generation of the voltage and current is quite low because of the characteristic of the mat which is flexible on the surface where it is mounted. Instead of pressing the piezoelectric disc, the mat is deformed based on the geometric structure of piezoelectric disc. Also, the pressure only concentrated on the area where the foot landed. Lastly, when it comes to durability, the PVC mat can be prone to puncture due to its soft characteristic that could affect the piezoelectric discs. The only advantage of this design is just the lightness of the mat that it could be moved easily.



Figure 3.32. Testing and measuring of the output of the first design

Design 2: Steel – Steel Model

Applying the similar arrays of piezoelectric discs used in the first design, the second design was built and tested.

Table 3.4. Current and Voltage Reading Using Design 2

Steps	Readings		Steps	Readings		Steps	Readings	
	Voltage (V)	Current (μA)		Voltage (V)	Current (μA)		Voltage (V)	Current (μA)
1	8	29	36	26.7	183	71	11.6	50
2	4.3	25	37	9.2	78	72	51.1	78
3	8.8	56	38	14.3	57	73	5.5	54
4	40.5	59	39	35.7	47	74	33.5	105
5	11.8	51	40	45.7	190	75	34.7	43
6	23.8	93	41	17.2	82	76	36.1	98
7	23.5	35	42	40.3	102	77	16.6	40
8	41.1	103	43	43.9	32	78	17.7	51
9	22	38	44	27.6	122	79	21.6	73
10	27.8	150	45	5.7	174	80	18.9	135
11	32.7	106	46	19.9	50	81	36.6	30
12	37.9	126	47	9.5	70	82	28.1	70
13	23.9	23	48	18.8	175	83	8.4	30
14	10.9	109	49	38.9	114	84	45.1	58
15	43	14	50	20.7	216	85	12.9	34
16	16.6	149	51	9	98	86	19.4	100
17	16.6	66	52	33.5	130	87	37.7	93
18	20.2	141	53	15.3	84	88	32.3	93
19	10.3	134	54	25.8	231	89	20.4	34
20	20.3	59	55	40.9	30	90	26.6	94
21	24.6	49	56	21.2	99	91	13.6	26
22	33	173	57	5.2	71	92	15.8	69
23	11.7	24	58	39.7	123	93	8.7	41
24	20.1	11	59	37.9	55	94	26.9	171
25	23.9	150	60	23.1	117	95	17.5	26
26	35	199	61	18.6	47	96	20.6	131
27	28.5	14	62	38.2	42	97	23.1	59
28	50.3	145	63	5.5	42	98	31.6	182
29	45.7	55	64	18.5	87	99	23.1	81
30	24.3	62	65	40.6	26	100	17.4	84
31	3.9	32	66	36.3	131	AVE	24.237	78.543
32	39.2	93	67	30.5	64	MAX	50.3	199
33	24.4	14	68	36.9	27	MIN	3.9	11
34	24.6	95	69	27.6	32			
35	15.1	67	70	22.3	77			

The table shows the data gathered by the researchers using the one with optimum design device. It shows that in every step, there is a corresponding value of current and voltage. The value of the current and voltage depends on the pressure applied. The greater the pressure, the higher the value. Also, the table shows the average, maximum and minimum value of the current and voltage for every one hundred (100) steps.

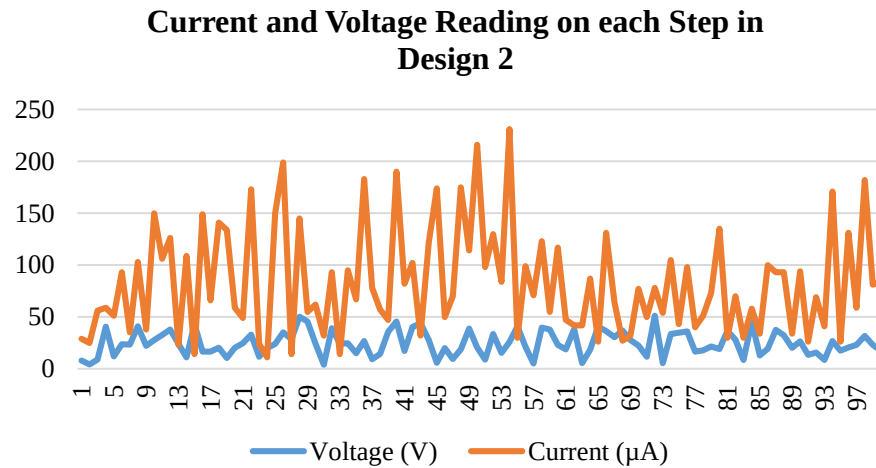


Figure 3.33. Graphical Representation of the Data of Table 4

Based on the data gathered, it is clearly stated that the generated voltage and current increased greatly compared to the first design. The pressure was distributed evenly on the whole area due to the flexibility and durability of the steel plane. Also, it cannot be penetrated easily by sharp objects.

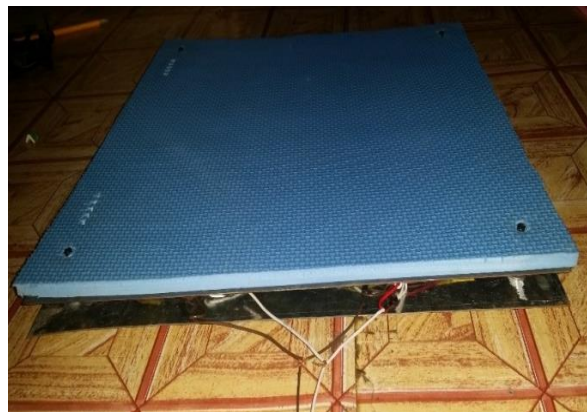


Figure 3.34. Built Steel-steel Design

Tests conducted on the design includes jumping and stepping on the mat at the same time to know if the device is tough enough to handle forceful pressure and without harming the piezoelectric disc inside. The researchers found out that the device is capable of handling heavy- weights or forceful pressure.

The only disadvantage of this design is that it is heavy compared to the design 1. Also, it produces noise whenever someone is stepping on it, but after adding a PVC mat layer on it, the noise was reduced.

Conversion of AC voltage to DC voltage by Rectifier

$$V_{dc} = \frac{2V_{max}}{\pi} = 0.637V_{max} = 0.9V_{RMS}$$

$$V_{dc}(\text{Average}) = 24.237V$$

$$V_{dc}(\text{Highest}) = 50.3V$$

$$V_{dc}(\text{Lowest}) = 3.9V$$

Using the formula above, the V_{rms} will be;

$$V_{rms}(\text{Average}) = 24.237 / 0.9 = \mathbf{26.93V} \quad ; \quad V_{p-p} = 26.93(2)(1.414) = \mathbf{76.158V}$$

$$V_{rms}(\text{Highest}) = 50.3 / 0.9 = \mathbf{55.89V} \quad ; \quad V_{p-p} = 55.89(2)(1.414) = \mathbf{158.057V}$$

$$V_{rms}(\text{Lowest}) = 3.9 / 0.9 = \mathbf{4.33V} \quad ; \quad V_{p-p} = 4.33(2)(1.414) = \mathbf{12.245V}$$

Objective 2: Efficiency of the Design

An experiment was conducted to determine the voltage stored on a certain rating of capacitor on each design. The researchers compared the number of voltages stored in a capacitor on the Design 1(mat-mat) and Design 2 (steel-steel plane).



Figure 3.35. Charging of Capacitor

Design 1: Mat - mat model

Table 3.5. Voltage Stored in a Capacitor in Every Ten steps for Mat-Mat Model

Voltage Stored in a Capacitor using Design 1					
STEPS	10uF	100uF	1000uF	2200uF	0.33F
10	0.72	0.27	0.1	0	0
20	0.84	0.38	0.2	0.01	0
30	1.36	0.52	0.4	0.02	0
40	1.45	0.68	0.5	0.03	0
50	1.68	0.71	0.5	0.04	0
60	1.81	0.84	0.6	0.04	0
70	2.21	0.92	0.7	0.05	0
80	2.42	0.96	0.7	0.05	0
90	2.32	1.17	0.7	0.06	0
100	2.4	1.2	0.8	0.06	0

The table shows that in every ten (10) steps, there is a corresponding number of voltages stored in a capacitor. The researchers used five (5) different capacitors. It shows that the mat-mat model could not charge-up a 0.33F.

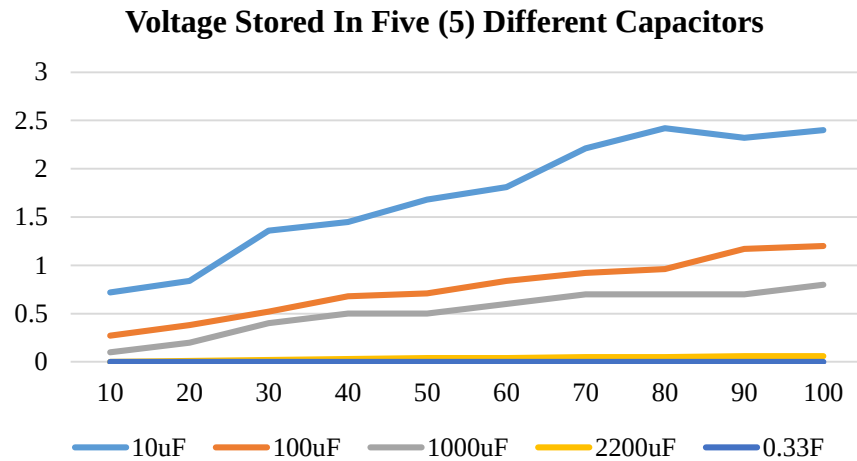


Figure 3.36. Graphical Representation of the Data of Table 5

The graph shows a clearer interpretation of data gathered from five (5) different capacitors of the Mat-Mat Model.

Design 2: Steel – Steel Model

Table 3.6. Voltage Stored in a Capacitor in Every Ten steps for Steel-Steel Model

Voltage Stored in a Capacitor using Design 2					
STEPS	10uF	100uF	1000uF	2200uF	0.33F
10	10.3	1.4	0.22	0.1	0.3
20	14.74	2.61	0.45	0.2	0.4
30	16.07	3.62	0.7	0.3	0.5
40	17.02	4.52	0.9	0.43	0.5
50	18.09	5.05	1.12	0.56	0.1
60	17.82	5.79	1.3	0.64	0.2
70	16.4	6.44	1.5	0.72	0.1
80	19.08	7	1.62	0.78	0.5
90	19.62	7.33	1.78	0.88	0.4
100	22.07	7.9	1.9	0.95	0.2

The table shows that Metal-Metal model stores more voltage compared to Mat-Mat Model. Here, the Steel-Steel Model could charge-up a 0.33F capacitor.

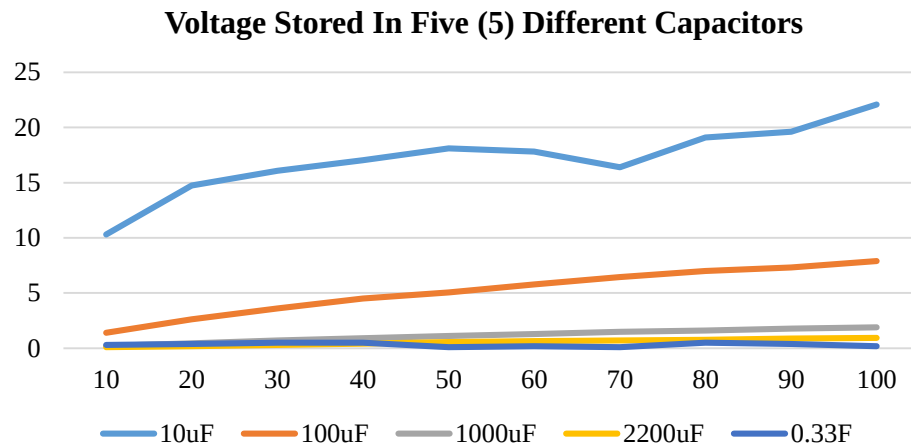


Figure 3.37. Graphical Representation of the Data of Table 6

The graph shows a clearer interpretation of data gathered from five (5) different capacitors of the Steel-Steel Model.

Based on the findings, the Design 2 (steel-steel plane) is more efficient compared to the Design 1 (mat-mat). The researchers calculated the voltage stored in a capacitor in every 10 steps on both designs.

At this point, the researchers concluded that the design 1(mat-mat) is not as efficient as design 2(steel-steel plane) in terms of design and efficiency. So, the researchers disregarded the first design and focused on the second design for testing and data gathering.

