Design of peak current mode-controlled Buck converter with high side current sensing technique for overcurrent protection

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Abstract: In this paper the design of peak current controlled buck converter with high side current sensing technique for overcurrent protected is proposed which in turn designed for the input of 50V at a switching frequency of 40 KHz. The proposal of this peak current control in the buck converter topology is performed with the high side current sensing technique to provide overcurrent protection. This overcurrent protection is performed by creating an over current alert whenever there arise an increase in the load current of 1A present in the high side current sensing element. This proposed system also attains an output voltage of 10V with a considerable output power dissipation of 10 watts providing a noise tolerant and stable dc output current. Majority of the power supplies focus to attain a stable power under all unique transient conditions and to achieve it they are designed with the closed loop feedback circuitry. To address the shortcomings of the voltage mode control, the design of current control method is implemented. To provide a fast response of the control loop of both the current and existing voltage loop the high side current sensing method is applied. All the design specifications are considered and the simulatin is performed using LT-SPICE.

Keywords: High – side current sense, Overcurrent protection, LTspice.

1. Introduction

Current-mode control is preferably used because of its major applications of being highly reliable, simple loop compensation method and load sharing techniques. The current mode control is implemented using high side current sense technique to provide a noise tolerant stable output providing overcurrent protection. Current sensing also serves few other purposes like allowing accuracy for current sharing in a multiphase power supply design.

The modified voltage mode is the current mode control where the inductor current is sensed and utilized for the input of PWM generator. Generally, the current control method has two loops one is for the voltage control and the other is for the current control which makes the system a little complex. But still the current control method provides few advantages to produce highly stable system with better transient responses. The current mode technique overcomes the shortcomings of the voltage mode control providing a better and effective power converter.

2. Objectives

- To control the peak current of the converter using the high-side transistor placement method.
- To provide higher reliability with fast, cycle-by-cycle current sensing for overcurrent protection.
- To detect load shorts.
- To reduce resistive loss and to improve efficiency.

3. Existing system

The general method needs the usage of a sense resistor in series with the output for the purpose of sensing the current. As a result, this produces resistive losses which will impact the efficiency of the system. The below equation (1) shows the losses in the sense resistor. Also, this method leaves the footprints of drawbacks like resistivity loss, poor overcurrent protection etc.

$$R_{SENSE_{loss}} = I_{OUT}^2 \times R_{SENSE} \quad \text{-----------------------------} \ (1)$$

Increase in the losses results in the reduction of the system's efficiency along with the rise in the operating temperature. When we consider with respect to cost, it is high because of the use of low milliohm resistors for current sensing which are costly when compared to the small signal resistors. In our circuit it is used as 100mili ohm.

The amplifier's cost might be raised when there is rise in the output voltage of the system. Suppose there is a need in saving the costs, the usage of biasing supply is implemented for the reduction of the common mode voltage range. This schematic presented in Figure 1 has many disadvantages, including the design complexity and cost. And these drawbacks will be considered in the proposed system [1].

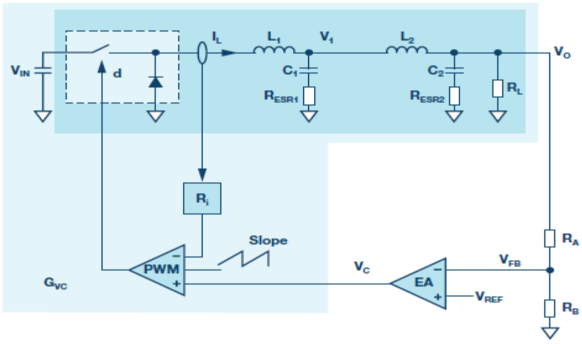

Fig 1 Current Controlled Buck Converter

4. Proposed system

This paper proposes the design of peak current controlled buck converter with high side sensing technique for overcurrent protection. [2] To sense the current in a buck topology the sense resistor can be placed in several positions. For detecting the peak inductor current the hide side sense element is placed on the top MOSFET.

