Microcontroller Application — Battery Charger

D/N: HA0052E

Preface

With the present wireless communication revolution, possession of a mobile phone is now a common sight in most developed countries. Along with the convenience of quick and easy communication, this situation has also brought with it a whole new area of business opportunities. But with every cell phone also comes a rechargeable battery and a battery charger. As the trend towards wireless internet continues to develop, cell phones with these added functions are now starting to prevail in the market, increasing yet further the need for rechargeable batteries and their associated chargers. In addition, the popularity of handheld devices like PDA, MP3 Walkman, and digital cameras all require batteries to operate, adding to the importance of rechargeable batteries. With this in mind, this article sets out to explain the special features of rechargeable batteries, after which an explanation will be given about how to design a quick-charge battery charger.

Holtek Semiconductor has currently released a battery charger microcontroller device, the HT46R47. This device can be universally used as the basis behind quick-charge battery chargers for the range of the most commonly used rechargeable batteries such as Ni-Cd, Ni-NH and Li-ion cells used in applications such as mobile phones, walkmans, PDAs and so on. This article will set out to explain the function of the HT46R47 in order to explain further the principles behind the charging of Ni-Cd, Ni-MH, and Li-ion batteries as well as giving an understanding of how to construct a suitable charger. After reading we hope readers will have the necessary knowledge to begin design of their own charger and distinguish the pros and cons of the presently available different types of batteries and chargers.

HT46R47 main features

Package	18DIP and 18SOP
I/O pin	13 pin
PWM output	In common use with PA0
PFD output	In common use with PA3
External Event Counter	In common use with PA4
External Interrupt	In common use with PA5
System Oscillator	Either RC oscillator or crystal/ceramic oscillator
ADC channel	4-channel analog input AN0~AN3 in common use with PB0~PB3
ADC resolution	9 bit ADC, 8-bit accuracy

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Operating Voltage	2.2V~5.5V
Program Memory EPROM	2048×14
Data Memory RAM	64×8
Timer	8-bit+7 level prescaler
Low Voltage Reset	3V±0.3V
Stack	6 levels

Table 1

Although the HT46R47 microcontroller was designed by Holtek with the battery charger market as the main focus, its range of application is far more diverse. For example, its comprehensive internal functions and flexibility make it suitable for a range of applications which require analog to digital functions. Its high noise immunity specification make it suitable for use in the household appliance application area whereas the internal PWM output function also provide a means of providing voltage control.

Battery and Charger

The most commonly used batteries in the market are the Ni-Cd, Ni-NH and Li-ion types, all of which have their capacity measured in mAh. This value indicates the amount of current the battery can supply for a certain amount of time. For example a 500 mAh battery should be able to supply 500mA continuously for 1 hour or 50mA for 10 hours. Simply speaking, the larger the battery capacity, measured in mAh, the longer the battery can supply current.

However in order to achieve maximum efficiency and cost-effectiveness from the battery it is essential to ensure that the battery is fully charged. To do this it is not only necessary to choose battery chargers that can recharge batteries in a short time but also to detect when the battery is in the fully charged state. For the purpose of a quick-charge in one hour, the current of the charger must stay at 500mAh/1h=500mA. For a so-called 500mAh capacity battery, a charging current of 500mA is called 1C. If Ni-Cd or Ni-NH batteries are recharged without first fully discharging, then they will suffer from a reduction in their overall capacity, a phenomenon known as the memory effect. Li-ion batteries however do not suffer from memory effect and will not experience the same capacity reduction if recharged without first fully discharging.

During the recharge process it is important to know when the battery has reached the fully charged condition. Without the ability to detect this condition, the charger will continue to source current into the battery even after it has reached the fully charged state, a situation which can cause damage to batteries. The following shows the method to detect the fully charged state of Ni-Cd, Ni-NH and Li-ion batteries.

Term Definitions

V_{BAT}: battery voltage, measured by taking the presently measured value and averaging it with the previous three measurements

V_{MAX}: highest safest battery voltage

V_{PEAK}: maximum value of V_{BAT}

ΔV: $V_{PEAK} - V_{BAT}$

The charging methods for both Ni-Cd and Ni-NH batteries are the same. The following describes several methods of detecting when the full charge condition has been reached.