Objective 3: Feasibility of Conducting the Design in the Main Entrance Gate

In order to determine the charging capability of the device, one factor to be considered is the number of people entering the entrance gate of Palawan State University within a certain timeframe. The table below shows the gathered data:

Table 3.7. Number of people Entering the Gate from Monday to Friday

TIME	Monday (9/10/18)	Tuesday (9/11/18)	Wednesday (9/12/18)	Thursday (9/13/18)	Friday (9/14/18)
8:00-8:10	315	247	157	300	265
8:10-8:20	245	150	103	255	120
8:20-8:30	176	136	92	167	136
8:30-8:40	167	182	88	150	179
8:40-8:50	150	259	59	156	260
8:50-9:00	210	238	105	200	220
9:00-9:10	172	203	100	180	203
9:10-9:20	112	187	89	110	175
9:20-9:30	87	104	94	87	120
9:30-9:40	67	97	83	80	100
9:40-9:50	86	91	60	76	91
9:50-10:00	122	85	65	120	85
10:00-10:10	132	112	47	110	125
10:10-10:20	142	127	102	152	127
10:20-10:30	98	126	90	80	115
10:30-10:40	49	98	67	57	98
10:40-10:50	120	78	50	126	78
10:50-11:00	145	72	45	150	65
11:00-11:10	55	53	40	65	53
11:10-11:20	52	59	42	60	59
11:20-11:30	62	77	37	62	77
11:30-11:40	46	86	30	56	80
11:40-11:50	67	75	41	70	75
11:50-12:00	72	73	40	65	70
12:00-12:10	98	102	65	100	102
12:10-12:20	220	123	72	208	123
12:20-12:30	189	159	198	190	165
12:30-12:40	197	147	185	189	147
12:40-12:50	200	188	190	210	170
12:50-13:00	282	243	165	257	243
13:00-13:10	267	250	102	250	180
13:10-13:20	225	267	100	245	210
13:20-13:30	187	213	83	190	198
13:30-13:40	157	169	76	145	169
13:40-13:50	135	189	50	120	168
13:50-14:00	156	155	45	156	155
14:00-14:10	138	134	48	130	120
14:10-14:20	75	89	38	70	89
14:20-14:30	79	79	30	79	75
14:30-14:40	65	87	46	72	87
14:40-14:50	86	83	83	68	65
14:50-15:00	140	56	50	109	56
15:00-15:10	76	53	43	82	45
15:10-15:20	89	66	34	89	66
15:20-15:30	75	59	42	75	60
15:30-15:40	80	48	25	85	50
15:40-15:50	62	40	37	60	35
15:50-16:00	51	66	46	58	29
TOTAL	6278	6080	3579	6171	5783
MIN.	46	40	25	56	29
MAX.	315	267	198	300	265
AVE	130.79	126.67	74.56	128.56	120.48

The table shows the number of people entering the gate from Monday to Friday. Monday got the highest number of people entering the gate while the Wednesday got the lowest number of people entering the gate.

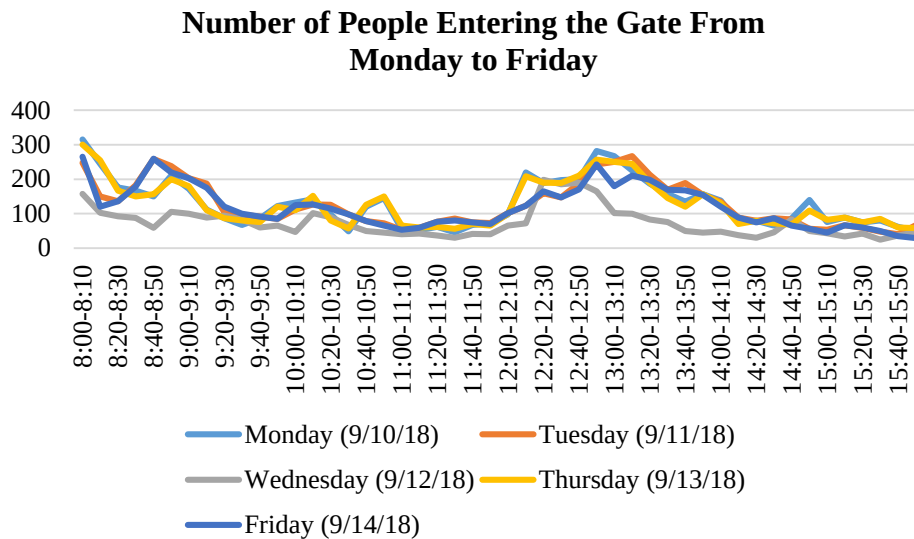


Figure 3.38. Graphical Representation of the Data of Table 7

The graph shows a clearer interpretation of the data gathered from Monday to Friday. It can be seen that Monday has the highest number of people entering the gate. It also shows that during 8:00 AM and lunch break has the highest number of people entering the gate.

Theoretical Computation of Charging Time of the 3.7V Li-Ion Battery

Table 3.8. Number of People Entering the Gate every One (1) Hour

TIME	Monday	Tuesday	Wednesday	Thursday	Friday	Average
8:00-9:00AM	1263	1212	604	1228	1180	1097.4
9:00-10:00 AM	656	767	491	653	774	668.2
10:00-11:00 AM	1041	613	401	675	608	667.6
11:00-12:00 NN	452	423	230	378	414	379.4
12:00-13:00 PM	1186	962	875	1154	950	1025.4
13:00-14:00 PM	1127	1243	456	1106	1005	987.4
14:00-15:00 PM	583	528	295	528	492	485.2
15:00-16:00 PM	433	332	227	449	285	345.2
TOTAL	6741	6080	3579	6171	5708	5655.8

Based from the previous table, the total average of people entered the gate per day is approximately 5656. The researchers assumed that every person steps on the piezo mat two (2) times so the total steps per day is 11312.

To compute for the total duration of charging of 3.7V Lithium-ion battery:

Battery

Power = Ah x V where;

Ah – ampere by time of the battery

V – voltage rating of the battery

$$\text{Power} = 5\text{Ah} \times 3.7\text{V} = 18.5 \text{ Wh}$$

$$\text{Power} = 18.5(\text{J/sec}) \times 60 \text{ sec/hour} = 1110 \text{ J}$$

Piezo disc

$$V_{\text{ave}} = 24.6\text{V}$$

$$\text{Capacitor rating} = 100 \times 10^{-6} \text{ f}$$

$$E = \frac{1}{2} CV^2$$

$$E = \frac{1}{2} \times 100 \times 10^{-6} \text{ f} \times (24.6\text{V})^2 = 0.030 \text{ J/step}$$

$$* 1110 \text{ J} / 0.030 \text{ J/step} = 37000 \text{ steps}$$

$$* 37000 \text{ steps} / 11312 \text{ steps/day} = \mathbf{3.27 \text{ days of charging}}$$

Theoretical computation to determine the charging time of battery thru piezo tile. At the battery side, the power is directly proportional to the ampere by time by rated voltage of the battery and results to the unit of watt-hour then the product is multiplied by 60 second per hour to come up with the unit Joule. At the piezo tile side, energy is the product of the

capacitor rating multiplied by the rated voltage of the piezo tile raise to the second power divided by two, and came up with the unit Joule per step. Then the ratio of the products, yields the number of total steps and to compute for the duration of charging the quotient is divided by average steps per day.

Actual Test of Charging Capability

The discharged 3.7V Li-Ion Battery is charged using the device and then the researchers counted the corresponding number of steps as the voltage increases.

Table 3.9. Corresponding Number of Steps as the Voltage Increases

Steps	Voltage Reading
Initial	1.62V
115	1.63V
242	1.64V
367	1.65V
476	1.66V
595	1.67V
712	1.68V
876	1.69V
1038	1.70V
1243	1.71V

Based on the experiment and data gathered, the built Piezoelectric Disc Mat could be used in Palawan State University as energy-harvesting device since it was capable of charging a battery.

Charging Time of Lead Acid Battery

The Lead Acid Battery is charged by the stepped-up 3.7V of the Lithium Ion Battery with the aid of the DC-DC Boost Converter module. It charged the 12-V Lead Acid battery by 1.48V before the 3.7V reached the 3.2V which took an approximately 2 hours.

Conclusion

With all the data gathered, experiments performed, and assessment of individual factors that may affect the device's performance, the researchers were able to know the answer to the study's objective.

The researchers found that the Design 2 (steel-steel plane model) was the optimum design for the device because of its durability and ability to produce more voltage and current compared to the Design 1 (mat-mat model). Also, Design 2 (steel-steel) was more efficient and more suitable to use in Palawan State University as energy-harvesting device.

However, the main drawback of their design is that they used the piezoelectric disc instead of other piezoelectric transducers that are designed for energy harvesting. Despite the lacking, the researchers were able to satisfy their objectives since the piezoelectric disc is still capable of gathering the desired outputs.

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Chapter 4

CONCLUSION

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The researchers found that the Design 2 (steel-steel plane model) was the optimum design for the device because of its durability and ability to produce more voltage and current compared to the Design 1 (mat-mat model). Also, Design 2 (steel-steel) was more efficient and more suitable to use in Palawan State University as energy-harvesting device.

However, the main drawback of their design is that they used the piezoelectric disc instead of other piezoelectric transducers that are designed for energy harvesting. Despite the lacking, the researchers were able to satisfy their objectives since the piezoelectric disc is still capable of gathering the desired outputs.

Chapter 5

RECOMMENDATION

After thorough analysis of the study, the researchers would like to recommend the following:

- To improve the device so that it can be used during rainy season
- To use Piezoelectric disc that are capable of harvesting massive energy; and
- To improve the array of the piezoelectric disc by making it more compact.

Glossary of Technical Terms

- **Current** - is the flow of electrical charge carriers like electrons.
- **Inverter** - is an electric apparatus that changes direct current (DC) to alternating current (AC).
- **Piezoelectricity** - is the electric charge that accumulates in certain solid materials in response to applied mechanical stress.
- **Transducer** - is a device that converts energy from one form to another.
- **Voltage** - is the electrical force that causes free electrons to move from one atom to another.

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APPENDIX A

PIEZOELECTRIC DISC

● Part Numbering

Piezoelectric Diaphragms

(Part Number)

7	N	B	-31R2	DM	-1R5		L	10
---	---	---	-------	----	------	--	---	----

① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

① Product ID

Product ID	
7	Ceramic Material

② Material

Code	Metal Plate Material
B	Brass
N	Nickel Alloy
S	SUS

③ Product

Code	Product
B	Piezoelectric Diaphragms

④ Metal Plate Diameter

Code	Metal Plate Diameter
-31R2	A hyphen (-) plus four digits alphanumerics express metal plate outer dimensions. A decimal point is expressed by the capital letter "R".

If there is no decimal point, the decimal point code is omitted.

⑤ Form of Piezoelectric Style

Code	Form of Piezoelectric Style
DM	Two digits express shape of ceramics.

For an Ag electrode, this digit remains blank, the corresponding code is omitted.

⑥ Resonant Frequency Type

Code	Resonant Frequency (kHz)
-1R5	A hyphen (-) and three digits alphanumerics express resonant frequency. A decimal point is expressed by the capital letter "R".

If there is no decimal point, the decimal point is omitted.

⑦ With Feedback Electrode

Code	With Feedback Electrode
C	With Feedback Electrode
—	Without Feedback Electrode

⑧ Product Specification

Code	Product Specification
L	With lead (available for RoHS)
—	No lead (omitted)

⑨ Individual Specification Code

Code	Individual Specification Code
10	These digits express a lead length, lead number, and presence/absence of a connector.

If the product has no individual specification, the corresponding code is omitted.

Application Matrix

		Application	Tele- phone	Watch	Clock	Medical Equip- ment	Fire/ Gas Alarm	Digital Camera	Toy	Bar Code Scanner	Printer	Note- PC PDA	DVD- Player	Micro- wave Oven	Air Condi- tioner	Fan Heater	Instru- ment Cluster
Piezoelectric Diaphragm	External Drive Type	Part Number															
		7BB-12-9		●	●	●		●	●			●					
		7BB-15-6			●	●			●			●					
		7BB-20-3	●		●	●	●		●	●							
		7BB-20-6	●		●	●			●	●							
		7BB-20-6L0	●		●				●	●							
		7BB-27-4	●		●		●		●	●							
		7BB-27-4L0	●														
		7BB-35-3	●														
		7BB-35-3L0				●	●										
		7BB-41-2	●					●	●								
		7BB-41-2L0	●					●	●								
	Self Drive Type	7NB-31R2-1	●				●		●	●							
		7BB-20-6C	●				●		●	●							
		7BB-20-6CL0	●				●			●							
		7BB-27-4C	●				●			●							
		7BB-27-4CL0	●														
		7BB-35-3C	●														
		7BB-35-3CL0					●										
		7BB-41-2C	●		●	●		●	●	●		●					
		7BB-41-2CL0	●		●	●		●	●	●	●	●	●		●	●	●
		7SB-34R7-3C	●		●	●			●	●	●	●	●	●	●	●	●
Piezoelectric Sounder	External Drive Type	PKM13EPYH4000-A0	●		●	●			●	●	●		●	●	●	●	●
		PKM13EPYH4002-B0	●		●	●		●	●	●	●	●	●	●	●		
		PKM17EPP-2002-B0							●		●		●	●	●	●	●
		PKM17EPPH4001-B0	●		●	●			●		●		●	●	●	●	●
		PKM17EWH2001	●		●	●			●		●		●	●	●	●	●
		PKM22EPH2001	●		●	●			●		●		●	●	●	●	
		PKM22EPPH2001-B0	●		●	●	●		●		●		●	●	●	●	●
		PKM22EPPH4001-B0							●		●		●	●	●	●	
		PKM22EPPH4005-B0	●		●	●		●	●	●	●	●	●		●		
		PKM22EPPH4007-B0	●			●		●	●	●	●	●			●		
		PKM22EPTH2001-B0															●
		PKM17EWH4000	●			●			●		●	●			●		
		PKLCS1212E2000-R1															
		PKLCS1212E20A0-R1	●						●					●	●	●	
		PKLCS1212E4001-R1						●	●	●	●	●		●			
		PKLCS1212E40A1-R1							●		●	●					●
	Self Drive Type	PKM24SPH3805	●				●		●		●	●			●	●	
		PKM30SPH2001-B0	●								●	●					
		PKM30SPH2501-B0	●														
Piezoelectric Buzzer		PKB24SPCH3601-B0	●			●							●				
		PKB24SWH3301	●		●				●		●	●		●	●	●	
Piezoelectric Ringer		PKM33EPH1201C															
		PKM34EWH1101C															
		PKM34EWH1201C															
		PKM44EWH1001C	●														

There are various applications besides those listed in the above table, including:

Burglar Alarm, Laundry Machine, Bath, Interphone, Chime, Back Buzzer, ME Instruments, Measuring Instruments, Vending Machine, Calculator, Automobile, Communication Radio, Hemadynamometer, Thermometer, Running Meter, Facsimile, Audio Timer, Automatic Controlling Devices.

