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Design and construction of a DC – DC power supply for powering USB soldering iron

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Power supply is an electrical device that converts electric current from a source to the desired voltage, current and frequency to power an electrical load. The universal serial bus (USB) soldering iron available in the market operates on a 5-volt direct current (DC) supply. Essentially, it can be powered by any cell phone charger that is capable of providing an output power of not less than 8 watts. Absence of constant power supply from the national grid at times inhibit effective use of this soldering iron. To power it directly from storage battery is inappropriate as most batteries are rated as 2.7, 3.7, 6, and 12 volts. This paper deals with the design and construction of an inexpensive portable regulated power supply to power a USB soldering iron from a 12 volt power supply. The circuit was designed and simulated using Proteus software "intelligent schematic input system (ISIS)" before the construction procedure. Deep discharge protection that safeguard storage battery against under voltage and reverse polarity protections were added to the design. These special features distinguished it from those available in the market. Two light emitting diodes (LED) serve as indicators for low and normal condition of battery while sound from a buzzer shows that the input terminals of the circuit were wrongly connected. The system was tested and found to work as anticipated.

Keywords: Voltage Regulator, Soldering Iron, USB, Power Supply, Deep Discharge.

1. Introduction

Linear regulators are used predominantly in ground-based equipment where the generation of heat and low efficiency isn't the major concern, and also where low cost and short design period are desired. Linear regulator can produce only one output voltage. It also losses energy informs of heat. Complete voltage regulator packages are readily available in current ratings up to 10 Amps; the assembly of a low voltage supply for load currents in this range is a relatively easy task [5]. Notwithstanding this, before proceeding with the task, a number of important circuit details must be worked out so that suitable components can be selected to work in conjunction with the regulator package [5]. In [12], a DC power supply which can maintains a constant output voltage irrespective of AC mains fluctuations or load variations is known as regulated DC power supply. A regulated power supply consists of an ordinary power supply and voltage regulating device. Figure 1 shows the block diagram of a regulated power supply.

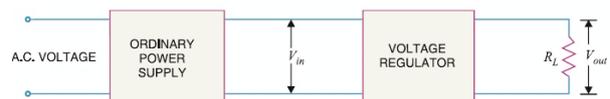


Figure: 1 Regulated DC Power Supply [12]

The output of ordinary power supply is fed to the voltage regulator which produces the final output. The output voltage remains constant whether the load current changes or there are fluctuations in the input AC voltage. Figure 2 shows a simple series voltage regulator using a transistor and Zener diode.

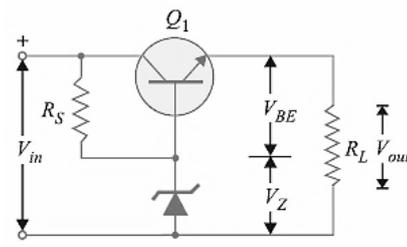


Figure: 2 Transistor Series Voltage Regulator [12]

The circuit is called a series voltage regulator because the load current passes through the series transistor Q_1 . The unregulated DC supply (V_{in}) is fed to the input terminals and the regulated output is obtained across the load (R_L). The Zener diode provides the reference voltage (V_Z). [10] has design and developed a simple but efficient digitally controlled regulated power supply with a variable voltage ranging from 0 to 15 V and a maximum output current of 5 A. [1] Carryout an experimental work to design and construct a 12 kV DC power supply that involved the use of Cockcroft-Walton multiplier. [7] used LM317 to design and construct a portable cheap DC regulated power supply for experiments in Physics college laboratory. [8] Analysed a high frequency link series-parallel resonance converter using AC complex analysis. [4] Analysed the current problems of power supply monitoring equipment in transmission line, illustrates the application limit of photovoltaic panels power currently used in the design of a new type of power supply. In this study a simple DC-DC regulated power supply for USB soldering iron is designed and constructed. The primary power source can be a storage battery or directly connected to solar panel. It was designed with special features such that a green LED is ON to indicate that the storage battery is sufficiently charged while red LED shows that the battery potential difference (PD) is too low. It was designed to operate from 10 to 18 volt.

