



# **Development of Portable Solar Device for Charging of Li-Ion Battery of Mobile Phone**

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**ABSTRACT:** As mobile phone became necessary thing in contemporary life there is a need to enable fast and easy charging of Li-Ion battery of 3.7 V in every place. Today most mobile phones have USB port by which mobile phone battery is charged. It is because of the reason that all computers have USB port. In that way it enables that user does not need to bring a charger with self to charge mobile phone battery. It is enough that user has computer beside self. USB port has 4 pins: 2 pins are dedicated for transfer of digital data and 2 pins are dedicated for power supply of 5 V. Battery of mobile phone is Li-Ion battery and its nominal voltage is 3.7 V. Because of that, power supply of 5 V from USB port is quite enough for charging of mobile phone battery. In this paper is presented portable solar charger for devices with Li-Ion battery of 3.7 V. Portable solar charger enables charging of Li-Ion battery in the places where there does not exist electric power source. Device has 2 rechargeable NiMH batteries type AA which can be charged by solar panel or by USB port. Portable solar charger has electronics which raise voltage from these 2 batteries to voltage of 5 V which is needed for charging Li-Ion battery.

**KEYWORDS:** Buck DC/DC converter, Boost DC/DC converter, Charger, USB, Solar panel.

## **I.INTRODUCTION**

Portable solar charger consists of solar panel, Buck DC/DC converter, Boost DC/DC converter, microcontroller and 2 rechargeable NiMH batteries type AA. These 2 rechargeable NiMH batteries can be charged by solar panel or by USB port of computer. Charger has Buck DC/DC converter by which controls constant current of charging from USB port. Charger has Boost DC/DC converter by which voltage from NiMH batteries from nominal 2.4 V to output 5 V is raised. Charging of mobile phone battery is done through USB female connector type A and charging of NiMH batteries is done through USB female connector type B. In that way possibility of wrong connecting cables is eliminated. USB female connector which is mounted on the board is called "receptacle". Male USB connector which is mounted on the USB cable is called "plug". The device is settled in the box which dimensions are 171x121x55 (dimensions are given in millimeters). Also this portable solar charger enables charging of all devices which have Li-Ion battery of 3.7 V as tablet PC or MP3 player and MP4 player. In figure 1 is shown portable solar charger, which is presented in this paper, in the mode of charging Li-Ion battery of mobile phone.



Fig. 1 Charging Li-Ion battery of mobile phone by portable solar charger

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In figure 2 is shown portable solar charger in the mode of charging NiMH battery inside portable charger by computer through USB port.



Fig. 2 Charging of NiMH batteries inside portable solar charger by computer through USB port

## II. POWER CHARACTERISTICS OF PORTABLE SOLAR AND USB CHARGER

There are 3 types of solar cells: monocrystalline, polycrystalline and amorphous. Monocrystalline silicon solar cells have the highest grade of efficiency which is in range from 17 % to 20 % [1]. Polycrystalline silicon solar cells have grade of efficiency from 15 % - 18 % [1]. Amorphous silicon solar cells have the lowest grade of efficiency which is in range from 5 % to 10 % [1]. Portable solar charger has polycrystalline solar panel which power is 0.8 W and which producer is the company "Multicomp" [2]. Voltage of solar panel in the point of maximum power exploitation is 3.85V. Intensity of the current during the maximum power exploitation is 210 mA. These characteristics of solar panel are given for the case when intensity of solar radiation is 1000 W/m<sup>2</sup>. Intensity of solar radiation of 1000 W/m<sup>2</sup> is very high and it can be achieved during summer. Current-voltage characteristic of solar panel is shown in the figure 3.

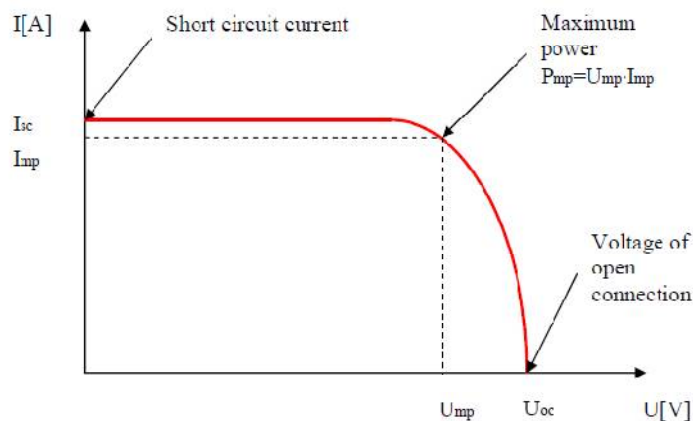


Fig. 3 Current-voltage characteristic of solar panel

Two NiMH batteries type AA occur inside portable solar charger. Their nominal voltage is 1.2 V and their capacity is 2600 mAh. These two batteries are serially connected. In that way battery which nominal voltage is 2.4 V and capacity is 2600 mAh is got. Nominal energy which these 2 batteries can store is 6.24 Wh and it is got from the equation (1):

$$E = C \cdot U \quad (1)$$

where

C=2600 mAh – nominal capacity of the battery

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$U=2.4\text{ V}$  – nominal voltage of the battery

