EE 464
STATIC POWER CONVERSION-II
Fall 2022-2023

Backflyp
Term Project Report

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Introduction

In this project, it is required to design a converter that converts 12V-18V DC to 48V DC with 48W power rating. The flyback converter topology was chosen because of the abundance of resources and guides at the design point. In order to receive a plus bonus from the project, at least 80% efficiency must be achieved. Therefore, considering its efficiency advantage, it was decided to operate the converter in DCM mode. This report presents the converter's design, manufacturing processes, simulation and practical test results.

Design Process

By aiming 90% percent efficiency and 0.5 max duty cycle, theoritical calculations are conducted.

$$L_P = \frac{(12 * 0.5)^2 * 0.9}{2 * 48 * 60kHz} = 5.625\ \mu H$$

$$I_{p,peak} = \frac{12 * 0.5}{5.625\mu * 60kHz} = 17.78A$$

$$I_{p,rms} = 17.78\sqrt{\frac{0.5}{3}} = 7.26A$$

$$I_{s,peak} = \frac{17.78}{2} = 8.89A$$

$$I_{s,rms} = 8.89\sqrt{\frac{0.5}{3}} = 3.63A$$

Transformer is designed according to below parameters;

$$J_{rms} = 4\frac{A}{mm^2} \quad B_{sat} = 0.2T \quad k_{cu} = 0.3$$

From area product formula;

$$WaAc = \frac{48}{2 * 0.3 * 4 * 0.2 * 60k} * 100 = 0.167\ cm^4$$

From the lab inventory, 00K3515E090 core is chosen with area values;

$$A_w = 151mm^2 \quad A_e = 84mm^2$$

$$WaAc = 151mm^2 * 84mm^2 = 1.27\ cm^4$$

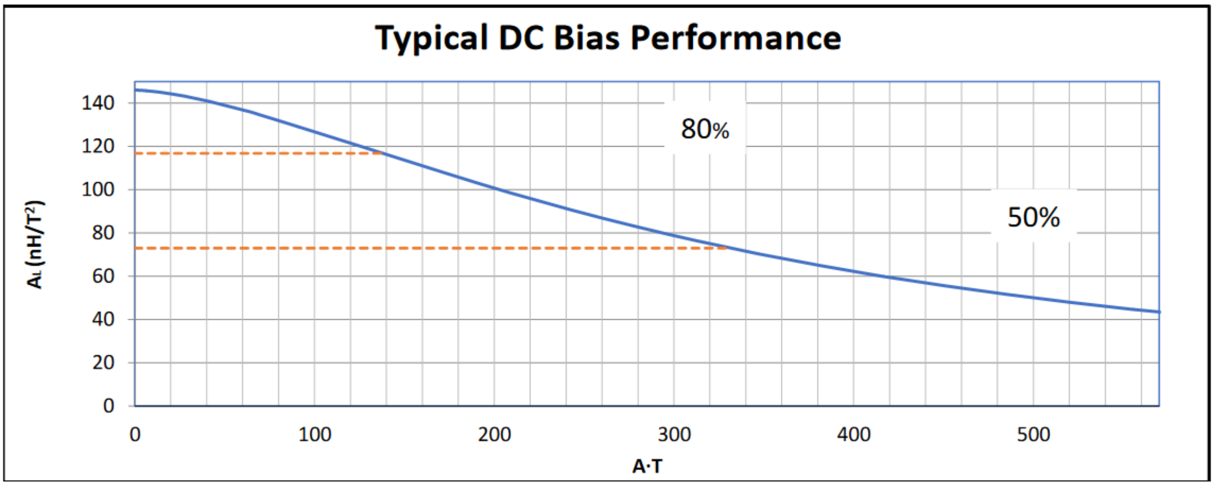

Figure 1. A_L Value Graph of the Core

The required inductance value is calculated before as $L_p = L_m = 5.625\ \mu H$. By looking Figure1 the primary winding value is estimated as $N_p = 7$.

$$A.T = 7.26 * 7 \approx 50 \quad \rightarrow \quad A_L \approx 140\ nH/T^2$$

$$L_p = L_m = 7^2 * 140 * 10^{-3} = 6.86\ \mu H$$

$$N_s = 2 * N_P = 2 * 7 = 14$$

For winding cables;

$$A_{pri} = \frac{7.26}{4} = 1.815mm^2 \qquad A_{sec} = \frac{3.63}{4} = 0.908mm^2$$

23	0.0226	0.57404	0.259	20.36	66.7808	4.7	0.729	53 kHz
24	0.0201	0.51054	0.205	25.67	84.1976	3.5	0.577	68 kHz
25	0.0179	0.45466	0.162	32.37	106.1736	2.7	0.457	85 kHz

Figure 2. Winding Cable Parameters

$$n_{pri} = \frac{1.815}{0.205} = 8.85 \approx 9 \qquad n_{sec} = \frac{0.908}{0.205} = 4.43 \approx 5$$

$$k_{cu} = \frac{9 * 0.205mm^2 * 7 + 5 * 0.205mm^2 * 14}{151\ mm^2} = 0.18$$

The transformer is wound according to the above calculations. The primary of the transformer is measured as 6µH and the secondary is 23.9µH. In addition, there is a leakage of approximately 6.5% (390nH) in the transformer. Due to this leakage and high current ripple, a sudden voltage jump occurs when the switch is closed. When it is desired to keep this jump at 80V levels, a very high level of loss occurs in the RCD snubber. Therefore, it was decided to keep the drain voltage at 150V. In addition, the RC snubber is placed in order to reduce the switching losses.

IRFP250N MOSFET is used to switch at the specified voltage level. The reason for using this MOSFET is that it is the only MOSFET with sufficient rating in the personal inventory. The important parameters of MOSFET are given in Table 1 below.

Table 1. IRFP250N Parameters

V_{DS}	200V
I_D	30A
$R_{DS(on)}$	0.075Ω
Q_g	123nC
R_{JC}	0.7 ˚C/W

At maximum condition, according to simulation, $6A_{rms}$ passes through the switch. The thermal resistances of thermal paste and heatsink are 0.5˚C/W and 9˚C/W respectively.

$$P_{cond} = 6^2 * 0.075 = 2.7W$$

$$P_{sw} = 18 * 6 * 60 * 10^3 * (43 + 33) * 10^{-9} = 0.49W$$

$$T_J = (2.7 + 0.49)W * (0.7 + 0.5 + 9)^\circ \frac{\mathrm{C}}{\mathrm{W}} + 25^\circ\mathrm{C} = 57.5\ ^\circ\mathrm{C}$$

So, there will be no need for extra cooling operation with a fan.