Piezoelectric Sound Components

muRata

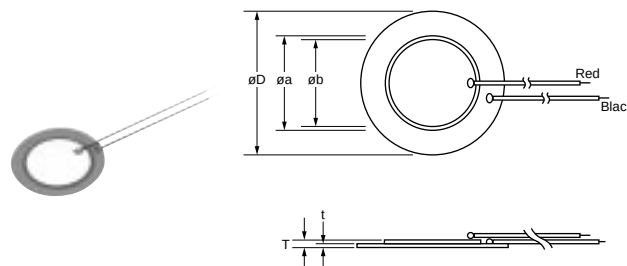
Piezoelectric Diaphragms

■ Features

1. Clear sound
2. Ultra thin and lightweight
3. No contacts: therefore, no noise and highly reliable
4. Low power consumption for voltage type

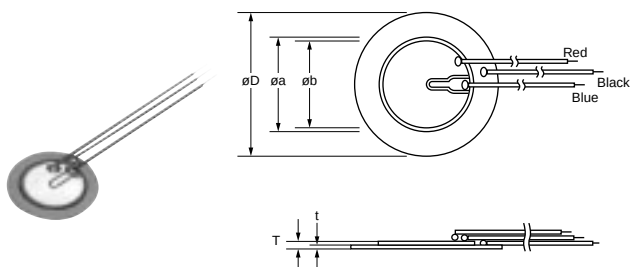
■ Applications

Clocks/Calculators/Digital camera/Various alarms
(Burglar alarms, etc.)



External Drive Type

Part Number	Resonant Frequency (kHz)	Resonant Impedance (ohm)	Capacitance (nF)	Plate Size dia. D (mm)	Element Size dia. a (mm)	Electrode Size dia. b (mm)	Thickness T (mm)	Plate Thickness t (mm)	Plate Material
7BB-12-9	9.0 ±1.0kHz	1000 max.	8.0 ±30% [1kHz]	12.0	9.0	8.0	0.22	0.10	Brass
7BB-15-6	6.0 ±1.0kHz	800 max.	10.0 ±30% [1kHz]	15.0	10.0	9.0	0.22	0.10	Brass
7BB-20-3	3.6 ±0.6kHz	500 max.	20.0 ±30% [1kHz]	20.0	14.0	12.8	0.22	0.10	Brass
7BB-20-6	6.3 ±0.6kHz	350 max.	10.0 ±30% [1kHz]	20.0	14.0	12.8	0.42	0.20	Brass
7BB-20-6L0	6.3 ±0.6kHz	1000 max.	10.0 ±30% [1kHz]	20.0	14.0	12.8	0.42	0.20	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-27-4	4.6 ±0.5kHz	200 max.	20.0 ±30% [1kHz]	27.0	19.7	18.2	0.54	0.30	Brass
7BB-27-4L0	4.6 ±0.5kHz	300 max.	20.0 ±30% [1kHz]	27.0	19.7	18.2	0.54	0.30	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-35-3	2.8 ±0.5kHz	200 max.	30.0 ±30% [1kHz]	35.0	25.0	23.0	0.53	0.30	Brass
7BB-35-3L0	2.8 ±0.5kHz	200 max.	30.0 ±30% [1kHz]	35.0	25.0	23.0	0.53	0.30	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-41-2	2.2 ±0.3kHz	250 max.	30.0 ±30% [1kHz]	41.0	25.0	23.0	0.63	0.40	Brass
7BB-41-2L0	2.2 ±0.3kHz	300 max.	30.0 ±30% [1kHz]	41.0	25.0	23.0	0.63	0.40	Brass (with Lead Wire: AWG32 Length 50mm)
7NB-31R2-1	1.3 ±0.5kHz	300 max.	40.0 ±30% [120Hz]	31.2	19.7	18.2	0.22	0.10	Nickel Alloy



Self Drive Type

Part Number	Resonant Frequency (kHz)	Resonant Impedance (ohm)	Capacitance (nF)	Plate Size dia. D (mm)	Element Size dia. a (mm)	Electrode Size dia. b (mm)	Thickness T (mm)	Plate Thickness t (mm)	Plate Material
7BB-20-6C	6.3 ±0.6kHz	500 max.	8.5 ±30% [1kHz]	20.0	14.0	12.8	0.42	0.20	Brass
7BB-20-6CL0	6.3 ±0.6kHz	800 max.	8.5 ±30% [1kHz]	20.0	14.0	12.8	0.42	0.20	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-27-4C	4.6 ±0.5kHz	200 max.	18.0 ±30% [1kHz]	27.0	19.7	18.2	0.54	0.30	Brass
7BB-27-4CL0	4.6 ±0.5kHz	350 max.	18.0 ±30% [1kHz]	27.0	19.7	18.2	0.54	0.30	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-35-3C	2.8 ±0.5kHz	200 max.	26.0 ±30% [1kHz]	35.0	25.0	23.0	0.53	0.30	Brass
7BB-35-3CL0	2.8 ±0.5kHz	200 max.	26.0 ±30% [1kHz]	35.0	25.0	23.0	0.53	0.30	Brass (with Lead Wire: AWG32 Length 50mm)
7BB-41-2C	2.2 ±0.3kHz	250 max.	24.0 ±30% [1kHz]	41.0	25.0	23.0	0.63	0.40	Brass
7BB-41-2CL0	2.2 ±0.3kHz	350 max.	24.0 ±30% [1kHz]	41.0	25.0	23.0	0.63	0.40	Brass (with Lead Wire: AWG32 Length 50mm)
7SB-34R7-3C	3.1 ±0.3kHz	150 max.	24.0 ±30% [1kHz]	34.7	25.0	23.4	0.50	0.25	Stainless

■ Node Diameter

Part Number	Node Diameter (mm)
7BB-20-6C	φ13.5
7BB-27-4C	φ17.5
7BB-35-3C	φ22.5
7BB-41-2C	φ26.5

• Sound diaphragms without feedback electrode also have the same node diameters.

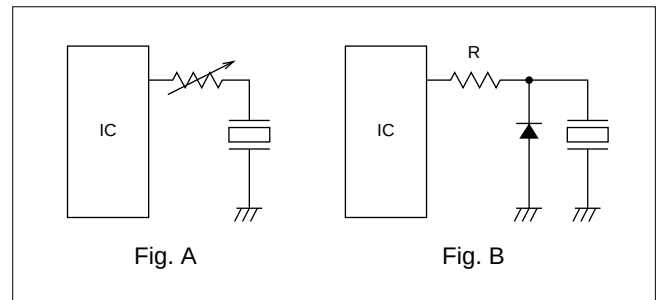
Piezoelectric Diaphragms Notice

■ Notice (Soldering and Mounting)

1. Applying load on the center area of the diaphragm may cause cracking in the ceramic element. When the diaphragm is supported by the edge, the load should be applied only around the edge.
2. Please consult with Murata or Murata representative if soldering of the component is needed.

■ Notice (Handling)

1. Please do not touch the component with bare hand because electrode may be corroded.
2. The component may be damaged if mechanical stress exceeding specifications is applied.
3. Take care to protect operating circuit from surge voltage resulting from excessive force, falling, shock or temperature change.
4. If DC voltage is applied to the component, silver migration may occur. Please pay full attention to avoid subjecting the component to DC voltage for long periods.
5. The resistor should be used as shown in Fig. A.
A suitable resistance value should be chosen, preferably $1\text{k}\Omega$ to $2\text{k}\Omega$. Instead of this measure, a diode may also be applied as shown in Fig. B.



6. Avoid excessive pulling of lead wire because wire may break or soldering point may come off.

APPENDIX B
LI POLYMER BATTERY

063450
LI-POLYMER BATTERY PACKS

Specification

Type: 063450 1000mAh

Prepared/Date	Auditing/Date	Approved/Date
WANG MAR 16, 2006	LI MAR 16, 2006	XIONG MAR 16, 2006

UNIONFORTUNE PRODUCT SPECIFICATION	Doc. No.	2006.3.16
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1 Scope

This product specification describes UNIONFORTUNE polymer lithium-ion battery. Please using the test methods that recommend in this specification. If you have any opinions or advices about the test items and methods, please contact us. Please read the cautions recommended in the specifications first, take the credibility measure of the cell's using.

2 Product Type, Model and Dimension

2.1 Type Polymer lithium-ion battery

2.2 Model 063450

2.3 Cell Dimension(Max, Thickness×Width×Length mm³) 6×34×50

Pack Dimension(Max, Thickness×Width×Length mm³) None

3 Specification

Item	Specifications	Remark
Nominal Capacity	1000 mAh	0.2C ₅ A discharge
Nominal Voltage	3.7V	Average Voltage at 0.2C ₅ A discharge
Charge Current	Standard 0.2 C ₅ A Max 1 C ₅ A	Working temperature 0~40℃
Charge cut-off Voltage	4.20±0.03V	
Standard Discharge Current	0.2C ₅ A	Working temperature 20~60℃
Max Discharge Current	2.0C ₅ A	Working temperature 0~60℃
Discharge cut-off Voltage	2.75 V	
Cell Voltage	3.7-3.9 V	When leave factory
Impedance	≤ 300 mΩ	AC 1KHz after 50% charge
Weight	Approx: 20g	
Storage temperature	≤1month	-20~45℃
	≤3month	0~30℃
	≤6month	20±5℃
Storage humidity	65±20% RH	Best 20±5℃ for long-time storage

4 General Performance

Definition of Standard charging method At 20±5℃ charging the cell initially with constant current 0.2C₅A till voltage 4.2V, then with constant voltage 4.2V till current declines to 0.05C₅A.

Item	Test Methods	Performance
4.1 0.2C Capacity	After standard charging, laying the battery 0.5h, then discharging at 0.2C ₅ A to voltage 2.75V, recording the discharging time.	≥ 300min
4.2 1C Capacity	After standard charging, laying the battery 0.5h, then discharging at 1C ₅ A to voltage 2.75V, recording the discharging time.	≥ 51min
4.3 Cycle Life	Constant current 1C ₅ A charge to 4.2V, then constant voltage charge to current declines to 0.05C ₅ A, stay 5min constant current 1C ₅ A discharge to 2.75V stay 5min. Repeat above steps till continuously discharging time less than 36min.	≥ 300times
4.4 Capability of keeping electricity	20±5℃ After standard charging, laying the battery 28days, discharging at 0.2C ₅ A to voltage 2.75V, recording the discharging time.	≥ 240min

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5□Environment Performance

Item		Test Methods	Performance
5.1	High temperature	After standard charging, laying the battery 4h at 60□, then discharging at 0.2C ₅ A to voltage 2.75V, recording the discharging time.	≥ 270min
5.2	Low temperature	After standard charging, laying the battery 4h at 0.2C ₅ A, then discharging at 0.2C ₅ A to voltage 2.75V, recording the discharging time.	≥ 210min
5.3	Constant humidity and temperature	After standard charging, laying the battery 48h at 40±2□ RH 93±2%. Recording 0.2C ₅ A discharging time	No distortion No electrolytes leakage ≥ 270 min
5.4	Temperature shock	After standard charging, battery stored at -20□ for 2 hours, then stored at 50□ for 2 hours. Repeat 10 times.	No electrolytes leakage

6□Mechanical Performance

Item		Test Methods	Performance
6.1	Vibration	After standard charging, put battery on the vibration table. 30 min experiment from X,Y,Z axis. Scan rate: 1 oct/min; Frequency 10-30Hz, Swing 0.38mm; Frequency 30-55Hz, Swing 0.19mm.	No influence to batteries' electrical performance and appearance.
6.2	Collision	After vibration test, batteries were laying on the vibration table about X, Y, Z axis. Max frequency acceleration: 100m/s ² ; collision times per minutes: 40~80; frequency keeping time 16ms; all collision times 1000±10.	No influence to batteries' electrical performance and appearance.
6.3	Drop	Random drop the battery from 10m height onto concrete one times.	No explosion or fire

7□Safety Test

Test conditions □ The following tests must be measured at flowing air and safety protection conditions. All batteries must standard charge and lay 24h.