2. Theory

A stable DC power supply is required for smooth operation of the USB soldering iron. A fixed three-terminal LM7805 voltage regulator was used. It has a minimum input voltage of 7.2 V, a maximum input voltage of 35 V, an output voltage of 5 V and a current rating of 500 mA [3]. In this work the input supply is from a 12 V lead acid battery. The output was adjusted to meet the USB soldering iron requirement of 5 V. To power the USB soldering iron the LM7805 current need to be modified. Moreover, regulator employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible [3]. Although designed primarily as fixed voltage regulators, it can be used with external components to obtain adjustable voltages and currents. The internal Block Diagram of the integrated circuit is shown in Figure 3.

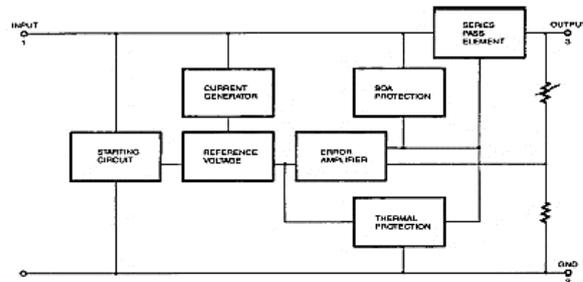


Figure: 3 LM7805 Internal Block Diagram. [3]

To boost the output current, it is recommended that an NPN transistor be connected as shown in Figure 4 [3].

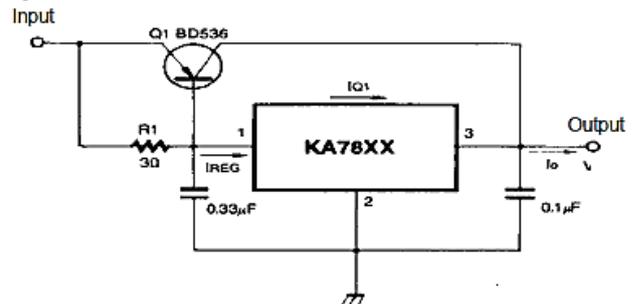


Figure: 4 The High Current Voltage Regulator [3]

3. Materials and Methods

3.1 Design Implementation

The design has two functional modules assembled as a device. Each module was designed as a separate entity. The two modules were assembled together on a single Vero board. The general block diagram of the system is as shown in Figure 5. The stages are the storage battery, regulator, reverse voltage/deep discharge protection, transistor and USB output.

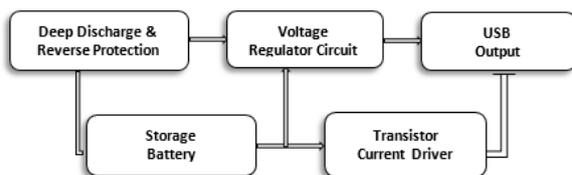


Figure: 5 Block diagram of the setup

3.2 Design of the Regulated Power Supply Circuit

To supply an extra current to the load, a power transistor (Q_1) is being added to the regulator's circuit. It is also known as an outboard bypass transistor. Current below 500 mA is to flow through the regulator. Above 500 mA the input current flows through the 3.3 Ω resistor which develops a voltage (Figure 6). When this voltage increases to around 0.7 V, (base emitter PD) the power transistor start to conduct and supply extra current to the load. The 22 Ω resistor limits excessive base current to the power transistor.

Heat sink was used to radiate excessive heat developed by the power transistor.