UC3843 IC is used to control the converter. The IC is a current-mode analog PWM controller. The IC can take input voltage up to 30V. Therefore, the input voltage can be supplied directly to the IC. In addition, there is a totem-pole structure at the output of the IC. Thus, the switch can be driven directly. In order to perform current-mode control, it is necessary to read 1V from the sense leg of the IC. The current on the transformer climbs up to about 20A at the maximum. Therefore, 50mohm is determined as the sense resistance. Sense resistance is created by paralleling 2 of 0.1ohm 4W SMT resistors. In order to get isolated feedback from the circuit output, PC817A optocoupler is used. 13V and 33V zener diodes are used in the secondary part of the optocoupler. The primary part of the optocoupler is connected to the IC by an RC compensation system.

At the output, allowable voltage ripple is 3% which is around 1.5V. With the simulation results 200μF capacitance value is seemed enough to meet this condition. To reduce the ESR effect of the capacitors 2x100μF capacitor used at the output. Also, although a

DC input is given from the input a 100µF capacitor is connected to input to supply instant current demands. A 10k resistor is connected to output to discharge the output capacitances in case no load. The values of the snubber capacitances and resitances are determined and tuned through simulations. BOM list of the converter is presented below Table 2.

Table 2. BOM List of the Converter

Component	Description	Amount
UC3843A	Current-Mode PWM Controller	1
00K3515E090	Kool Mµ E Core	2
PC817A	Optocoupler	1
MBR10150	150V 10A Schottky Diode	2
13V Zener	-	1
33V Zener	-	1
18V Zener	-	1
IRFP250N	200V 30A MOSFET	1
100µF 63V Capacitor	Output Capacitors	2
100µF 200V Capacitor	Input Capacitor	1
10kΩ Resistor	-	3
100 mΩ Resistor	4W SMT Shunt Resistor	2
1kΩ Resistor	-	3
15R Resistor	Gate Resistance	1
100kΩ Resistor	-	1
5.6kΩ Resistor	-	2
430R Resistor	-	1
220pF Capacitor	-	1
2.2nF Capacitor	-	2
10nF Capacitor	-	1
22nF Capacitor	-	1
100 nF Capacitor	-	3
470nF Capacitor	-	1

