# DEVELOPMENT OF BATTERY IMPEDANCE TESTER

MOHD SHAHIR BIN MOHD SARIF

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Faculty of Electrical & Electronics Engineering
University Malaysia Pahang

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# DEDICATION

*Dedicated, in thankful appreciation for support, encouragement and understanding*
*to my beloved families, lecturers and fellow friends*

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# ABSTRACT

Introduces an applicable method for measuring battery's internal impedance and conductance techniques have been advocated in the determination of the condition of lead-acid batteries in service. The battery itself has an internal resistance that makes it difficult to control the charging and discharging process because the capacity of the battery is estimated by the potential difference between the two electrodes of the battery, named external voltage. The usefulness of these "ohmic" techniques lies in an understanding of the bounds and domain of the measurement. Impedance model contains a lot of information that can indicate performance of battery**.** Therefore, establishment of accurate impedance model is very important**.** The impedance behaviour during individual discharge cycles as well as over its cycle life is obtained**.** Frequency response and battery impedance behaviour generally observed for a of commercially available batteries. The impedance is calculated by the ratio of voltage and current variation.

# ABSTRAK

Memperkenal dan mengaplikasi cara bagi teknik mengukur kerintangan dan kearuhan dalam bateri yang dikenal pasti dengan didalam lead acid bateri. Dalam bateri sendiri mempunyai kerintangan dalaman yang membuatkan ianya sukar untuk mengawal process mengecas dan proses mengenyahcas kerana kapasiti bateri yang dijangka oleh perbezaan potensi berbeza di antara dua elektrod pada bateri. Yang dikenali sebagai voltan luaran. Keguanaan teknik ohmic adalah bagi memahami ikatan dan domain pada pengukuran. Model kerintangan mempunyai banyak maklumat yang boleh menunjukkan prestasi bateri. Kerintangan model yang tepat amat penting. Sifat kerintangan sewaktu keadaan mengnyahcas adalah lebih besar dari keadaan jangka hayat bateri. Frekuensi respon dan sifat kerintangan bateri secara keseluruhannya dilihat bagi julat secara komersial. Kerintangan dikira berdasarkan oleh nisbah variasi arus dan voltan

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| DC | - | Direct current |
| ESL | - | Effective Series Inductance |
| ESR | - | Equivalent series resistance |
| PCB | - | Printed circuit board |
| CCM | - | Continuous current mode |
| IC | - | Integrated circuit |
| Vin | - | Input voltage |
| Vo | - | Output voltage |
| Vramp | - | Ramp voltage |
| Verror | - | Error voltage |
| Vswitch | - | Switch voltage |
| D | - | Duty cycle |
| Ts | - | Switching period |
| fs | - | Switching frequency |

# LIST OF APPENDICES

# CHAPTER 1

## 1.0 Introduction

In recent years there has been considerable activity and debate regarding the use of internal "resistance" characteristics as a battery condition measurement. The interest reflects the desire for simple electronic means to replace discharge testing as a practical determination of residual battery capacity, particularly given the increased usage of seal lead-acid (SLA) batteries. The available techniques, which include AC impedance and conductance methods and momentary DC loading, all involve controlled current or voltage perturbations to determine a representation of the internal ohmic condition of the battery. Internal battery resistance has been proposed as a means to track battery life but greater interest lies in reported claims of specific correlation between cell impedance or conductance with battery capacity. More recent reports indicate that the currently available single-frequency internal ohmic determination techniques cannot, in general, provide unequivocal absolute battery capacity information. However, the techniques have been shown to have some merit as a comparative tool, and thus are useful indetecting early trends in rogue cells and components with poor conduction integrity. In this sense, battery impedance, conductance or resistance measurements are now currently best viewed as an aid in assessment of battery state-of-health. Telstra is cautiously incorporating simple impedance measurements into various battery and power system maintenance routines. Advocacy of merit of any one determination method over the other is both of interest and a source of confusion to the end-user. For AC techniques, the selection of measurement frequency appears empirical in origin, drawn from very limited determinations of the frequency response of specific types of batteries. Furthermore, the published literature on fundamental impedance characteristics of lead-acid batteries is not unequivocal. Electrochemical impedance spectroscopy has been used in studies of electrode and plate behaviour during charging and discharging, but there has been only limited application to the near equilibrium condition for lead-acid batteries on float duty. The *ohmic* response of the battery depends on the measurement frequency and the state of the battery and has been reported to be affected, to varying degrees, by many fundamental cell characteristics, including cell design temperature and capacity. An understanding of the behaviour of lead-acid batteries on float is of paramount importance for stand-by applications. The frequency response of lead-acid batteries is important in determining the relative merits of various AC perturbation techniques currently used to probe the state-of-health of lead-acid batteries on standby duty.

## 1.1 Objectives of the Project

The objectives of the project are:

1.) To study the characteristic and operation of battery impedance.
2.) To Analyze the operation of battery impedance.
3.) To develop a practical battery charger for battery impedance based on simulation parameters and outcomes.

## 1.2 Project Scope

The scopes of this project are as follows:

1.) Designing the battery charger circuit and discharge circuit
2.) Develop a Printed Circuit Board (PCB) based on the parameters during simulation

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In this chapter, the basis theories of continuous battery impedance tester alongside the architecture of the circuit will be reviewed. The type of batteries, and technique are described.

## 2.2 Battery Charger

With technical knowledge, batteries can be charged manually with a power supply featuring user-adjustable voltage and current limiting. charge termination is not automated. To observe the state-of-charge according to voltage and current behaviors. Lower the charge voltage or disconnect the charge when the battery is full. Because of difficulties in detecting full charge with nickel-based batteries, It recommend only charging lead acid and Li-ion batteries manually.

Before connecting the battery, calculate the charge voltage according to the number of cells in series, and then set the desired voltage and current limit. To charge a 12-volt lead acid battery (six cells) to a voltage limit of 2.40V, set the voltage to 14.40V (6 x 2.40). Select the charge current according to battery size. For lead acid this is between 10 and 30 percent of the rated capacity. A 10Ah battery at 30 percent charges at about 3A. Starter batteries charge at lower currents, and an 80Ah pack would charge at about 10 percent of the rating, or 8A. Higher currents are possible.

Observe the battery temperature, voltage and current during charge. Charge only at ambient temperatures in a well-ventilated room. Once the battery is fully charged and the current has dropped to three percent of the rated Ah, the charge is completed. Disconnect the charge. High self-discharge (soft electrical short) may prevent the current from going to the anticipated low current level when fully charged. Disconnect the charge also when the current has bottomed out and cannot go lower. Float charge for operational readiness, lower the charge voltage to about 2.25V/cell.

It can also use the power supply to equalize a lead acid battery by setting the charge voltage 10 percent higher than recommended. The time in overcharge is critical and must be carefully observed. When using the power supply to perform equalizing.

A power supply can also reverse sulfation but there is no guarantee of success. When applying a charge, a totally sulfated lead acid may draw very little current at first, and as the sulfation layer dissolves the current will gradually increase and increase the charge voltage above the recommended level, set the current limiting to the lowest practical value and observe the battery voltage.

Lithium-ion charges similarly to lead acid and use the power supply also but use extra caution. voltage threshold to 4.20V/cell and make certain that none of the cells connected in series exceeds this voltage. Full charge is reached when the cell(s) reach 4.20V/cell voltage and the current drops to three percent of the rated current, or has bottomed out and cannot go down further. Once fully charged, disconnect the battery. Never allow a cell to dwell at 4.20V for more than a few hours.

Full-charge detection is difficult to assess because the voltage signature varies with the applied charge current, use the temperature rise on a rapid charge as an indication for full charge. When charging at a low current, estimate the level of remaining charge and calculate the charge time. An empty 2Ah NiMH will charge in three hours at 500mA. The trickle charge must be reduced to 0.05C.

## 2.3 Lead Acid Battery

Lead acid was the first rechargeable battery for commercial use. Despite its advanced age, the lead chemistry continues to be in wide use today, and there are good reasons for its popularity; lead acid is dependable and inexpensiveon cost-per-watt base. There are few other batteries that deliver bulk power as cheaply as lead acid, and this makes the battery cost-effective for automobiles, golf cars, forklifts, marine and uninterruptible power supplies (UPS).

But lead acid has disadvantages; it is heavy and is less durable than nickel- and lithium-based systems when deep-cycled. A full discharge causes strain and each discharge/charge cycle permanently robs the battery of a small amount of capacity. This loss is small while the battery is in good operating condition, but the fading increases once the performance drops to half the nominal capacity. This wear-down characteristic applies to all batteries in various degrees.

Depending on the depth of discharge, lead acid for deep-cycle applications provides 200 to 300 discharge/charge cycles. The primary reasons for its relatively short cycle life are grid corrosion on the positive electrode, depletion of the active material and expansion of the positive plates. These changes are most prevalent at elevated operating temperatures and high-current discharges. Charging a lead acid battery is simple but the correct voltage limits must be observed, and here there are compromises. A high voltage limit improves performance but form grid corrosion on the positive plate. While sulfation can be reversed if serviced in time, corrosion is permanent.

Lead acid does not lend itself to fast charging and with most types, a full charge takes 14 to16 hours. The battery must always be stored at full state-of-charge.

Low charge causes sulfation, a condition that robs the battery of performance. Adding carbon on the negative electrode reduces this problem but this lowers the specific energy.

Lead acid has a moderate life span and is not subject to memory as nickel-based systems are. Charge retention is best among rechargeable batteries. While NiCd loses approximately 40 percent of its stored energy in three months, lead acid self-discharges the same amount in one year. Lead acid work well at cold temperatures and is superior to lithium-ion when operating in subzero conditions.

### 2.3.1 Characteristics

They remain the technology of choice for automotive SLI (Starting, Lighting and Ignition) applications because they are robust, tolerant to abuse, tried and tested and because of their low cost. For higher power applications with intermittent loads however, Lead acid batteries are generally too big and heavy and they suffer from a shorter cycle life and typical usable power down to only 50% Depth of Discharge (DOD). Despite these shortcomings Lead acid batteries are still being specified for PowerNet applications (36 Volts 2 kWh capacity) because of the cost, but this is probably the limit of their applicability and NiMH and Li-Ion batteries are making inroads into this market. For higher voltages and cyclic loads other technologies are being explored.

Lead-acid batteries are composed of a Lead-dioxide cathode, a sponge metallic Lead anode and a Sulphuric acid solution electrolyte. This heavy metal element makes them toxic and improper disposal can be hazardous to the environment.

The cell voltage is 2 Volts

### 2.3.2 Discharge

During discharge, the lead dioxide (positive plate) and lead (negative plate) react with the electrolyte of sulfuric acid to create lead sulfate, water and energy.

### 2.3.3 Charge

During charging, the cycle is reversed: the lead sulfate and water are electro-chemically converted to lead, lead oxide and sulfuric acid by an external electrical charging source.

### 2.3.4 Advantages

1.) Low cost.
2.) Reliable. Over 140 years of development.
3.) Robust. Tolerant to abuse.
4.) Tolerant to overcharging.
5.) Low internal impedance.
6.) Can deliver very high currents.
7.) Indefinite shelf life if stored without electrolyte. .
8.) Wide range of sizes and capacities available.
9.) Many suppliers world wide.
10.) The world's most recycled product.

### 2.3.5 Shortcomings

1.) Very heavy and bulky.
2.) Typical coulombic charge efficiency only 70% but can be as high as 85% to 90% for special designs.
3.) Danger of overheating during charging
4.) Not suitable for fast charging
5.) Typical cycle life 300 to 500 cycles .
6.) Must be stored in a charged state once the electrolyte has been introduced to avoid deterioration of the active chemicals.

Gassing is the production and release of bubbles of hydrogen and oxygen due to the breakdown of water in the electrolyte during the charging process, particularly due to excessive charging, causing loss of electrolyte. In large battery installations this can cause an explosive atmosphere in the battery room. Because of the loss of electrolyte, Lead acid batteries need regular topping up with water. Sealed batteries however are designed to retain and recombine these gases.

Sulphation may occur if a battery is stored for prolonged periods in a completely discharged state or very low state of charge, or if it is never fully charged, or if electrolyte has become abnormally low due to excessive water loss from overcharging and/or evaporation. Sulphation is the increase in internal resistance of the battery due to the formation of large lead sulphate crystals which are not readily reconverted back to lead, lead dioxide and sulphuric acid during re-charging. In extreme cases the large crystals may cause distortion and shorting of the plates. Sometimes sulphation can be corrected by charging very slowly (at low current) at a higher than normal voltage.

Shedding or loss of material from the plates may occur due to excessive charge rates or excessive cycling. The result is chunks of lead on the bottom of the cell, and actual holes in the plates for which there is no cure. This is more likely to occur in SLI batteries whose plates are composed of a Lead "sponge", similar in appearance to a very fine foam sponge. This gives a very large surface area enabling high power handling, but if deep cycled, this sponge will quickly be consumed and fall to the bottom of the cells.

1.) Toxic chemicals
2.) Very heavy and bulky

Lead acid batteries can work down to temperatures below -45 °C, however, like all batteries the discharge rate and effective capacity are reduced at low temperatures. In the case of Lead acid batteries the capacity falls by about 1% per degree for temperatures below +20 °C so that at the lowest temperatures cranking capacity is seriously impaired.

### 2.4 Decomposition of the Electrolyte

Cells with gelled electrolyte are prone to deterioration of the electrolyte and unexpected failure. Such cells are commonly used for emergency applications such as UPS back up in case of loss of mains power. So as not to be caught unawares by an unreliable battery in an emergency situation, it is advisable to incorporate some form of regular self test into the battery.

## 2.5 Charging

1.) Charge immediately after use.
2.) Lasts longer with partial discharges.
3.) Charging method: constant voltage followed by float charge.
4.) Fast charge not possible but charging time can be reduced using the V Taper charge control method.

## 2.6 Applications

1.) Automotive and traction applications.
2.) Standby/Back-up/Emergency power for electrical installations.
3.) Submarines
4.) UPS (Uninterruptible Power Supplies)
5.) Lighting
6.) High current drain applications.
7.) Sealed battery types available for use in portable equipment.

### 2.7 Costs

1.) Low cost
2.) Flooded lead acid cells are one of the least expensive sources of battery power available.
3.) Deep cycle cells may cost up to double the price of the equivalent flooded cells.

### 2.8 Varieties of Lead Acid Batteries

Over the years battery manufacturers have introduced a range of additives such as Calcium, Antimony and Selenium to improve various battery performance parameters. For the same reason, different cell and battery constructions have been developed to optimise various aspects of battery performance.

### 2.8.1 Lead Calcium Batteries

Lead acid batteries with electrodes modified by the addition of Calcium providing the following advantages:

1.) More resistant to corrosion, overcharging, gassing, water usage, and self-discharge, all of which shorten battery life.
2.) Larger electrolyte reserve area above the plates.
3.) Higher Cold Cranking Amp ratings.
4.) Little or No maintenance.

### 2.8.2 Lead Antimony Batteries

Lead acid batteries with electrodes modified by the addition of Antimony providing the following advantages:

1.) Improved mechanical strength of electrodes - important for EV and deep discharge applications
2.) Reduced internal heat and water loss due to gassing, however the water loss is still greater than the equivalent loss in Lead Calcium batteries.
3.) Longer service life than Calcium batteries.
4.) Easier to recharge when completely discharged.
5.) Lower cost.

Lead Antimony batteries have a higher self discharge rate of 2% to 10% per week compared with the 1% to 5% per month for Lead Calcium batteries.

### 2.8.3 Valve Regulated Lead Acid (VRLA) Batteries

This construction is designed to prevent electrolyte loss through evaporation, spillage and gassing and this in turn prolongs the life of the battery and eases maintenance. Instead of simple vent caps on the cells to let gas escape, VRLA have pressure valves that open only under extreme conditions. Valve-regulated batteries also need an electrolyte design that reduces gassing by impeding the release to the atmosphere of the oxygen and hydrogen generated by the galvanic action of the battery during charging. This usually involves a catalyst that causes the hydrogen and oxygen to recombine into water and is called a recombinant system. Because spillage of the acid electrolyte is eliminated the batteries are also safer.

### 2.8.4 AGM Absorbed Glass Mat Battery

Also known as Absorptive Glass Micro-Fibre

Used in VRLA batteries the Boron Silicate fibreglass mat which acts as the separator between the electrodes and absorbs the free electrolyte acting like a sponge. Its purpose is to promote recombination of the hydrogen and oxygen given off during the charging process. No silica gel is necessary. The fibreglass matt absorbs and immobilises the acid in the matt but keeps it in a liquid rather than a gel form. In this way the acid is more readily available to the plates allowing faster reactions between the acid and the plate material allowing higher charge/discharge rates as well as deep cycling.

This construction is very robust and able to withstand severe shock and vibration and the cells will not leak even if the case is cracked.

AGM batteries are also sometimes called "starved electrolyte" or "dry", because the fibreglass mat is only 95% saturated with Sulfuric acid and there is no excess liquid. Nearly all AGM batteries are sealed valve regulated "VRLA". AGM's have a very low self-discharge rate of from 1% to 3% per month

### 2.8.5 Gel Cell

This is an alternative recombinant technology to also used in VRLA batteries to promote recombination of the gases produced during charging. It also reduces the possibility of spillage of the electrolyte. Prone to damage if gassing is allowed to occur, hence charging rates may be limited. They must be charged at a slower rate (C/20) to prevent excess gas from damaging the cells. They cannot be fast charged on a conventional automotive charger or they may be permanently damaged.

### 2.8.6 SLI Batteries (Starting Lighting and Ignition)

This is the typical automotive battery application. Automotive batteries are designed to be fully charged when starting the car; after starting the vehicle, the lost charge, typically 2% to 5% of the charge, is replaced by the alternator and the battery remains fully charged. These batteries are not designed to be discharged below 50% Depth of Discharge (DOD) and discharging below these levels can damage the plates and shorten battery life.

### 2.8.7 Sealed Lead Acid

The first sealed, or maintenance-free, lead acid emerge in the mid-1970s. The engineers argued that the term “sealed lead acid” is a misnomer because no lead acid battery can be totally sealed. This is true and battery designers added a valve to control venting of gases during stressful charge and rapid discharge. Rather than submerging the plates in a liquid, the electrolyte is impregnated into a moistened separator, a design that resembles nickel- and lithium-bases system. This enables to operate the battery in any physical orientation without leakage.

The sealed battery contains less electrolyte than the flooded type, hence the term “acid-starved.” Perhaps the most significant advantage of the sealed lead acid is the ability to combine oxygen and hydrogen to create water and prevent water loss. The recombination occurs at a moderate pressure of 0.14 bar (2psi). The valve serves as safety vent if gases buildup during over-overcharge or stressful discharge.

Driven by these advantages, several types of sealed lead acid have emerged and the most common are *gel*, also known as *valve-regulated lead acid* (VRLA), and *absorbent glass mat* (AGM). The gel cell contains a silica type gel that suspends the electrolyte in a paste. Smaller packs with capacities of up to 30A are called SLA (sealed lead acid). Packaged in a plastic container, these batteries are used for small UPS, emergency lighting, ventilators for healthcare and wheelchairs. Because of economical price, dependable service and low maintenance, the SLA remains the preferred choice for biomedical and healthcare in hospitals and retirement homes. The VRLA is the larger gel variant used as power backup for cellular repeater towers, Internet hubs, banks, hospitals and other sites.

The AGM is a newer design and suspends the electrolytein aspecially designed glass mat. This offers several advantages to lead acid systems, including faster charging and instant high load currents on demand. AGM works best as a mid-range battery with capacities of 30 to 100Ah and is less suited for large systems, such as UPS. Typical uses are starter batter for motorcycles, start-stop function for micro-hybrid cars, as well as marine and RV that need some cycling.

With cycling and age, the capacity of AGM fades gradually; gel, on the other hand, has a dome shaped performance curve and stays in the high performance range longer but then drops suddenly towards the end of life. AGM is more expensive than flooded, but is cheaper than gel.(Gel would be too expensive for start/stop use in cars.)

Unlike the flooded, the sealed lead acid battery is designed with a low over-voltage potential to prohibit the battery from reaching its gas-generating potential during charge. Excess charging causes gassing, venting and subsequent water depletion and dry out. Consequently, gel, and in part also AGM, cannot be charged to their full potential and the charge voltage limit must be set lower than that of a flooded. The float charge on full charge must also be lowered. In respect to charging, the gel and AGM are no direct replacements to the flooded type. If no designated charger is available with lower voltage settings, disconnect the charger after 24 hours of charge. This prevents gassing due to a float voltage that is set too high

The optimum operating temperature for a VRLA battery is 25°C (77°F); every 8°C (15°F) rise above this temperature threshold cuts battery life in half. Lead acid batteries are rated at a 5-hour (0.2C) and 20-hour (0.05C) discharge. The battery performs best when discharged slowly and the capacity readings are notably higher at a slow discharge rate. however, deliver high pulse currents of several C if done for only a few seconds. This makes the lead acid well suited as a starter battery, also known as starter-light-ignition (SLI). The high lead content and the sulfuric acid make lead acid environmentally unfriendly.