- By measuring ΔV: in a fully charged condition the battery voltage will fall. If successive reductions of 10mV is detected 8 times (ΔV > 10mV for 8 times), the battery will be taken as being in a fully charged state.
- By measuring V_{PEAK}: if V_{BAT} is found to be less than V_{PEAK} after a time period of one minute then the battery can be considered fully charged, however if V_{BAT} is greater than or equal to V_{PEAK} after one minute the timer should be reset and the value measured again after a similar period of time.
- By measuring V_{MAX}: when V_{BAT} reaches V_{MAX}, the battery can be considered fully charged.
- By using a safe timing method: if the charging time is greater than the setup time, the battery can be considered fully charged.
- By measuring battery temperature: when the battery is in the fully charged condition the temperature will rise if charging continues, providing a fully charged measurement parameter.

For Li-ion batteries, detecting a fully charged condition is different, a few methods of which are shown below:

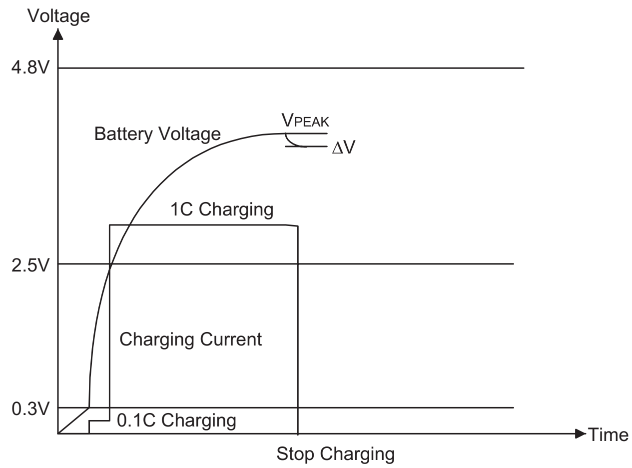
- Li-ion batteries demonstrate the characteristic of having a 4.1V voltage when in the fully charged condition. To begin the charging process first charge with a constant current of 1C, when the battery voltage reaches 4.1V, change the process to charge the battery with a constant voltage source of 4.1V. If the voltage increases beyond 4.1V, then reduce the charging current. If the voltage is less than 4.1V, then do not change the charging current. When the charging current reduces to 0.1C, this indicates that fully charged condition has been reached.
- By measuring V_{MAX}: when V_{BAT} reaches V_{MAX}, the battery could be considered as fully charged.
- By using a safe timing method: as long as the charging time is longer than some predetermined time, the battery can be considered as fully charged.

Fast charging of Ni-Cd, Ni-NH and Li-ion batteries can only be done after the battery voltage has exceeded 2.5V. Until this point is reached the battery has to be charged at a current of 0.1C, after the battery voltage has exceeded 2.5V then a fast charge current of 1C can be applied.

In battery charger design it is also necessary to include a function to automatically detect if a battery has been placed in the charger. To achieve this, the charger should from time to time check the voltage on the battery holder, if this voltage exceeds 0.3V then it could be assumed that a battery has been placed in the charger, if the voltage is less than 0.3V then it could be assumed no battery has been placed in the charger. When detected, the placed battery should be placed in a

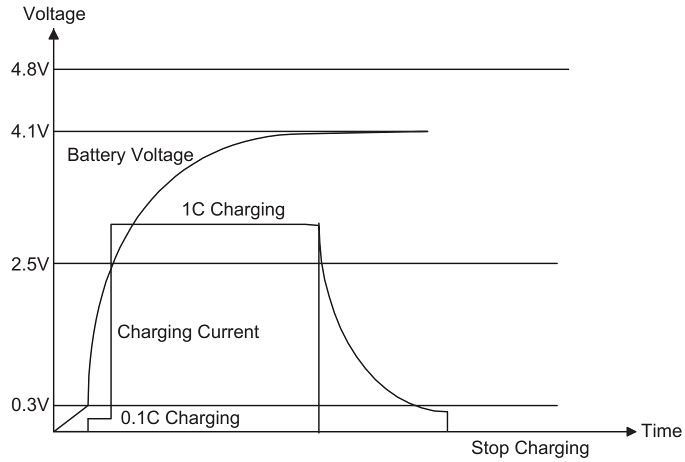
Standby condition ready for charging. Because of the limitation of only being able to charge one set of batteries at a time, the standby batteries need to be charged individually. If, after charging, the battery is not removed from the charger it will remain in the standby condition. To fully prevent it being charged again it must be removed from the charger. As for discharging before charging, Ni-Cd and Ni-NH batteries need to be discharged with a current of 0.1C. When the voltage falls to below 2.2V, the charger will stop discharging the battery and begin the charging cycle automatically. As Li-ion batteries do not suffer from memory effect, they do not require discharging.