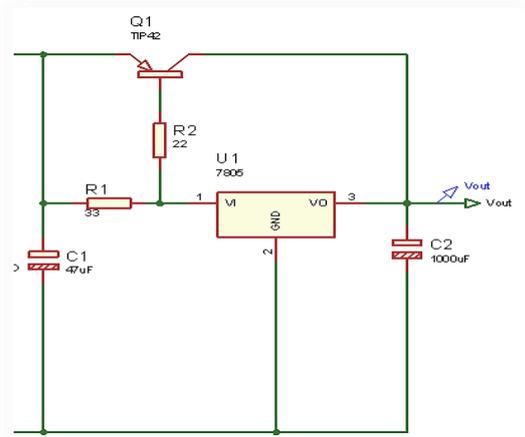


Figure: 6 Circuit Design of the Voltage Regulator

A fully charged lead acid battery has PD of 13.5 V, during discharging it may also drop to 10 V. The soldering iron is rated 8 W, therefore is expected to draw a current of 1.6 A. The power dissipation in the bypass transistor is:

$$\frac{V_{CE} \times I_c}{V_{CE} = V_{CC} - V_{REG}} \quad \begin{matrix} 1 \\ 2 \end{matrix}$$

where; V_{CE} is the PD across collector- emitter of the transistor in volts, I_c is the collector current in amperes and V_{REG} is the regulated PD in volts.

Fully charged battery has a PD of about 13.5 V. From equation 2 the Power dissipated is $(13.5 - 5.0) \times 1.6 = 13.6 \text{ watts}$

As the battery PD drops to 10 V, the power dissipated is 8 watts.

The current and PD across R_2 is 1.6 A and 0.7 V respectively, therefore should be of a power rating of more than 1.12 watt.

3.3 Design of the Deep Discharge and Reverse Polarity Protection Circuits

This module is expected to protect the storage battery from deep discharge and the circuit as a whole from destruction when battery terminals were interchanged. The circuit design is shown in Figure 6. A relay is used to cut OFF the battery voltage when it falls below 10 V and switch it ON when above 10 V. It also switches the circuit ON when the applied voltage rises higher than the cut off voltage. A red LED indicator is ON to show that battery level has drop below 10 V, while a green LED glows when the potential difference of the source is greater than 10 V.

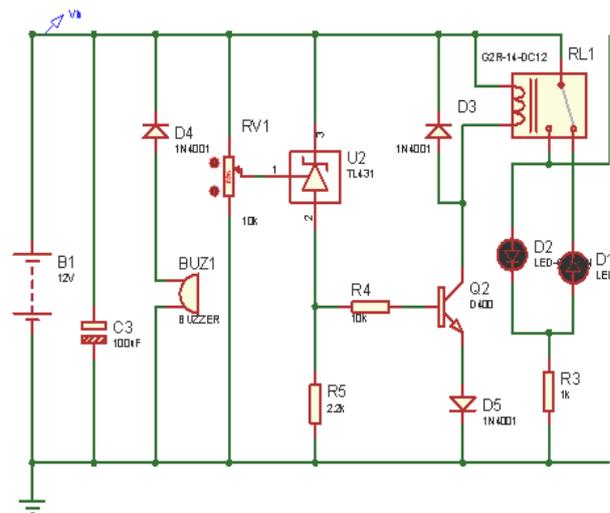


Figure: 6 Circuit Design of the Deep Discharge/Reverse Voltage Protection

The switching process employed 2SD400 NPN transistors. Using the transistor as a switch, a small base current controls a much larger collector load current [11]. This shows that;

$$I_c(max) > \frac{\text{Supply Voltage } (V_c)}{\text{Load Resistance } (R_L)} \quad 3$$

In [13], the transistor is biased so that the maximum amount of base current is applied, ensuing in maximum collector current. This causes the minimum collector emitter voltage to drop as a result in the depletion layer being as small as possible and maximum current flow through the transistor. Since the transistor is now operating at the saturation region V_{CE} is almost zero and maximum current I_c flows through the transistor to the load. To ensure that the transistor remain saturated, it has been suggested that I_c should be calculated 30% higher than its saturation value [7]. While the maximum potential difference applied to the circuit is 13.5 V, an epitaxial planar silicon transistors (2SD400) with a maximum collector current rating of 1 A [9] is used in the design.