Item		Test Methods	Performance
7.1	Over charge	At 20±5□ charging batteries with constant current 3C ₅ A to voltage 4.8V, then with constant voltage 4.8V till current decline to 0. Stop test till batteries' temperature 10□ lower than max temperature.	No explosion or fire
7.2	Over discharge	At 20±5□ discharge battery with 0.2C ₅ A continuously 12.5h.	No explosion or fire
7.3	Short-circuit	At 20±5□ connect batteries' anode and cathode by wire which impedance less than 50mΩ, keep 6h.	No explosion or fire
7.4	Extrusion	At 20±5□ put the battery in two parallel steal broad, add pressure 13kN.	No explosion or fire
7.5	Thermal shock	Put the battery in the oven. The temperature of the oven is to be raised at 5±1□ per minute to a temperature of 130±2□ and remains 60 minutes.	No explosion or fire

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8 ☐ Cautions

1. Cautions of batteries' operation

The batteries must be careful of proceed the operation for it's soft package.

☐ Aluminum packing materials

The aluminum packing material was easily damaged by the sharp edge part, such as nickel-tabs.

- ☐ forbid to use the sharp part touching the battery;
- ☐ should cleaning working condition, avoiding the sharp edge part existence;
- ☐ forbid to pierce the battery with nail and other sharp items;
- ☐ the battery was forbidden with metal, such as necklace, hairpin etc in transportation and storage.

☐ Sealed edge

Sealing edge is very easily damaged and don't bend it.

The Al interlayer of package has good electric performance. It's forbidden to connect with exterior component for preventing short-circuits.

☐ Folding edge

The folding edge is formed in batteries' processes and passed all hermetic tests, don't open or deform it. The Al interlayer of package has good electric performance. It's forbidden to connect with exterior component for preventing short-circuits.

☐ Tabs

The batteries' tabs are not so stubborn especially for aluminum tabs. Don't bend tabs.

☐ Mechanical shock

Don't fall, hit, bent the batteries' body.

☐ Short-circuit

Short-circuit is strictly prohibited. It should damage batteries badly.

2. Standard Test Environment for polymer lithium-ion batteries

Environment temperature: 20 ± 5 ☐

Humidity: 45-85%

3. Cautions of charge & discharge

☐ charge

Charging current should be lower than values that recommend below. Higher current and voltage charging may cause damage to cell electrical, mechanical, safety performance and could lead heat generation or leakage.

- ☐ Batteries charger should charging with constant current and constant voltage mode;
- ☐ Charging current should be lower than (or equal to) $1C_5A$;
- ☐ Temperature $0 \sim 40$ ☐ is preferred when charging;
- ☐ Charging voltage must be lower than 4.25V.

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- ☐ discharge
- ☐ Discharging current must be lower than (or equal to) $2C_5A$;
- ☐ Temperature $0\sim 60^{\circ}C$ is preferred when discharging;
- ☐ Discharging voltage must not be lower than 2.75V.
- ☐ over-discharge

It should be noted that the cell would be at an over-discharge state by its self-discharge. In order to prevent over-discharge, the cell shall be charged periodically to keeping voltage between 3.6-3.9V. Over-discharge may cause loss of cell performance. It should be noted that the cell would not discharge till voltage lower than 2.5V.

4.Storage of polymer lithium-ion batteries

The environment of long-time storage:

Temperature: $20\pm 5^{\circ}C$

Humidity: 45-85%;

Batteries were 40~60% charged.

5.Transportation of polymer lithium-ion batteries

The batteries should transportation with 10~50% charged states.

6.Others

Please note cautions below to prevent cells' leakage, heat generation and explosion.

Prohibition of disassembly cells;

Prohibition of cells immersion into liquid such as water or seawater;

Prohibition of dumping cells into fire;

Prohibition of using damaged cells. The cells with a smell of electrolyte or leakage must be placed away from fire to avoid firing.

In case of electrolyte leakage contact with skin, eye, physicians shall flush the electrolyte immediately with fresh water and medical advise is to be sought.

9. Notice of Designing Battery Pack

9.1 Pack design

Battery pack should have sufficient strength and battery should be protected from mechanical shock. No sharp edge components should be inside the pack contain the battery.

9.2 PCM design

The overcharge threshold voltage should not be exceed 4.25V.

The over-discharge threshold voltage should not be lower than 2.75V.

The PCM should have short protection function built inside.

9.3 Tab connection

Ultrasonic welding or spot welding is recommended to connect battery with PCM or other parts.

If apply manual solder method to connect tab with PCM, the notice below is very important to ensure battery performance.

- ☐ The electric iron should be temperature controlled and ESD safe;
- ☐ Soldering temperature should not exceed $350^{\circ}C$;
- ☐ Soldering time should not be longer than 3s, keep battery tab cold down before next soldering;
- ☐ Soldering times should not exceed 5 times;
- ☐ Directly heat cell body is strictly prohibited, battery may be damaged by heat above approx. $100^{\circ}C$

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9.4 Cell fixing

The battery should be fixed to the battery pack by its large surface area. No cell movement in the battery pack should be allowed.

9.5 Cells replacement

The cell replacement should be done by professional people.

Prohibit short-circuit between cells' Al package and exterior component.

10. Cell Drawing:

APPENDIX C

LM2577 STEP-UP BOOSTER

www.ti.com

SNOS658D – JUNE 1999 – REVISED APRIL 2013

LM1577/LM2577 SIMPLE SWITCHER® Step-Up Voltage Regulator

Check for Samples: [LM1577](#), [LM2577](#)

FEATURES

- Requires Few External Components
- NPN Output Switches 3.0A, can Stand off 65V
- Wide Input Voltage Range: 3.5V to 40V
- Current-mode Operation for Improved Transient Response, Line Regulation, and Current Limit
- 52 kHz Internal Oscillator
- Soft-start Function Reduces In-rush Current During Start-up
- Output Switch Protected by Current Limit, Under-voltage Lockout, and Thermal Shutdown

TYPICAL APPLICATIONS

- Simple Boost Regulator
- Flyback and Forward Regulators
- Multiple-output Regulator

DESCRIPTION

The LM1577/LM2577 are monolithic integrated circuits that provide all of the power and control functions for step-up (boost), flyback, and forward converter switching regulators. The device is available in three different output voltage versions: 12V, 15V, and adjustable.

Requiring a minimum number of external components, these regulators are cost effective, and simple to use. Listed in this data sheet are a family of standard inductors and flyback transformers designed to work with these switching regulators.

Included on the chip is a 3.0A NPN switch and its associated protection circuitry, consisting of current and thermal limiting, and undervoltage lockout. Other features include a 52 kHz fixed-frequency oscillator that requires no external components, a soft start mode to reduce in-rush current during start-up, and current mode control for improved rejection of input voltage and output load transients.

Connection Diagrams

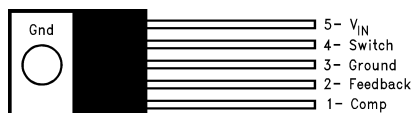


Figure 1. 5-Lead (Straight Leads) TO-220 (T) – Top View
See Package Number KC

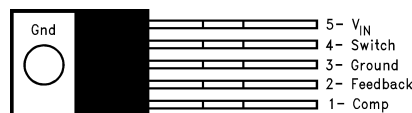


Figure 2. 5-Lead (Bent, Staggered Leads) TO-220 (T) – Top View
See Package Number NDH0005D



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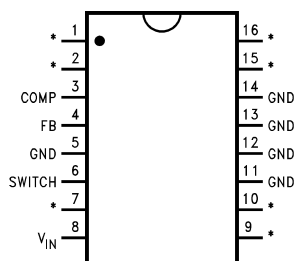
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LM1577, LM2577



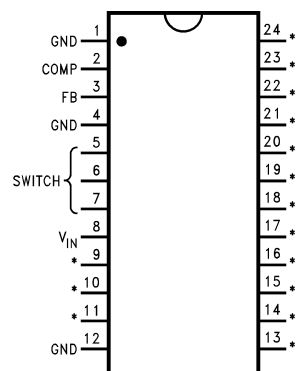
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*No Internal Connection

Figure 3. 16-Lead PDIP (N) – Top View
See Package Number NBG0016G



*No internal Connection

Figure 4. 24-Lead SOIC Package (M) – Top View
See Package Number DW

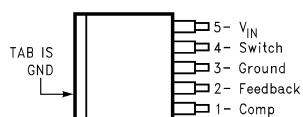


Figure 5. 5-Lead DDPak/TO-263 (S) SFM Package – Top View
See Package Number KTT0005B



Figure 6. 5-Lead DDPak/TO-263 (S) SFM Package – Side View

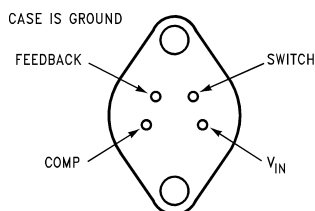
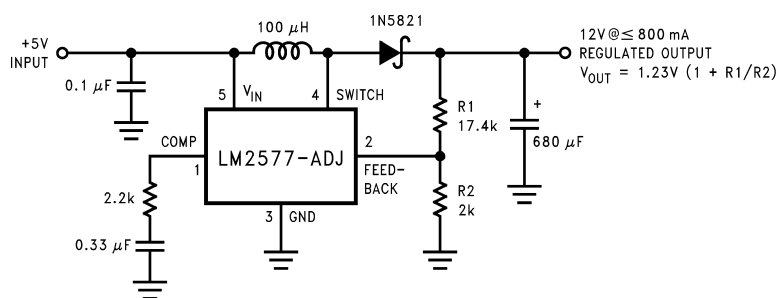


Figure 7. 4-Lead TO-220 (K) – Bottom View
See Package Number NEB0005B

Typical Application



Note: Pin numbers shown are for TO-220 (T) package.



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Absolute Maximum Ratings⁽¹⁾⁽²⁾

Supply Voltage		45V
Output Switch Voltage		65V
Output Switch Current ⁽³⁾		6.0A
Power Dissipation		Internally Limited
Storage Temperature Range		–65°C to +150°C
Lead Temperature	Soldering, 10 sec.	260°C
Maximum Junction Temperature		150°C
Minimum ESD Rating	C = 100 pF, R = 1.5 kΩ	2 kV

- (1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating ratings indicate conditions the device is intended to be functional, but device parameter specifications may not be ensured under these conditions. For ensured specifications and test conditions, see the Electrical Characteristics.
- (2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.
- (3) Due to timing considerations of the LM1577/LM2577 current limit circuit, output current cannot be internally limited when the LM1577/LM2577 is used as a step-up regulator. To prevent damage to the switch, its current must be externally limited to 6.0A. However, output current is internally limited when the LM1577/LM2577 is used as a flyback or forward converter regulator in accordance to the Application Hints.

Operating Ratings

Supply Voltage		$3.5V \leq V_{IN} \leq 40V$
Output Switch Voltage		$0V \leq V_{SWITCH} \leq 60V$
Output Switch Current		$I_{SWITCH} \leq 3.0A$
Junction Temperature Range	LM1577	$-55^{\circ}C \leq T_J \leq +150^{\circ}C$
	LM2577	$-40^{\circ}C \leq T_J \leq +125^{\circ}C$

Electrical Characteristics—LM1577-12, LM2577-12

Specifications with standard type face are for $T_J = 25^{\circ}C$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5V$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-12 Limit ⁽¹⁾⁽²⁾	LM2577-12 Limit ⁽³⁾	Units (Limits)
SYSTEM PARAMETERS Circuit of Figure 29 ⁽⁴⁾						
V_{OUT}	Output Voltage	$V_{IN} = 5V$ to 10V $I_{LOAD} = 100$ mA to 800 mA ⁽¹⁾	12.0			V
				11.60/ 11.40	11.60/ 11.40	V(min)
				12.40/ 12.60	12.40/ 12.60	V(max)
$\frac{\Delta V_{OUT}}{\Delta V_{IN}}$ (1)	Line Regulation	$V_{IN} = 3.5V$ to 10V $I_{LOAD} = 300$ mA	20			mV
				50/ 100	50/ 100	mV(max)
$\frac{\Delta V_{OUT}}{\Delta I_{LOAD}}$ (2)	Load Regulation	$V_{IN} = 5V$ $I_{LOAD} = 100$ mA to 800 mA	20			mV
				50/ 100	50/ 100	mV(max)
η	Efficiency	$V_{IN} = 5V$, $I_{LOAD} = 800$ mA	80			%
DEVICE PARAMETERS						
I_S	Input Supply Current	$V_{FEEDBACK} = 14V$ (Switch Off)	7.5			mA
				10.0/ 14.0	10.0/ 14.0	mA(max)
		$I_{SWITCH} = 2.0A$	25			mA
		$V_{COMP} = 2.0V$ (Max Duty Cycle)		50/ 85	50/ 85	mA(max)

- (1) All limits ensured at room temperature (standard type face) and at temperature extremes (boldface type). All limits are used to calculate Outgoing Quality Level, and are 100% production tested.
- (2) A military RETS electrical test specification is available on request. At the time of printing, the LM1577K-12/883, LM1577K-15/883, and LM1577K-ADJ/883 RETS specifications complied fully with the boldface limits in these columns. The LM1577K-12/883, LM1577K-15/883, and LM1577K-ADJ/883 may also be procured to Standard Military Drawing specifications.
- (3) All limits ensured at room temperature (standard type face) and at temperature extremes (boldface type). All room temperature limits are 100% production tested. All limits at temperature extremes are ensured via correlation using standard Statistical Quality Control (SQC) methods.
- (4) External components such as the diode, inductor, input and output capacitors can affect switching regulator performance. When the LM1577/LM2577 is used as shown in the Test Circuit, system performance will be as specified by the system parameters.