### 2.8.8 Starter and Deep-cycle Batteries

The starter battery is designed to crank an engine with a momentary high power burst, the deep-cycle battery, on the other hand, is built to provide continuous power for a wheelchair or golf car. From the outside, both batteries look alike; however, there are fundamental differences in design. While the starter battery is made for high peak power and does not like deep cycling, the deep-cycle battery has a moderate power output but permits cycling.

Starter batteries have a CCA rating imprinted in amperes; CCA refers to cold cranking amps, which represents the amount of current a battery can deliver at cold temperature. SAE J537 specifies 30 seconds of discharge at –18°C (0°F) at the rated CCA ampere without dropping below 7.2 Volts. (SAE stands for Society of Automotive Engineers.)

Starter batteries have a very low internal resistance, and the manufacturer achieves this by adding extra plates for maximum surface area **Figure 2.1**. The plates are thin and the lead is applied in a sponge-like form that has the appearance of fine foam. This method extends the surface area of the plates to achieve low resistance and maximum power. Plate thickness isless important here because the discharge is short and the battery is recharged while driving;the emphasis is on power rather than capacity.

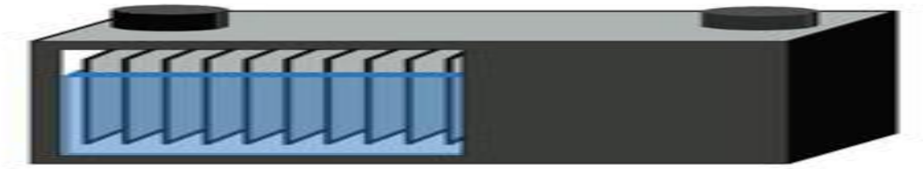


Figure 2.1 : Starter battery

The starter battery has many thin plates in parallel to achieve low resistance with high surface area. The starter battery does not allow deep cycling.

Deep-cycle lead acid batteries for golf cars, scooters and wheelchairs are built for maximum capacity and high cycle count. The manufacturer achieves this by making the lead plates thick **Figure 2.2**. Although the battery is designed for cycling, full discharges still induce stress, and the cycle count depends on the depth-of-discharge (DoD). Deep-cycle batteries are marked in Ah or minute of runtime.

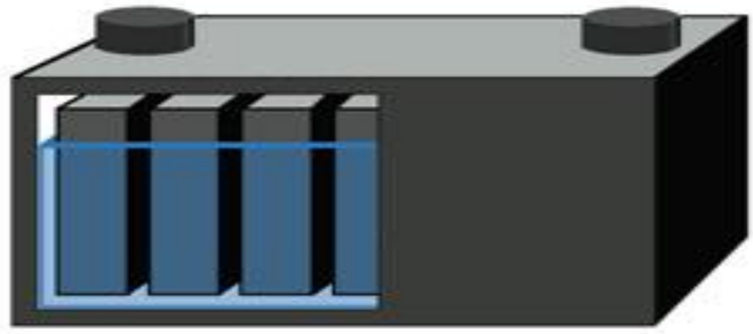


Figure 2.2: Deep-cycle battery

The deep-cycle battery has thick plates for improved cycling abilities. The deep-cycle battery generally allows about 300 cycles

A starter battery cannot be swapped with a deep-cycle battery and vice versa. While an inventive senior may be tempted to install a starter battery instead of the more expensive deep-cycle on his wheelchair to save money, the starter battery won’t last because the thin sponge-like plates would quickly dissolve with repeated deep cycling. There are combination starter/deep-cycle batteries available for trucks, buses, public safety and military vehicles, but these units are big and heavy. As a simple guideline, the heavier the battery is, the more lead it contains, and the longer it will last. Table 3 compares the typical life of starter and deep-cycle batteries when deep-cycled.

**Table 2.1:** Cycle performance of starter and deep-cycle batteries**.**

| Depth of Discharge | Starter Battery | Deep-cycle Battery |
|---|---|---|
| 100% | 12–15 cycles | 150–200 cycles |
| 50% | 100–120 cycles | 400–500 cycles |
| 30% | 130–150 cycles | 1,000 and more cycles |

A discharge of 100% refers to a full discharge; 50% is half and 30% is a moderate discharge with 70% remaining.

Lead is toxic and environmentalists would like to replace the lead acid battery with another chemistry. Europe succeeded to keep nickel-cadmium batteries out of consumer products, and authorities try to do it with the starter battery. The choices are NiMH and lithium-ion, but at a price tag of $3,000 for Li-ion, this will not fly. In addition, Li-ion has poor performance at sub-freezing temperature. Regulators hope that advancements in the electric powertrain will lower the cost, but such a large price reduction to match the low-cost lead acid may not be possible. Lead acid will continue to be the battery of choice to crank the engines.

**Table 2.2:** Advantages and limitations of lead acid batteries. Dry systems have advantages over flooded but are less rugged.

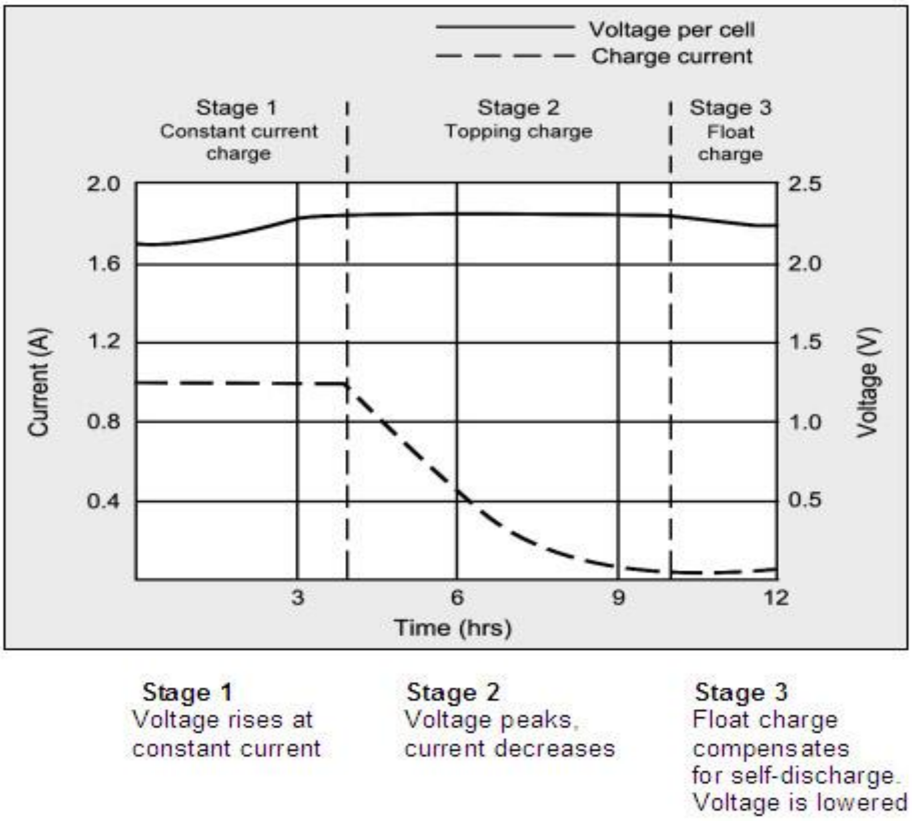
| | |
|---|---|
| **Advantages** | Inexpensive and simple to manufacture; low cost per watt-hour<br>Low self-discharge; lowest among rechargeable batteries<br>High specific power, capable of high discharge currents<br>Good low and high temperature performance |
| **Limitations** | Low specific energy; poor weight-to-energy ratio<br>Slow charge; fully saturated charge takes 14 hours<br>Must be stored in charged condition to prevent sulfation<br>Limited cycle life; repeated deep-cycling reduces battery life<br>Flooded version requires watering<br>Transportation restrictions on the flooded type<br>Not environmentally friendly |

## 2.9 Charging Lead Acid

Lead acid charging uses a voltage-based algorithm that is similar to lithium-ion. The charge time of a sealed lead acid battery is 12–16 hours, up to 36–48 hours for large stationary batteries. With higher charge currents and multi-stage charge methods, the charge time can be reduced to 10 hours or less; however, the topping charge may not be complete. Lead acid is sluggish and cannot be charged as quickly as other battery systems.

Lead acid batteries should be charged in three stages, which are constant-current charge, topping charge and float charge. The constant-current charge applies the bulk of the charge and takes up roughly half of the required charge time; the topping charge continues at a lower charge current and provides saturation, and the float charge compensates for the loss caused by self-discharge. **Figure 2.3** illustrates these three stages

**Figure 2.3** : Charge stages of a lead acid battery



The battery is fully charged when the current drops to a pre-determined level or levels out in stage 2. The float voltage must be reduced at full charge.

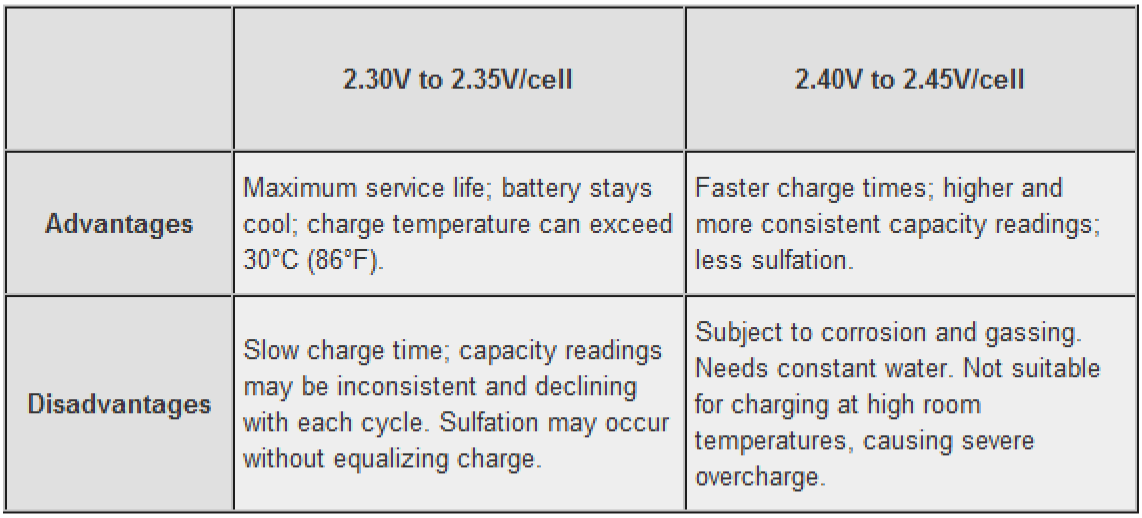
During the constant-current charge, the battery charges to 70 percent in 5–8 hours; the remaining 30 percent is filled with the slower topping charge that lasts another 7–10 hours. The topping charge is essential for the well-being of the battery and can be compared to a little rest after a good meal. If deprived, the battery will eventually lose the ability to accept a full charge and the performance will decrease due to sulfation. The float charge in the third stage maintains the battery at full charge.

The switch from Stage 1 to 2 occurs seamlessly and happens when the battery reaches the set voltage limit. The current begins to drop as the battery starts to saturate, and full charge is reached when the current decreases to the three percent level of the rated current. A battery with high leakage may never attain this low saturation current, and a plateau timer takes over to initialize the charge termination.

The correct setting of the charge voltage is critical and ranges from 2.30 to 2.45V per cell. Setting the voltage threshold is a compromise, and battery experts refer to this as "dancing on the head of a needle." On one hand, the battery wants to be fully charged to get maximum capacity and avoid sulfation on the negative plate; on the other hand, an over-saturated condition causes grid corrosion on the positive plate and induces gassing.

To make "dancing on the head of a needle" more difficult, the battery voltage shifts with temperature. Warmer surroundings require slightly lower voltage thresholds and a cold ambient prefers a higher level. Chargers exposed to temperature fluctuations should include temperature sensors to adjust the charge voltage for optimum charge efficiency. If this is not possible, it is better to choose a lower voltage for safety reasons. **Table 2.3** compares the advantages and limitations of various peak voltage settings

**Table 2.4 :** Effects of charge voltage on a small lead acid battery (SLA)



| | **2.30V to 2.35V/cell** | **2.40V to 2.45V/cell** |
|---|---|---|
| **Advantages** | Maximum service life; battery stays cool; charge temperature can exceed 30°C (86°F). | Faster charge times; higher and more consistent capacity readings; less sulfation. |
| **Disadvantages** | Slow charge time; capacity readings may be inconsistent and declining with each cycle. Sulfation may occur without equalizing charge. | Subject to corrosion and gassing. Needs constant water. Not suitable for charging at high room temperatures, causing severe overcharge. |

Once fully charged through saturation, the battery should not dwell at the *topping voltage* for more than 48 hours and must be reduced to the *float voltage* level. This is especially critical for sealed systems because these systems are less able to tolerate overcharge than the flooded type. Charging beyond what the battery can take turns the redundant energy into heat and the battery begins to gas. The recommended float voltage of most low-pressure lead acid batteries is 2.25 to 2.27V/cell. (Large stationary batteries float at 2.25V at 25°C (77°F.) Manufacturers recommend lowering the float charge at ambient temperatures above 29°C (85°F).

Whereas the voltage settings in **Table 2.3** apply to low-pressure lead acid batteries with a pressure relief valve of about 34kPa (5psi), cylindrical sealed lead acid, such as the Hawker Cyclon cell, requires higher voltage settings and the limits should be set according to the manufacturer’s specifications. Failing to apply the recommended voltage will cause a gradual decrease in capacity due to sulfation. The Hawker Cyclon cell has a pressure relief setting of 345kPa (50psi) and this allows some recombination of the gases generated during charge.

Aging batteries pose a challenge when setting the optimal float charge voltage because each cell has its own age-related condition. Weak cells may go into hydrogen evolution as part of overcharge early on, while the stronger ones undergo oxygen recombination in an almost starved state. Connected in a string, all cells receive the same charge current and controlling individual cell voltages is almost impossible. A float current that is too high for the faded cell might starve the strong neighbor and cause sulfation due to undercharge. Companies have developed cell-balancing devices, which are placed on the battery and compensate the differences in cell voltages that occur as a result of cell inbalance.

*Ripple voltage* imposed on the voltage of large stationary batteries also causes a problem. The voltage peak constitutes an overcharge, causing hydrogen evolution, while the valleys induce a brief discharge that creates a starved state that results in electrolyte depletion. Manufacturers typically limit the ripple to five percent, or 5A for a 100Ah battery.

Much has been said about pulse charging of lead acid batteries. There are apparent advantages in reducing sulfation; however, manufacturers and service technicians are divided on the benefits, and the results are inconclusive. If sulfation could be measured with accuracy and the pulses applied as a corrective service, then the remedy could be beneficial. Assumptions without knowing the underlying results can be harmful.

Most stationary batteries are kept on float charge. To reduce stress, the so-called *hysteresis charge* disconnects the float current when the battery is full. As the terminal voltage drops due to self-discharge, an occasional topping charge replenishes the lost energy. In essence, the battery is only “borrowed” from time to time for brief moments. This mode works well for installations that do not draw a load when on standby.

Lead acid batteries must always be stored in a charged state. A topping charge should be applied every six months to prevent the voltage from dropping below 2.10V/cell. With AGM, these requirements can be somewhat relaxed.

Measuring the open circuit voltage (OCV) while in storage provides a reliable indication as to the state-of-charge of the battery. A voltage of 2.10V at room temperature reveals a charge of about 90 percent. Such a battery is in good condition and needs only a brief full charge prior to use. If the voltage drops below 2.10V, the battery must be charged to prevent sulfation. Observe the storage temperature when measuring the open circuit voltage. A cool battery increases the voltage slightly and a warm one lowers it. Using OCV to estimate state-of-charge works best when the battery has rested for a few hours, because a charge or discharge agitates the battery and distorts the voltage.

A low voltage suggests partial charge due to long storage or a high self-discharge induced by a possible micro-short. Battery users have indeed found that a pack arriving at a lower than specified voltage has a higher failure rate than the others. Although in-house service can often bring such batteries to full performance, the time and equipment required adds to operational costs.

## 2.10 Watering

Watering is the single most important step in maintaining a flooded lead acid battery, a requirement that is all to often neglected. The frequency of watering depends on usage, charge method and operating temperature. A new battery should be checked every few weeks to determine the watering requirement. This prevents the electrolyte from falling below the plates. Avoid exposed plates at all times, as this will sustain damage, leading to reduced capacity and lower performance.

Exposed plates will sustain damage, leading to reduced capacity and lower performance. If the plates are exposed, immediately fill the battery with distilled or de-ionized water to cover the plates, and then apply a charge. Do not fill to the correct level before charging as this could cause an overflow during charging. Always top up to the desired level after charging. Never add electrolyte as this upsets the specific gravity and induces rapid corrosion. Watering systems eliminate low electrolyte levels by automatically adding the right amount of water.

## 2.11 Simple Guidelines for Charging Lead Acid Batteries

1.) Charge in a well-ventilated area. Hydrogen gas generated during charging is explosive.

2.) Choose the appropriate charge program for flooded, gel and AGM batteries. Check manufacturer’s specifications on recommended voltage thresholds.

3.) Charge lead acid batteries after each use to prevent sulfation. Do not store on low charge.

4.) The plates of flooded batteries must always be fully submerged in electrolyte. Fill battery with distilled or de-ionized water to cover the plates if low. Tap water may be acceptable in some regions. Never add electrolyte.

5.) Fill water level to designated level *after* charging. Overfilling when the battery is empty can cause acid spillage.

6.) Formation of gas bubbles in a flooded lead acid indicates that the battery is reaching full state-of-charge (hydrogen on negative plate and oxygen on positive plate).

7.) Reduce float charge if the ambient temperature is higher than 29°C (85°F).
8.) Do not allow a lead acid to freeze. An empty battery freezes sooner than one that is fully charged. Never charge a frozen battery.

9.) Do not charge at temperatures above 49°C (120°F)

## 2.12 Multisim Software

The use of a circuit simulator is more and more necessary in teaching electrical engineering or power electronics. This technique makes it possible to obtain results when the hardware is missing . Simulation being widely used in the industry it is thus necessary for engineers to apply this technique. Among many simulation softwares on the market, Pspice has various advantages:

1.) It is based on the industrial standard Multisim and thus gives access to vast libraries of models developed by manufacturers.
2.) Multisim is a very popular software in industry.
3.) It is quite easy to learn for beginners.

## 2.13 Bridge rectifier

A diode bridge is an arrangement of four (or more) diodes in a bridge circuit configuration that provides the same polarity of output for either polarity of input. When used in its most common application, for conversion of an alternating current (AC) input into direct current a (DC) output, it is known as a bridge rectifier. A bridge rectifier provides full-wave rectification from a two-wire AC input, resulting in lower cost and weight as compared to a rectifier with a 3-wire input from a transformer with a center-tapped secondary winding.

The essential feature of a diode bridge is that the polarity of the output is the same regardless of the polarity at the input. The diode bridge circuit is also known as the Graetz circuit after its inventor, physicist Leo Graetz

### 2.13.1Basic Operation

According to the conventional model of current flow originally established by Benjamin Franklin and still followed by most engineers today, current is assumed to flow through electrical conductors from the positive to the negative pole. In actuality, free electrons in a conductor nearly always flow from the negative to the positive pole. In the vast majority of applications, however, the *actual* direction of current flow is irrelevant. Therefore, in the discussion below the conventional model is retained.

In the diagrams below, when the input connected to the left corner of the diamond is positive, and the input connected to the right corner is negative, current flows from the upper supply terminal to the right along the red (positive) path to the output, and returns to the lower supply terminal via the blue (negative) path.

