PV SOLAR – WIRELESS ENERGY SOURCE

Project Team

Amjad M Shalaldeh Mohamad S. abu Samra

Project Supervisors

Dr. Samer Hana

Submitted to the College of Engineering
in partial fulfillment of the requirements for the degree of
Bachelor degree in Industrial automation Engineering

Palestine Polytechnic University

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According to the orientations of the supervisor on the project and the examined committee is by the agreement of a staffers all, sending in this project to the Electrical Engineering Department are in the College of the Engineering and the Technology by the requirements of the department for the step of the bachelor's degree.

Project Supervisor Signature

……………………………………………

Department Administrator Signature

……………………………………………

الاهداء

قاسينا وسهرنا وتعبنا وها نحن اليوم وبحمد الله نطوي سهر الليالي وتعب السنين التي مضت
ونقدم بين طيات الكتاب خلاصة مشوارنا....

اليك حبيبي وسيدي يا منارة العلم وهداية البشرية , يا من انقذتني برسالتك من ظلمات الجهل
وكنت النجم الذي اهتدي به اذا ما اسود ليلي يا سيدي و نبي محمد صلى الله عليه وسلم....

الى اطيب قلب واجمل ابتسامة واعذب حديث , اليك امي يا من كنت شريكتي في سهري وتعبي
وحزني وفرحي أدامك الله تاجاً فوق روؤسنا يا من كنتي لي اماً واختاً وصديقة....

اليك يا من ضحيت بعمرك من اجلي وأثرت راحتي على راحتك وأحرقت شمعة أيامك وشبابك
من اجل ان تضعني على اول الطريق اليك ابي حفظك الله من كل شر وأطال في عمرك....

الي من حبهم سكن في اعماق قلبي الذين ادعو لهم لهم بالسر والعلن أن يحفظهم الله من كل شر
وأن يبقيهم نوراً لدربي وسنداً لي اليكم اخوتي واخواتي....

اليكم يا من وهبتكم لي الحياة وكنتم سنداً لي على طول الطريق يا من كنتم سبباً في زرع
الابتسامة
على وجهي حتى في اصعب الظروف .... اصدقائي واحبابي....
اليهم جميعاً اهدي هذا العمل

والله ولي التوفيق

أمجد محمود الشلالدة

محمد صقر ابو سمرة

شكر وتقدير

في مثل هذه اللحظات يتوقف اليراع ليفكر قبل أن يخط الحروف ليجمعها في كلمات ... تتبعثر الأحرف وعبثاً أن يحاول تجميعها في سطور

سطوراً كثيرة تمر في الخيال ولا يبقى لنا في نهاية المطاف إلا قليلاً من الذكريات وصور تجمعنا

برفاق كانوا إلى جانبنا ...

فواجب علينا و وداعهم ونحن نخطو خطواتنا الأولى في غمار الحياة
فلا نبدأ بالشكر إلا من منحنا القوة والعقل لنصل الى هذه اللحظات الجميلة ... من نطق بكتابه بأولى كلاماته "إقرأ " الى جل في علاه رب العالمين ...

كما ونخص بالجزيل الشكر والعرفان إلى كل من أشعل شمعة في دروب علمنا

وإلى من وقف على المنابر وأعطى من حصيلة فكره لتنير دربنا

إلى الأساتذة الكرام في كلية الهندسة وفي قسم الهندسة الكهربائية ونخص بالذكر

المهندس سامي السلامين

المهندس مكاوي إحريز

المهندس نبيل جويلس

ونتوجه بجزيل الشكر والعرفان إلى

الدكتور سمير خضر

الذي قام بالاشراف على هذا المشروع فله منّا كلّ التقدير والاحترام ....

Abstract

This project aims design and implementation a wireless energy source that capable to energize different kinds of loads wirelessly. It consists of solar Photovoltaic source, power conditioning unit, power transmission unit and power receiving unit where the energy being transferred wirelessly using the principle of electromagnetic transfer of energy.

This design should be applied for energizing loads such as cell phones, rarely located loads, and other loads where transferring the power throughout conductors are difficult, inapplicable and expensive. A prototype model should be implemented in order to verify the obtained results with respect to the amount of transferred power, accuracy and efficiency.

This is a pilot project that being funded by the deanship of graduates studies at PPU.

ملخص

يتلخص البحث في تصميم وبناء وحدة تغذية لاسلكية باستخدام الطاقة الشمسية وذلك لتزويد بعض الاجهزة الالكترونية بالطاقة الكهربائية (جهاز حاسوب محمول ، جهاز تلفون محمول ، شاحن كهربائي ، ووحدات انارة ...).
تتلخص فكرة المشروع (البحث) في تحويل طاقة الأشعة الشمسية الى طاقة كهربائية من خلال لوحات **PV Solar Panels** وما يتطلب لتحقيق ذلك من مراحل هندسية ، ومن ثم نقل هذه الطاقة الى ما يسمى نقطة بث **(Transmitting Point)** حيث سيحدث نظام رنين داخل دائرة الابتدائي لمحول كهربائي لتنقل الطاقة مغناطيسيا الى ملفات دائرة الثانوي ، حسث سيتم معالجتها والعمل على تجهيزها لشحن إحدى الاجهزة المذكورة أعلاه من خلال نقطة بث تسمى **(Emitting Point)**.

ما يتم تحقيقه بهذه الصورة هو الإستغناء عن مصدر الطاقة التقليدي ، ومن ثم إتاحة الفرصة لمستهلكي الطاقة (طلبة الجامعات على سبيل المثال ...) الاستفادة من نقاط بث الطاقة لشحن أجهزتهم دون تكليف الجامعه أي مصاريف إضافية ... .

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Introduction

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Chapter One

Introduction

1.1 Overview.

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1.3 Problem Statement.

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1.5 Theory.

1.6 Time Schedule.

1.2 Overview:

This project will detail the need and usefulness of wireless power transmission and furthermore the feasibility of using inductive coupling as the means for wireless power transmission. Thus some points about general circuits may not be explicitly stated as they have been taken as common knowledge for the intended audience. However, it is intended that anyone with an interest in electrical circuits and more importantantly transformer theory or electromagnetic fields would be able to understand and follow the subject matter outlined.

The Project will outline our teams design process and the logical steps we took in our experimentation and design of the final unit. The first section of the document will explicitly illustrate the problem and what the group intended to accomplish. With the complexity of the problem in mind and what we must accomplish our team then began research on the available means to transmit power without a physical connection. Once the initial background research was accomplished it was necessary to layout the advantages and disadvantages of all the available means for wireless power transmission. Once all the necessary criteria for each system were known we chose the best solution for the problem. After our team had chosen upon using inductive coupling we all began to review the major theories that would determine the constraints of the system and what pieces of hardware must be designed to achieve the transmission of wireless power. Furthermore because we are transmitting power through the surrounding area we had to be sure that our system would not endanger others and be FCC compliant. Once the basic system components were known our team divided up the work load, set the necessary deadlines, and began designing the following circuits and hardware: power supply, oscillator, transmission coil, receiving coil, voltage booster/rectifier, and LED flashing circuit. After the entire system was integrated into a working unit it was time to determine how well the system operated and the feasibility of wireless power transfer through inductive coupling. Additionally, future improvements that could greatly improve the overall system will be discussed. Finally, the cost of producing the system, any references our team used, and extra calculations will be presented in the appendices.

Although wireless charging might sound like the stuff of science fiction, this is not a far-fetched vision of the future. The technology and theory behind wireless charging have been around for a long time – the idea was initially suggested by Nikola Tesla, who demonstrated the principle of wireless charging at the turn of the century. The technology is also closer to you than you may think: it is already a reality in such devices as electric toothbrushes and surgically implanted devices, like artificial hearts.

Wireless charging, also known as inductive charging, is based on a few simple principles. The technology requires two coils: a transmitter and a receiver. An alternating current is passed through the transmitter coil, generating a magnetic field. This in turn induces a voltage in the receiver coil; this can be used to power a mobile device or charge a battery.

So we will use solar energy - converted into electrical energy and stored in the battery - charging smart phones and laptops, after converted using a transmitter to a reception received wirelessly based on the principle of transformers.

1.3 Problem:

In the past two decades alternative power sources have been developed massively, and with large energy production scales. Despite that there are several obstacles that faced this sector such as the cost of transmitted energy.

The problem is : to design and implement a model that should transfer the generated PV power without or with minimum use of conductors (Wireless Energy Transmission).

1.4 Problem Statement:

For the completion of this project, we were asked to wirelessly transfer the power of an AC oscillating waveform into a DC voltage on the receiving end which will be used to Shipping a mobile device or Laptop to demonstrate the instantaneous power transfer. The frequency of oscillation of the AC signal must not exceed 100MHz. The power transfer needs to be done over a two feet distance or greater. The transferred AC power needs to be converted to DC power and boosted up enough to drive a low power display design, such as an LED or mobile in continuous or pulsed mode.

The whole system must be FCC compliant (FCC: Federal Communications Commission).

1.5 The Importance of Research :

1. Solar energy consumption in many ways in the life .
2. Daily consumption of solar energy causes the financial burden on society widely .
3. Getting rid of the traditional system in transferring of energy by using the wires .

4- Through this device charging more than your laptop, whether devices or smart phones from the same shipping point.

5- This device can be developed and exploited in the service of human life in other forms and utilization of solar energy in remote and isolated areas.

6- The possibility of shipping in areas where there are no electricity because of our dependence mainly on the exploitation of solar energy.

7- A turning point and a new revolution in the world of technology.

8-Publication of a scientific paper or more in the field of renewable energy used in nutrition wireless.

1.6 Theory:

The solar panel commonly used gives an output of about 12V which can be converted into high voltage and high frequency source by using RF oscillator and amplifiers. This can act as a source to the transmitter coil of wireless electricity setup. Wireless Electricity works on the principle of magnetic resonant coupling system. This system basically consists of two insulated copper coils, one transmitter and the other receiver. Electric power from the AC power source is made to flow through it primary coil or the transmitter and the frequency is set equal to the secondary coil placed at a distance in resonance with primary coil. The magnetic field generated due to current in the primary coil induces current in the secondary coil and thus a magnetic field around it. The magnetic field of the two coils couple tightly and transfer power efficiently due to resonance.

1.7 Time Schedule.

Table 1-1:Time table of our project during one year from 5/2/2014 to 5/1/2015

Week /task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Gives the idea and choosing the team	■	■	■												The second semester time																	
Collecting Information about the project			■	■	■																											
Reading					■	■	■	■																								
Scope the project						■	■	■																								
Block diagram									■	■																						
Selection of Technique ,comp circuit design											■	■																				
Circuit diagram											■	■	■	■																		
Documentation				■	■	■	■	■	■	■	■	■	■	■	■																	
Collection of component																■	■	■	■													
Build circuit																The first semester time		■	■	■	■											
Interfacing using PIC & other programs																				■	■	■	■									
Building project (practical)																							■	■	■	■	■					
Testing the Project																											■	■	■	■		
Recommendations																														■	■	
Conclusion																															■	
Project Documentation																				■	■	■	■	■	■	■	■	■	■	■	■	■

2

CHAPTER TWO

COMPONENTS OF PROJECT

2

CHAPTER TWO

COMPONENTS OF PROJECT

PART A: PV-SOLAR

2.1 Introduction.

2.2 A Solar Panel.

- 2.2.1 Photovoltaic cell.
- 2.2.2 Solar Electric Photovoltaic Module.

2.3 Charge controller.

- 2.3.1 The function of the charge controller.
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- 2.3.4 Types of charge Controller.

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- 2.4.1 Introduction.
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- 2.5.1 Inverter Operation.
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PART B : Wireless Power

PART A: PV-SOLAR

2.1 Introduction:

A basic PV system consists of five main components. The *solar panel*, *charge controller*, *the battery*, *inverter*, and *the load*. The solar panel are collecting the energy of the sun and generating electricity. Charge controller is responsible of regulation of charging the batteries. The inverter responsible of converting DC/AC power, the load refers to any device that requires electrical power- It will be in our project is a charging base for the wireless mobile device- and is the sum of the consumption of all electrical equipment's connected to the system and it will be discussed in chapter four.

2.2 A Solar Panel:

2.2.1 Photovoltaic Cell:

Photovoltaics' (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics' include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide /sulfide. Due to the increased demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years.

A single PV cell is a thin semiconductor wafer made of two layers generally made of highly purified silicon (PV cells can be made of many different semiconductors but crystalline silicon is the most widely used). The layers have been doped with boron on one side and phosphorous on the other side, producing surplus of electrons on one side and a deficit of electrons on the other side.

On average, the amount of solar energy falling onto a square meter at the equator of planet earth is 1000 w/m2. This number varies wildly depending on circumstances and location but illustrates the point that solar energy can provide significant amounts of power for outdoor wireless applications.

2.2.1.1 Physical Characteristics of The Solar Cell

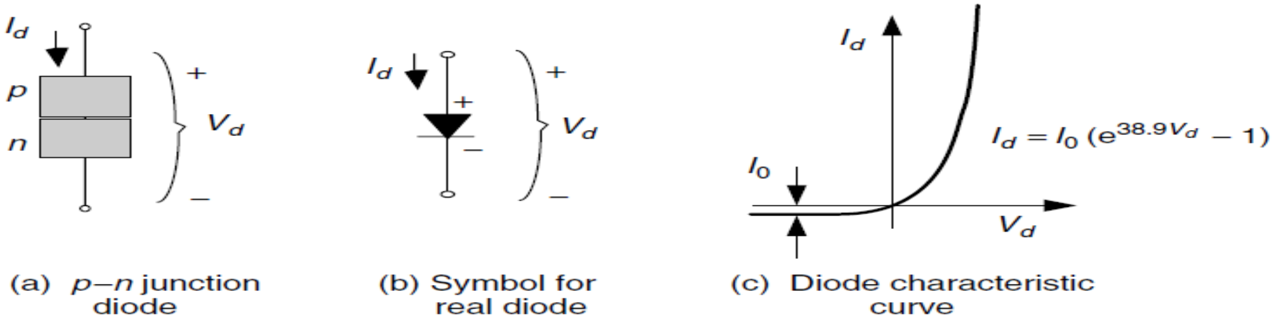


Figure2–1 : A p–n junction diode allows current to flow easily from the p-side to the n-side.

$$I_d = I_0\left(e^{\frac{qV_d}{kT}} - 1\right) \qquad \text{…………………………………………………… (2.1)}$$

Where:

I_d: Is the diode current in the direction of the arrow.

V_d: Is the voltage across the diode terminals from the p-side to the n-side (V).

I_0: Is the reverse saturation current (A).

q: Is the electron charge (1.602×10^{-19} C).

k: Is Boltzmann's constant (1.381×10^{-23} J/K).

T: Is the junction temperature (K).

At T= 25^0C:

$$\frac{qV_d}{kT} = \frac{1.602\times10^{-19}C}{1.381\times10^{-23}\,J/K}\cdot\frac{V_d}{298K} = 38.9V_d$$

$$I_d = I_0\left(e^{38.9V_d} - 1\right) \qquad \text{…………………………………………………… (2.2)}$$

2.2.1.2 A More Accurate Equivalent Circuit for a PV Cell.

A simple equivalent circuit model for a photovoltaic cell consists of a real diode in parallel with an ideal current source in Figure 2-2. The ideal current source delivers current in proportion to the solar flux to which it is exposed.

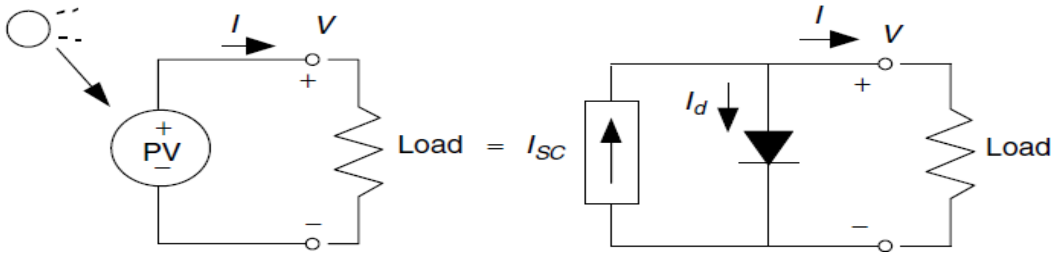
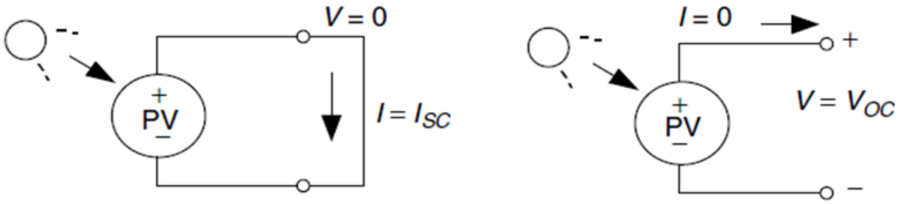


Figure 2–2 : A simple equivalent circuit for a photovoltaic cell



(a) "Short-circuit current" (b) "Open-circuit voltage"

Figure2–3: Two parameters for photovoltaics' the short-circuit current I_{SC} and the open-circuit voltage $V_{OC.}$

There are two conditions of particular interest for the actual PV and for its equivalent circuit. in Figure2-3, they are:

The current that flows when the terminals are shorted together (the short-circuit current, I_{SC})

The voltage across the terminals when the leads are left open (the open-circuit voltage, VOC)

When the leads of the equivalent circuit for the PV cell are shorted together, no current flows in the (real) diode since $V_d = 0$, so all of the current from the ideal source flows through the shorted leads. Since that short-circuit current must equal I_{SC}, the magnitude of the ideal current source itself must be equal to I_{SC}. Now we can write a voltage and current equation for the equivalent circuit of the PV cell Figure 2-3.[2]

Start with:

$$I = I_{SC} - I_d \qquad \text{……………………………………………………………………..(2.3)}$$

And then substitute (2-2) into (2-3) to get

$$I = I_{SC} - I_0\left(e^{38.9V_d} - 1\right) \qquad \text{………………………………………………………………..(2.4)}$$

When the leads from the PV cell are left open, I = 0 and we can solve (2.4) for the open-circuit voltage V_{OC}

$$V_{OC} = \frac{kT}{q}\ln\left(\frac{I_{SC}}{I_0} + 1\right) \quad \Rightarrow \quad V_{OC} = 0.0257\ln\left(\frac{I_{SC}}{I_0} + 1\right) \qquad \text{……………………………..(2.5)}$$

In both of these equations, short-circuit current, I_{SC}, is directly proportional to solar insulation, which means that we can now quite easily plot sets of PV current–voltage curves for varying sunlight. Also, quite often laboratory specifications for the performance of photovoltaics' are given per cm^2 of junction.

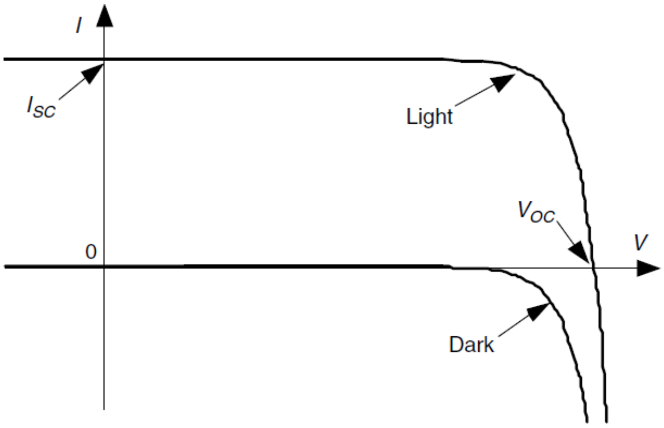


Figure 2–4: Photovoltaic current–voltage relationship for "dark" (no sunlight) and "light" (an illuminated cell).

A More Accurate Equivalent Circuit for a PV Cell:

There are times when a more complex PV equivalent circuit than the one Figure 2-5 is needed In our simplified equivalent circuit for the shaded cell, the current through that cell's current source is zero and its diode is back biased so it doesn't pass any current either (other than a tiny amount of reverse saturation current). This means that the simple equivalent circuit suggests that no power will be delivered to a load if any of its cells are shaded. While it is true that PV modules are very sensitive to shading, the situation is not quite as bad as that. So, we need a more complex model if we are going to be able to deal with realities such as the shading problem. Figure 2-5 a PV equivalent circuit that includes some parallel leakage resistance R_P. The ideal current source I_{SC} in this case delivers current to the diode, the parallel resistance, and the load. [1]

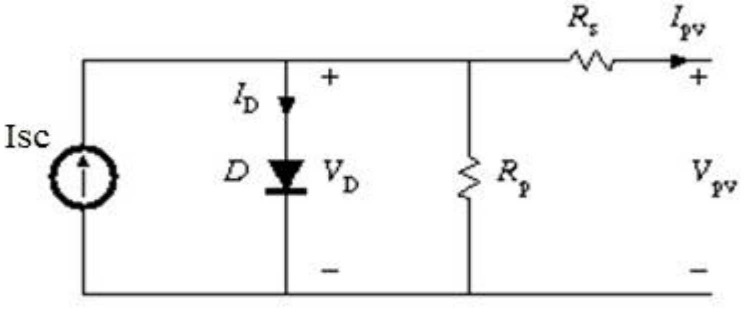


Figure 2–5 : Equivalent Circuit for a PV Cell.

$$I_{SC} = I_d + I_p + I \tag{2.6}$$

$$I = I_{SC} - I_d = I_{SC} - I_0\left(e^{qV/kT} - 1\right) \tag{2.7}$$

$$V_d = V + R_S I \tag{2.8}$$

$$I = I_{SC} - I_0\left(\exp\left[q\left(\frac{V + IR_S}{kT}\right)\right] - 1\right) \tag{2.9}$$

$$I = I_{SC} - I_0\left[e^{38.9(V+IR_S)} - 1\right] - \frac{1}{R_P}\left(V + IR_S\right) \tag{2.10}$$

$$R_P > \frac{100V_{OC}}{I_{SC}} \qquad R_S < \frac{0.01V_{OC}}{I_{SC}}$$

To find value of the module voltage (V):

$$V_{\text{module}} = n\left(V_d - IR_S\right) \tag{2.11}$$

To find power of module (KW):

$$P = V_{\text{module}} * I_{\text{module}} \tag{2.12}$$

2.2.2 Solar Electric Photovoltaic Modules

2.2.2.1 Photovoltaic Modules

A PV module consists of many PV cells wired in parallel to increase current and in series to produce a higher voltage. 36 cell modules are the industry standard for large power production.

There are currently four commercial production technologies for PV Modules:

Single Crystalline Monocrystalline,

This is the oldest and more expensive production PV cell technique, but it's also the most efficient sunlight conversion technology available. Module efficiency averages about 10% to 12%* [3].

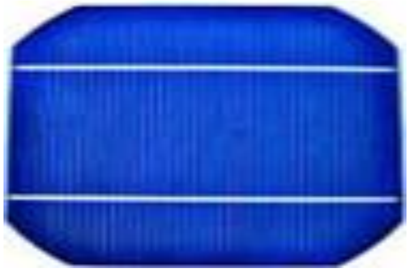


Figure 2–6 Single Crystal

Polycrystalline or Multicrystalline

This has a slightly lower conversion efficiency compared to single crystalline but manufacturing costs are also lower. Module efficiency averages about 10% to 11%* [3] **.**

Figure2-7 Shows
Multicrystaline PV cell

String Ribbon

This is a refinement of polycrystalline production, there is less work in production so costs are even lower. Module efficiency averages 7% to 8%*.

Figure 2–8 Thin film PV cell .

2.3 Charge Controller:

A charge controller, charge regulator or battery regulator limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may prevent against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life . The terms "charge controller" or "charge regulator" may refer to either a stand-alone device, or to control circuitry integrated within a battery pack, battery-powered device, or battery recharge Stand-alone charge controllers [6].

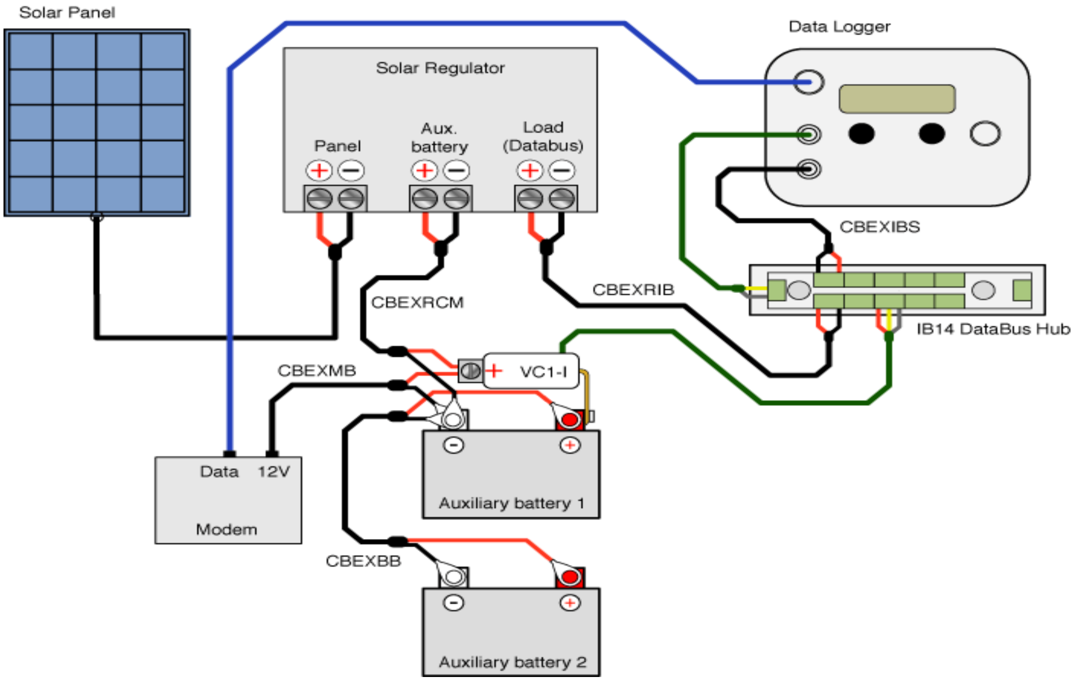


Figure2–9 Connection of a regulator in a solar system.

2.3.1 The Function of The Charge Controller:

Blocking Reverse Current:

Photovoltaic (PV) panels work by pumping current through your battery in one direction. At night, the panels may pass a bit of current in the reverse direction, causing a slight discharge from the battery. (Our term “battery” represents either a single battery or bank of batteries.) The potential loss is minor, but it is easy to prevent. Some types of wind and hydro generators also draw reverse current when they stop, but most do not, except under fault conditions.

In most controllers, charge current passes through a semiconductor (a transistor) which acts like a valve to control the current. It is called a semiconductor because it passes current in only one direction[6].

2.3.2 Charge Controller Circuit:

This circuit to charge batteries automatically depend on battery voltage; when the voltage reach required value the charge will disconnect and vice versa;Figure2-11 the equivalent circuit of charge controller [4].

Figure 2–6 commercial charge controller .

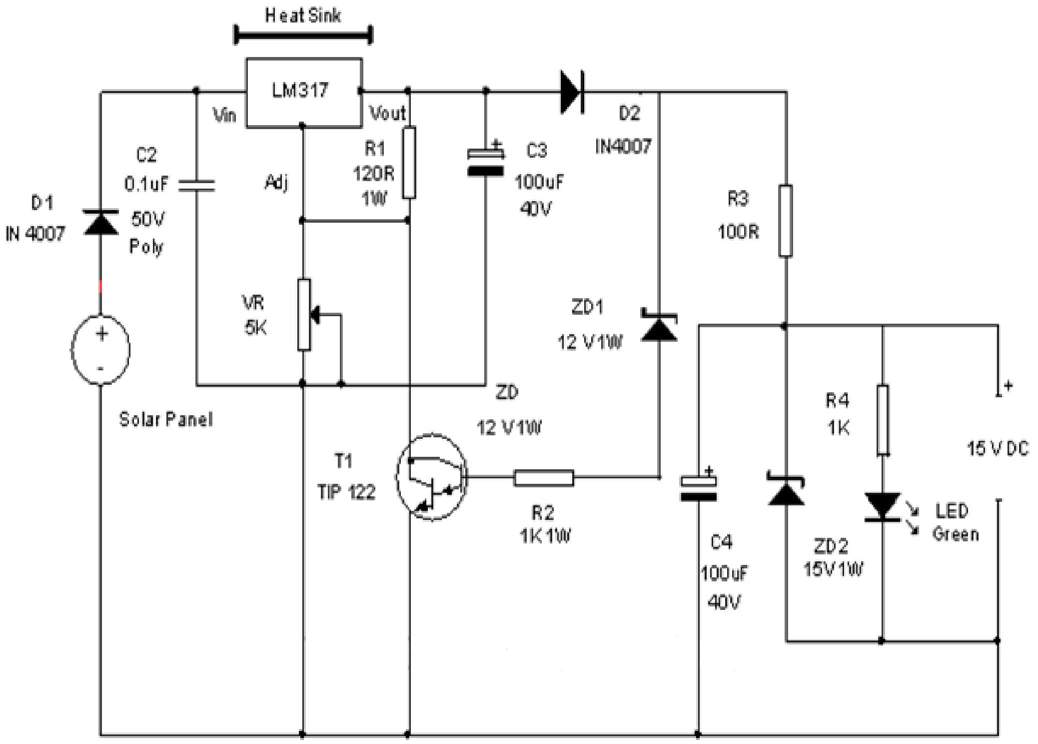


Figure2–7: Charge controller circuit.

2.3.2 Types of Charge Controllers:

Interaction with Inverter:

Since the majority of charge controllers have been installed in off-grid systems, their default settings may not be appropriate for a grid-connected system. The charge controller must be set up such that it does not interfere with the proper operation of the inverter. In particular, the controller must be set up such that charging the batteries from the PV array takes precedence over charging from the grid. For more information, contact the manufacturer.

Interaction with Batteries:

The charge controller must be selected to deliver the charging current appropriate for the type of batteries used in the system. For example, on a 12V system, flooded lead-acid batteries have a voltage of 14.6V to 15.0V when fully charged, while sealed lead-acid batteries are fully charged at 14.1 V. Refer to the battery manufacturer for the charging requirements of particular batteries [4]. Selection Charge controllers are selected based on:

PV array voltage – The controller’s DC voltage input must match the nominal voltage of the solar array.

PV array current – The controller must be sized to handle the maximum current produced by the PV array.

2.4 Batteries:

2.4.1 Introduction:

The function of the batteries is to store the energy when the PV is supplying energy and to provide it to the system when the coming energy from the PV is under the needed amount of the energy and this function need a special kind of batteries according to the nature of the system from the daily repeated charging and discharging of the batteries.[6]

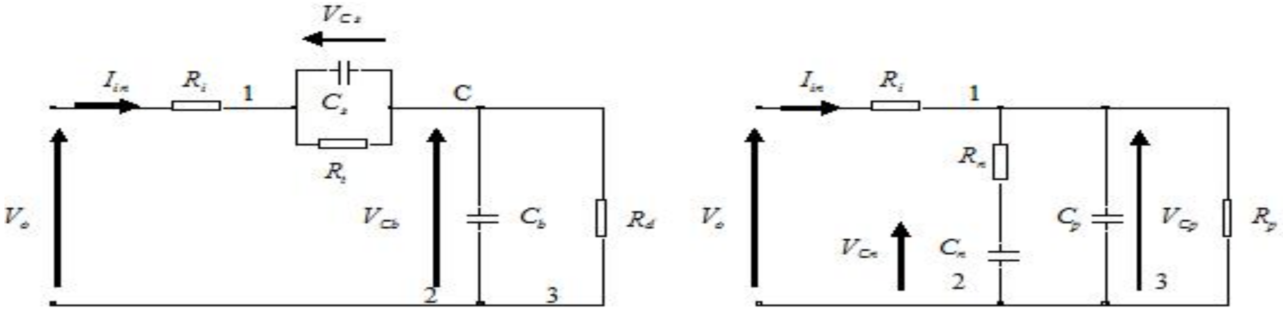


Figure 2–8: Battery model.

2.4.2 PV Batteries:

Batteries accumulate excess energy created by your PV system and store it to be used at night or when there is no other energy input. Batteries can discharge rapidly and yield more current that the charging source can produce by itself, so pumps or motors can be run intermittently.

