

Michigan State University Electrical Engineering Department

ECE 480 Design Team 3: Designing Low Voltage, Low Current Battery Chargers

Application Note

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Abstract:

The following application note displays team 3's design of an adjustable battery charger for their power monitoring system. The article first explains the research required for the battery's parameters for charging. It then outlines a generic design for the battery charger before explaining how to choose individual components specific for this design. The article closes with an explanation of the design's limitations and recommendations for further design improvement.

Introduction:

Voltage imbalances are a very common occurrence in large three phase factories and cause thousands of dollars' worth of damage to equipment. Team 3 has been tasked with designing a system that can be placed within a factory to monitor the power flow and alert users when there is an issue with the power. This system is to be primarily powered by a 120 VAC wall outlet. In the event that this device loses power, such event could go unnoticed for days if it was assumed that no issue with power flow had occurred. Therefore, Team 3 decided to implement a back-up power system to notify the user when the primary power supply fails.

The decision was made to use a battery power supply as the means of back-up power. Considerations were made for large capacitors to act as a form of stored power but with limitations of time, the team reverted to a more known and commonly used method of energy storage. A battery that was able to power the microcontroller long enough to send an email alert as well as a battery charger design able to charge the battery yet also have the protection to cease charging when the battery was fully charged was needed.

Objective:

Many common battery charger designs are available. The objective of this application note is for the user to become acquainted with this battery charger design, its benefits and limitations, and be able to design a similar charger using their own battery parameters at the conclusion of this article.

Design Procedure:

1. Selecting a Battery:

Before one can design a battery charger, the battery itself must be chosen. In this example, a battery configuration was needed with terminal voltage greater than 6V and with enough power to power the microcontroller with 300 mA of current for at least one minute. These restrictions came from the necessity of a voltage regulator to regulate the voltage to 5V to power the microcontroller. They also come from the delay time for loss of power before sending an email notification prematurely as well as the time to send an email itself. Therefore a 9V NiMH battery

was chosen. This battery is rated at 175 mAh which was plenty to power the microcontroller for the time needed.

Another consideration that should go into selecting a battery is that not every battery is rechargeable. Rechargeable and disposable batteries are made up of different chemicals. Recharging a battery not intended to be recharged could cause overheating and explosion [1]. For this reason, a rechargeable 9V energizer battery was chosen.

2. Researching Parameters:

Once a battery has been selected, research must be done to determine what voltage the battery will be allowed to charge to and at what rate. This must be determined because irreversible damage can be done to a battery by charging it too fast or too much. It can overheat as well as lose its capacity to store charge [2]. The exact chemistry of the damage will not be covered in this application note, however, because it is not the focus.

Without knowing the high-end design and chemical make-up of the battery, it is hard for a user to determine the rate at which the battery should be charged unless clearly specified. Nominal voltage is clearly labeled on common batteries. From basic circuit analysis, it can be concluded that the charging voltage must be slightly higher than the rated voltage for a current to flow into the battery to charge it.

A simple and safe way to discover which rate that a battery should be charged at is to research common battery chargers that manufacturers have made for the chosen battery. Manufacturers document the specifications of battery chargers openly. If the user was to select one of the battery chargers that are already designed for the battery and determine what rate the charger charges the battery, assumptions can be made that this is a safe and effective rate to charge the selected battery.

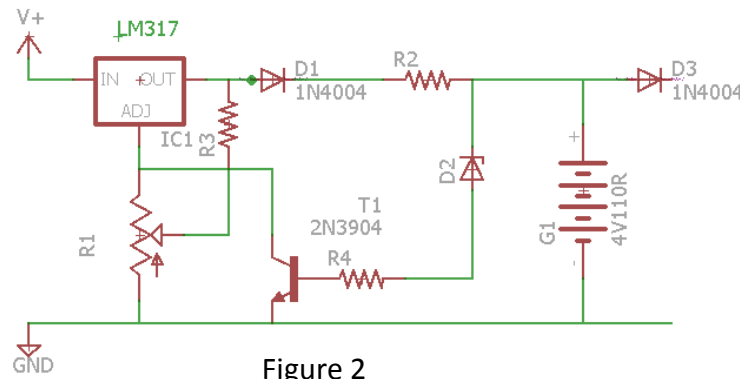
In this example, a rechargeable 9v Energizer battery was chosen. Research was done by selecting multiple chargers made by Energizer Holdings Inc. and finding a common current draw into the battery from the charger. This was found on Energizer's website and was between 16 and 30 mA. This can be seen below in Figure 1.