Converter's Last Version Simulation Results

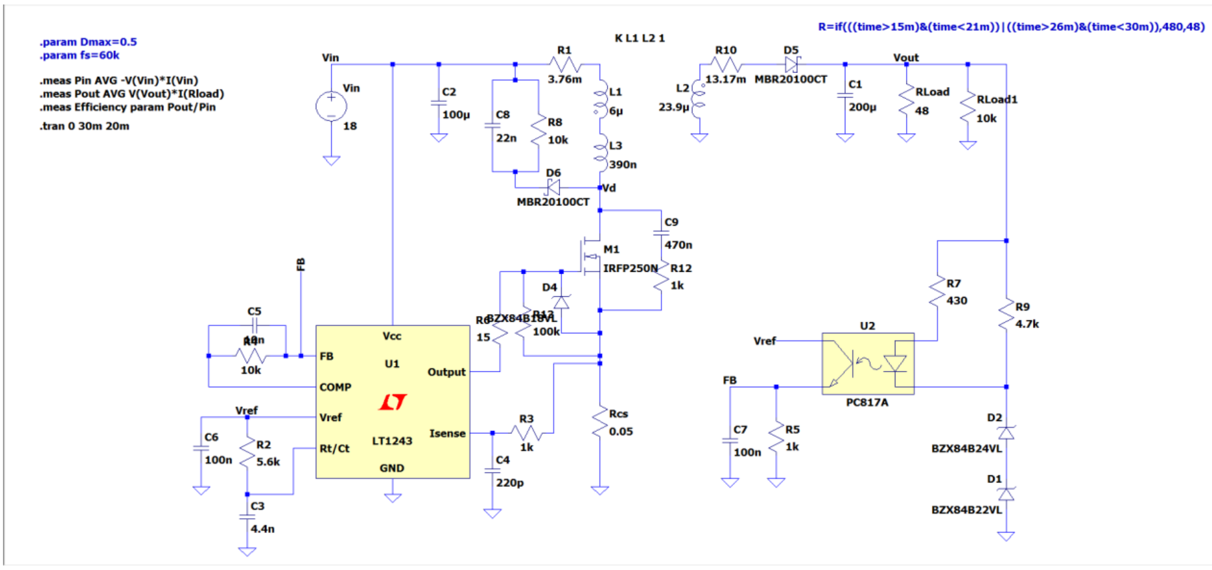

Figure 3. Overall Circuit

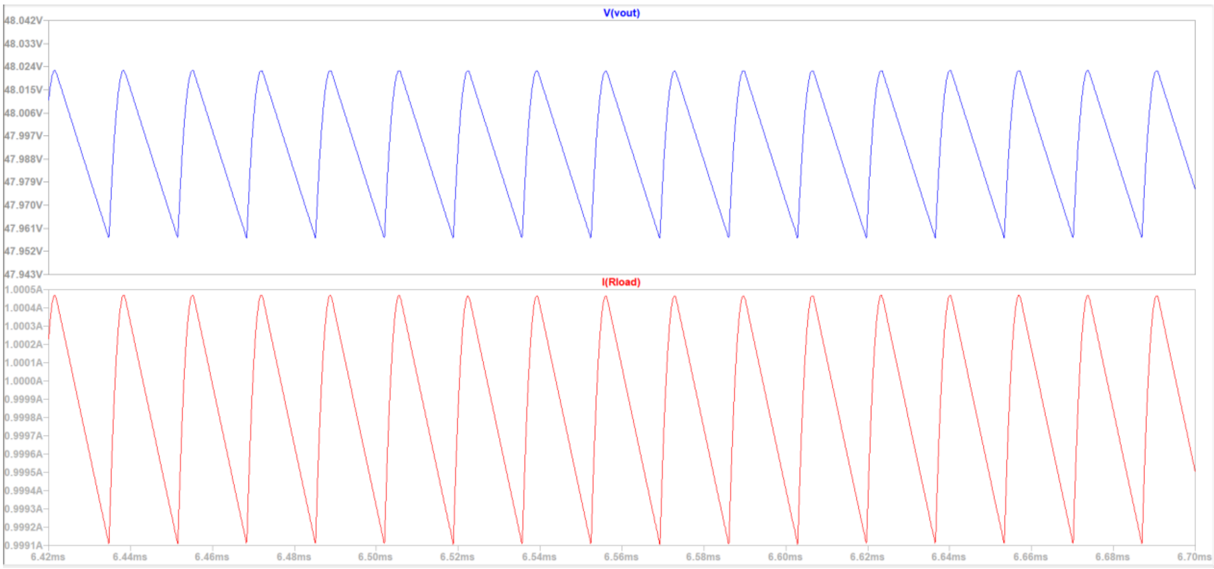

Figure 4. 18V – 100% Load Output Voltage and Load Current Graphs

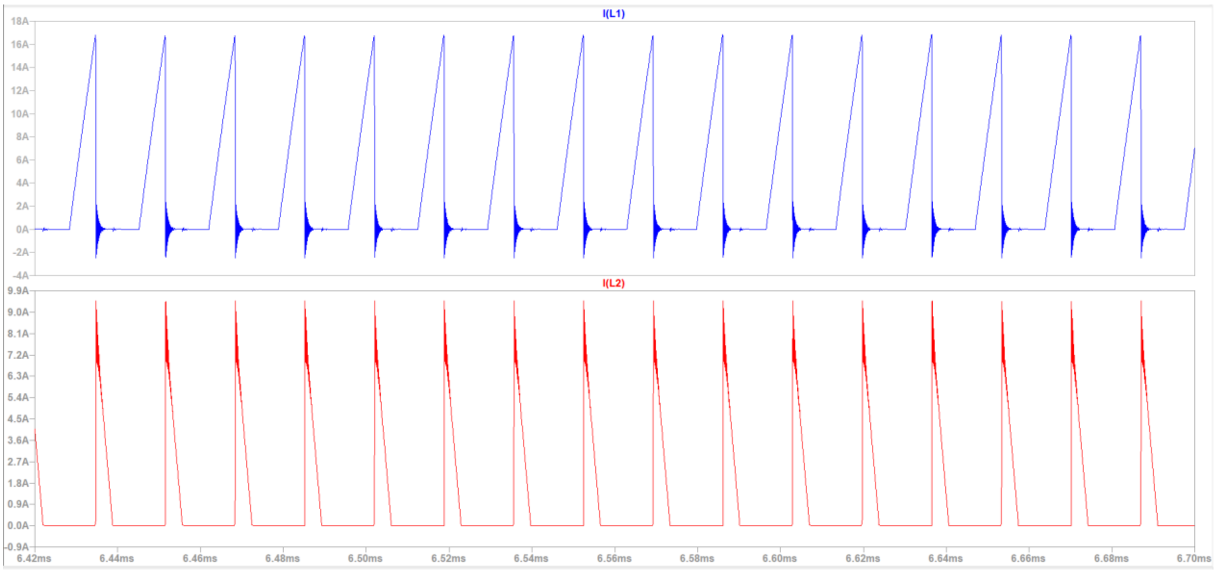

Figure 5. 18V – 100% Load Transformer Current Graphs

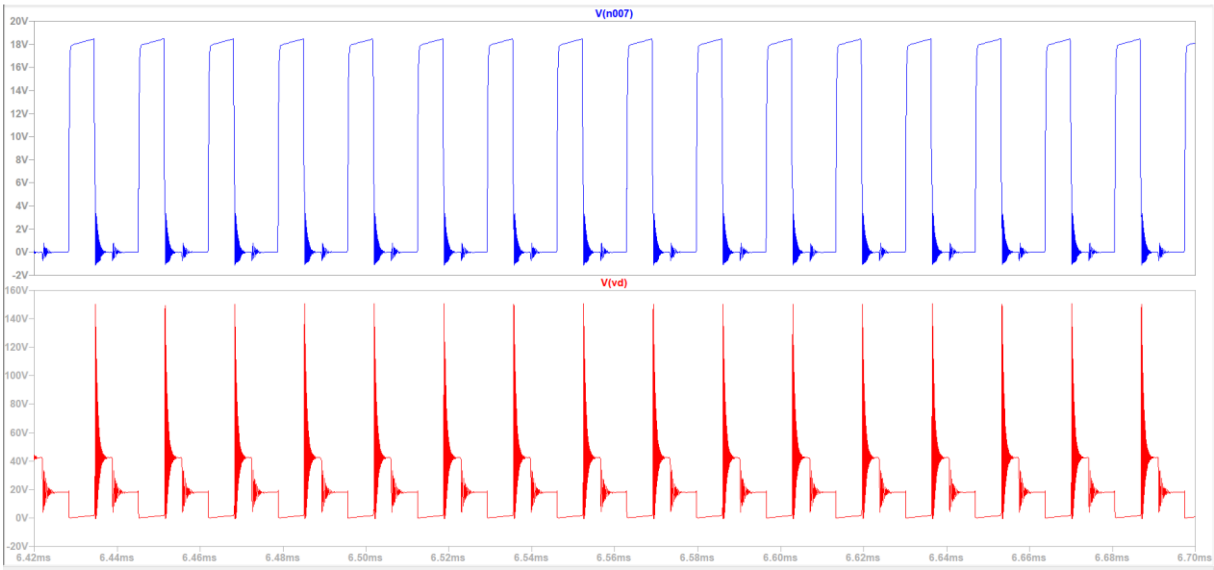

Figure 6. 18V – 100% Load MOSFET Gate and Drain Voltages

Table 3. 18V – 100% Load Efficiency of the Converter According to Simulation

P_{in}	59.24 W
P_{out}	47.96 W
Efficiency	81%

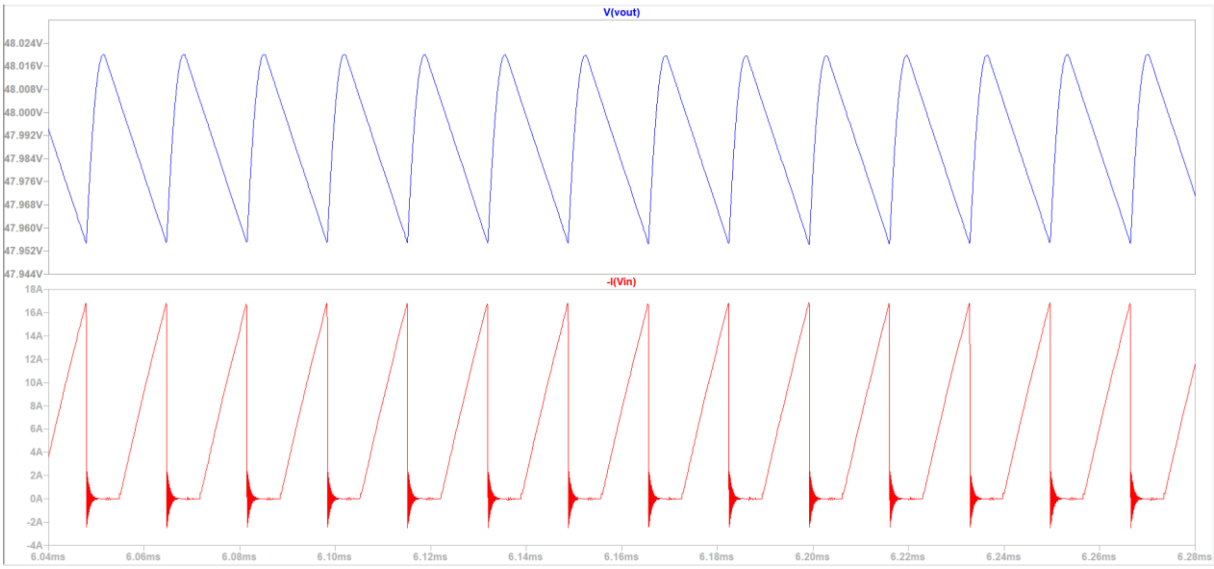

Figure 7. 12V – 100% Load Output Voltage and Input Current Graphs