2.4.3 Battery Types:

In PV systems, lead-acid batteries are most common due to their wide availability in many sizes, low cost and well understood performance characteristics. In a few critical, low temperature applications nickel-cadmium cells are used, but their high initial cost limits their use in most PV systems. There is no “perfect battery” and it is the task of the PV system designer to decide which battery type is most appropriate for each application.

In general, electrical storage batteries can be divided into two major categories, primary and secondary batteries.[6].

2.4.3.1 Primary Batteries:

Primary batteries can store and deliver electrical energy, but cannot be recharged. Typical carbon-zinc and lithium batteries commonly used in consumer electronic devices are primary batteries. Primary batteries are not used in PV systems because they cannot be recharged.

2.4.3.2 Secondary Batteries:

A secondary battery can store and deliver electrical energy, and can also be recharged by passing a current through it in an opposite direction to the discharge current. Common lead-acid batteries used in Automobiles and PV systems are secondary batteries. Table 2-1 lists common secondary battery types and their characteristics which are of importance to PV system designers. A detailed discussion of each battery type follows.

Type Secondary Batteries:

1.Lead Acid.

2. Nickel Cadmium.

3. Nickel Metal Hydride.

4. Lithium-Ion.

2.2.4 Energy Storage:

The battery sizing calculation is straightforward:

$$Battery\_Capacity(Ahrs) = Current\_Consumption(A)*Dark\_Hours(hrs) \quad \text{…..(2.11)}$$

2.5 Inverter :

The batteries in your PV systems store direct current (DC) power which can be used for certain applications but most of the conventional household appliances use alternative current (AC) power. The Inverter converts low voltage DC into higher voltage AC.

Electricity transmits more efficiently at higher voltages and it's the standard used worldwide. 120 or 240 volt in the USA at 60 cycles per second. Inverters are available in a wide range of wattage capabilities.

Brand-name inverters are highly reliable. Efficiency averages about 90% for most models, check the CEC certification before you purchase. Poor performance and high failure rates are common with cheap imported inverters without CEC certification.[8]

2.5.1 Inverter Operation:

Early inverters produced a square wave alternating current which at times resulted in problems while operating with solid-state equipment.

Now, modern inverters produce a modified sine wave which takes care of most of the problems that square-wave inverters had. Modified sine wave is not quite the same as power company electricity. They are lower cost, very efficient and most appliances will accept it although there are some notable exceptions. Check the *additional information* link on the right for inverter problems and troubleshooting. Modified sine wave inverters are a good choice for smaller sized PV systems[8].

2.5.2 Inverter Output Ratings:

Inverters are sized according to the watts they can deliver. All inverters are capable of briefly sustaining much higher loads than they can run continuously. For maximum performance, check the inverter's specifications for accurate continuous power rating[8].

PART B : Wireless Power

2.6 Interdiction

This project will detail the need and usefulness of wireless power transmission and furthermore the feasibility of using inductive coupling as the means for wireless power transmission. Thus some points about general circuits may not be explicitly stated as they have been taken as common knowledge for the intended audience. However, it is intended that anyone with an interest in electrical circuits and more importantantly transformer theory or electromagnetic fields would be able to understand and follow the subject matter outlined.

The Project will outline our teams design process and the logical steps we took in our experimentation and design of the final unit. The first section of the document will explicitly illustrate the problem and what the group intended to accomplish. With the complexity of the problem in mind and what we must accomplish our team then began research on the available means to transmit power without a physical connection. Once the initial background research was accomplished it was necessary to layout the advantages and disadvantages of all the available means for wireless power transmission.

Although wireless charging might sound like the stuff of science fiction, this is not a far-fetched vision of the future. The technology and theory behind wireless charging have been around for a long time – the idea was initially suggested by Nikola Tesla, who demonstrated the principle of wireless charging at the turn of the century. The technology is also closer to you than you may think: it is already a reality in such devices as electric toothbrushes and surgically implanted devices, like artificial hearts.

Wireless charging, also known as inductive charging, is based on a few simple principles. The technology requires two coils: a transmitter and a receiver. An alternating current is passed through the transmitter coil, generating a magnetic field. This in turn induces a voltage in the receiver coil; this can be used to power a mobile device or charge a battery[11].

So we will use solar energy - converted into electrical energy and stored in the battery - charging smart phones and laptops, after converted using a transmitter to a reception received wirelessly based on the principle of transformers.

The solar panel commonly used gives an output of about 12V which can be converted into high voltage and high frequency source by using RF oscillator and amplifiers. This can act as a source to the transmitter coil of wireless electricity setup. Wireless Electricity works on the principle of magnetic resonant coupling system. This system basically consists of two insulated copper coils, one transmitter and the other receiver. Electric power from the AC power source is made to flow through the primary coil or the transmitter and the frequency is set equal to the secondary coil placed at a distance in resonance with primary coil. The magnetic field generated due to current in the primary coil induces current in the secondary coil and thus a magnetic field around it. The magnetic field of the two coils couple tightly and transfer power efficiently due to resonance. There is efficient energy exchange between tuned resonant objects and also very little energy is transferred to extraneous or off-resonant objects.

Merits of Wireless Transmission

i) Non-radiative power transfer uses magnetic field.
ii) Highly resonant coupling minimizes energy to off-resonant objects[11].

Benefits over electromagnetic radiation or radio waves

Radio waves are not feasible for power transmission because the nature of radiations is such that it spreads across the place and resulting into a large amount of radiation being wasted [13]. While lasers and microwaves require uninterrupted line of sight to transmit and also they are very dangerous. In this coupling system the energy that is not used by the receiver doesn’t get radiated to the surrounding but remains in the vicinity of the transmitter. This ensures sampling as well as minimal wastage of power.

Wireless Power Transmission System

WPT is a point-to-point power transmission. For the WPT, we had better concentrate power to receiver. It was proved that the power transmission efficiency can approach close to 100%.To concentrate the transmitted power and to increase transmission efficiency, we have to use higher frequency. By use of the magnetron and the klystron high-power microwaves, (1-10 GHz radio waves) can be transmitted[14].

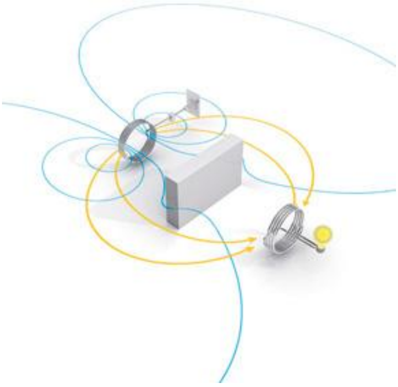


Figure 2-13: Wireless Power Transmission System.

2.7 History

Transfer energy wirelessly is the process in any system where the transfer of electrical energy from the power source to an electrical load without the presence of conductive wires .

Date of wireless transmission of energy

• 1820: Andrei Mariomber put Ampere's law , which states that an

electric current flowing in a conductor generates a magnetic field around Mosul .

• 1831: Michael Faraday's law Farradayuda to induce , one of the basic laws of electromagnetism .

• 1864: James Clerk Maxwell put a mathematical model for the behavior of electromagnetic radiation so inclusive views ,

experiences and previous laws related to electricity and magnetism and optics into one theory .

• 1888: Heinrich Rudolf Hertz confirms the existence of electromagnetic radiation .

Take it as a generation of electromagnetic radiation , which made the first radio transmitter .

• 1891: Nicolas Tzlaigom developed a device Hz.

• 1893: Nikola Tesla lead a presentation in which a group of lighting lamps wirelessly.

• 1894: Nikola Tesla shines wirelessly to a set of vacuum tubes using induction Allekerodenamiki .

• 2007: a research team at the Massachusetts Institute of Technology succeeded in lighting the lamp 60 Watt 's ability to wirelessly at a distance of two meters and effectively up to 40% .

2.7.1 Ampere's law:

is the law of the world Andrea amp and equivalent magnetic law Gaoussou is also the fourth equations Maxwyl wins law that the integration of linear magnetic field on a closed path equals the intensity of the current macro- passing in that path , but this law is a special case is acceptable only when the electric field is constant and the amount of change the time is equal to zero[13].

$$\nabla \mathrm{X}\, H = Jc \qquad \text{(2.12)}$$

2.7.2 James Clerk Maxwell

Then realized the fault or negligence of the law to the changing electrical fields in time, so the stream by adding the offset to the equation which has proved the possibility of creating a magnetic field by electric current or time- variable electric field turned to the law :

Where : $\nabla . H = Jc + Jd$ …………………………………………………………… (2.13)

Jc: Delivery Current density .

Jd: Displacement Current density.

And can Incant of this equation the current law in several ways.

Ohm's Law:

By Ohm's law $I = V \setminus R$ where v is a voltage and R is the resistance of material

The measured power unit Amp (A).

Possible by the ability where

$P = V * I$ and this law can show power.

$I = P \setminus V$ is known that P is the effective capacity is measured in watts (WATT).

2.7.3 Faraday's law

Faraday's law to induce Alkahromenatisa is a physical law in the field of electromagnetism. Ampere is the law drafted by the Faraday law in 1831 , based on scientific experiments carried out . According to the law , the amount of electromotive force Induced generated in a file or a conductor is directly proportional to the time rate which cuts the connector to the magnetic lines of the iceberg .

2.7.4 Base Linz

The direction of the induced electric current generated in a file or a connector change goes against AIDS.

Maxwell found that light is an electromagnetic wave speed equal to the speed of light . This means that the light waves of electromagnetic energy , and it became clear that the electric charge generated an electric field around a static , generates a magnetic field which is moving . As well as the change in the electric field generates a magnetic field , and the text of the law (amp) . And that the change in the magnetic field generates an electric field and the text of this law (Faraday) . This fact is the genesis of the electromagnetic waves as the oscillatory electrical charge generated in the space two electric and magnetic , any room (electromagnetic) variable and this area is moving in the vacuum speed of light itself (3exp8 m / s) of any of 300,000 km / sec .

$C = 1 / ((\varepsilon . \mu) (1/2)) = 3\, exp8.$ .... (2.14)

The light intensity (I) or the intensity of the electromagnetic wave is
(Energy per unit time per unit area and perpendicular to the direction of wave propagation)
$I = \varepsilon . (Eexp2). c$
Where (E) the intensity of the electric field or magnetic (B).
Determines the approximate range of the electromagnetic spectrum from radio waves with a wavelength long to gamma rays with a very short wavelength and high energy . And any visible light that the human eye can monitor Mujath located between the extent of the ultraviolet to the infrared . It is worth mentioning that there are no boundaries separating regions of the spectrum from each other. When the fall of electromagnetic waves on the surface and in the vertical body absorbs these rays that power is called the power of radiation appear calculated through the following relationship :

$F = P / \alpha$ ....(2.15)

where α constant of power radiation
Where P is the energy per unit of time is no ability for absorbing electromagnetic wave and P can be obtained through the following relationship :

$P = u / c$ ....(2.16)
where u is the electromagnetic energy.

2.7.5 Nikola Tesla :

Nikolai Tesla was the first to develop the designs for wireless power transmission. Tesla was famed for his work in the research and work with alternating current. His wireless research began with his original transformer design and though a series of experiments that separated the primary and the secondary coils of a transformer. Tesla performed many wireless power transmission experiments near

Colorado Springs. In Tesla's experimentation, Tesla was able to light a filament with only a single connection to earth [14]. Tesla's findings lead him to design the Wardenclyffe plant as a giant mushroom shaped wireless power transmitter. Tesla was never able to complete construction of this project.

2.8 TYPES OF WIRELESS POWER TRANSMISSION

Types of Wireless Power Transmission includes

- Induction.
- Radio Waves.
- Evanescent Wave Coupling.
- LASER.

2.8.1 INDUCTION:

When magnetic flux flowing through a circuit changes, an electromotive force (emf) along with current are induced in the circuit. This effect is for example used in dynamos, electric motors and transformers. The central principle behind electromagnetic induction is Faraday's law, which relates to the induced electromotive force (emf) in any closed loop including a closed circuit. Induction can be used as a means of wireless power transfer. A changing current in one coil creates an emf, which in turn induces a current in another coil.

The coils are not in contact and in this way energy can very simply be transported over short distances. This is used in for example an electric toothbrush charger. The short distance that is required for induction is the largest drawback of this way of wireless energy transfer, because it limits the applicability to very close-range situations[15].

2.8.2 RADIO WAVES:

The key component for wireless power transfer by radio waves is the rectenna. A rectenna is a combination of a rectifying circuit and an antenna. The antenna receives the electromagnetic power and the rectifying circuit converts it to DC electric power.

A simple rectenna can be constructed from a Schottky diode placed between the antenna dipoles. The diode rectifies the current induced in the antenna by the microwaves[16]. Schottky diodes are used because they have the lowest voltage drop and highest speed and therefore waste the least amount of power due to conduction and switching[20].

The amount of power that can be transferred is limited. For safety reasons, the transmitted power is limited by regulations, for instance by the Federal Communications Commission (FCC), and the received power is attenuated, mainly due to free-space path loss. Furthermore, because portable devices have small dimensions, the rectenna should have small dimensions as well. This results in a small antenna area and, consequently, a low amount of received power. Because of these limitations, wireless power transfer using radio waves is mainly suitable for low-power applications, e.g. a low-power wireless sensor[20].

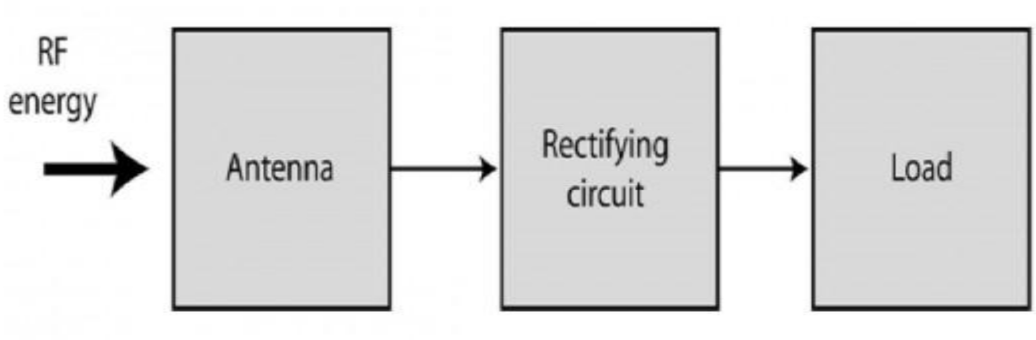


Figure 2-14: Wireless Power Transfer by Radio Waves is the Rectenna.

2.8.3 EVANESCENT WAVE COUPLING:

Evanescent wave coupling is a technique that has recently been investigated by researchers at MIT.

The physics behind this technique is rather complicated. At a glance, it basically extends the principle of magnetic induction to mid-range applications up to a few meters. The main difference is the use of resonance; if sender and receiver have the same magnetic resonance frequency, energy can efficiently be transported, while losses to the non-resonant environment are small. Using resonance, for the same geometry, power can be transported approximately 106 times more efficiently than without resonance. The experimental setup used by the MIT researchers is shown. The coils can be compared to antennas;

the electric and magnetic fields produced by antennas can generally be divided into the near field, which is dominant at close ranges, and the far field. The far field, responsible for electromagnetic waves, radiates energy into the environment. The near field does not radiate, so no energy is lost, except when the sender and receiver have the same resonance frequency. In that case energy is transported from the sender to the receiver[17]. The main achievement of the MIT team is to have figured out how to fine tune the system so that the near field extends to distances of a few meters, simultaneously limiting the power radiated through the far field.

One of the benefits is that most common materials do not interact with magnetic fields, so obstructing objects do not have much influence. This also goes for human tissue and therefore health risks are low. The coils shown above are too large for applications in i.e. a cell phone, but the receiving coil can be made smaller. The researchers state that the transmitted power can be kept constant, if the size of the sending coil is increased to keep the product of the sizes of both coils equal. The efficiency of the above setup is around 40 to 50% for wireless power transfer over 2 meters[16].

2.8.4 LASER

Power delivery that starts with sunlight has many advantages such as sustainability and the fact that the sun is present every day. However solar cells have limited efficiency and sunlight is not available at night. An alternative is to generate artificial light, from a laser, transmit it through air, and then convert it into electricity.

New refinements are making this alternative more attractive. NASA has demonstrated flight of a lightweight model plane powered by laser beam, directed at a panel of infrared-sensitive photovoltaic cells mounted on the bottom of the aircraft.

A theoretical setup consists of a laser (Light Amplification by Stimulated Emission of Radiation) and a photovoltaic, or solar cell.

First electricity is converted by the laser into a laser beam, which consists of coherent radiation. Next this beam is pointed towards a photovoltaic cell receiver, which in turn converts the received light energy back into electricity. This is generally called ―power beaming‖.

Both steps are not highly efficient and also a direct line of sight between laser and the photovoltaic cells is required[20].

2.9 Possible Solutions:

In our research, as well as practical knowledge, we knew of three possibilities to design a device. There are the use of antennas, inductive coupling, and laser power transfer. In addition, we had to be aware of how antennas and inductive coupling would be affected by the frequency we select.

2.10 Magnetic Resonant Coupling:

Wireless power transfer via magnetic resonant coupling is experimentally demonstrated in a system with a large source coil and either one or two small receivers. Resonance between source and load coils is achieved with lumped capacitors terminating the coils. A circuit model is developed to describe the system with a single receiver, and extended to describe the system with two receivers. With parameter values chosen to obtain good fits, the circuit models yield transfer frequency responses that are in good agreement with experimental measurements over a range of frequencies that span the resonance. Resonant frequency splitting is observed experimentally and described theoretically for the multiple receiver system. In the single receiver system at resonance, more than 50% of the power that is supplied by the actual source is delivered to the load. In a multiple receiver system, a means for tracking frequency shifts and continuously retuning the lumped capacitances that terminate each receiver coil so as to maximize efficiency is a key issue for future work[20].

Inductive coupling is an old and well-understood method of wireless power transfer. The source drives a primary coil, creating a sinusoidally varying magnetic field, which induces a voltage across the terminals of a secondary coil, and thus transfers power to a load. This mechanism, responsible for power transfer in a transformer, where the magnetic field is typically confined to a high permeability core, also functions when the region between the primary and secondary coils is simply air. Inductive coupling without high permeability cores is used, for example, to power RF ID tags and medical implants [15]–[16]. A common technique for increasing the voltage received by the device to be powered is to add a parallel capacitor to the secondary to form a resonant circuit at the operating frequency [14], [15]. Application of this principle has also been demonstrated for powering robot swarms [20]. In this case, resonance was used on the primary but not on the secondary windings on the robots. This was done to minimize performance variations resulting from interactions among the robots. Recent work [20] has shown that when resonance is used on both the primary and secondary, power can be transferred with very little radiated loss and with 40%–50% of the source power delivered to the load, even when the secondary coil links only a relatively small part of the magnetic field that is created by the primary. A coupled-mode analysis of the interaction between a pair of resonant coils has also been presented [20], [17]. Finally, an inductively coupled radio frequency wireless transmission system has been described, with reference to multiple resonant peaks for multiple receivers [17].

In the work described here, there are two new contributions:

1) We demonstrate power transfer from a single resonant source coil to multiple resonant receivers, focusing upon the resonant frequency splitting issues that arise in multiple receiver applications.

2) We show that resonant coupling systems with either single or multiple receivers can be modeled using a relatively simple circuit description. The model rigorously takes into account mutual coupling between all coils, and does not make approximations usually associated with the coupled mode approach [8]. This description makes it clear that high Q resonant coupling is key to the efficiency of the system, through an implementation where the primary coil is inductively coupled to the power source and the receiving coils are inductively coupled to the loads.

We expect this work to form a basis for understanding and extending the resonant coupling mechanism to multiple mobile receivers. The main challenge for such a system is to adjust the lumped capacitances at the terminals of the receivers as they move with respect to the source coil and with respect to one another.

2.10.1 Magnetism:

A fundamental force of nature, which causes certain types of materials to attract or repel each other. Permanent magnets, like the ones on your refrigerator and the earth's magnetic field, are examples of objects having *constant* magnetic fields.

Oscillating magnetic fields vary with time, and can be generated by alternating current (AC) flowing on a wire. The strength, direction, and extent of magnetic fields are often represented and visualized by drawings of the magnetic field lines.

As electric current, *I*, flows in a wire, it gives rise to a magnetic field, *B*, which wraps around the wire. When the current reverses direction, the magnetic field also reverses its direction.

The blue lines represent the magnetic field that is created when current flows through a coil. When the current reverses direction, the magnetic field also reverses its direction.

2.10.2 Electromagnetism:

A term for the interdependence of time-varying electric and magnetic fields. For example, it turns out that an oscillating magnetic field produces an electric field and an oscillating electric field produces a magnetic field.

2.10.3 Magnetic Induction:

A loop or coil of conductive material like copper, carrying an alternating current (AC), is a very efficient structure for generating or capturing a magnetic field.

If a conductive loop is connected to an AC power source, it will generate an oscillating magnetic field in the vicinity of the loop. A second conducting loop, brought close enough to the first, may “capture” some portion of that oscillating magnetic field, which in turn, generates or induces an electric current in the second coil. The current generated in the second coil may be used to power devices. This type of electrical power transfer from one loop or coil to another is well known and referred to as magnetic induction. Some common examples of devices based on magnetic induction are electric transformers and electric generators.

2.10.4 Energy/Power Coupling:

Energy coupling occurs when an energy source has a means of transferring energy to another object. One simple example is a locomotive pulling a train car—the mechanical coupling between the two enables the locomotive to pull the train, and overcome the forces of friction and inertia that keep the train still—and, the train moves. Magnetic coupling occurs when the magnetic field of one object.

An electric transformer is a device that uses magnetic induction to transfer energy from its primary winding to its secondary winding, without the windings being connected to each other. It is used to “transform” AC current at one voltage to AC current at a different voltage.

interacts with a second object and induces an electric current in or on that object. In this way, electric energy can be transferred from a power source to a powered device. In contrast to the example of mechanical coupling given for the train, magnetic coupling does not require any physical contact between the object generating the energy and the object receiving or capturing that energy.

2.11 Resonance

2.11.1 Resonance:

Resonance is a property that exists in many different physical systems. It can be thought of as the natural frequency at which energy can most efficiently be added to an oscillating system. A playground swing is an example of an oscillating system involving potential energy and kinetic energy. The child swings back and forth at a rate that is determined by the length of the swing. The child can make the swing go higher if she properly coordinates her arm and leg action with the motion of the swing. The swing is oscillating at its resonant frequency and the simple movements of the child efficiently transfer energy to the system. Another example of resonance is the way in which a singer can shatter a wine glass by singing a single loud, clear note. In this example, the wine glass is the resonant oscillating system. Sound waves traveling through the air are captured by the glass, and the sound energy is converted to mechanical vibrations of the glass itself. When the singer hits the note that matches the resonant frequency of the glass, the glass absorbs energy, begins vibrating, and can eventually even shatter. The resonant frequency of the glass depends on the size, shape, thickness of the glass, and how much wine is in it.

2.11.2 Resonant Magnetic Coupling:

Magnetic coupling occurs when two objects exchange energy through their varying or oscillating magnetic fields. Resonant coupling occurs when the natural frequencies of the two objects are approximately the same.

Two idealized resonant magnetic coils, shown in yellow. The blue and red color bands illustrate their magnetic fields. The coupling of their respective magnetic fields is indicated by the connection of the color bands.

2.11.3 Types of Wireless feeding:

Direct Wireless Power :
When all the power a device needs is provided wirelessly, and no batteries are required.

Automatic Wireless Charging:

When a device with rechargeable batteries charges itself while still in use or at rest, without requiring a power cord or battery replacement. This mode is for a mobile device. understanding is transferring electric energy or power over distance without wires—is quite simple. Understanding how it works is a bit more involved. We'll start with the basics of electricity and magnetism.

Electricity: The flow of electrons (current) through a conductor (like a wire), or charges through the atmosphere (like lightning). A convenient way for energy to get from one place to another!
An illustration representing the earth's magnetic field.

2.12 Safety

Magnetic coupled resonance system transmits power even when there are obstacles in between the transmitter and receiver. Human beings or other objects placed in between the coils don't have any harmful effects on them. It is quite safe for humans. The magnetic field tend to interact very weakly with the biological tissues of the body and so are not prone to cause any damage to any living beings.

2.13 Constraints

The only constraint that the system encounters is the decrease in efficiency when the receiver coil is moved away from the transmitter and also formation of nodes and antinodes. These are the areas that still need to be worked out and require further investigation.

3

CHAPTER THREE

THE BLOCK DIAGRAM

3

CHAPTER THREE

THE BLOCK DIAGRAM

3.1 (Part One) Photovoltaic

3.1.1 PV Cells

3.1.2 Charge Controller

3.1.3 Inverter

3.1.4 Battery

3.1.5 Small "Stand-Alone" Systems (off grid)

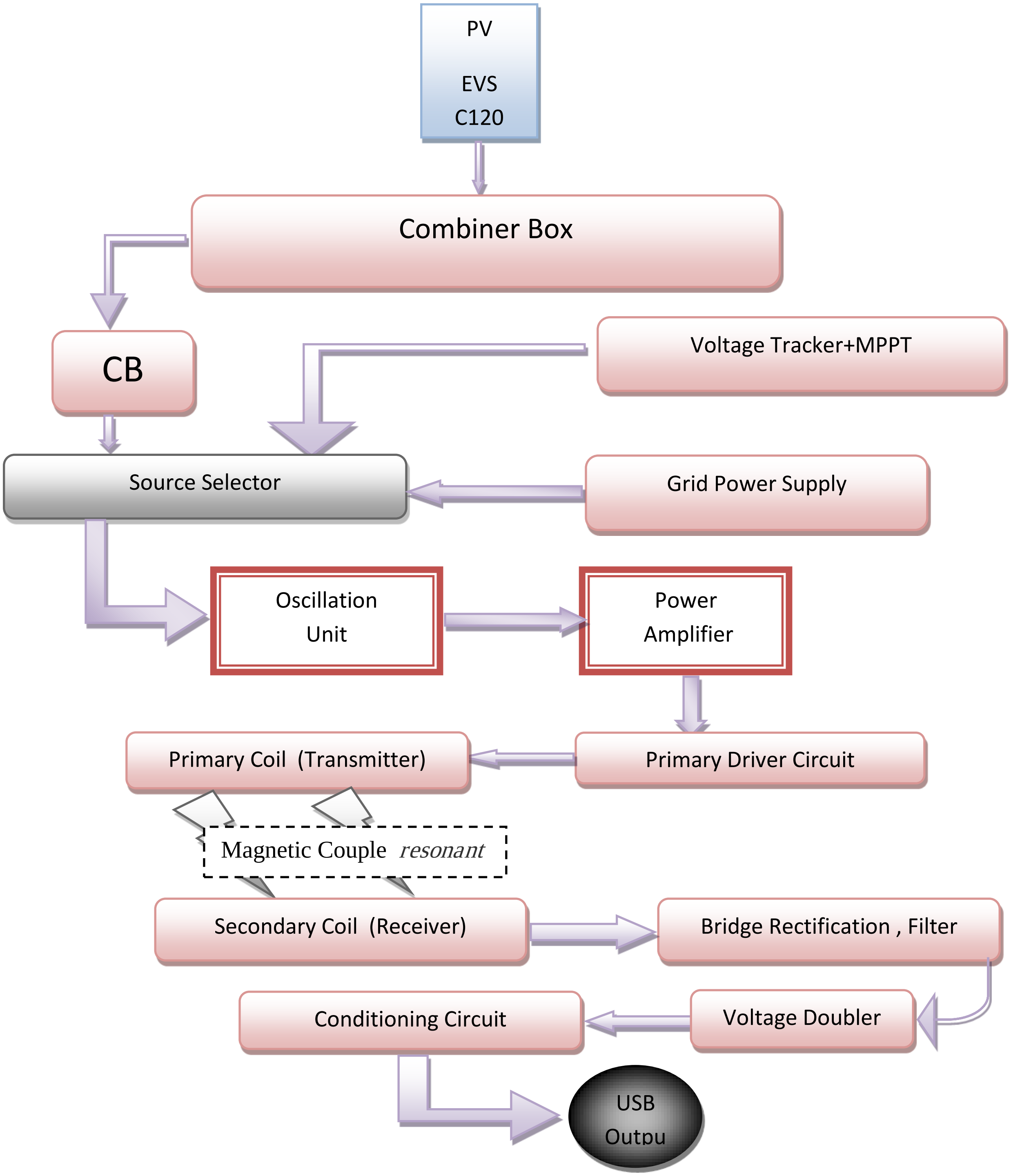
3.2 (Part Two) Wireless Power Transmission

3.2.1 Block Diagram

3.2.2 Block Description

Generally:

The input to the system is solar energy convert it to power and the system transfers the power wirelessly to the receiver . Figuer 3-1 the Wireless transmission System.



Figuer 3-1 the Wireless transmission System.

3.1 (Part One) Photovoltaic :

Photovoltaic is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity.

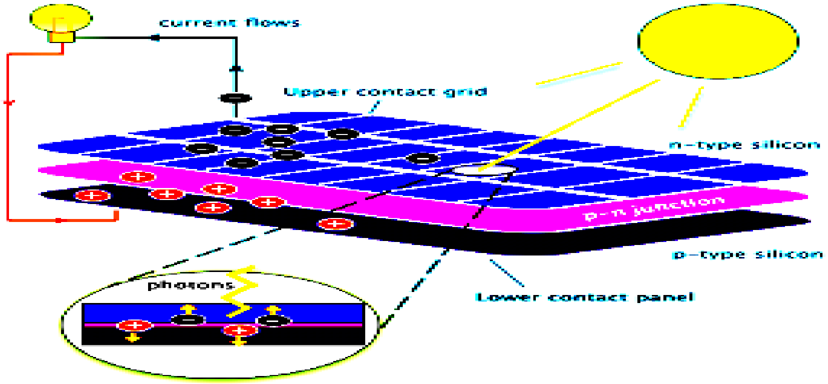
3.1.1 PV Cells :

Electricity is the result of the flow of electrons. All matter at its lower level is made of atoms. Most atoms may be thought of as a nucleus containing positively charged particles with an equal number of negatively charged electrons orbiting round it. Each element has a distinctive number of electrons which are arranged in concentric ‘shells’ around the nucleus, each shell representing a level of energy. A stable arrangement of electrons for the atom is 2 in the first shell, 8 in the second and 8 in the third.

The top surface of the cell is designed to allow the maximum amount of light onto the silicon. Hence, electrical contacts (electrodes) which carry the free electrons through the circuit are screen-printed onto the surface of the cell. This has the effect of minimizing the losses on the uppermost surface of the cell. Rear electric contacts are applied across a larger area of the cell as there is no need for light penetration underneath.

A single cell does not produce enough power on its own to be of any practical use. A cell typically produces around 0.6 volts in an ‘open circuit’ situation (no load) and 0.45 volts under load. However, several cells can be linked together in series into a ‘module’ to collectively produce a useful amount of electricity. A module consists of about 36 cells and will produce a ‘nominal’ voltage of around 16 volts. Such a module could be (say) used to charge a 12v battery.

The modules that form the solar-panel are more typically linked together in greater numbers to generate higher voltages; 48 or 60 cells linked will produce approximately 28 and 36 volts respectively in an open-circuit situation. Figuer 3-2 the PV Cells.



Figuer 3-2 :the PV Cells.

3.1.2 Charge controller:

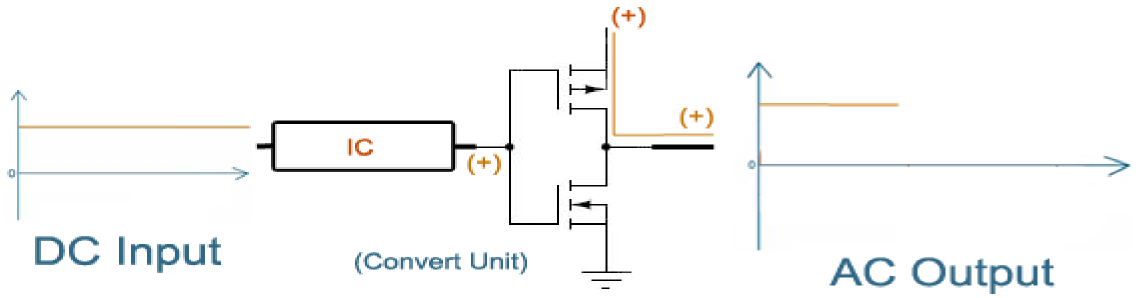
A charge controller may be used to power DC equipment with solar panels. The charge controller

provides a regulated DC output and stores excess energy in a battery as well as monitoring the battery voltage to prevent under / overcharging.