LM1577, LM2577



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Electrical Characteristics—LM1577-12, LM2577-12 (continued)

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5\text{V}$, and $I_{\text{SWITCH}} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-12 Limit ⁽¹⁾⁽²⁾	LM2577-12 Limit ⁽³⁾	Units (Limits)
V_{UV}	Input Supply Undervoltage Lockout	$I_{\text{SWITCH}} = 100\text{ mA}$	2.90			V
				2.70/ 2.65	2.70/ 2.65	V(min)
				3.10/ 3.15	3.10/ 3.15	V(max)
f_o	Oscillator Frequency	Measured at Switch Pin $I_{\text{SWITCH}} = 100\text{ mA}$	52			kHz
				48/ 42	48/ 42	kHz(min)
				56/ 62	56/ 62	kHz(max)
V_{REF}	Output Reference Voltage	Measured at Feedback Pin $V_{IN} = 3.5\text{V to }40\text{V}$ $V_{\text{COMP}} = 1.0\text{V}$				V
			12	11.76/ 11.64	11.76/ 11.64	V(min)
				12.24/ 12.36	12.24/ 12.36	V(max)
$\frac{\Delta V_{\text{REF}}}{\Delta V_{IN}}$	Output Reference Voltage Line Regulator	$V_{IN} = 3.5\text{V to }40\text{V}$	7			mV
R_{FB}	Feedback Pin Input Resistance		9.7			k Ω
G_M	Error Amp Transconductance	$I_{\text{COMP}} = -30\text{ }\mu\text{A to }+30\text{ }\mu\text{A}$ $V_{\text{COMP}} = 1.0\text{V}$	370			μmho
				225/ 145	225/ 145	$\mu\text{mho}(\text{min})$
				515/ 615	515/ 615	$\mu\text{mho}(\text{max})$
A_{VOL}	Error Amp Voltage Gain	$V_{\text{COMP}} = 1.1\text{V to }1.9\text{V}$ $R_{\text{COMP}} = 1.0\text{ M}\Omega^{(5)}$	80			V/V
				50/ 25	50/ 25	V/V(min)
	Error Amplifier Output Swing	Upper Limit $V_{\text{FEEDBACK}} = 10.0\text{V}$	2.4			V
				2.2/ 2.0	2.2/ 2.0	V(min)
		Lower Limit $V_{\text{FEEDBACK}} = 15.0\text{V}$	0.3			V
	Error Amplifier Output Current	$V_{\text{FEEDBACK}} = 10.0\text{V to }15.0\text{V}$ $V_{\text{COMP}} = 1.0\text{V}$		0.40/ 0.55	0.40/ 0.55	V(max)
			± 200			μA
				$\pm 130/\pm 90$	$\pm 130/\pm 90$	$\mu\text{A}(\text{min})$
I_{SS}	Soft Start Current	$V_{\text{FEEDBACK}} = 10.0\text{V}$ $V_{\text{COMP}} = 0\text{V}$		$\pm 300/\pm 400$	$\pm 300/\pm 400$	$\mu\text{A}(\text{max})$
			5.0			μA
				2.5/ 1.5	2.5/ 1.5	$\mu\text{A}(\text{min})$
D	Maximum Duty Cycle	$V_{\text{COMP}} = 1.5\text{V}$ $I_{\text{SWITCH}} = 100\text{ mA}$		7.5/ 9.5	7.5/ 9.5	$\mu\text{A}(\text{max})$
			95			%
				93/ 90	93/ 90	%(min)
$\frac{\Delta I_{\text{SWITCH}}}{\Delta V_{\text{COMP}}}$	Switch Transconductance		12.5			A/V
I_L	Switch Leakage Current	$V_{\text{SWITCH}} = 65\text{V}$ $V_{\text{FEEDBACK}} = 15\text{V (Switch Off)}$	10			μA
				300/ 600	300/ 600	$\mu\text{A}(\text{max})$
V_{SAT}	Switch Saturation Voltage	$I_{\text{SWITCH}} = 2.0\text{A}$ $V_{\text{COMP}} = 2.0\text{V (Max Duty Cycle)}$	0.5			V
				0.7/ 0.9	0.7/ 0.9	V(max)
	NPN Switch Current Limit		4.5			A
				3.7/ 3.0	3.7/ 3.0	A(min)
				5.3/ 6.0	5.3/ 6.0	A(max)

- (5) A 1.0 M Ω resistor is connected to the compensation pin (which is the error amplifier's output) to ensure accuracy in measuring A_{VOL} . In actual applications, this pin's load resistance should be $\geq 10\text{ M}\Omega$, resulting in A_{VOL} that is typically twice the ensured minimum limit.

Electrical Characteristics—LM1577-15, LM2577-15

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5\text{V}$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-15 Limit ⁽¹⁾⁽²⁾	LM2577-15 Limit ⁽³⁾	Units (Limits)
SYSTEM PARAMETERS Circuit of Figure 30 ⁽⁴⁾						
V_{OUT}	Output Voltage	$V_{IN} = 5\text{V to }12\text{V}$ $I_{LOAD} = 100\text{ mA to }600\text{ mA}$ (1)	15.0			V
				14.50/ 14.25	14.50/ 14.25	V(min)
				15.50/ 15.75	15.50/ 15.75	V(max)
$\frac{\Delta V_{OUT}}{\Delta V_{IN}}$	Line Regulation	$V_{IN} = 3.5\text{V to }12\text{V}$ $I_{LOAD} = 300\text{ mA}$	20	50/ 100	50/ 100	mV mV(max)
$\frac{\Delta V_{OUT}}{\Delta I_{LOAD}}$	Load Regulation	$V_{IN} = 5\text{V}$ $I_{LOAD} = 100\text{ mA to }600\text{ mA}$	20	50/ 100	50/ 100	mV mV(max)
η	Efficiency	$V_{IN} = 5\text{V}$, $I_{LOAD} = 600\text{ mA}$	80			%
DEVICE PARAMETERS						
I_S	Input Supply Current	$V_{FEEDBACK} = 18.0\text{V}$ (Switch Off)	7.5			mA
				10.0/ 14.0	10.0/ 14.0	mA(max)
		$I_{SWITCH} = 2.0\text{A}$ $V_{COMP} = 2.0\text{V}$ (Max Duty Cycle)	25			mA
				50/ 85	50/ 85	mA(max)
V_{UV}	Input Supply Undervoltage Lockout	$I_{SWITCH} = 100\text{ mA}$	2.90			V
				2.70/ 2.65	2.70/ 2.65	V(min)
				3.10/ 3.15	3.10/ 3.15	V(max)
f_O	Oscillator Frequency	Measured at Switch Pin $I_{SWITCH} = 100\text{ mA}$	52			kHz
				48/ 42	48/ 42	kHz(min)
				56/ 62	56/ 62	kHz(max)
V_{REF}	Output Reference Voltage	Measured at Feedback Pin $V_{IN} = 3.5\text{V to }40\text{V}$ $V_{COMP} = 1.0\text{V}$				V
			15	14.70/ 14.55	14.70/ 14.55	V(min)
				15.30/ 15.45	15.30/ 15.45	V(max)
$\frac{\Delta V_{REF}}{\Delta V_{IN}}$	Output Reference Voltage Line Regulation	$V_{IN} = 3.5\text{V to }40\text{V}$	10			mV
R_{FB}	Feedback Pin Input Voltage Line Regulator		12.2			k Ω
G_M	Error Amp Transconductance	$I_{COMP} = -30\text{ }\mu\text{A to }+30\text{ }\mu\text{A}$ $V_{COMP} = 1.0\text{V}$	300			μmho
				170/ 110	170/ 110	$\mu\text{mho(min)}$
				420/ 500	420/ 500	$\mu\text{mho(max)}$
A_{VOL}	Error Amp Voltage Gain	$V_{COMP} = 1.1\text{V to }1.9\text{V}$ $R_{COMP} = 1.0\text{ M}\Omega$ ⁽⁵⁾	65			V/V
				40/ 20	40/ 20	V/V(min)

- (1) All limits ensured at room temperature (standard type face) and at temperature extremes (boldface type). All limits are used to calculate Outgoing Quality Level, and are 100% production tested.
- (2) A military RETS electrical test specification is available on request. At the time of printing, the LM1577K-12/883, LM1577K-15/883, and LM1577K-ADJ/883 RETS specifications complied fully with the boldface limits in these columns. The LM1577K-12/883, LM1577K-15/883, and LM1577K-ADJ/883 may also be procured to Standard Military Drawing specifications.
- (3) All limits ensured at room temperature (standard type face) and at temperature extremes (boldface type). All room temperature limits are 100% production tested. All limits at temperature extremes are ensured via correlation using standard Statistical Quality Control (SQC) methods.
- (4) External components such as the diode, inductor, input and output capacitors can affect switching regulator performance. When the LM1577/LM2577 is used as shown in the Test Circuit, system performance will be as specified by the system parameters.
- (5) A 1.0 M Ω resistor is connected to the compensation pin (which is the error amplifier's output) to ensure accuracy in measuring A_{VOL} . In actual applications, this pin's load resistance should be $\geq 10\text{ M}\Omega$, resulting in A_{VOL} that is typically twice the ensured minimum limit.

LM1577, LM2577



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Electrical Characteristics—LM1577-15, LM2577-15 (continued)

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5\text{V}$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-15 Limit ⁽¹⁾⁽²⁾	LM2577-15 Limit ⁽³⁾	Units (Limits)
	Error Amplifier Output Swing	Upper Limit $V_{FEEDBACK} = 12.0\text{V}$	2.4			V
				2.2/ 2.0	2.2/ 2.0	V(min)
		Lower Limit $V_{FEEDBACK} = 18.0\text{V}$	0.3			V
				0.4/ 0.55	0.40/ 0.55	V(max)
	Error Amp Output Current	$V_{FEEDBACK} = 12.0\text{V}$ to 18.0V $V_{COMP} = 1.0\text{V}$	± 200			μA
				$\pm 130/\pm 90$	$\pm 130/\pm 90$	$\mu\text{A}(\text{min})$
				$\pm 300/\pm 400$	$\pm 300/\pm 400$	$\mu\text{A}(\text{max})$
I_{SS}	Soft Start Current	$V_{FEEDBACK} = 12.0\text{V}$ $V_{COMP} = 0\text{V}$	5.0			μA
				2.5/ 1.5	2.5/ 1.5	$\mu\text{A}(\text{min})$
				7.5/ 9.5	7.5/ 9.5	$\mu\text{A}(\text{max})$
D	Maximum Duty Cycle	$V_{COMP} = 1.5\text{V}$ $I_{SWITCH} = 100\text{ mA}$	95			%
				93/ 90	93/ 90	%(min)
$\frac{\Delta I_{SWITCH}}{\Delta V_{COMP}}$	Switch Transconductance		12.5			A/V
I_L	Switch Leakage Current	$V_{SWITCH} = 65\text{V}$ $V_{FEEDBACK} = 18.0\text{V}$ (Switch Off)	10			μA
				300/ 600	300/ 600	$\mu\text{A}(\text{max})$
V_{SAT}	Switch Saturation Voltage	$I_{SWITCH} = 2.0\text{A}$ $V_{COMP} = 2.0\text{V}$ (Max Duty Cycle)	0.5			V
				0.7/ 0.9	0.7/ 0.9	V(max)
	NPN Switch Current Limit	$V_{COMP} = 2.0\text{V}$	4.3			A
				3.7/ 3.0	3.7/ 3.0	A(min)
				5.3/ 6.0	5.3/ 6.0	A(max)