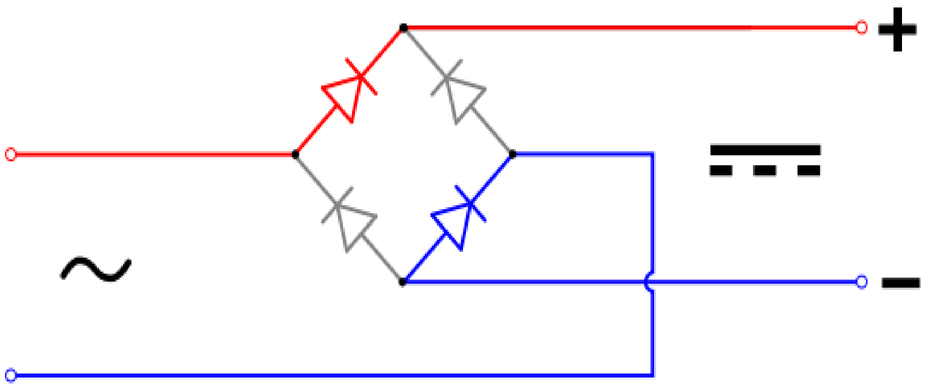


**Figure 2.4 :** Positive current flow in bridge rectifier

When the input connected to the left corner is negative, and the input connected to the right corner is positive, current flows from the uppersupply terminal to the right along the red (positive) path to the output **Figure 2.4**, and returns to the lower supply terminal via the blue (negative) path.

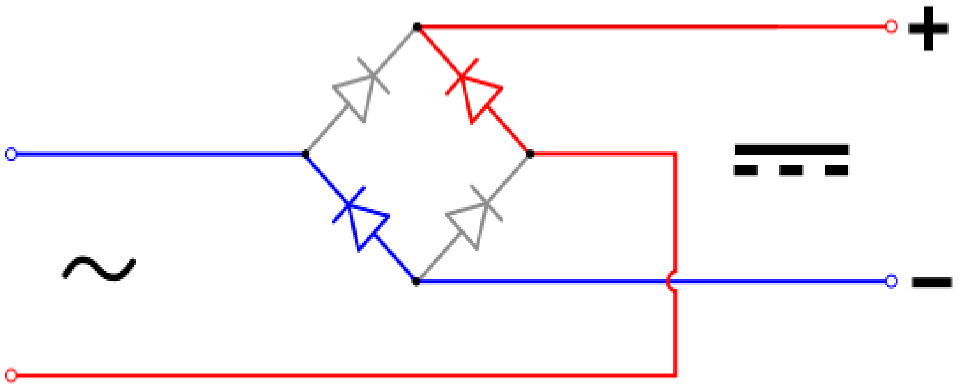


**Figure 2.5 :** Negative current flow in bridge rectifier

In each case, the upper right output remains positive and lower right output negative **Figure 2.5**. Since this is true whether the input is AC or DC, this circuit not only produces a DC output from an AC input, it can also provide what is sometimes called "reverse polarity protection". That is, it permits normal functioning of DC-powered equipment when batteries have been installed backwards, or when the leads (wires) from a DC power source have been reversed, and protects the equipment from potential damage caused by reverse polarity.

Prior to the availability of integrated circuits, a bridge rectifier was constructed from "discrete components", i.e., separate diodes. Since about 1950, a single four-terminal component containing the four diodes connected in a bridge configuration became a standard commercial component and is now available with various voltage and current ratings

### 2.14 Terminal Adjustable Regulator

The LM117 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 1.5A over a 1.2V to 37V output range as shown in **Figure 2.6**. They are exceptionally easy to use and require only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM117 is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM117 series offers full overload protection available only in IC's. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM117 is useful in a wide variety of other applications. Since the regulator is “floating” and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, avoid short-circuiting the output.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment pin and output, the LM117 can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

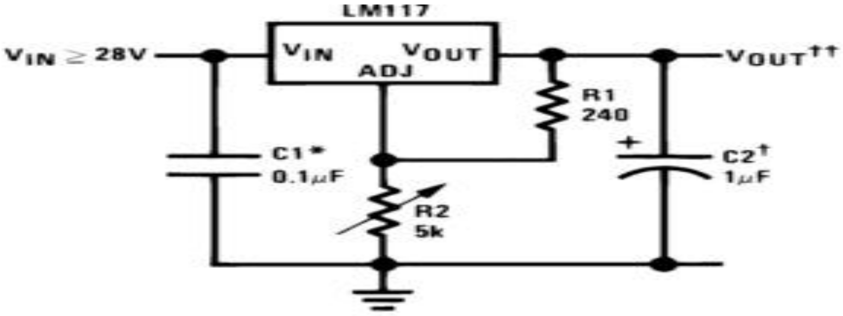


**Figure 2.6** : IC voltage Regulator

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

Batteries are widely used as a power source in many power electronic circuits. The optimum operation of a battery based energy storage system requires a proper model af battery which could be used to simulate behavior. One of the advantages of impedance based modeling method is the simplicity of electrical loss analysis in charge and discharge process which could be considered to calculate the efficiency and find out how to improve it.

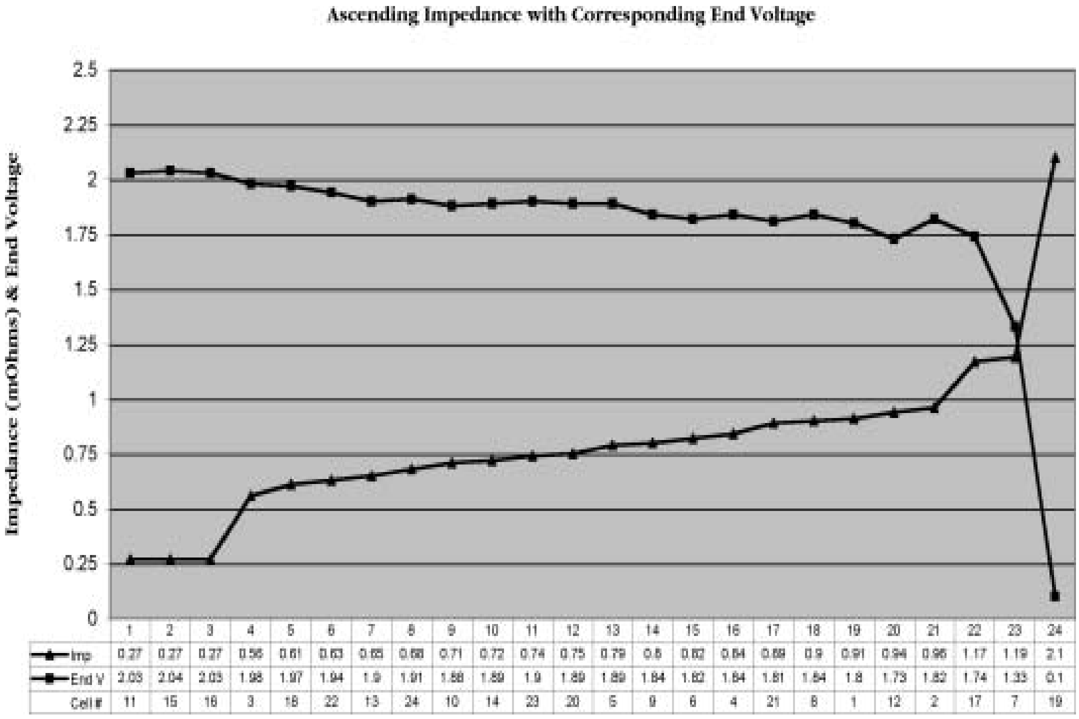
## 3.2 Impedance

Impedance, an internal ohmic test, is resistance in ac terms. With regard to dc battery systems, impedance indicates the condition of batteries without harming or stressing them in any way. Since it tests the condition of the entire electrical path of a battery from terminal plate to terminal plate, impedance can find weaknesses in cells and intercell connectors easily and reliably. Basically, impedance is determined by applying an ac current signal, measuring the ac voltage drop across the cell or intercell connector and calculating impedance using Ohm’s Law. In practice, not only is the ac voltage drop measured but so is the ac current. The ac current is measured because of other ac currents in a battery that are additive (subtractive).

Other ac currents are present from the charger system. The test is performed by applying an ac test signal to the terminal plates. Then measure both the total ac current in the string and the voltage drop of each unit in the string by measuring each cell and intercell connector consecutively until the entire string is measured. Impedance is calculated, displayed and stored. As cells age, the internal impedance increases as depicted in **Figure 3.1**. By measuring impedance, the condition of each cell in the string can be measured and trended to determine when to replace a cell or the string which helps in planning for budgetary needs. The impedance test is a true four-wire, Kelvin-type measurement that provides excellent reliability and highly reproducible data on which to base sound decisions with regard to battery maintenance and replacement. Impedance is able to find weak cells so that proactive maintenance can be performed. After all, the battery is a cost but it is supporting a critical load or revenue stream. If a single cell goes open then the entire string goes off line and the load is no longer supported. Therefore, it is important to find the weak cells before they cause a major failure. The graph in **Figure 3.1** shows the effect of decreasing capacity on impedance. There is a strong correlation between impedance and capacity so that weak cells are ably and reliably found in sufficient time to take remedial action. The graph shows the reorganized impedance data in ascending order with each cell’s corresponding load test end voltage. (Impedance in milliohms coincidentally is the same scale as the voltage, 0 to 2.5). This view, that is ascending impedance/descending voltage, groups the weak cells on the right side of the graph to find them easily.

## 3.3 Impedance Theory

A battery is not simply resistive. There is also a capacitive term. After all, a battery is a capacitor, a storage device, and resistors cannot store electricity. **Figure 3.2** shows an electrical circuit, known as the Randles Equivalent Circuit, that depicts a battery in simple terms. There are those who would have people believe that the capacitive term is not necessary and that the resistance is the only part that needs measuring. Impedance measures both the dc resistance (the real component in impedance) and the reactance (the imaginary components in impedance). Only by measuring both can the capacitive term start to be understood. The other argument used against impedance is that frequency is a variable in the reactance part of the impedance equation. The only parts that affect the final result are the parts that vary within the battery, namely resistance and capacitance, which paint the whole capacity/condition picture.*:*



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ▲ Imp | 0.27 | 0.27 | 0.27 | 0.56 | 0.61 | 0.63 | 0.65 | 0.68 | 0.71 | 0.72 | 0.74 | 0.75 | 0.79 | 0.8 | 0.82 | 0.84 | 0.89 | 0.9 | 0.91 | 0.94 | 0.96 | 1.17 | 1.19 | 2.1 |
| ■ End V | 2.03 | 2.04 | 2.03 | 1.98 | 1.97 | 1.94 | 1.9 | 1.91 | 1.88 | 1.89 | 1.9 | 1.89 | 1.89 | 1.84 | 1.82 | 1.84 | 1.81 | 1.84 | 1.8 | 1.73 | 1.82 | 1.74 | 1.33 | 0.1 |
| Cell # | 11 | 15 | 16 | 3 | 18 | 22 | 13 | 24 | 10 | 14 | 23 | 20 | 5 | 9 | 6 | 4 | 21 | 8 | 1 | 12 | 2 | 17 | 7 | 19 |

**Figure 3.1 :** Ascending Impedance with Corresponding End Voltage

In the diagram shown in **Figure 3.2**, Rm is the metallic resistance, Re is the electrolyte resistance, Rct is the charge transfer resistance, Wi is the Warburg impedance and Cdl is the capacitance of the double layer. Rm includes all of the metallic components one post to the other post, i.e., post, top lead and grids and to a certain degree, the paste. Re is the resistance of the electrolyte which doesn't vary that much on a bulk basis. But at the microscopic level in the pores of the paste, it can be significant. Rct is the resistance of the exchange of ions from the acid to the paste. If the paste is sulphated, then Rct increases or if that portion of the paste is not mechanically (electrically) attached to the grid so that electrons cannot flow out of the cell. Warburg impedance is essentially insignificant and is a function of the specific gravity. Cdl is what probably makes the most important contribution to battery capacity. By only measuring dc resistance, capacitance, an important part of the cell, is ignored. Impedance measures both dc resistance and capacitance. A battery is complex and has more than one electrochemical process occurring at any given time, e.g., ion diffusion, charge transfer, etc. The capacity (capacitor) decreases during a discharge due to the conversion of active material and depletion of the acid. Also, as the plates sulphate, the resistance of the charge transfer increases since the sulphate is less conductive than the active material

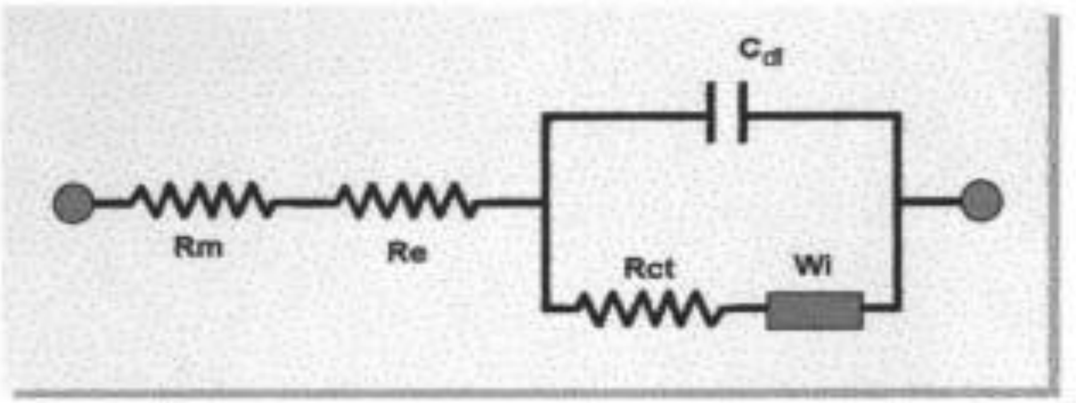


**Figure 3.2 :** Randles Equivalent Circuit

### 3.4 Impedance and Conductance Testing

The discussion about the battery equivalent circuit in the section on Performance Characteristics shows that we can expect the battery impedance to increase with age.

Battery manufacturers have their own definitions and conventions for Impedance and Conductance based on the test method used. Though not strictly correct they serve their purpose.

The test method involves applying a small AC voltage "E" of known frequency and amplitude across the cell and measuring the in phase AC current "I" that flows in response to it.

The Impedance "Z " is calculated by Ohm's Law to be Z=E/I

The Conductance "C" is similarly calculated as C=I/E (the reciprocal of the impedance)

Note that the impedance increases as the battery deteriorates while the conductance decreases. Thus C correlates directly with the battery's ability to produce current whereas Z gives an inverse correlation. The conductance of the cell therefore provides an indirect approximation to the State of Health of the cell. This measurement can be refined by taking other factors into account. These are outlined in the page about State of Health.

In addition to impedance and conductance these tests will obviously detect cell defects such as shorts, and open circuits.

These test methods can be used with different cell chemistries however different calibration factors must be built into the test equipment to take into account differences in the aging profiles of the different chemistries.

Impedance and conductance testing are reliable, safe, accurate, fast and they don't affect the battery performance. They can be carried out while the battery is in use or they can be used to continuously monitor the battery performance, avoiding the need for load testing or discharge testing

### 3.5 Internal Resistance

It is necessary to know the internal resistance of the cell in order to calculate the Joule heat generation or $I^2R$ power loss in the cell, however a simple measurement with an ohmmeter is not possible because the current generated by the cell itself interferes with the measurement.

To determine the internal resistance, first it is necessary to measure the open circuit voltage of the cell. Then a load should be connected across the cell causing a current to flow. This will reduce the cell voltage due to the IR voltage drop across the cell which corresponds to the cell's internal resistance. The cell voltage should then be measured again when the current is flowing. The resistance is calculated by ohms law from the voltage difference between the two measurements and the current which is flowing through the cell.

## 3.6 Factors that influence internal resistance

1.) Metallic

The metallic part of the path behaves like any normal conductor and is affected by the following:

  1.) Temperature

  Resistance increases with higher temperatures.

  2.) Post Corrosion

  Resistance will start to increase as post cross sections erode.

  3.) Grid Corrosion

  All lead acid batteries eventually die of this. Resistance increases sharply as this key part of the path starts to fall apart.

  4.) Plate Growth

  *As* positive plates grow, especially in lead calcium, paste pellets begin to lose contact with the grid causing high resistance connections which affect battery's high current performance.

  5.) Plate to Strap Connection

  A poor lead bum by the manufacturer can cause a high resistance connection.

2.) The electrochemical

The electrochemical  part of the path behaves considerably different than a metallic conductor and is affected by the following:

  1.) Temperature

Electrolyte resistance decreases with increase in temperature.

2.) State of Charge

The paste of a battery that has been floating low starts to convert to lead sulphate PbSO, which has a higher resistance than the fully charged lead and lead dioxide. Drying Out

### 3.7 Charging Sealed Lead Acid batteries

Charging Sealed Lead Acid (SLA) batteries does not seem a particularly difficult process, but the hard part in charging an SLA battery is maximising the battery life. Simple constant current / constant voltage chargers will do the job for a while, but the battery life expectancy quoted by the manufacturer will be greatly reduced by using non-intelligent chargers. Maximising the life of your SLA battery by using an intelligent charger is not only cost effective, it is also better for the environment.Charging techniques it is important to understand the battery chemistry and what happens during normal charge and discharge cycles.

Typically the positive plates in an SLA battery are made from lead dioxide and the negative plates from a sponge lead. The electrolyte is usually sulphuric acid mixed with a gelling agent and is largely absorbed and held by insulating separators between the plates, see Figure 1.

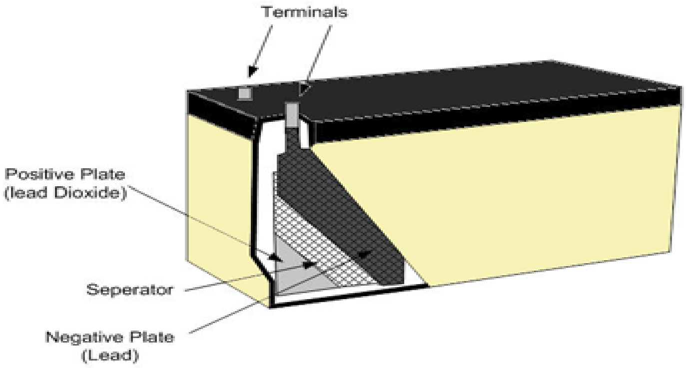


**Figure 3.3 :** Battery structure

When an SLA battery is being discharged; the lead (Pb) on the negative plate and the lead dioxide ($PbO2$) on the positive plate are converted to lead sulphate ($PbSO4$). At the same time the sulphuric acid ($H2SO4$) is converted to water ($H2O$).

In a normal charge, the chemical reaction is reversed. The lead sulphate and water are electro-chemically converted to lead, lead dioxide and sulphuric acid. During a full charge cycle any gasses produced need to be re-combined in a so called ‘oxygen cycle’. Oxygen is generated at the positive plates during the latter stages of the charge cycle, this reacts with and partially discharges in the sponge lead of the negative plates. As charging continues, the oxygen produced also re-combines with the hydrogen being produced on the negative plate forming water. With correct and accurate cell voltage control all gasses produced during the charge cycle will be re-combined completely into the negative plates and returned to water in the electrolyte.

If an SLA battery is over-charged, the excess cell voltage will result in the conversion of electrolyte into large amounts of hydrogen and oxygen gasses which cannot be recombined by the normal processes. A pressure-release valve will open and vent the excess gas, resulting in the loss of electrolyte and a loss of capacity.

If the battery is undercharged, the low cell voltage will cause the charge current to diminish to zero well before full capacity is reached. This will allow some of the lead sulphate produced during discharge to remain on the plates, where it will crystallise, which also causes a permanent loss of capacity.

It is also important to remember that SLA batteries have a self discharge rate of approximately 5% per month. This is less than most other forms of rechargeable batteries, but has to be considered. Manufacturers recommend recharging when the battery reaches about 70% of its capacity (approximately 2.1 volts per cell). They use this to calculate the maximum life of the battery, but this is very difficult to implement in a real world application.

### 3.7.1 Charging techniques

1.) Constant Voltage Charging:

This method is the most commonly used for SLA batteries as the individual cells tend to share the voltage and equalize the charge between them. It is important to limit the initial charging current to prevent damage to the battery. However, with a single fixed voltage, it is impossible to properly balance the requirements of a fast charge cycle against the danger of overcharge.

