The Charger Design with SEPIC Converter

Introduction

Recently, the hand-held devices become more and more popular, such as Personal Digital Assistant (PDA), CD workman, digital camera etc… need a great quantity battery for normal operation. Considering the economic effect, the battery chargers for recycle rechargeable battery, like NiMH or NiCd, are extremely important. In this article will introduce the design idea of charger circuit at first. Then directed against the characteristics of rechargeable battery and use AIC1781 to design a charge protector only for NiMH/NiCd battery.

Design Idea of Battery Charger

I'll give an example to illustrate the relationship between rechargeable battery and battery charger. Assume that the battery is a cup, and regards the constant current, which from charger, as the water pour into the cup. The more water pour into the cup, the more volumes will be in the cup. Contrast with the battery and charger, the more current flow into the battery the more battery voltage will be appeared. Therefore we can use this concept to design an ideal charger.

The ideal charger must provide following characteristics:

When the battery voltage achieves it's maximum voltage, the charger must be turn off to prevent damaging the device, which connect to battery.

It can supply a constant current to the battery. And terminate the charge current when the battery voltage doesn't increase any more or decreases cause the saturation voltage.

It must terminate the charge current when the charge time is too long to prevent damaging the device.

It must provide a function of discharge- before-charge to precondition the battery, which suffer from "memory effect".

When the battery terminate charge, the charger must supply a trickle charge current to prevent the loss of battery due to it's self-discharging.

When the battery voltage is lower than the initial voltage, the charger doesn't proceed charging due to estimates the battery hasn't put in or broken. When the battery voltage is higher than the initial voltage, the charger supplies a constant current to battery for fast charging. When the battery voltage achieves the saturation voltage, the charger terminates fast charging. After fast charging, the charger supplies a trickle current to prevent the loss of battery due to it's self-discharging. Fig. 1 illustrates the characteristics of charger.

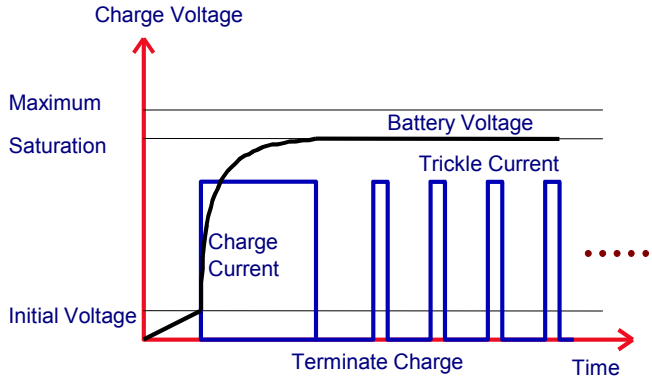


Fig.1 The charge curve of charger

Design Guide

Fig. 2 shows the structure of charger. It includes a constant current supplier and a battery protector. Following will describe the design guide of constant current converter, and then integrates the battery protector to achieve the charger design.

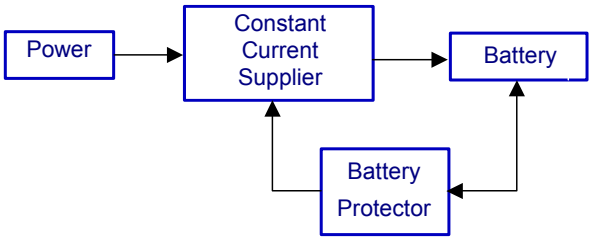


Fig. 2 The Structure of Charger

A. Constant Current Converter Design

We use AIC1628 to set up a Signal End Primary Inductor Circuit (SEPIC) to supply a constant current. Following will describe the characteristics and operation principle of SEPIC.

A.1 The principle of SEPIC

Fig. 3 shows the scheme of SEPIC. It can raise the output voltage to a suitable range, and can supply an isolation route to isolate the input and output terminal after terminate charging. But this circuit has two disadvantages; one is low efficiency and the other needs two inductor. The efficiency isn't the major factor when we design charger, and we can use the coupling inductor to solve the other disadvantage. Therefore the SEPIC is a good choice for constant current converter design.