3.1.3 Inverter:

A solar inverter, or PV inverter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. It is a critical component in a photovoltaic system, allowing the use of ordinary commercial appliances.

The grid-tie inverter converts the solar-panel direct current to alternating current which matches the voltage and frequency of the National Grid. Typical inverters are powered by the solar panels themselves and work at around 94% efficiency. Therefore, some electricity generated by the panels is lost in the conversion from DC to AC. Most inverters attempt to maximize the output from the panels by performing a process call Maximum Power Point Tracking (MPPT) which optimizes the power drawn from the panels at any particular point in time. Figuer 3-3 .



Figuer 3-3 : The working principle of Inverter.

3.1.4 Battery:

Batteries are often used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather). Other reasons batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters. In most cases, a battery charge controller is used in these systems to protect the battery from overcharge.

Solar cell produce a DC voltage, but the load voltage is DC or AC, high voltage or low voltage, because that we need the devices which give us the voltage which we need.

3.1.5 Small "Stand-Alone" Systems (off grid)

A free standing or **Stand Alone PV System** is made up of a number of individual photovoltaic modules (or panels) usually of 12 volts with power outputs of between 50 and 100+ watts each. These PV modules are then combined into a single array to give the desired power output. A simple *stand-alone PV system* is an automatic solar system that produces electrical power to charge banks of batteries during the day for use at night when the suns energy is unavailable. A stand alone small scale PV system employs rechargeable batteries to store the electrical energy supplied by a PV panels or array. Stand alone PV systems are ideal for remote rural areas and applications where other power sources are either impractical or are unavailable to provide power for lighting, appliances and other uses. In these cases, it is more cost effective to install a single stand alone PV system than pay the costs of having the local electricity company extend their power lines and cables directly to the home;Figure3-4 : the block diagram of a simple *Stand-Alone PV system*.

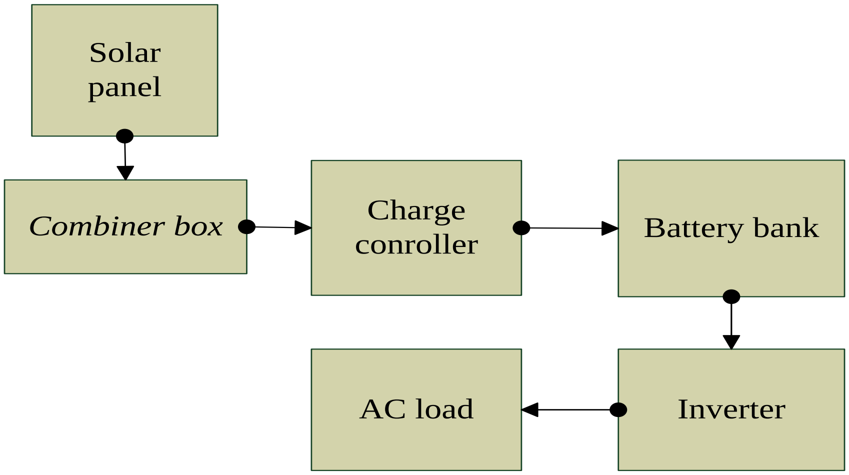


Figure 3–4 Block diagram of Stand-Alone

A stand alone photovoltaic (PV) system is an electrical system consisting of array of one or more PV modules, conductors, electrical components, and one or more loads. But a small-scale PV system does not have to be attached to a roof top or building structures for domestic applications, they can be used for camper vans, RV's (Recreational vehicle), boats, tents, camping and any other remote location. Many companies now offer portable solar kits that allow you to provide your own reliable and free solar electricity anywhere you go even in hard to reach locations; Figure 3-5 : the simplified stand-alone system. [9]

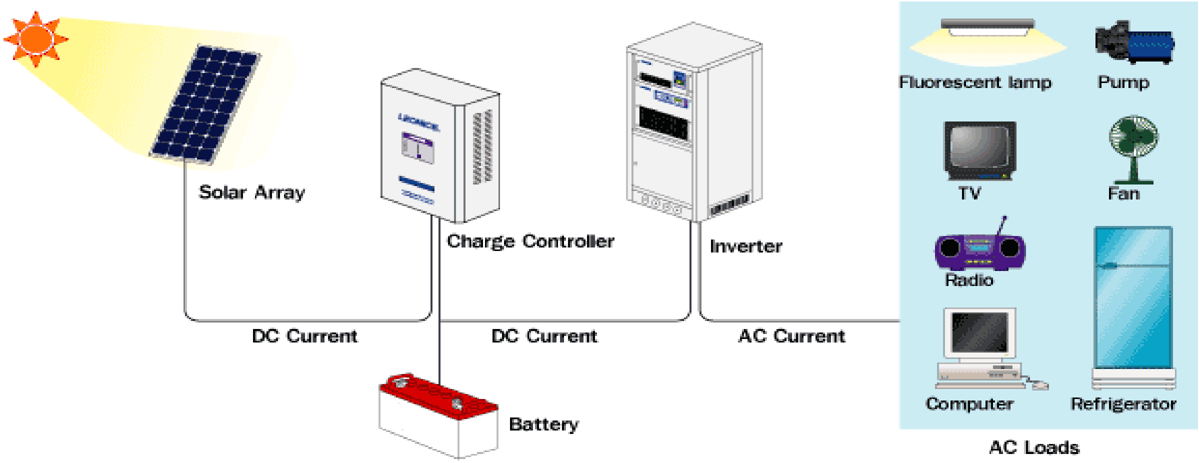


Figure3–5 Simplified Stand-Alone system.

3.2 (Part Two) Wireless Power Transmission:

Scheme represents the energy transfer methods , what is identified in green has been adopted in our project , Figure 3–6 .

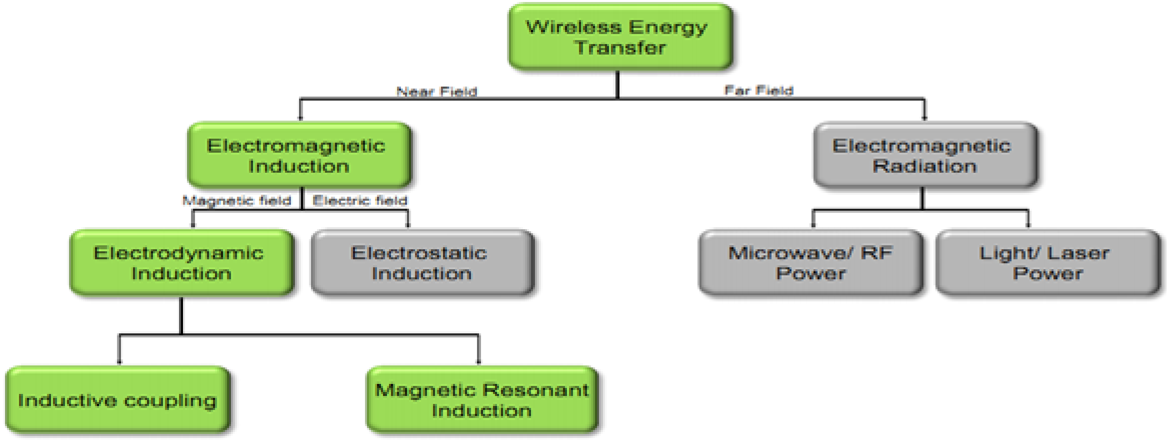


Figure 3–6 : Scheme represents the energy transfer methods / what is identified in green has been adopted in our project .

Sketch of the mechanism of energy transfer between the transmitter circuit and the receiver circuit , Figure 3–6.

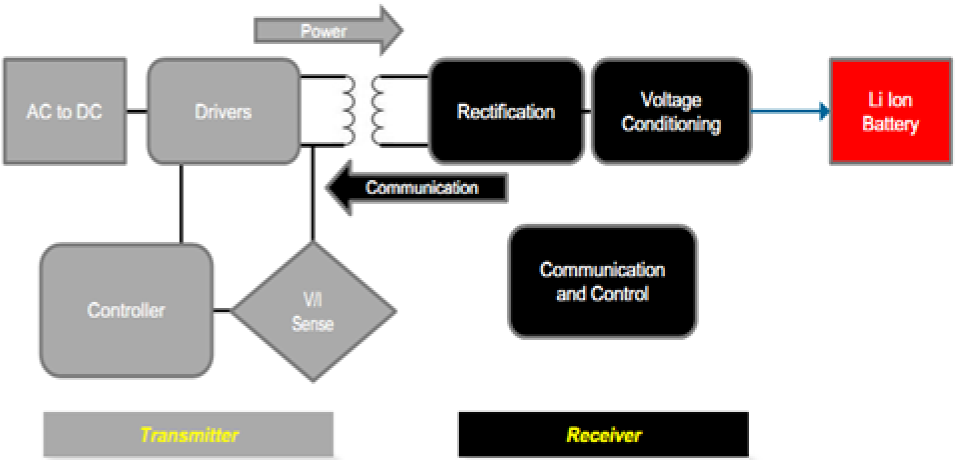


Figure 2–7 :Sketch of the mechanism of energy transfer between the transmitter circuit and the receiver circuit.

3.2.1 Block Diagram

The block diagram for the transmission setup is Figure 3.8.

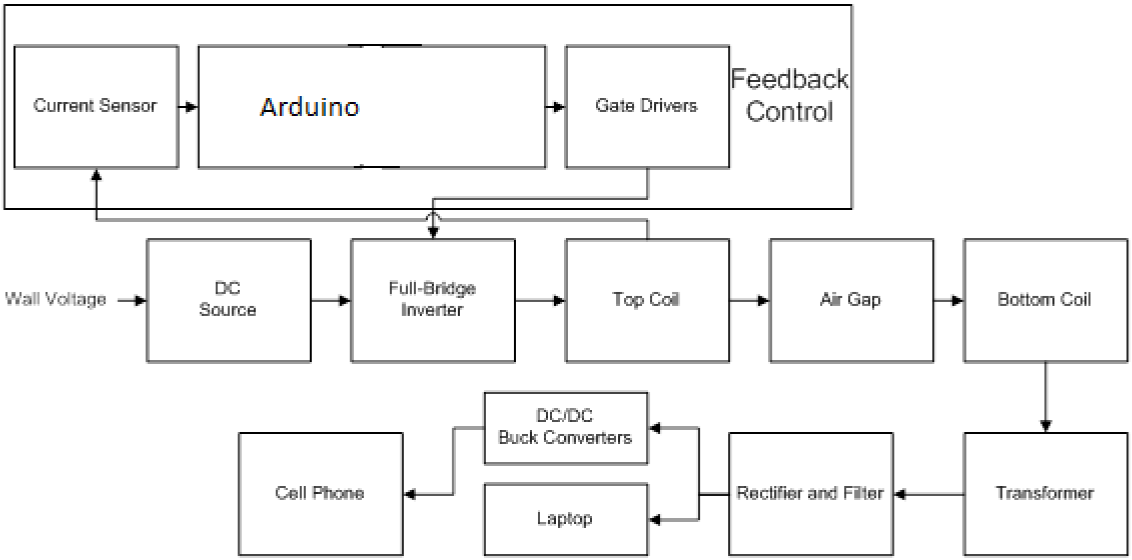


Figure 3-8: Block Diagram for Wireless Power

3.2.2 Block Descriptions :

The different blocks shown in the block diagram were implemented separately and then integrated together. Below are descriptions of each block and specifications for each.

3.2.2.1 DC Source :

The DC source takes in the input from the wall voltage which is a 50 Hz sinusoid. Using diodes, the voltage is rectified and passed through a PI filter. The original design specified a 1 % voltage ripple, but this ripple requirement was excessive and difficult to meet at such a low frequency. The final design chosen had a voltage ripple of less than 5 % and was more than suitable.

3.2.2.2 Full Bridge Inverter :

The full bridge inverter is a circuit that uses four switches, a DC source, and a load. The four switches are setup in an H-bridge with the middle being the load. In this case the load is the top coil. Two of the switches are connected from the high side DC source to opposite sides of the coil. The remaining two switches are connected from the low side of the DC source to opposite sides of the coil. High side switches have opposite duty cycles and the low side switches are connected such that the DC source is applied across the load. The result is a square wave being applied across the coil. The switches are MOSFETs that have the capability to carry the max current and can block the full DC voltage.

3.2.2.3 Gate Drivers :

Gate drivers are used to turn on and off the switches. The gate drivers take in a timing signal and output a voltage high enough and with enough current to drive MOSFETs on and off at the same frequency of the timing signal.

3.2.2.4 Arduino :

The Arduino Uno is a microcontroller board based on the ATmega328 . It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

3.2.2.5 Current Sensing :

The current sensing circuit is used to tell the Arduino how much current is being pulled from the DC source. It uses a precision .15 Ω resistor on the output of the DC source and that voltage is feed into an op-amp circuit that produces a voltage proportional to the current. This voltage is designed to be within the range of inputs for the Arduino.

3.2.2.6 Coils and Air Gap :

The coils are each made out of 10 turns of (OO AWG) magnet tube copper. They are separated by about 63 cm and have a diameter of about 31.5 cm. The power transfer between them is done through resonant magnetic coupling.

3.2.2.7 Transformer :

A transformer is used to scale down the voltage to around 18 V. This is done before the signal is converted to DC because high frequency transformers are small and relatively efficient.

3.2.2.8 Rectifier and Filter :

A similar circuit is used to convert the AC signal from the transformer to a DC signal. Different diodes are used due to the high frequency nature of the signal. Smaller capacitors are used in the filter because the frequency is much higher than the 50 Hz signal filtered the top filter. The capacitors are also ceramic because electrolytic capacitors have a much lower self resonant frequency, after which they begin to behave like inductors.

3.2.2.9 Buck Converter:

A buck converter is used to convert the 18 V for the computer down to 5 V for charging the cell phone. It was ordered to save us the trouble of making our own and its ability to keep the voltage regulated with a large input voltage range.

Dc to Dc Converter (Chopper):

A chopper is a static device that converts fixed dc input to a variable dc output voltage directly types of chopper:

A- Step-down

A converter where output voltage is lower than the input voltage (like a buck converter).

B- Step-up

A converter that outputs a voltage higher than the input voltage (like a boost converter).

C – Buck –Boost Converter

Step up and step down .

The methods control at chopper circuit :

- **Pulse Width Modulation (PWM).**

Periodic time is constant but the control by changing duty cycle

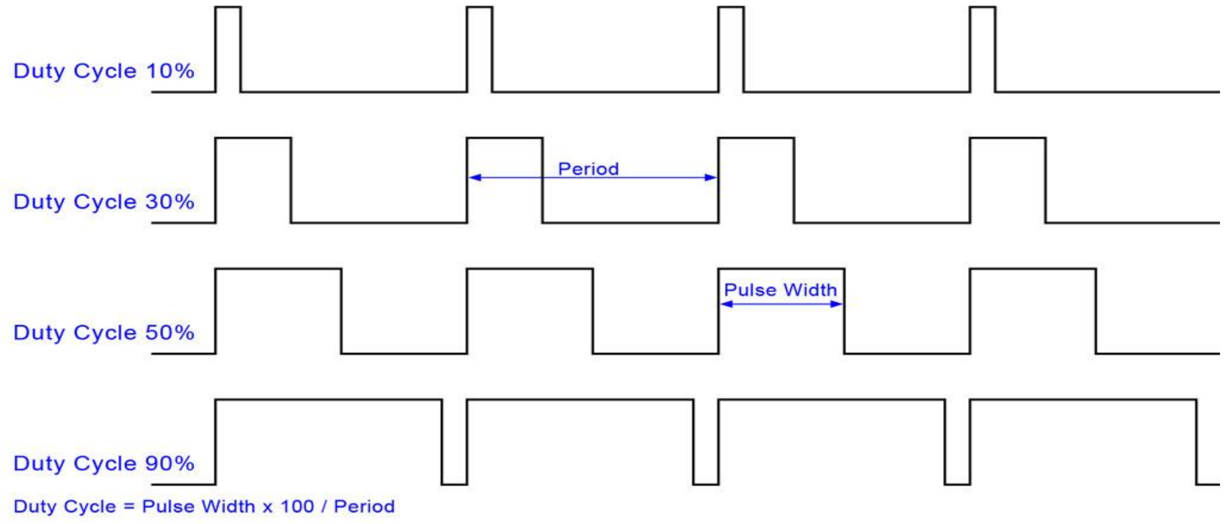


Figure 3-9 :Pulse Width Modulation (PWM).

- **Pulse Frequency Modulation (PFM).**

Variable frequency by periodic time change, on time is constant.

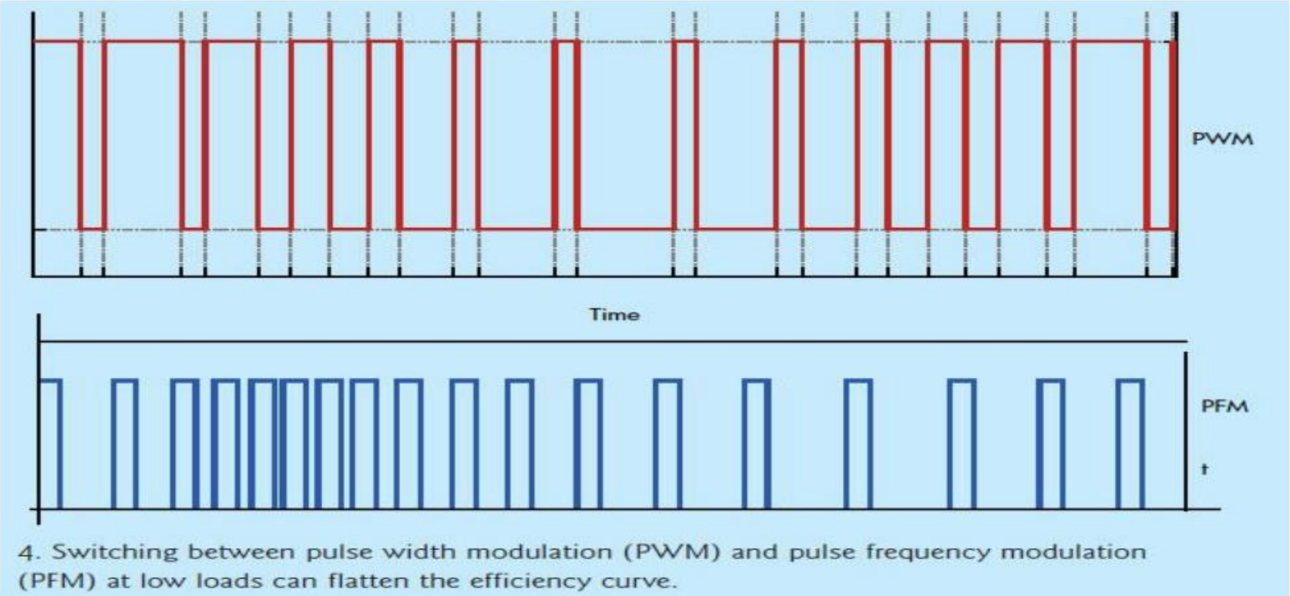


Figure 3-10 :Pulse Frequency Modulation (PFM).

3.2.1.10 load

Although it is important to achieve high efficiency, it is also crucial to ensure that the system is able to deliver the required power with respect to the load resistance. The transmitted power should decrease when the load impedance increases.

Error in selecting component values will result in the opposite direction of operation, i.e., the transmitter will increase its output when the load resistance increases. The switching regulator will attempt to maintain its power delivery by increasing its input resistance or decrease its duty cycle, resulting in a positive feedback. Poor efficiency will be observed due to excess power dissipated as heat, and device failure may occur due to overvoltage.

The most important part is the load because it's limited transmitted power , the used load in our project is phone so that we need special calculations , show in the next chapter.

4

CHAPTER FOUR

DESIGN AND ANALYSIS THE SYSTEM

4

Chapter Four

Design and Analysis the System

Chapter Four : Design and Calculations

4.1 Grid Solar System

- **4.1.1 Energy consumption**
- **4.1.2 PV array sizing**
- **4.1.3 Inverter Sizing**
- **4.1.4 The Value Fuses Combiner**
- **4.1.5 Small “ Stand –alone” System**
- **4.1.6 Storge System**
- **4.1.7 Final PV System Design**

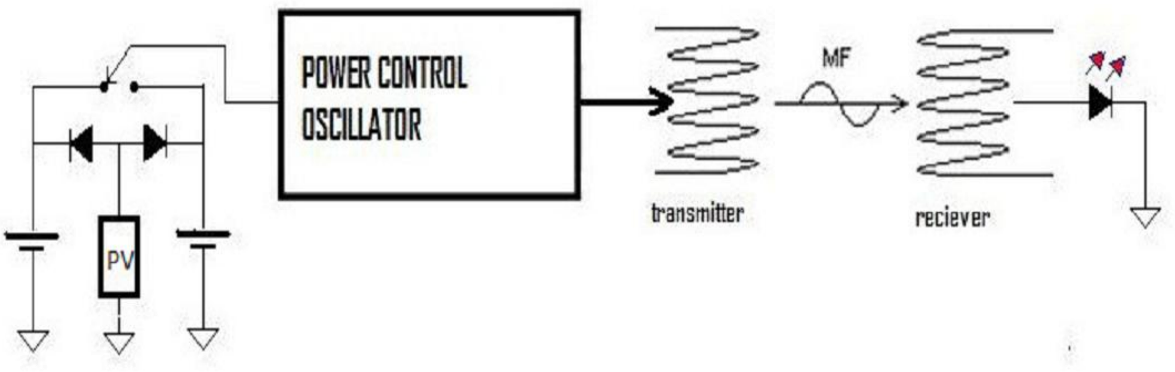
4.2 Transfer Electrical Energy Wirelessly using Magnetic Resonance

- **4.2.1 LITERATURE REVIEW**
- **4.2.2 Design Procedures**
- **4.2.3 Design Details**

Tasks:

1-The Design of A Solar Power System, and the work necessary Calculations.

2-Design a System to Transfer Electrical Energy Wirelessly using Magnetic Resonance , and the work necessary Calculations ; This is a distance of not less than 50 cm.



Figuer 4-1: Photovoltaic and Wireless Transmission System.

1

4.1 Grid Solar System :

4.1.1 Energy consumption

In our project we need to provide three Mobile powered devices (namely a final Load), by any load does not exceed 15 watts.

Calculating the average of energy consumption:

$E\left(\frac{W}{h}\right) = 3 * 5(W) = 15\frac{W}{h}$ =0.015 KW

$E\left(\frac{W}{day}\right) = 0.015 * 18(h) = 0.270\ KW$

18 hour: Average daily use of the device

4.1.2 PV array sizing

Calculating the Ac power daily :

$$E_{avg.}\left(KWh/day\right) = P_{AC} \times \left(H/day\ @1sun\right) \tag{4.1}$$

$$P_{AC} = \frac{E_{avg.}\left(KWh/day\right)}{H/day\ @1sun} \tag{4.2}$$

Where:

P_{AC}: Ac Power per day.

H: Average solar energy input/day (KWh/m^2.day).

$E_{avg.}$: The average daily load energy (KWh/day).

$$P_{AC} = \frac{0.27\left(KWh/day\right)}{5.4\left(KWh/m^2 \cdot day\right)} = 0.05KW$$

$$P_{DC} = \frac{P_{AC}}{\eta_{con}} \tag{4.3}$$

P_{DC}: DC Power per Day.

η: Conversion Efficiency is equal 0.75

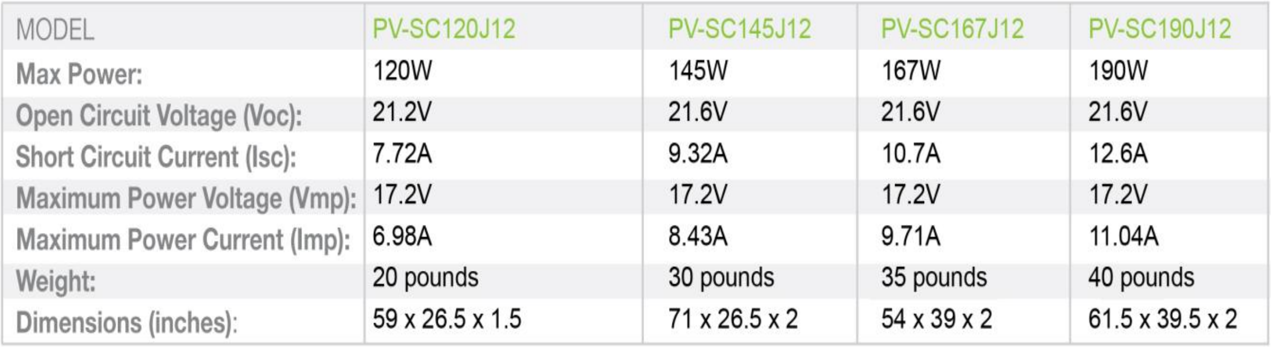
$$P_{DC} = \frac{0.05KW}{0.75} = 0.067KW$$

$$PV\left(area\right) = \frac{P_{DC}}{\left(H/day@1sun\right) \cdot \eta_{PV}} \tag{4.4}$$

$$PV\left(area\right) = \frac{67}{1000 \times 0.145} = 0.462m^2$$

The PV chosen (solar Cinergy polycrystalline panel PV SC145j12) from Table 4-2.

Table 2-1 Characteristics of PV



MODEL	PV-SC120J12	PV-SC145J12	PV-SC167J12	PV-SC190J12
Max Power:	120W	145W	167W	190W
Open Circuit Voltage (Voc):	21.2V	21.6V	21.6V	21.6V
Short Circuit Current (Isc):	7.72A	9.32A	10.7A	12.6A
Maximum Power Voltage (Vmp):	17.2V	17.2V	17.2V	17.2V
Maximum Power Current (Imp):	6.98A	8.43A	9.71A	11.04A
Weight:	20 pounds	30 pounds	35 pounds	40 pounds
Dimensions (inches):	59 x 26.5 x 1.5	71 x 26.5 x 2	54 x 39 x 2	61.5 x 39.5 x 2

$$No.\,of\ \mathrm{mod}\,ule = \frac{P_{DC}}{PV\ module(watt)} \tag{4.5}$$

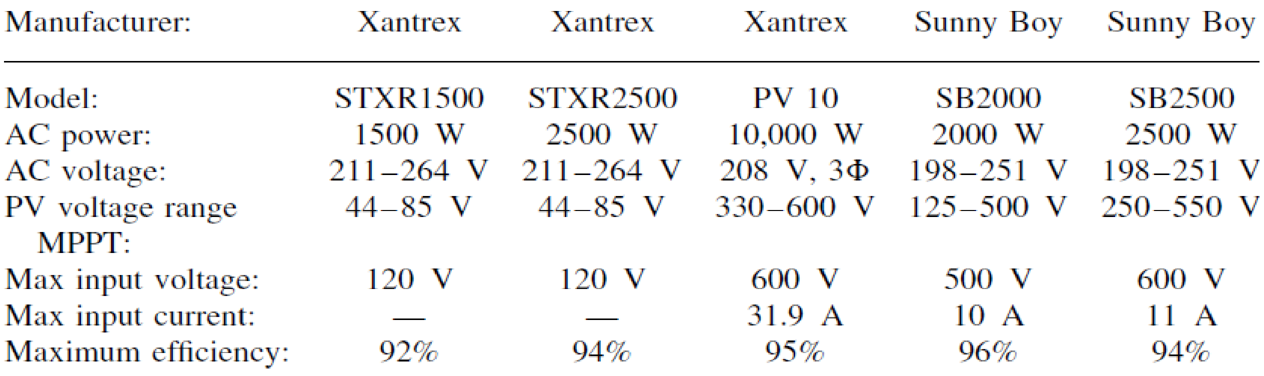
Use one plate of (solar Cinergy polycrystalline panel PV SC120j12)is enough .

$V_{mp} = 17.2v$ $\quad V_{OC} = 21.2v$ $\quad \eta_{PV} = 14.5\%$

4.1.3 Inverter Sizing:

In order to size the grid tied inverter suitable to PV system the main parameters should be determined from Table 4-3:

Table 2-2: Characteristics Inverter



Manufacturer:	Xantrex	Xantrex	Xantrex	Sunny Boy	Sunny Boy
Model:	STXR1500	STXR2500	PV 10	SB2000	SB2500
AC power:	1500 W	2500 W	10,000 W	2000 W	2500 W
AC voltage:	211–264 V	211–264 V	208 V, 3Φ	198–251 V	198–251 V
PV voltage range MPPT:	44–85 V	44–85 V	330–600 V	125–500 V	250–550 V
Max input voltage:	120 V	120 V	600 V	500 V	600 V
Max input current:	—	—	31.9 A	10 A	11 A
Maximum efficiency:	92%	94%	95%	96%	94%

V_{input} Should be located in the inverter MPPT voltage range (210~264V) and Max input voltage is equal 120V.

The efficiency > 92%

No. of module in series * max power voltage in PV is equal 1 * 17.2 = 17.2 V the MPPT range of 44–85 V for the inverter, so we chosen inverter “Xantrex (STXR 1500W) from Table4-3.

4.1.4 The Value Fuses Combiner:

- Combiner fuses > $I_{Sc} \times 1.25 \times 1.25$ = 7.27*1.25*1.25 =11.5A.

1.25: NEC(**National Electrical Code**) Current.

- Array of disconnect fuse > Combiner fuses * NO of string

Array of disconnect fuse > 11.5 * 1= 11.5A

- Inverter fuse > NEC current $\times \frac{\text{Ac power(inv)}}{220\text{V}}$

Inverter fuse > 1.25 $\times \frac{1500\text{W}}{220\text{V}}$ = 8.5A .

4.1.5 Small “Stand-Alone” Systems (off grid)

Later on chapter three, we explain the idea of small “Stand-Alone” solar system (Off Grid), and the block diagram shown in Figure 3-3 explain all system equipments, now we want to show our considerations in design and installation to apply this system properly.

PV array sizing

$$PV_{(area)} = \frac{E_{avg}}{H\times \mu\eta_{PV} \times TCF \times\eta_{batt}\times\eta_{inv}} \tag{4.6}$$

E_{avg}: The average daily load energy (KWh/day).

H: Average solar energy input/day (KWh/m^2.day).

η_{PV}: PV module efficiency.

TCF: Temperature correction factor.

η_{batt}: The battery efficiency.

η_{inv}:the inverter efficiency.

$$PV_{(area)} = \frac{0.27Kw}{5.4(KWh/m^2day) \times 0.145 \times 0.8 \times 0.9 \times 0.96} = 0.5\ m^2$$

$$PV_{(peake\ power)} = PV_{(area)} \times PSI \times \mu\eta_{PV} \tag{4.7}$$

$$PV_{(peake\ power)} = 0.5 \times 1000 \times 0.145 = 73\ watt$$

$$No\ of\ module = \frac{PV_{(peake\ power)}}{PV\ module(watt)} \tag{4.8}$$

$$No\ of\ module = \frac{73(watt)}{150(watt)} = 0.4867\ module$$

- ⇨ The PV chosen (solar Cinergy polycrystalline panel PV SC120j12) from Table 4-2
- ⇨ Choose one PV Panel just .

4.1.6 Design of the Storage system :

If they must provide 2 days of storage for a load that needs 30 Ah/day at 12 V,

$$Capacity(C) = Ampere\ (A) * hours(h) \tag{4.9}$$

C =30Ah , and the Average daily work order = 6 hours

⇨ I = 30 / 6 hours = 5 Ampere .

The storage capacity can be calculated according to the following relation

$$Battary\ storage = \frac{N_c \times Ah}{DOD \times \eta_{batt} \times \eta_{inv}} \qquad (4.10\ )$$

N_C: Number of continuous cloudy day =3day

DOD: The allowable depth of discharge for the batteries =0.8

$$Battary\ storage = \frac{3\times30}{0.8\times0.9\times0.96} = 130.1Ah\ .$$

From the Figure 4-2 we chose the Ratio is based on a rated capacity at C/20 and 25^{O}C. And we chose the type of battery from Table 4-2 (Surette 12SC11PS).

