Design & Implementation of Buck Converter

By

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(Dec. 2018- Jan. 2019)

Abstract

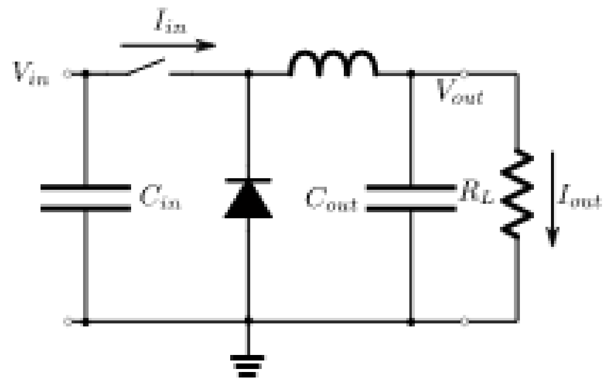
In this report, the step by step design of a buck converter is presented. The buck converter is designed to step 24V DC down to 12V DC. The design includes PCB layout, diagrams heat sink calculations for optimal use.

The report is intended to document to the process of building a small converter circuit and the necessary steps undertaken for fabricating a converter.

1.1 INTRODUCTION

Buck converters find widespread applications in power electronics. Buck converters provide a suitable mechanism for stepping down voltage without the use of a transformer. By manipulating the duty cycle and frequency the output voltage is maintained.

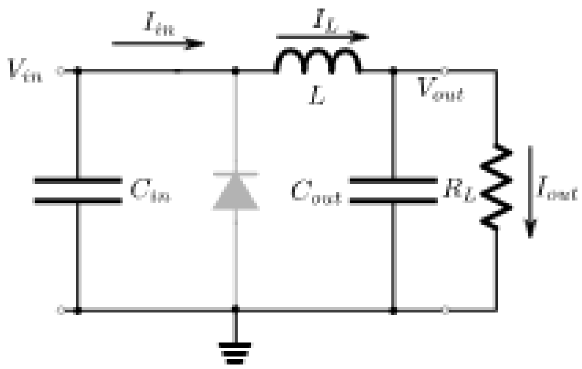
1.2 WORKING



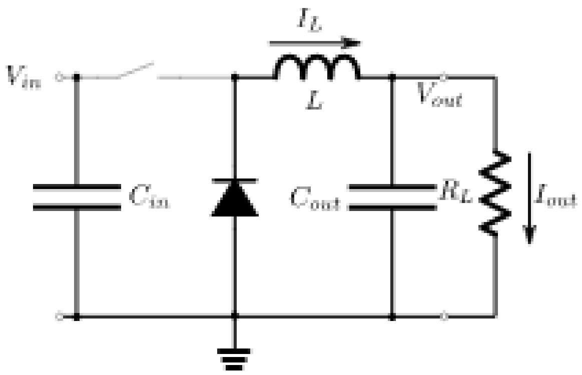
The switch is turned on and off periodically: ton is the time it is on, toff is the time it is off and T=ton+toff is the period. We can also define duty cycle as D=ton/T the fraction of the period the switch is on. For the sake of simplicity, we assume that the ripple in the output voltage is so small that we may consider it constant during a cycle. This is known as the small-ripple approximation and really simplifies our calculations. Let's analyze separately the circuit when the switch is on and when it is off.

On State:

When the switch is on, the power supply is connected to the inductor and the diode is reverse polarized. The circuit reduces to:



Off State:



Assuming the diode is ideal (we will later consider it not to be) and its voltage drop is zero, the diode now shunts the connection between the inductor and ground.We operate the converter in the continuous mode, where the inductor current never reaches zero during the off state.

1.3 DESIGN EQUATIONS

Source: here

In steady- state,

$$\int_0^T vL(t)dt=(Vin-Vout)DT+-Vout(1-D)T=0$$

Vout=DVin

but Vout= 12V, Vin= 24V

=>D= 0.5

$L=Vin-Vout.\ DT/\ \Delta I_L$

ΔI_L= .3A (3% ripple)

L= 80uH

$C=\Delta I_L T/8\Delta V_C$

when ΔV_C=.375mV

C= 40uF

1.4 CHOICE OF PWM CONTROLLER

IC 3842 is a fixed-frequency current-mode control schemes IC with a minimal external parts count.