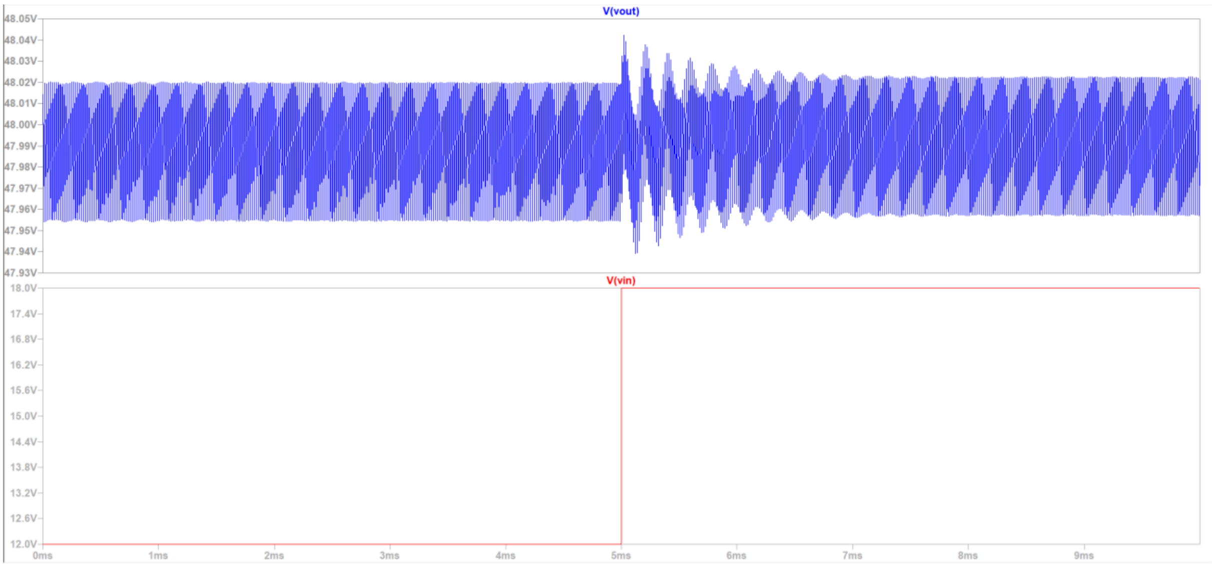

Figure 8. Transient Response of Input Voltage Change

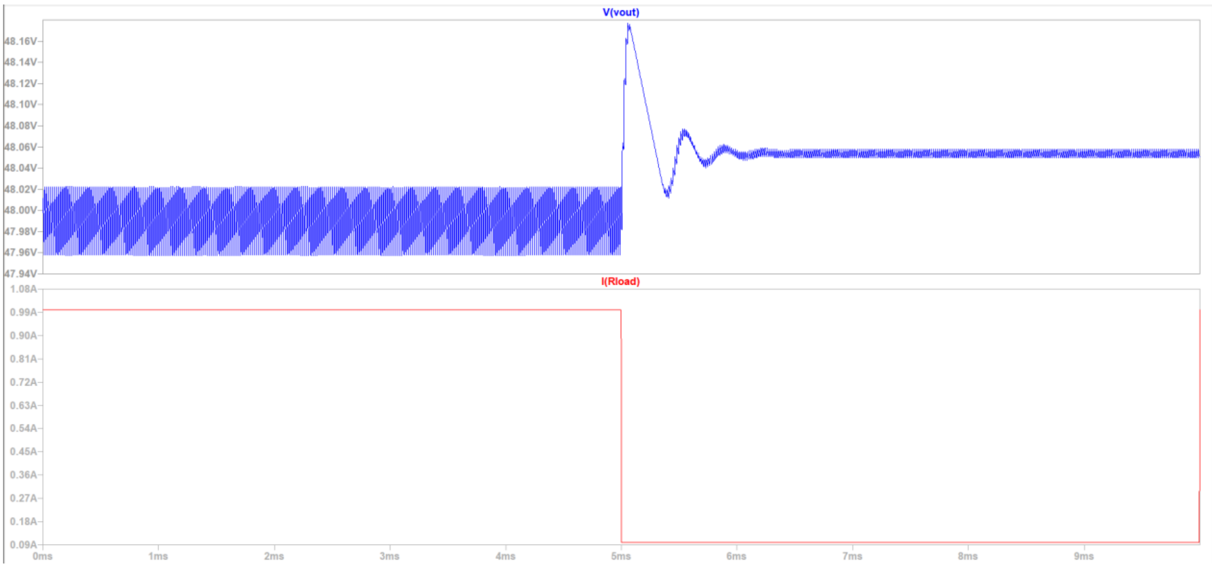

Figure 9. Transient Response of Load Change

PCB Design and Production

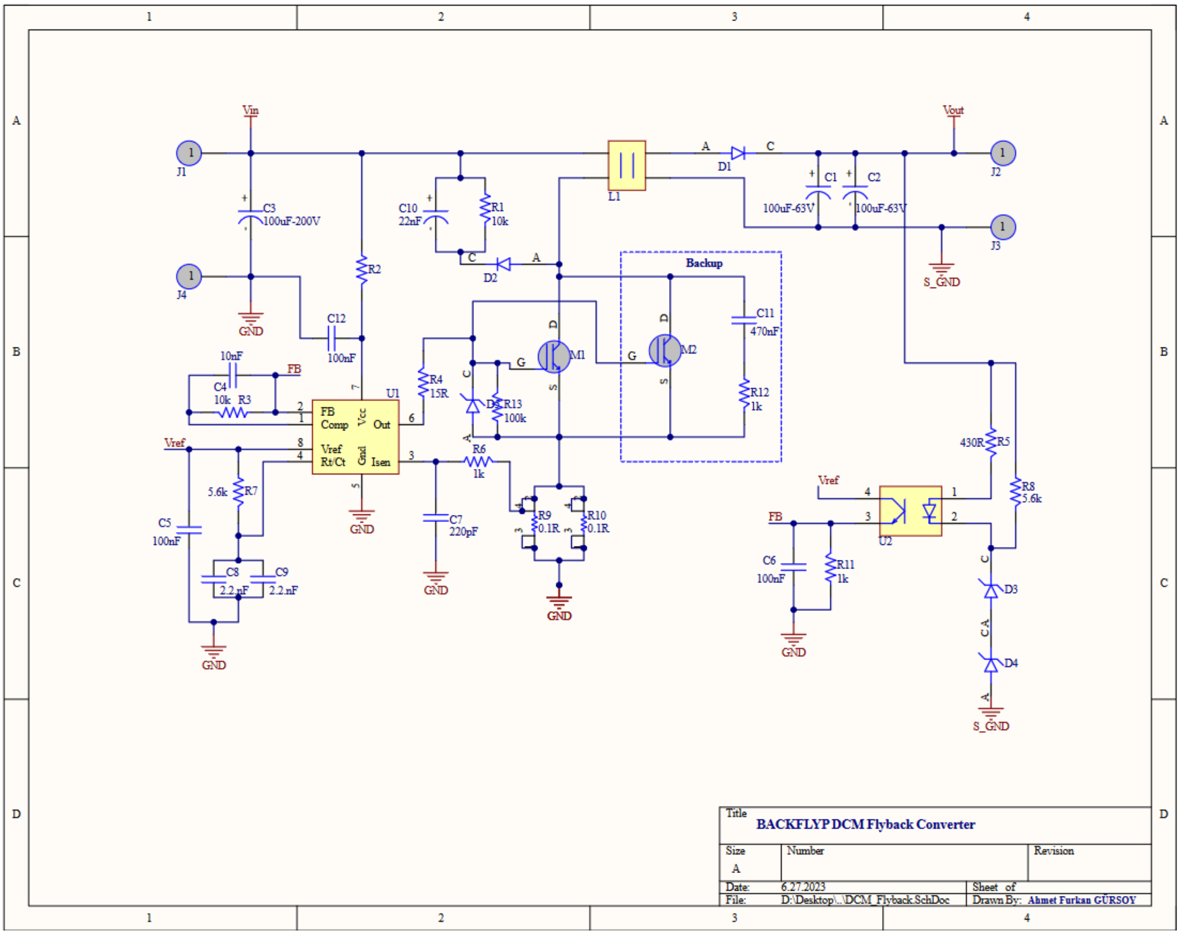

Figure 10. Schematic of the Converter

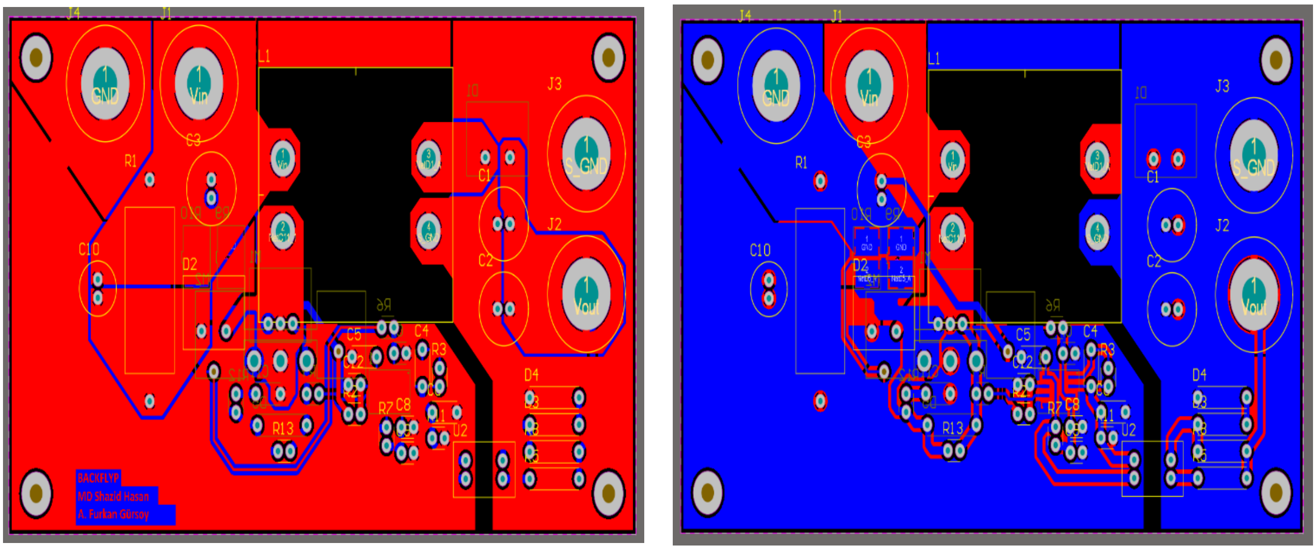

Figure 11. Top and Bottom Layer of the PCB

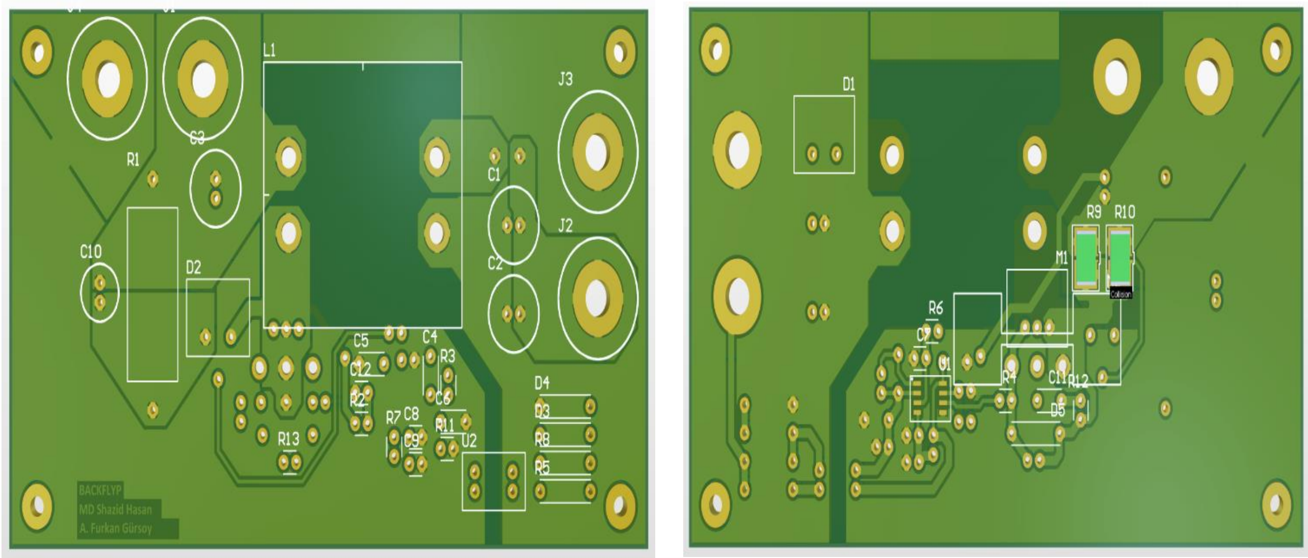

Figure 12. 3D Top and Bottom of the PCB

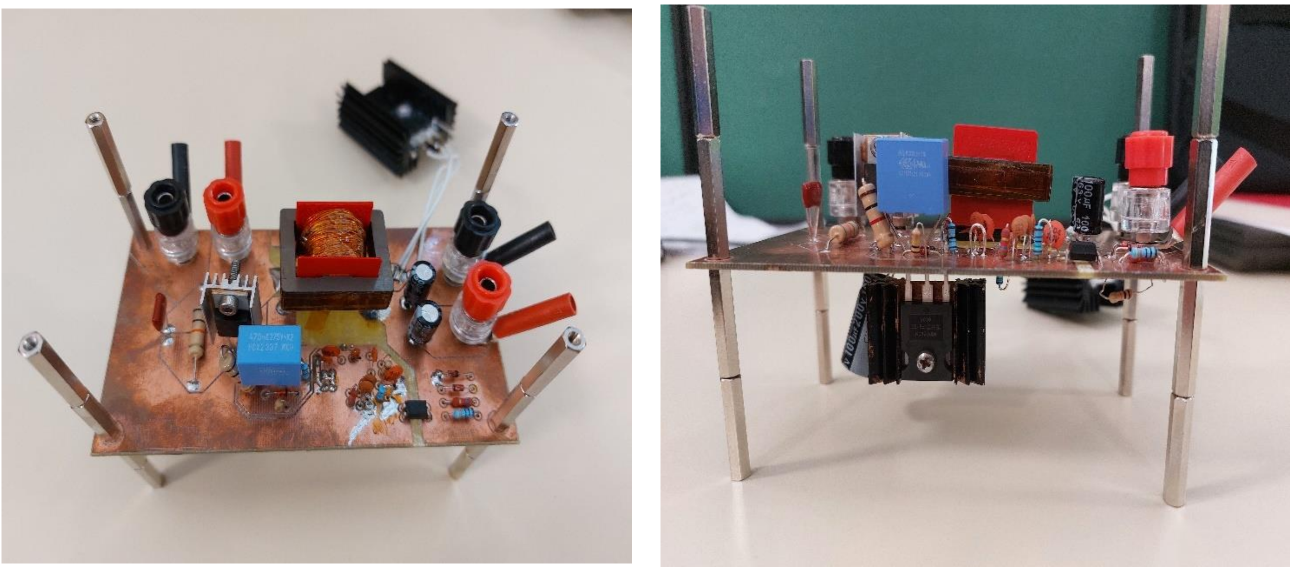

Figure 13. Physical Construction

Practical Test Results

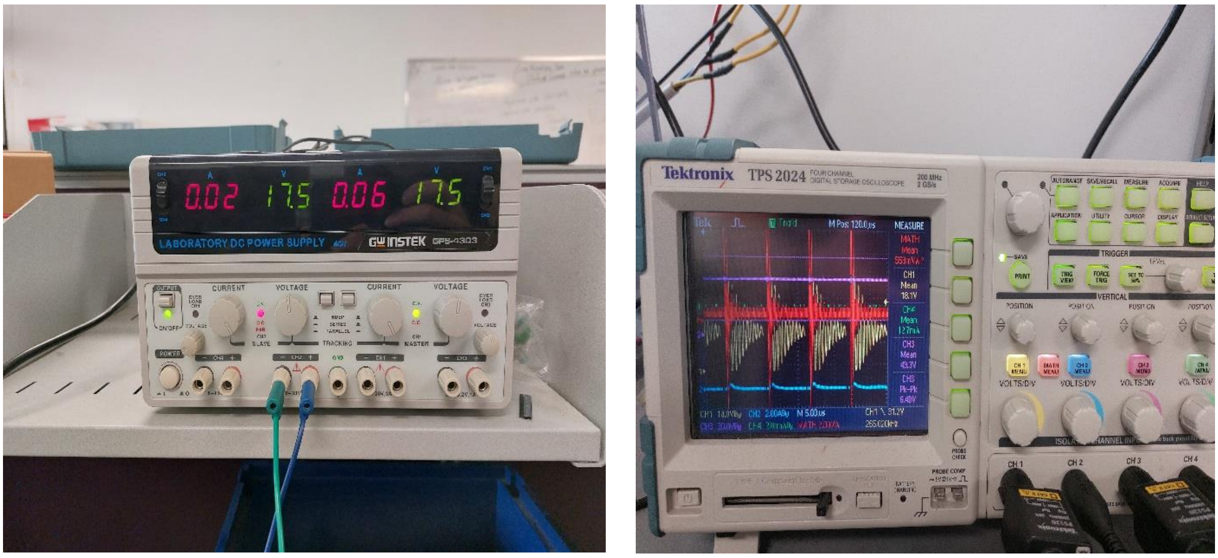

Figure 14. 18V No Load Condition