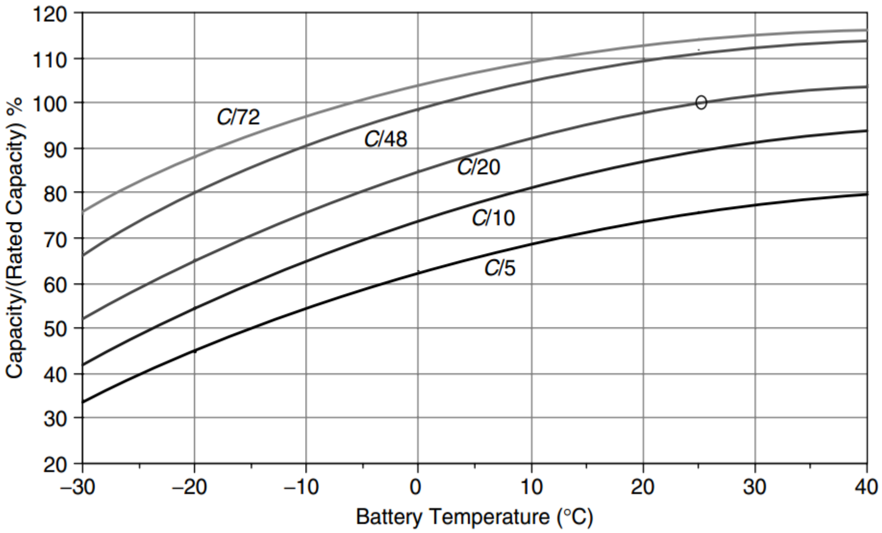
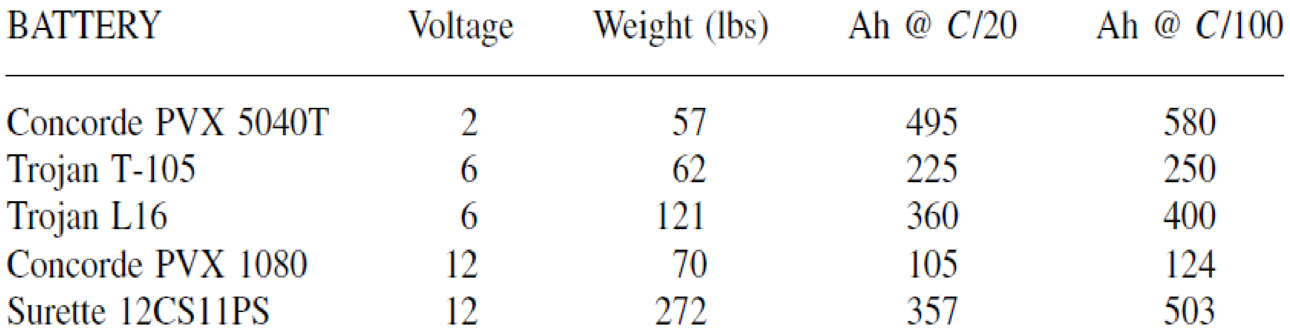


Figure 4–2 Lead-acid battery capacity depends on discharge rate and temperature

Table خطأ! لا يوجد نص من النمط المعين في المستند.-3 Characteristics of batteries



BATTERY	Voltage	Weight (lbs)	Ah @ $C/20$	Ah @ $C/100$
Concorde PVX 5040T	2	57	495	580
Trojan T-105	6	62	225	250
Trojan L16	6	121	360	400
Concorde PVX 1080	12	70	105	124
Surette 12CS11PS	12	272	357	503

If a 12 V system is chosen, the required amp. Hours of batteries=390/12=33 AH. If 12 V blocks with 100 AH each are chosen, 2 batteries (12 V, 200 AH) connected in parallel are needed, Figure 4-3 the system design of batteries.

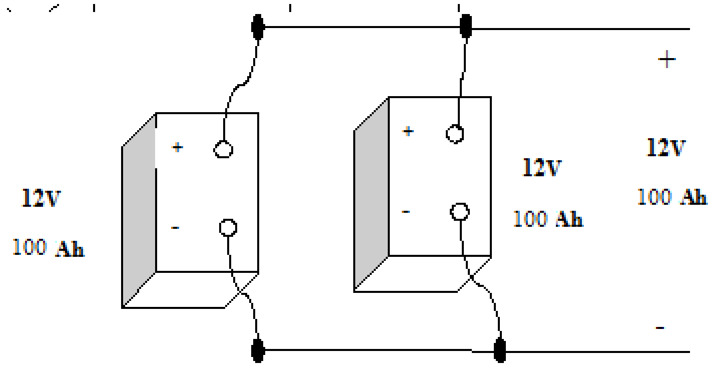


Figure 4–3 :System design of batteries.

Inverter Sizing :

V_{input} Should be located in the inverter MPPT voltage range (211~264V) and Max input voltage is equal 120V.

The efficiency > 96%

NO of module in sires × max power voltage in PV is equal $3 \times 17.2 = 51.6$v the MPPT range of 44–85 V for the inverter, **s**o we choose the inverter type of Xantrex “STXR2500”from Table 4-3.

4.1.7 Final PV System design:

The final design in solar system we must connect 1 modules in series (1 string) in Figure 4-4.

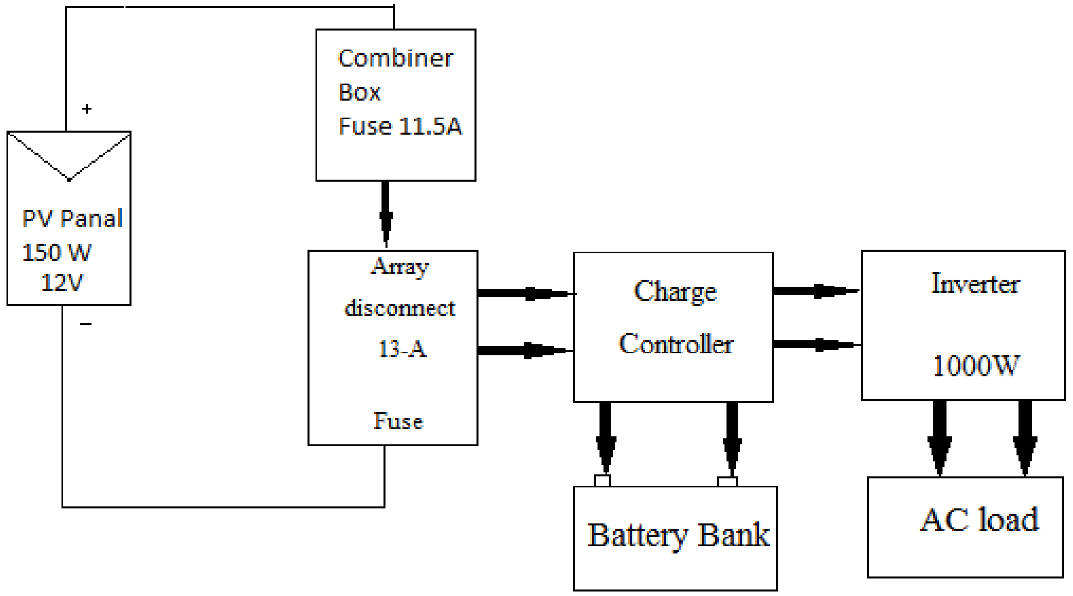


Figure 4–4 : The final design of the solar system

Results for Stand-Alone solar system:

After the theoretical calculations of this type of solar systems we conclude to the following:

The amount of energy that the system feed is 73 W.

The system needs to 1 modules.

The system needs inverter with 1000W.

The area used in the system $1m^2$.

The system needs two battery.

The costs of the system 1300$, it is high expensive.

4.2 Transfer Electrical Energy Wirelessly using Magnetic Resonance :

4.2.1 Literature Review :

For better comprehension theories related to Magnetic Resonant Coupling, quality factor and optimization techniques for wireless power transfer systems are presented here along with the working principles and constructions of various components. Magnetic coupling is an old and well understood method in the field of wireless power transfer. But as the magnetic field decay very quickly, magnetic field is effective only at a very short distance [24]. By applying resonance with in magnetic coupling, the power transfer at a greater distance can be obtained. For near field wireless power transfer, Magnetic resonant coupling can be the most effective method than any other method available. The block diagram for the whole experiment is shown below. It is consisting of an AC source, rectifier, oscillator, transmitter, secondary sources and load coil. It is observed that the voltage at a distance is better with an intermediate coil than without intermediate coil [25] .

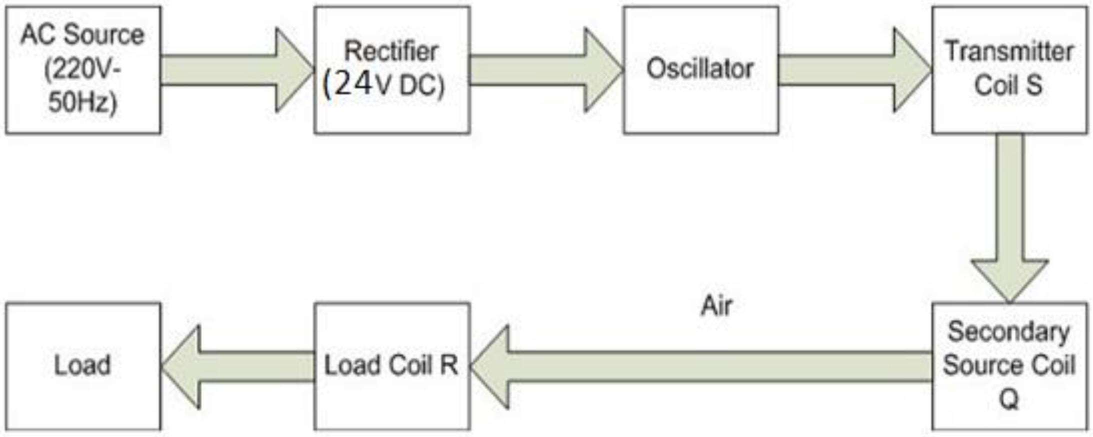


Figure 4.5 : Block diagram of the wireless power transfer system.

4.2.2 DESIGN PROCEDURES:

The overall concept for mutually inductive coils is an idea from an MIT experiment used to transmit power to power a light bulb [24]. The size of the inductors was increased and the number of turns increased due to ideal equations in hopes of lowering resonant frequency and increasing transmission efficiency. Many of the circuits were laid out from general knowledge of circuits or circuit diagrams given in datasheets . MATLAB simulation was done wherever possible to verify design before actual testing.

4.2.2.1 DC Source:

The DC source was designed with a rectifier and filter circuit. A full bridge rectifier was chosen because they have less ripple than a half bridge rectifier because the frequency is twice as fast. This means the filter has to supply the voltage for only half as long so it has less time to decay. Figure 4.6 shows the difference in the two rectifiers.

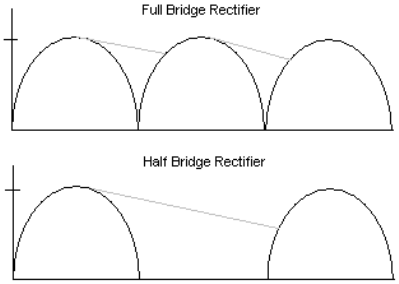


Figure 4.6: Rectifier Plots .

The capacitors were chosen with relatively high values and the design choice was verified in MATLAB with a simulation. Originally, 470 µF capacitors were used, but they did not provide the filtering needed in order to meet specifications. Various sizes were tried, and new 1000 µF capacitors were ordered to drive the size and voltage ripple down.

4.2.2.2 Full-Bridge Inverter and Gate Drivers:

The full bridge circuit is a generic circuit found on page 212 of [23]. The switches were chosen based on max frequency, current carrying capabilities, and voltage blocking. The speed is important because our switching frequency is several MHz at high voltage and a reasonable amount of current. The gate drivers were chosen because they have the appropriate frequency requirements and are designed to drive MOSFETs, also they have an inverting and non-inverting signals. This means that it can drive all of the MOSFETs. At first, the gate drivers and MOSFETs chosen were not fast enough to be able to handle the high switching frequency needed to make our coils resonant.

4.2.2.3 Coils and Air Gap:

The coils were designed using a series of ideal equations. If the coils are treated as windings around a transformer the reluctance can be calculated using equation (4.11) .

$$\Re = \frac{\ell}{\mu_o \mu_r A} \qquad (4.11\,)$$

where

l is the length of the circuit in meters .

$\mu 0$ is the permeability of vacuum, equal to $4\pi \times 10^{-7}$ henry per meter .

μ_r is the relative magnetic permeability of the material (dimensionless) .

μ is the permeability of the material ($\mu = \mu_0 \mu_r$) .

A is the cross-sectional area of the circuit in square meters .

$$\Rightarrow \mathcal{R} = \frac{20\,m}{4\pi * 10^{-7} \;\; *0.9999906 \; * \; 3.14 *10^{-4}} \quad = \quad 5.07 * 10^{6} \; \frac{A.turns}{weber}$$

Using the dimensions given and the relative permeability of air the reluctance is $2.026x10^{6}\frac{A}{Nm}$. The reluctance can be used to find the mutual inductance using equation(4.12).

$$M = \frac{4\pi N_1 N_2}{\Re} = \frac{4\pi N_1 N_2 \mu_o \mu_r A}{\ell} \quad (4.12)$$

$$\Rightarrow \; M = 4 * 3.14 * 10 * \frac{10}{5.07*10^{10}} = 2.477*10\text{^}{-4}$$

The resonant frequency is given in equation(4.13).

$$f = \frac{1}{2\pi\sqrt{MC}} = \frac{\sqrt{\ell}}{2\pi\sqrt{4\pi N_1 N_2 \mu_o \mu_r AC}} \quad (4.13)$$

Therefore, in order to reduce the resonant frequency using the mutual inductance the number of turns should be maximized, the area should be maximized, and the distance between the coils should be minimized. The distance between the coils was varied to observe the effects on coupling due to coil distance but would eventually be set around six feet to simulate the distance between a tabletop and ceiling. A value of 10 turns was chosen because it was a large value, but not large enough to start contributing too much unwanted factors from series resistance and winding capacitance. The diameter was set to 1 meter because it is large value but not too unreasonable of a size for a pad on or under a desk. The actual expected frequency can be calculated by finding the capacitance which is given by equation(4.14).

$$C = \frac{\varepsilon_o A}{\ell} \Rightarrow f = \frac{\ell}{2\pi A\sqrt{4\pi N_1 N_2 \mu_o \mu_r \varepsilon_o}} \quad (4.14)$$

$\Rightarrow f = 395.814$ kHz

Substituting in values for (4.13) and (4.14) results in a resonant frequency of 395.814 kHz. This is a very rough value because of losses in the air and non-ideal elements in the circuits. The actual measured natural frequency is around 3.4 MHz when measured using a signal generator with amplitude 20 $V_{p\text{-}p}$.

4.2.2.4 Transformer :

The transformer was designed based on the turn ratio needed to scale down the voltage and current requirements to prevent magnetic flux saturation of the core. The saturation magnetic flux is given by(4.15).

$$B_{sat} = \frac{i_{\max} \mu N}{\ell} \qquad (4.15\ )$$

The core losses were attempted to be minimized using (4.15). The number of turns was kept to a minimum to prevent losses from series resistance in the windings.

4.2.2.5 Rectifier and Filter:

The rectifier was chosen using a single diode to prevent loss because there is only current flowing through one diode and the frequency is fast enough that the full-wave is not need. The diode chosen had its frequency verified by looking at [26]. The capacitor was picked such that its resonant frequency is above 6 MHz because it will not act like a capacitor above this frequency. The inductance from the connections dominates the impedance, and a smaller capacitor was chosen than in the top filter because the self resonant frequency is higher. Ceramic capacitors tend to have a lower capacitance than electrolytic capacitors, but in this case the frequency is high enough that a lower capacitance is acceptable.

4.3 DESIGN DETAILS

4.3.1 DC Source

The DC source comprises of a rectifier circuit using 1N1188 diodes and a PI filter.

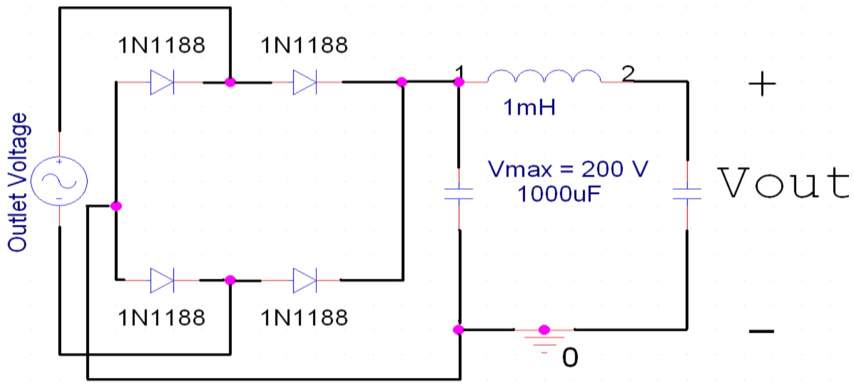


Figure 4.7: Wall Voltage to DC Rectifier and Filter (DC Source)

The 1N1188 diodes were chosen because they can carry more than 1 A and can block up to 400 VDC. They were also readily available in the parts shop. The voltage ripple from this circuit is hard to calculate on paper due to the fact that it is a third order filter. The inductor was chosen at a standard part value and verified in PSPICE that it can regulate the current properly. A PSPICE simulation was run with Dbreak diodes in place of the 1N1188, because there is no PSPICE model available for the 1N1188. The diodes should not noticeably affect the output voltage. The output signal is connected by switches operating at the speed that the full-bridge inverter is expected to operate at. The purpose of the switches is not to test the full-bridge inverter circuit, but make sure that the output voltage is properly regulated.

4.3.2 Full-Bridge Inverter/Gate Drivers

This inverter takes in the voltage from the DC source and through using the Arduino and gate drivers, outputs signal in the form of a square wave with a frequency that is controlled by the Arduino and is adjusted based on induced current in the coil. The gate drivers are ICs that take in the signal from the output the right amount of voltage to turn on and off the power MOSFETs in the full-bridge inverter. The power MOSFETs are IRF6785s. They were chosen because they had the correct current and voltage ratings from [25]. The trouble with our original MOSFETs was that they were nowhere near fast enough to switch at our estimated resonant frequency of 3.4 MHz. The IRF6785s are very small and efficient in order to be able to switch very quickly, while still allowing the current needed.

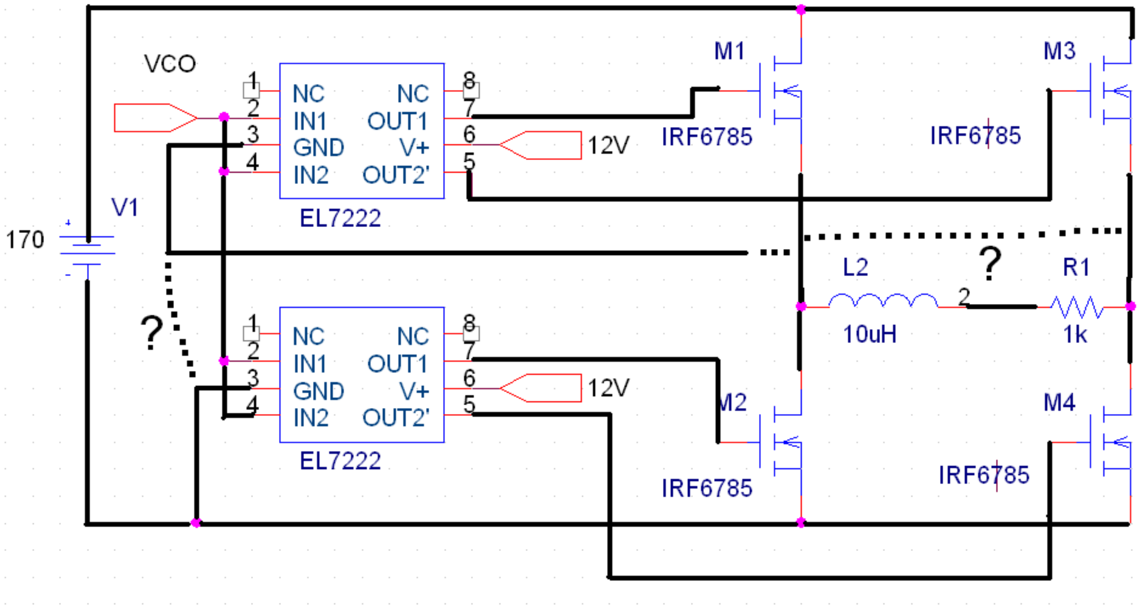


Figure 4.8: Gate Drivers and Full-Bridge Circuit

Figure 4.8 the final design for the gate driver and full-bridge inverter circuit. The MOSFETs were changed to IRF6785s due to the fact that the IRF640s were not fast enough to operate at the frequency needed. To simulate the circuit the drivers were replaced with voltages pulses with rise and fall times of corresponding to the drivers. This was done because the no PSPICE models were available for the drivers, and the main concern with drivers is that they can operate fast enough. The gate drivers that were used in the final design are used for driving frequencies in the RF range, so they should be plenty fast.

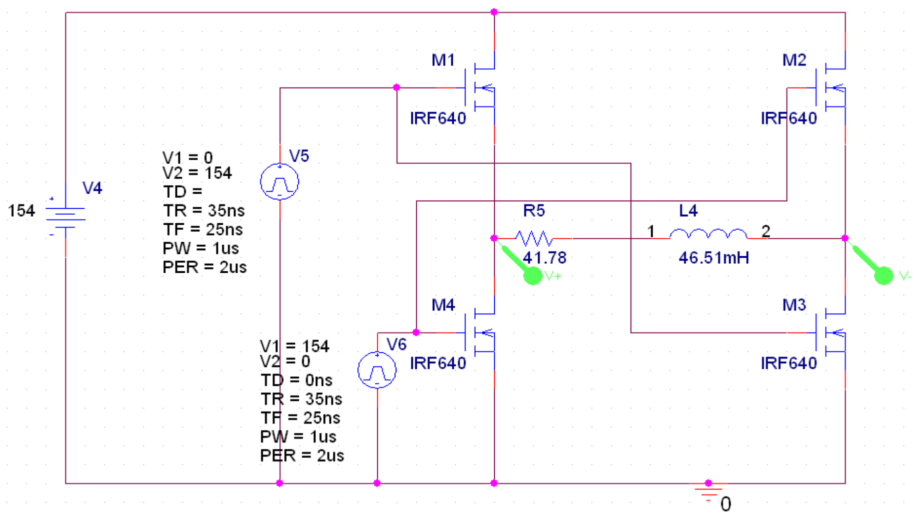


Figure 4.9: PSPICE Test Circuit for Full-Bridge Inverter

The output from the full bridge inverter is as expected and is a square wave that oscillates from +150 V to -150 V at the specified frequency.

Unfortunately the MOSFETs chosen for the H-bridge had two main problems. The first problem was that they did not turn off fast enough. This will result in two MOSFETs being on at the same time and shorting out the voltage source. In order to correct these problems, two solutions were attempted. The first involved increasing the current through the MOSFETs. This should help because the turn off time is related to the charge stored on the MOSFET and increasing the current should help the charge to dissipate faster. The current was still limited by the power dissipation capabilities of the resistor and the turn off time was decreased, but not enough to operate the H-bridge. The other solution was increasing the supply voltage to the gate drivers so they can use more power to turn off the MOSFETs. This did not help noticeably. The next step would be to measure the capacitances and resistances of the MOSFETs to see if the RC time constant could be decreased. This might require a new PCB if the long turn off times are an artifact of the board layout.

The second problem is turning on and off the MOSFETs. The bottom two MOSFETs can be controlled with a single gate driver because they share the same source, but the top two transistors have their sources connected across the load. If one gate driver was connected across them, the load would be shorted out. One solution for this problem was to use PMOS transistors up top instead of NMOS transistors. PMOS's are connected in the opposite way as NMOS transistors so the voltage drop could be applied across the gate and source since the source and gate are connected. The transistors that were found were actually a little faster than the NMOS transistors, but they could not go all the way to 3.5 MHz. According to [25], the PMOS transistors should be fast enough. The other problem is that two gate drivers are needed because the ground of the first gate driver needs to be the negative terminal of the voltage source and the second gate driver for the PMOSs needs to be connected to the positive terminal of the voltage source. Both isolation issues are drawn on Figure 4.9 with dashed lines.

This creates problems because the gate drivers need to have the same ground in order to reference the signal from the Arduino . These problems could be potentially solved by using a transformer that could have enough output coils for each gate driver. Several circuits were attempted to transform the signal, but the gate drivers either got hot because there signal has a DC component since it goes from 0 to 12 V and DC signals don't go through transformers. When a high pass filter was attempted to removed the DC component the output signal was static. More time would be needed in order to figure out problems with the transformer, but it is probably the best solution to the isolation problem. The two transformer circuits used were found in [26]. They are also in Figure 4.10 and Figure .

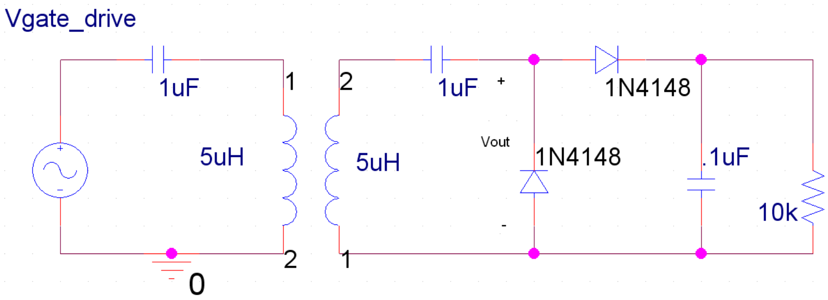


Figure 4.10: First Transformer Isolation Circuit

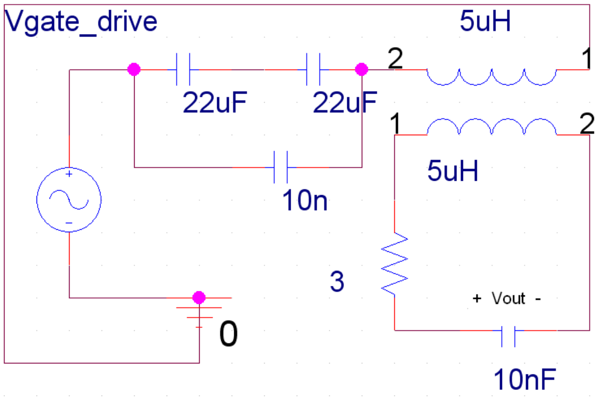


Figure 4.11: Second Transformer Isolation Circuit

4.3.3 Arduino :

The Arduino Uno is a microcontroller board based on the ATmega328 . It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

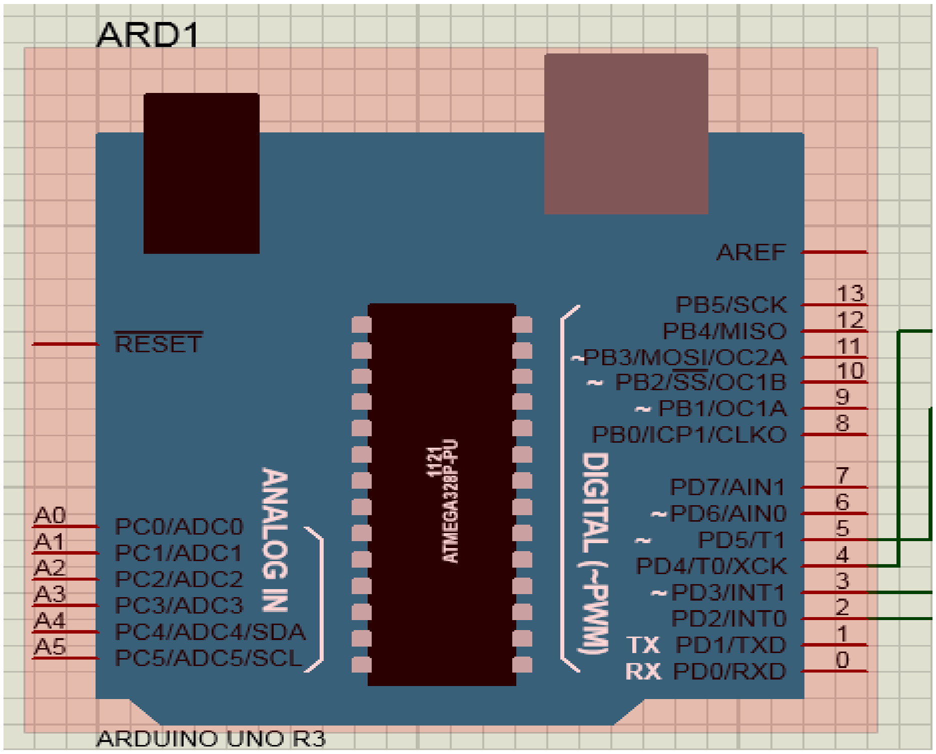


Figure 4.12:Ardino Module

4.3.4 Current Sensor

A very low resistance resistor will be put in series with the coil. The voltage is then measured across it to determine the current through the coil based on the voltage drop and resistance. The extra parts in this circuit are to protect the op-amp. The op-amp was not rated for 150-170 V common mode voltage, but it was found on the datasheet that this circuit would work [26].

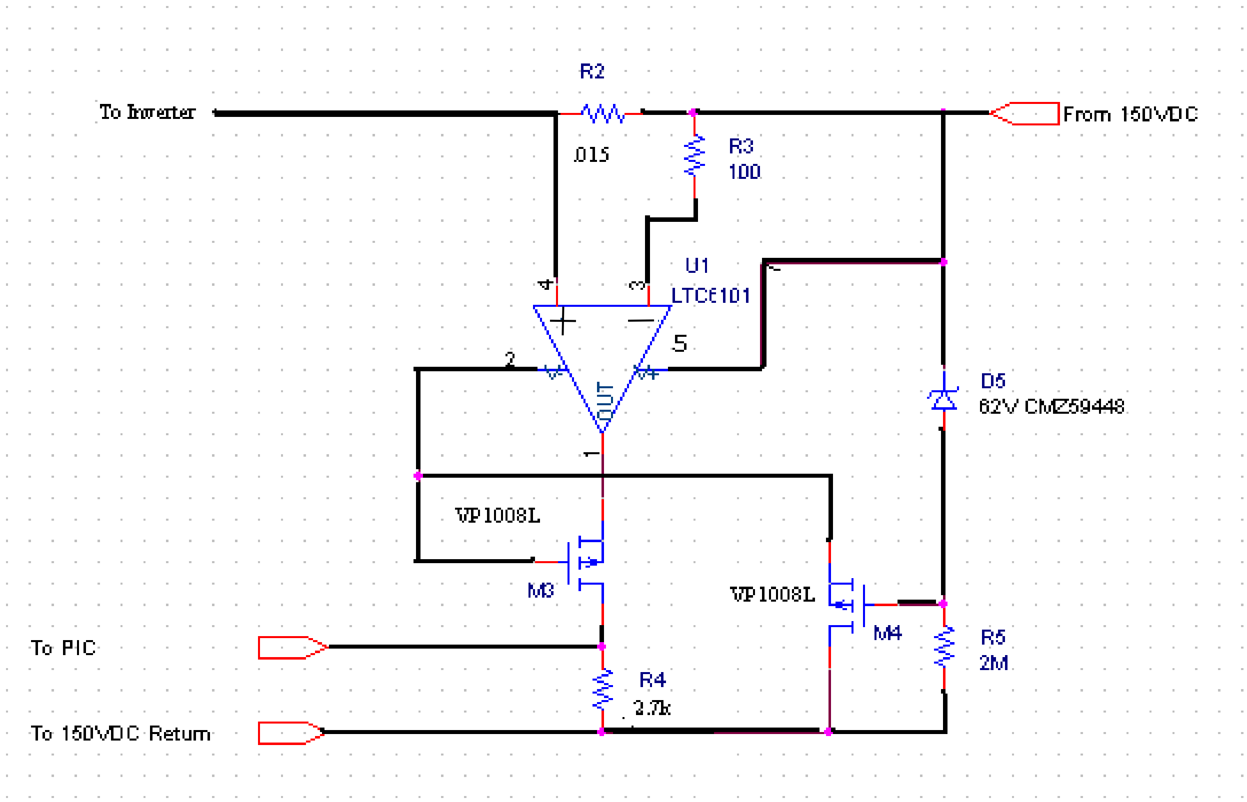


Figure 4.13: Current Sense Circuit

4.3.5 Coils

An inductor made with about 10 turns and a diameter of around 31.5 m. It will also have a current limiting resistor in series to make sure nothing burns up. An inductor like the top coil that will receive the electromagnetic waves transmitted by the top coil and have a current and voltage induced to power the devices. The inductance of either coil was around 27 mH. This was lower than calculated but still relatively high. Preliminary tests were done on the coils to find their resonant frequency. Multiple frequencies were found, including 3.4 MHz, 6 MHz, and one around 9 MHz. The most resonant of these being the 6 MHz signal, but the 3.4 MHz was chosen for the target frequency, due to the fact that it is easier to find parts for and will work nearly as well. These frequencies were far from the expected frequency. This could be due to a multitude of factors including skin effect of the 00 AWG wire, imperfections in the windings, incorrect permeability numbers, incorrect estimates of capacitance, and fringing among others.

