Project Report: Design and Hardware Implementation of a DC-DC Boost Converter

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May 2024

Abstract

This report details the design, hardware implementation, and testing of a DC-DC boost converter. The primary objective was to develop a circuit capable of stepping up a 10 V DC input to a 15 V DC output, supplying a load current of 1 A at a switching frequency of 15 kHz. The project covers the theoretical design calculations, component selection, circuit construction, and experimental validation of the converter's performance in Continuous Conduction Mode (CCM).

Contents

1 Objective

The objective of this project is to design, implement, and test a DC-DC boost converter. The converter is designed to step up a **10 V DC input** to a **15 V DC output**, with a switching frequency of **15 kHz** and the capability to supply a **1 A load current**. The project involves component selection, hardware assembly, and experimental validation of the converter's operation.

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2 System Components

The converter was constructed using several key components. The primary control and power stage elements are detailed below.

- **PWM Controller:** A **TL494IN PWM control circuit** on a custom module generates the switching pulses.
- **MOSFET Driver:** A **TC4427AEPA dual MOSFET driver IC** provides a high-current gate drive signal to the power switch.
- **Power Switch:** An **IRFZ44NPbF power MOSFET** is used as the main switching element.
- **Inductor (L):** A **1 mH toroidal inductor** serves as the main energy storage element.
- **Capacitor (C):** A **470 µF electrolytic capacitor** is used to smooth the output voltage.

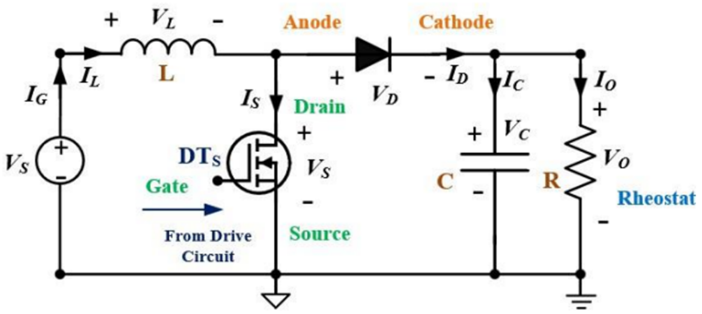

Figure 1: Circuit Diagram of the DC-DC Boost Converter.

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3 Design and Theoretical Calculations

The converter's operation in Continuous Conduction Mode (CCM) is governed by the following design calculations.

3.1 Duty Cycle (D)

The duty cycle (D) is calculated from the input and output voltage relationship:

$$V_o = \frac{V_{in}}{1-D} \implies D = 1 - \frac{V_{in}}{V_o} = 1 - \frac{10\text{ V}}{15\text{ V}} = \mathbf{0.333} \text{ or } \mathbf{33.3\%} \tag{1}$$

3.2 Inductor Current Analysis

For an ideal converter, the average inductor current (I_L) and its ripple (ΔI_L) are calculated as follows.

$$I_L = \frac{I_o}{1-D} = \frac{1\text{ A}}{1-0.333} = \mathbf{1.5\ A} \tag{2}$$

$$\Delta I_L = \frac{V_{in} \cdot D}{L \cdot f_s} = \frac{10\text{ V} \cdot 0.333}{(1 \times 10^{-3}\text{ H}) \cdot (15 \times 10^3\text{ Hz})} = \mathbf{0.222\ A} \tag{3}$$

The minimum inductor current ($I_{L,min}$) is therefore:

$$I_{L,min} = I_L - \frac{\Delta I_L}{2} = 1.5 - \frac{0.222}{2} = \mathbf{1.389\ A} \tag{4}$$

Since $I_{L,min} > 0$, the converter is confirmed to operate in CCM.

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4 Hardware Implementation

The circuit was first prototyped on a breadboard for initial validation and later assembled on a perfboard for a more robust final version.