Charging curve for Ni-Cd and Ni-NH batteries.



- If the measured voltage on the rechargeable battery is lower than 0.3V, the charging process will not be executed. When the voltage exceeds 0.3V, the charger will charge the battery with a constant current of 0.1C until the voltage reaches 2.5V at which point the charging current will be increased to 1C. Depending upon the charger, whenever the V_{PEAK} status or ΔV occurs, the charging process will end.
- If the voltage of a rechargeable battery exceeds V_{MAX}, (V_{MAX}=4.8V), this will be detected as an over voltage error condition and the charger will cease operation. Possible reasons for this may be a wrongly inserted battery.
- If the charging time exceeds 80 minutes, this indicates a battery of larger capacity which will require a longer charging time. Other reasons for longer charging times may be a battery in poor condition, in which case the charger may be unable to detect a V_{PEAK} status or ΔV condition and therefore continue charging. A default charging time of 80 minutes will also provide a safety precaution against overcharging and possible damage to the battery or other dangerous conditions.

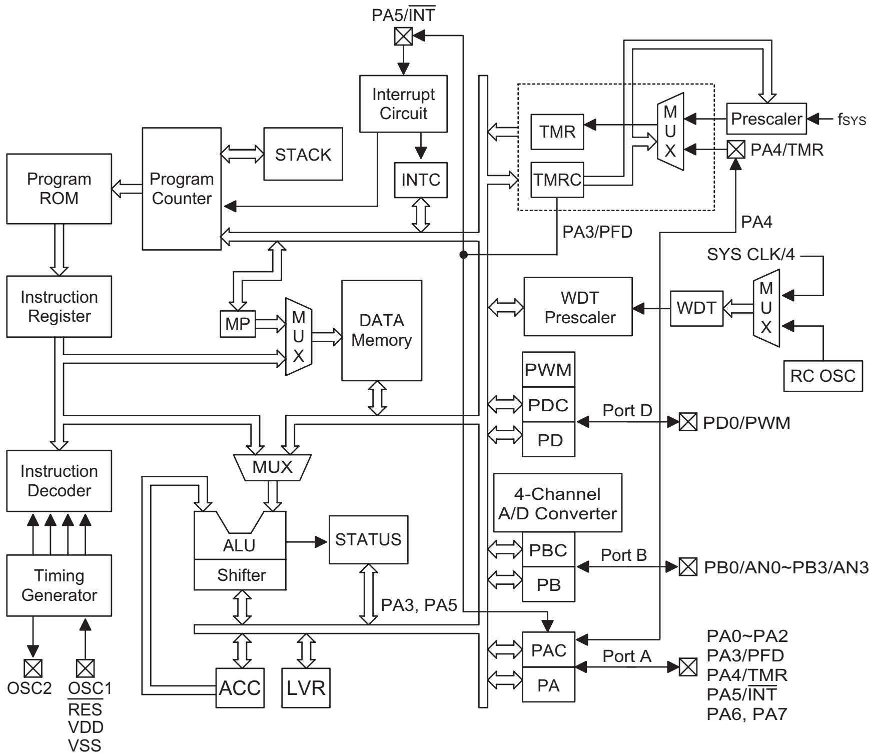
Charging curve for Li-ion batteries.



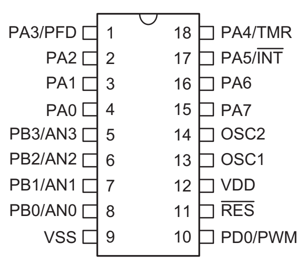
- If the measured voltage on the Li-ion battery is lower than 0.3V, the charging process will not be executed. Once the voltage exceeds 0.3V, the battery will be charged with a 0.1C constant current until the voltage reaches 2.5V, at which point the charging current will increase to 1C. When the voltage reaches 4.1V, the battery will be charged with a constant voltage source at a fixed voltage of 4.1V. When this occurs the charging current will start to fall slowly. When the charging current falls below 0.1C the charging process will stop.
- If the charging voltage of a rechargeable battery is larger than 4.8V, this may indicate an incorrect placement of the battery in the charger, in such a case the charger should cease charging to avoid any possible danger.
- If the charging time exceeds 80 minutes, the battery may still need a longer charging time if it has a larger capacity. Another reason for longer charging times may be that the battery is in poor condition resulting in the battery being unable to reach its fully charged voltage level. By keeping the charging time limited to 80 minutes potential situations of overcharging and other possible dangerous situations can be avoided.