4.3.6 Transformer

The transformer was not made because we were never able to get a voltage on the bottom coil so it was hard to figure out a turn ratio and what the saturation current would be.

4.3.7 Half Wave Rectifier

A diode that will take the signal induced in the bottom coil and cut off the negative side of the AC, helping to create a DC signal.

Filter: A series 1mH inductor and a capacitor to ground that will filter the signal output by the rectifier making it a smoother signal.

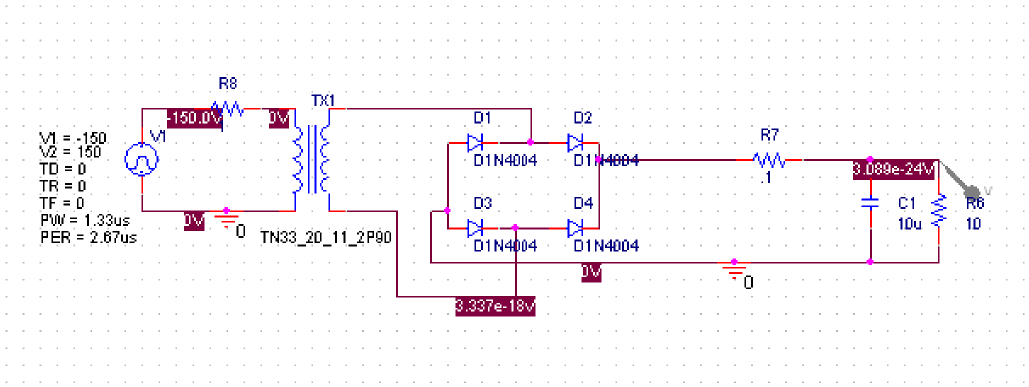


Figure 4.14: Circuit Diagram for Transformer, Rectifier, and Filter

4.3.8 DC/DC Buck Converter

A Buck-Converter will step the 18 V for the laptops down to 5 V for a phone. Initial tests found that the regulation by this buck converter is outstanding, changing 1 mV or less through the recommended input voltage range.

5

Chapter Five

Implementation, Experiments and results

5

Chapter Five

Implementation, Experiments and Results

5.1 Introduction :

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

5.2 System components and Circuits :

5.2.1 Photovoltaic Solar System:

5.2.1.1 Photovoltaic Panels :

Solar Cinergy polycrystalline panel PV SC145j12 , Vo.c =21.6 V ,

Is.c =9.32 A , Vmp =17.2 V , Imp=8.43 A . Show Appendix A

Figure 5-1 : PV panel of Solar system.

5.2.1.2 Inverter :

1000W MPPT Solar photovoltaic on Grid Tie/Tied Power Inverter PV, Pure Sine Wave, dc 12v to ac220v (SUN-1000G). Show Appendix B

Figure 5-2: Inverter of Solar system

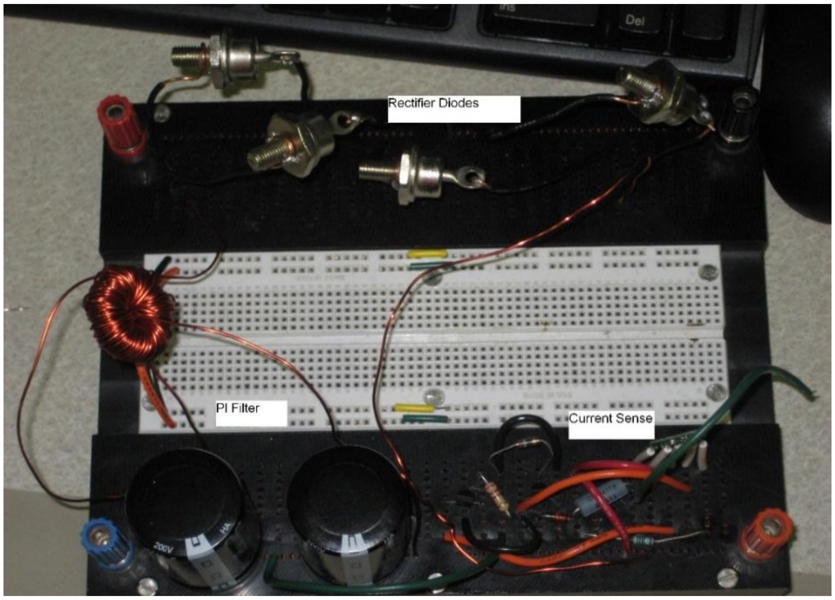
5.2.1.3 Battery:

T-1275 Deep Cycle 12V Golf Car, Marine, RV, Solar Battery Specs, Volt = 12 @56 amp = 102 Ah , 20 Hr Rate = 150 Plates / Cell = 17 Length = 12 7/8 , Width = 7 1/8 Height = 10 7/8 , Weight = 82 lbs. Show Appendix C .

Figure 5-3: Battery of Solar system

5.2.2 Wireless Energy Transfer:

These are pictures taken of our physical circuits. The last picture is a picture of our coils.. Figure (5-4), is the DC source and current sense circuit on a power board. Figure (5-5), the circuit with the Arduino and gate drive . Figure (5-6) is the buck converter circuit. Figure 5-7: Photo showing one of experiments done on the project , Figure 5-8: Photo showing coils used on the project for experience , Figure (5-9) is our PCB with our MOSFETs .



. Figure 5-4: DC Source and Current Sense

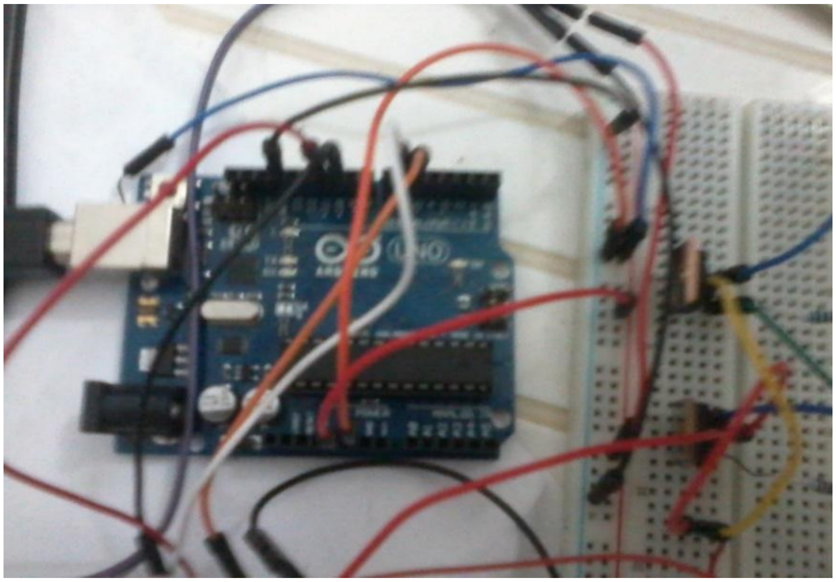


Figure 5-5: Arduino and Gate Driver

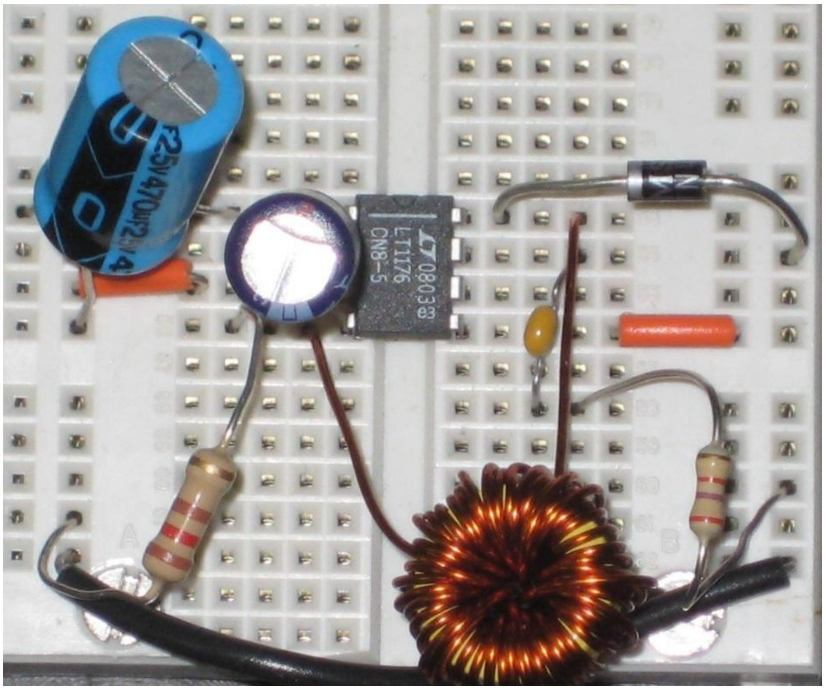


Figure 5-6: Buck Converter Picture

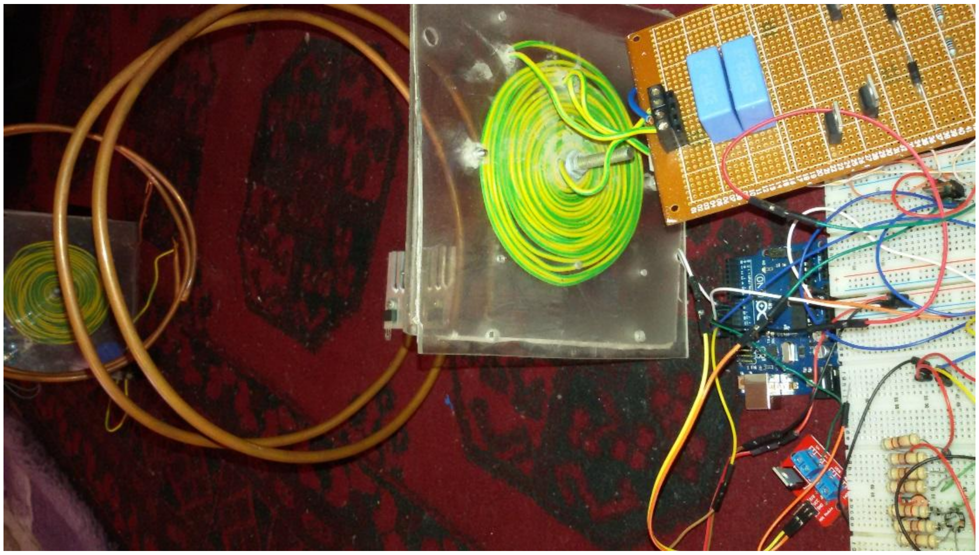


Figure 5-7: Photo showing one of experiments done on the project

Figure 5-8: Photo showing coils used on the project for experience

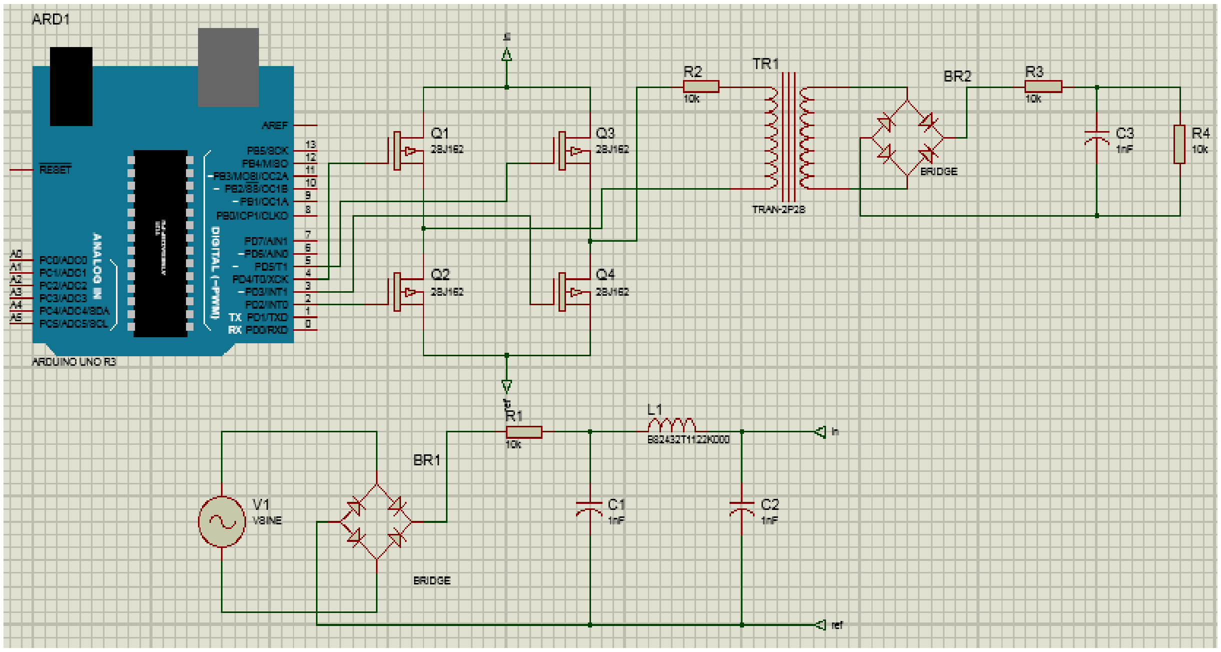
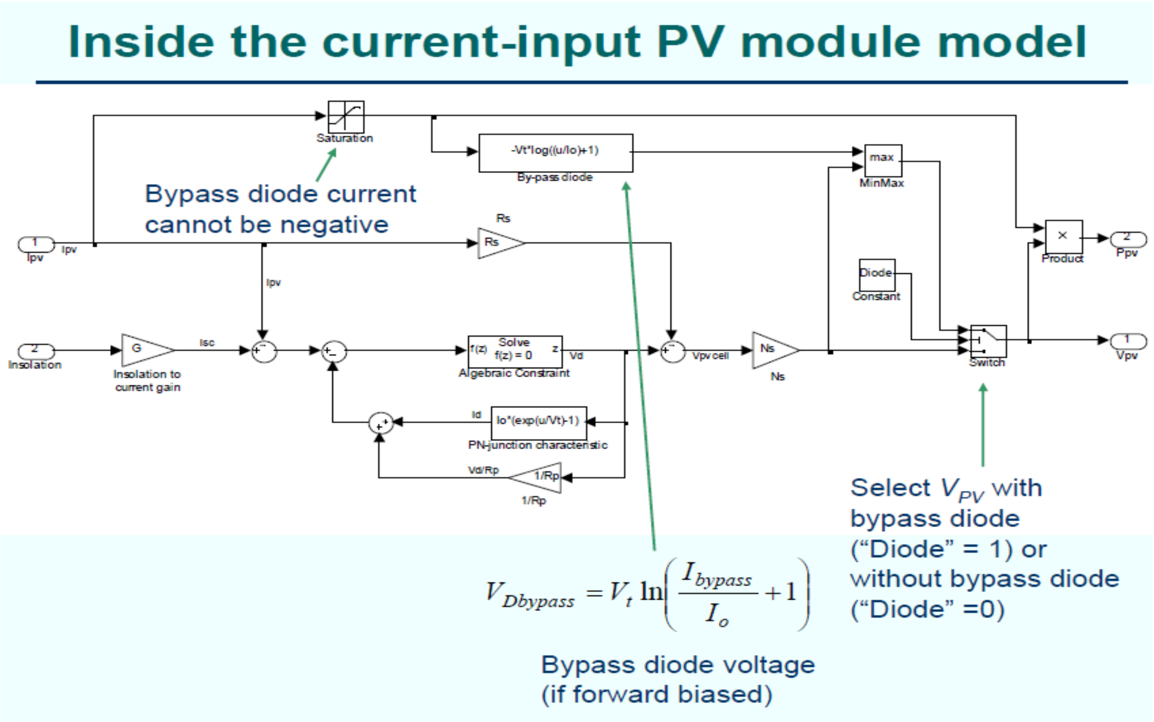


Figure 5-9: PCB.

5.3 Testing and Results.

System testing and results using Matlab Simulation :

5.3.1 PV Solar System:



Inside the current-input PV module model

Bypass diode current cannot be negative

Select V_{PV} with bypass diode (“Diode” = 1) or without bypass diode (“Diode” =0)

$$V_{Dbypass} = V_t \ln\left(\frac{I_{bypass}}{I_o}+1\right)$$

Bypass diode voltage (if forward biased)

Figure 5-10 : Inside the current –input PV module model .

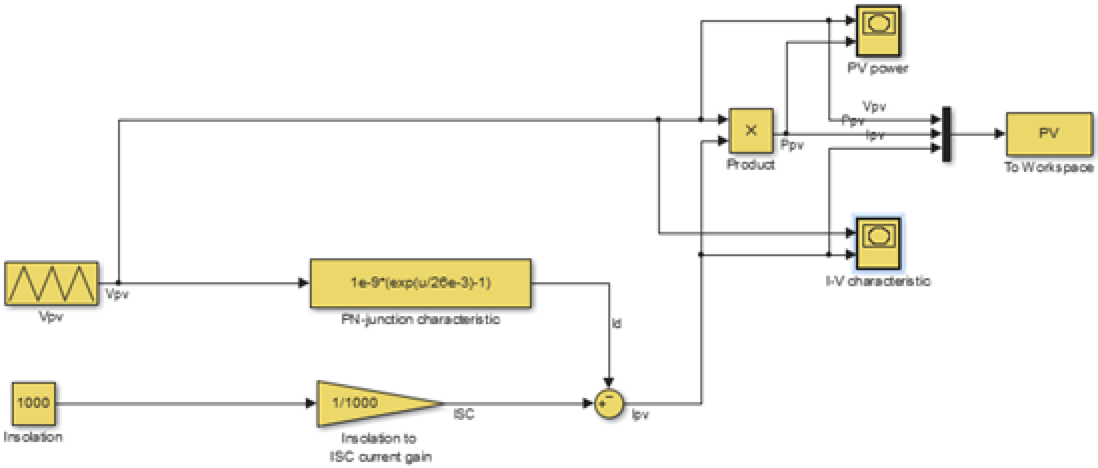


Figure 5-11 :PV Module Characteristics using Matlab Simulink ..

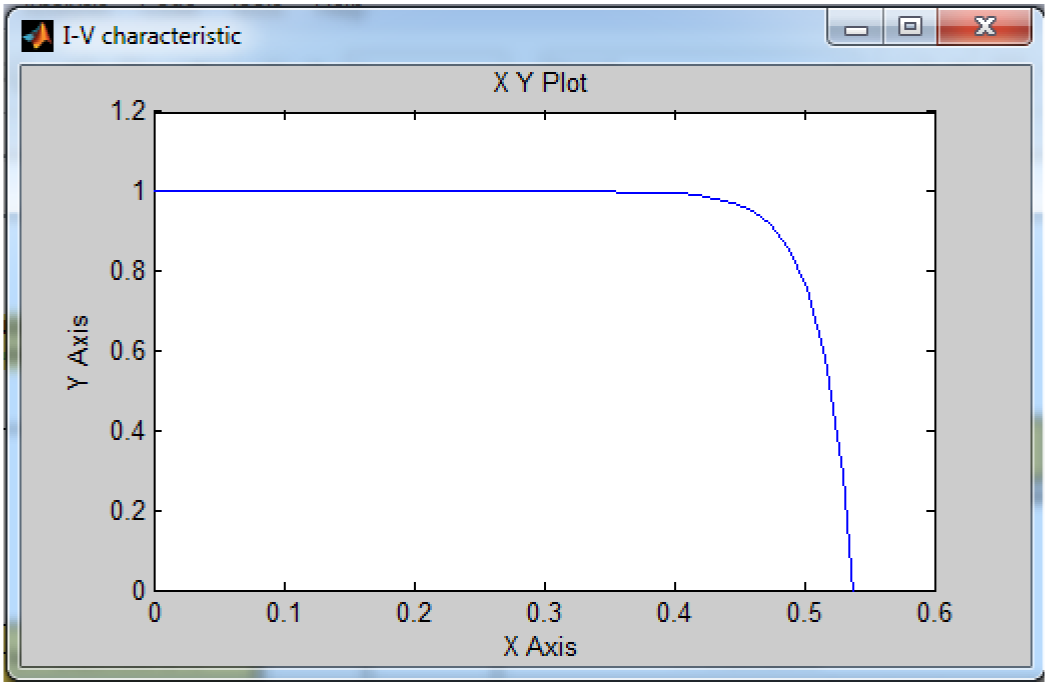


Figure 5-12 : I – V Characteristics

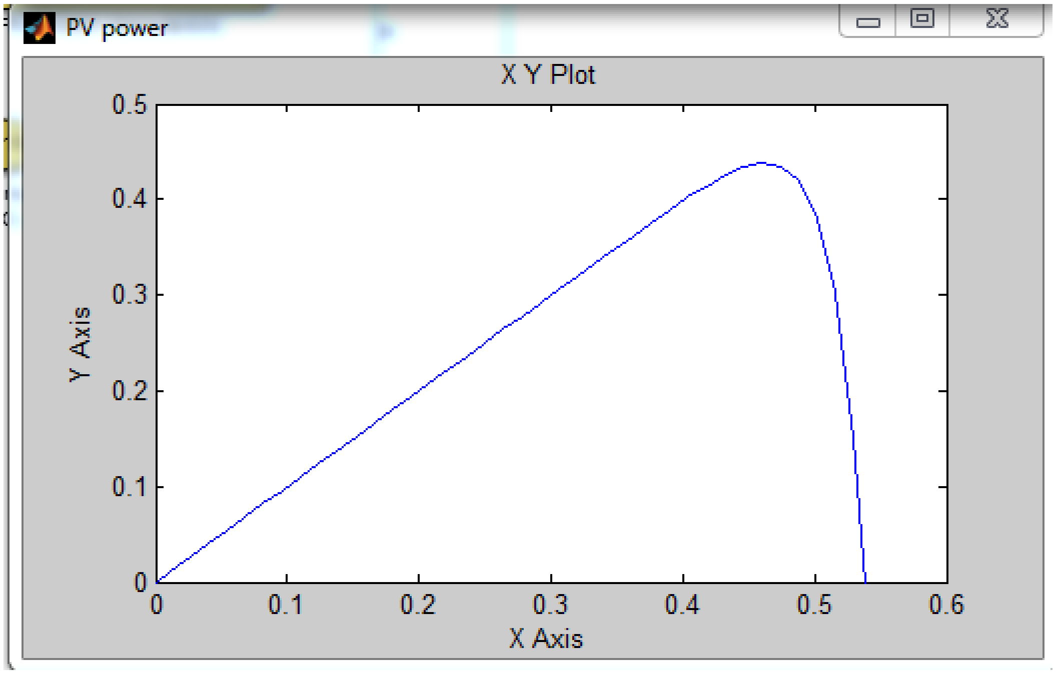


Figure 5-13: PV Power Characteristics

5.3.2 Wireless Power Transfer :

5.3.2.1 DC Source:

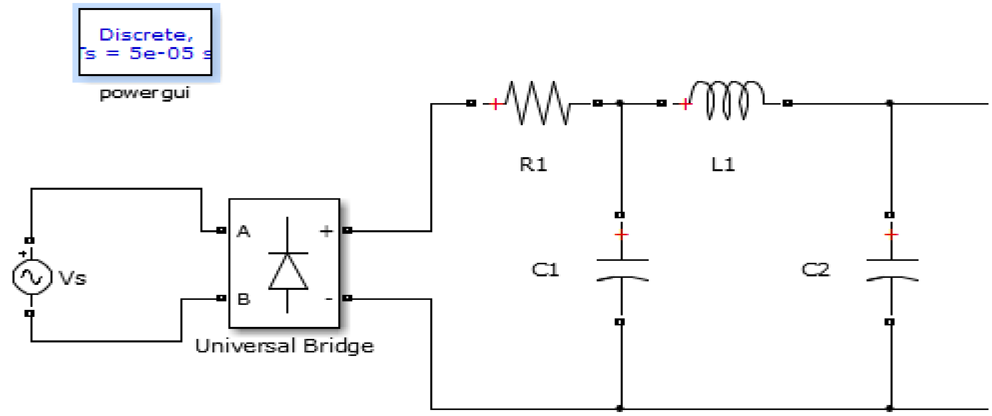


Figure 5-14 : DC Source using Matlab Simulink

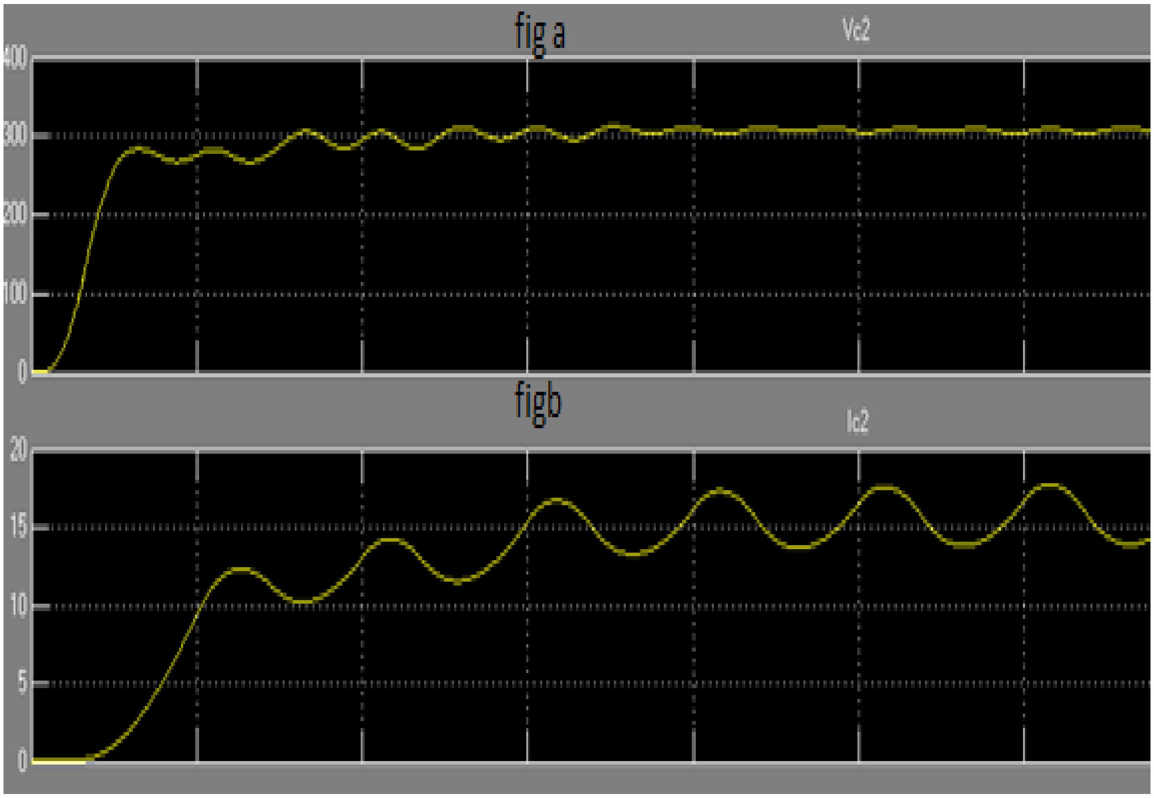


Figure 5-15 : fig a _ Relationship represents the value of the voltage(volt) on the cap. (c 2) & fig b _ Relationship represents the value of the current(Amp.) on the cap. (c 2)

5.3.2.2 Full Bridge Inverter :

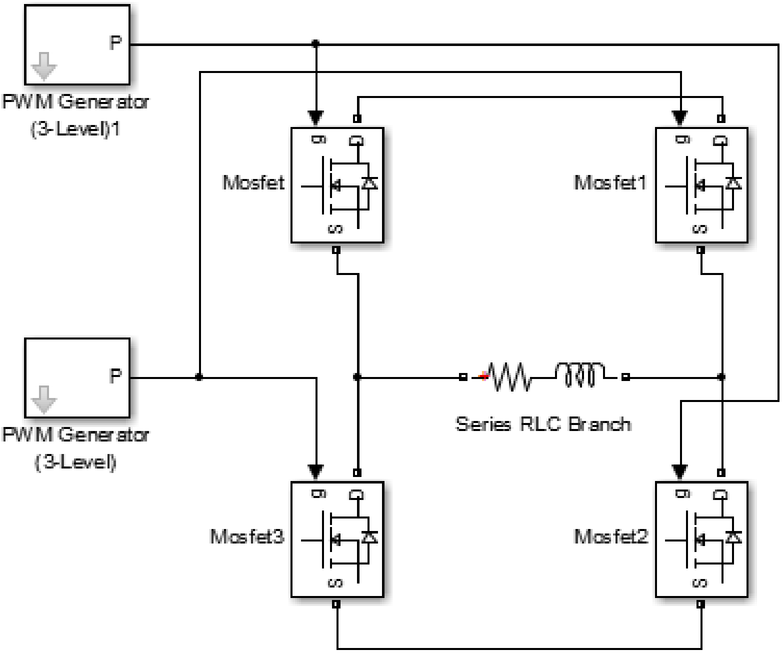


Figure 5-16 : Full Bridge Inverter Circuit

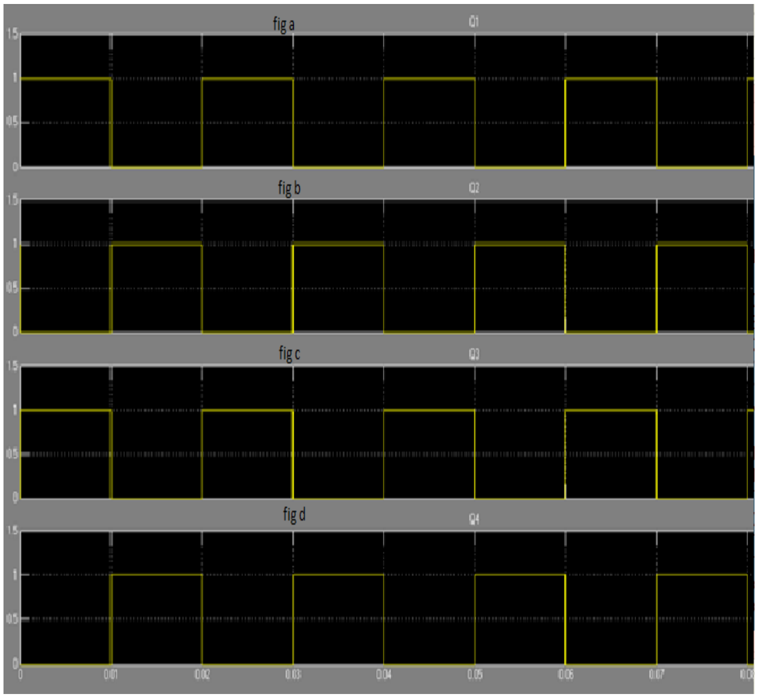


Figure 5-17: Relationship represents directed to form the MOSFET gate (Q1-Q4)

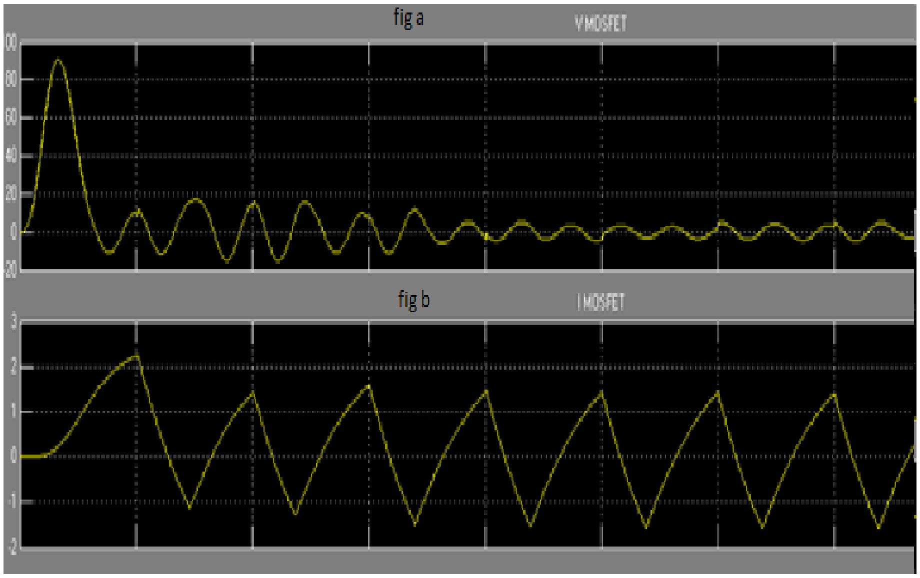


Figure 5-18 :fig (a)Relationship represents the voltage value (volt) & fig (b)Relationship represents the current value (Amp.) .