While using a transistor to turn on a relay coil, it is essential to use a Snubber diode a reverse biased diode across the coil. This is to prevent the kickback voltage from destroying the transistor [6]. The materials used in the construction are listed in Table 1. The circuit diagram on “Proteus”, is presented in Figures 7.

Table 1: Materials used for construction

S/N	Component	Description	Quantity
1	Transistor	BD536	1
2	Transistor	2SD400	1
3	Shunt Regulator	TL431	1
4	Voltage Regulator	LM7805CT	1
5	Diode	1N14001	1
6	LED	RED	1
7	LED	Green	1
8	Capacitor	100 μ F	1
9	Capacitor	4.7 μ F	1
10	Capacitor	1000 μ F	1
11	Capacitor	3.3 Ω	1
12	Buzzer	12 V	1
13	Resistor	2.2 k Ω	1
14	Resistor	1 k Ω	1
15	Resistor	10 k Ω	1
16	Resistor	3.3 k Ω	1
17	Fuse	2.0 A	1
18	Coil Relay	12 V	1

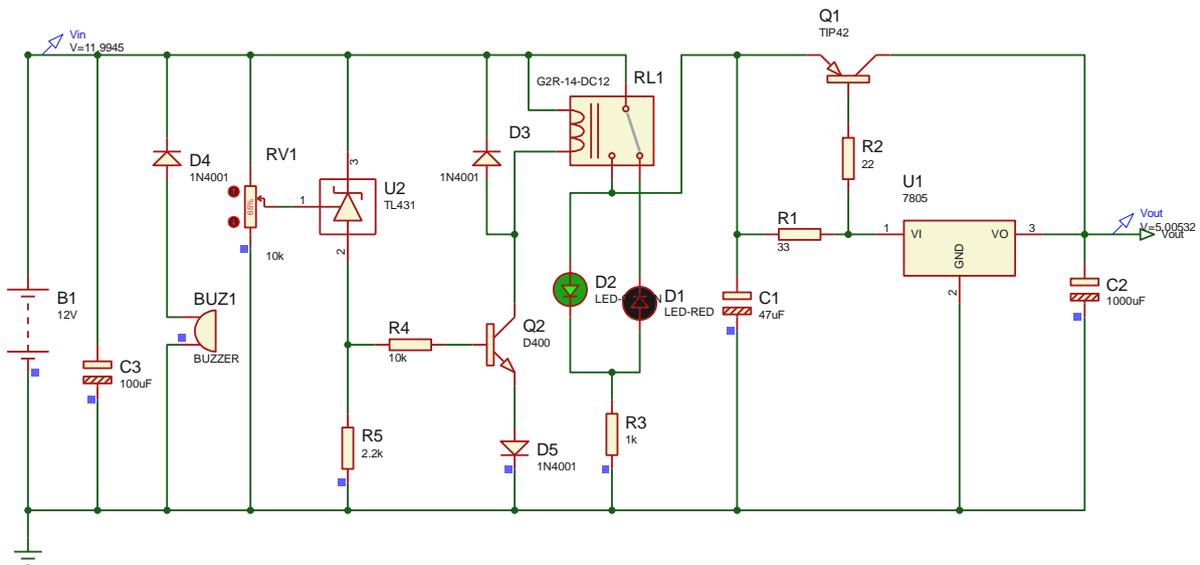


Figure: 7 Complete Circuit Design on Proteus

3.4 System Construction

The components were individually tested before soldering and the Vero board surface was sand papered to ensure good joint. Both the regulated power supply and reverse/deep discharge protection modules were constructed on a piece

of Vero board as shown in Plate 1. The input terminals were connected via crocodile clips. To improve transient response and stability of the circuit a 100 μ F smoothing capacitor was connected across the terminals of the input supply.