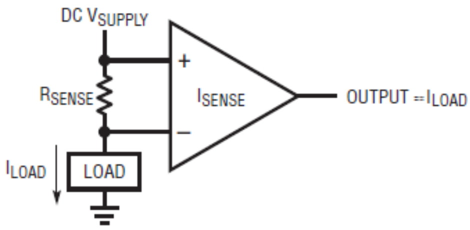

Fig 2 High Side Current Sense

[3] The peak current control method makes use of the current waveform that is fed into the PWM generator For a fast response of current loop along with the voltage loop the high side transistor placement is implemented.

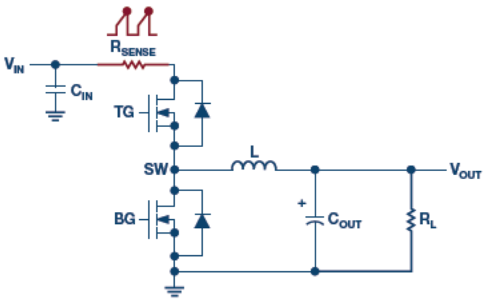

Fig 3 Buck Regulator with High Side Placement

High-side sensing technique is the most likely utilized technique where loads are subjected to ground making them a short circuit. It is always safer to keep the load away from battery than the ground which in turn results in less connector corrosion.[4] This high-side current sense makes use of a comparator in order to create a over current alert whenever there arises an increase in the load current of 1A. The OC-Alert signal is implemented for active low mode. Through this is makes sure that the system is protected from over current.

[5]This high-side current sensing with comparator circuit paves way for an over current alert whenever there arises a need for the overcurrent protection. This circuit with rail-to-rail inputs produces the over current alert at the output of the comparator that is connected with the high - side current sensing.

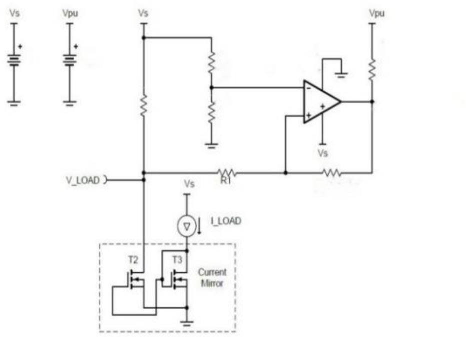

Fig 4 Proposed High Side Current Sense Method

5. Design consideration

The design consideration of the proposed system includes the current controlled buck regulator and the high side sensing with comparator [6]. The following design considerations provide the equation details that have to be focused while designing and implementing this system.

5.1 Buck Regulator:

The buck regulator is controlled by adjusting the duty ratio and provides the charging and discharging of the inductor with respect to the on and off state of the switch [7]. The duty ratio is determined as (2),

$$Vo = D * \mathrm{I}$$ ------------------------------------ (2)

The inductor of the buck regulator is calculated as (3),

$$Lmin = \frac{(1-D}{2j}$$ ------------------------------------ (3)

The capacitor of the buck regulator is calculated as (4),

$$C = \frac{1-i}{8L(\frac{\Delta V_i}{Vo}}$$ ------------------------------------- (4)

5.2 Peak Current Control Mode:

Current mode controlled is subjected to sub harmonic oscillations when they are operating at duty cycle>50% When there is a disturbance in the peak current Δ I also rise at the end of the duty cycle [8]. This main focus of this falls on the slope compensation, modulator gain and output filter.

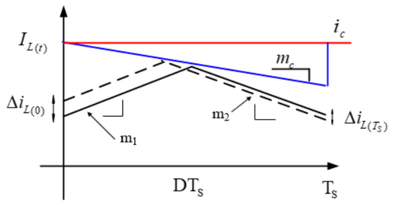

Fig 5 Slope Compensation

[9]The stability criterion for the slope compensation of the current control mode is given below as (5),

$$1 > \frac{m_2 - m_C}{m_1 + m_C} \quad \text{------------------------------------} \ (5)$$

The current sense element is the resistor which remains as one of the considerations of modulator gain.