Batteries of a mobile phone are the rechargeable Li-Ion batteries which voltage is 3.7 V and capacity is in range from 600 mAh to few thousands of mAh. Li-Ion battery which has capacity of 600 mAh can store energy of 2.2 Wh. Li-Ion battery which has capacity of 2000 mAh can store energy of 7.4 Wh. Transfer energy from NiMH battery to Li-Ion is done by Boost DC/DC converter. Boost DC/DC converter, which is used in this charger, has grade of efficiency of 89 %. It means that one small part of energy stored in NiMH battery has been lost on dissipation of electronic components. No matter of that, significant energy can be transfer from NiMH battery to Li- Ion battery. NiMH batteries are connected to solar panel by schottky diode (figure 4). Schottky diode is used because voltage on it is less than common diode and in that way power loss is decreased. Switch, between solar panel and schottky diode, is used in order to prevent overcharging NiMH battery when NiMH battery is fully charged. This switch is not necessary. It is enough that portable solar charger is moved away from the sun when NiMH battery is fully charged.

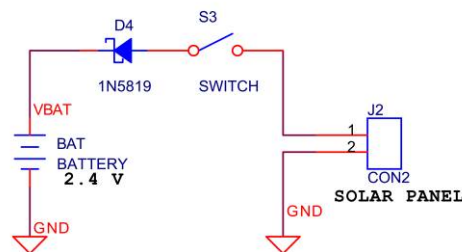


Fig. 4 Battery charging by solar panel

Neither device has grade of efficiency of 100 %. To get nominal capacity from the battery it is necessary to income 120% of nominal capacity in the battery [3]. It is because of the reason that during the battery charging exist losses caused from heating and electrolysis. Time of battery charging by constant current is given by equation (2).

$$t = \frac{1.2 \cdot C}{I} \quad (2)$$

Solar panel presents source of electric power which voltage and current are variable (figure 3). Work point of solar panel is set by load which is connected to solar panel. In this case it is NiMH battery. Voltage from solar panel is equal to sum of voltages from schottky diode and NiMH battery. Current intensity of the solar panel is determined by voltage on it and characteristic of solar panel. During charging of NiMH battery, voltage on the battery is higher than nominal voltage and can be in range from 1.5V to 1.7V. Because of that, resulting voltage on these two NiMH batteries is in range from 3 V to 3.4 V. Voltage on the schottky diode is 0.3 V, when current of 200 mA streams through it. From this analysis can be seen that this solar panel is appropriated because his voltage, during the maximum power consumption is 3.85 V. If these two serially connected batteries charge from solar panel which power is 0.8 W, during very sunny day, then battery charging current is 210 mA. It means that, in that condition, charging time from solar panel is about 15 hours in the case that NiMH batteries have nominal capacity of 2600 mAh and that they were fully empty before charging.

### III.ELECTRONICS FOR NIMH BATTERY CHARGING THROUGH USB PORT

Microcontroller ATMEGA 8 [4] is used for controlling of NiMH batteries charging when charging is done through USB port. Microcontroller ATMEGA 8 and the connections with the rest of electronics are shown in figure 5. Program for microcontroller is written in C program language.

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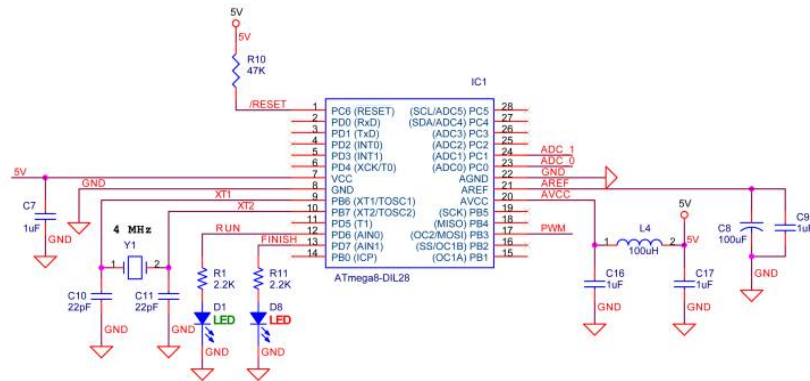


Fig. 5 Microcontroller ATMEGA 8 and the connections with the rest of electronics

The nominal voltage of USB power supply is 5 V. This voltage can be in range from 4.4 V to 5.25 V [5]. The maximum current which can be delivered through USB port of computer is 500 mA [6]. In this portable solar charger charging current of NiMH batteries through USB port is 360 mA. Current consumption of microcontroller ATMEGA 8 which works on the clock of 4 MHz is 10 mA. It means that overall current consumption of this charger is 370 mA in the mode of NiMH batteries charging through USB port. This portable solar charger could not be connected on the external USB hub. External USB hub with 4 output ports has limitation of output currents. The sum of its output currents can not exceed 500 mA. The only type of USB hub on which output USB port can be connect is USB hub with its own power supply. Such USB hub is more expensive than the common USB hub. Battery charging through USB port is finished after time of timer is elapsed. This timer is integrated in microcontroller ATMEGA 8. The time of timer is set on 8 hours and 40 minutes, because capacity of NiMH batteries is 2600 mAh and current of charging is 360 mA (equation 2). Charging of 8 hours and 40 minutes should be applied only if NiMH batteries are fully empty. User can stop charging NiMH batteries earlier by disconnecting USB cable between charger and computer before timeout of timer. NiMH battery charging can also be realized by common voltage source of 5 V with USB connector on its output and which power is minimum 2 W (figure 6).