The operation principle of SEPIC is: when Q1 turns ON, the input source stores energy in the inductor L1. At this time the inductor voltage equals to input voltage, and the energy stores in capacitor C1 will transfer into inductor L2. The energy of loading is supplied by capacitor C2. When Q1 turns OFF, the energy stored in inductor L1 transfer to C1. The energy stored in L2 will transfer to C2 through D1 and supplying the energy to loading. Fig. 4 and 5 show the equivalent circuit when Q1 turn ON and OFF. Fig. 6 and 7 show the voltage and current waveforms of SEPIC.

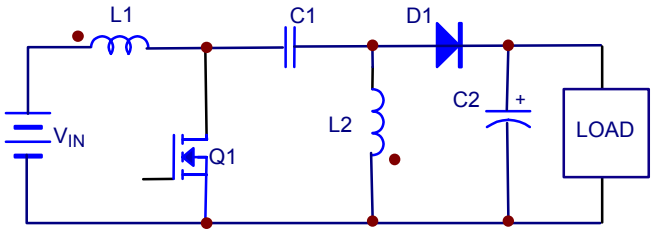


Fig. 3 The Scheme of SEPIC

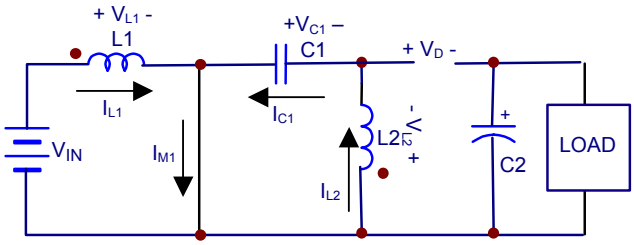


Fig. 4 The Equivalent Circuit when Q1 Turns ON

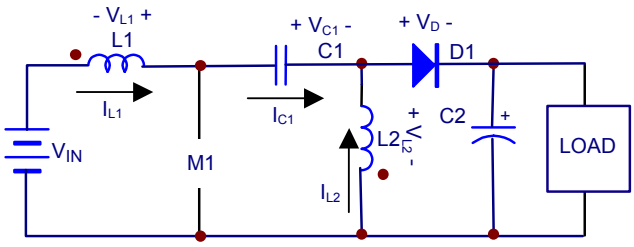


Fig. 5. The Equivalent Circuit when Q1 Turns OFF

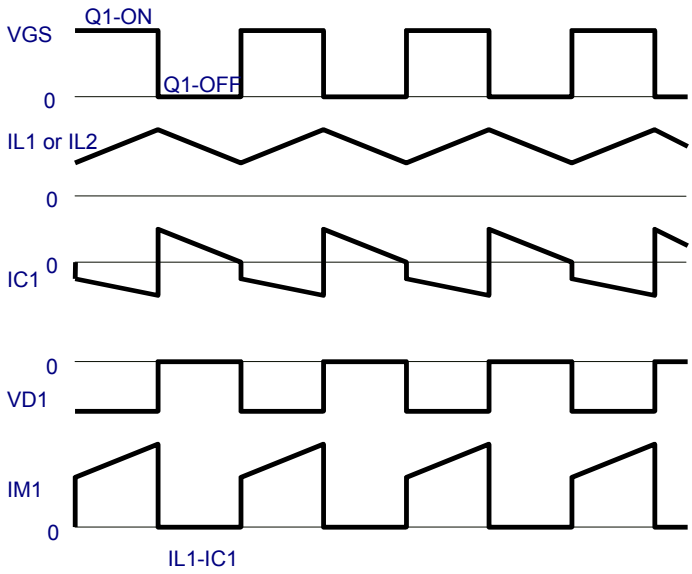


Fig. 6. The voltage waveforms of SEPIC

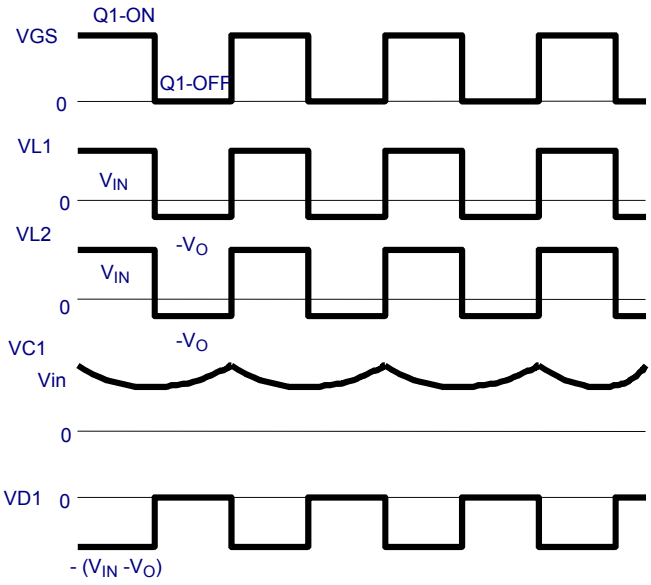


Fig. 7 The current waveforms of SEPIC

A.2 Components Selection

At steady state, the characteristic of inductor is the voltage-second balance. If the powers lose can be ignored then the input power equal to the output one. The relationship of power when the switch turns ON and OFF can be shown as

$V_{IN} \times D \times T_S = V_{OUT} \times (1 - D) \times T_S$ .....(1)

Then we can get the relationship between input and output voltage

$$\frac{V_{OUT}}{V_{IN}} = \frac{D}{1-D} \quad \text{.....(2)}$$

Similarly, the relationship between input and output current can be shown as

$$\frac{I_{IN}}{I_{OUT}} = \frac{D}{1-D} \quad \text{.....(3)}$$

When the duty cycle is determined the value of inductor can be decided also

$$L_1 \geq \frac{V_{OUT} \times T_S \times (1-D)^2}{2 \times I_{OUT-BOUNDARY}} \quad \text{.....(4)}$$