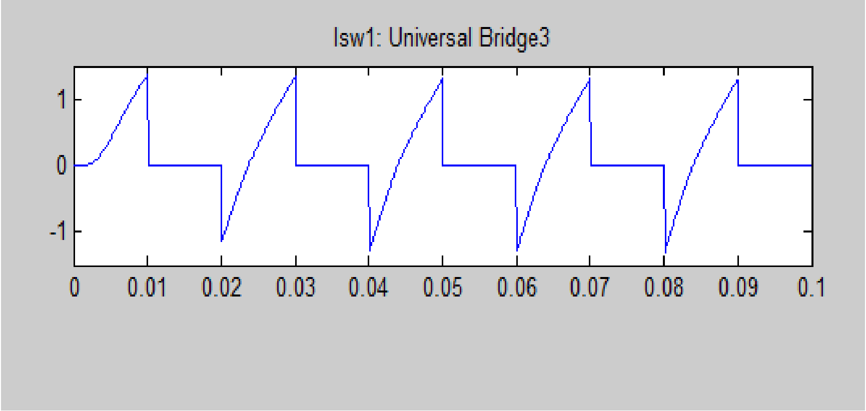


Figure 5-19: Relationship represents the current value for Mosfet .

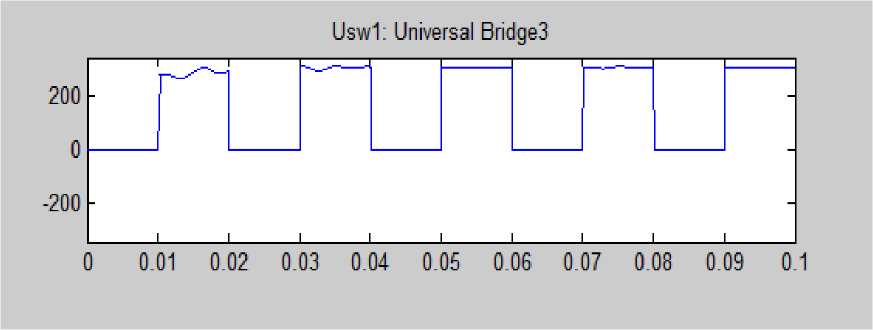


Figure 5-20 :Relationship represents the voltage value for Mosfet .

5.3.2.3 Coils and Air Gap

Figure 5-21:Transmitter and Receiver Coil using Matlab Simulink .

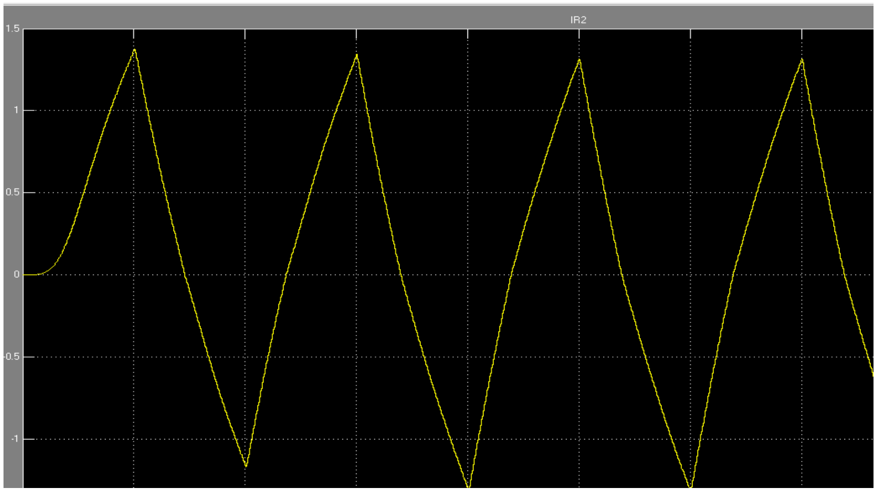


Figure 5-22:Relationship represents the current value of the resistance

5.3.2.3 Rectifier and Filter :

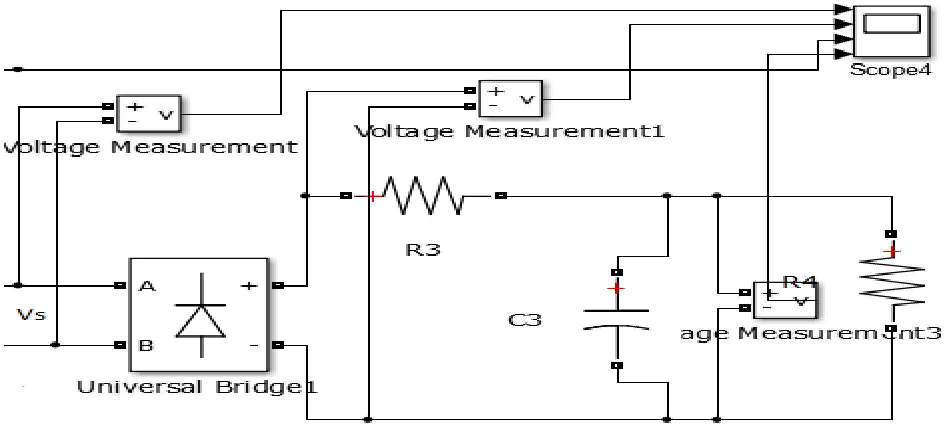


Figure 5-23:Rectifier and Filter and Load element using Matlab Simulink .

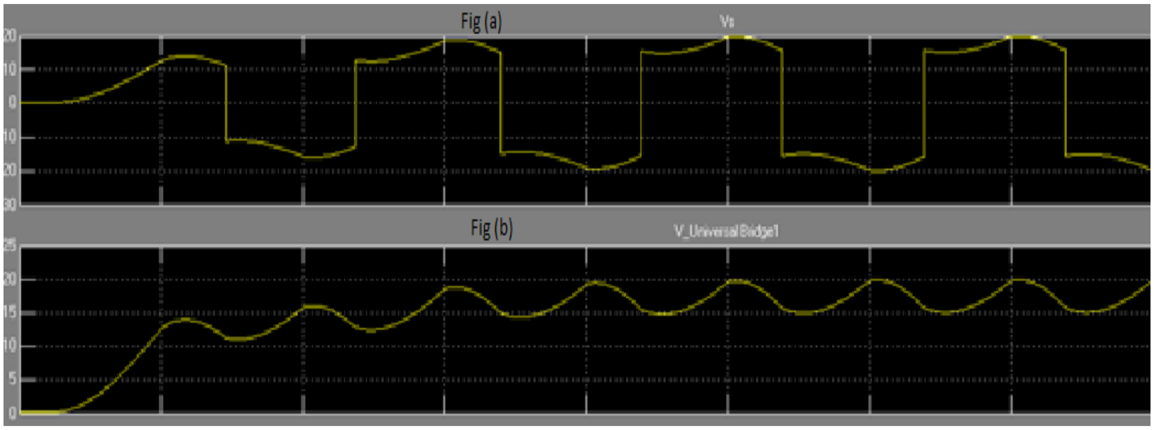


Figure 5-24 :fig (a) Relationship describes the voltage value of the inside Rectifier circuit & fig (b) Relationship describes the value of the outside voltage of Rectifier circuit .

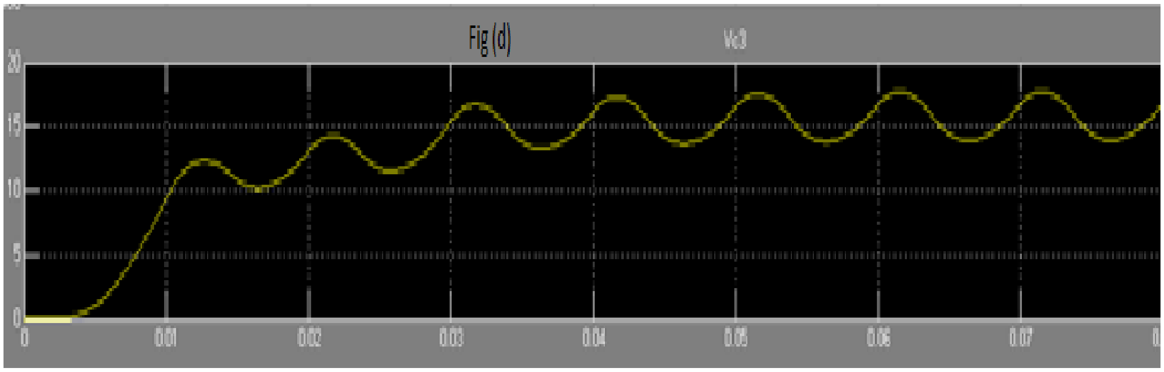


Figure 5-25: Relationship describes the voltage value of cap.(c3).

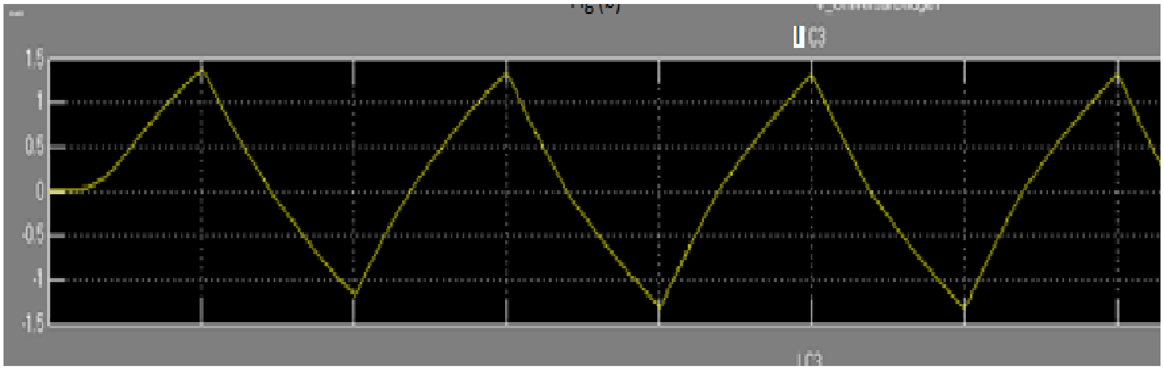


Figure 5-26: Relationship describes the current value of cap.(c3).

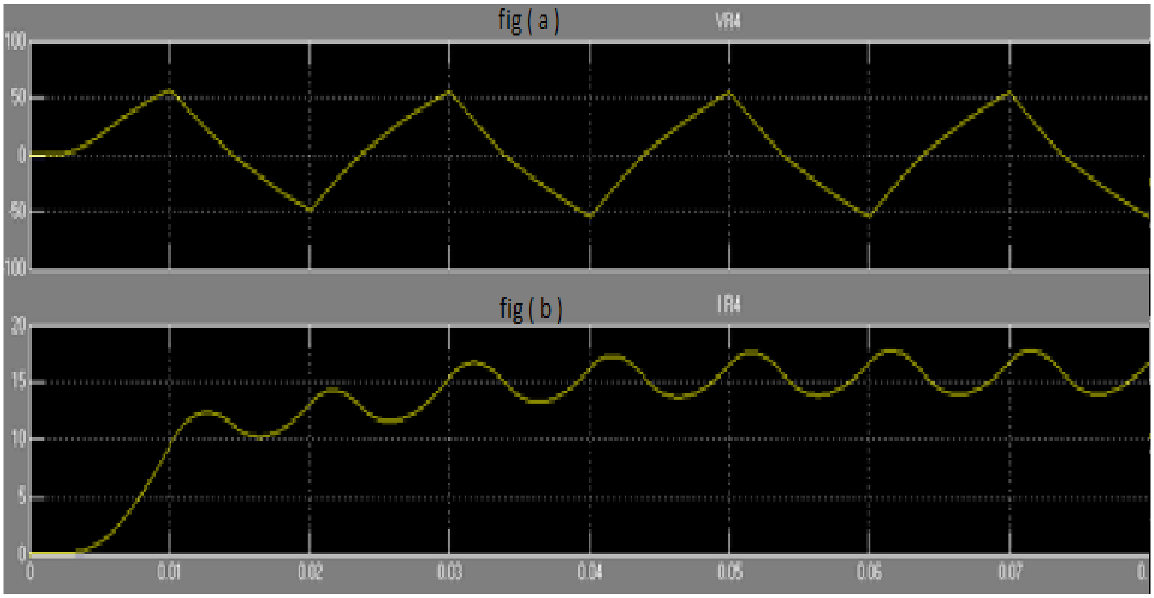


Figure 5-27 :fig (a) Relationship describes the voltage value of the Load   & fig (b) Relationship describes the value of the load .

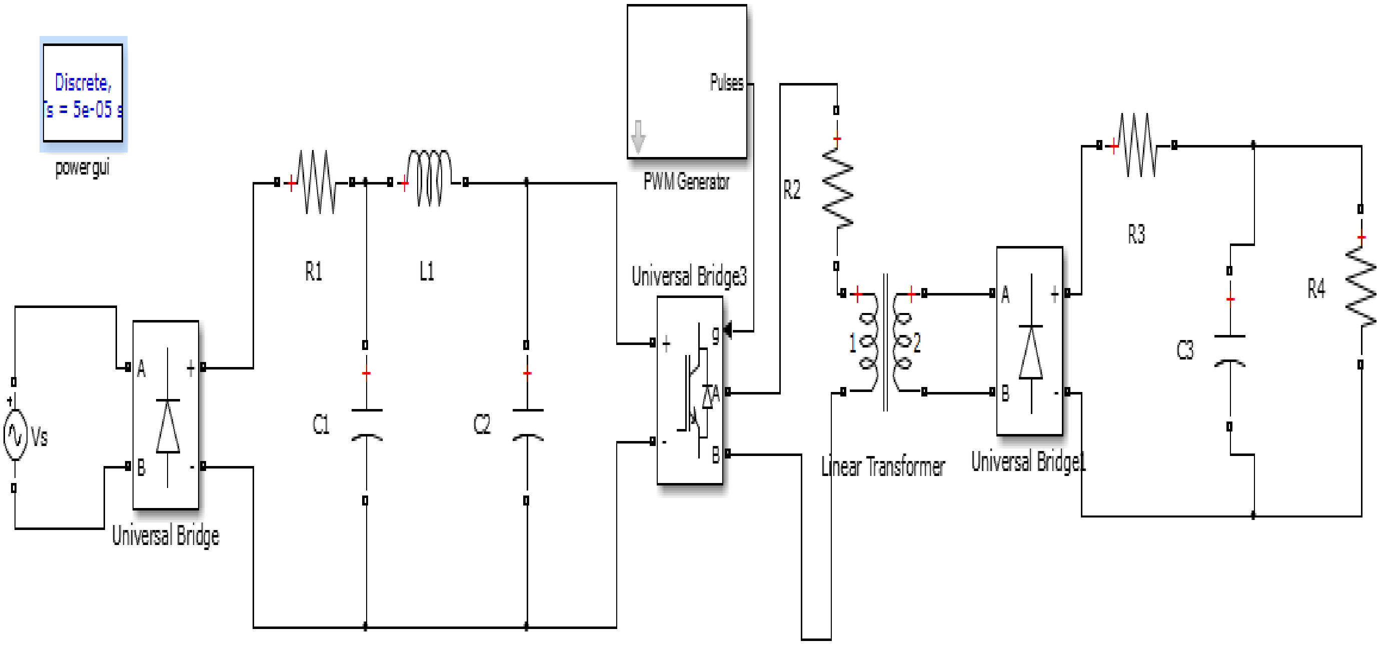


Figure 5-28:Final energy circuit using MATLAB

5.4.2 The circuit efficiency.

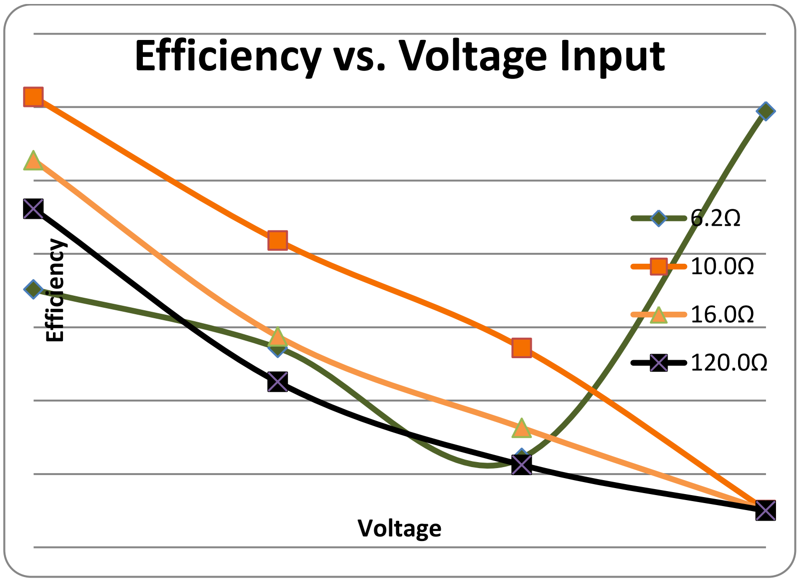


Figure 5.29: Efficiency vs. Voltage Input

Looking at the graph, the efficiency increases as the load resistor decreases and the input voltage increases. The exception to this trend is the 6.2 **Ω** resistor because it is at the limits of power output and the converter could only give 3.3 V with this resistor. These efficiencies are not good, and in order to improve this circuit it would have to be built from scratch instead of using an IC. This would allow for more control of variables and more current could be pulled.

The transmission efficiency was measured through the voltage coupling. It was around 22%, which is under the specification. The coupling test was done at a much lower voltage than when fully rated and the higher voltage will induce higher currents that will in turn produce a higher magnetic field and hopefully give better coupling. The circuit overall efficiency was calculated using(5.1).

$$\eta_{total} = \eta_{DCsource}\left(\frac{P_{in} - P_{loss}}{P_{in}}\right) \tag{5.1}$$

The efficiency of the DC source is about 97% and the loss of about 1.2 W in the top half of the circuit at 60 W of power in results in a total efficiency of 95%. That value is then multiplied times the transmission efficiency to find the total efficiency.

Table5-1: Table Theoretical and practical comparison for 10 watt bulb

Distance	Output Voltage (Theoretical)	Output Voltage (Practical)
7cm	17 volts	14 volts
10cm	15 volts	11.1 volts
15cm	12 volts	8 volts
21cm	11 volts	6 volts

6

Chapter Six

Recommendation, Challenges and Conclusions.

6

Chapter Six

Recommendation, Challenges and Conclusions.

6.1 Conclusion
6.2 Problems and Solutions
6.3 Accomplishments
6.4 Future Work

6.1 Conclusion

Apart from losses due to non-ideal characteristics of the inductor and capacitor, radiation loss and ohmic loss; the total power transmitted might not be received because of the loading effect of the receiver which causes the system to “de-tune” from resonance and weakening the coupling factor. Also wave attenuation occurs when it passes through a lossy dielectric medium (free space, air). If the effect of the losses can be minimized then the efficiency of the overall system can be improved to desired levels.

In our project the main goal was to design and implement a system that transmits power without wire. In this purpose, a transmitter circuit was implemented. At the end of the transmitter circuit an antenna was connected, which transmits the power. Another antenna was used to receive the power wirelessly from the transmitter circuit. In this project hollow copper pipes were used as antenna, because it has high Q-factor and high power handling performance.

It requires a huge task to implement the whole project. During implementation a number of remarkable problems have been faced and have been solved as well. Though these implementation sessions requires patience, it made real joy after successful solution.

6.2 Problems and Solutions

The Problems that were faced during the testing period as well as the solution are given below:

At the inaugural state project, it has to overcome some hurdles to take the decision of development considering the lowest consumption of implementation.
Since efficient midrange wireless power transmission is a recent technology, there is not enough information available about this technology. The work has been done in this project is totally new and different than any other power transmission method.

It was at first thought that in the circuit Vacuum Tube transistors would be used which provides much higher power than the typical power MOSFETs. Later this idea was eliminated as vacuum could not be found in the shops available.

At first, the transmitter circuit did not oscillate; instead it shorted the power supply and one MOSFET and inductor heated up rapidly. Later it was found short circuit that was caused by power supply voltage which was rising too slowly on power-up. This was solved by using a switch on the low voltage side that was placed between arduino and the rectifier.

Another problem faced when the Arduino started to oscillate so that very little power was available on the load coil. Because the receiver coil was slightly out of resonance, it could not pick up the power properly. This was solved by building both LC-tank circuits with identical loops and capacitances, so that 3rd of the circuits have the same resonant frequency.

The project was not functional at the end of our time to work. All components except the full-bridge inverter worked as expected. The filters and other control circuitry were more efficient than estimated in the beginning of the class but other parts of the project were much less efficient than planned. To meet the desired specifications, the entire project would have to be working properly and some new parts may have to be ordered.

6.3 Accomplishments

- Proved that power can be transmitted via resonantly coupled coils
- Multiple resonant frequencies found at many coil spacing
- Arduino able to regulate frequency based on current measured
- Frequency of DC wall voltage filtered with a small voltage ripple
- 300 KHz signal able to be filtered with a small voltage ripple

6.4 Future Work

In order to get this circuit working the inverter would need to be looked into much further. Someone who has a lot of experience working with higher voltage and/or higher frequency inverters would undoubtedly have no trouble solving the problems associated with voltage isolation, dead time, and operating speeds. The next step would be to run rated current through the MOSFETs to see if they turn off as fast as the datasheet [26] claims. The next step would be to look into very fast PWM chips with programmable dead time or PMOSs that create dead time due to slightly slower operation than the NMOSs. Finally an isolation transformer would work to create isolation from the gate drivers to turn on the NMOSs or turn off the PMOSs. We simply could not get the pulse transformer to work as [26] specified. With some more work, this circuit could work and become another step toward consumer wireless power.

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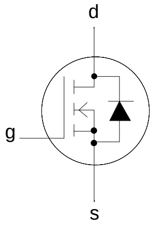
PowerMOS transistor Avalanche energy rated

IRF830

FEATURES

- Repetitive Avalanche Rated
- Fast switching
- High thermal cycling performance
- Low thermal resistance

SYMBOL



QUICK REFERENCE DATA

V_{DSS} = 500 V

I_D = 5.9 A

$R_{DS(ON)} \leq 1.5\ \Omega$

GENERAL DESCRIPTION

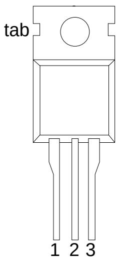
N-channel, enhancement mode field-effect power transistor, intended for use in off-line switched mode power supplies, T.V. and computer monitor power supplies, d.c. to d.c. converters, motor control circuits and general purpose switching applications.

The IRF830 is supplied in the SOT78 (TO220AB) conventional leaded package.

PINNING

PIN	DESCRIPTION
1	gate
2	drain
3	source
tab	drain

SOT78 (TO220AB)



LIMITING VALUES

Limiting values in accordance with the Absolute Maximum System (IEC 134)

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{DSS}	Drain-source voltage	T_j = 25 ˚C to 150˚C	-	500	V
V_{DGR}	Drain-gate voltage	T_j = 25 ˚C to 150˚C; R_{GS} = 20 kΩ	-	500	V
V_{GS}	Gate-source voltage		-	± 30	V
I_D	Continuous drain current	T_{mb} = 25 ˚C; V_{GS} = 10 V	-	5.9	A
		T_{mb} = 100 ˚C; V_{GS} = 10 V	-	3.7	A
I_{DM}	Pulsed drain current	T_{mb} = 25 ˚C	-	24	A
P_D	Total dissipation	T_{mb} = 25 ˚C	-	125	W
T_j, T_{stg}	Operating junction and storage temperature range		- 55	150	˚C

AVALANCHE ENERGY LIMITING VALUES

Limiting values in accordance with the Absolute Maximum System (IEC 134)

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
E_{AS}	Non-repetitive avalanche energy	Unclamped inductive load, I_{AS} = 4.2 A; t_p = 0.21 ms; T_j prior to avalanche = 25˚C; $V_{DD} \leq 50$ V; R_{GS} = 50 Ω; V_{GS} = 10 V; refer to fig:17	-	287	mJ
E_{AR}	Repetitive avalanche energy[1]	I_{AR} = 5.9 A; t_p = 2.5 µs; T_j prior to avalanche = 25˚C; R_{GS} = 50 Ω; V_{GS} = 10 V; refer to fig:18	-	10	mJ
I_{AS}, I_{AR}	Repetitive and non-repetitive avalanche current		-	5.9	A

---

[1] pulse width and repetition rate limited by T_j max.

THERMAL RESISTANCES

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
$R_{th\ j\text{-}mb}$	Thermal resistance junction to mounting base		-	-	1	K/W
$R_{th\ j\text{-}a}$	Thermal resistance junction to ambient	in free air	-	60	-	K/W

ELECTRICAL CHARACTERISTICS

T_j = 25 ˚C unless otherwise specified

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
$V_{(BR)DSS}$	Drain-source breakdown voltage	V_{GS} = 0 V; I_D = 0.25 mA	500	-	-	V
$\Delta V_{(BR)DSS}$ / ΔT_j	Drain-source breakdown voltage temperature coefficient	V_{DS} = V_{GS}; I_D = 0.25 mA	-	0.1	-	%/K
$R_{DS(ON)}$	Drain-source on resistance	V_{GS} = 10 V; I_D = 3 A	-	1.2	1.5	Ω
$V_{GS(TO)}$	Gate threshold voltage	V_{DS} = V_{GS}; I_D = 0.25 mA	2.0	3.0	4.0	V
g_{fs}	Forward transconductance	V_{DS} = 30 V; I_D = 3 A	2	3.6	-	S
I_{DSS}	Drain-source leakage current	V_{DS} = 500 V; V_{GS} = 0 V	-	1	25	µA
		V_{DS} = 400 V; V_{GS} = 0 V; T_j = 125 ˚C	-	30	250	µA
I_{GSS}	Gate-source leakage current	V_{GS} = ±30 V; V_{DS} = 0 V	-	10	200	nA
$Q_{g(tot)}$	Total gate charge	I_D = 6 A; V_{DD} = 400 V; V_{GS} = 10 V	-	53	64	nC
Q_{gs}	Gate-source charge		-	4	6	nC
Q_{gd}	Gate-drain (Miller) charge		-	28	34	nC
$t_{d(on)}$	Turn-on delay time	V_{DD} = 250 V; R_D = 39 Ω; R_G = 12 Ω	-	10	-	ns
t_r	Turn-on rise time		-	33	-	ns
$t_{d(off)}$	Turn-off delay time		-	92	-	ns
t_f	Turn-off fall time		-	40	-	ns
L_d	Internal drain inductance	Measured from tab to centre of die	-	3.5	-	nH
L_d	Internal drain inductance	Measured from drain lead to centre of die	-	4.5	-	nH
L_s	Internal source inductance	Measured from source lead to source bond pad	-	7.5	-	nH
C_{iss}	Input capacitance	V_{GS} = 0 V; V_{DS} = 25 V; f = 1 MHz	-	610	-	pF
C_{oss}	Output capacitance		-	96	-	pF
C_{rss}	Feedback capacitance		-	54	-	pF

SOURCE-DRAIN DIODE RATINGS AND CHARACTERISTICS

T_j = 25 ˚C unless otherwise specified

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
I_S	Continuous source current (body diode)	T_{mb} = 25˚C	-	-	5.9	A
I_{SM}	Pulsed source current (body diode)	T_{mb} = 25˚C	-	-	24	A
V_{SD}	Diode forward voltage	I_S = 6 A; V_{GS} = 0 V	-	-	1.2	V
t_{rr}	Reverse recovery time	I_S = 6 A; V_{GS} = 0 V; dI/dt = 100 A/µs	-	390	-	ns
Q_{rr}	Reverse recovery charge		-	4	-	µC

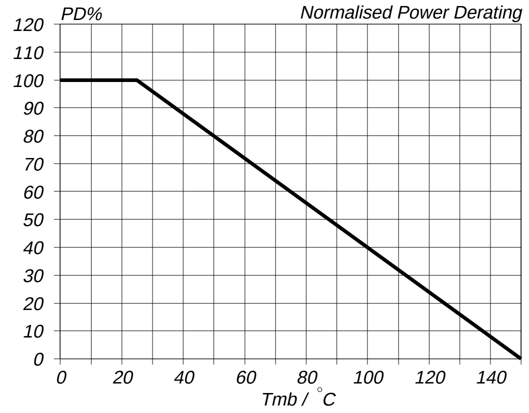


Fig.1. Normalised power dissipation.
$PD\% = 100 \cdot P_D/P_{D\ 25\ ^\circ C} = f(T_{mb})$

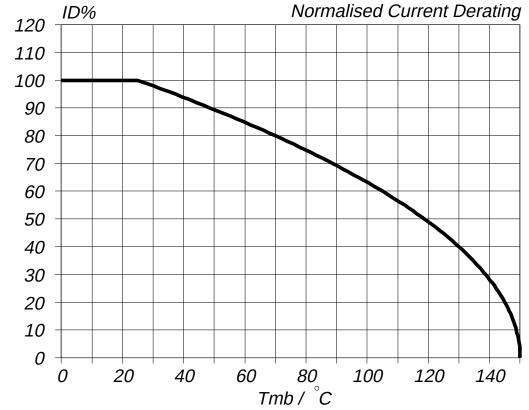


Fig.2. Normalised continuous drain current.
$ID\% = 100 \cdot I_D/I_{D\ 25\ ^\circ C} = f(T_{mb})$; conditions: $V_{GS} \geq 10$ V

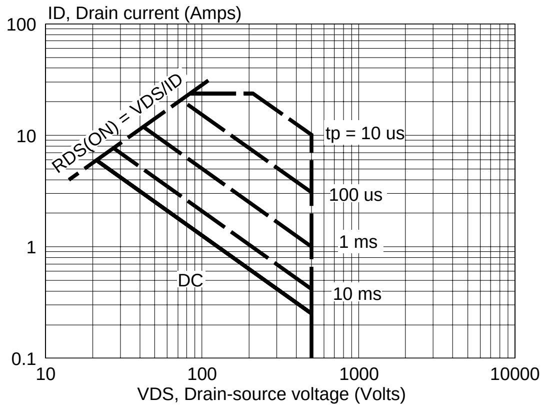


Fig.3. Safe operating area. $T_{mb} = 25\ ^\circ C$
I_D & $I_{DM} = f(V_{DS})$; I_{DM} single pulse; parameter t_p

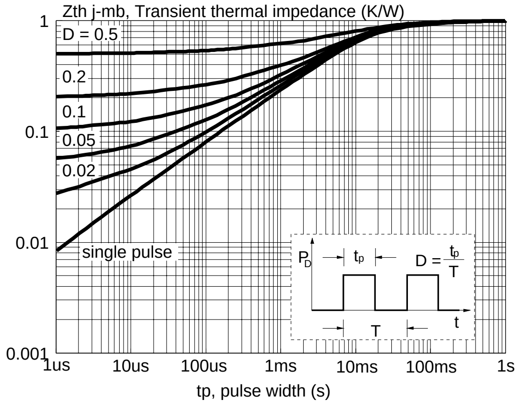


Fig.4. Transient thermal impedance.
$Z_{th\ j\text{-}mb} = f(t)$; parameter $D = t_p/T$