Datasheet	Picture	Battery Chemistry	Cell Sizes	Charge Rate	Charge Time (hrs.)	Charge Control	Weight (g)	Height (mm)	Length (mm)	Width (mm)
CH15MN2 "Rapid"		NIMH	1 to 4 AA 1 to 4 AAA	AA - 8.6 Amps AAA - 3.2 Amps	0.25	Yes	180	36	120	80
CHFC2 "Universal"		NIMH	2 or 4 AA 2 or 4 AAA 2 or 4 C/D 1 9V	P>AA - 0.45-1.0 Amps AAA - 0.45-1.0 Amps C/D - 0.55 Amps 9V - 0.03 Amps	6	Yes	109	83.5	50	30
CHFCV2E "Uni Value"		NIMH	2 or 4 AA 2 or 4 AAA 2 or 4 C/D 1 or 2 9V	AA - 0.2 Amps AAA - 0.2 Amps C/D - 0.2 Amps 9V - 0.016 Amps	16.5	Yes	500	52	204	100

Figure 1: Battery charger specifications table [3]

3. Battery Charger Design Explanation:

The battery charger design chosen for this project was one that was adjustable, did not need logic control as a DC/DC buck or boost converter would, and had the protection to shut itself off. One such design was covered in Dr. Wierzba's ECE 402 notes for Michigan State University [4]. It is shown below in Figure 2. The figure has been redrawn in Eagle PCB software for better viewing.



This charger has the ability to limit current draw with the correct component selection, stops charging when the battery voltage has reached a certain magnitude, and is fairly cheap to build.

The main component of the design is the LM317 variable voltage regulator. It will supply a voltage output that is 1.25V greater than the voltage at the adjust pin. In order to make this an “adjustable” voltage regulator, a feedback resistor is needed. Resistor R3 in Figure 2 serves this purpose. A current will flow through the resistor in the direction from V_{out} to V_{adjust} . If we assume the transistor is to be cut off, all of this current must flow through the potentiometer R1. By varying the resistance of R1, the user can adjust the total voltage output of the regulator. However, to do limitations of the LM317, it cannot boost the voltage and therefore the output voltage can never be greater than the input voltage.

In the event that the battery voltage is greater than the output of the voltage regulator for any reason, D1 serves as a block to prevent the battery from unwanted back feed of the regulator. One such event could occur when power in the circuit is lost. The output of the LM317 would fall to zero while the battery would still have charge.

The Zener diode, D2, serves as the overvoltage protection for the charger. If the battery voltage reaches such point that it is greater than the Zener diode, the diode will break down and conduct. When D2 passes current, this will forward bias the transistor T1. Resistor R4 is placed to limit the forward biasing voltage of T1. If for some reason the battery voltage is far greater than the Zener voltage combined with the V_{be} voltage of the transistor, damage could be done and therefore R4 is needed.

In the event that the transistor is forward biased, more current will be drawn from the collector terminal. This current must come from current passing through resistor R3. However, current

through R3 is fixed and in result, current through the potentiometer will reduce to accommodate the current draw through the resistor. When this happens, the overall voltage applied to the adjust pin will be lowered. This will lower the total Vout voltage and cease the battery from charging.

Resistor R2 serves as an indirect control for the charging rate of the battery. The current into the battery would be calculated as shown below:

$$I_{\text{charge}} = (V_{\text{out}} - V_{\text{batt}})/R2$$

If the user already knows what their battery voltage range will be as well as the Vout range allowed by the LM317, resistor R2 can be chosen to provide the correct range of charging rates for the battery.