And the capacitor can be calculated as

$$C_1 = \frac{D \times T_S \times I_{IN}}{V_{C1}} \quad \text{.....(5)}$$

B. Charger Protector Design

We use AIC1781 to accomplish the charger protector. Fig. 8 shows the pin configuration of AIC1781. This IC has following characteristics

- Fast charge control of NiMH/NiCd batteries, even with a fluctuating charging current.
- Fast charge termination by: $\Delta T/\Delta t$, $-\Delta V$, $0\Delta V$, safety timer, maximum temperature, maximum voltage.
- Selectable LED display mode for battery status.
- Five pulsed trickle charge mode.
- Discharge-before-charge function available for eliminating memory effect.

Due to the datasheet of AIC1781 describes the design guide in detail. Next, we will enter the charger design directly.

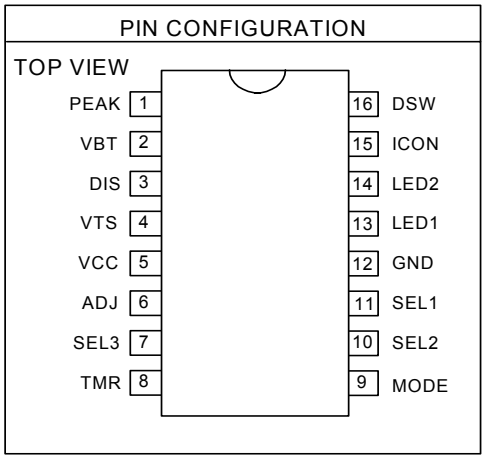


Fig. 8. The Pin Configuration of AIC1781

Circuit Design Step

A. Components determine

A.1 Before designing the constant current circuit, the output voltage of SEPIC must be determined first. Though the values of RA and RB of charger circuit are recommended. After experiments, we find that expect the VBT needs to be considered, the relationship of maximum voltage, battery voltage and the output voltage of SEPIC all need to be considered. The relationship as shown

$V_{MAX} > V_{SEPIC} > V_{BT}$.....(6)

Now, there are eight NiMH batteries need to be charged, the normal voltage is

$V_{BT} = 1.5 \times 8 = 12.0V$.....(7)

At there, we set the maximum voltage is 15V. From the datasheet of AIC1781 we can find that when the VBT voltage gets bigger than 2V, the charger will be terminated. Therefore we can calculate the values of RA and RB

$$15 \times \frac{RB}{RA + RB} > 2 \quad \text{.....(8)}$$

If we chose RB is 68kΩ, then RA must smaller than 442kΩ. We choose this value is 430kΩ.