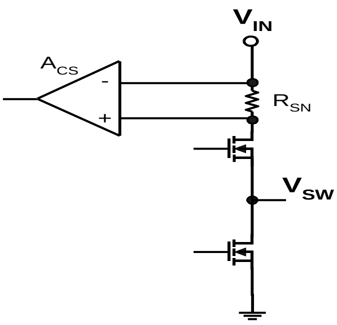

Fig 6 Modulator Gain

The output filter of the current controlled buck converter is depicted as shown in the Fig 7

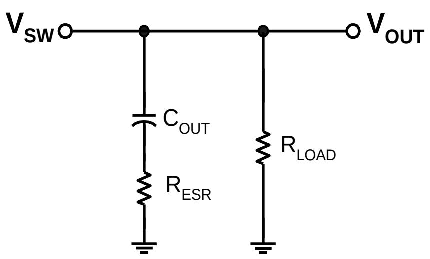

Fig 7 Output Filter

5.3 Proposed High Side Current Sensing Technique:

The proposed high side current sensing technique focus in the usage of a comparator in which the overcurrent alert signal is created at the end of the comparator's output. The comparator is designed for an open drain output stage in order to level shift the signal. The value of the shunt resistor that is the resistor near the supply voltage is calculated along with the consideration of the fact that the shunt voltage being ten times larger than the offset voltage of the comparator.

Parameters	**Values**
Input voltage	50v
Output voltage	10v
Inductor	100uH
Output capacitor	100uF
Output Load Resistor	10ohms
Current sense input current	1A
Switching frequency	40khz
Duty ratio	0.2

Table 1 Simulation Values

6. Implementation of the proposed system

The implementation of the proposed system of high side current sensing technique into current controlled buck converter is simulated using the parameters given in the table1.

The high side current sense circuit with comparator output is shown in the Fig 8.

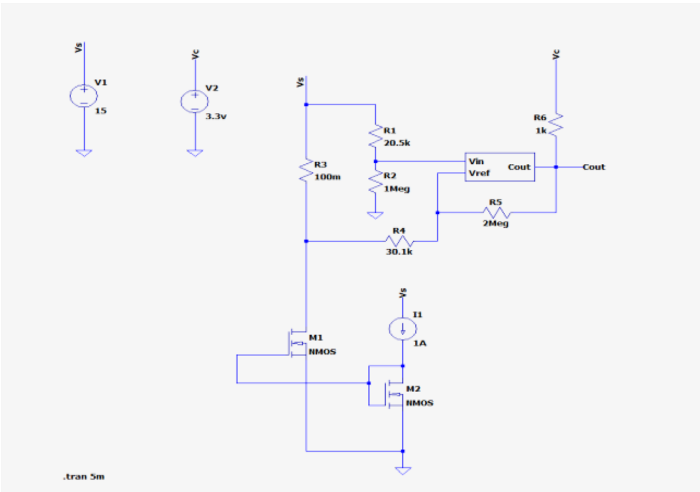

Fig 8 Proposed High Side Current Sense Circuit

The proposed high side current sense circuits include a comparator with rail to rail inputs Fig 9 depicts the comparator for high side current sense technique.

Fig 9 Comparator

The implementation of the proposed system includes a pwm generator to provide the duty cycle to the switch .Fig 10 depicts the pwm generator [10].

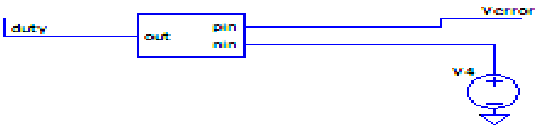

Fig 10.PWM Generator

Fig 11 shows the peak current controlled buck converter with high side current sensing circuit that is designed in this paper.