Current Control scheme is one where the inductor current in the circuit is detected and used instead of the triangular waveforms used in the voltage mode control. The current sensing can also be done by using the on-resistance of high side MOSFET or a current sense resistor instead of the inductor current. Since the current mode has two types of feedback loops: voltage loop and current loop, the control exerted is relatively complex. However the current mode provides the advantage of a substantially simplified phase compensation circuit design. Other benefits include the highly stable feedback loop and a faster load transient response than that of the voltage mode.

The IC also ensures improved line regulation, enhanced load response characteristics, and a simpler, easier to design control loop

1.4 SIMULATION

To verify the calculated values of the components in the buck converter design, a simulation was carried out on Plexim.

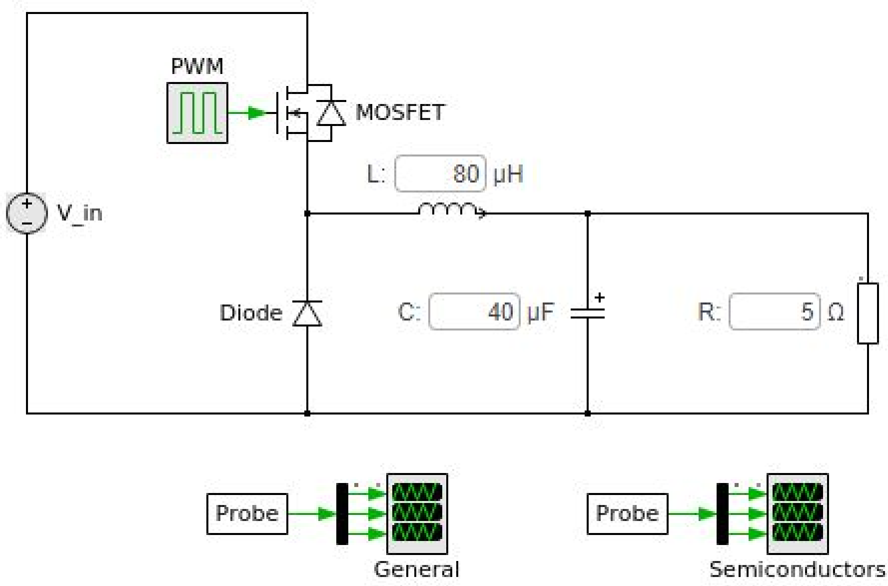


Fig 1: Circuit

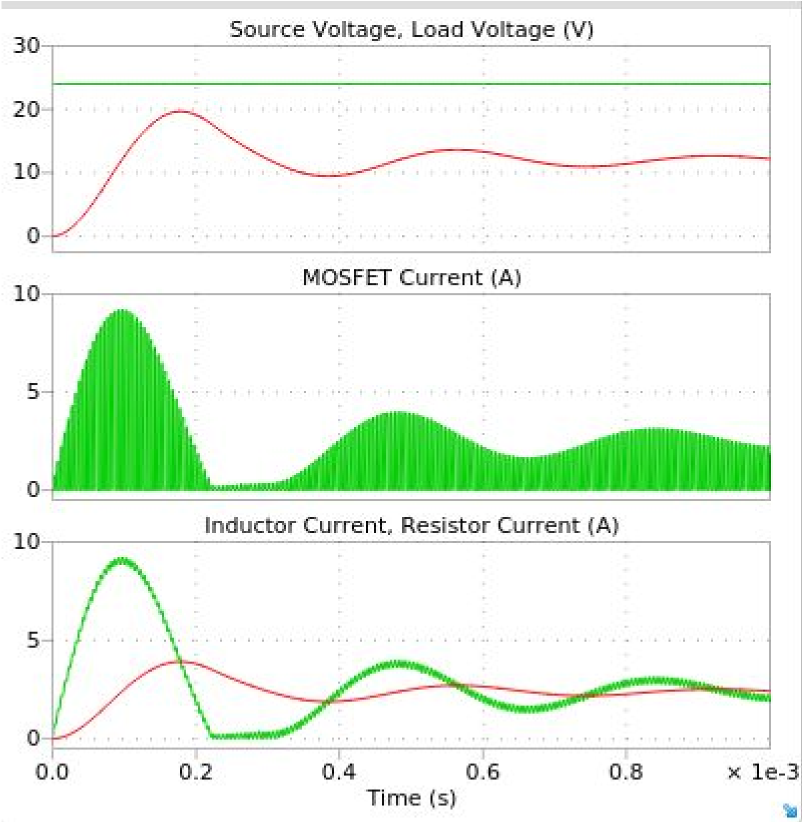


Fig 2: General Output waveforms at 200Khz switching frequency