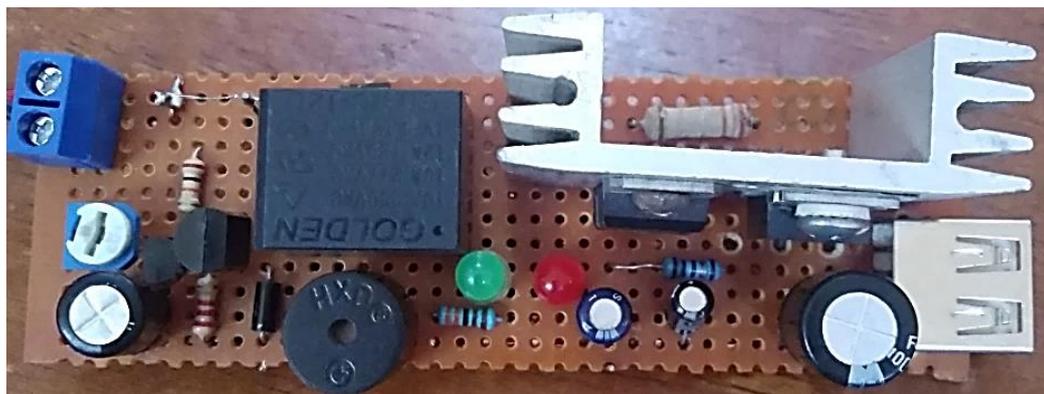


Plate 1: Photograph of the constructed Circuit

4. Results and Discussion

4.1 Computer Simulations

After designing the circuit, it was implemented on Proteus software. During the simulation the input voltage was varied from 10 to 13.5 volts while

noting the corresponding values of the output voltages. Inputs voltages of 10, 11.5 and 13.5 V were applied to voltage regulation section of the circuit. The results show a constant output voltage of 5.01 V with respect to time in millisecond as shown in Figure 8. This shows that regulation section is working properly.



Figure: 8 Simulations of the Voltage Regulator Stage in Proteus

The relay switches ON when transistor Q_2 is in saturated state. The simulation of the transistor in saturated state is also shown in figure 9. The $5\text{ K}\Omega$ potentiometer is used to set the saturation state of the transistor. In an unsaturated state output gradually diminishing to zero, hence the relay circuit turns OFF. In this paper the cut-off voltage was set to 10 V. Green LED indicator turns ON to show that the battery PD is greater

than 10 V while the Red LED turns ON when the voltage drops to 10 V, which shows that charging is obligatory. No current flows in the circuit when the terminals were in the reverse order. A sound from the buzzer shows that the input terminals is wrongly connected. The results of the simulation compare well with the anticipated ones from the design.