The final Diode, D3 serves as a back feed protection from the rest of the circuit. When primary power is present, there will be no need for the battery to power any device and the circuit voltage will be greater than that of the battery. This will keep diode D3 as well as the battery being charged to an undesired voltage. In the event of a loss of power, the circuit voltage will drop to less than that of the battery forcing diode D3 to begin conducting and allowing the battery to power the circuit. This diode was not included in Dr. Wierzbą's design of the circuit but is necessary if the battery is to be integrated into the rest of a circuit design.

4. Selecting Components:

From the design, the LM317 as well as the 2N3904 transistor have been chosen for the user. Diodes D1 and D3 are suggested to be 1N4004 but do not need to be. These serve only the purpose of blocking reverse voltage and conduction current when necessary. They are suggested to be 1N4004 because these are diodes that can maintain conditioning of large amounts of current, in terms of circuit boards, without failing. In this example, the LM317, 2N3904, and both 1N4004 will be used because they were readily available during the prototype stage of the design.

As stated previously, a 9V NiMH rechargeable battery will be selected for use. If the Vbe-on of the transistor is assumed to be 0.6V, then a selection for the Zener diode can be made. Keeping in mind that we must allow the battery to charge slightly above its rated voltage in order to ensure a proper charge, the user must select a Zener diode that has a greater breakdown voltage than the battery terminal voltage. For this example, a 9V Zener diode was chosen that would allow the battery to charge to the voltage shown below:

$$V_{\text{batt}} = 9\text{V (Zener)} + 0.6\text{V (transitory)} = 9.6\text{V}$$

The selection of resistor R4 is not as strict as other components as long as it is within reason. Its purpose is to dampen large voltage differences between the battery and the series combination of the Zener diode and Vbe-on of the transistor. In this example, a 1KΩ resistor is selected.

The selection of the potentiometer R1 and the resistor R3 are the most difficult components to choose in this design because many assumptions must be made and they are dependent upon each other. Below is Figure 3 with the design with components labels that have already been selected as well as other labels needed for this explanation. The provided power supply is a 12V source as shown.

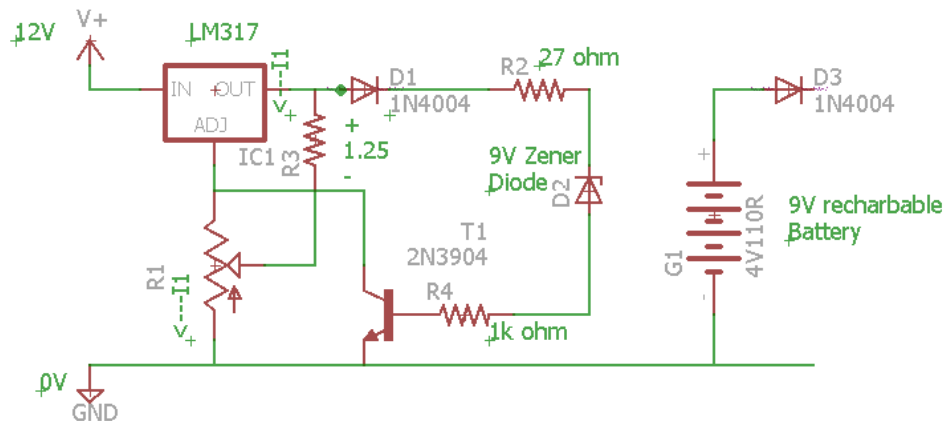


Figure 3

As stated, the voltage between the adjust pin and the output pin on the LM317 is 1.25V. All of the current that flows through R3 will flow through the lower portion of the potentiometer if the transistor is assumed to be cut off. One more assumption must be made before calculations can be made. The user must select what their target Vout voltage would be. If Vout is chosen too large, resistor R2 will need to be large in order to drop the larger voltage across it while limiting the charging rate of the battery. In this example, 10.5V is chosen as the target output voltage. This decision is made with the fact that there will be a slight drop from Vin to Vout on the LM317 and that the voltage must also be greater than 9.6 volts to force the battery to charge. With these choices, the desired voltage across the potentiometer can be solved for. This is done below:

$$V_{pot} = 10.5 - 1.25 = 9.25V$$

Because we have 2 variables for one problem, either R1 or R3 can be selected and then by the user before solving for the second component. In this example, a 5 kΩ pot was readily available during prototyping. Its value while making calculations was taken to be Rpot/2 to provide a greater range of variance for the final output voltage. Knowing the desired voltage and resistance of the pot, the user can solve for the necessary current through R1. This is shown below:

$$I_{pot} = V_{pot} / (R_{pot}/2) = 9.25 / 2500 = 3.7 \text{ mA}$$

The feedback resistor R3 must now be selected such that a 1.25 V drop will force 3.7 mA of current to flow. The calculation can be seen below:

$$R3 = 1.25 / I_{pot} = 1.25 / 3.7m = 337.83 \Omega$$

The closest available resistor available in this example was a 330Ω resistor which was selected.

The final component to be decided upon is the current limiting resistor R2. Before selecting the resistor, the user must have made a decision from their research in part 2 of this application note as to how fast they wish to charge the battery. In this example, 30 mA was the maximum any battery charger charged the selected battery. It was therefore chosen that 30 mA will be the maximum charging rate of this design.

Assumptions must be made before proceeding on how low the battery voltage will be before charging. In Team 3's design, the battery is disconnected from the circuit after it has served its purpose as backup power. Therefore, the battery is not expected to discharge very much. An assumption was made that the battery terminal voltage will not fall farther than 9V. The last assumption that must be made is that the V_{d-on} voltage of D1 will be 0.7V. All of these assumptions are made with common circuit analysis knowledge.

Knowing the lowest point the battery voltage will reach, the V_{d-on} voltage, and the output voltage of the LM317, the user can now calculate the value of the current limiting resistor R2. The voltage as well as the resistance can be solved for as follows:

$$V_{r2} = V_{out} - V_d - V_{batt} = 10.5 - 0.7 - 9 = 0.8 \text{ V}$$

$$R2 = V_{r2} / I_{chargemax} = 0.8 / 30\text{m} = 26.6666$$

The closest resistance value available in this example was 27Ω which was selected.

Before concluding the component selection, it is good practice to solve for the power dissipated by each component and ensure that it can handle such magnitude. The small voltages and current in this example allow assumption to be made that the standard component selected are within tolerance. Figure 4 displays the final schematic and Figure 5 displays the physical realization of this design.