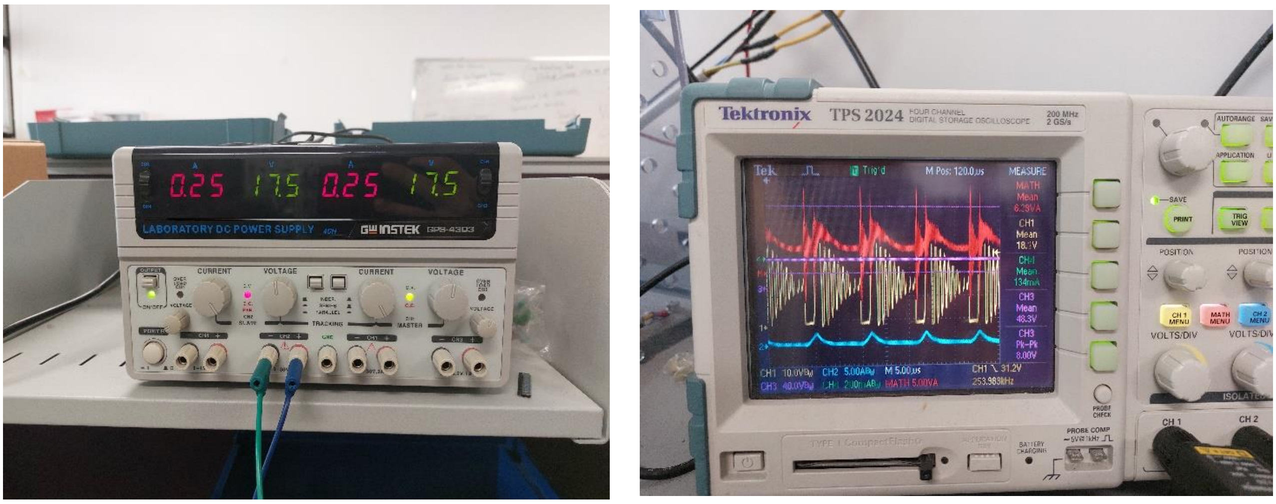

Figure 15. 18V - 10% Load Condition

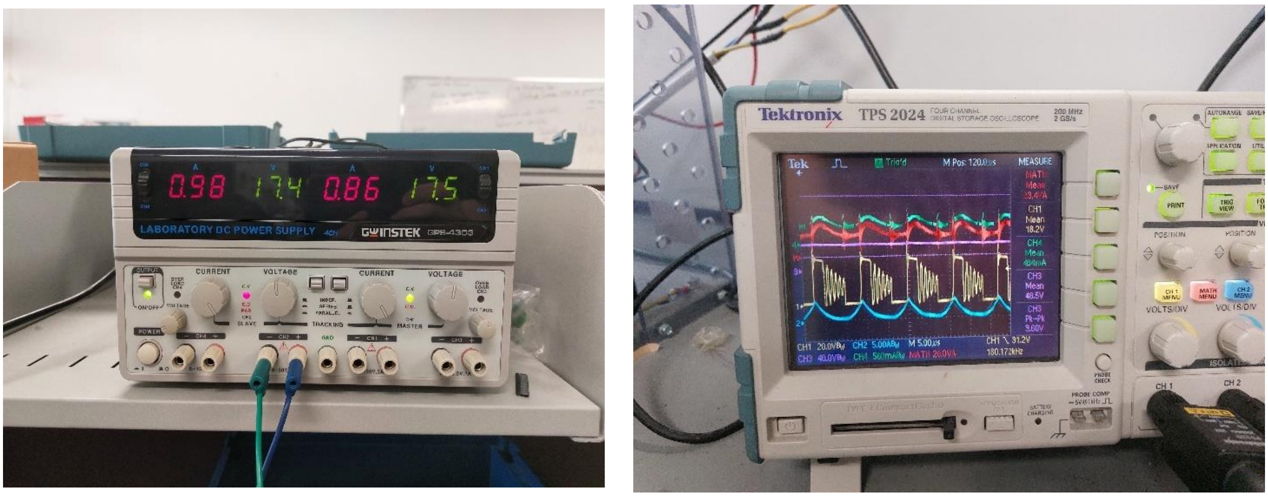

Figure 16. 18V - 50% Load Condition

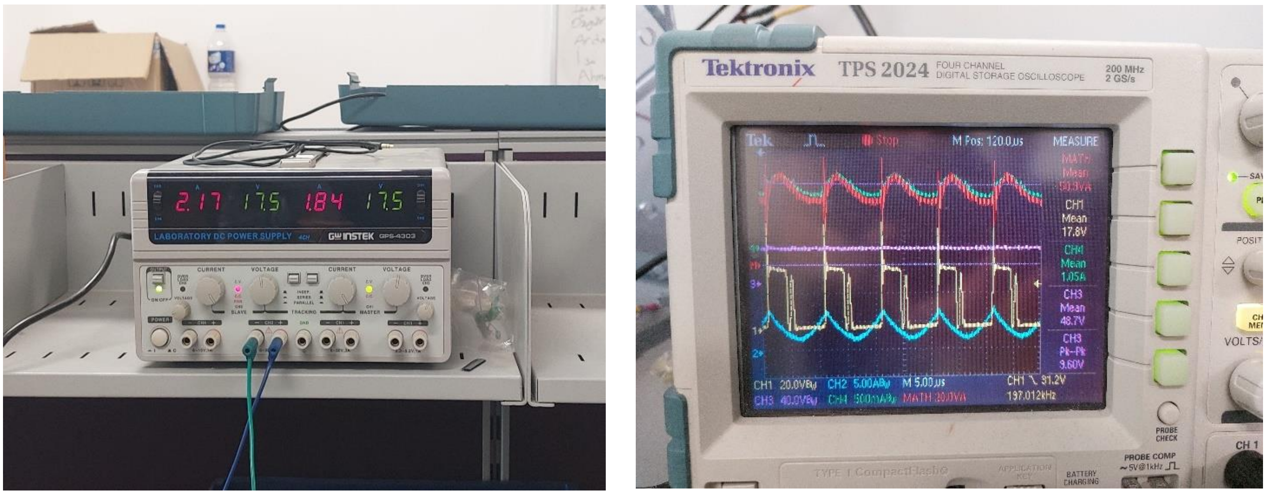

Figure 17. 18V - 100% Load Condition

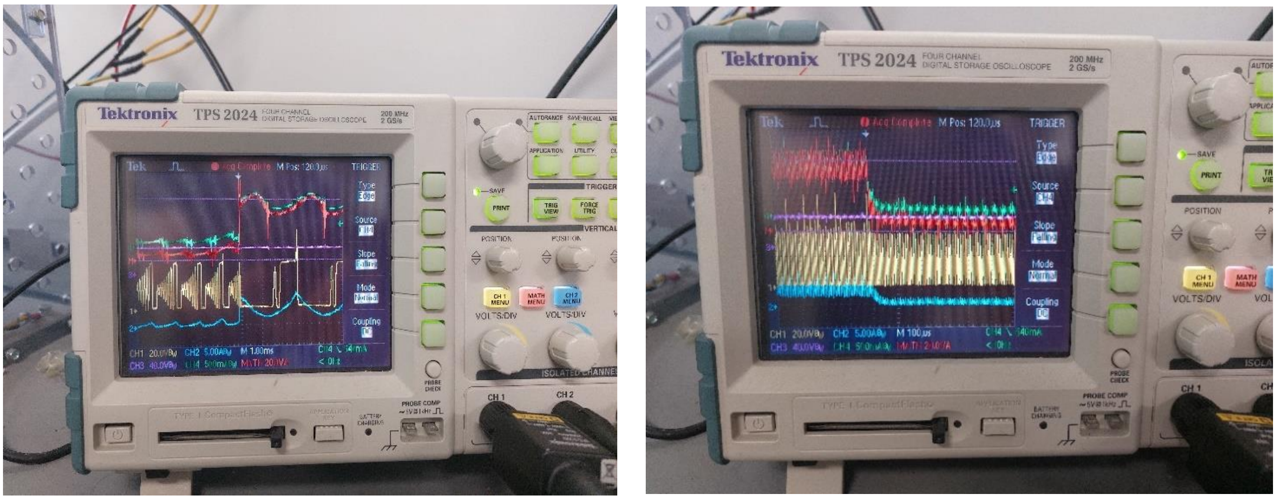

Figure 18. Low to High Load Transient Responses

Figure 19. 15V - 10% Load Condition

Figure 20. 12V - 10% Load Condition

Figure 21. 12V - 50% Load Condition

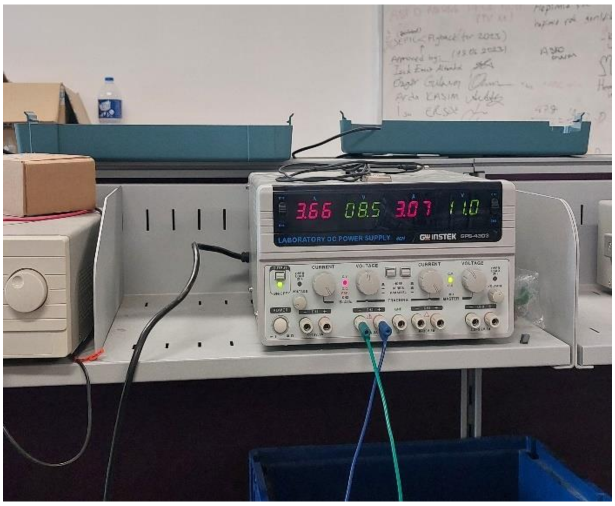

Figure 22. 12V - 100% Load Condition

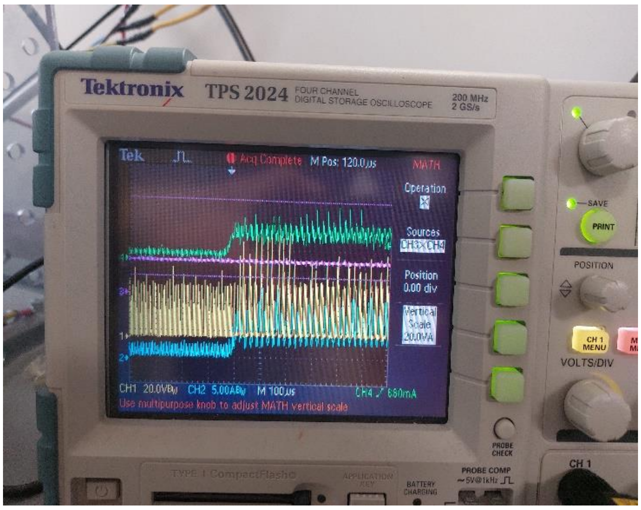

Figure 23. 12V to 18V Transient Response

Test Results and Discrepancies Between Simulation and Practical Results