Fig. 6 Voltage source of 5 V with USB connector on its output

Green LED diode marks that microcontroller has power supply for its work and it is lit on when charger is connected through USB port to computer. During the charging of NiMH batteries by USB port, red LED diode is lit off. After the time of timer, which is equal to 8 hours and 40 minutes, is elapsed, red LED diode is lit on and microcontroller stops battery charging. In that way user knows that charging of NiMH battery is finished. In order to decrease the consumption of microcontroller, it is necessary that microcontroller works on as lower frequency, as possible. Microcontroller has few thousands transistors in itself. Every transistor has parasitic capacity on its output. During the change of logical state from 1 to 0, parasitic capacitor on the transistor's output is discharging. During the change of logical state from 0 to 1, parasite capacitor on the transistor's output is charging. If microcontroller works on the higher



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frequency than parasite capacitors of transistors are charging and discharging faster. For less time transistor charges and discharges, higher current of charging and discharging is necessary. Because of that microcontroller which works on higher frequency has higher current consumption. The best way is that microcontroller works on the frequency of 1 MHz. Problem occurs because crystal of 1 MHz is extremely expensive and very often it is difficult to find it in the market. Every microcontroller has integrated RC oscillator which frequency is equal to 1 MHz. Watchdog timer, which is integrated in microcontroller, is connected to this oscillator. This RC oscillator can be used for clock of microcontroller, but it is not good way because the frequency of clock is dependent on parameters of RC circuits. Parameters of RC circuits are dependent on temperature and during the time there are accessible changes. Because of that microcontroller ATMEGA 8 is connected to crystal quartz which frequency is equal to 4 MHz. This crystal quartz of 4 MHz is cheap and it is commercially available. Microcontroller ATMEGA 8 has 3 timers: timer 0, timer 1 and timer 2. In microcontroller ATMEGA 8 is integrated pulse width modulator which includes timer 2. By setting appropriated bits in control register of timer 2, TCCR2, clock frequency of pulse width modulator is asserted. Clock frequency of pulse width modulator is asserted to the frequency of 4 MHz, which means that frequency of outside clock is brought directly to pulse width modulator. Frequency of modulated pulses, which control the work of Buck DC/DC converter, is set by equation:

$$T_s = n \cdot T_0 \quad (3)$$

where:

$T_s$  – period of modulated pulses

$T_0$  – period of clock of pulse width modulator

$n$  – number of ticks of timer until interrupt is occurred

As period of signal is inverse value of frequency, frequency of modulated pulses is determined from last equation:

$$f_s = \frac{f_0}{n} \quad (4)$$

where:

$f_s$  – frequency of modulated pulses

$f_0$  – clock frequency of pulse width modulator (4 MHz)

Number  $n$  is linked with initial value of timer 2:

$$n = 256 - n_0 \quad (5)$$

where:

$n_0$  – initial value of timer 2.

Timer 2 is 8-bits timer and it counts from its initial value to until 255. The interrupt occurs after next tick, after value of 255. Because of that value 256 is occurred in equation (5). When interrupt occurs, in subroutine of timer 2, initial value  $n_0$  in timer 2 is written and corrected value in OCR2 register is written. If initial value of timer 2 is equal to 56, then  $n$  is equal to 200, so frequency of modulated pulses is equal to 20 kHz. As frequency of modulated pulses is higher, it is less ripple of voltage and ripple of current of Buck DC/DC converter. But as frequency of modulated pulses is higher, interrupt occurs for short time interval because time of interruption of timer is equal to period of modulated pulses. If frequency of modulated pulses is 20 kHz, then interrupt of timer happen every 50  $\mu$ s. Entrance to subroutine, demands time of few  $\mu$ s and execution of subroutine longs few  $\mu$ s. In this case 50  $\mu$ s is quite enough for execution program and subroutines. Time of execution of instruction dependence from frequency of clock at which microcontroller works and in this case it is 4 MHz. If microcontroller works at 16 MHz, the time of instruction would be smaller, but in that case current consumption of microcontroller would be increased. If frequency of modulated pulses is equal to 40 kHz, then subroutine of timer occurs every 25  $\mu$ s and this program which is written for microcontroller of solar charger could not



be executed for such less time. Because of that, it is chosen that frequency of modulated pulses is equal to 20 kHz. In figure 7 are shown time diagrams of pulse width modulator.