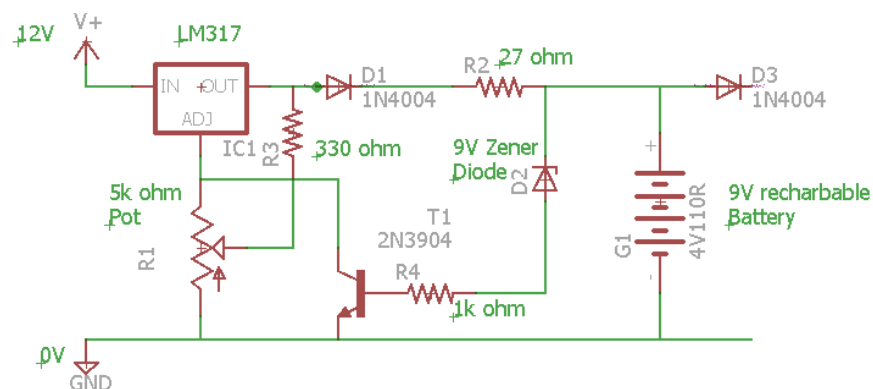


Figure 4

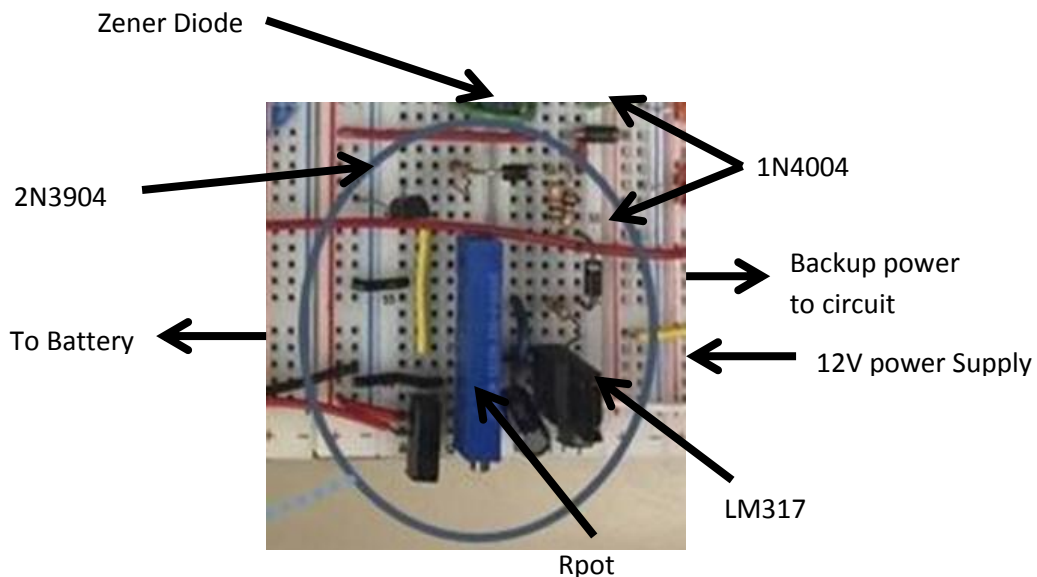


Figure 5

Limitations:

As the title of this article states, this design is for a low voltage, low current battery charger. Many limitations arise from the current draw capable of the LM317 to the maximum voltage output. Figure 6 below displays the maximum operating range of the LM317 as given by its data sheet found on Texas Instruments' website [5].

LM317 3-Terminal Adjustable Regulator	
1 Features • Output Voltage Range Adjustable From 1.25 V to 37 V • Output Current Greater Than 1.5 A • Internal Short-Circuit Current Limiting • Thermal Overload Protection • Output Safe-Area Compensation	3 Description The LM317 device is an adjustable three-terminal positive-voltage regulator capable of supplying more than 1.5 A over an output-voltage range of 1.25 V to 37 V. It requires only two external resistors to set the output voltage. The device features a typical line regulation of 0.01% and typical load regulation of 0.1%. It includes current limiting, thermal overload protection, and safe operating area protection. Overload protection remains functional even if the

Figure 6

The voltage output can range from 1.25 to 37 with this regulator, but remember that the output can never be larger than the input. This design cannot boost voltage in any way and therefore limits the ability to charge batteries of higher voltage than the power supply's voltage.

The datasheet states that the output current can reach 1.5 A. this may seem like a large voltage, but the constraint comes from the high thermal impedances of the LM317. When a larger current is forced through the regulator, the regulator dissipates more power to buck the voltage to the desired magnitude. This power consumed turns to heat. The Junction to ambient thermal resistance of the LM317 chosen for this example was 53 degrees Celsius/Watt [5]. This means if the voltage regulator drops 2 volts from input to output and passes 500 mA of current, the junction temperature will be 53 degrees above ambient temperature. Therefore, while the datasheet states it can handle up to 1.5A, considerations have to be made for the total power dissipated and heat produced. The maximum operating temperature as stated by the data sheet is 125 degrees Celsius.

Conclusions and Recommendations:

Using this application note, the user should be able to properly choose a battery for their application and be able to select components for the battery charger as well as understand how it works. The users should understand the limits of the design and be able to decide if this battery charger design will be able to accommodate their charging needs.

Some recommendations that would further improve the battery charging system are to use a larger input voltage when charging this large of a battery. This will allow for a greater variance in the output voltage and a wider range of charging rates. With the present design, the output voltage cannot be increased much further than 10.5 V due to the drop between input and output voltages. This means that the charging rate could not increase much further if the same limiting resistor were to be used. Turning the potentiometer in hopes of selecting a larger adjust voltage could only reach a certain point before the output voltage reached its limit. However, if a higher input voltage was used, the output voltage could be increased further.

A drawback of using a higher input voltage is that there would be a greater voltage drop between the input and output voltages that would lead to a larger power dissipation and heat production. However, in this particular example, such a low current is drawn from the voltage regulator that this would not greatly affect the heat production.

References:

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