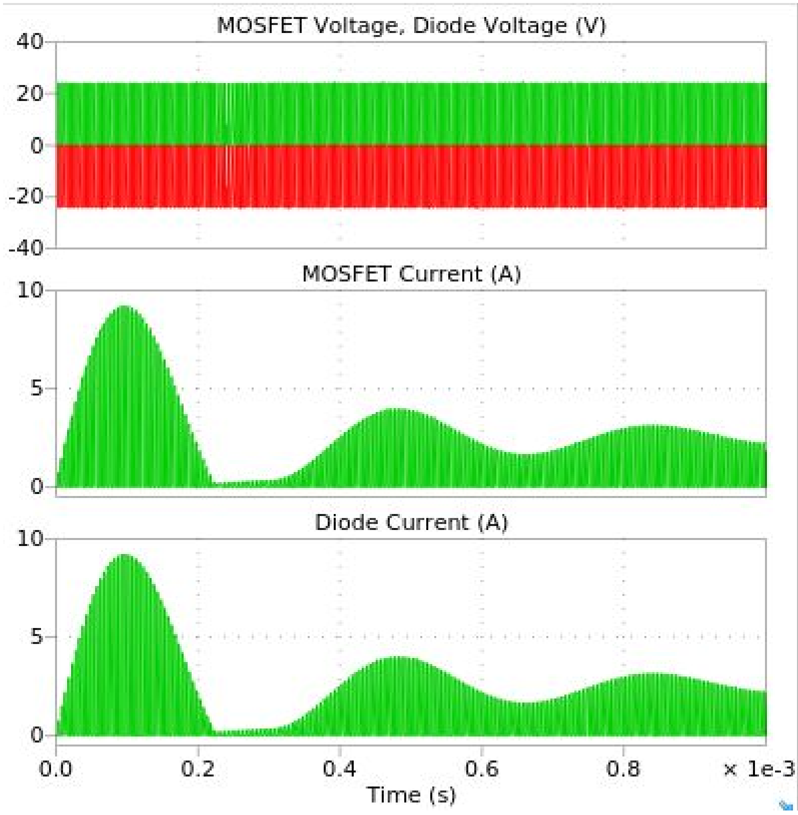


Fig 3: Semiconductor probe waveforms

1.5 BILL OF MATERIALS

BUCK CONVERTER: 24V- 12V, 10A

	Component	Specification	Quantity
1	Inductor	Powder Core 26, 80uH, 42mm dia	1
2	Electrolytic Capacitor, input, polarised	2mF*	1
3	Electrolytic Capacitor, output, polarised	40uF, ESR= 0.15	1
4	Current Transformer	White Yellow, 21mm diameter Ferrite core	1
5	IC 3842	8 pin package	1
6	Switching Diode	Schottky diode, >14W	1
7	MOSFET	IRFZ44	1
8	Resistor- Compensation, bleeder, *current measure series, Rgs	10k, 1/8W	4
9	Resistor, Voltage divider	56.0k, 1/8W	2
10	“	3.3k, 1/8W	1
11	Resistor- Rosc	6.8k, 1/8W	
12	Capacitor- polarised- Compensation	10nF	1
13	“- Cosc	5.1nF	1
14	PNP transistor	Ic/Ib>10, 2N222	1

15	Diode	0.7 drop Silicon	2
16	Resistor for switch disch 1	100ohm, 1W	1
17	Resistor for switch disch 2	22ohm, 1/8 W	1
18	Resistor CT	0.75ohm, 1.5W*	1
19	Rth	4.2kohm, 1/8W	1
20	Cth, polarised	100pF	1

1.5 THERMAL LOSS CALCULATION FOR HEAT SINK DESIGNS

Heat sinks are used in electronic devices and assemblies to provide supplemental cooling that is required to prevent overheating of components.