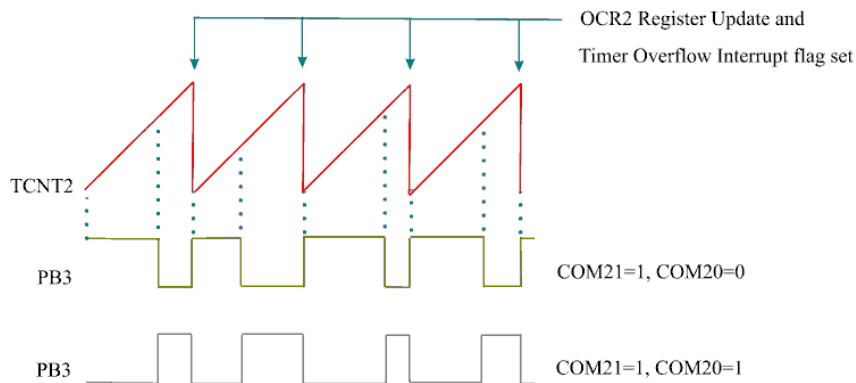


Fig. 7 Time diagrams of PWM

Duty cycle can be in range from 0 to 100. Number  $n$  correspond to changes of duty cycle and can be in range from 0 to 200. It means that lowest change  $\Delta n=1$ , corresponds changes of duty cycle for  $\Delta D=0.5$ . It is necessary to choose such frequency of modulated pulses and such frequency of clock pulse width modulator that number  $n$  is as higher as possible. As number  $n$  is higher, than for  $\Delta n=1$  change of duty cycle  $\Delta D$  is minimum. In that way more accuracy of regulation is achieved. If it is possible, it is best to set  $n$  to 200 because then  $\Delta D=0.5$  and in this case it is possible. If it is not possible it is best to set  $n=100$  because then  $\Delta D=1$ . Of course, it is always necessary to set frequency of modulated pulses as higher as possible, but in such way that there is quite enough time that program can be executed. Pulse width modulator is consisted of timer 2, OCR2 register, comparator and wave generator. In register OCR2 is set value from comparing with value of timer. Value of timer and value of OCR2 register come on the input of 8-bits comparator. When these 2 values become equal, it makes change on the output of PWM modulator. Depending on how bits COM21 and COM20 are set in control register TCCR2, there will be pulse or pause when value of timer becomes greater than value of register OCR2. The output pin PB3 of microcontroller ATMEGA 8 is connected with output of the pulse width modulator and it is used for controlling of work of Buck DC/DC converter. If bits COM21 and COM20 have value of logic one, then on the pin PB3 is pulse (logic 1) when value of timer is greater than value of register OCR2 and pause (logic 0) when value of timer is less than value of register OCR2. Buck DC/DC converter with current regulation is used for realization of charger of NiMH batteries (figure 8).

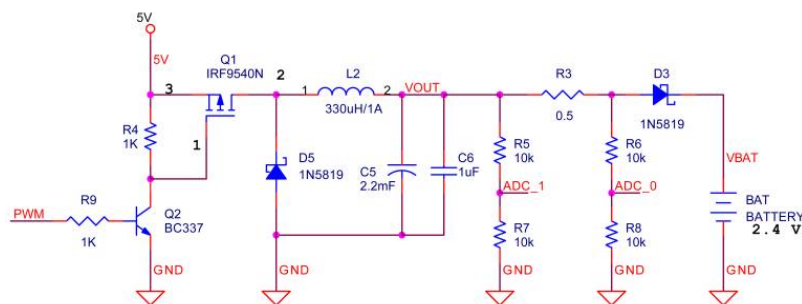


Fig. 8 Buck DC/DC converter with accompanied electronics for measurement and regulation of current

Transistors  $Q_1$  and  $Q_2$  together with resistors  $R_4$  and  $R_9$  present controlled switch of Buck DC/DC converter. Transistor  $Q_2$  is NPN transistor BC337 and transistor  $Q_1$  is P-MOSFET transistor IRF9540N. When signal PWM from pulse width modulator, which comes on pin PB3 of microcontroller, is equal to logic one then transistors  $Q_1$  and  $Q_2$  are turned on. When signal PWM from pulse width modulator is equal to logic zero than transistors  $Q_1$  and  $Q_2$  are turned off. Buck



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DC/DC converter is consisted of controlled switch, inductor  $L_2$ , diode  $D_5$  and capacitors  $C_5$  and  $C_6$ . Used inductor  $L_2$  has inductance  $330 \mu\text{H}$  and its maximum allowable current is 1 A. When Buck DC/DC converter works in continual mode, what here happens, output voltage of Buck DC/DC converter is given by next equation [7]:

$$V_{OUT} = D \cdot V_{IN} \quad (6)$$

where:

$D$  – duty cycle of pulses

$V_{IN}$  – input voltage in Buck DC/DC converter

Resistor  $R_3$  has small resistance which is equal to  $0.5 \Omega$  and it is used for current regulation. Voltage of resistor  $R_3$  is measured by splitters of voltages and by 10-bits A/D converter which is integrated in microcontroller ATMEGA 8. One splitter of voltage is consisted of resistors  $R_5$  i  $R_7$  and the other splitter of voltage is consisted of resistors  $R_6$  and  $R_8$ . To make charging current constant and equal to 360 mA, it is necessary that voltage on resistor of  $0.5 \Omega$  is constant and equal to 180 mV. Measured voltage on resistor  $R_3$  is comparing with constant value of 180 mV. If measured voltage is less than 180 mV, duty cycle is increased for minimum value  $\Delta D$ . If measured voltage is higher than 180 mV, duty cycle is decreased for minimum value  $\Delta D$ . If measured voltage is equal to 180 mV, duty cycle is unchanged. For accuracy of measurement, 10 measurements are done and voltage  $U_{R3}$  is computed as average value from this 10 measurements. After that a new value of duty cycle is computed by algorithm in figure 9 and new value is written in OCR2 register in subroutine. Voltage  $V_{ADC0}$  comes on the channel 0 of 10-bits A/D converter is given by next equation:

$$V_{ADC0} = \frac{d_0}{1023} \cdot V_{REF} \quad (7)$$

where:

$d_0$  – digital value of measured voltage on the channel 0

$V_{REF} = 2.56\text{V}$  – voltage reference of 10-bits A/D converter

Voltage  $V_{ADC1}$  comes on the channel 1 of 10-bits A/D converter is given by next equation:

$$V_{ADC1} = \frac{d_1}{1023} \cdot V_{REF} \quad (8)$$

where:

$d_1$  – digital value of measured voltage on the channel 1

The voltage which comes on the input of A/D converter can not be higher than voltage reference of A/D converter and this condition is fulfilled on the both channels. The both splitters of voltage (figure 8) divide voltage 2 times. Because of that and because of last 2 equations, the expression of measured voltage is given by next equation:

$$U_{R3} = \frac{2(d_1 - d_0)V_R}{1023} \quad (9)$$

The error of the measurement is caused by the ripple of Buck DC/DC converter and by the error of the A/D converter. Value of ripple of Buck DC/DC converter is determined by value of inductance of inductor  $L_2$ , value of capacitance of capacitor  $C_5$ , switching frequency  $f_s$  and value of increment or decrement of duty cycle  $\Delta D$ . The error of A/D converter is caused by accuracy of voltage reference and minimum resolution of the A/D converter. Minimum resolution of the A/D converter is 1 bit ( $\Delta d = 1$ ). Error of the measurement caused by minimum resolution is got from the last equation:



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$$\Delta U_{R3} = \frac{2(\Delta d_1 - \Delta d_0)V_R}{1023} \quad (10)$$

The maximum error in the measurement of the voltage  $U_{R3}$  occurs when errors occur in the same time at the both channels and in that way that one measured voltage is higher for 1 bit than it is in reality, and the other measured voltage is lower for 1 bit than it is in reality. It means that in these cases  $\Delta d_1 = 1$  and  $\Delta d_0 = -1$  or  $\Delta d_1 = -1$  and  $\Delta d_0 = 1$ . For  $\Delta d_1 = 1$  and  $\Delta d_0 = -1$  the error of the measured voltage is:

$$\Delta U_{R3} = \frac{4V_R}{1023} = 10mV \quad (11)$$

This error can be significantly decreased by averaged results of measurements. Because of that, real error of voltage of  $U_{R3}$  is much less than 10 mV. By measurements it is established that this error is 5 to 10 times less and the measured voltage  $U_{R3}$  is in range from 178 mV to 182 mV. Stability and precision of voltage reference  $V_R$  has influence on the accuracy of the measurement. The error of the measured charging current is got by next equation:

$$\Delta I_{OUT} = \frac{\Delta U_{R3}}{R_3} = 20mA \quad (12)$$

Because of averaging of measured value,  $\Delta I_{OUT}$  has much smaller value than 20 mA about 5 to 10 times less and is in range from 2 mA to 4 mA. Tolerance of resistance of resistor  $R_3$  has influence on the accuracy of the measurement of battery charging current. It is taken resistor  $R_3$  with tolerance of resistance of  $\pm 1\%$ . There are resistors on the market with tolerance of  $\pm 0.1\%$  but they are too expensive and for this application there is no need for such an expensive resistor. For choosing appropriated sensitive resistor  $R_3$  it is necessary to make compromise. From the one side, it is needed that resistance of resistor  $R_3$  is much higher because resolution of the measured charging current is smaller (equation 12) and in that way precision of measurement is increased. From the other side, increasing resistance of sensitive resistor  $R_3$  will increase voltage on the resistor  $R_3$  because charging current is constant and is equal to 360 mA. Increasing voltage  $U_{R3}$  can not be high because there is minimum voltage on the input of the Buck DC/DC converter for which Buck DC/DC converter must work properly. The problem which occurs here is that input voltage of the Buck DC/DC converter is not much higher than output voltage of Buck DC/DC converter and all electronics must be projected very carefully. Algorithm of current regulation of battery charging is given in the figure 9. In figure 9,  $U_{ASR}$  presents asserted voltage of 180 mV and  $U_{R3}$  presents averaged measured voltage. Voltage reference of A/D converter is integrated voltage reference in microcontroller ATMEGA 8 and it is equal to 2.56 V. Because filtering of the voltage reference is necessary, there is a need that pin "AREF" of microcontroller is connected to electrolytic capacitor and ceramic capacitor (figure 5). Because of higher accuracy of the measurement it is always better to have higher voltage reference of A/D converter, but in this case it is not possible to use 5 V for voltage reference of A/D converter. It is because of the reason that voltage from USB port can be less than 5 V. Voltage on the input of the Buck DC/DC converter is equal:

$$V_{IN} = R_{Q1}DI_{OUT} + R_{L2}I_{OUT} + R_3I_{OUT} + V_{D3} + V_{BAT} \quad (13)$$

where:

$R_{Q1} = 0.12 \Omega$  – resistance of P-MOSFET IRF9540N

$R_{L2} = 0.56 \Omega$  – resistance of inductor  $L_2$

$I_{OUT}$  – current of battery charging

$V_{D3}$  – voltage on the schottky diode  $D_3$

$V_{BAT}$  – voltage on the battery



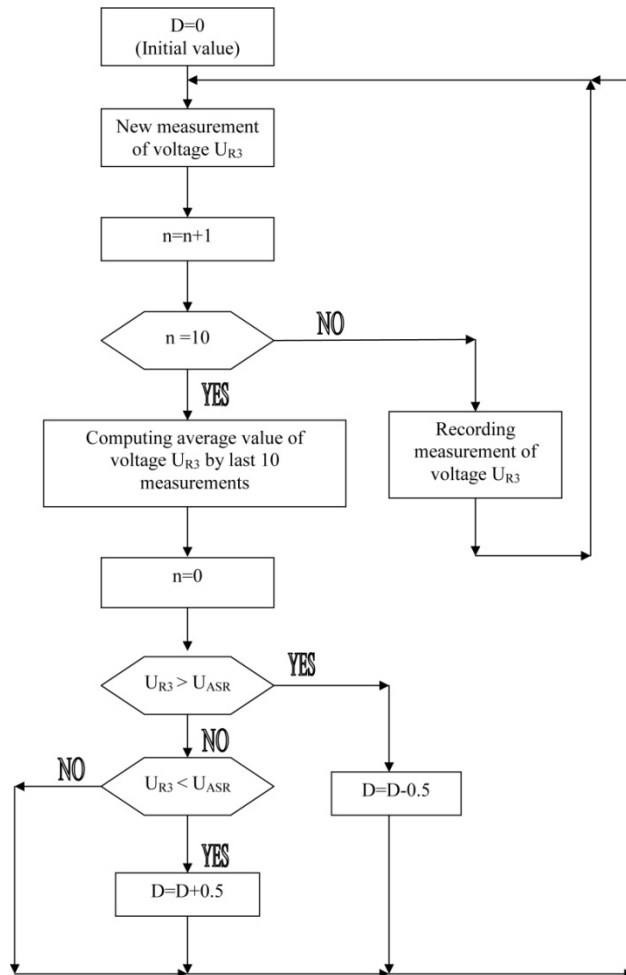


Fig. 9 Flowchart for generating constant current of battery charging

Resistance of inductor  $L_2$  is  $0.56 \Omega$  and DC voltage on it is 202 mV. Voltage on the sensitive resistor  $R_3$  is constant and it is equal to 180 mV. When current of 360 mA streams through schottky diode 1N5819, voltage on it is 0.37 V. Voltage on the NiMH battery during the charging is higher than nominal value. For the older battery, which has more cycles of charging and discharging, the voltage on it during the charging is higher and it can be up to 1.7 V. For battery which is not too old, the voltage on it during the charging is about 1.5 V. Because of that, maximum voltage on 2 NiMH, serially connected, can be up to 3.4 V in the worst case. Current streams through out transistor P-MOSFET IRF9540N only for time  $DTs$  during period  $Ts$ . During the rest time of period  $Ts$  there is no current through P-MOSFET IRF9540N. Because of that, average current which streams through P-MOSFET IRF9540N is  $DI_{OUT}$ . Maximum value of  $D$  is got for minimum value of input of Buck DC/DC converter  $V_{IN}$  and maximum value of output of the Buck DC/DC converter  $V_{OUT}$ . The output voltage of the Buck DC/DC converter is:

$$V_{OUT} = R_3 I_{OUT} + V_{D3} + V_{BAT} \quad (14)$$

The maximum output voltage  $V_{OUT}$  is getting when NiMH batteries is old and in that case  $V_{BAT}$  has maximum value and is equal to 3.4 V. In this case  $V_{OUT}$  is equal to 3.95 V (equation 14). It is worst case which can happen and it must be observed. In that way this charger enables a great number of cycles charging and discharging of NiMH battery. USB port is connected to the input of Buck DC/DC converter through LC filter (figure 10).

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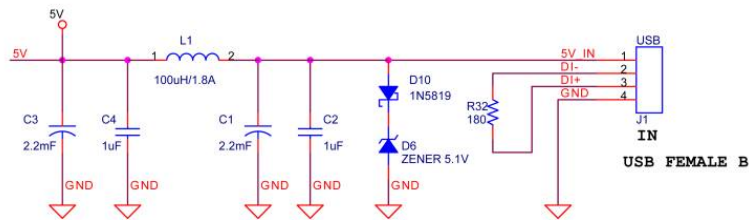


Fig. 10 Input interface

The minimum voltage on the USB port is 4.4 V. Inductor  $L_1$  has resistance  $0.18 \Omega$  and when current of 370 mA (sum of charging current and current of power supply of microcontroller) streams through it, DC voltage on the inductor  $L_1$  is equal to 67 mV. It means that minimum input voltage of the Buck DC/DC converter is equal to 4.333V.

$$V_{IN,MIN} = V_{USB,MIN} - V_{RL1} \quad (15)$$

where:

$V_{IN,MIN}$  – minimum input voltage in Buck DC/DC converter

$V_{USB,MIN}$  – minimum voltage of power supply of USB port

$V_{RL1}$  – voltage on the inductor  $L_1$  caused by resistance of inductor  $L_1$

In that case duty cycle has maximum value and is equal to 0.91.

$$D_{MAX} = \frac{V_{OUT,MAX}}{V_{IN,MIN}} = \frac{3.95V}{4.333V} \quad (16)$$

Because of that maximum voltage on the P-MOSFET IRF9540N is 39 mV. Now all values for the all added parts in equation (13) are got for the worst case:

$$R_{Q1}D_{MAX}I_{OUT} = 39 \text{ mV}$$

$$R_{L2}I_{OUT} = 202 \text{ mV}$$

$$R_3I_{OUT} = 180 \text{ mV}$$

$$V_{D3} = 370 \text{ mV}$$

$$V_{BAT,MAX} = 3.4 \text{ V}$$

By adding all these values in equation (13), value of 4.2 V is got. That value is less than it is minimum input voltage of Buck DC/DC converter which is equal to 4.333 V. It means that projected electronics works properly. This LC filter is needed for 2 reasons. First reason is that noise which causes Buck DC/DC converter is not superimposed to the voltage of 5 V from USB port. Second reason is that it is needed to become accumulated energy in the inductor to avoid current limitation. It is important because Buck DC/DC converter takes great current from voltage source in the short time intervals. Input current of Buck DC/DC converter is not continual. Input current of Buck DC/DC converter is pulsed current. Microcontroller is power supplied from that voltage source. Used inductor  $L_2$  has inductance  $100 \mu\text{H}$  and its maximum allowable current is 1.8 A. Protection of over voltage on the circuit input is realized. It is because of the reason that maximum voltage of power supply of microcontroller is 5.5 V. This protection consists of serial connection of one schottky diode 1N5819 and zener diode which breakdown voltage is 5.1 V and maximum power is 5 W (figure 10). It means that this serial connection of schottky diode and zener diode can sink current of 1 A and overall voltage on them would not be higher than 5.5 V. It is quite enough because maximum current of USB port is 0.5 A. Pin D+ from USB connector and pin D- from USB connector are connected through resistor which resistance is  $180 \Omega$ . The housing of female USB connector type B is necessary to be connected with ground. If this is not done, during pulling out USB cable from USB connector can appear disturbance which can cause computer to turn off.

## IV.ELECTRONICS FOR REALIZATION OF OUTPUT VOLTAGE

Nominal voltage on the NiMH batteries is 2.4 V. To raise this voltage from NiMH batteries on to 5 V it is necessary that Boost DC/DC converter is used. This Boost DC/DC converter is based on fix switching regulator ADP1111ANZ-5 [8] (figure 11). Integrated circuit ADP1111ANZ-5 is fix switching regulator which controls work of Boost DC/DC converter. Its main feature is that minimum input voltage is 2 V. Inside this integrated circuit ADP1111ANZ-5 occurs all electronics for controlling work of Boost DC/DC converter: voltage reference, comparator with hysteresis, oscillator and output driver. Inductor  $L_3$  which is used in this Boost DC/DC converter has inductance 33  $\mu\text{H}$  and its maximum allowable current is 3 A.

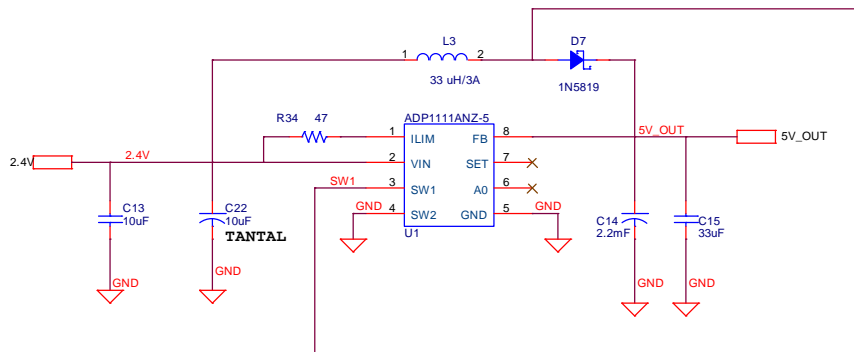


Fig. 11 Boost DC/DC converter raises voltage from 2 V to 5 V

In the datasheet of ADP1111ANZ-5 is written that voltage source which is realized by this integrated circuit has output voltage of 5 V if input voltage is 3 V. If input voltage is decreased than output voltage is decreased too. As Li-Ion battery has voltage of 3.7 V, a voltage of 4 V is enough for charging Li-Ion battery. By experimental way, it is established that for input voltage of 2.4 V output voltage of this Boost DC/DC converter is 4.2 V and output current is 200 mA. The advantage of this Boost DC/DC converter is high grade of efficiency which is 89 % and easy realization which include lower price. The disadvantage of this Boost DC/DC converter is slow charging of Li-Ion battery. In the table 1 experimental result is shown which are achieved with this Boost DC/DC converter. The aim of this experiment was to find grade of efficiency of this Boost DC/DC converter and also to find maximum output current when output voltage is higher than 4 V. In the realized experiment, the Boost DC/DC converter was loaded with resistor of variable resistance and on the input of Boost DC/DC converter constant voltage source of 2.4 V resides. For various resistances on the output of the Boost DC/DC converter the input and output voltage and input and output current are measured.