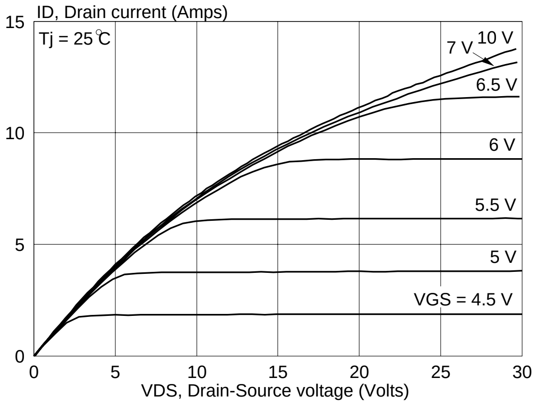


Fig.5. Typical output characteristics.
$I_D = f(V_{DS})$; parameter V_{GS}

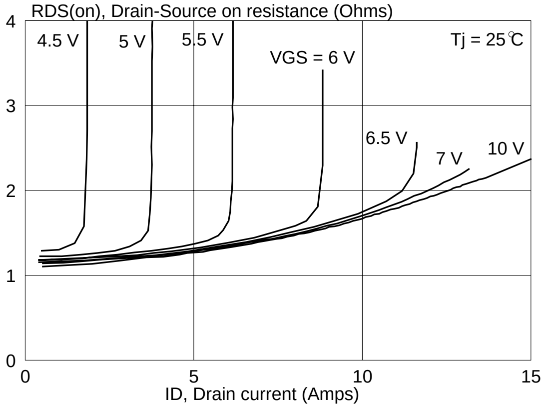


Fig.6. Typical on-state resistance.
$R_{DS(ON)} = f(I_D)$; parameter V_{GS}

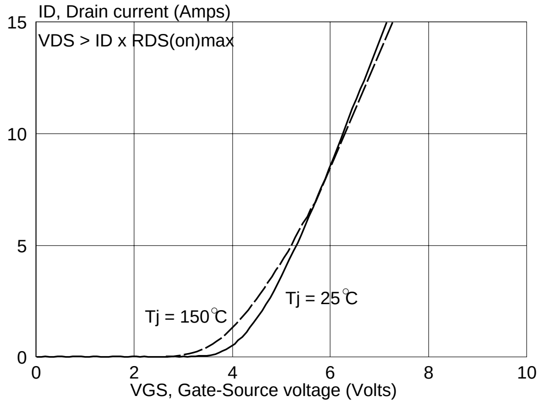


Fig.7. Typical transfer characteristics. $I_D = f(V_{GS})$; parameter T_j

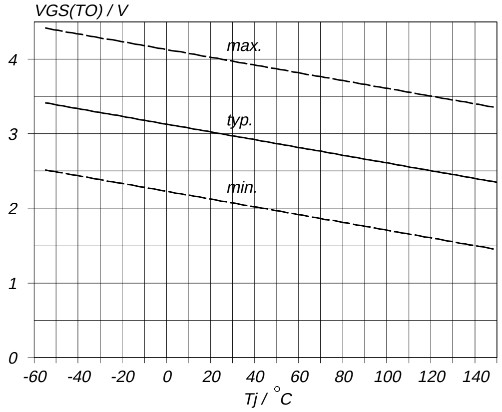


Fig.10. Gate threshold voltage. $V_{GS(TO)} = f(T_j)$; conditions: $I_D = 0.25$ mA; $V_{DS} = V_{GS}$

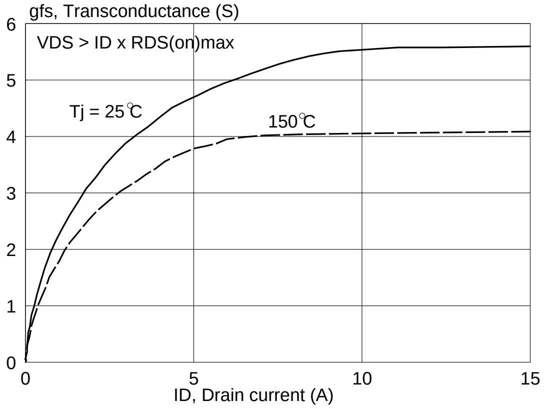


Fig.8. Typical transconductance. $g_{fs} = f(I_D)$; parameter T_j

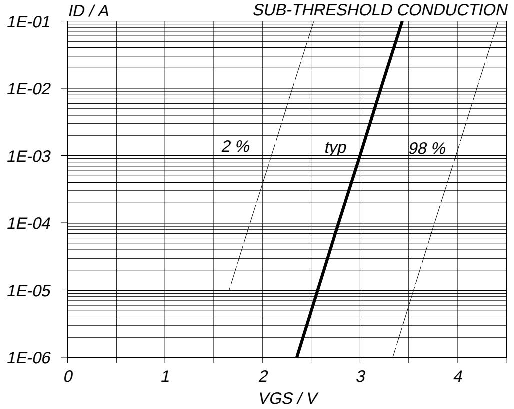


Fig.11. Sub-threshold drain current. $I_D = f(V_{GS})$; conditions: $T_j = 25$ ˚C; $V_{DS} = V_{GS}$

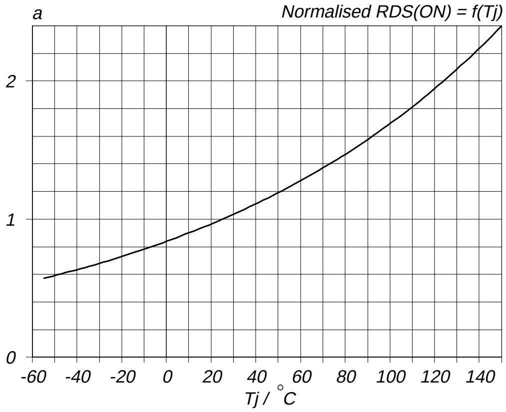


Fig.9. Normalised drain-source on-state resistance. $a = R_{DS(ON)}/R_{DS(ON)25\ ^\circ C} = f(T_j)$; $I_D = 3$ A; $V_{GS} = 10$ V

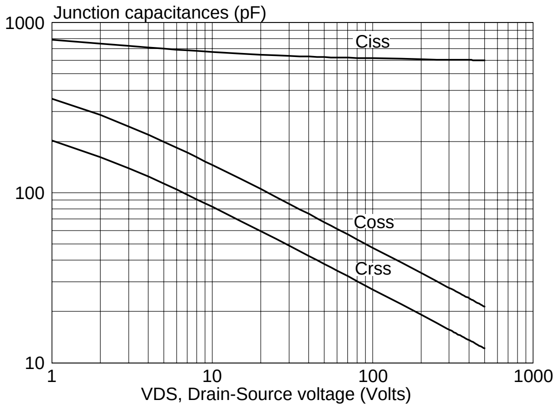


Fig.12. Typical capacitances, C_{iss}, C_{oss}, C_{rss}. $C = f(V_{DS})$; conditions: $V_{GS} = 0$ V; f = 1 MHz

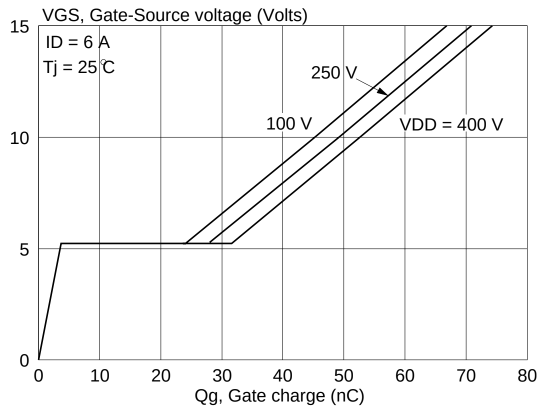


Fig.13. Typical turn-on gate-charge characteristics. $V_{GS} = f(Q_G)$; *parameter* V_{DS}

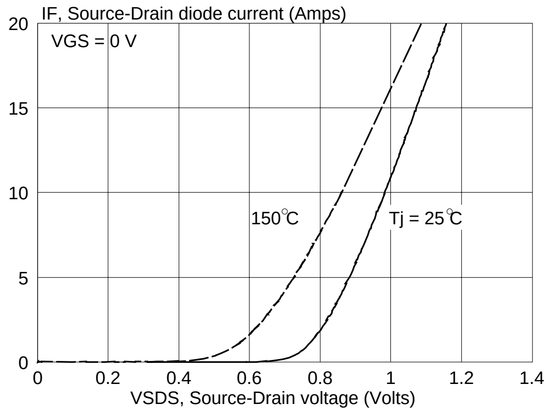


Fig.16. Source-Drain diode characteristic. $I_F = f(V_{SDS})$; *parameter* T_j

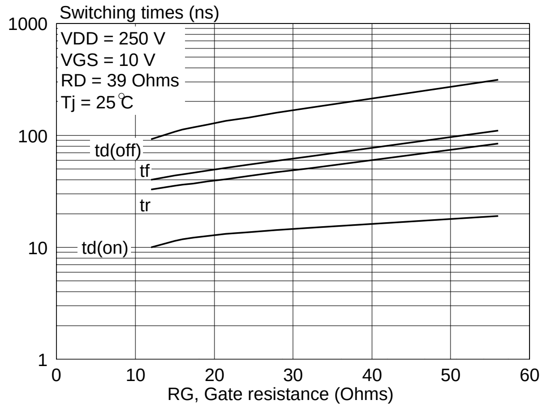


Fig.14. Typical switching times; $t_{d(on)}$, t_r, $t_{d(off)}$, $t_f = f(R_G)$

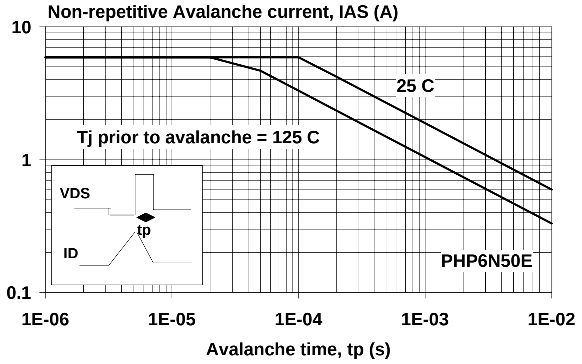


Fig.17. Maximum permissible non-repetitive avalanche current (I_{AS}) *versus avalanche time* (t_p); *unclamped inductive load*

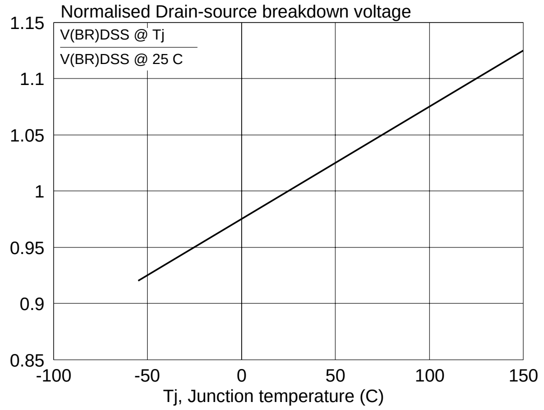


Fig.15. Normalised drain-source breakdown voltage; $V_{(BR)DSS}/V_{(BR)DSS\ 25\ ^{\circ}C} = f(T_j)$

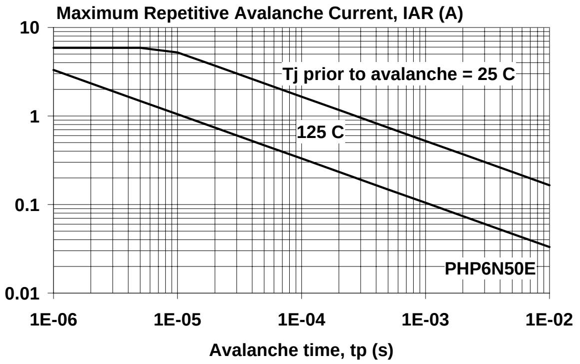
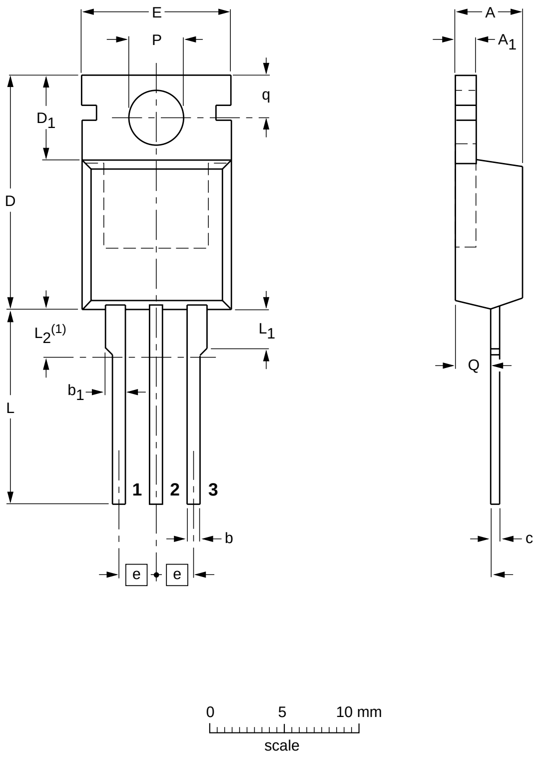


Fig.18. Maximum permissible repetitive avalanche current (I_{AR}) *versus avalanche time* (t_p)

MECHANICAL DATA

Plastic single-ended package; heatsink mounted; 1 mounting hole; 3-lead TO-220 **SOT78**



DIMENSIONS (mm are the original dimensions)

UNIT	A	A_1	b	b_1	c	D	D_1	E	e	L	L_1	$L_2^{(1)}$ max.	P	q	Q
mm	4.5 4.1	1.39 1.27	0.9 0.7	1.3 1.0	0.7 0.4	15.8 15.2	6.4 5.9	10.3 9.7	2.54	15.0 13.5	3.30 2.79	3.0	3.8 3.6	3.0 2.7	2.6 2.2

Note

1. Terminals in this zone are not tinned.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT78		TO-220				97-06-11

Fig.19. SOT78 (TO220AB); pin 2 connected to mounting base (Net mass:2g)

Notes

1. This product is supplied in anti-static packaging. The gate-source input must be protected against static discharge during transport or handling.
2. Refer to mounting instructions for SOT78 (TO220AB) package.
3. Epoxy meets UL94 V0 at 1/8".

DEFINITIONS

Data sheet status	
Objective specification	This data sheet contains target or goal specifications for product development.
Preliminary specification	This data sheet contains preliminary data; supplementary data may be published later.
Product specification	This data sheet contains final product specifications.
Limiting values	
Limiting values are given in accordance with the Absolute Maximum Rating System (IEC 134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of this specification is not implied. Exposure to limiting values for extended periods may affect device reliability.	
Application information	
Where application information is given, it is advisory and does not form part of the specification.	
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LIFE SUPPORT APPLICATIONS

These products are not designed for use in life support appliances, devices or systems where malfunction of these products can be reasonably expected to result in personal injury. Philips customers using or selling these products for use in such applications do so at their own risk and agree to fully indemnify Philips for any damages resulting from such improper use or sale.

FAIRCHILD
SEMICONDUCTOR™

IRF510

Data Sheet **January 2002**

5.6A, 100V, 0.540 Ohm, N-Channel Power MOSFET

This N-Channel enhancement mode silicon gate power field effect transistor is an advanced power MOSFET designed, tested, and guaranteed to withstand a specified level of energy in the breakdown avalanche mode of operation. All of these power MOSFETs are designed for applications such as switching regulators, switching convertors, motor drivers, relay drivers, and drivers for high power bipolar switching transistors requiring high speed and low gate drive power. These types can be operated directly from integrated circuits.

Formerly developmental type TA17441.

Ordering Information

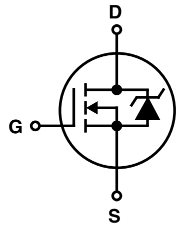
PART NUMBER	PACKAGE	BRAND
IRF510	TO-220AB	IRF510

NOTE: When ordering, include the entire part number.

Features

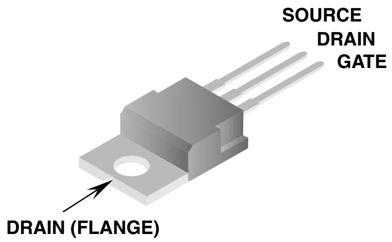
- 5.6A, 100V
- $r_{DS(ON)} = 0.540\Omega$
- Single Pulse Avalanche Energy Rated
- SOA is Power Dissipation Limited
- Nanosecond Switching Speeds
- Linear Transfer Characteristics
- High Input Impedance
- Related Literature
  - TB334 “Guidelines for Soldering Surface Mount Components to PC Boards”

Symbol



Packaging

JEDEC TO-220AB



Absolute Maximum Ratings $T_C = 25^oC$, Unless Otherwise Specified

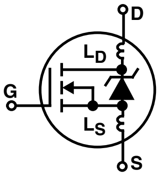
		IRF510	UNITS
Drain to Source Voltage (Note 1)	V_{DS}	100	V
Drain to Gate Voltage ($R_{GS} = 20k\Omega$) (Note 1)	V_{DGR}	100	V
Continuous Drain Current	I_D	5.6	A
$T_C = 100^oC$	I_D	4	A
Pulsed Drain Current (Note 3)	I_{DM}	20	A
Gate to Source Voltage	V_{GS}	±20	V
Maximum Power Dissipation	P_D	43	W
Linear Derating Factor		0.29	W/^{o}C
Single Pulse Avalanche Energy Rating (Note 4)	E_{AS}	19	mJ
Operating and Storage Temperature Range	T_J, T_{STG}	-55 to 175	^{o}C
Maximum Temperature for Soldering			
Leads at 0.063in (1.6mm) from Case for 10s	T_L	300	^{o}C
Package Body for 10s, See Techbrief 334	T_{pkg}	260	^{o}C

CAUTION: Stresses above those listed in “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

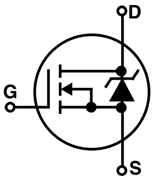
NOTE:

1. $T_J = 25^oC$ to 150^oC.

Electrical Specifications $T_C = 25^oC$, Unless Otherwise Specified

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Drain to Source Breakdown Voltage	BV_{DSS}	$V_{GS} = 0V$, $I_D = 250\mu A$, (Figure 10)	100	-	-	V
Gate to Threshold Voltage	$V_{GS(TH)}$	$V_{GS} = V_{DS}$, $I_D = 250\mu A$	2.0	-	4.0	V
Zero-Gate Voltage Drain Current	I_{DSS}	$V_{DS} = 95V$, $V_{GS} = 0V$	-	-	25	μA
		$V_{DS} = 0.8$ x Rated BV_{DSS}, $V_{GS} = 0V$, $T_J = 150^oC$	-	-	250	μA
On-State Drain Current (Note 2)	$I_{D(ON)}$	$V_{DS} > I_{D(ON)} \times r_{DS(ON)MAX}$, $V_{GS} = 10V$ (Figure 7)	5.6	-	-	A
Gate to Source Leakage Current	I_{GSS}	$V_{GS} = \pm 20V$	-	-	±100	nA
Drain to Source On Resistance (Note 2)	$r_{DS(ON)}$	$V_{GS} = 10V$, $I_D = 3.4A$ (Figures 8, 9)	-	0.4	0.54	Ω
Forward Transconductance (Note 2)	g_{fs}	$V_{GS} = 50V$, $I_D = 3.4A$ (Figure 12)	1.3	2.0	-	S
Turn-On Delay Time	$t_{d(ON)}$	$I_D \approx 5.6A$, $R_{GS} = 24\Omega$, $V_{DD} = 50V$, $R_L = 9\Omega$, $V_{DD} = 50V$, $V_{GS} = 10V$ MOSFET switching times are essentially independent of operating temperature	-	8	12	ns
Rise Time	t_r		-	25	63	ns
Turn-Off Delay Time	$t_{d(OFF)}$		-	15	7	ns
Fall Time	t_f		-	12	59	ns
Total Gate Charge (Gate to Source + Gate to Drain)	$Q_{g(TOT)}$	$V_{GS} = 10V$, $I_D = 5.6A$, $V_{DS} = 0.8$ x Rated BV_{DSS}, $I_{G(REF)} = 1.5mA$ (Figure 14) Gate charge is essentially independent of operating temperature.	-	5.0	30	nC
Gate to Source Charge	Q_{gs}		-	2.0	-	nC
Gate to Drain “Miller” Charge	Q_{gd}		-	3.0	-	nC
Input Capacitance	C_{ISS}	$V_{GS} = 0V$, $V_{DS} = 25V$, f = 1.0MHz (Figure 11)	-	135	-	pF
Output Capacitance	C_{OSS}		-	80	-	pF
Reverse-Transfer Capacitance	C_{RSS}		-	20	-	pF
Internal Drain Inductance	L_D	Measured From the Contact Screw On Tab To Center of Die Modified MOSFET Symbol Showing the Internal Devices Inductances 	-	3.5	-	nH
		Measured From the Drain Lead, 6mm (0.25in) From Package to Center of Die	-	4.5	-	nH
Internal Source Inductance	L_S	Measured From The Source Lead, 6mm (0.25in) From Header to Source Bonding Pad	-	7.5	-	nH
Junction to Case	$R_{\theta JC}$		-	-	3.5	^{o}C/W
Junction to Ambient	$R_{\theta JA}$	Free air operation	-	-	80	^{o}C/W

Source to Drain Diode Specifications

PARAMETER	SYMBOL	Test Conditions		MIN	TYP	MAX	UNITS
Continuous Source to Drain Current	I_{SD}	Modified MOSFET Symbol Showing the Integral Reverse P-N Junction Diode		-	-	5.6	A
Pulse Source to Drain Current (Note 3)	I_{SDM}			-	-	20	A
Source to Drain Diode Voltage (Note 2)	V_{SD}	$T_J = 25^oC$, $I_{SD} = 5.6A$, $V_{GS} = 0V$ (Figure 13)		-	-	2.5	V
Reverse Recovery Time	t_{rr}	$T_J = 25^oC$, $I_{SD} = 5.6A$, $dI_{SD}/d_t = 100A/\mu s$		4.6	96	200	ns
Reverse Recovered Charge	Q_{RR}	$T_J = 25^oC$, $I_{SD} = 5.6A$, $dI_{SD}/d_t = 100A/\mu s$		0.17	0.4	0.83	μC

NOTES:

2. Pulse test: pulse width ≤ 300μs, duty cycle ≤ 2%.
3. Repetitive rating: pulse width limited by max junction temperature. See Transient Thermal Impedance curve (Figure 3).
4. $V_{DD} = 25V$, start $T_J = 25^oC$, $L = 910\mu H$, $R_G = 25\Omega$, peak $I_{AS} = 5.6A$.