HT46R47 MCU Application Example

A brief explanation of the HT46R47 MCU will now be given, first however the block diagram shown will be discussed.



The following is the pin assignment for the HT46R47 MCU



HT46R47
–18 DIP-A/SOP-A

By consulting the block diagram and pin assignment diagrams, the functions of the HT46R47 MCU can be outlined as follows:

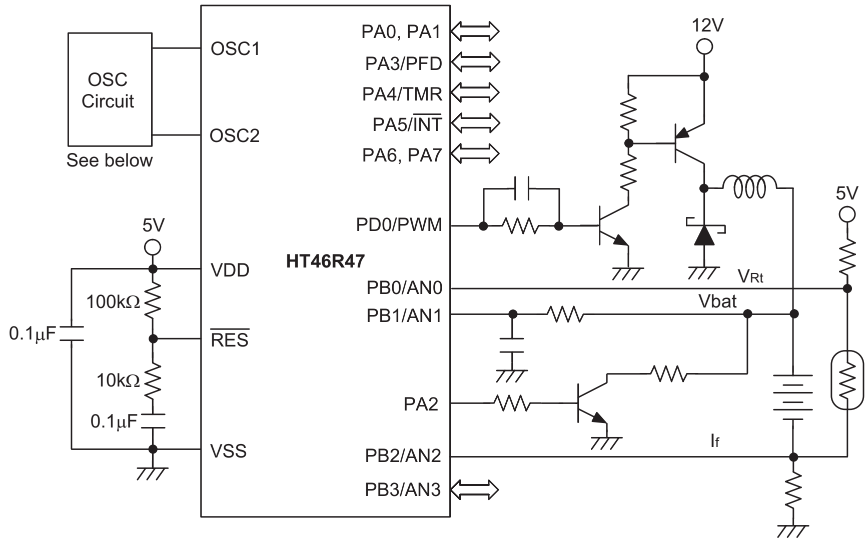
- The HT46R47 uses Holtek's 8-bit RISC microcontroller. This controller incorporates a powerful instruction set of 63 instructions and has a 6-level hardware stack. The internal Watch Dog Timer can prevent erroneous operation due to software malfunctions by automatically resetting the microcontroller. A Low Voltage Reset is included to detect the power supply voltage and automatically reset the device should this voltage fall below a certain value. Ample application code memory capacity is provided in the way of an internal 2K program memory, while an Option Rom is provided to store the selectable options and functions chosen by the user. An internal ram data memory of 64 bytes is also provided for temporary storage of values during program execution. Several kinds of interrupts are provided in the way of an external interrupt pin, an internal timer interrupt and external timer/counter interrupt. An additional interrupt is also provided from the 9-bit Analog to Digital Converter.
- There are 13 I/O pins provided, PA provides 8 pins, PB an additional 4 pins and one more pin provided from PD. Several multi-functional pins are included within these I/O pins. Pin PA3 is a multi-function pin and provides a PFD output on this pin, while PA4 is also multi-functional having an external event-counter function. PA.5 provides the external interrupt pin while PD0 provides the PWM output function. The analog input pins AN0~AN3 for the ADC are provided by the pins PB0~PB3. Regarding these multi-function pins it should be noted that the function of PA3/PFD and PD0/PWM must be chosen from the option menu, the value of which will then be fixed during the programming of the device. If pin PA4 is to be setup as a timer input then it must be configured as an input pin. In the same way if pin PA5 is to be setup as an external interrupt pin then it must be configured as an input pin. The multi-function PB0~PB3/AN0~AN3 pins can be configured as I/O pins or as analog input pins under software control.
- The input to the internal 8-bit timer/counter can be sourced from either the external timer pin or from the internal reference frequency. By using the internal reference frequency the system clock can be divided to give a range of 8 different frequencies for use as the timer/counter input clock, which with a maximum division ratio of 128 provides a flexible timer clock source. The PFD output frequency is also controlled by the 8-bit timer/counter. The PFD frequency is controlled by the overflow bit of the 8-bit timer/counter divided by 2. For example if the timer/counter input clock period is 1us, and if the timer/counter is preset to a value of 6, then because the timer/counter is a count-up type, every 250 counts or 250us the timer/counter will issue an overflow condition, which when divided by 2 provides the PFD output. The period of the PFD output can therefore be calculated as follows:

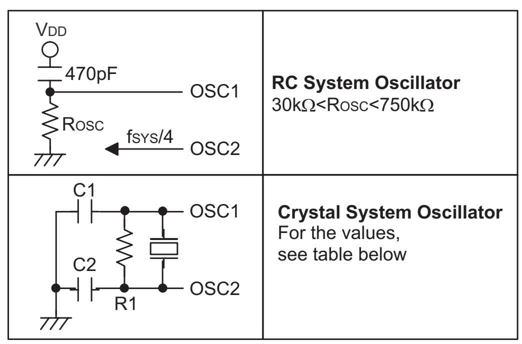
  $1\mu s \times (256\text{-}6) \times 2 = 500\mu s$

  Therefore the PFD output has a frequency of 1/500μs, which is equal to 2kHz.

  By using the above method to setup the 8-bit timer counter, various values of PFD frequency can be generated.

- The internal PWM function can be utilised to provide the best method of current control for battery charger applications. The application circuit attached to the specification for the HT46R47 should be consulted for this control application.



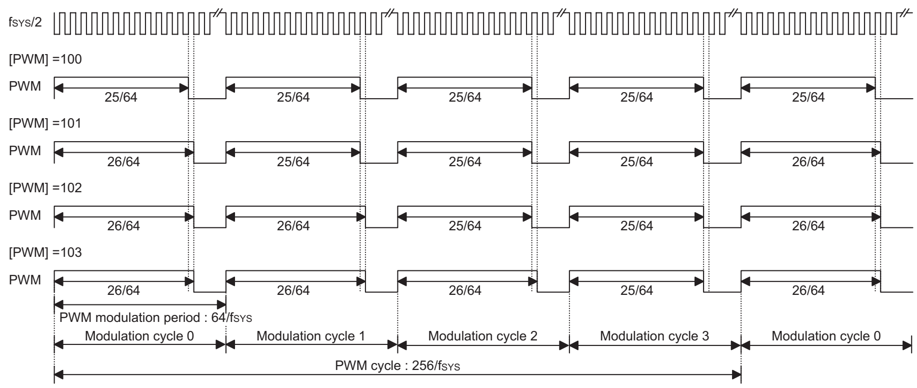


OSC Circuit

The PD0/PWM pin is connected to an NPN transistor via a parallel connected RC pair, which in turn controls the on/off condition of the PNP transistor connected to this circuit. When the PWM output signal is high both the NPN and PNP transistors are on and the inductor is connected to the 12V supply resulting in a charging current being supplied to the battery. When the PWM output is low, the NPN and PNP transistors will be off and the 12V supply will be disconnected from the inductor and consequently the charging current to the battery will be turned off. The current created by the collapsing field around the inductor will be discharged via the Schottky diode. By controlling the duty cycle of this PWM signal the stored energy in the inductor can be regulated providing a means of current control.

To achieve the PWM function the required PWM option must be selected. The duty cycle of the PWM signal follows the value placed into the 8-bit PWM temporary register. Note that the frequency of the PWM output signal is fixed at the value of the system clock divided by 256, but is increased a factor of 4 by dividing the PWM signal into 4 sections, giving a PWM output frequency equal to the system clock divided by 4. Higher frequency signals give better overall charging efficiencies. If it is required to change the frequency of the PWM signal, then the only way is to change the system frequency. It is also necessary to configure the PD0 pin as an output to enable the PWM output. Note also that the value of PD0 must be set high to enable the PWM output, if set low the output will remain in a low condition.

The following diagram explains in more detail the operation of the PWM:



- Product flexibility is enhanced greatly by incorporating a 4-channel 9-bit ADC into the device. The 4 analog inputs are in common use with the PB I/O pins. The clock source for the ADC has 3 options and can be selected depending upon the user conversion time requirements. If 8-bit ADC accuracy is adequate for the application then the converted value can be directly read from a single ADC read register without having to be concerned about the additional register and conversion process for the extra bit.