Electrical Characteristics—LM1577-ADJ, LM2577-ADJ

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5\text{V}$, $V_{FEEDBACK} = V_{REF}$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-ADJ Limit ⁽¹⁾⁽²⁾	LM2577-ADJ Limit ⁽³⁾	Units (Limits)
SYSTEM PARAMETERS Circuit of Figure 31 ⁽⁴⁾						
V_{OUT}	Output Voltage	$V_{IN} = 5\text{V to } 10\text{V}$ $I_{LOAD} = 100\text{ mA to } 800\text{ mA}$ ⁽¹⁾	12.0			V
				11.60/ 11.40	11.60/ 11.40	V(min)
				12.40/ 12.60	12.40/ 12.60	V(max)
$\Delta V_{OUT}/\Delta V_{IN}$	Line Regulation	$V_{IN} = 3.5\text{V to } 10\text{V}$ $I_{LOAD} = 300\text{ mA}$	20			mV
				50/ 100	50/ 100	mV(max)
$\Delta V_{OUT}/\Delta I_{LOAD}$	Load Regulation	$V_{IN} = 5\text{V}$ $I_{LOAD} = 100\text{ mA to } 800\text{ mA}$	20			mV
				50/ 100	50/ 100	mV(max)
η	Efficiency	$V_{IN} = 5\text{V}$, $I_{LOAD} = 800\text{ mA}$	80			%
DEVICE PARAMETERS						
I_S	Input Supply Current	$V_{FEEDBACK} = 1.5\text{V}$ (Switch Off)	7.5			mA
				10.0/ 14.0	10.0/ 14.0	mA(max)
		$I_{SWITCH} = 2.0\text{A}$ $V_{COMP} = 2.0\text{V}$ (Max Duty Cycle)	25			mA
V_{UV}	Input Supply Undervoltage Lockout	$I_{SWITCH} = 100\text{ mA}$		50/ 85	50/ 85	mA(max)
			2.90			V
				2.70/ 2.65	2.70/ 2.65	V(min)
f_O	Oscillator Frequency	Measured at Switch Pin $I_{SWITCH} = 100\text{ mA}$		3.10/ 3.15	3.10/ 3.15	V(max)
			52			kHz
				48/ 42	48/ 42	kHz(min)
V_{REF}	Reference Voltage	Measured at Feedback Pin $V_{IN} = 3.5\text{V to } 40\text{V}$ $V_{COMP} = 1.0\text{V}$		56/ 62	56/ 62	kHz(max)
						V
			1.230	1.214/ 1.206	1.214/ 1.206	V(min)
$\Delta V_{REF}/\Delta V_{IN}$	Reference Voltage Line Regulation	$V_{IN} = 3.5\text{V to } 40\text{V}$		1.246/ 1.254	1.246/ 1.254	V(max)
			0.5			mV
I_B	Error Amp Input Bias Current	$V_{COMP} = 1.0\text{V}$	100			nA
				300/ 800	300/ 800	nA(max)
G_M	Error Amp Transconductance	$I_{COMP} = -30\text{ }\mu\text{A to } +30\text{ }\mu\text{A}$ $V_{COMP} = 1.0\text{V}$	3700			μmho
				2400/ 1600	2400/ 1600	μmho (min)
				4800/ 5800	4800/ 5800	μmho (max)
A_{VOL}	Error Amp Voltage Gain	$V_{COMP} = 1.1\text{V to } 1.9\text{V}$ $R_{COMP} = 1.0\text{ M}\Omega$ ⁽⁵⁾	800			V/V
				500/ 250	500/ 250	V/V(min)
	Error Amplifier Output Swing	Upper Limit $V_{FEEDBACK} = 1.0\text{V}$	2.4			V
				2.2/ 2.0	2.2/ 2.0	V(min)
		Lower Limit $V_{FEEDBACK} = 1.5\text{V}$	0.3			V
				0.40/ 0.55	0.40/ 0.55	V(max)

- (1) All limits ensured at room temperature (standard type face) and at temperature extremes (boldface type). All limits are used to calculate Outgoing Quality Level, and are 100% production tested.
- (2) A military RETS electrical test specification is available on request. At the time of printing, the LM1577K-12/883, LM1577K-15/883, and LM1577K-ADJ/883 RETS specifications complied fully with the boldface limits in these columns. The LM1577K-12/883, LM1577K-15/883, and LM1577K-ADJ/883 may also be procured to Standard Military Drawing specifications.
- (3) All limits ensured at room temperature (standard type face) and at temperature extremes (boldface type). All room temperature limits are 100% production tested. All limits at temperature extremes are ensured via correlation using standard Statistical Quality Control (SQC) methods.
- (4) External components such as the diode, inductor, input and output capacitors can affect switching regulator performance. When the LM1577/LM2577 is used as shown in the Test Circuit, system performance will be as specified by the system parameters.
- (5) A 1.0 M Ω resistor is connected to the compensation pin (which is the error amplifier's output) to ensure accuracy in measuring A_{VOL} . In actual applications, this pin's load resistance should be $\geq 10\text{ M}\Omega$, resulting in A_{VOL} that is typically twice the ensured minimum limit.

LM1577, LM2577



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Electrical Characteristics—LM1577-ADJ, LM2577-ADJ (continued)

Specifications with standard type face are for $T_J = 25^\circ\text{C}$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5\text{V}$, $V_{FEEDBACK} = V_{REF}$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-ADJ Limit ⁽¹⁾⁽²⁾	LM2577-ADJ Limit ⁽³⁾	Units (Limits)
	Error Amp Output Current	V _{FEEDBACK} = 1.0V to 1.5V V _{COMP} = 1.0V	±200			μA
				±130/ ±90	±130/ ±90	μA(min)
				±300/ ±400	±300/ ±400	μA(max)
I _{SS}	Soft Start Current	V _{FEEDBACK} = 1.0V V _{COMP} = 0V	5.0			μA
				2.5/ 1.5	2.5/ 1.5	μA(min)
				7.5/ 9.5	7.5/ 9.5	μA(max)
D	Maximum Duty Cycle	V _{COMP} = 1.5V I _{SWITCH} = 100 mA	95			%
				93/ 90	93/ 90	%(min)
ΔI _{SWITCH} /ΔV _{C OMP}	Switch Transconductance		12.5			A/V
I _L	Switch Leakage Current	V _{SWITCH} = 65V V _{FEEDBACK} = 1.5V (Switch Off)	10			μA
				300/ 600	300/ 600	μA(max)
V _{SAT}	Switch Saturation Voltage	I _{SWITCH} = 2.0A V _{COMP} = 2.0V (Max Duty Cycle)	0.5			V
				0.7/ 0.9	0.7/ 0.9	V(max)
	NPN Switch Current Limit	V _{COMP} = 2.0V	4.3			A
				3.7/ 3.0	3.7/ 3.0	A(min)
				5.3/ 6.0	5.3/ 6.0	A(max)
THERMAL PARAMETERS (All Versions)						
θ _{JA} θ _{JC}	Thermal Resistance	K Package, Junction to Ambient K Package, Junction to Case	35 1.5			°C/W
θ _{JA} θ _{JC}		T Package, Junction to Ambient T Package, Junction to Case	65 2			
θ _{JA}		N Package, Junction to Ambient ⁽⁶⁾	85			
θ _{JA}		M Package, Junction to Ambient ⁽⁶⁾	100			
θ _{JA}		S Package, Junction to Ambient ⁽⁷⁾	37			

- (6) Junction to ambient thermal resistance with approximately 1 square inch of pc board copper surrounding the leads. Additional copper area will lower thermal resistance further. See thermal model in "Switchers Made Simple" software.
- (7) If the DDPK/TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package. Using 0.5 square inches of copper area, θ_{JA} is 50°C/W ; with 1 square inch of copper area, θ_{JA} is 37°C/W ; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W .

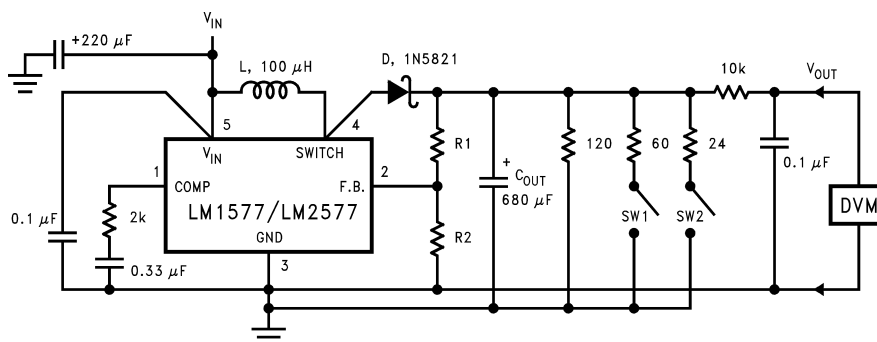
LM1577, LM2577



SNOS658D – JUNE 1999 – REVISED APRIL 2013

www.ti.com

LM1577-ADJ, LM2577-ADJ Test Circuit



L = 415-0930 (AIE)

D = any manufacturer

C_{OUT} = Sprague Type 673D

Electrolytic 680 μF, 20V

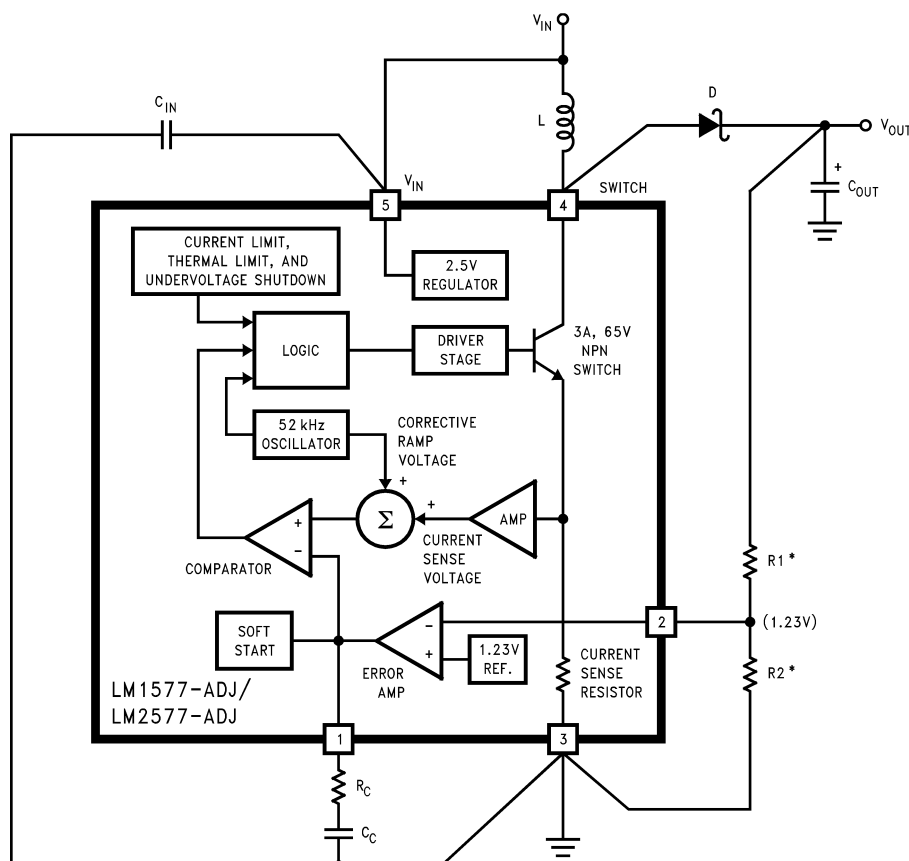
R1 = 48.7k in series with 511Ω (1%)

R2 = 5.62k (1%)

Note: Pin numbers shown are for TO-220 (T) package

Figure 31. Circuit Used to Specify System Parameters for ADJ Versions

Application Hints

**Note:** Pin numbers shown are for TO-220 (T) package

*Resistors are internal to LM1577/LM2577 for 12V and 15V versions.