A.2 Second is setting the output voltage of SEPIC. If this voltage sets lower than batteries, then the batteries voltage charge until the output voltage of SEPIC and terminate charging. But at this time, maybe the batteries haven't saturated. In this article, the output voltage of SEPIC is set at 13V, and then the feedback resistors are

$$13 < 1.22 \times (1 + \frac{R_{REF1}}{R_{REF2}}) \quad \text{.....(9)}$$

If R_{REF2} is 68KΩ, then R_{REF1} must bigger than 31.86KΩ. We set this value is 33KΩ.

A.3 Then is to decide the value of charge current, which depend on a resistor R_{LIMIT}. Suppose the charge current is 1.5A, and then R_{LIMIT} can be calculated

$$R_{Limit} = \frac{V_{CL}}{I_{Limit}} = \frac{60mV}{1.5A} = 40m\Omega \quad \text{.....(10)}$$

In this article, the value is 33mΩ.

A.4 The output voltage of SEPIC that can be calculated after decided R_{REF1} and R_{REF2} is 13.42V. The value of duty cycle can be calculated from (2) is 0.53. Suppose the switching frequency is 100kHz~200kHz, the maximum charge current is 1A. Then the value of L1 is

$$L1 > \frac{13.42 \times 10\mu \times (1 - 0.53)^2}{2 \times 1.5} = 9.88\mu H \quad \text{.....(11)}$$

Since the magnitudes of stored energy depend on L1, we choose the value is 33μH.

A.5 The isolation capacitor C1 can be calculated from (5)

$$C1 > \frac{0.53 \times 10\mu \times 1.128}{13.42 \times 0.05} = 8.91\mu F \quad \text{.....(12)}$$

There are two-way current would follow into the isolation capacitor C1 during switch Q1 turns ON and OFF respectively. Therefore the ESR of C1 must small to prevent the power dissipation. We choose the electrolytic capacitor that from HERMEI, LT series,

and 47μF/50V.

B. Circuit Structure and Performance

Fig. 9 shows the complete charger circuit. During charging, there is a voltage from the ICON pin of AIC1781 to turns the transistor Q3 on. At this while, R_{REF2} connect to ground, there is a constant current from SEPIC and start fast charging. After fast charging, ICON will deliver a low signal to turns Q3 OFF. At this while, R_{REF2} is floating and the voltage between R_{REF1} are equal to each other. Then the voltage flows into FB pin is bigger than the internal reference voltage 1.22V, and terminate charging. It can support a discharge route by SW1, and selectable charge protect functions by SW2~SW5. Fig. 10 is the recommended layout. Fig. 11 and 12 show the current and voltage waveforms during SEPIC turns ON and OFF respectively.