Power Dissipation values (10% Duty Cycle)

a. Switching diode: 24*6W* DC= 144W* DC= 14.4W

b. MOSFET Dissipation

From Electronics Design:

$PD_{DEVICE\ TOTAL} = PD_{RESISTIVE} + PD_{SWITCHING}$

$PD_{SWITCHING}$= 14.4 W

$PD_{RESISTIVE}$ = \\[I_{LOAD2} × $R_{DS(ON)HOT}$\\] × (V_{OUT}/V_{IN})

where
$R_{DS(ON)HOT} = R_{DS(ON)SPEC}$ × \\[1 + 0.005 × ($T_{J(HOT)} - T_{SPEC}$)\\]

$R_{DS(ON)SPEC}$= 34mΩ, $T_{J(HOT)}$= 105 deg C, T_{SPEC}= 25 deg C

$PD_{RESISTIVE}$ =23.51 W

$PD_{DEVICE\ TOTAL}$ = 37.91W

$$T_J = P(R_{case} + R_1 + R_2) + T_a$$

Where:

T_J = junction temperature

P = power dissipated

R_{case} = thermal resistance of device junction to case

R_1 = thermal resistance of device junction to air (if no heat sink) or thermal resistance of heat sink

R_2 = thermal resistance of device junction to air

Fig: Thermal Resistance Equations of Heat Sink

Based on the thermal resistance consderations, ordered HS19 - AS of 100mm length from the catalog of Anatal Systems, Pune

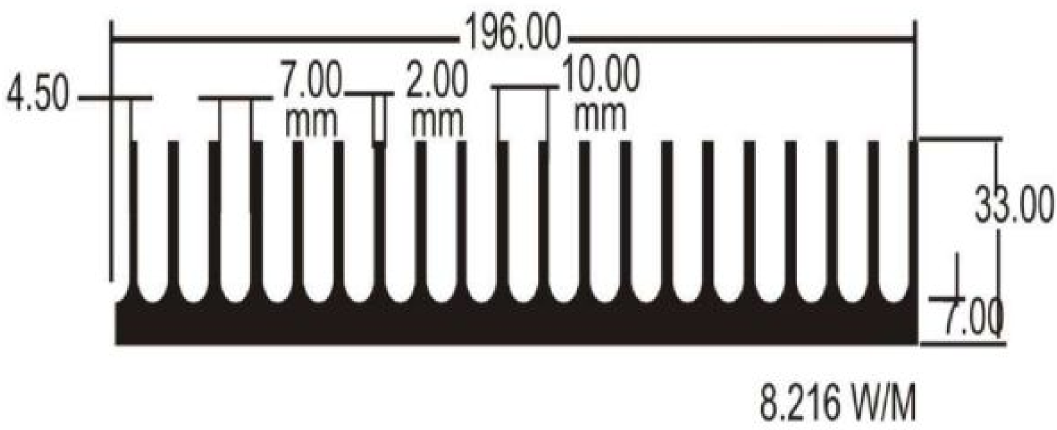
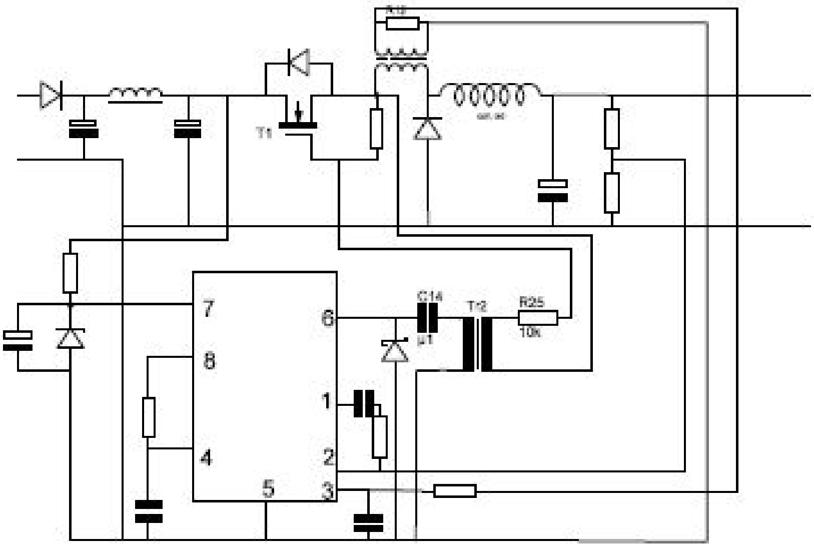