Figure 32. LM1577/LM2577 Block Diagram and Boost Regulator Application

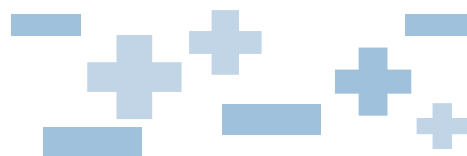
APPENDIX D

FIAMM LEAD ACID BATTERY



Model	VdS	Nominal voltage (V)	Capacity (Ah)				Weight (kg)	Dimensions (mm)				Temp. (°C)			TP*	Terminal Type
			Discharge 20 h rate 1.75V/cell	Discharge 10 h rate 1.75V/cell	Discharge 5 h rate 1.70V/cell	Discharge 1.5 h rate 1.60V/cell		L	W	H	TH*	Charge	Discharge	Storage		
FG10121		6	1.2	1.08	1.00	0.78	0.28	97	24	52	59	0 ÷ 40	-20 ÷ 50	-20 ÷ 50	2	Faston 4.8
FG10301	•	6	3.0	2.7	2.55	1.95	0.62	134	34	60	67				2	Faston 4.8
FG10381		6	3.8	2.88	2.72	2.08	0.60	66	33	118	125				7	Faston 4.8
FG10451		6	4.5	3.6	3.4	2.6	0.74	70	47	100	106				1	Faston 4.8
FG10721		6	7.2	6.3	5.95	4.55	1.15	151	34	94	100				2	Faston 4.8
FG11201/2	•	6	12	10.8	9.6	7.5	1.76	151	50	93	99				2	Faston 4.8 / 6.3
FG20086		12	0.8	0.72	0.63	0.53	0.33	96	25	62	62	0 ÷ 40	-20 ÷ 50	-20 ÷ 50	5	Wire+Connector
FG20121	•	12	1.2	1.06	0.98	0.8	0.57	97	49	51	57				4	Faston 4.8
FG20121A		12	1.2	1.08	1.0	0.78	0.52	97	43	52	59				4	Faston 4.8
FG20201	•	12	2.0	1.83	1.65	1.37	0.80	178	35	60	67				2	Faston 4.8
FG20271		12	2.7	2.43	2.25	1.76	1.06	79	56	99	105				3	Faston 4.8
FG20341		12	3.4	3.0	2.9	2.2	1.24	134	67	60	67				4	Faston 4.8
FG20451		12	4.5	4.1	3.8	3.0	1.48	90	70	101	107				3	Faston 4.8
FG20721/2	•	12	7.2	6.7	6.0	5.0	2.43	151	65	94	100				4	Faston 4.8 / 6.3
FG21201/2	•	12	12	11.3	10	8.4	3.73	151	98	95	100				4	Faston 4.8 / 6.3
FG21703	•	12	17	15.5	13.9	11.2	5.90	181	76	167	167				6	Flag Ø5.5
FG21803		12	18	16.9	15	12.7	5.80	181	76	167	167				6	Flag Ø5.5
FG22703	•	12	27	24.4	22.1	18.4	9.00	166	175	125	125	0 ÷ 40	-20 ÷ 50	-20 ÷ 50	6	Flag Ø5.5
FG24204	•	12	42	37.9	34.4	28.5	13.8	197	165	170	170				6	Flag Ø6.5
FG27004	•	12	70	64.4	58.5	47.4	22.6	350	166	174	174				6	Flag Ø6.5

*TH = total height including terminals



Constant Current discharge table (Amperes)

Final Voltage: 9.9 V - Temperature: 25°C

Model	5 min	10 min	15 min	20 min	30 min	45 min	1 hour	2 hours	3 hours	5 hours	10 hours	20 hours
FG20451	14.4	10.1	7.61	6.13	4.33	3.15	2.50	1.50	1.10	0.74	0.42	0.23
FG20721	27.1	18.3	13.8	11.1	8.11	5.91	4.73	2.66	1.88	1.21	0.67	0.37
FG20722	30.1	21.2	16.2	12.8	9.13	6.41	4.97	2.67	1.88	1.21	0.67	0.37
FG21201/2	38.0	26.9	20.7	16.7	12.5	9.21	7.42	4.23	3.14	2.02	1.12	0.62
FG21803	58.3	39.3	29.7	24.1	17.9	13.3	10.8	6.28	4.61	3.06	1.70	0.93
FG22703	84.5	60.6	47.7	39.4	28.7	21.1	17.6	9.68	6.93	4.54	2.53	1.39
FG24204	146	101	76.5	62.7	46.9	34.0	26.7	14.6	10.5	6.97	3.87	2.16
FG27004	224	164	126	102	76.1	55.5	43.6	24.5	17.7	11.7	6.49	3.58

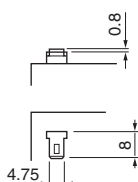
Constant Power discharge table (Watts per bloc)

Final Voltage: 9.9 V - Temperature: 25°C

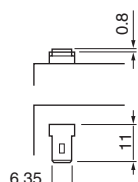
Model	5 min	10 min	15 min	20 min	30 min	45 min	1 hour	2 hours	3 hours	5 hours	10 hours	20 hours
FG20451	145	106	80.8	66.1	47.5	35.2	28.2	17.1	12.7	8.65	4.90	2.71
FG20721	272	189	146	119	88.8	65.9	53.3	30.5	21.7	14.1	7.84	4.34
FG20722	302	219	170	138	99.9	71.5	56.1	30.5	21.7	14.1	7.84	4.34
FG21201/2	382	278	218	179	137	103	83.8	48.4	36.2	23.4	13.1	7.23
FG21803	585	406	313	258	196	148	122	71.8	53.1	35.5	19.8	10.9
FG22703	848	626	503	423	314	235	199	111	79.9	52.7	29.4	16.3
FG24204	1469	1040	806	673	513	379	301	167	121	81.0	45.1	25.2
FG27004	2250	1688	1322	1100	833	619	492	281	204	136	75.6	41.8

Terminal Type

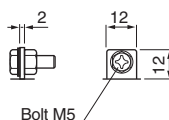
■ Faston 4.8



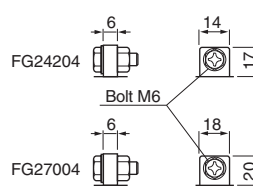
■ Faston 6.3



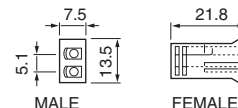
■ Flag Ø5.5



■ Flag Ø6.5



■ Wire+Connector



Technical Features

- **Grids:** gravity casted grids with high purity lead calcium tin alloy
- **Separators:** electrolyte fully absorbed in glass mat "AGM" separators with extremely high micro porosity
- **Terminal posts:** faston, wire+connector or flag depending on the model
- **Post seals:** high integrity post seal design prevents acid leakage over a wide temperature range
- **One-way safety valves** allow excess gas to escape when overcharging
- **Container and cover:** made of thick walled ABS plastics, designed for unsurpassed mechanical strength
- **Shelf life:** < 2% self-discharge per month at 20°C allows 6 months shelf life

Applicable Standards

- IEC 60896 Part 21 - VRLA methods of testing
- IEC 60896 Part 22 - VRLA requirements
- UL Recognized
- Eurobat "Standard Commercial" - 3-5 years

FIAMM Manufacturing

- ISO 9001 - Quality Management System
- ISO 14001 - Environmental Management System
- OHSAS 18001 - Workplace Safety & Health

APPENDIX E

IRF 630 MOSFET



IRF630 IRF630FP

N-channel 200V - 0.35Ω - 9A TO-220/TO-220FP
Mesh overlay™ II Power MOSFET

General features

Type	V _{DSS}	R _{DS(on)}	I _D
IRF630	200V	<0.40Ω	9A
IRF630FP	200V	<0.40Ω	9A

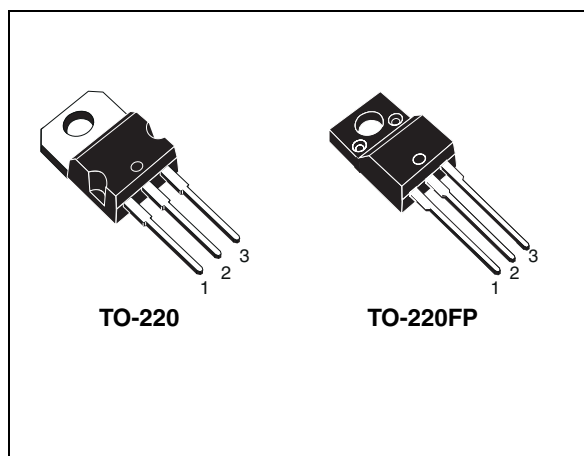
- Extremely high dv/dt capability
- Very low intrinsic capacitances
- Gate charge minimized

Description

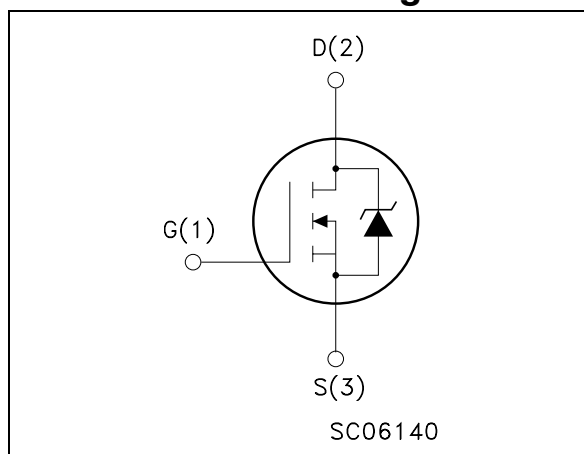
This power MOSFET is designed using the company's consolidated strip layout-based MESH OVERLAY™ process. This technology matches and improves the performances compared with standard parts from various sources.

Applications

- Switching application



Internal schematic diagram



1 Electrical ratings

Table 1. Absolute maximum ratings

Symbol	Parameter	Value		Unit
		TO-220	TO-220FP	
V _{DS}	Drain-source voltage (V _{GS} = 0)	200		V
V _{DGR}	Drain-gate voltage (R _{GS} = 20 kΩ)	200		V
V _{GS}	Gate-source voltage	± 20		V
I _D	Drain current (continuous) at T _C = 25°C	9	9 ⁽¹⁾	A
I _D	Drain current (continuous) at T _C =100°C	5.7	5.7 ⁽¹⁾	A
I _{DM} ⁽²⁾	Drain current (pulsed)	36	36 ⁽¹⁾	A
P _{TOT}	Total dissipation at T _C = 25°C	75	30	W
	Derating factor	0.6	0.24	W/°C
dv/dt ⁽³⁾	Peak diode recovery voltage slope	5		V/ns
V _{ISO}	Insulation winthstand voltage (DC)	--	2000	V
T _J T _{stg}	Operating junction temperature Storage temperature	-65 to 150 150		°C

1. Limited only by maximum temperature allowed
2. Pulse width limited by safe operating area
3. $ISD \geq 9\text{A}$, $di/dt \leq 300\text{A}/\mu\text{s}$, $V_{DD} \leq V(BR)DSS$, $T_J \leq T_{JMAX}$

Table 2. Thermal data

Symbol	Parameter	Value		Unit
		TO-220	TO-220FP	
$R_{thj-case}$	Thermal resistance junction-case Max	1.67	4.17	$^\circ\text{C}/\text{W}$
R_{thj-a}	Thermal resistance junction-ambient Max	62.5		$^\circ\text{C}/\text{W}$
$R_{thc-sink}$	Thermal resistance case-sink typ	0.5		$^\circ\text{C}/\text{W}$
T_l	Maximum lead temperature for soldering purpose	300		$^\circ\text{C}$

Table 3. Avalanche characteristics

Symbol	Parameter	Value	Unit
I_{AR}	Avalanche current, repetitive or not-repetitive (pulse width limited by T_J Max)	9	A
E_{AS}	Single pulse avalanche energy (starting $T_J = 25^\circ\text{C}$, $I_d = I_{AR}$, $V_{dd} = 50\text{V}$)	160	mJ

2 Electrical characteristics

($T_{CASE}=25^{\circ}\text{C}$ unless otherwise specified)

Table 4. On/off states

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source breakdown voltage	$I_D = 250\ \mu\text{A}$, $V_{GS} = 0$	200			V
I_{DSS}	Zero gate voltage drain current ($V_{GS} = 0$)	$V_{DS} = \text{Max rating}$, $V_{DS} = \text{Max rating @ } 125^{\circ}\text{C}$			1 50	μA μA
I_{GSS}	Gate body leakage current ($V_{DS} = 0$)	$V_{GS} = \pm 20\text{V}$			± 100	nA
$V_{GS(th)}$	Gate threshold voltage	$V_{DS} = V_{GS}$, $I_D = 250\ \mu\text{A}$	2	3	4	V
$R_{DS(on)}$	Static drain-source on resistance	$V_{GS} = 10\text{V}$, $I_D = 4.5\text{A}$		0.35	0.40	Ω

Table 5. Dynamic

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$g_{fs}^{(1)}$	Forward transconductance	$V_{DS} > I_{D(on)} \times R_{DS(on)max}$, $I_D = 4.5\text{A}$	3	4		S
C_{iss} C_{oss} C_{rss}	Input capacitance Output capacitance Reverse transfer capacitance	$V_{DS} = 25\text{V}$, $f = 1\text{ MHz}$, $V_{GS} = 0$		540 90 35	700 120 50	pF pF pF
$t_{d(on)}$ t_r	Turn-on Delay Time Rise Time	$V_{DD} = 100\text{V}$, $I_D = 4.5\text{A}$, $R_G = 4.7\Omega$, $V_{GS} = 10\text{V}$ (see Figure 14)		10 15	14 20	ns ns
Q_g Q_{gs} Q_{gd}	Total gate charge Gate-source charge Gate-drain charge	$V_{DD} = 160\text{V}$, $I_D = 9\text{A}$ $V_{GS} = 10\text{V}$		31 7.5 9	45	nC nC nC

1. Pulsed: pulse duration=300 μs , duty cycle 1.5%

Table 6. Source drain diode

Symbol	Parameter	Test conditions	Min	Typ.	Max	Unit
I_{SD}	Source-drain current				9	A
$I_{SDM}^{(1)}$	Source-drain current (pulsed)				36	A
$V_{SD}^{(2)}$	Forward on voltage	$I_{SD}=9A$, $V_{GS}=0$			1.5	V
t_{rr} Q_{rr} I_{RRM}	Reverse recovery time Reverse recovery charge Reverse recovery current	$I_{SD}=9A$, $di/dt = 100A/\mu s$, $V_{DD}=50V$, $T_J=150^\circ C$ (see Figure 16)		170 0.95 11		ns μC A