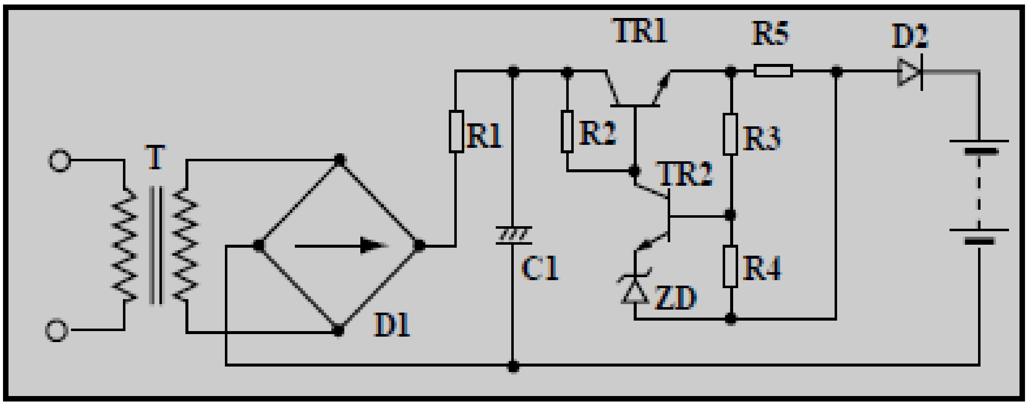


**Figure 3.4 :** Constant Current Charging Circuit

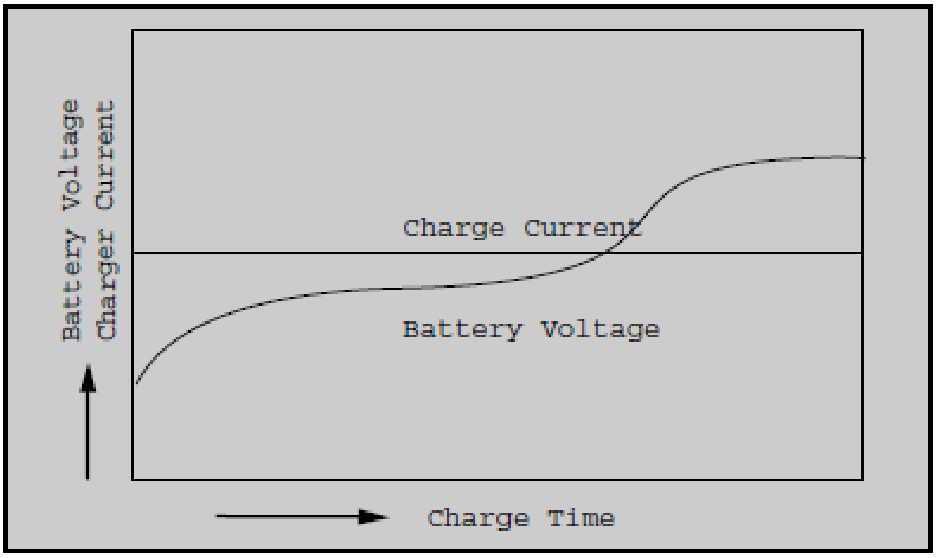


**Figure 3.5 :** Constant Current Charge Characteristics

2.) Constant Current Charging:

This method can be used for a single 2V cell but is not recommended for charging a number of series connected cells, a battery, at the same time. This is because some cells will reach full charge before others and it is very difficult to determine when the battery has reached a fully charged state. If the charge is continued at the same rate, for any extended period of time, severe overcharge may occur to some cells, resulting in damage to the battery.

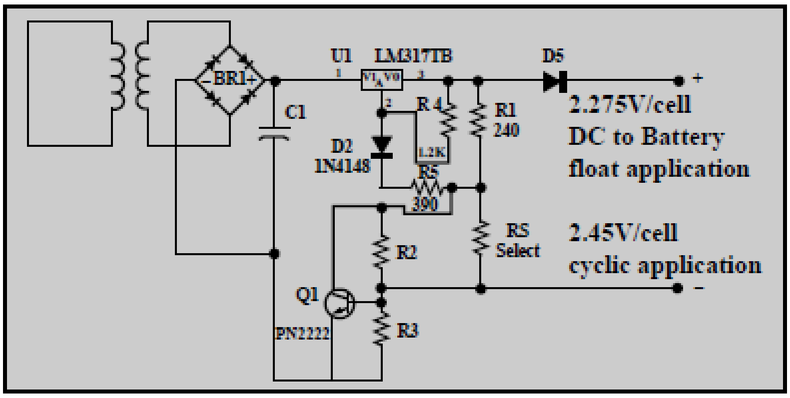


**Figure 3.6 :** Constant Current Charge Circuit

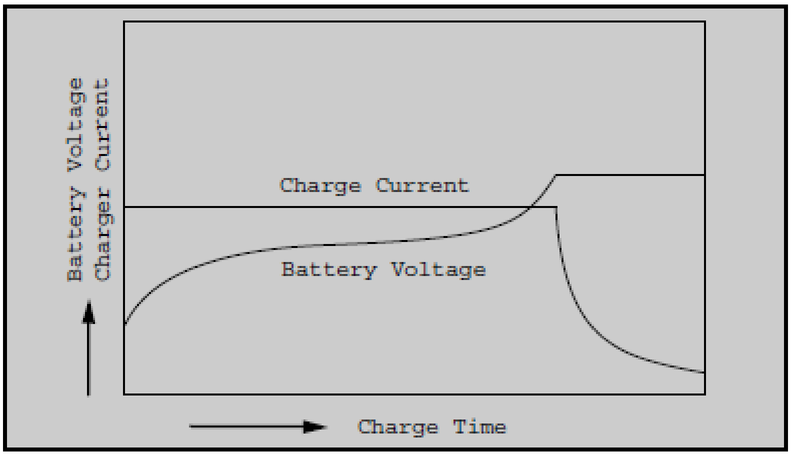


**Figure 3.7 :** Constant Current Charge Characteristics

3.) Taper Current Charging:

This method is not really recommended for charging SLA batteries as it can often shorten battery service life due to poor control of the final fully charged voltage. However, because of the simplicity of the circuit and subsequent low cost, taper current charging is often used to charge a number of series connected batteries that are subject to cyclic use. When using this method it is recommended that the charging time is either limited or that a charging cut-off circuit is incorporated to prevent overcharge.

4.) Two Stage Constant Voltage Charging:

This method is a recommended for charging SLA batteries in a short period of time and then maintaining them in a fully charged float (or standby) condition.

Each of the above has its advantages and disadvantages, but using a simple charger design may not be cost effective in the long term. Checking battery condition and replacing batteries with lost capacity is very costly and environmentally unfriendly.

Another important factor that has to be considered when charging an SLA battery is temperature. As the temperature rises, electrochemical activity in a battery increases, so the charging voltage should be reduced to prevent overcharge. Conversely as temperature falls, the change voltage should be increased to avoid undercharge.

Using a combination of the constant current charging and two stage constant voltage charging techniques and also by monitoring the battery terminal voltage and temperature a multi-stage charge profile can be implemented to reduce stress on the battery while giving the shortest possible charge time.

## 3.8 Discharging

The purpose of a battery is to store and release energy at the desired time and in a controlled manner. Examines discharges under different C-rates and evaluates the depth to which a battery can safely be depleted.

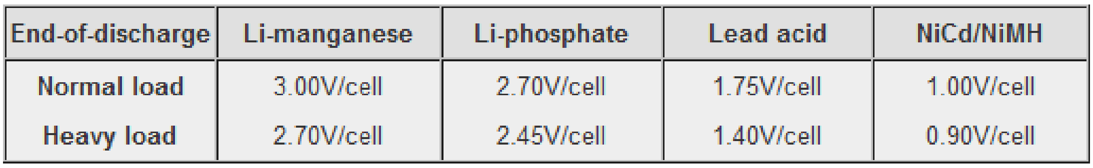
### 3.8.1 Depth of Discharge

The end-of-discharge voltage for lead acid is 1.75V/cell. At this level, roughly 95 percent of the energy is spent and the voltage would drop rapidly if the discharge were to continue. To protect the battery from over-discharging, most devises prevent operation beyond the specified end-of-discharge voltage.

removing the load after discharge, the voltage of a healthy battery gradually recovers and rises towards the nominal voltage. Differences in the metal concentration of the electrodes enable this voltage potential when the battery is empty. An aging battery with elevated self-discharge cannot recover the voltage because of the parasitic load.

A high load current lowers the battery voltage, and the end-of-discharge voltage threshold should be set lower accordingly. Internal cell resistance, wiring, protection circuits and contacts all add up to overall internal resistance. The cut-off voltage should also be lowered when discharging at very cold temperatures; this compensates for the higher-than-normal internal resistance.

**Table 3.1 :** Recommended end-of-discharge voltage under normal and heavy load



| End-of-discharge | Li-manganese | Li-phosphate | Lead acid | NiCd/NiMH |
|---|---|---|---|---|
| Normal load | 3.00V/cell | 2.70V/cell | 1.75V/cell | 1.00V/cell |
| Heavy load | 2.70V/cell | 2.45V/cell | 1.40V/cell | 0.90V/cell |

Some battery analyzers apply a secondary discharge (recondition) that drains the battery voltage of a nickel-based battery to 0.5V/cell and lower, a cut-off point that is below what manufacturers specify. These analyzers (Cadex) keep the discharge load low to stay within an allowable current while in sub-discharge range. A cell breakdown with a weak cell is possible and reconditioning would cause further deterioration in performance rather than making the battery better. This phenomenon can be compared to the experience of a patient to whom strenuous exercise is harmful.

### 3.8.2 Discharge Cycle

Most understand a discharge/charge cycle as delivering all stored energy, but this is not always the case. Rather than a 100 percent depth of discharge (DoD), manufacturers prefer rating the batteries at 80 percent DoD, meaning that only 80 percent of the available energy is being delivered and 20 percent remains in reserve. A less-than-full discharge increases service life, and manufacturers argue that this is closer to a field representation because batteries are seldom fully discharged before recharge.

There are no standard definitions of what constitutes a discharge cycle. A smart battery that keeps track of cycle count may require a depth of discharge of 70 percent to define a discharge cycle; anything less does not count as a cycle. There are many other applications that discharge the battery less. Starting a car, for example, discharges the battery by less than 5 percent, and the depth of discharge in satellites is 6 to 10 percent before the onboard batteries are being recharged during the satellite day. Furthermore, a hybrid car only uses a fraction of the capacity during acceleration before the battery is being recharged.

The cycle life of sealed lead-acid is directly related to the depth of discharge. The typical number of discharge/charge cycles at 25°C (77°F) with respect to the depth of discharge is:

1.) 150 - 200 cycles with 100% depth of discharge (full discharge)
2.) 400 - 500 cycles with 50% depth of discharge (partial discharge)
3.) 1000 and more cycles with 30% depth of discharge (shallow discharge)

### 3.8.3 Guidelines for Discharging Batteries

1.) The battery performance decreases with cold temperature and increases with heat.

2.) Heat increases battery performance but shortens life by a factor of two for every 10°C increase above 25–30°C (18°F above 77–86°F).

3.) Although better performing when warm, batteries live longer when kept cool.

4.) Operating a battery at cold temperatures does not automatically permit charging under these conditions. Only charge at moderate temperatures.

5.) Use heating blankets if batteries need rapid charging at cold temperatures.

6.) Prevent over-discharging. Cell reversal can cause an electrical short.

7.) A moderate DC discharge is better for a battery than pulse and aggregated loads.

8.) A battery exhibits capacitor-like characteristics when discharging at high frequency. This allows higher peak currents than is possible with a DC load.

9.) Lead acid is sluggish and requires a few seconds of recovery between heavy loads.

The seal lead-acid battery should not be discharged beyond 1.75V per cell, nor should it be stored in a discharged state. The cells of a discharged lead-acid sulphated, a condition that renders the battery useless if left in that state for a few days. Always keep the open terminal voltage at 2.10V and higher.

### 3.9 Theoretical Equation

A voltage source (V_bat)
An eternal resistance (R_bat)

Both (V_bat) and (R_bat) may change during charge and discharge.
Also (R_bat) usually increases with time.

During the charge, we read the charging current (I_chg) and at the same time we read the voltage (V_chg) on the battery terminals.
We cut the charge [that is (I_chg) becomes 0 Amp] and at the same time we re-read the battery voltage which is now (V_bat) itself at this moment (since its current is zero).

We will notice that V_chg > V_bat
So now we have (V_bat), calculate (R_bat) at the moment of measurement.

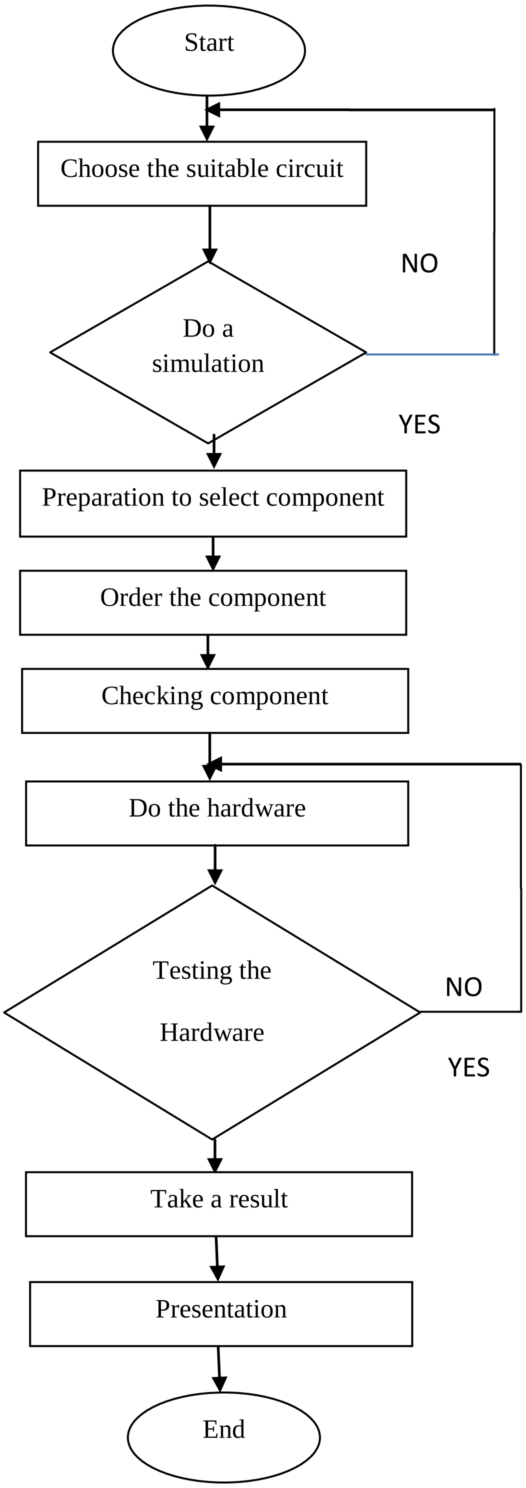
We know that during the charge:
V_chg = V_bat + I_chg * R_bat
This gives:

R_bat = (V_chg - V_bat) / I_chg

The same method can be followed during the battery discharge:

R_bat = (V_bat - V_dis ) / I_dis

### 3.10 Flowchart



# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Introduction.

At the end of the project, the objective of the project should be the most item need to consider as achieving the goal. The title of the project, development of battery impedance tester able to be applying as the one of the tool to measure the impedance battery. Therefore, the result is divided into two main parts which is:

1.) Simulation on circuit.
2.) Hardware development (On progressing)

The result covered the scope of the project been specific at the Chapter 1, therefore the added of the scope or other than the scope range are not considered as the main result, and that might be the outcome from the research only and not been included on this paper. However, the result consisted the part of simulation that is related but not specific on the components been used on the hardware level due to the lack of the libraries and part of the simulation tools.

## 4.2 Simulation of battery charger

Multisim software has been used for simulation which is a kind simulation software and easy to used, with this software are able to design a circuit and to simulate with the lab view on the Multisim. The simulation circuit is shown in **Figure 4.1** below

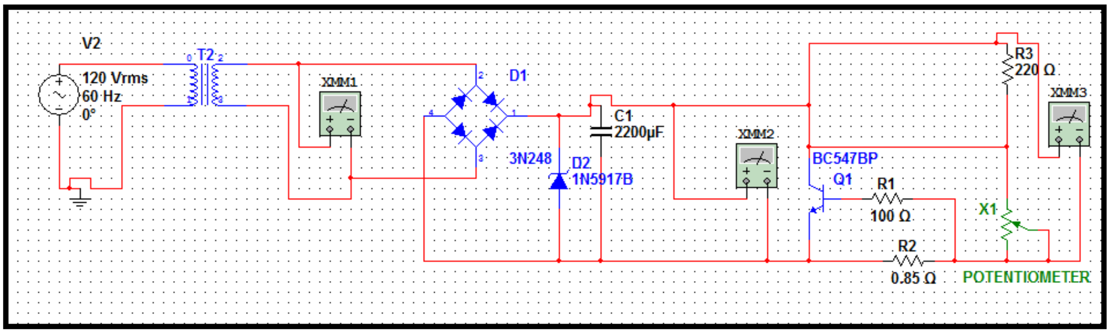
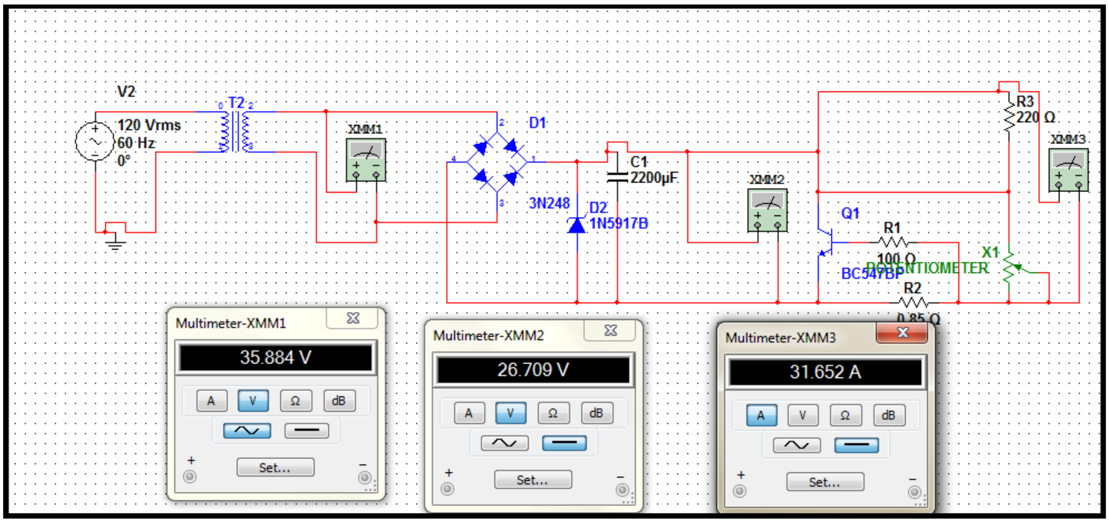


**Figure 4.1** Simulation circuit battery charger

The circuit of battery charger using variable resistor 10 KΩ to control voltage output to charge battery, range between 0 to 24 Volt.



Multimeter-XMM1: 35.884 V

Multimeter-XMM2: 26.709 V

Multimeter-XMM3: 31.652 A

**Figure 4.2 :** Simulation circuit battery charger with parameter

The measurement used to predict most sealed lead acid (SLA) battery failures today is impedance. Impedance is comprised of the vector of DC resistance and reactance ( capacitive and inductive). Ohm’s lay say that

$$E= I*Z \text{ and } Z = \sqrt{(R^2 + i^2)}$$

Where R is real component, resistance, and i is the imaginary component, reactance, which is frequency dependent. Frequency is constant then reactance does not change due to frequency. However, both real and imaginary components can change due to valid changes in the condition of the battery.

**Figure 4.3** : battery charger box

Inductance will change with cell size but will change very little within a given cell type. The internal impedance of the cell will vary mainly due to change in metallic resistance, capacitance and to a lesser extent by charge transfer resistance and so much by inductance.

$$X_c = 1/(2\prod fC) \text{ and } X_L = 2\prod fL$$

f = frequency

C = capacitance

L = inductance

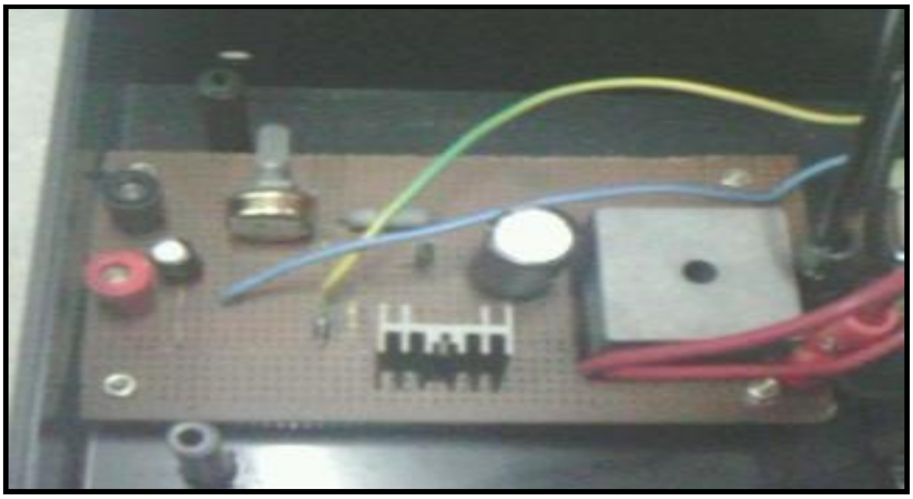


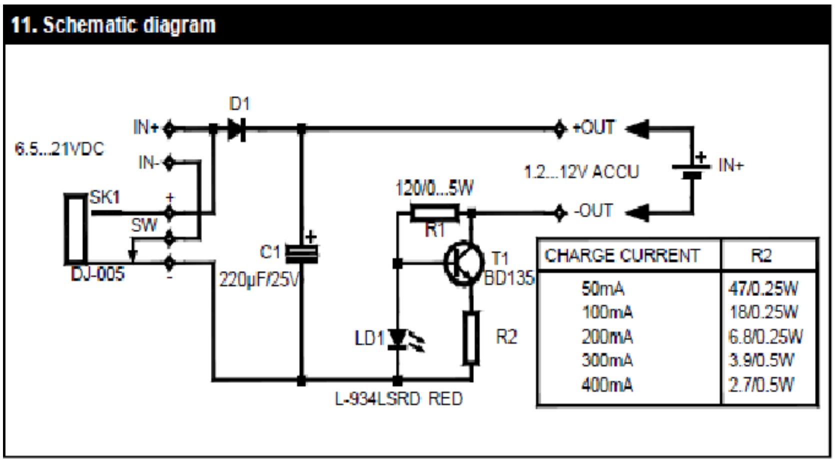
**Figure 4.4** : Circuit battery charger

It is evident from mathematical equations of capacitance reactance and inductive reactance that different values for impedance will be obtained at different frequencies. Impedance at constant frequency can not vary due to changing frequency. The term, 2∏f, become a constant ant htus the reactance only varies due to real changes in capacitance and inductance. Measuring impedance at the sama frequency over time shows that impedance does, in fact weak cells caused by real changes in cell condition.