Typical Performance Curves Unless Otherwise Specified

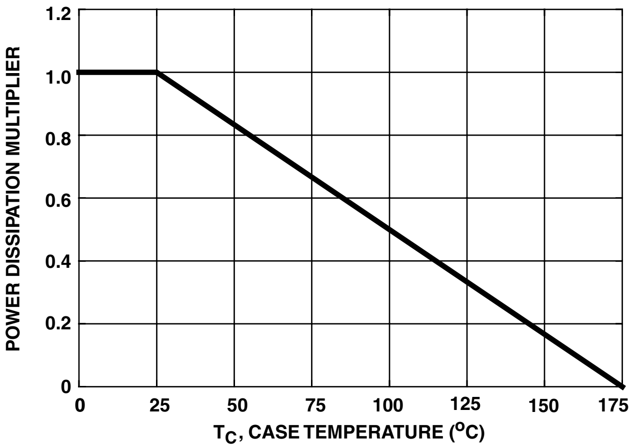


FIGURE 1. NORMALIZED POWER DISSIPATION vs CASE TEMPERATURE

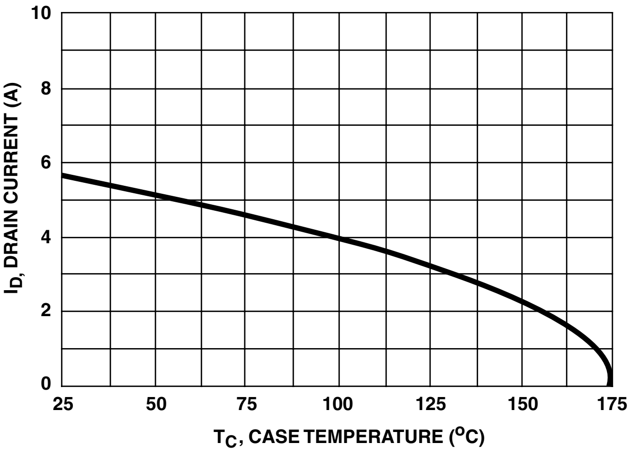


FIGURE 2. MAXIMUM CONTINUOUS DRAIN CURRENT vs CASE TEMPERATURE

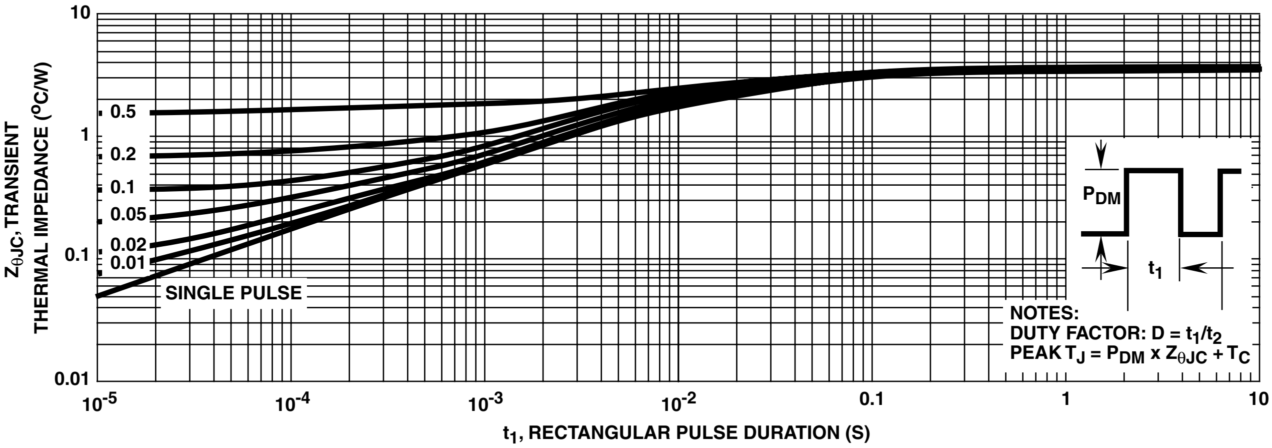


FIGURE 3. MAXIMUM TRANSIENT THERMAL IMPEDANCE

Typical Performance Curves Unless Otherwise Specified **(Continued)**

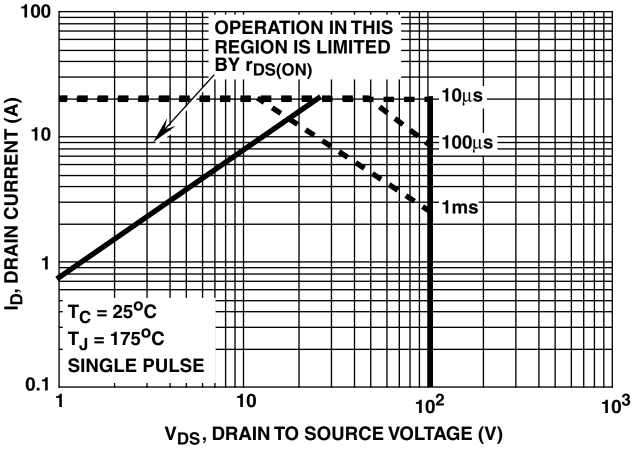


FIGURE 4. FORWARD BIAS SAFE OPERATING AREA

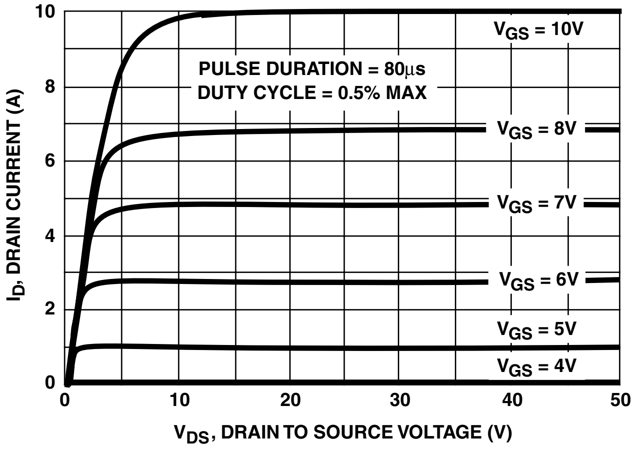


FIGURE 5. OUTPUT CHARACTERISTICS

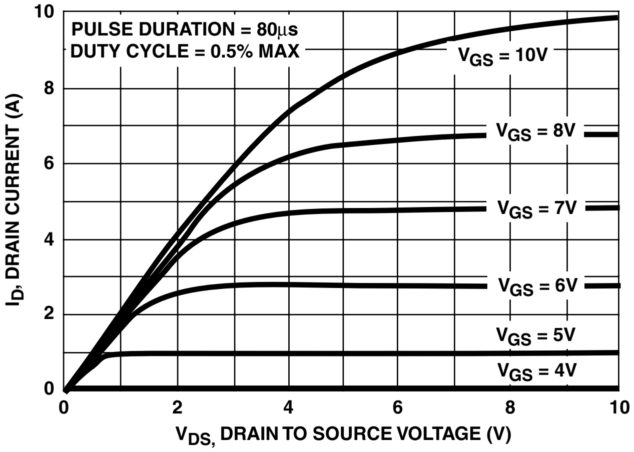


FIGURE 6. SATURATION CHARACTERISTICS

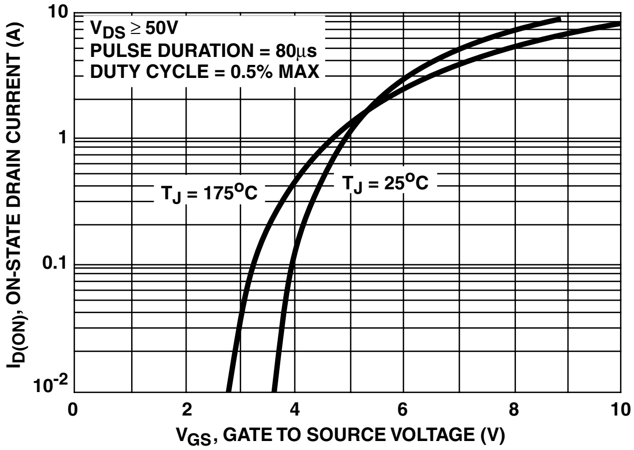


FIGURE 7. TRANSFER CHARACTERISTICS

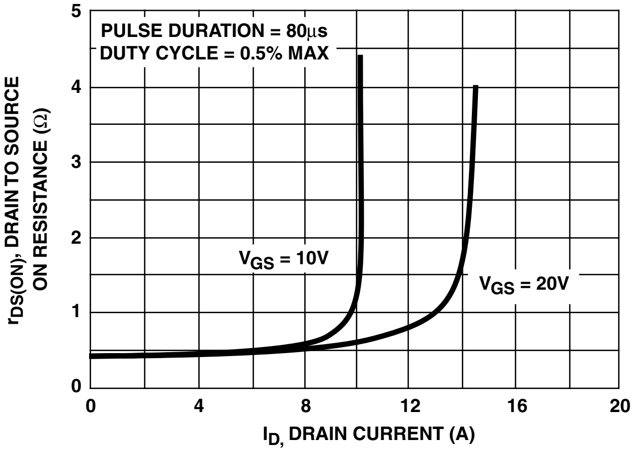


FIGURE 8. DRAIN TO SOURCE ON RESISTANCE vs GATE VOLTAGE AND DRAIN CURRENT

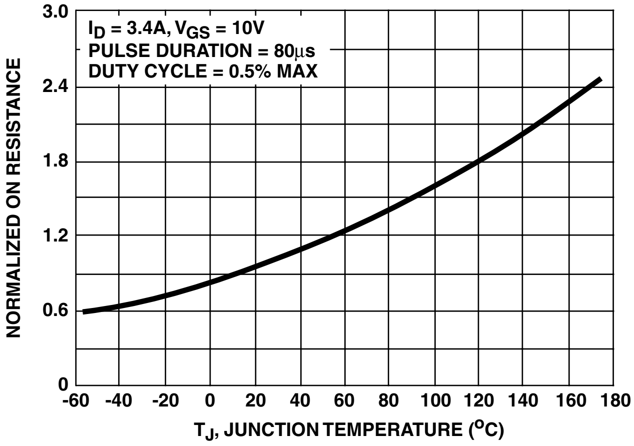


FIGURE 9. NORMALIZED DRAIN TO SOURCE ON RESISTANCE vs JUNCTION TEMPERATURE

Typical Performance Curves Unless Otherwise Specified **(Continued)**

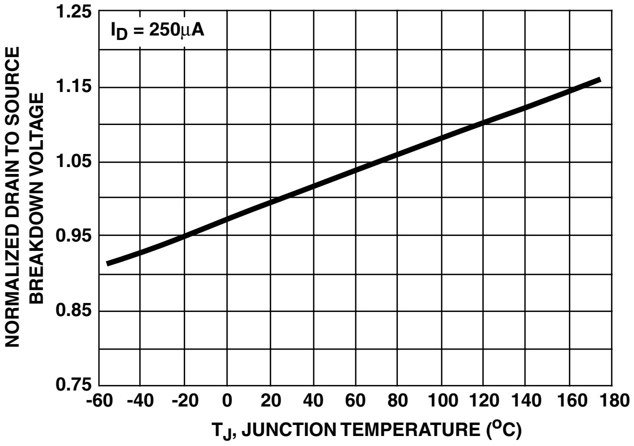


FIGURE 10. NORMALIZED DRAIN TO SOURCE BREAKDOWN VOLTAGE vs JUNCTION TEMPERATURE

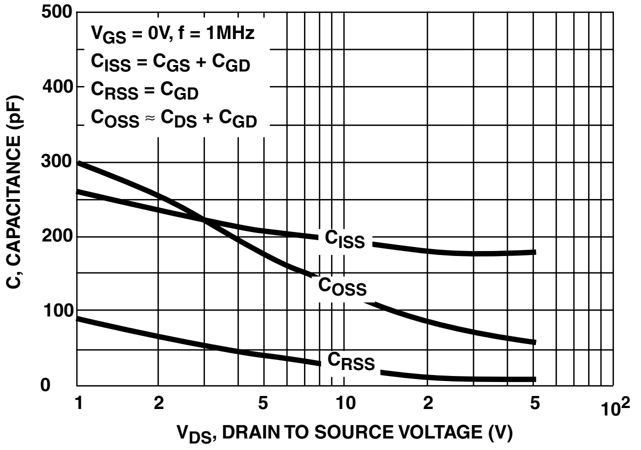


FIGURE 11. CAPACITANCE vs DRAIN TO SOURCE VOLTAGE

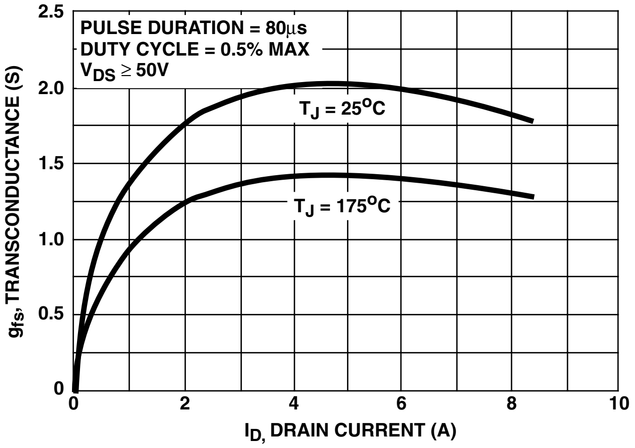


FIGURE 12. TRANSCONDUCTANCE vs DRAIN CURRENT

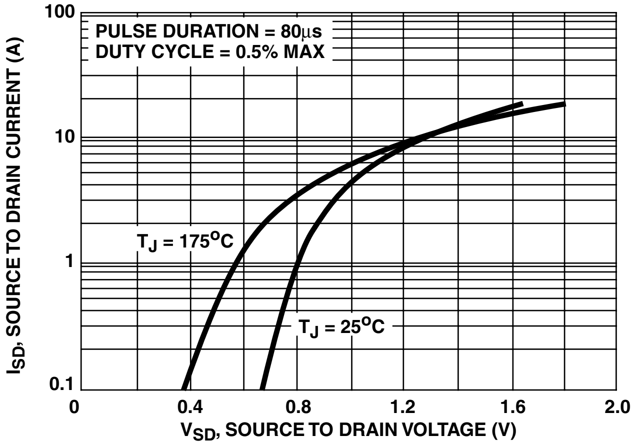


FIGURE 13. SOURCE TO DRAIN DIODE VOLTAGE

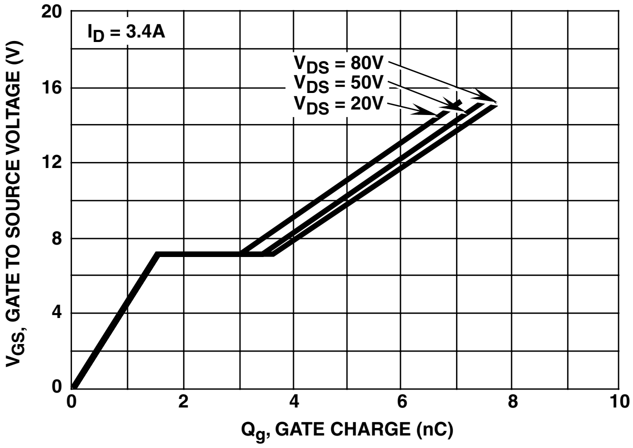


FIGURE 14. GATE TO SOURCE VOLTAGE vs GATE CHARGE

Test Circuits and Waveforms

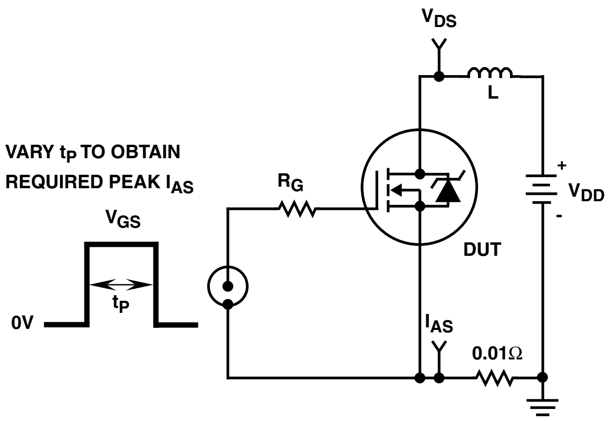


FIGURE 15. UNCLAMPED ENERGY TEST CIRCUIT

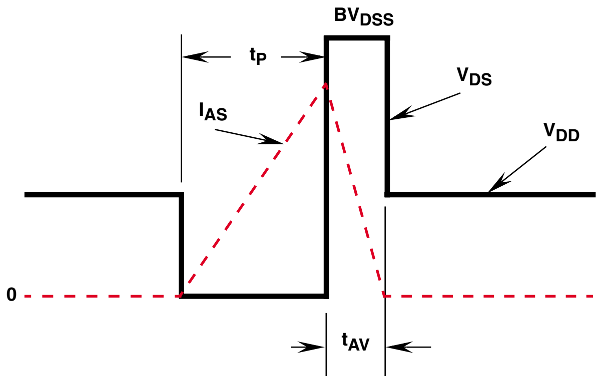


FIGURE 16. UNCLAMPED ENERGY WAVEFORMS

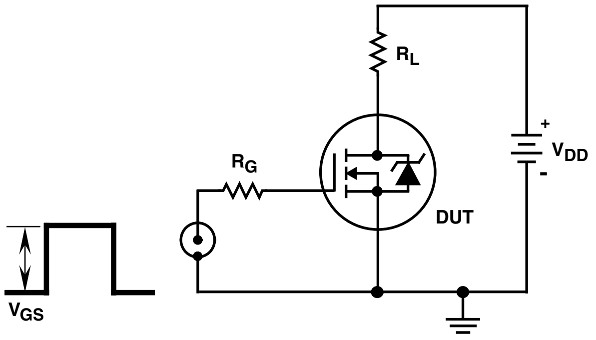


FIGURE 17. SWITCHING TIME TEST CIRCUIT

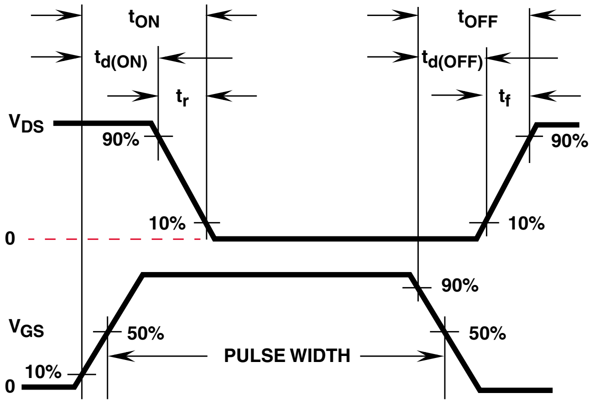


FIGURE 18. RESISTIVE SWITCHING WAVEFORMS

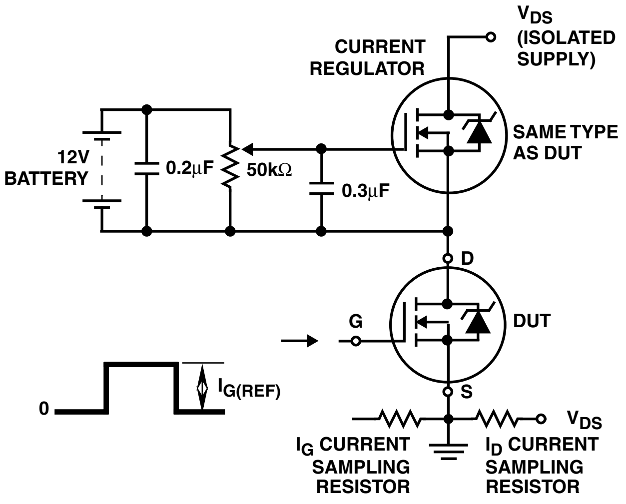


FIGURE 19. GATE CHARGE TEST CIRCUIT

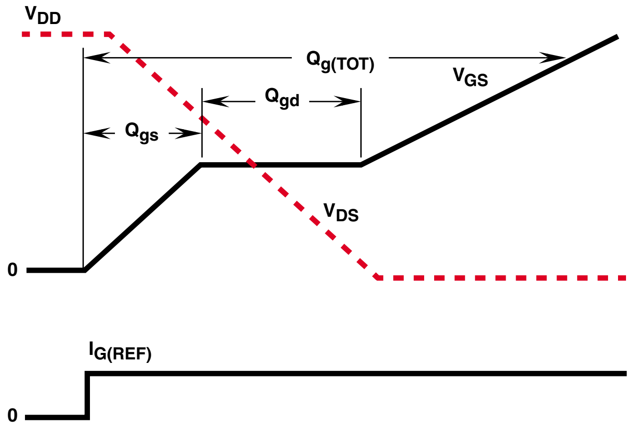


FIGURE 20. GATE CHARGE WAVEFORM

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PRODUCT STATUS DEFINITIONS

Definition of Terms

Datasheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This datasheet contains preliminary data, and supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
No Identification Needed	Full Production	This datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
Obsolete	Not In Production	This datasheet contains specifications on a product that has been discontinued by Fairchild semiconductor. The datasheet is printed for reference information only.

Rev. H4

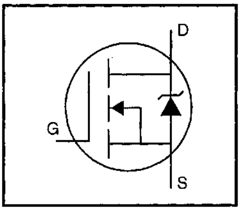
International
IOR Rectifier

PD-9.376H

IRF840

HEXFET® Power MOSFET

- Dynamic dv/dt Rating
- Repetitive Avalanche Rated
- Fast Switching
- Ease of Paralleling
- Simple Drive Requirements



V_{DSS} = 500V

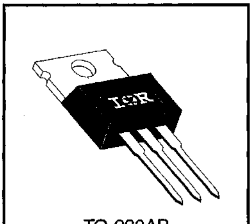
$R_{DS(on)}$ = 0.85Ω

I_D = 8.0A

Description

Third Generation **HEXFETs** from International Rectifier provide the designer with the best combination of fast switching, ruggedized device design, low on-resistance and cost-effectiveness.

The TO-220 package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 watts. The low thermal resistance and low package cost of the TO-220 contribute to its wide acceptance throughout the industry.



TO-220AB

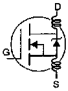
Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10 V	8.0	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10 V	5.1	
I_{DM}	Pulsed Drain Current ①	32	
P_D @ T_C = 25°C	Power Dissipation	125	W
	Linear Derating Factor	1.0	W/°C
V_{GS}	Gate-to-Source Voltage	±20	V
E_{AS}	Single Pulse Avalanche Energy ②	510	mJ
I_{AR}	Avalanche Current ①	8.0	A
E_{AR}	Repetitive Avalanche Energy ①	13	mJ
dv/dt	Peak Diode Recovery dv/dt ③	3.5	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to +150	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting Torque, 6-32 or M3 screw	10 lbf•in (1.1 N•m)	

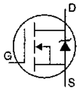
Thermal Resistance

	Parameter	Min.	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	—	1.0	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	—	0.50	—	
$R_{\theta JA}$	Junction-to-Ambient	—	—	62	

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

	Parameter	Min.	Typ.	Max.	Units	Test Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	500	—	—	V	V_{GS}=0V, I_D= 250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	0.78	—	V/°C	Reference to 25°C, I_D= 1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	—	0.85	Ω	V_{GS}=10V, I_D=4.8A ④
$V_{GS(th)}$	Gate Threshold Voltage	2.0	—	4.0	V	V_{DS}=V_{GS}, I_D= 250μA
g_{fs}	Forward Transconductance	4.9	—	—	S	V_{DS}=50V, I_D=4.8A ④
I_{DSS}	Drain-to-Source Leakage Current	—	—	25	μA	V_{DS}=500V, V_{GS}=0V
		—	—	250		V_{DS}=400V, V_{GS}=0V, T_J=125°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS}=20V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS}=-20V
Q_g	Total Gate Charge	—	—	63	nC	I_D=8.0A
Q_{gs}	Gate-to-Source Charge	—	—	9.3		V_{DS}=400V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	—	32		V_{GS}=10V See Fig. 6 and 13 ④
$t_{d(on)}$	Turn-On Delay Time	—	14	—	ns	V_{DD}=250V
t_r	Rise Time	—	23	—		I_D=8.0A
$t_{d(off)}$	Turn-Off Delay Time	—	49	—		R_G=9.1Ω
t_f	Fall Time	—	20	—		R_D=31Ω See Figure 10 ④
L_D	Internal Drain Inductance	—	4.5	—	nH	Between lead, 6 mm (0.25in.) from package and center of die contact 
L_S	Internal Source Inductance	—	7.5	—		
C_{iss}	Input Capacitance	—	1300	—	pF	V_{GS}=0V
C_{oss}	Output Capacitance	—	310	—		V_{DS}=25V
C_{rss}	Reverse Transfer Capacitance	—	120	—		f=1.0MHz See Figure 5

Source-Drain Ratings and Characteristics

	Parameter	Min.	Typ.	Max.	Units	Test Conditions
I_S	Continuous Source Current (Body Diode)	—	—	8.0	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ①	—	—	32		
V_{SD}	Diode Forward Voltage	—	—	2.0	V	T_J=25°C, I_S=8.0A, V_{GS}=0V ④
t_{rr}	Reverse Recovery Time	—	460	970	ns	T_J=25°C, I_F=8.0A
Q_{rr}	Reverse Recovery Charge	—	4.2	8.9	μC	di/dt=100A/μs ④
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is neglegible (turn-on is dominated by L_S+L_D)				

Notes:

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

② V_{DD}=50V, starting T_J=25°C, L=14mH R_G=25Ω, I_{AS}=8.0A (See Figure 12)

③ I_{SD}≤8.0A, di/dt≤100A/μs, V_{DD}≤$V_{(BR)DSS}$, T_J≤150°C

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

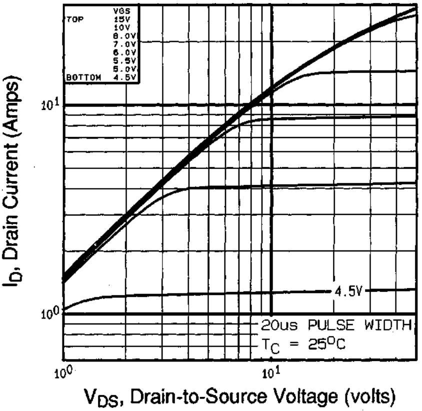


Fig 1. Typical Output Characteristics, TC=25°C

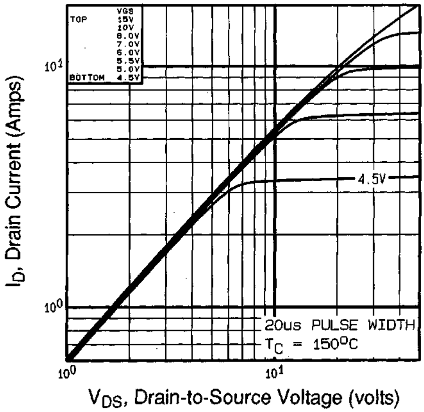


Fig 2. Typical Output Characteristics, TC=150°C

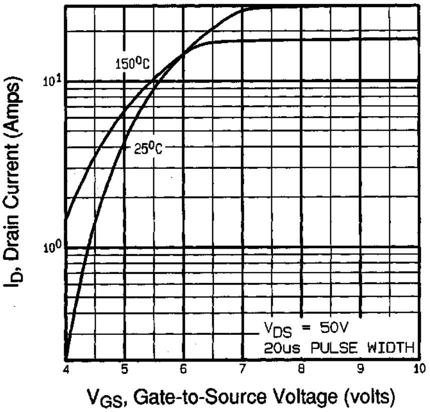


Fig 3. Typical Transfer Characteristics

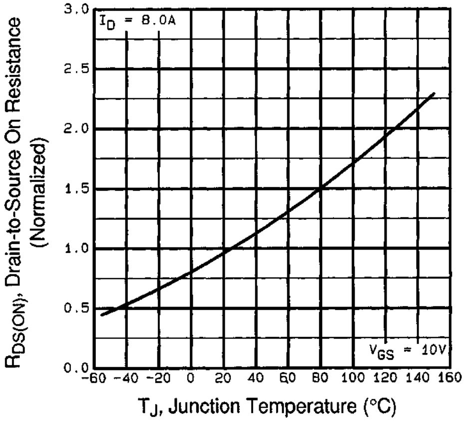


Fig 4. Normalized On-Resisance Vs. Temperature

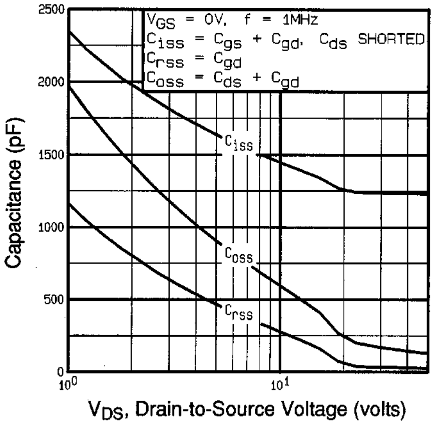


Fig 5. Typical Capacitance Vs. Drain-to-Source Voltage

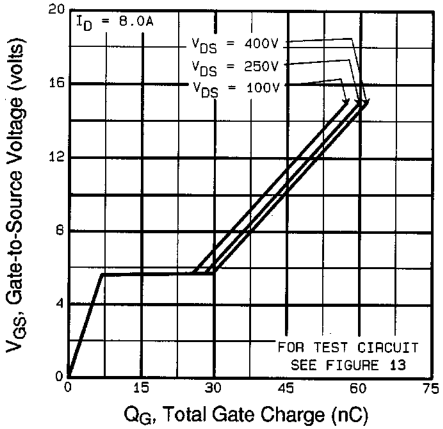


Fig 6. Typical Gate Charge Vs. Gate-to-Source Voltage

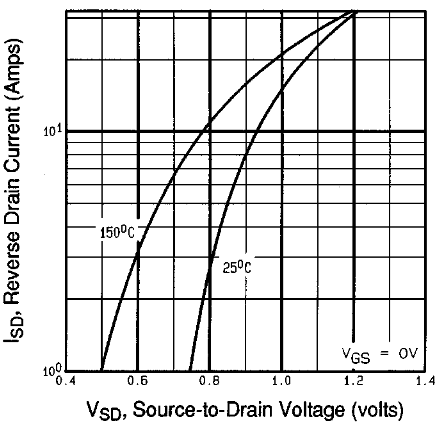


Fig 7. Typical Source-Drain Diode Forward Voltage

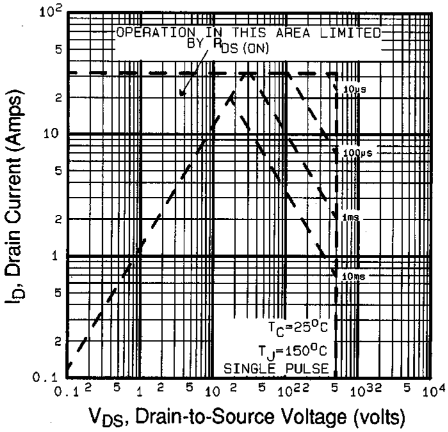


Fig 8. Maximum Safe Operating Area

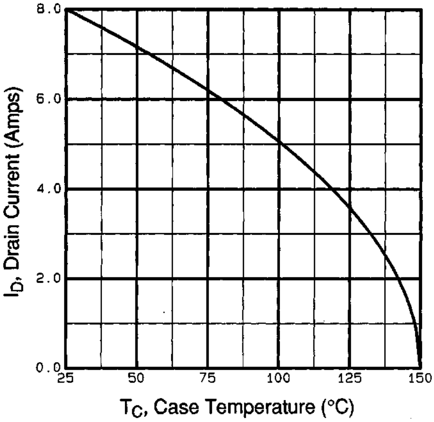


Fig 9. Maximum Drain Current Vs. Case Temperature

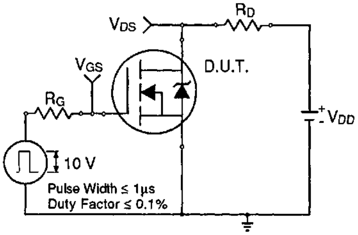


Fig 10a. Switching Time Test Circuit

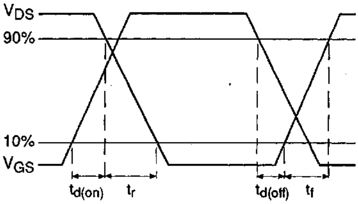


Fig 10b. Switching Time Waveforms

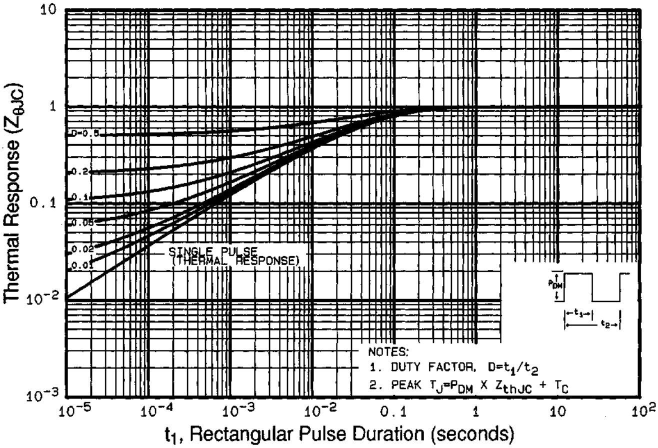


Fig 11. Maximum Effective Transient Thermal Impedance, Junction-to-Case

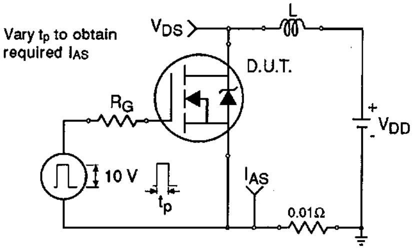


Fig 12a. Unclamped Inductive Test Circuit

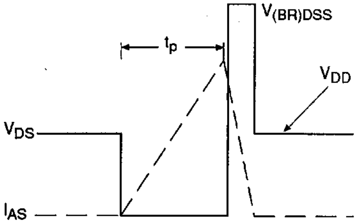


Fig 12b. Unclamped Inductive Waveforms

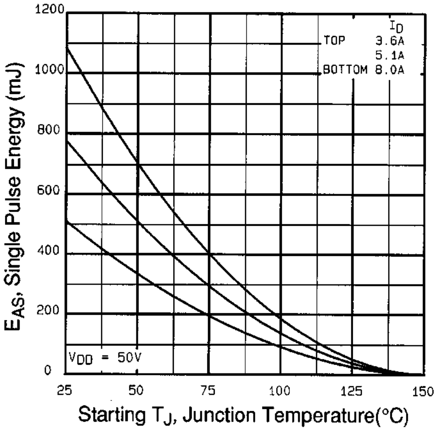
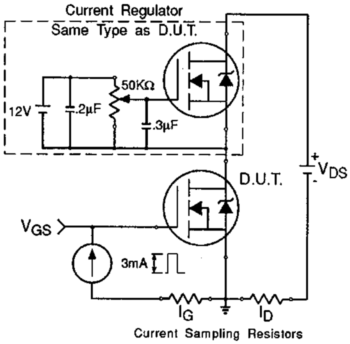


Fig 12c. Maximum Avalanche Energy Vs. Drain Current



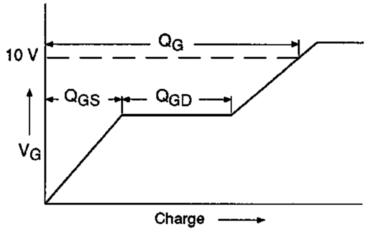


Fig 13a. Basic Gate Charge Waveform

Fig 13b. Gate Charge Test Circuit

Appendix A: Figure 14, Peak Diode Recovery dv/dt Test Circuit – See page 1505

Appendix B: Package Outline Mechanical Drawing – See page 1509

Appendix C: Part Marking Information – See page 1516

Appendix E: Optional Leadforms – See page 1525

Phono® Solar

SHARE THE SUN, POWER THE FUTURE!

ABOUT PHONO SOLAR

Phono Solar Technology Co., Ltd. is one of the fastest growing Solar Panel Manufacturers in Australia.

The Phono Diamond 250w Solar Panel is considered to be the pinnacle of Solar technology, and like its namesake, the Diamond Solar panel is designed and built to last an eternity even in the harsh Australian climate.

Developed by China's finest Solar R&D team and constructed from the highest quality materials in advanced automated facilities, Phono Solar panels are ideal for use in large scale power plans, commercial and residential installs.

Outstanding performance in weak-light conditions

PID Anti-PID available on request [1]

Excellent temperature coefficient giving higher yields in the long term

IP68 IP68 connectors enhance the reliability of the PV system

Positive current sorting

5400PA Certified to withstand increased loads of up to 5400Pa

25 YEAR 10-year product warranty
25-year performance warranty[2]

Durability assured:

Salt mist corrosion certification

Ammonia corrosion certification

Fire test certification

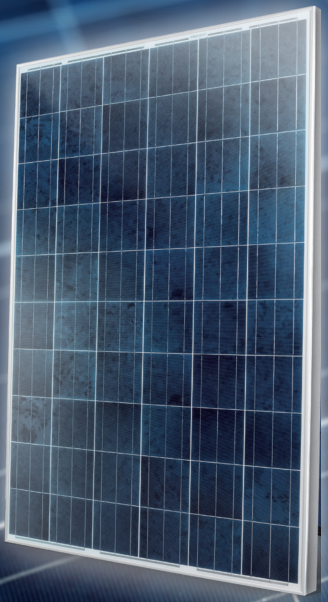
Blowing sand resistance certification

- Manufacturing facility certified by ISO 9001, ISO 14001 and OHSAS 18001
- Internal quality control has standards higher than both IEC and UL
- Product quality is assured through the use of branded components
- Free module recycling through PV Cycle Association membership[3]

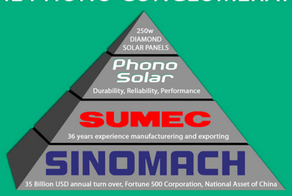
HIGH PERFORMANCE SOLAR MODULES

250W POLY

DIAMOND SERIES



THE PHONO CONGLOMERATE



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PO Box 1848, Port Macquarie NSW 2444 | www.phonosolar.com | support@phonosolar.com

SOLAR MODULES 250W

Phono® Solar

MECHANICAL CHARACTERISTICS

Solar Cells	Polycrystalline 156mm x 156mm square, 6 × 10 pieces in series
Dimension	Length: 1640mm (64.6 inch)
	Width: 992mm (39.1 inch)
	Height: 35mm (1.4 inch)/40mm (1.6 inch)
Weight	18kg (39.7 lbs) / 19kg (41.9lbs)
Front Glass	3.2mm toughened glass
Frame	Anodized aluminium alloy
Cable	$4mm^2$(IEC) / 12AWG(UL), 900mm
Junction Box	IP 67 rated

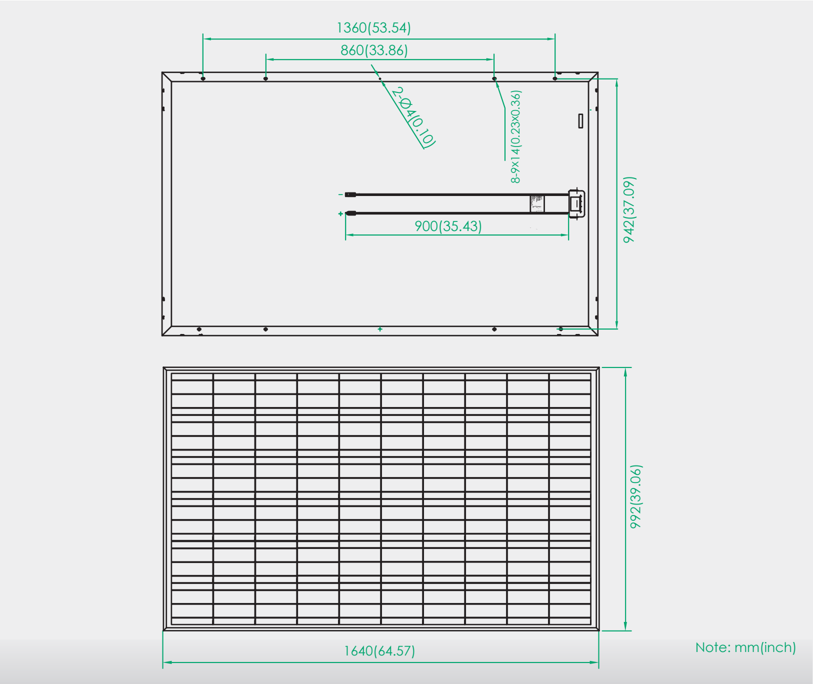
ABSOLUTE MAXIMUM RATING

Parameter	Values
Operating Temperature	From -40 to +85℃
Hail Diameter @ 80km/h	Up to 25mm
Surface Maximum Load Capacity	Up to 5400Pa
Maximum Series Fuse Rating	15A
IEC Application Class (IEC61730)	A
Fire Rating (UL 1703)	C
Maximum System Voltage	DC 1000V(IEC)
	DC 600V(UL)/1000V(ETL)

ELECTRICAL TYPICAL VALUES[4],[5]

Model	Rated Power (P_{mpp})	Rated Current (I_{mpp})	Rated Voltage (V_{mpp})	Short Circuit Current (I_{sc})	Open Circuit Voltage (V_{oc})	Module Efficiency (%)
PS250P-20/U	250W	8.30A	30.2V	8.70A	37.8V	15.37

DIMENSIONS



TEMPERATURE CHARACTERISTICS

NOCT (Nominal Operation Cell Temperature)	45℃ ± 2℃
Voltage Temperature Coefficient	-0.31%/K
Current Temperature Coefficient	+0.07%/K
Power Temperature Coefficient	-0.40%/K

WEAK LIGHT PERFORMANCE

Intensity [W/m²]	I_{mpp}	V_{mpp}
1000	1.0	1.000
800	0.8	0.996
600	0.6	0.990
400	0.4	0.983
200	0.2	0.952

PACKING CONFIGURATION

Container	40' HQ	
	35mm	40mm
Pieces per pallet	28	24
Pallets per container	28	28
Pieces per container	784	672

Note: This datasheet is not legally binding. Phono Solar reserves the right to make specifications changes without notice. Further information can be found on our website: www.phonosolar.com

1. Anti-PID modules are only available upon request.
2. In compliance with our warranty terms and conditions.
3. In PV Cycle member countries only, see: www.pvcycle.org
4. Defined as standard deviation of thousands measurements. Absolute power values depend on the measuring system. They can differ by +/-5% from one measuring system to another.
5. Measurement conditions under irradiance level of Standard Test Conditions(STC): 1000W/m², Air mass 1.5 Spectrum, cell temperature of 25°C.

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