Fig: Similar design from catalog of Himal Systems, Chennai

1.6 SCHEMATIC (MADE ON DIPTRACE)

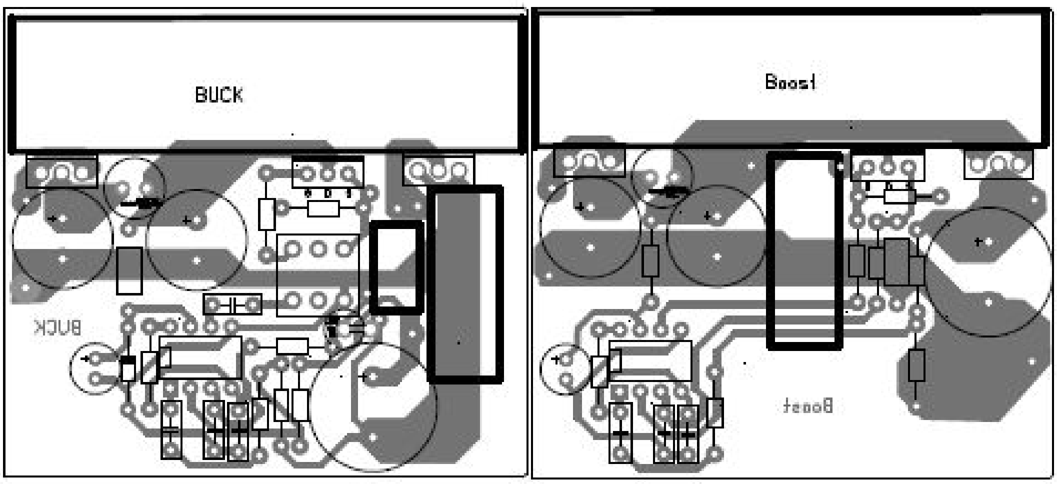


Major components:

1. SWITCH/MOSFET
2. DIODE
3. INDUCTOR
4. CAPACITOR
5. CONTROL CCT FOR IC 3842
6. CURRENT TRANSFORMER

1.7 PCB DESIGN ON DIPTRACE

(BOOST CONVERTER DESIGNED BY ANOTHER INTERN)



1.8 FABRICATION

a. Version 1 from a PCB manufacturing factory in Pune, assembled at Service Matters Inc.

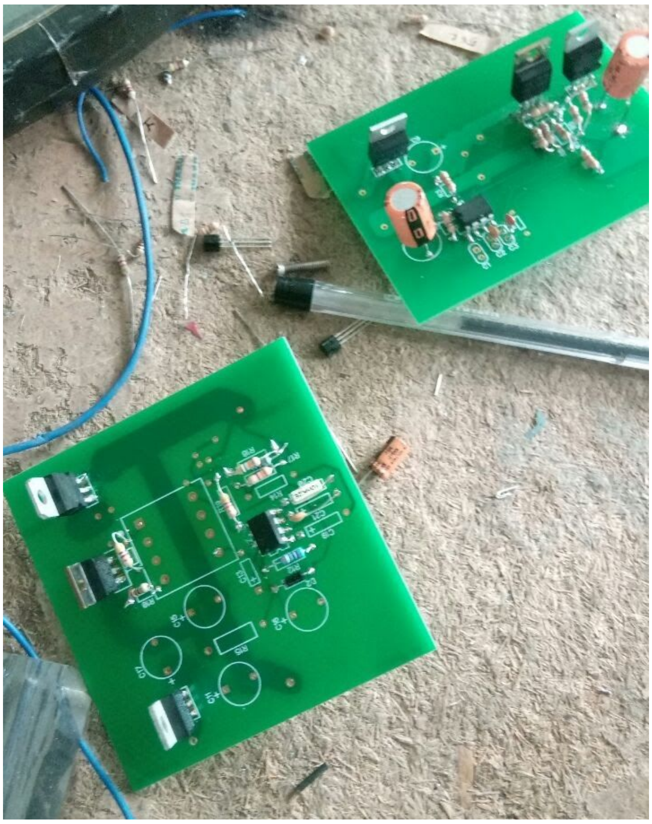


Fig: Assembly of Buck and boost circuits (printed in reverse)

Comments:
While the circuit was printed we didn't know to print it inverted, and thus we had to abandon this version. There was also too little space for the heatsink.

b. Fabrication using CNC Milling Machine manufactured by Interface Design Associates Pvt. Ltd.