**Figure 4.5 :** Transformer 3Amp, 56Volt

**Figure 4.6 :** Measurements on output voltage battery charger

On the measurement, the value of the output DC is 20 Vdc which rectified from 240 Vac in single phase source of the socket outlet. The power stage of this board is working as the output is constant and without disturbance due to the non-load test measurement.



| CHARGE CURRENT | R2 |
|---|---|
| 50mA | 47/0.25W |
| 100mA | 18/0.25W |
| 200mA | 6.8/0.25W |
| 300mA | 3.9/0.5W |
| 400mA | 2.7/0.5W |

**Figure 4.7 :** Schematic Diagram

## 4.3 Battery Voltage Indicator

This project describes how to make a digital voltmeter using a PIC microcontroller. A HD44780 based character LCD is used to display the measured voltage. The PIC microcontroller used in this project is PIC16F688 that has 12 I/O pins out of which 8 can serve as analog input channels for the in-built 10-bit ADC. The voltage to be measured is fed to one of the 8 analog channels. The reference voltage for AD conversion is chosen to be the supply voltage Vdd (+5 V). A resistor divider network is used at the input end to map the range of input voltage to the ADC input voltage range (0-5 V). The technique is demonstrated for input voltage ranging from 0-20 V

## 4.4 Circuit Diagram

Since the PIC port cannot take 20V input directly, the input voltage is scaled down using a simple resistor divider network. The resistors R1 and R2 scale down the input voltage ranging from 0-20V to 0-5V, before it is applied to PIC16F688's analog input channel, AN2. A 5.1V zener diode connected in parallel between the port pin AN2 and the ground provides protection to the PIC pin in case the input voltage accidentally goes beyond 20V. The circuit diagram and the prototype built on a breadboard are shown below.

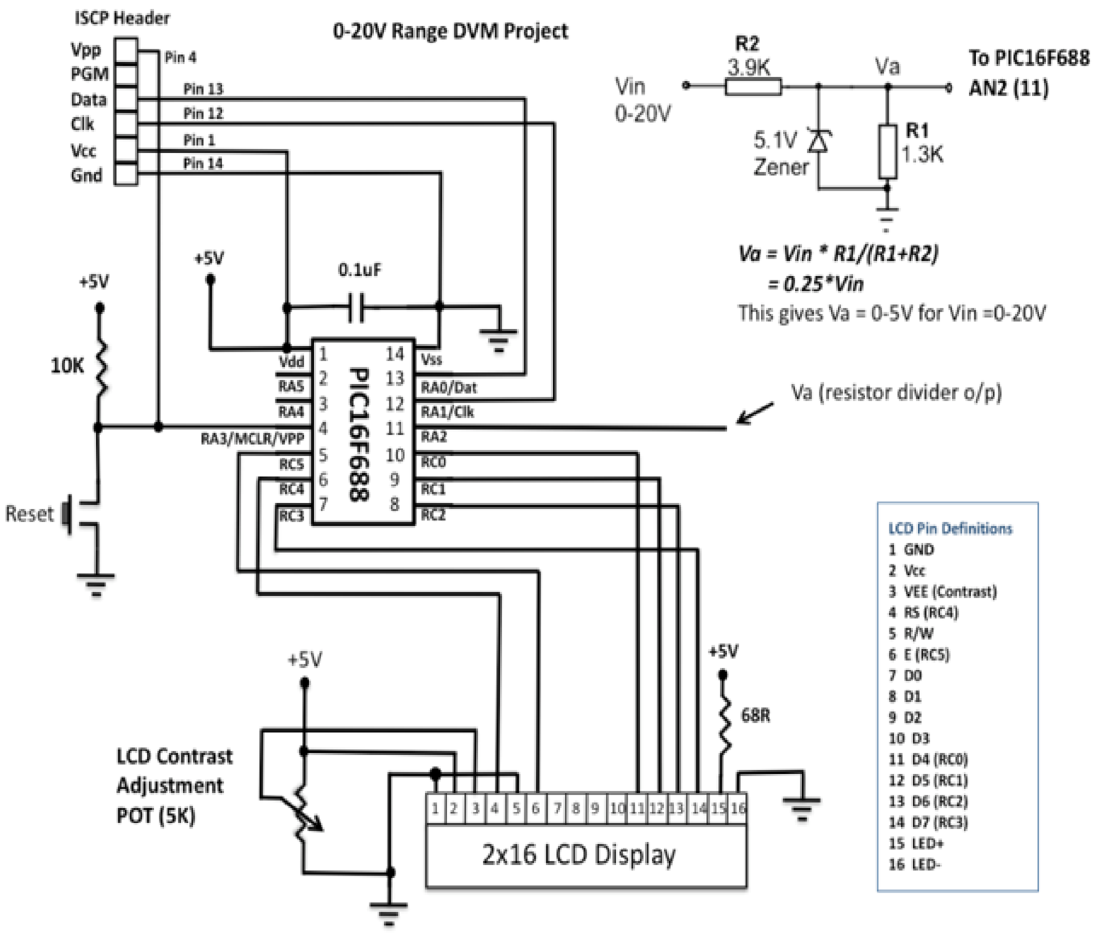


**Figure 4.8 :** Schematic Diagram For LCD

**Important:** You need a regulated +5V supply for accuracy of the output. The ADC uses Vdd as the reference for conversion, and all computations are done with Vdd = 5V. You can get a regulated +5V using a LM7805 linear regulator IC.

## 4.5 Display Calculation

The accuracy depends upon the accuracy of the resistors at the input end and the stability of reference voltage, Vdd = +5V. I found Vdd is stable to +5.02 V. I measured R1 and R2, and their values are 1267 and 3890 Ohms. So this gives,

5.02 V Analog I/P ---> 0-1023 Digital Count
=> Resolution = (5.02 - 0)/(1023-0) = 0.004907 V/Count

Va = 1267*Vin/(1267+3890) = 0.2457*Vin
=> I/P voltage = 4.07*Va = 4.07* Digital Count * 0.004907
= 0.01997 * Digital Count
= 0.02*Digital Count (Approx.)

To avoid floating point, use I/P voltage = 2*Digital Count.

Example, suppose Vin = 7.6V. Then,
Va = 0.2457*Vin = 1.87V
=> Digital Count = 1.87/0.004907 = 381
=> Calculated I/P Voltage = 2*381 = 0762 = 07.6V (First 3 digits of 4 digit product)

## 4.6 PIC16F688

### Program Memory Organization

The PIC16F688 has a 13-bit program counter capable of addressing a 4k x 14 program memory space. Only the first 4k x 14 (0000h-01FFF) for the PIC16F688 is physically implemented. Accessing a location above these boundaries will cause a wrap around within the first 4k x 14 space. The Reset vector is at 0000h and the interrupt vector is at 0004h.The PIC16F688 is covered by this data sheet. It is available in 14-pin PDIP, SOIC and TSSOP packages.

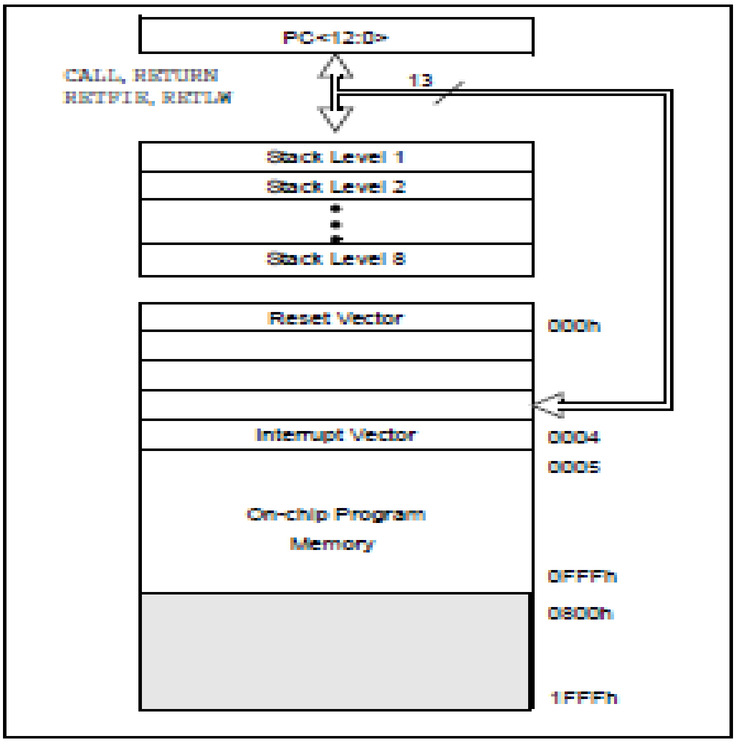


**Figure 4.9 :** Program Memory Map and Stack for the PIC16F688

### 4.7 Data EEPROM and FLASH

The data EEPROM and Flash program memory is readable and writable during normal operation (over the full VDD range). This memory is not directly mapped in the register file space. Instead, it is indirectly addressed through the Special Function Registers. There are six SFRs used to read and write this memory:

- EECON1
- EECON2
- EEDATA
- EEDATH
- EEADR
- EEADRH

The EEPROM data memory allows single-byte read and writes. The Flash program memory allows single-word reads and four-word block writes. Program memory write operations automatically perform an erase-before write on blocks of four words. A byte write in data EEPROM memory automatically erases the location and writes the new data (erase-before-write). The write time is controlled by an on-chip timer. The write/erase voltages are generated by an on-chip charge pump, rated to operate over the voltage range of the device for byte or word operations.

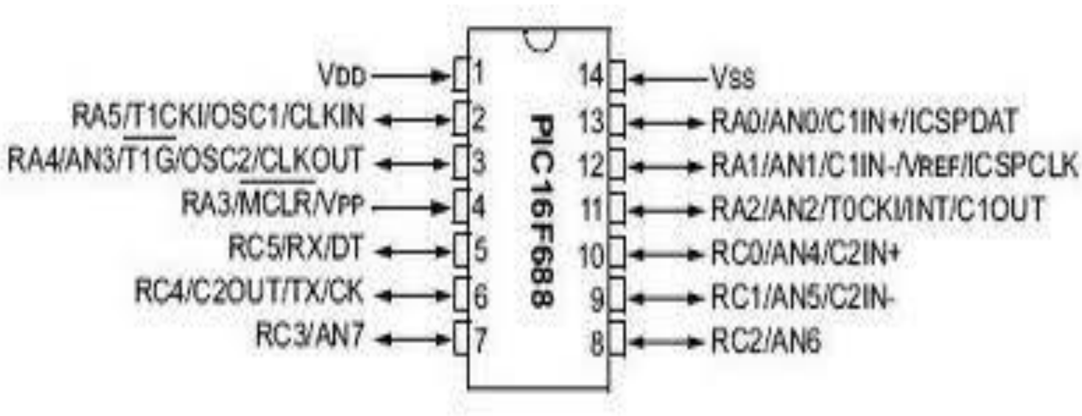


**Figure 4.10 :** PIC 16F688 pin out

**Figure 4.11 :** Prototype Battery Impedance Tester

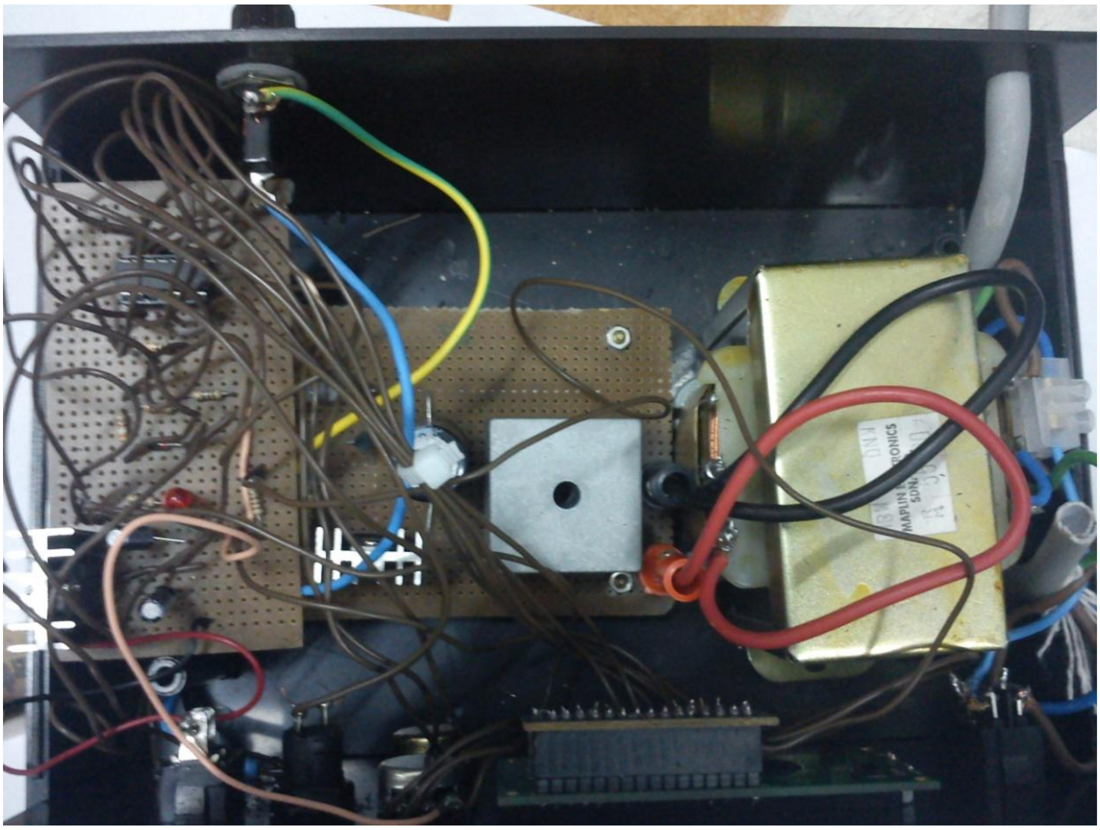


**Figure 4.12 :** Circuit for Battery Tester

**Figure 4.13 :** Load Equipment To Test Battery

## 4.8 Discussion

The internal resister is created by the following three components, Surface resistance by discharge reaction called activation bipolaration. Electron diffusing resistance or called pure resistance of $PbSO_4$ and metal Pb, Ion conduction resistance due to the diffusion of $H_2SO_4$ ion. Among them, terms of decrease shortly (order of μs) after the current stops. The time constant of ion diffusion is several seconds. In this experiment, 60ms is effective to reduce the effect of term. The duty ratio of current stopping time is 2% during the charging and discharging. The experimental result confirmed that the control of internal voltage by such system is useful to prolong battery life. The use of additive increases internal voltage and is believed to produce the prolongation more effectively. This experiment confirmed that the internal voltage control works well for the process of charging-discharging. The life of batteries is significantly extended for repeating the deep cycle use compared with the method by the conventional external voltage control. This means that the capacity of batteries can sufficiently utilized when the internal voltage control is used. By the deep charging of batteries the effect of sulfation can be avoided..

# CHAPTER 5

## 5.1 Conclusions

The general impedance characteristics over a wide frequency range for a number of different types of leadacid batteries has been studied. Generally similar behaviour is observed and all batteries exhibit predominantly resistive behaviour. The impedance is found to affected by the state of charge of the battery. The impedance in the resistive region of the impedance characteristics does not exhibit any significant variation with temperature between 25°C and 75°C. The impedance behaviour at low frequencies can be used to discern the fully charged and float condition, and thus may be meritorious for in-service standby batteries.

Impedance can find most but not all of these failures modes and short-term losses in capacity. Multiple frequency testing of battery impedance has been underway for sometime now. This approach requires a relatively accurate model of a cell and should be able to indicate what areas of the battery construction and chemical processes are varying over time. By knowing these parameters, it is expected to learn what processes are showing signs of aging, defect, or damage. To measuring the impedance of the battery.

The behavior of commercially available SLAbatteries are studied by measuring the battery impedance under test using the proposed charging and discharging methods. The proposed circuit can be transformed into an battery measuring instrument.

## 5.2 Recommendations on the future design

Future recommendation on the design should be able to develop the PC based on battery impedance tester, since at this point the development of battery impedance tester are not been applied due to time and cost involve on this matter. By knowing the conditions of battery impedance early or as they start, one may be able to eliminate some of these situations, thereby lengthening the life of a battery system and possibly predicting when replacement will be needed and budgetary planning. Such an advanced system would also relieve the strain in the relationship of the battery user versus battery manufacturer.