First of all, the circuit has generally performed correctly. Except for the 12V full load option, it was able to provide the required voltage and load values. In the tests carried out at the beginning, the input capacity was placed as 20uF 50V. While running the tests, the capacitor exploded while operating at 18V - 60% load. The capacitor was predicted to explode due to high current ripple and the capacitance was replaced with 100uF 200V. As seen in Figure 7, although the circuit works correctly at 12V - 100% load in the simulation, it is observed that the voltage at the input source decreases in the practical circuit in Figure 22. In the simulation, the efficiency was calculated as 81% at 18V - 100% load, as seen in Table 3. However, efficiency in the practical circuit calculated as;

$$\eta = \frac{47.8 * 1.05}{17.5 * 4.01} * 100 = 71.5\%$$

Cable and core losses are not taken into account in the simulation. In addition, the converter, which works with 60kHz in theory and simulation, works with 72kHz in practice. This situation is predicted to increase the switching losses and AC resistance losses. The difference in yield is thought to be due to these reasons. Although not presented in the results, there was no component exceeding 65 ˚C in temperature measurements at 18V - 100% load.

Conclusion

This paper was written to cover the design, production, simulation and testing phases of a Flyback converter operating in DCM mode. Inconsistencies in theory, simulation, and test points are noted in the report. Theoretical magnetic design, practical transformer production and PCB design are experienced throughout the design and production processes. During the test processes, problems that were not visible in the simulation that the high current ripple created were understood. In addition, it has been seen that DCM is not as advantageous as described in the design guides in terms of efficiency.