  Normally, when making an A/D conversion, it is important to consider the condition of the power supply, to make sure that none of the output pins are switching during this period, which can create an unwanted noise source and perhaps influence the conversion value. Returning to normal operation can be done after the A/D conversion is complete. Suitable filtering of the power supply and ADC input lines can further reduce potential errors. Care should also be taken with the PCB layout and power supply and ADC analog input leads to ensure minimum interference. It is recommended that a 0.1μF capacitor is placed between VDD and VSS to reduce the effects of power supply noise.

  Better ADC accuracy can be achieved by choosing clock sources under 1MHz. The speed of conversion has a relationship to the accuracy of the ADC output with lower speeds giving higher accuracies.

After this introduction to the Holtek battery charger MCU, it is now possible by using the device specification and application circuit, to design a two cell Ni-MH, Ni-Cd or Li-ion fast battery charger. The specification is as follows:

- Double cell charger
- Two DIP SW

Switch 1	Switch 2	Status
OFF	OFF	Charge the Ni-MH and Ni-Cd battery directly without discharge
ON	OFF	Discharge the Ni-MH and Ni-Cd battery before charging
OFF	ON	Charge the Li-ion battery without discharge
ON	ON	Charge the Li-ion battery without discharge

- Each battery holder has two LEDs to indicate the following:

LED 1	LED 2	Status
OFF	OFF	Empty
OFF	ON	Charging
ON	OFF	Discharging or standby
ON	ON	Fully charged

- Design principle: Before designing a suitable charger, it is necessary to understand the different characteristics of each kind of rechargeable battery. There are several methods to determine if a Ni-Cd or Ni-MH battery is fully charged: one method is to detect a sudden reduction in the battery voltage, another is to detect a rise in battery temperature. Using the method of temperature rise to detect a fully charged battery may however be erroneous due to the effects of the surrounding temperature. It is therefore recommended that the method of checking for a sudden reduction in battery voltage is used as this has proven to be a reliable method. Additional protection is also provided in the way of measuring charging times and stopping the charging process if the time exceeds 80 minutes to prevent overcharging and battery damage. In the case of Li-ion batteries, when fully charged, the voltage will be maintained at 4.1V, so when this condition is reached, the charge current will be reduced to less than 50mA. Also if after 80 minutes the battery has not reached a full charge condition then the charging process will be terminated.

  In the case of Ni-MH or Ni-Cd batteries, it is also required to provide an indicator to show if discharging is required. Note that discharging before recharging can reduce any memory effects that may have been built up in the battery prior to this charging process. Li-ion batteries do not suffer from memory effect and therefore do not require discharging. For multi-cell charging, note that Ni-MH and Ni-Cd batteries need to be charged in series.
- Charging current: Charging the battery with a fast charge current of 500mA or slow charge current of 50mA depends on the battery voltage. If the voltage exceeds 2.5V, then a fast charge value of 500mA can be used. If the voltage is lower than 2.5V, a slow charge value of 50mA should be used which can switch to 500mA after the battery voltage reaches a value higher than

2.5V. To control the charging current the PWM function in the HT46R47 will be used in addition to an A/D voltage input pin to create a fixed current controller.

- Application circuit analysis: When recharging battery 0, turn off its discharge circuit and also the charge and discharge circuit of battery 1. The LED will display the charging status of battery 0 and PD0 generates the PWM signal. The charging current to battery 0 can be read through the voltage on PB2/A2. If the current is less than the desired value, the PWM value can be increased to increase the inductor current. This will then increase the charging current of battery 0. If the current is larger than that required, the PWM value can be reduced to lower the inductor current and decrease the charging current. Ensure that the current is within the default range for stable charging with fixed current. As to the alternative of charging with values other than the 50mA or 500mA current values, the principles remain the same except that the voltage of PB2/AN2 and the PWM value will be different. After charging for 1 second, discharge for 10ms, and then measure the battery voltage of battery 0. An average of this value and the previous 3 values should be calculated, after which a decision can be made if the battery is fully charged or not. After a full charge condition has been reached the charger should be stopped and a full charge indication given, otherwise the charging process should continue.