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# APPENDICES A

## Gant Chart for PSM 1

| Week<br>Task | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choose a title | 🟦 | | | | | | | | | | | | | |
| Write abstract | | 🟦 | | | | | | | | | | | | |
| Submit abstract | | | 🟦 | | | | | | | | | | | |
| Literature Review | | | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |
| Method | | | | | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | | | |
| Write Proposal | | | | | | | 🟦 | 🟦 | | | | | | |
| Submit proposal | | | | | | | | 🟦 | | | | | | |
| Draft Final Proposal | | | | | | | | | 🟦 | 🟦 | 🟦 | 🟦 | | |
| Submit Final Proposal | | | | | | | | | | | | | 🟦 | 🟦 |

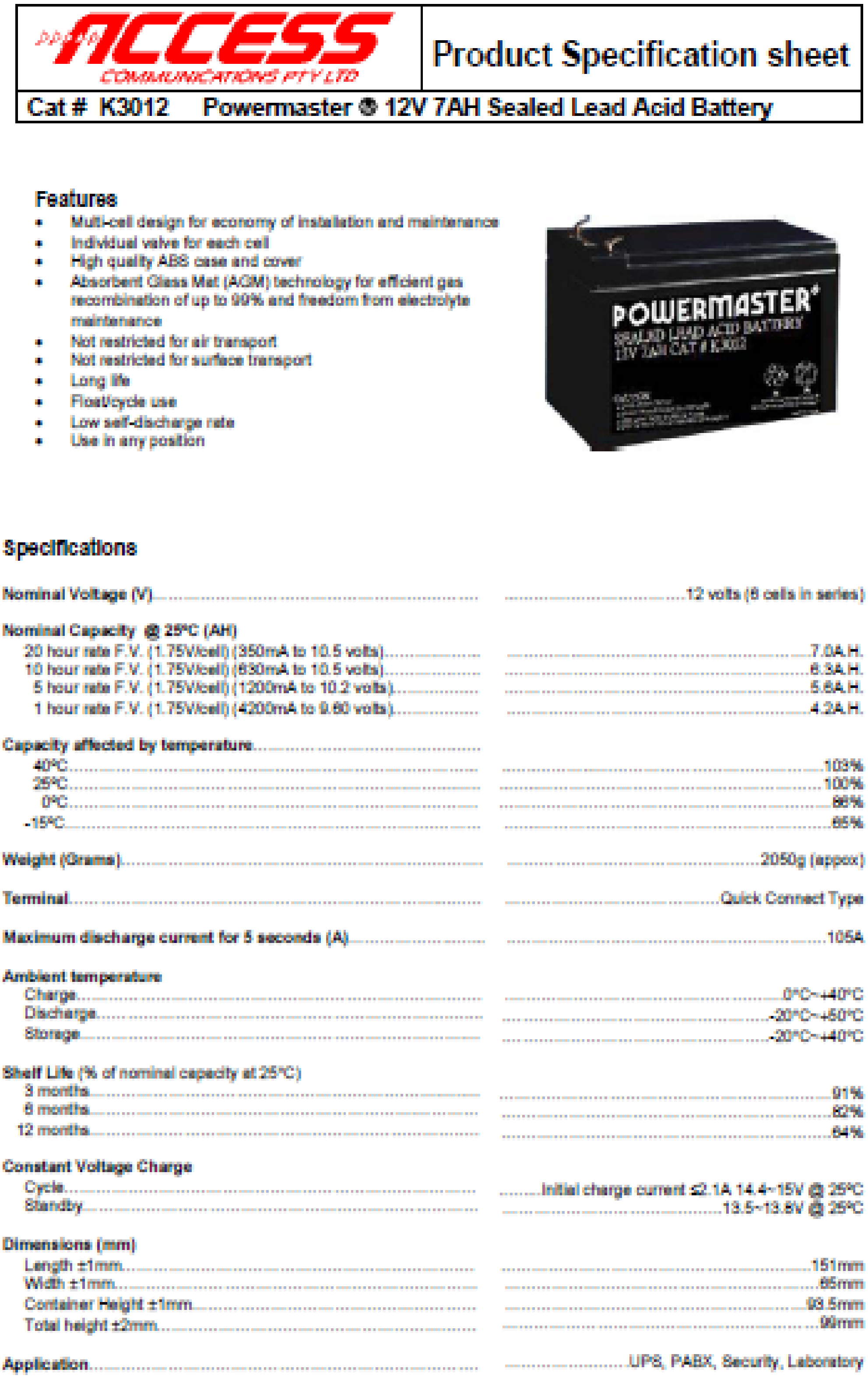
# APPENDICES B

## Gant Chart for PSM 2

| Week<br>Task | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choose the suitable circuit | 🟨 | 🟨 | | | | | | | | | | | | |
| Do a simulation | | | 🟨 | 🟨 | 🟨 | | | | | | | | | |
| Preparation to select component | | | | | 🟨 | 🟨 | | | | | | | | |
| Order the component | | | | | | 🟨 | 🟨 | 🟨 | | | | | | |
| Component received | | | | | | | | | 🟨 | | | | | |
| Checking component | | | | | | | | | | 🟨 | | | | |
| Do the hardware | | | | | | | | | | 🟨 | 🟨 | | | |
| Testing the hardware | | | | | | | | | | | | 🟨 | 🟨 | |
| Presentation | | | | | | | | | | | | | | 🟨 |

# APPENDIX C

Battery K3012



ACCESS COMMUNICATIONS PTY LTD

## Product Specification sheet

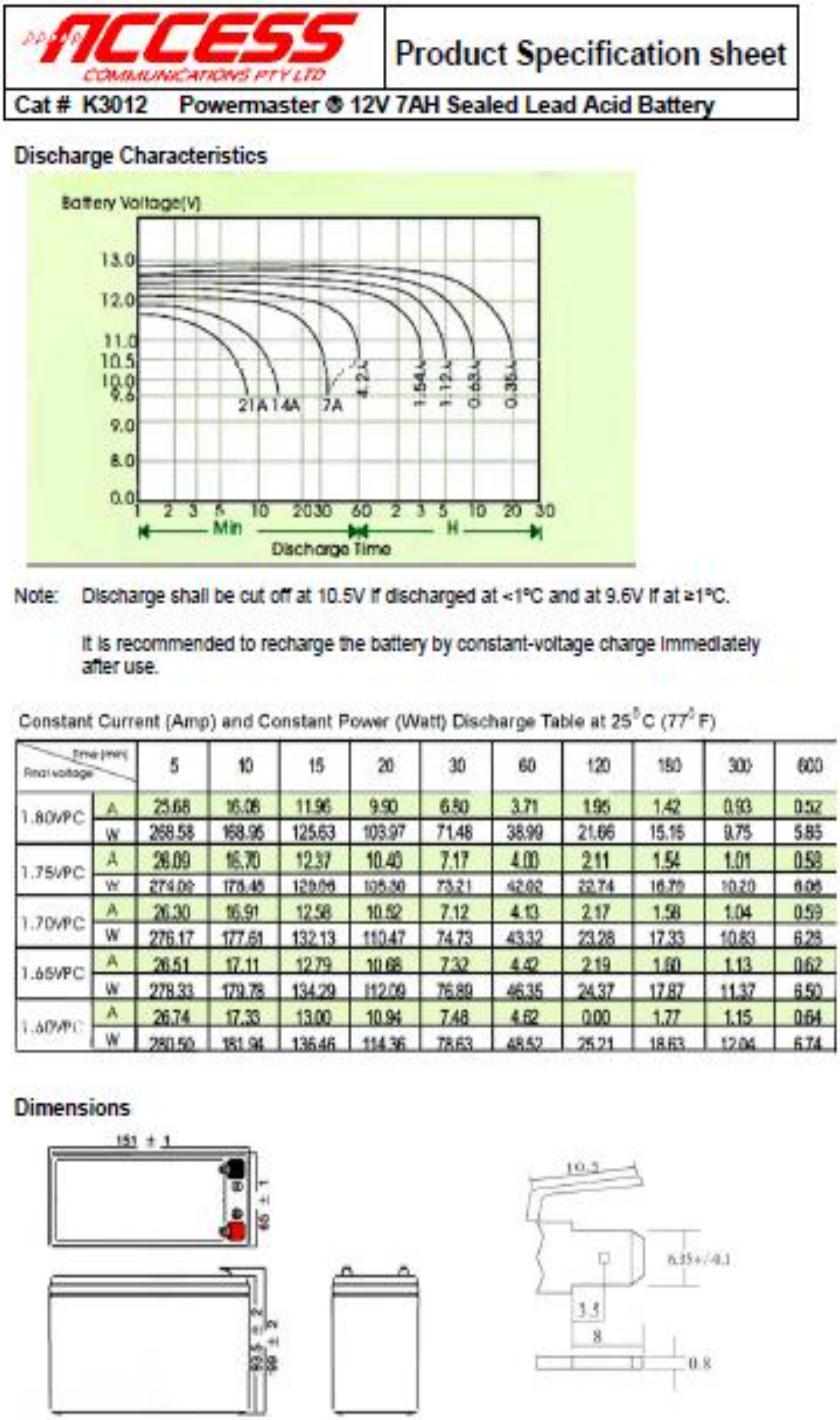
**Cat # K3012 Powermaster ® 12V 7AH Sealed Lead Acid Battery**

### Features

- Multi-cell design for economy of installation and maintenance
- Individual valve for each cell
- High quality ABS case and cover
- Absorbent Glass Mat (AGM) technology for efficient gas recombination of up to 99% and freedom from electrolyte maintenance
- Not restricted for air transport
- Not restricted for surface transport
- Long life
- Float/cycle use
- Low self-discharge rate
- Use in any position

### Specifications

| | |
|---|---|
| **Nominal Voltage (V)** | 12 volts (6 cells in series) |
| **Nominal Capacity @ 25ºC (AH)** | |
| 20 hour rate F.V. (1.75V/cell) (350mA to 10.5 volts) | 7.0A.H. |
| 10 hour rate F.V. (1.75V/cell) (630mA to 10.5 volts) | 6.3A.H. |
| 5 hour rate F.V. (1.75V/cell) (1200mA to 10.2 volts) | 5.6A.H. |
| 1 hour rate F.V. (1.75V/cell) (4200mA to 9.60 volts) | 4.2A.H. |
| **Capacity affected by temperature** | |
| 40ºC | 103% |
| 25ºC | 100% |
| 0ºC | 86% |
| -15ºC | 65% |
| **Weight (Grams)** | 2050g (appox) |
| **Terminal** | Quick Connect Type |
| **Maximum discharge current for 5 seconds (A)** | 105A |
| **Ambient temperature** | |
| Charge | 0ºC~+40ºC |
| Discharge | -20ºC~+50ºC |
| Storage | -20ºC~+40ºC |
| **Shelf Life** (% of nominal capacity at 25ºC) | |
| 3 months | 91% |
| 6 months | 82% |
| 12 months | 64% |
| **Constant Voltage Charge** | |
| Cycle | Initial charge current ≤2.1A 14.4~15V @ 25ºC |
| Standby | 13.5~13.8V @ 25ºC |
| **Dimensions (mm)** | |
| Length ±1mm | 151mm |
| Width ±1mm | 65mm |
| Container Height ±1mm | 93.5mm |
| Total height ±2mm | 99mm |
| **Application** | UPS, PABX, Security, Laboratory |



ACCESS COMMUNICATIONS PTY LTD

# Product Specification sheet

**Cat # K3012 Powermaster ® 12V 7AH Sealed Lead Acid Battery**

## Discharge Characteristics

Note: Discharge shall be cut off at 10.5V if discharged at <1°C and at 9.6V if at ≥1°C.

It is recommended to recharge the battery by constant-voltage charge immediately after use.

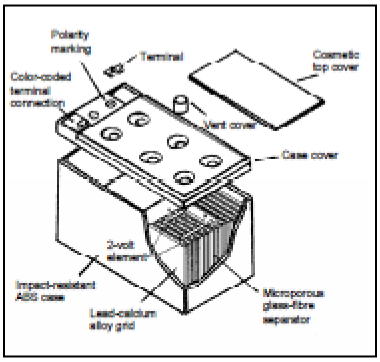
Constant Current (Amp) and Constant Power (Watt) Discharge Table at 25°C (77°F)

| Time (min) / Final voltage | | 5 | 10 | 15 | 20 | 30 | 60 | 120 | 180 | 300 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.80VPC | A | 25.68 | 16.06 | 11.96 | 9.90 | 6.50 | 3.71 | 1.95 | 1.42 | 0.93 | 0.52 |
| | W | 268.58 | 168.96 | 125.63 | 103.97 | 71.48 | 38.99 | 21.66 | 15.16 | 9.75 | 5.85 |
| 1.75VPC | A | 26.09 | 16.70 | 12.37 | 10.40 | 7.17 | 4.00 | 2.11 | 1.54 | 1.01 | 0.58 |
| | W | 274.06 | 178.48 | 129.06 | 105.30 | 73.21 | 42.02 | 22.74 | 16.79 | 10.20 | 6.06 |
| 1.70VPC | A | 26.30 | 16.91 | 12.58 | 10.52 | 7.12 | 4.13 | 2.17 | 1.58 | 1.04 | 0.59 |
| | W | 276.17 | 177.61 | 132.13 | 110.47 | 74.73 | 43.32 | 23.28 | 17.33 | 10.83 | 6.28 |
| 1.65VPC | A | 26.51 | 17.11 | 12.79 | 10.68 | 7.32 | 4.42 | 2.19 | 1.60 | 1.13 | 0.62 |
| | W | 278.33 | 179.78 | 134.29 | 112.09 | 76.89 | 46.35 | 24.37 | 17.87 | 11.37 | 6.50 |
| 1.60VPC | A | 26.74 | 17.33 | 13.00 | 10.94 | 7.48 | 4.62 | 0.00 | 1.77 | 1.15 | 0.64 |
| | W | 280.50 | 181.94 | 136.46 | 114.36 | 78.63 | 48.52 | 25.21 | 18.63 | 12.04 | 6.74 |

## Dimensions

| ACCESS COMMUNICATIONS PTY LTD | Product Specification sheet |
|---|---|
| Cat # K3012 Powermaster ® 12V 7AH Sealed Lead Acid Battery | |

# CONSTRUCTION



**Plates (Electrodes)**

Plate construction is the key to producing a good battery. Powermaster® sealed lead-acid rechargeable batteries are constructed using the latest technology and equipment to cast grids from a lead-calcium alloy, free of antimony. The small amount of calcium and tin in the grid alloy imparts strength to the plate and guarantees durability even in extensive life-cycle service. Lead oxide paste is added to the grid to form the electrically active material. In the charged state, the negative plate paste is pure lead and the positive plate paste is lead oxide. Both of these are in a porous or spongy form to optimise surface area and thereby maximise capacity.

**Electrolyte**

Immobilised dilute sulphuric acid: $H_2SO_4$.

**Separators**

The plate separators used in Powermaster® sealed lead-acid rechargeable batteries are made of woven glass fibre cloth with high heat and oxidation resistance. This material also offers superior electrolyte absorption and retention and is an excellent ion conductor.

**Relief Valve**

In case of excessive gas pressure build-up inside the battery (usually caused by abnormal charging) the relief valve will open and relieve the pressure. The one-way valve not only ensures that no air gets into the battery where the oxygen would react with the plates causing internal discharge, but it also represents an important safety device in the event of excessive overcharge. Vent release pressure is between 2-6 psi. The seal ring material is neoprene rubber.

**Terminals**

The AMP quick-connect type terminals are constructed of tin plated brass and sealed with a special epoxy material.

**Container**

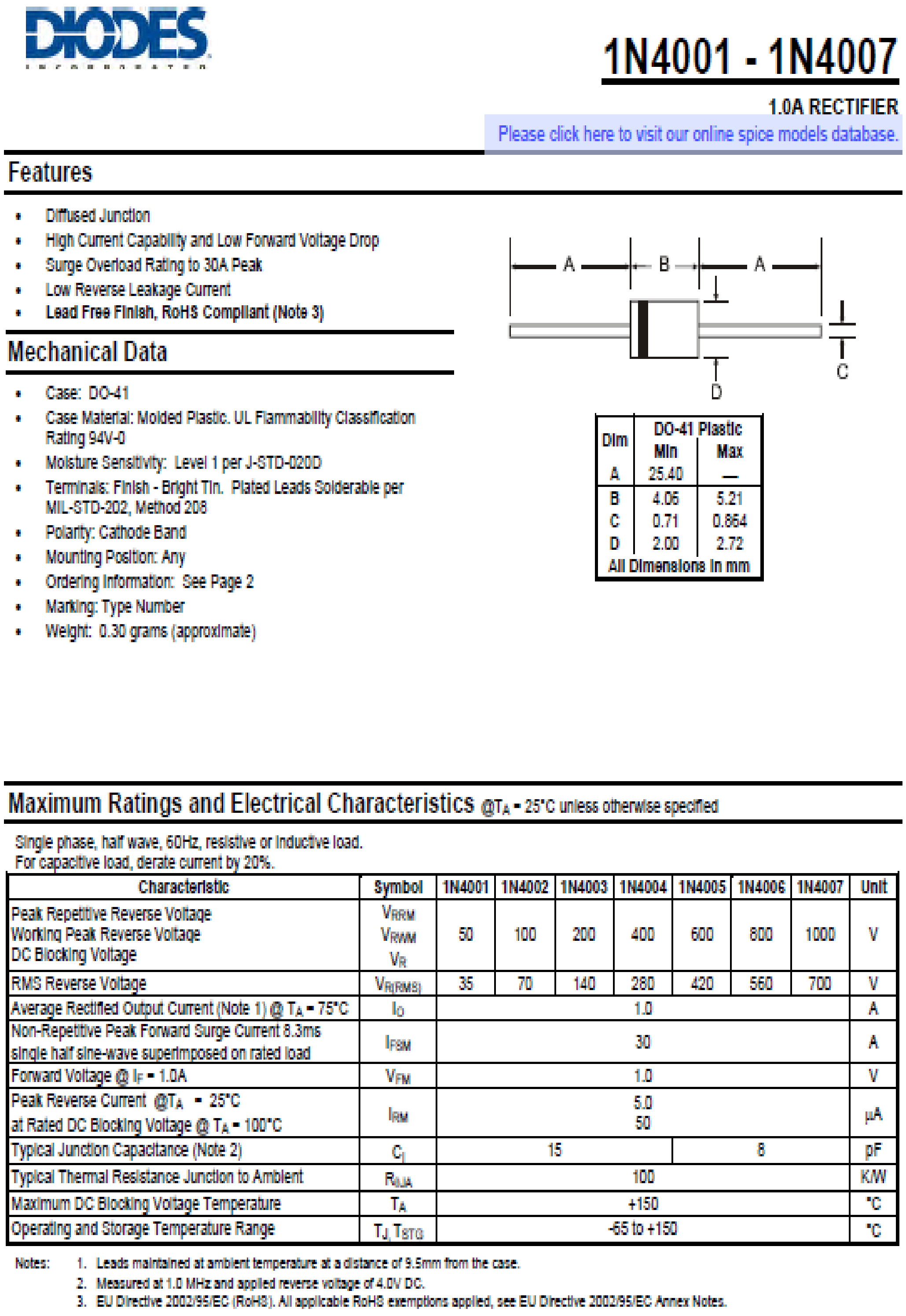
The ABS housing is resistant to chemicals and flammability.

**Case Sealing**

The tongue and groove joint is polyurethane sealed.

# APPENDIX D

DIODE 1N4001-1N4007



DIODES INCORPORATED

## 1N4001 - 1N4007

1.0A RECTIFIER

Please click here to visit our online spice models database.

### Features

- Diffused Junction
- High Current Capability and Low Forward Voltage Drop
- Surge Overload Rating to 30A Peak
- Low Reverse Leakage Current
- **Lead Free Finish, RoHS Compliant (Note 3)**

### Mechanical Data

- Case: DO-41
- Case Material: Molded Plastic. UL Flammability Classification Rating 94V-0
- Moisture Sensitivity: Level 1 per J-STD-020D
- Terminals: Finish - Bright Tin. Plated Leads Solderable per MIL-STD-202, Method 208
- Polarity: Cathode Band
- Mounting Position: Any
- Ordering Information: See Page 2
- Marking: Type Number
- Weight: 0.30 grams (approximate)

| Dim | DO-41 Plastic | |
|---|---|---|
| | Min | Max |
| A | 25.40 | — |
| B | 4.06 | 5.21 |
| C | 0.71 | 0.864 |
| D | 2.00 | 2.72 |
| All Dimensions in mm | | |

### Maximum Ratings and Electrical Characteristics @$T_A$ = 25°C unless otherwise specified

Single phase, half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

| Characteristic | Symbol | 1N4001 | 1N4002 | 1N4003 | 1N4004 | 1N4005 | 1N4006 | 1N4007 | Unit |
|---|---|---|---|---|---|---|---|---|---|
| Peak Repetitive Reverse Voltage<br>Working Peak Reverse Voltage<br>DC Blocking Voltage | $V_{RRM}$<br>$V_{RWM}$<br>$V_R$ | 50 | 100 | 200 | 400 | 600 | 800 | 1000 | V |
| RMS Reverse Voltage | $V_{R(RMS)}$ | 35 | 70 | 140 | 280 | 420 | 560 | 700 | V |
| Average Rectified Output Current (Note 1) @ $T_A$ = 75°C | $I_O$ | 1.0 | | | | | | | A |
| Non-Repetitive Peak Forward Surge Current 8.3ms single half sine-wave superimposed on rated load | $I_{FSM}$ | 30 | | | | | | | A |
| Forward Voltage @ $I_F$ = 1.0A | $V_{FM}$ | 1.0 | | | | | | | V |
| Peak Reverse Current @$T_A$ = 25°C<br>at Rated DC Blocking Voltage @ $T_A$ = 100°C | $I_{RM}$ | 5.0<br>50 | | | | | | | µA |
| Typical Junction Capacitance (Note 2) | $C_j$ | 15 | | | | 8 | | | pF |
| Typical Thermal Resistance Junction to Ambient | $R_{θJA}$ | 100 | | | | | | | K/W |
| Maximum DC Blocking Voltage Temperature | $T_A$ | +150 | | | | | | | °C |
| Operating and Storage Temperature Range | $T_J, T_{STG}$ | -65 to +150 | | | | | | | °C |

Notes:
1. Leads maintained at ambient temperature at a distance of 9.5mm from the case.
2. Measured at 1.0 MHz and applied reverse voltage of 4.0V DC.
3. EU Directive 2002/95/EC (RoHS). All applicable RoHS exemptions applied, see EU Directive 2002/95/EC Annex Notes.