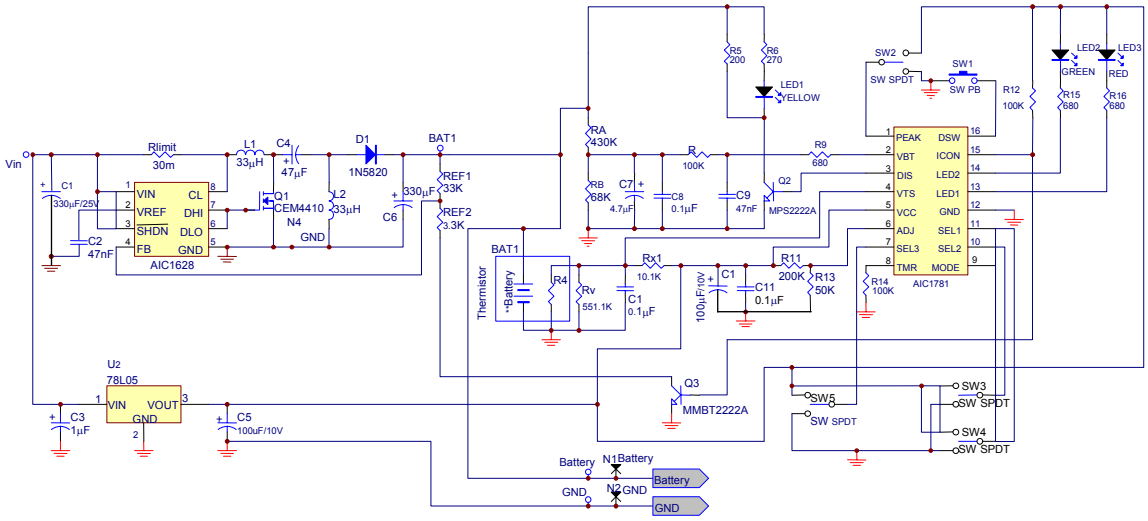
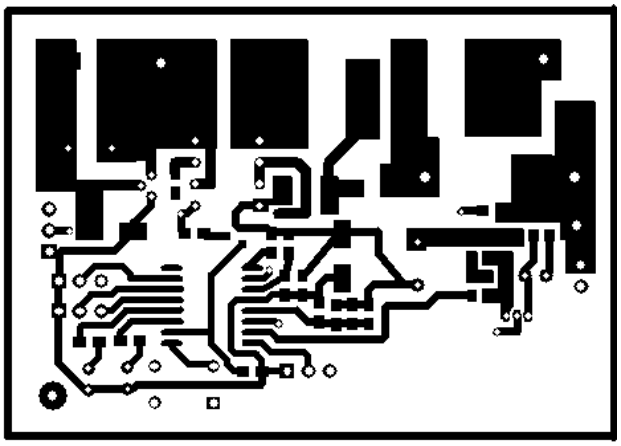
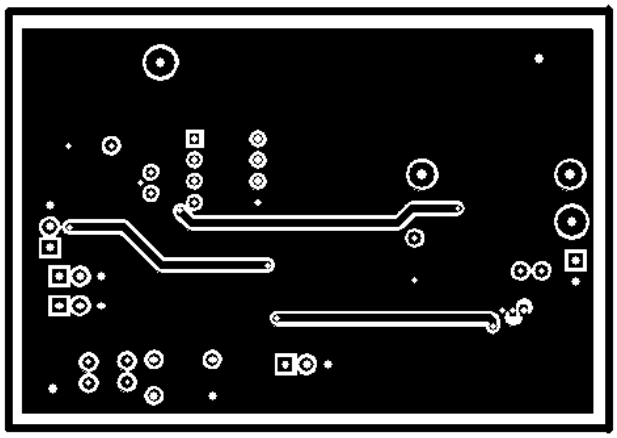


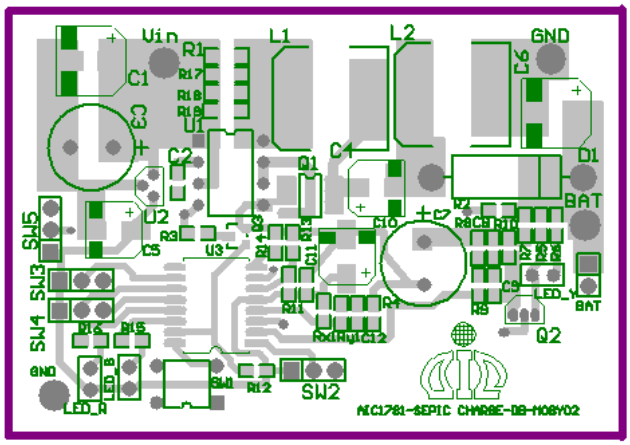
Fig. 9 The Complete Charger Circuit



(Top Layer)



(Bottom Layer)



(Top Over layer)

