# EE 464
# STATIC POWER CONVERSION-II
# Fall 2022-2023

# Backflyp
# Term Project Magnetic Design and Simulation 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. In this report, theoretical calculations of the converter and simulations of ideal and non-ideal states are presented.

## Design Procedure

Since the importance of the use of the materials in the inventory was understood in the project carried out last year, it was decided to use the IRF540N MOSFET(100V 28A), one of the MOSFETs in the inventory. In order to stay in the safe zone, the voltage on the MOSFET was decided to be 42V in the loop where the switch is closed. After examining the design guides, it was decided that maximum duty cycle of 0.5 would be appropriate.

$$V_{Qmax} = V_{RO} + V_{in,max}$$

$$V_{RO} = V_{Qmax} - V_{in,max}$$

$$V_{RO} = 42 - 18 = 24V$$

$$V_{RO} = \frac{N_1}{N_2} * V_{out} \rightarrow \frac{N_1}{N_2} = \frac{1}{2}$$

$$P_{in} = \frac{P_{out}}{0.9} = \frac{48}{0.9} = 53.33W$$

Calculations were made according to the efficiency of 0.9, since it is estimated that the efficiency will be lower than the calculated one in practice. The operating frequency is determined as 60 kHz in order to avoid skin depth and to be able to use thicker cable while winding transformer.

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

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

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

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

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

At the end of the researches, it was decided that the magnetic design parameters should be as follows. The current density is taken higher than normal because the number of cables that need to be paralleled for transformer winding is wanted to be reduced. If it is detected that the transformer is overheating, an external cooling operation will be performed.

$$J_{rms} = 5\frac{A}{mm^2} \quad B_{sat} = 0.2T \quad k_{cu} = 0.3$$

From area product formula;

$$WaAc = \frac{48}{2 * 0.3 * 5 * 0.2 * 60k} * 100 = 0.133\ cm^4$$

In the researches, it has been seen that E cores are frequently used with flyback. Although it was initially thought to use a gapped ferrite core, it was decided that a kool mu core would be more suitable instead of making gap calculations. From the catalog of Magnetics, 00K2510E090 core is chosen with area values;

$$A_w = 77.8mm^2 \quad A_e = 38.5mm^2$$

$$WaAc = 77.8mm^2 * 38.5mm^2 = 0.3\ cm^4$$

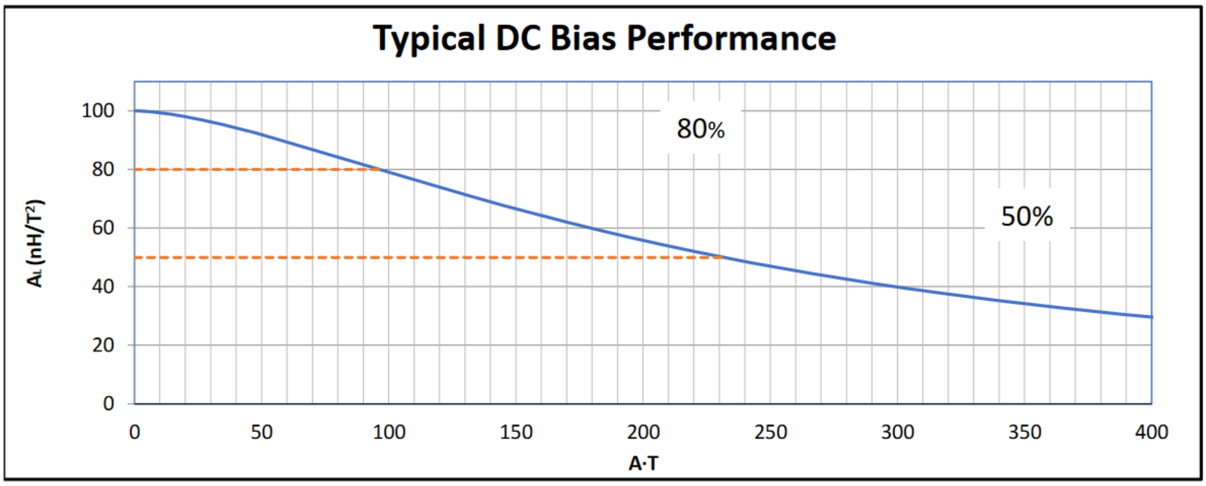


**Figure 1.** $A_L$ Value Graph of the Core

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 $N_p = 8$.