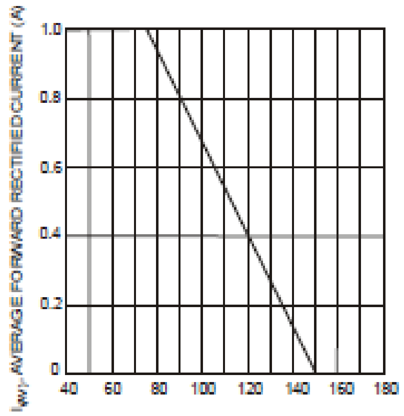


Fig. 1 Forward Current Derating Curve

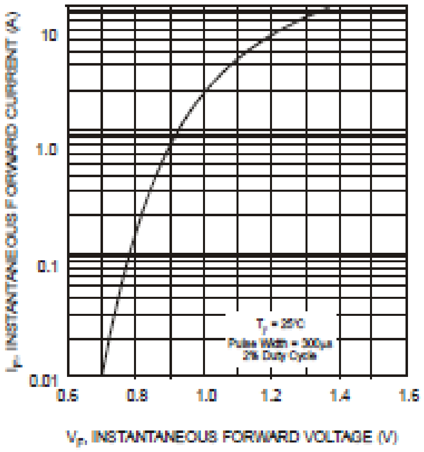


Fig. 2 Typical Forward Characteristics

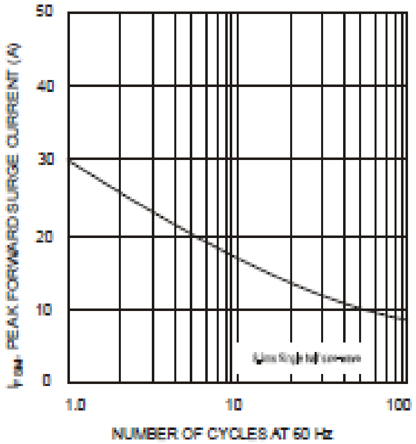


Fig. 3 Max Non-Repetitive Peak Fwd Surge Current

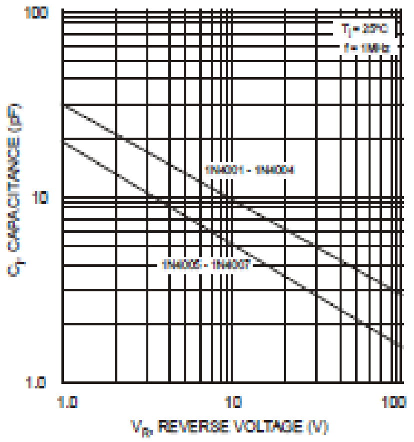


Fig. 4 Typical Junction Capacitance

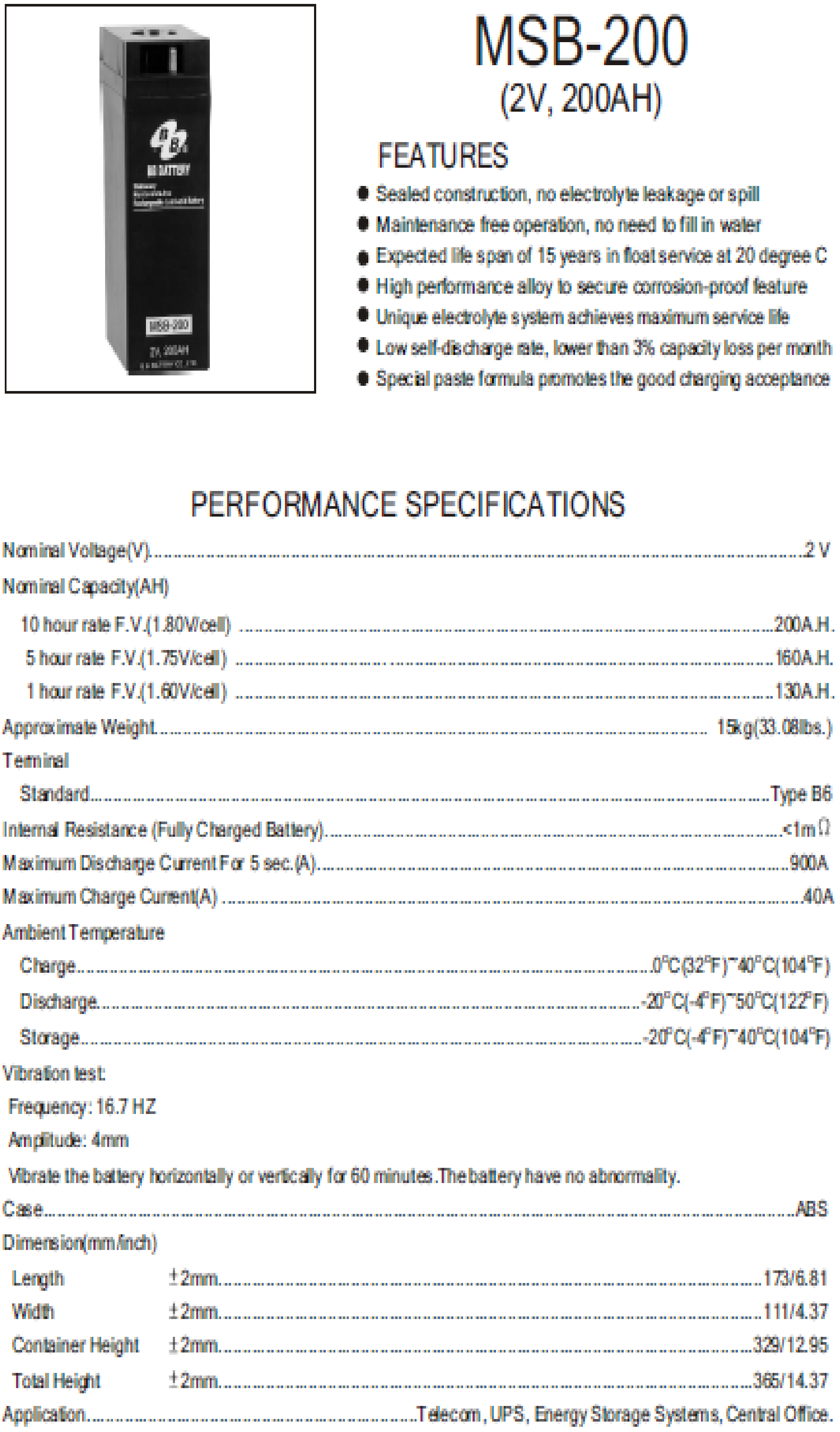
## Ordering Information (Note 4)

| Device | Packaging | Shipping |
|---|---|---|
| 1N4001-B | DO-41 Plastic | 1K/Bulk |
| 1N4001-T | DO-41 Plastic | 5K/Tape & Reel, 13-inch |
| 1N4002-B | DO-41 Plastic | 1K/Bulk |
| 1N4002-T | DO-41 Plastic | 5K/Tape & Reel, 13-inch |
| 1N4003-B | DO-41 Plastic | 1K/Bulk |
| 1N4003-T | DO-41 Plastic | 5K/Tape & Reel, 13-inch |
| 1N4004-B | DO-41 Plastic | 1K/Bulk |
| 1N4004-T | DO-41 Plastic | 5K/Tape & Reel, 13-inch |
| 1N4005-B | DO-41 Plastic | 1K/Bulk |
| 1N4005-T | DO-41 Plastic | 5K/Tape & Reel, 13-inch |
| 1N4006-B | DO-41 Plastic | 1K/Bulk |
| 1N4006-T | DO-41 Plastic | 5K/Tape & Reel, 13-inch |
| 1N4007-B | DO-41 Plastic | 1K/Bulk |
| 1N4007-T | DO-41 Plastic | 5K/Tape & Reel, 13-inch |

Notes: 4. For packaging details, visit our website at http://www.diodes.com/datasheets/ap02008.pdf.

# APPENDIX E

MSB-200 Data Sheet



# MSB-200

## (2V, 200AH)

### FEATURES

- Sealed construction, no electrolyte leakage or spill
- Maintenance free operation, no need to fill in water
- Expected life span of 15 years in float service at 20 degree C
- High performance alloy to secure corrosion-proof feature
- Unique electrolyte system achieves maximum service life
- Low self-discharge rate, lower than 3% capacity loss per month
- Special paste formula promotes the good charging acceptance

### PERFORMANCE SPECIFICATIONS

| | |
|---|---|
| Nominal Voltage(V) | 2 V |
| Nominal Capacity(AH) | |
| 10 hour rate F.V.(1.80V/cell) | 200A.H. |
| 5 hour rate F.V.(1.75V/cell) | 160A.H. |
| 1 hour rate F.V.(1.60V/cell) | 130A.H. |
| Approximate Weight | 15kg(33.08lbs.) |
| Terminal | |
| Standard | Type B6 |
| Internal Resistance (Fully Charged Battery) | <1mΩ |
| Maximum Discharge Current For 5 sec.(A) | 900A |
| Maximum Charge Current(A) | 40A |
| Ambient Temperature | |
| Charge | 0°C(32°F)~40°C(104°F) |
| Discharge | -20°C(-4°F)~50°C(122°F) |
| Storage | -20°C(-4°F)~40°C(104°F) |

Vibration test:

Frequency: 16.7 HZ

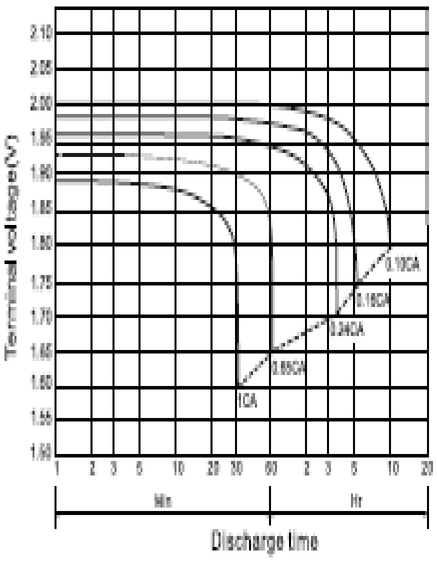
Amplitude: 4mm

Vibrate the battery horizontally or vertically for 60 minutes.The battery have no abnormality.

| | | |
|---|---|---|
| Case | | ABS |
| Dimension(mm/inch) | | |
| Length | ±2mm | 173/6.81 |
| Width | ±2mm | 111/4.37 |
| Container Height | ±2mm | 329/12.95 |
| Total Height | ±2mm | 365/14.37 |
| Application | | Telecom, UPS, Energy Storage Systems, Central Office. |

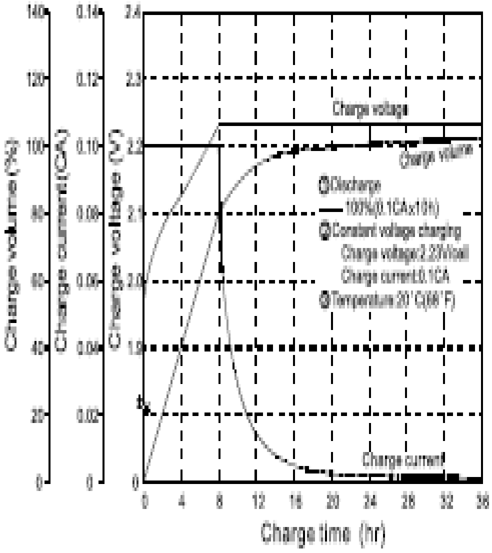
### MSB-200 Battery Discharge Characteristics (25°C/77°F)

Note : C=10HR Nominal Capacity(Ah)

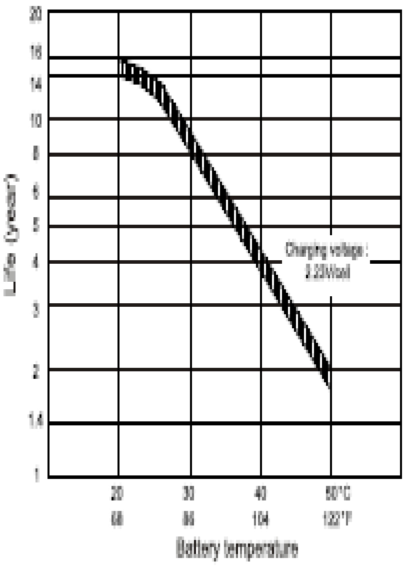


### Battery Charging Characteristics

(Typical example of the charge characteristic for the standby use)



### Effect of Temperature on Long Term Float Life



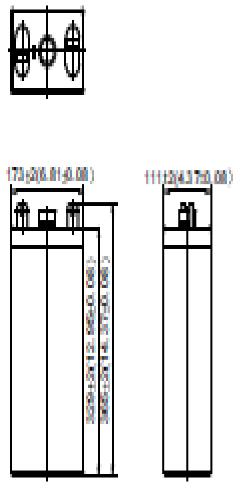
### Charging Procedure

| Application | Charging method | Charging Voltage at 20°C (V/cell) | Temperature compensation coefficient (mV/°C/cell) | Max. charging current (A) | Charging time 0.1CA, 20°C (h) | |
|---|---|---|---|---|---|---|
| | | | | | 100% discharge | 50% discharge |
| For standby power source | Constant voltage (with current restriction) | 2.23~2.25 | -3 | 40 | 24 | 20 |

*Temperature compensation of charging voltage is not needed, when the batteries are used within 5°C to 35°C range.

### Outer Dimensions

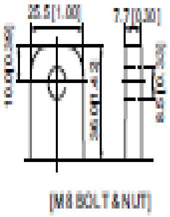
mm(inch)



### Terminal Type

mm(inch)

● Terminal B6



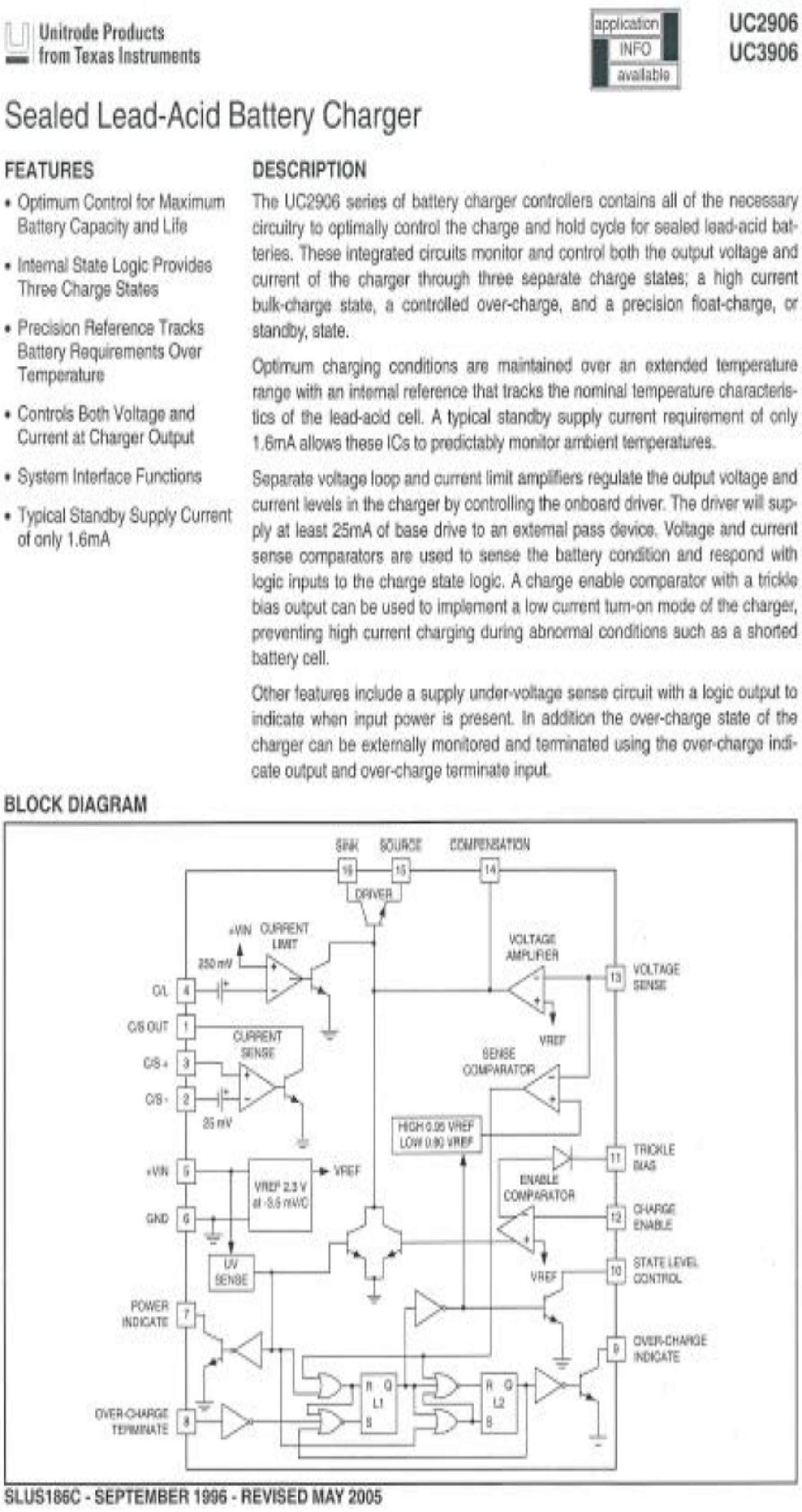
[M8 BOLT & NUT]

### Constant Power Discharge Characteristics at 25°C/77°F

| Final Voltage | Discharge time | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30Min | 1Hr | 2Hr | 3Hr | 4Hr | 5Hr | 6Hr | 8Hr | 10Hr | 12Hr | 20Hr |
| | Battery output power(W) | | | | | | | | | | |
| 1.80V | 291 | 198 | 109 | 94.6 | 75.8 | 65.8 | 57.3 | 47.6 | 39.1 | 30.9 | 19.3 |
| 1.70V | 350 | 224 | 122 | 103.0 | 82.4 | 70.5 | 60.9 | 50.1 | 42.7 | 32.0 | 20.0 |
| 1.60V | 379 | 233 | 127 | 106.1 | 85.2 | 72.5 | 62.6 | 51.4 | 43.5 | 32.8 | 20.4 |

# APPENDIX F

Sealed Lead-Acid Data Sheet



**Unitrode Products from Texas Instruments**

application INFO available

**UC2906**
**UC3906**

## Sealed Lead-Acid Battery Charger

### FEATURES

- Optimum Control for Maximum Battery Capacity and Life
- Internal State Logic Provides Three Charge States
- Precision Reference Tracks Battery Requirements Over Temperature
- Controls Both Voltage and Current at Charger Output
- System Interface Functions
- Typical Standby Supply Current of only 1.6mA

### DESCRIPTION

The UC2906 series of battery charger controllers contains all of the necessary circuitry to optimally control the charge and hold cycle for sealed lead-acid batteries. These integrated circuits monitor and control both the output voltage and current of the charger through three separate charge states; a high current bulk-charge state, a controlled over-charge, and a precision float-charge, or standby, state.

Optimum charging conditions are maintained over an extended temperature range with an internal reference that tracks the nominal temperature characteristics of the lead-acid cell. A typical standby supply current requirement of only 1.6mA allows these ICs to predictably monitor ambient temperatures.

Separate voltage loop and current limit amplifiers regulate the output voltage and current levels in the charger by controlling the onboard driver. The driver will supply at least 25mA of base drive to an external pass device. Voltage and current sense comparators are used to sense the battery condition and respond with logic inputs to the charge state logic. A charge enable comparator with a trickle bias output can be used to implement a low current turn-on mode of the charger, preventing high current charging during abnormal conditions such as a shorted battery cell.

Other features include a supply under-voltage sense circuit with a logic output to indicate when input power is present. In addition the over-charge state of the charger can be externally monitored and terminated using the over-charge indicate output and over-charge terminate input.