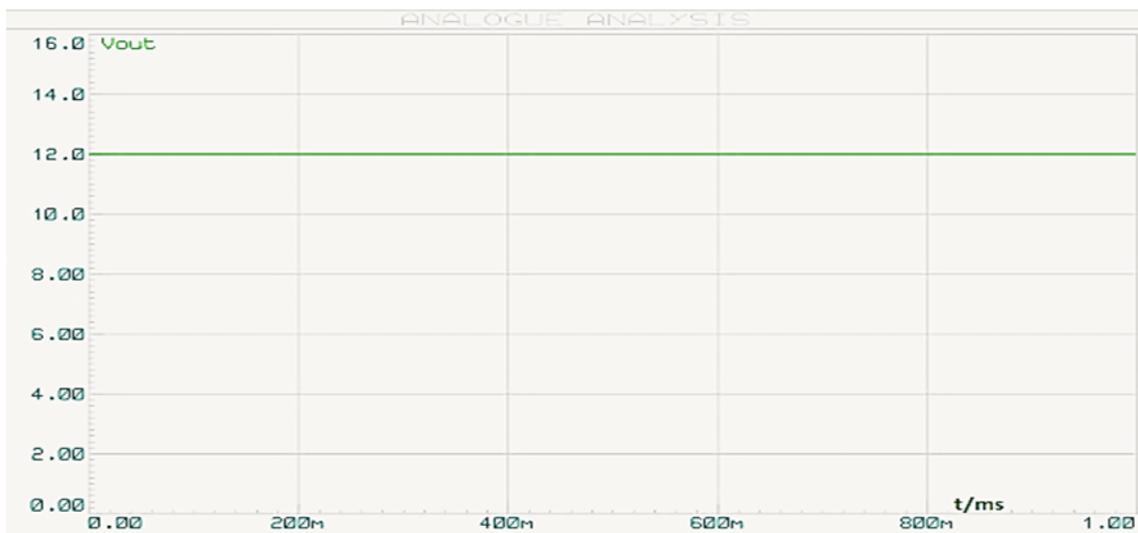


Figure: 9 Simulations of the Reverse Polarity/Deep Discharge Control Stage in Proteus

4.2 System Tests

After the construction, the circuit was subjected to appropriate tests to ascertain the working condition of the two parts of the system. A voltmeter was connected across the output of the circuit protection and found to be ON only when the input PD is 10.3 V or higher. The output PD of the circuit was found to be 5.17 V on no load and 5.12 when loaded with the soldering iron. This output was maintained for an input supply between 10.3 and 18 volts. Power rating of the

system was estimated by connecting it to a motorcycle lead acid battery 12 V, 4.5 A of potential difference of 12.7 V. A non-inductive variable load (resistor) was connected to the output of the constructed power supply. The variable load was then varied from $2\ \Omega$ to $10\ \Omega$ while noting the corresponding values of the output voltages. Potential differences were measured with respect to resistances across. Results obtained were tabulated and represented graphically in Figure 10.

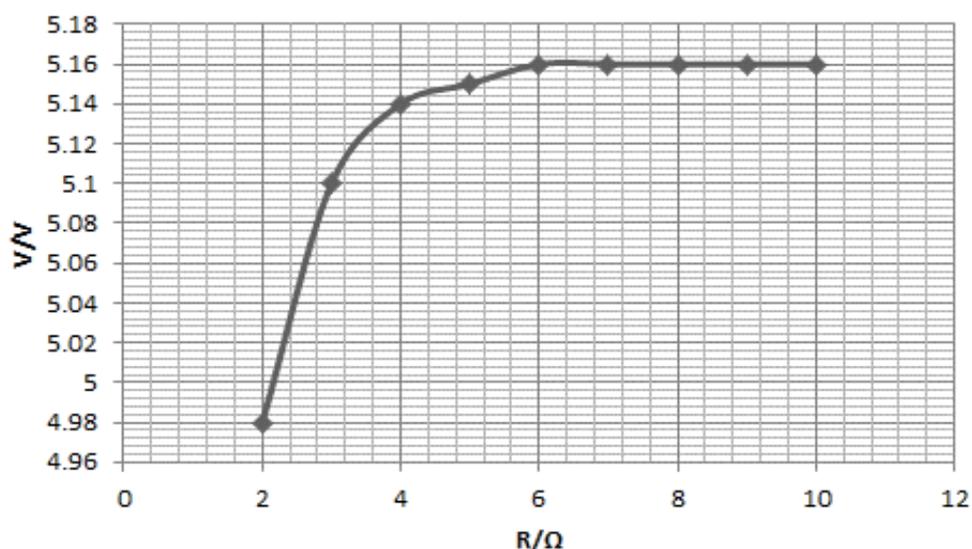


Figure: 10 Power PD VS Resistive Load

Figure 10 shows that as the load resistance varies from 2 to 4 Ω the output voltage increases almost linearly from 4.9 to 5.16 V. The voltage then stabilizes at 5.16 V as the load resistance increases beyond 6 Ω , the output potential is proportional to the load across its terminals. The result shows that system is working properly within the measured parameters by providing a suitable working voltage for the USB soldering iron of around 5 volts.

5. Conclusion

The power supply system operates on input voltages ranging from 10 to 13.5 volt. Constant direct current output of about 5 volts was obtained within the range. It is suitable for powering an 8 watt USB soldering iron for minor works at home or in the laboratory. From the test and analysis conducted the power system was found to be working adequately.

Conflict of Interest

The author declares that there is no conflict of interest.

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