TABLE I  
EXPERIMENTAL RESULTS OF MEASUREMENT OF BOOST DC/DC CONVERTER

| $V_{IN}$<br>[V] | $I_{IN}$<br>[mA] | $V_{OUT}$<br>[V] | $I_{OUT}$<br>[mA] | $\eta$<br>[%] | $P_D$<br>[mW] |
|-----------------|------------------|------------------|-------------------|---------------|---------------|
| 2.4             | 175              | 4.86             | 75                | 86.8          | 56            |
| 2.4             | 220              | 4.74             | 100               | 89.8          | 54            |
| 2.4             | 270              | 4.65             | 125               | 89.7          | 67            |
| 2.4             | 315              | 4.52             | 150               | 89.7          | 78            |
| 2.4             | 360              | 4.34             | 175               | 87.9          | 105           |
| 2.4             | 390              | 4.2              | 200               | 89.7          | 96            |

From this table it can be seen that the average grade of efficiency is 89 % and that output current of 200 mA can be achieved when output voltage is higher than 4 V. In datasheet of ADP1111ANZ-5 is written that maximum power dissipation is 500 mW. Because of that, it is necessary to limit switch current by connecting resistor of 47  $\Omega$  between pins "I<sub>LIM</sub>" and "V<sub>IN</sub>" of integrated circuit ADP1111ANZ-5 (figure 11). Dissipation of the Boost DC/DC converter  $P_D$  is defined as difference between input power and output power.

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$$P_D = V_{IN}I_{IN} - V_{OUT}I_{OUT} \quad (17)$$

Dissipation of this Boost DC/DC converter consist of dissipation of the switcher ADP1111ANZ-5, dissipation of diode  $D_{12}$  and the dissipation of the inductor  $L_3$  which resistance is equal to  $0.066 \Omega$ .

$$P_D = P_{ADP1111} + P_{D12} + P_{L3} \quad (18)$$

where:

$P_{ADP1111}$  – dissipation of switcher ADP1111ANZ-5

$P_{D12}$  – dissipation of diode  $D_{12}$

$P_{L3}$  – dissipation of the inductor  $L_3$

From the data from the table 1 it can be seen that dissipation of the Boost DC/DC converter  $P_D$  is always less than 500 mW. As dissipation of ADP1111ANZ-5 is less than dissipation of the Boost DC/DC converter, than dissipation of ADP1111ANZ-5 is always less than 500 mW. It is possible to make realization of Boost DC/DC converter with higher output current which can decrease time of charging. This realized Boost DC/DC converter has switcher and external switching transistor by which high output current is possible. The disadvantage of this Boost DC/DC converter is low grade of efficiency because high output current causes high dissipation on the external switching transistor. Because this device is battery supplied it is more important to make Boost DC/DC converter of high efficiency and the speed of battery charging is less important. On the output of Boost DC/DC converters protection from over voltage is realized by serial connection of schottky diode 1N5819 and zener diode of 5.1 V. It is used only in the case of malfunction of Boost DC/DC converter to protect mobile phone. Voltage from the output of Boost DC/DC converter is connected to female USB connector type A (figure 12). Pin D+ and D- from the USB connector are connected by resistor which resistance is  $180 \Omega$ . The yellow LED diode marks that Boost DC/DC converter works. Switch is resided between NiMH batteries and the input of Boost DC/DC converter. In that way unneeded consumption of NiMH batteries is prevented when Boost DC/DC converter is not used.

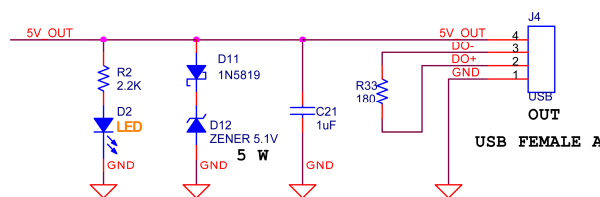


Fig. 12 The output of Boost DC/DC converter is connected to USB connector

## V.CONCLUSION

Here is presented original device for battery charging on the remote places without electric power source. It has shown practically application of power electronics, especially two mostly used DC/DC converters: Buck DC/DC converter and Boost DC/DC converter. It has made connection between theory and practice. It is shown original method for current controlling of Buck DC/DC converter. Also it is created Boost DC/DC converter with minimum power losses which presents the best solution for increasing voltage from 2.4 V to 5 V. During the development of portable solar charger the compromise was made in choosing power of solar panel, capacity of NiMH batteries and time of charging of NiMH batteries. In this paper can be seen that power of solar panel determines power characteristics of charger. Power of solar panel much depends on its size, but also depends of the types of solar panel (monocrystalline, polycrystalline and amorphous). By using solar panel of higher power, portable solar charger would be a much higher in size because it would use solar panel of much higher size which demands a higher box for device. That device would have shorter time of charging by solar panel, but for such higher dimension this device would lose its sense because the



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aim is that this charger is easily portable.

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## BIOGRAPHY



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