### BLOCK DIAGRAM

SLUS186C - SEPTEMBER 1996 - REVISED MAY 2005

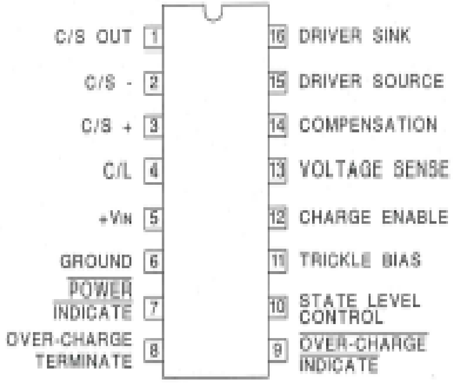
## ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| Supply Voltage (+VIN) | 40V |
| Open Collector Output Voltages | 40V |
| Amplifier and Comparator Input Voltages | −0.3V to +40V |
| Over-Charge Terminate Input Voltage | −0.3V to +40V |
| Current Sense Amplifier Output Current | 80mA |
| Other Open Collector Output Currents | 20mA |
| Trickle Bias Voltage Differential with respect to VIN | −32V |
| Trickle Bias Output Current | −40mA |
| Driver Current | 80mA |
| Power Dissipation at $T_A$ = 25°C (Note 2) | 1000mW |
| Power Dissipation at $T_C$ = 25°C (Note 2) | 2000mW |
| Operating Junction Temperature | −55°C to +150°C |
| Storage Temperature | −65°C to +150°C |
| Lead Temperature (Soldering, 10 Seconds) | 300°C |

**Note 1:** *Voltages are referenced to ground (Pin 6). Currents are positive into, negative out of, the specified terminals.*

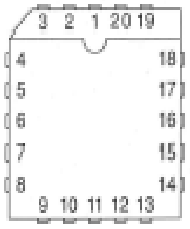
**Note 2:** *Consult Packaging section of Databook for thermal limitations and considerations of packages.*

**DIL-16, SOIC-16 (TOP VIEW)**
**J or N Package, DW Package**



## CONNECTION DIAGRAMS

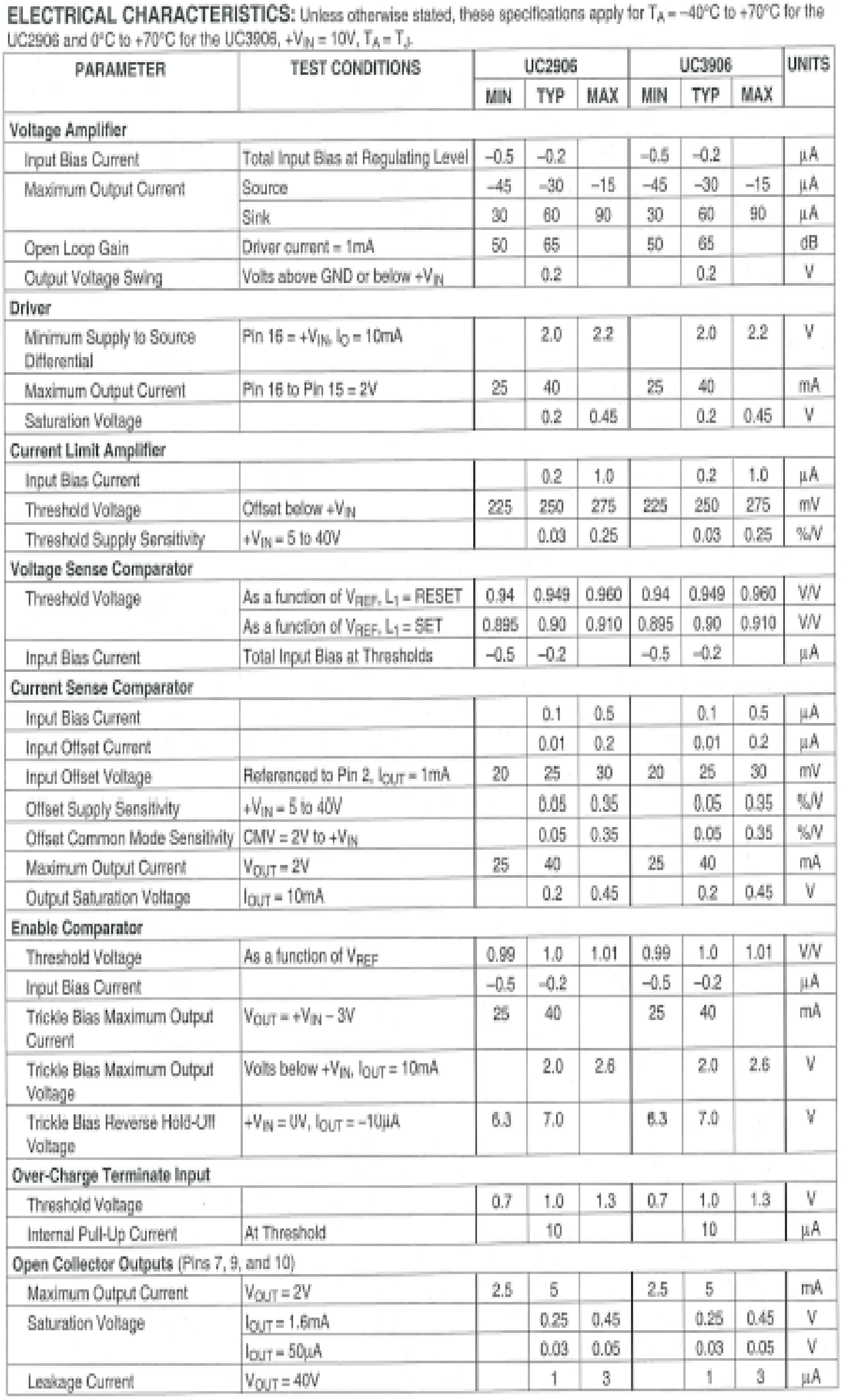
**PLCC-20, LCC-20 (TOP VIEW)**
**Q, L Packages**



| PIN FUNCTION | PIN |
|---|---|
| N/C | 1 |
| C/S OUT | 2 |
| C/S- | 3 |
| C/S+ | 4 |
| C/L | 5 |
| N/C | 6 |
| +VIN | 7 |
| GROUND | 8 |
| POWER INDICATE | 9 |
| OVER CHARGE TERMINATE | 10 |
| N/C | 11 |
| OVER CHARGE INDICATE | 12 |
| STATE LEVEL CONTROL | 13 |
| TRICKLE BIAS | 14 |
| CHARGE ENABLE | 15 |
| N/C | 16 |
| VOLTAGE SENSE | 17 |
| COMPENSATION | 18 |
| DRIVER SOURCE | 19 |
| DRIVER SINK | 20 |

**ELECTRICAL CHARACTERISTICS:** Unless otherwise stated, these specifications apply for $T_A$ = −40°C to +70°C for the UC2906 and 0°C to +70°C for the UC3906, $+V_{IN}$ = 10V, $T_A = T_J$.

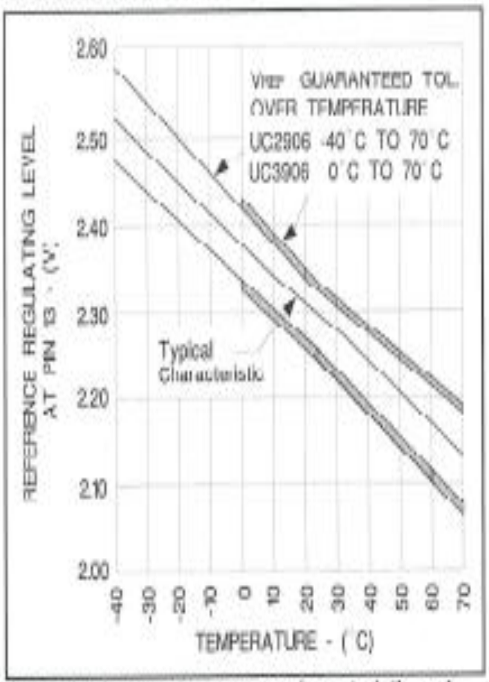
| PARAMETER | TEST CONDITIONS | UC2906 | | | UC3906 | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| **Input Supply** | | | | | | | | |
| Supply Current | $+V_{IN}$ = 10V | | 1.6 | 3.3 | | 1.6 | 3.3 | mA |
| | $+V_{IN}$ = 40V | | 1.8 | 3.6 | | 1.8 | 3.6 | mA |
| | $+V_{IN}$ = 40V, $T_A$ = −40°C to 85°C | | 1.8 | 4 | | | | mA |
| Supply Under-Voltage Threshold | $+V_{IN}$ = Low to High | 4.2 | 4.5 | 4.8 | 4.2 | 4.5 | 4.8 | V |
| Supply Under-Voltage Hysteresis | | | 0.20 | 0.30 | | 0.20 | 0.30 | V |
| **Internal Reference (VREF)** | | | | | | | | |
| Voltage Level (Note 3) | Measured as Regulating Level at Pin 13 w/ Driver Current = 1mA, $T_J$ = 25°C | 2.275 | 2.3 | 2.325 | 2.270 | 2.3 | 2.330 | V |
| Line Regulation | $+V_{IN}$ = 5 to 40V | | 3 | 8 | | 3 | 8 | mV |
| Temperature Coefficient | | | −3.5 | | | −3.5 | | mV/°C |



**ELECTRICAL CHARACTERISTICS:** Unless otherwise stated, these specifications apply for $T_A = -40°C$ to $+70°C$ for the UC2906 and $0°C$ to $+70°C$ for the UC3906, $+V_{IN} = 10V$, $T_A = T_J$.

| PARAMETER | TEST CONDITIONS | UC2906 | | | UC3906 | | | UNITS |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| **Voltage Amplifier** | | | | | | | | |
| Input Bias Current | Total Input Bias at Regulating Level | –0.5 | –0.2 | | –0.5 | –0.2 | | µA |
| Maximum Output Current | Source | –45 | –30 | –15 | –45 | –30 | –15 | µA |
| | Sink | 30 | 60 | 90 | 30 | 60 | 90 | µA |
| Open Loop Gain | Driver current = 1mA | 50 | 65 | | 50 | 65 | | dB |
| Output Voltage Swing | Volts above GND or below $+V_{IN}$ | | 0.2 | | | 0.2 | | V |
| **Driver** | | | | | | | | |
| Minimum Supply to Source Differential | Pin 16 = $+V_{IN}$, $I_O$ = 10mA | | 2.0 | 2.2 | | 2.0 | 2.2 | V |
| Maximum Output Current | Pin 16 to Pin 15 = 2V | 25 | 40 | | 25 | 40 | | mA |
| Saturation Voltage | | | 0.2 | 0.45 | | 0.2 | 0.45 | V |
| **Current Limit Amplifier** | | | | | | | | |
| Input Bias Current | | | 0.2 | 1.0 | | 0.2 | 1.0 | µA |
| Threshold Voltage | Offset below $+V_{IN}$ | 225 | 250 | 275 | 225 | 250 | 275 | mV |
| Threshold Supply Sensitivity | $+V_{IN}$ = 5 to 40V | | 0.03 | 0.25 | | 0.03 | 0.25 | %/V |
| **Voltage Sense Comparator** | | | | | | | | |
| Threshold Voltage | As a function of $V_{REF}$, $L_1$ = RESET | 0.94 | 0.949 | 0.960 | 0.94 | 0.949 | 0.960 | V/V |
| | As a function of $V_{REF}$, $L_1$ = SET | 0.895 | 0.90 | 0.910 | 0.895 | 0.90 | 0.910 | V/V |
| Input Bias Current | Total Input Bias at Thresholds | –0.5 | –0.2 | | –0.5 | –0.2 | | µA |
| **Current Sense Comparator** | | | | | | | | |
| Input Bias Current | | | 0.1 | 0.5 | | 0.1 | 0.5 | µA |
| Input Offset Current | | | 0.01 | 0.2 | | 0.01 | 0.2 | µA |
| Input Offset Voltage | Referenced to Pin 2, $I_{OUT}$ = 1mA | 20 | 25 | 30 | 20 | 25 | 30 | mV |
| Offset Supply Sensitivity | $+V_{IN}$ = 5 to 40V | | 0.05 | 0.35 | | 0.05 | 0.35 | %/V |
| Offset Common Mode Sensitivity | CMV = 2V to $+V_{IN}$ | | 0.05 | 0.35 | | 0.05 | 0.35 | %/V |
| Maximum Output Current | $V_{OUT}$ = 2V | 25 | 40 | | 25 | 40 | | mA |
| Output Saturation Voltage | $I_{OUT}$ = 10mA | | 0.2 | 0.45 | | 0.2 | 0.45 | V |
| **Enable Comparator** | | | | | | | | |
| Threshold Voltage | As a function of $V_{REF}$ | 0.99 | 1.0 | 1.01 | 0.99 | 1.0 | 1.01 | V/V |
| Input Bias Current | | –0.5 | –0.2 | | –0.5 | –0.2 | | µA |
| Trickle Bias Maximum Output Current | $V_{OUT} = +V_{IN} - 3V$ | 25 | 40 | | 25 | 40 | | mA |
| Trickle Bias Maximum Output Voltage | Volts below $+V_{IN}$, $I_{OUT}$ = 10mA | | 2.0 | 2.6 | | 2.0 | 2.6 | V |
| Trickle Bias Reverse Hold-Off Voltage | $+V_{IN}$ = 0V, $I_{OUT}$ = –10µA | 6.3 | 7.0 | | 6.3 | 7.0 | | V |
| **Over-Charge Terminate Input** | | | | | | | | |
| Threshold Voltage | | 0.7 | 1.0 | 1.3 | 0.7 | 1.0 | 1.3 | V |
| Internal Pull-Up Current | At Threshold | | 10 | | | 10 | | µA |
| **Open Collector Outputs** (Pins 7, 9, and 10) | | | | | | | | |
| Maximum Output Current | $V_{OUT}$ = 2V | 2.5 | 5 | | 2.5 | 5 | | mA |
| Saturation Voltage | $I_{OUT}$ = 1.6mA | | 0.25 | 0.45 | | 0.25 | 0.45 | V |
| | $I_{OUT}$ = 50µA | | 0.03 | 0.05 | | 0.03 | 0.05 | V |
| Leakage Current | $V_{OUT}$ = 40V | | 1 | 3 | | 1 | 3 | µA |

## OPERATION AND APPLICATION INFORMATION



***Internal reference temperature characteristic and tolerance.***

### Dual Level Float Charger Operations

The UC2906 is shown configured as a dual level float charger in Figure 1. All high currents are handled by the external PNP pass transistor with the driver supplying base drive to this device. This scheme uses the TRICKLE BIAS output and the charge enable comparator to give the charger a low current turn on mode. The output current of the charger is limited to a low-level until the battery reaches a specified voltage, preventing a high current charging if a battery cell is shorted. Figure 2 shows the state diagram of the charger. Upon turn on the UV sense circuitry puts the charger in state 1, the high rate bulk-charge state. In this state, once the enable threshold has been exceeded, the charger will supply a peak current that is determined by the 250mV offset in the C/L amplifier and the sensing resistor $R_S$.

To guarantee full re-charge of the battery, the charger's voltage loop has an elevated regulating level, $V_{OC}$, during state 1 and state 2. When the battery voltage reaches 95% of $V_{OC}$, the charger enters the over-charge state, state 2. The charger stays in this state until the OVER-CHARGE TERMINATE pin goes high. In Figure 1, the charger uses the current sense amplifier to generate this signal by sensing when the charge current has tapered to a specified level, $I_{OCT}$. Alternatively the over-charge could have been controlled by an external source, such as a timer, by using the OVER-CHARGE INDICATE signal at Pin 9. If a load is applied to the battery and begins to discharge it, the charger will contribute its full output to the load. If the battery drops 10% below the float level, the charger will reset itself to state 1. When the load is removed a full charge cycle will follow. A graphical representation of a charge, and discharge, cycle of the dual lever float charger is shown in Figure 3.

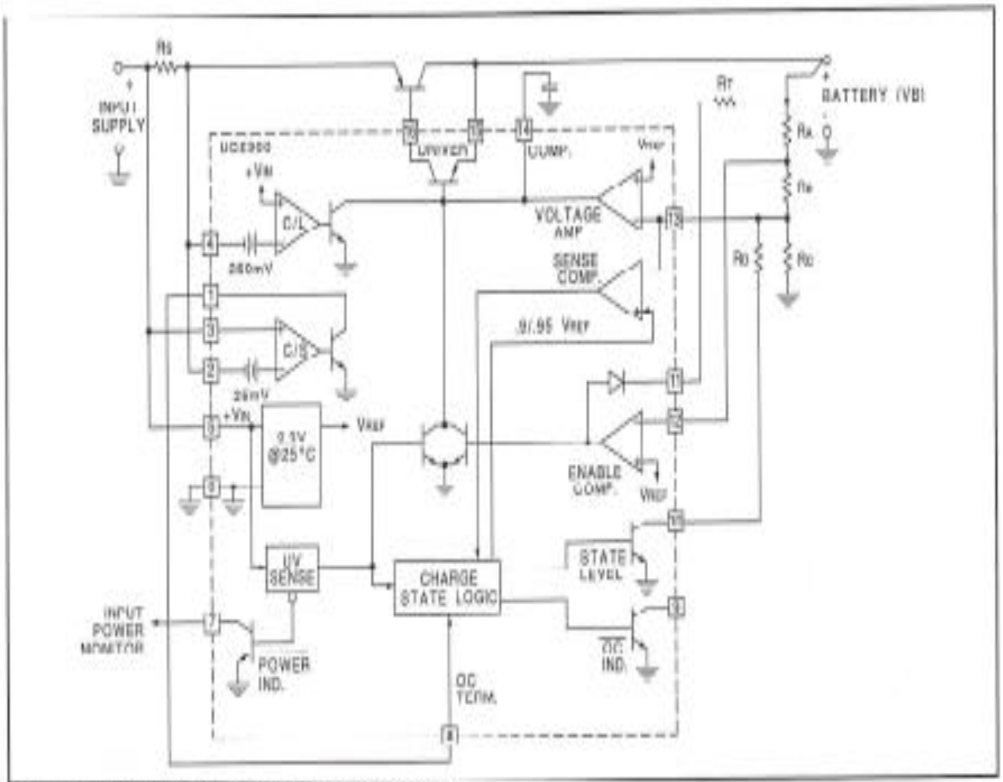


***Figure 1. The UC2906 in a dual level float charger.***

**Design Procedure**

1) Pick divider current, $I_D$. Recommended value is 50µA to 100µA.

2) $R_C = 2.3V / I_D$

3) $R_A + R_B = R_{SUM} = (V_F - 2.3V) / I_D$

4) $R_D = 2.3V \bullet R_{SUM} / (V_{OC} - V_F)$

5) $R_A = (R_{SUM} + R_X)(1 - 2.3V / V_T)$
WHERE: $R_X = R_C \bullet R_D / (R_C + R_D)$

6) $R_B = R_{SUM} - R_A$

7) $R_S = 0.25V / I_{MAX}$

8) $R_T = (V_{IN} - V_T - 2.5V) / I_T$

9) $I_{OCT} = \frac{I_{MAX}}{10}$

Note: $V_{12} = 0.95\,V_{OC}$,
$V_{31} = 0.90\,V_F$,

For further design and application information see UICC Application Note U-104

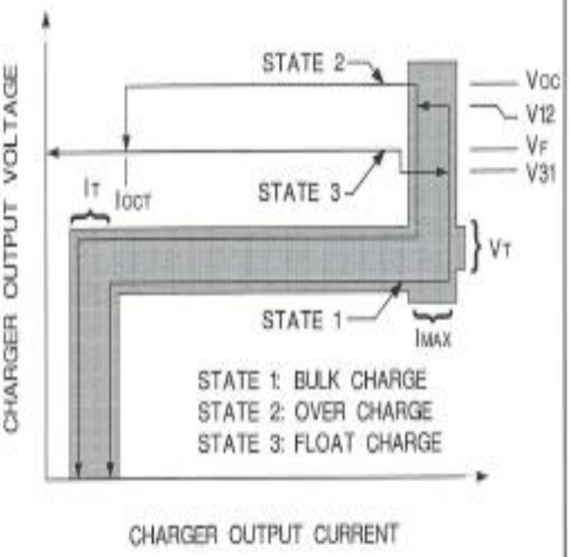
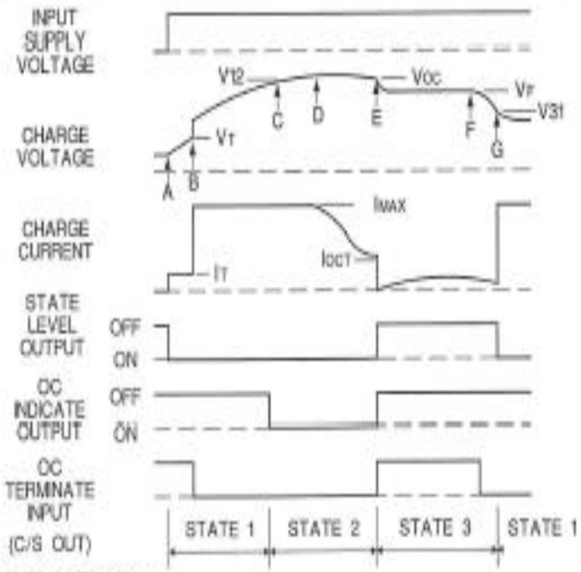


*Figure 2. State diagram and design equations for the dual level float charger.*



**Explanation: Dual Level Float Charger**

A. Input power turns on, battery charges at trickle current rate.

B. Battery voltage reaches $V_T$ enabling the driver and turning off the trickle bias output, battery charges at $I_{MAX}$ rate.

C. Transition voltage $V_{12}$ is reached and the charger indicates that it is now in the over-charge state, state 2.

D. Battery voltage approaches the over-charge level $V_{OC}$ and the charge current begins to taper.

E. Charge current tapers to $I_{OCT}$. The current sense amplifier output, in this case tied to the OC TERMINATE input, goes high. The charger changes to the float state and holds the battery voltage at $V_F$.

F. Here a load (>$I_{MAX}$) begins to discharge the battery.

G. The load discharges the battery such that the battery voltage falls below $V_{31}$. The charger is now in state 1, again.