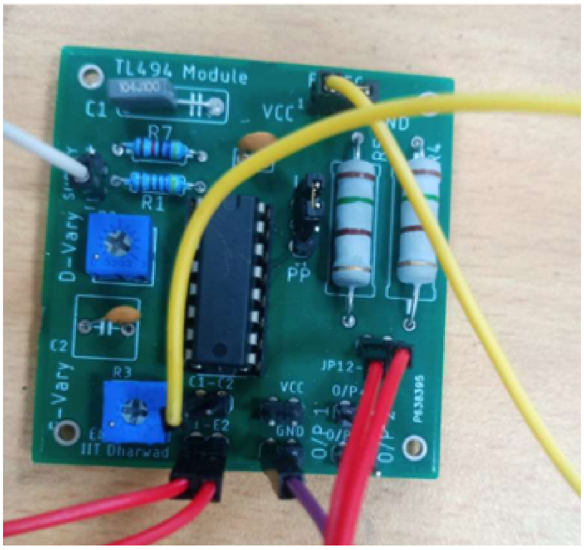

Figure 2: The TL494 PWM Generator Module.

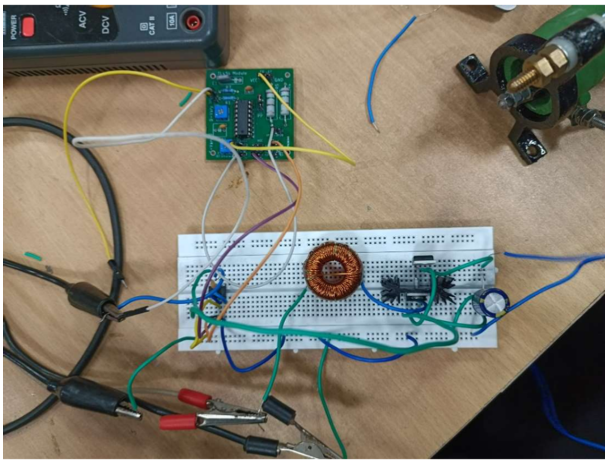

Figure 3: Initial circuit prototyped on a breadboard.

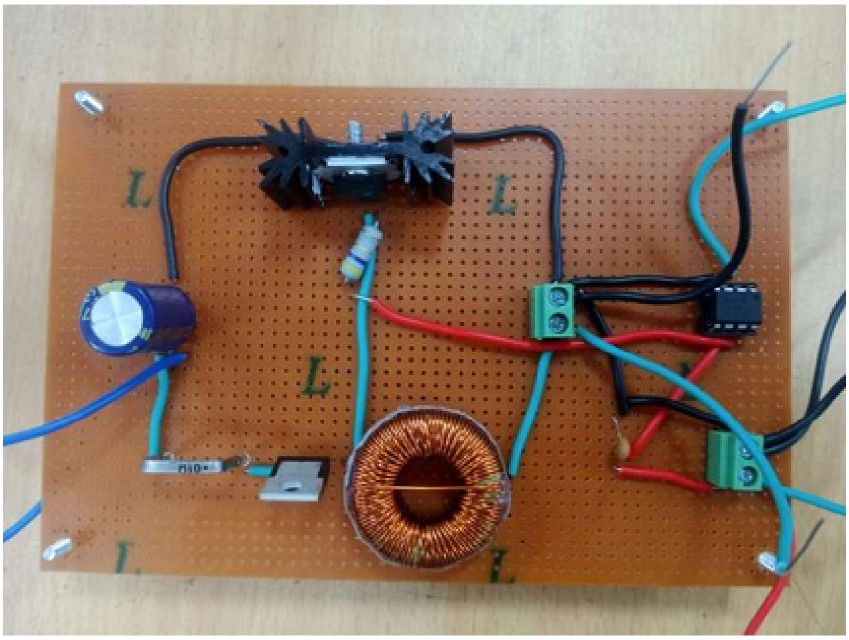

Figure 4: Final hardware implementation on a perfboard.

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5 Experimental Results and Analysis

5.1 PWM Signal Verification

The PWM signal from the gate driver was measured using an oscilloscope. The measured frequency was **15.38 kHz** and the duty cycle was **33.6%**. These results closely match the theoretical design targets, validating the correct operation of the control circuit.