1. Pulse width limited by safe operating area
2. Pulsed: pulse duration=300 μs , duty cycle 1.5%

3 Test circuit

Figure 14. Switching times test circuit for resistive load

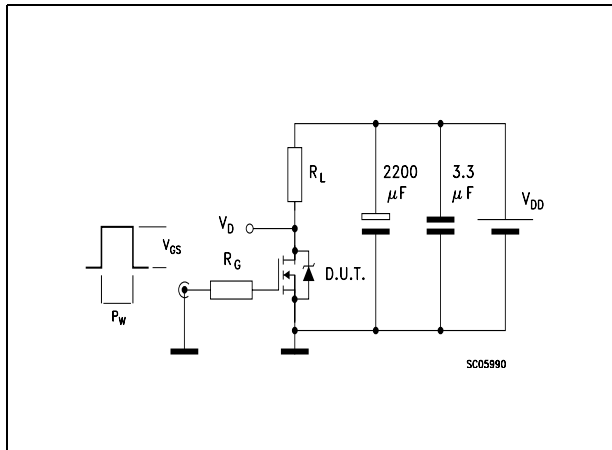


Figure 15. Gate charge test circuit

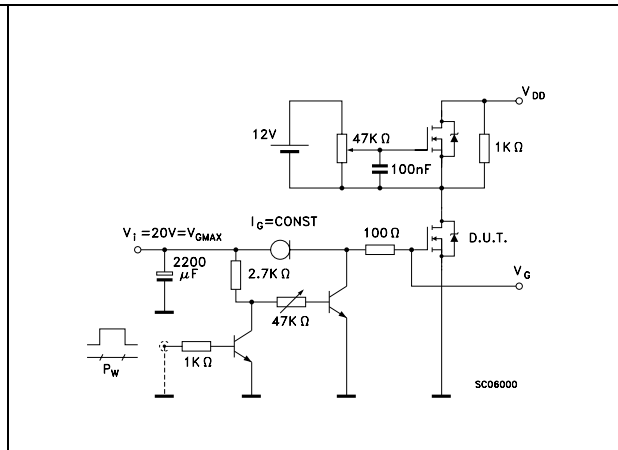


Figure 16. Test circuit for inductive load switching and diode recovery times

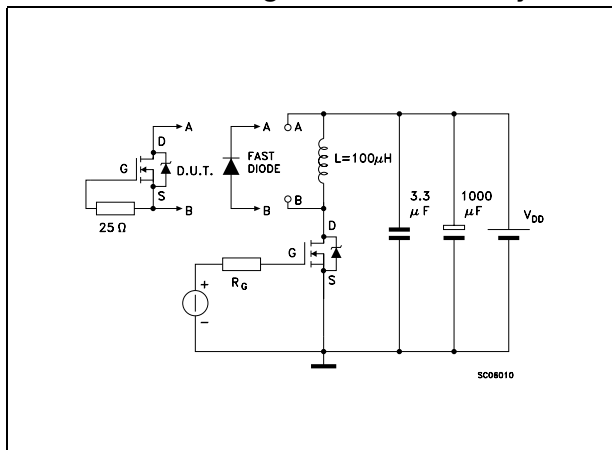


Figure 17. Unclamped Inductive load test circuit

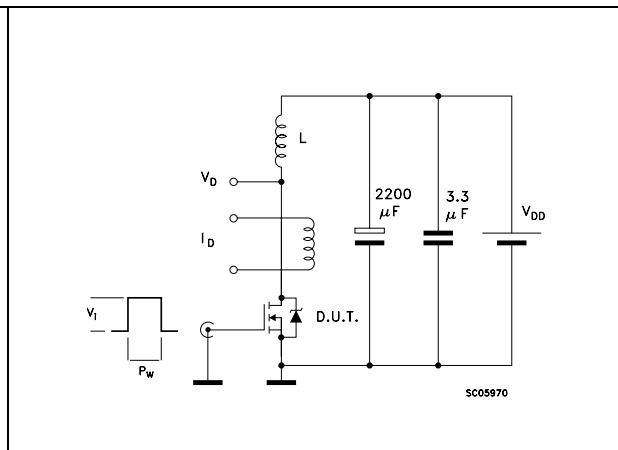


Figure 18. Unclamped inductive waveform

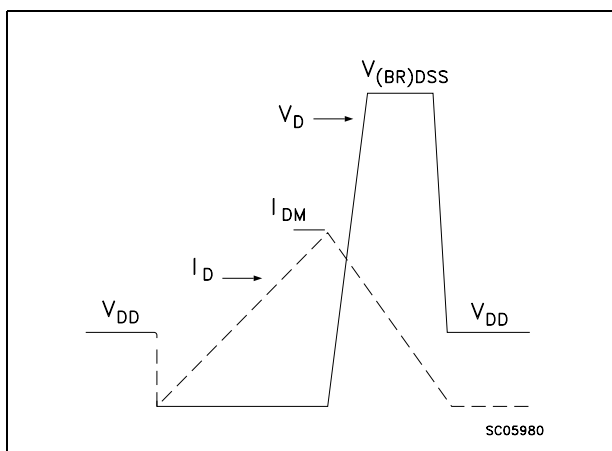
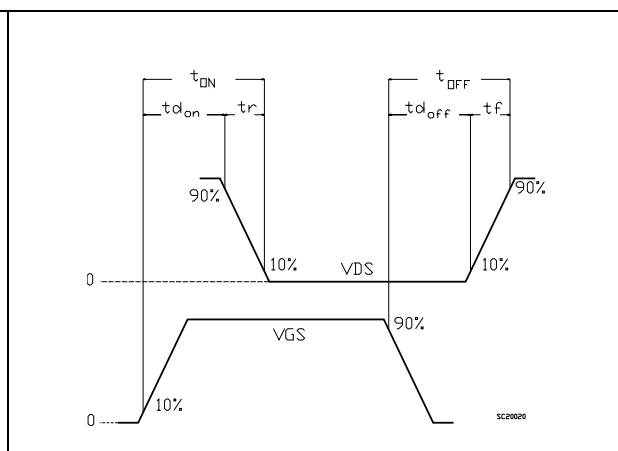


Figure 19. Switching time waveform



APPENDIX F

1N400X DIODES



1N4001 THRU 1N4007

1.0 AMP SILICON RECTIFIERS

FEATURES

- * The plastic package carries Underwriters Laboratory Flammability Classification 94V-0
- * Low cost construction utilizing void-free molded plastic technique
- * Diffused junction
- * Low reverse leakage
- * High current capability
- * Easily cleaned with Freon, Alcohol, Chlorothen, and similar solvents
- * High temperature soldering guaranteed :
265°C/10 seconds/.375" (9.5mm) lead lengths at 5 lbs (2.3kg) tension

MECHANICAL DATA

- * Case: Molded plastic
- * Polarity: Color band denotes cathode end
- * Lead: Plated axial lead, solderable per MIL-STD-202E method 208C
- * Mounting position: Any
- * Weight: 0.012 ounce, 0.3 gram

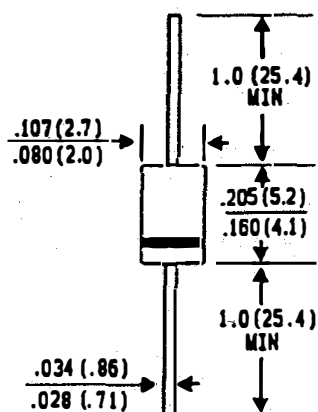
VOLTAGE RANGE

50 to 1000 Volts

CURRENT

1.0 Ampere

DO-41



Dimensions in inches and (millimeters)

MAXIMUM RATINGS AND ELECTRICAL CHARACTERISTICS

Ratings at 25°C ambient temperature unless otherwise specified.

Single phase, half wave, 60 Hz, resistive or inductive load.

For capacitive load derate current by 20%.

	SYMBOLS	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	UNITS
Maximum Recurrent Peak Reverse Voltage	V _{rrm}	50	100	200	400	600	800	1000	V
Maximum RMS Voltage	V _{rms}	35	70	140	280	420	560	700	V
Maximum DC Blocking Voltage	V _{dc}	50	100	200	400	600	800	1000	V
Maximum Average Forward Rectified Current .375" (9.5mm) lead length at TA=75°C	I(AV)	1.0							A
Peak Forward Surge Current 8.3 ms single half sine wave superimposed on rated load (JEDEC method)	I _{fsm}	30							A
Maximum instantaneous Forward Voltage at 1.0A DC	V _F	1.1							V
Maximum Reverse Current at Rated DC @TA=25°C	I _R	5.0							uA
Blocking Voltage per element @TA=100°C	HTIR	50							uA
Maximum DC Reverse Current Average, Full cycle .375" (9.5mm) lead length at TL=75°C	HTIR	30							uA
Typical Junction Capacitance (Note1)	C _J	30							pf
Typical Thermal Resistance (Note2)	R _{THja}	50							°C/W
Operating and Storage Temperature Range	T _j , T _{stg}	-65 TO +175							°C

NOTES:

1. Measured at 1.0 MHz and applied reverse voltage of 4.0 Volts.
2. Thermal Resistance from Junction to Ambient at .375" (9.5mm) lead length, P.C. board mounted.

RATINGS AND CHARACTERISTIC CURVES 1N4001 THRU 1N4007

FIG. 1 — FORWARD CURRENT DERATING CURVE

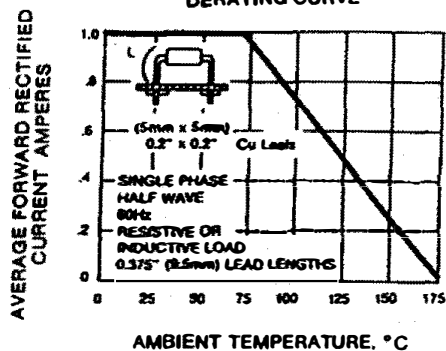


FIG. 2 — TYPICAL FORWARD CHARACTERISTICS

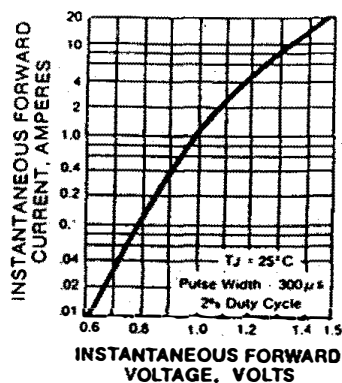


FIG. 3 — MAXIMUM NON-REPETITIVE PEAK FORWARD SURGE CURRENT

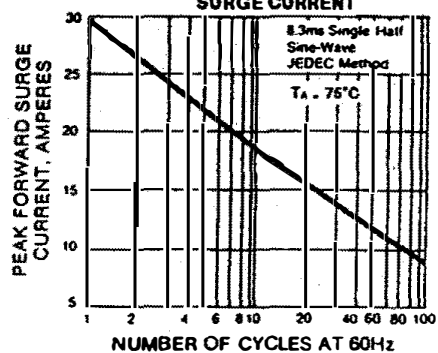


FIG. 4 — PEAK FORWARD SURGE CURRENT

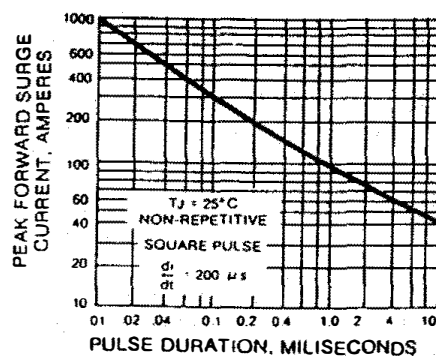


FIG. 5 — TYPICAL JUNCTION CAPACITANCE

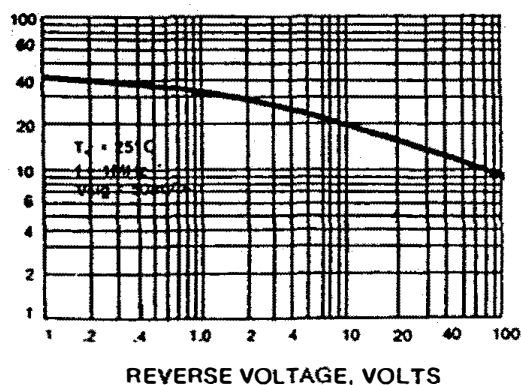
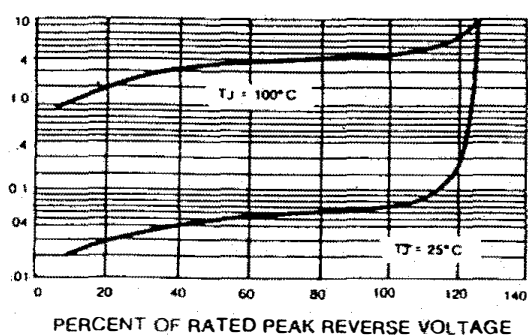


FIG. 6 — TYPICAL REVERSE CHARACTERISTICS



APPENDIX G

COMPLETE CIRCUIT DIAGRAM