PCB milling is typically a non-chemical process and as such it can be completed in a typical office or lab environment without exposure to hazardous chemicals. High quality circuit boards can be produced using this process based on the milling accuracy.

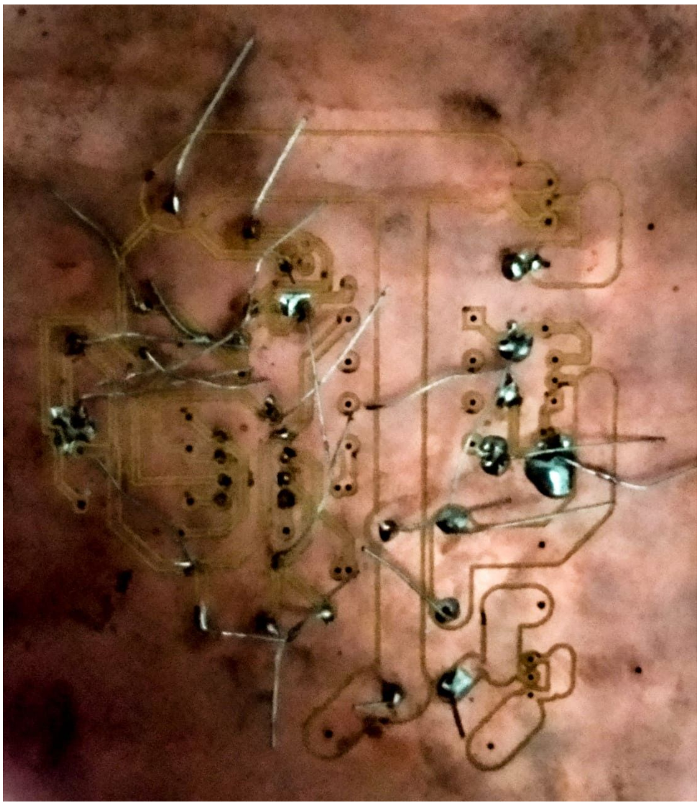


Fig: Partly assembled milled copper plate (due to constraints in drill bit size on the board)

Steps:

1. Export G code from PCB design software into CNC software
2. Avoid any sharp edges in the design stage itself
3. Mark ends of a single side copper clad board and mount it so it can withstand vibrations

4. Choose the drill bit size and adjust the height above the board manually
5. Pause the program execution periodically to dust away excess copper fibres on the job
6. Make sure there are drill bits to accommodate the through hole components

1.9 Testing & Conclusions

1. Both PCBs failed during testing owing to fabrication errors.
2. The first had connectivity errors after etching and the channel for 20A current was too narrow to carry the entire current.
3. The second could not be completed because of time constraints after the drill bits were unavailable at the factory in Interface Design Pvt. Ltd.
4. The control circuit of the PWM IC may have played a role in the failure as well, but because of the manufacturing errors, this hypothesis could not be verified. Simulation softwares lacked the exact current mode IC so the design could be verified.
5. A number of versions of the PCB were made until it was optimal and error free.
6. The heat sink didn't arrive as per specifications from a local manufacturer in Pune, which made mounting impossible on either board.
7. The heat dissipation would have made the board unwieldy and unusable in the industry. Using a different configuration or heat sinking system is a suitable alternative to the design proposed.

1.10 Acknowledgements

Thanks to Interface Design Associates Pvt. Ltd. and mentor Dr. B. Vaidyanathan for their guidance on the project.

Thanks to Service Matters Ltd. for permitting use of their office space to assemble the first PCB.

Thanking all faculty of the Dept. of Electronics and Telecommunication at the College of Engineering, Pune for their support and guidance in establishing a foundation that helped me see this project through.