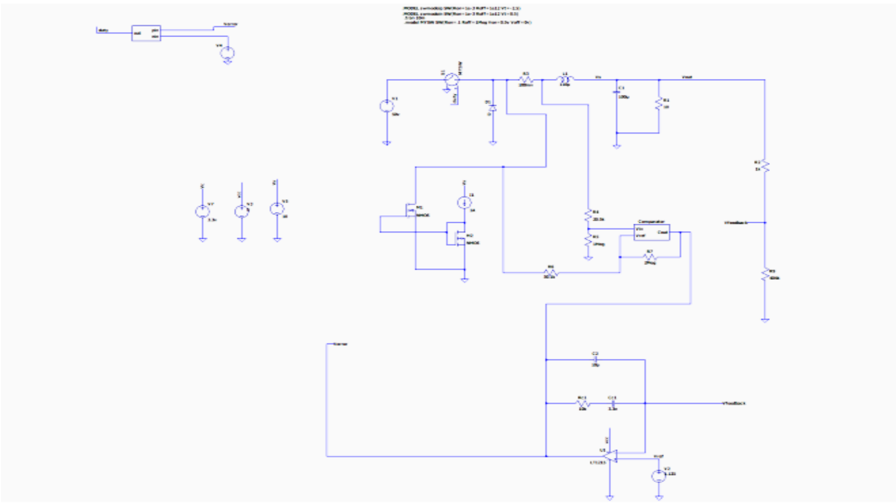

Fig 11 Circuit of the Proposed System

7. Results

The peak current controlled [11] buck converter with high side current sensing is simulated with the parameters provided in the table 1 and the results of the simulation is given below,

[12]The simulation result of the comparator's output stage of the high side current sense technique is given below in the Fig 12

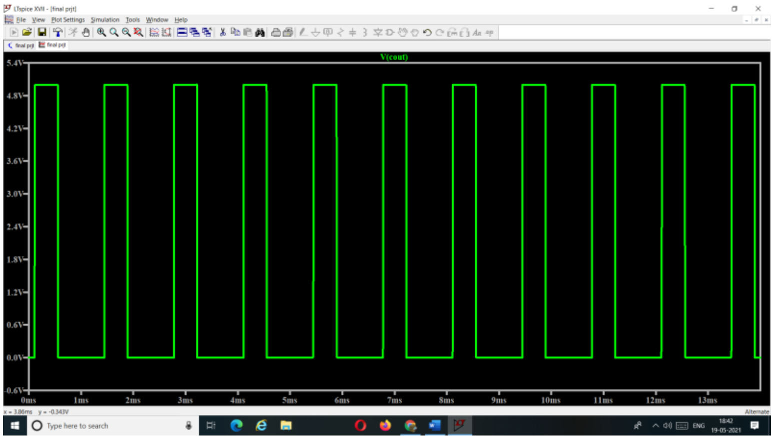

Fig 12 Comparator's Output

The feedback voltage is provided to the error amplifier and the output of the error amplifier stage [13] is depicted in Fig 13.

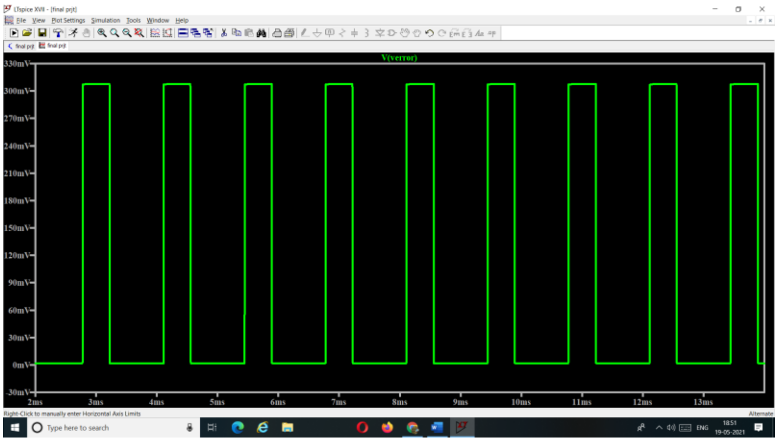

Fig 13 Output Stage of the Error Amplifier

The error amplifier's output is sampled with input of the pwm generator and generates the duty cycle which is the output stage of the pwm generator as shown in Fig 14.