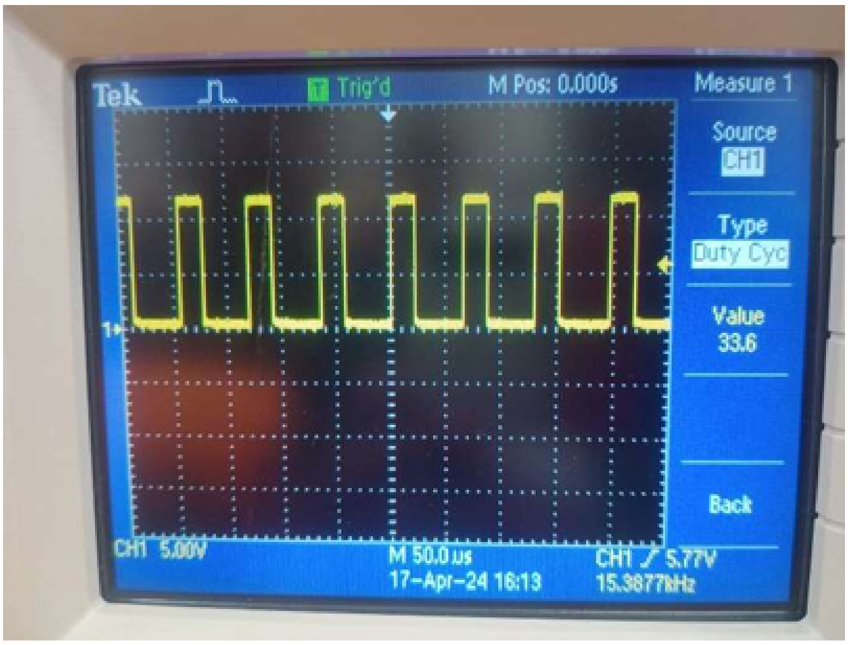

Figure 5: Oscilloscope measurement showing a Duty Cycle of 33.6%.

5.2 CCM Operation and Waveforms

The yellow square wave in Figure 6 represents the gate voltage, and the red triangular wave represents the inductor current. The inductor current ramps up when the gate is high and ramps down when the gate is low. As the waveform's minimum point is clearly above zero, this confirms the converter is operating correctly in Continuous Conduction Mode.

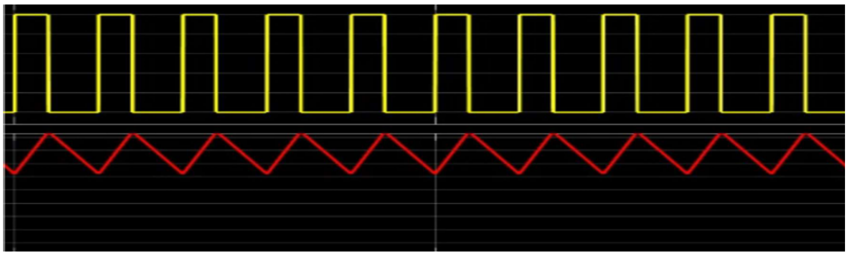

Figure 6: Gate signal (top) and inductor current (bottom) in CCM.

5.3 Transition to Discontinuous Conduction Mode (DCM)

To transition to DCM, the load resistance must be increased beyond a critical value (R_{crit}), which lightens the load.

$$R_{crit} = \frac{2 \cdot L \cdot f_s}{D(1-D)^2} = \frac{2 \cdot (1\text{ mH}) \cdot (15\text{ kHz})}{0.333(1-0.333)^2} \approx \mathbf{202.7\,\Omega} \tag{5}$$

Operating with a load resistance greater than 202.7 Ω would demonstrate DCM.

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6 Conclusion

This project successfully demonstrated the end-to-end process of designing, building, and testing a DC-DC boost converter. Theoretical calculations were validated by experimental results, with the PWM controller generating the correct signal and the power stage operating as expected in Continuous Conduction Mode.