Fig. 10 The recommend layout

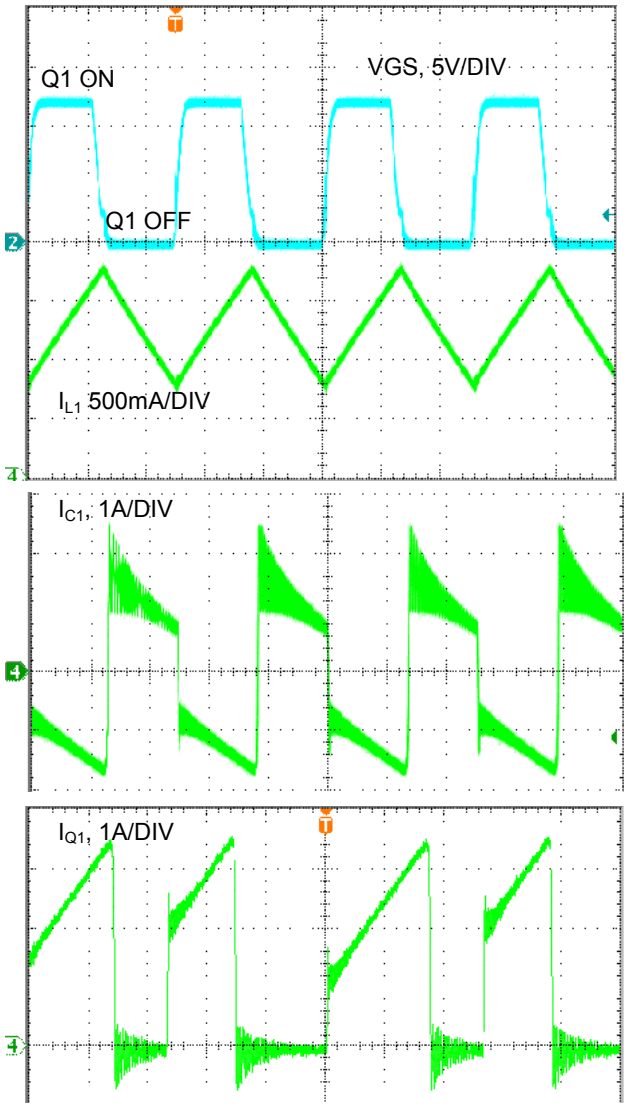


Fig. 11 The Current Waveforms of SEPIC

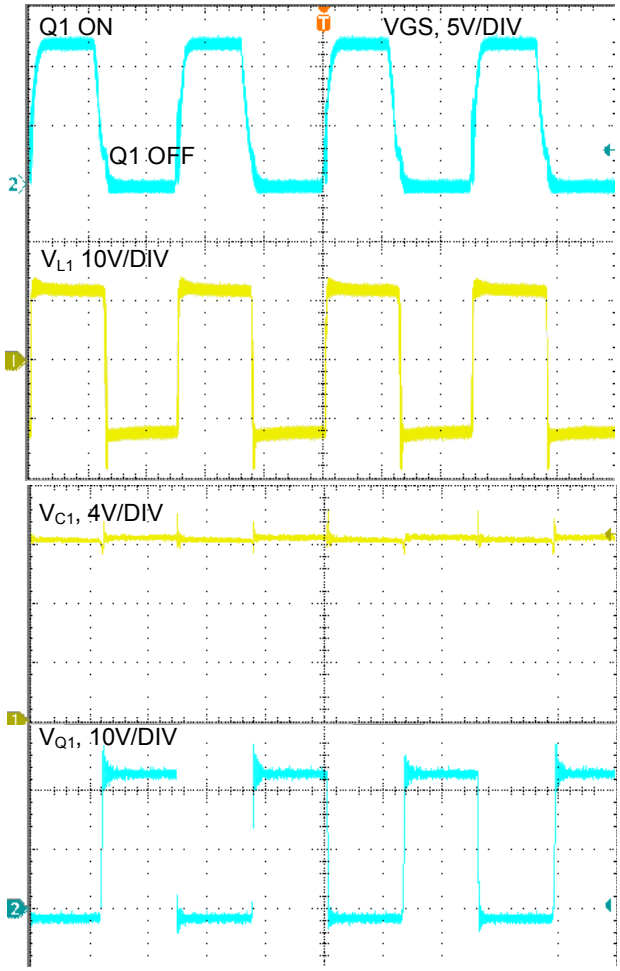


Fig. 12. The Voltage Waveforms of SEPIC

Conclusion

In charger design, the most difficult problem is how to design a desire current for battery. In this article, we suggest using the SEPIC to be a constant current supporter for charger circuit. The SEPIC can support a desire current and can isolate the input and output terminal after fast charging. The charger circuit, which designed in this article, only needs changing several resistors to apply at the charger, which for any numbers of rechargeable batteries. This method is helpful for charger design.