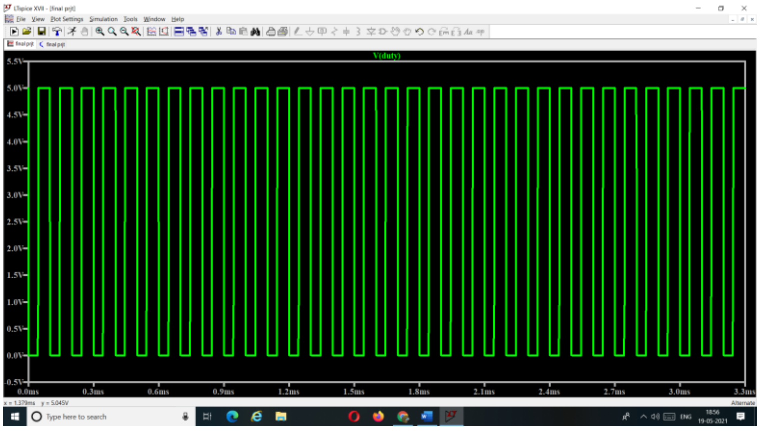

Fig 14 Output Stage of PWM Generator

The performance of the inductor depends upon the on and off of the switch in which the on stage leads to the charging of the inductor and the off stage leads to the discharging of the inductor as shown in Fig 15.

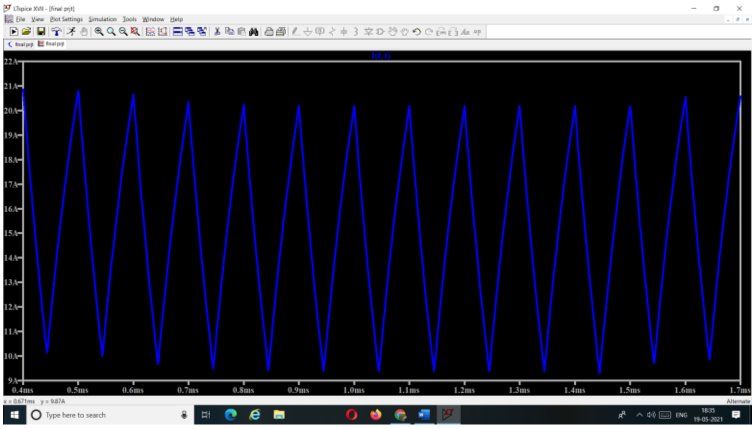

Fig 15 Inductor Performance

The output stage of the proposed systems provides the level down of input voltage 50 to 10V, and the input current is modified into noise tolerant steady current whereas this provides a considerable output power dissipation of 10w as in Fig 16.

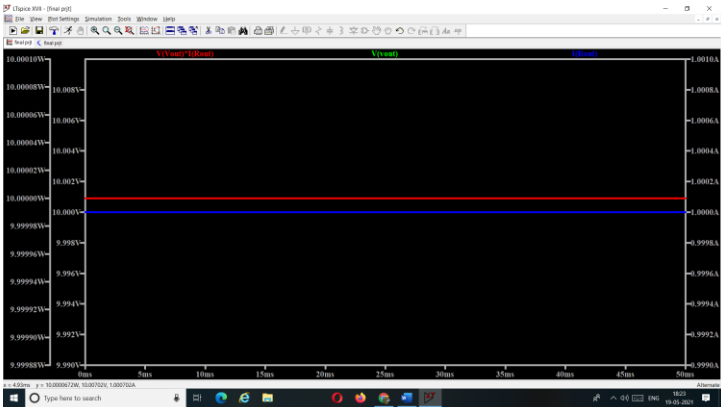

Fig 16 Output stage

8. Conclusions

As per the above results, it is found that this proposed design of peak current controlled buck converter with high side current sensing technique for overcurrent protection. The use of the high side current sense mainly focusses on the stable common mode voltage which in turn provides an over current alert and as per this design when there arises an over current at the load current more than 1A this creates an over current alert thus providing an over current protection to the system. The major drawback of the current sense element is its inability to tolerate noise. This proposed system provides noise tolerant stable dc output with respect to desired conditions of input voltage being 50v at a switching frequency of about 40 kHz, the required output voltage obtained is 10 V with a considerable output power dissipation of about 10watts under ideal conditions and also all the design considerations mentioned above are satisfied. LTspice simulations are being used to calculate the parameters and this provides the required performance corresponding waveforms. The output voltage across the load resistor approximately equals to 10V with a maximum output ripple of 0.5% Simulations of peak current controlled buck converter with high side current sensing technique was done and the required design specifications are also satisfied.

9. Acknowledgment

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