  When discharging battery 0, turn off its charge circuit and the charge and discharge circuit of battery 1. An LED will show the discharging status of battery 0. Discharge battery 0 until the voltage is less than 2.2V, after which the charging process can begin.

  The process of charging battery 1 is the same and can be executed in the same way.

  The charging method for Li-ion batteries is similar except there is no need to discharge before charging.

- The unused I/O pins can be used to make a four LED and 2-switch input. The timer can be used to hold the value of V_{PEAK} for 1 minute and to measure the 80 minute charging time. The system uses a 4MHz RC oscillator.

- Before charging, it is necessary to select the required HT46R47 functions:

  PB0/AN0: the voltage of the rechargeable battery in the first battery holder, used as ADC input.

  PB1/AN1: the voltage of the rechargeable battery in the second battery holder, used as ADC input.

  PB2/AN2: a detector for the rechargeable battery during charging, used as an ADC input.

  PB3/AN3 and PA7: two input switches, pins configured as inputs.

  PA4, PA5 and PA6: 4 LED indicators to show the function of the charger using a scanning display.

  PA0: controls the charging of the second battery using a transistor switch used as an output function.

  PA1: controls the charging of the first-cell battery using a transistor switch used as an output function.

  PA2: controls the discharging of the first-cell battery using a transistor switch used as an output function.

  PA3: controls the discharging of the second-cell battery using a transistor switch used as an output function.

  PD0/PWM: controls the charging current using a transistor switch to control the PWM output function.

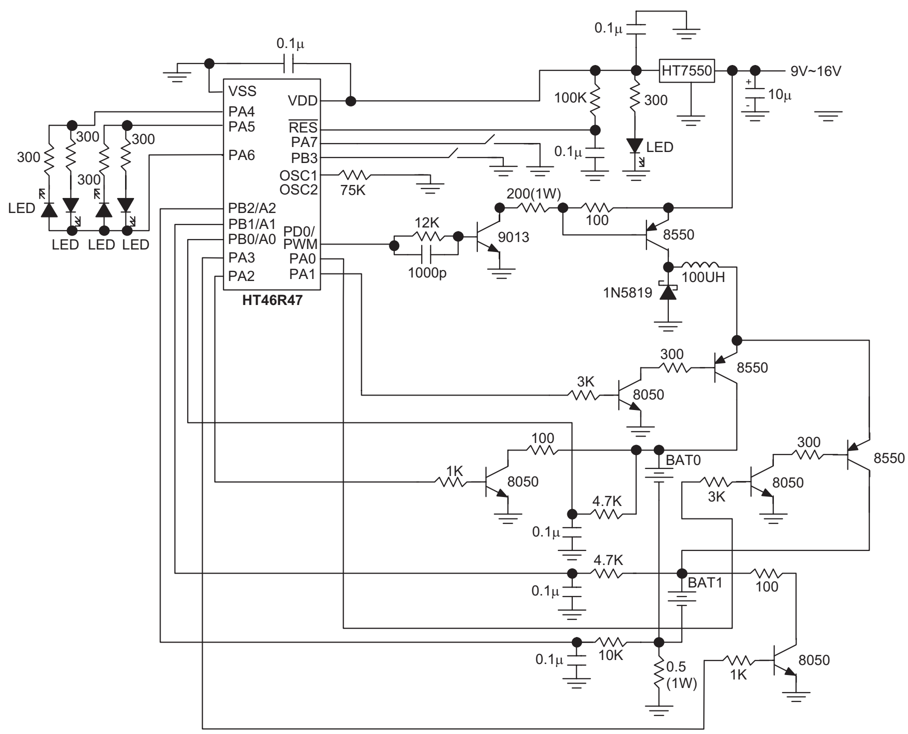
TIMER: to generate 0.04 sec interrupts, functions as timer and scan timing generation for the LEDs.

Watch Dog Timer * (WDT): provides auto reset function as protection against program errors.

Low voltage reset function: provides an auto-reset function if the power supply voltage falls below a certain level.

RC oscillator system frequency: a resistor of 75kΩ if connected between OSC1 and ground will give a system frequency of about 4MHz.

A Practical Charger Circuit Reference:



We hope that this short article has give its readers a better understanding of how the Holtek battery charger microcontroller functions as well as providing some information on rechargeable battery charging techniques. With this information we hope designers will be in a better position to design related battery charger products.