$$A.T = 7.26 * 8 \approx 60 \quad \rightarrow \quad A_L \approx 90\ nH/T^2$$

$$L_p = L_m = 8^2 * 90 * 10^{-3} = 5.76\ \mu H$$

Estimation is verified then;

$$N_s = 2 * N_P = 2 * 8 = 16$$

For winding cables;

$$A_{pri} = \frac{7.26}{5} = 1.452mm^2 \qquad A_{sec} = \frac{3.63}{5} = 0.726mm^2$$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 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

$$n_{pri} = \frac{1.452}{0.205} = 7.07 \approx 7 \qquad n_{sec} = \frac{0.726}{0.205} = 3.54 \approx 4$$

$$k_{cu} = \frac{7 * 0.205mm^2 * 8 + 4 * 0.205mm^2 * 16}{77.8\ mm^2} = 0.316$$

Fill factor is verified too, then cable losses are calculated;

$$R_{pri} = \frac{6 * 29.06 * 10^{-3} * 84.198 * 10^{-3}}{7} = 2.1\ m\Omega$$

$$R_{sec} = \frac{12 * 29.06 * 10^{-3} * 84.198 * 10^{-3}}{4} = 3.67\ m\Omega$$

$$P_{cu} = 7.26^2 * 2.1 * 10^{-3} + 3.63^2 * 3.67 * 10^{-3} = 159\ mW$$

Core loss is calculated according to below formula;

$$P_{core} = aB^b f^c$$

Constants given from manufacturer are $a = 46.32 \quad b = 1.988 \quad c = 1.541$ then;

$$P_{core} = 46.32 * 0.2^{1.988} * 60^{1.541} = 1.038\ W$$

# Ideal Case Simulation

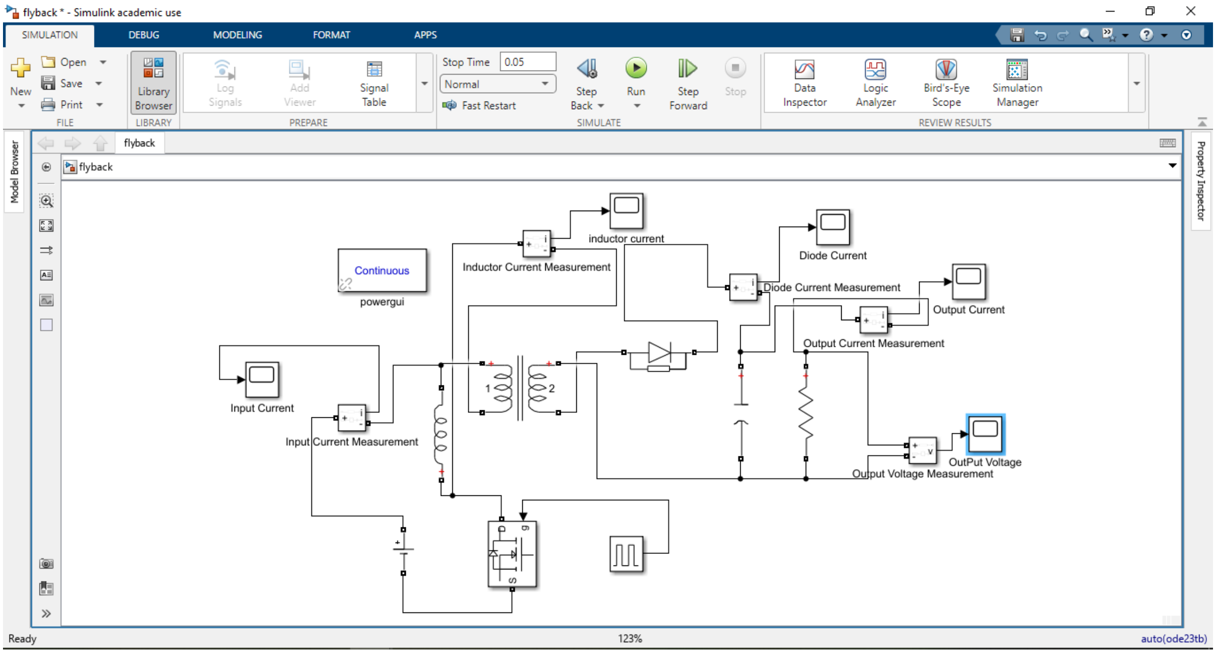


**Figure 3.** Flyback Converter Scheme on Simulink

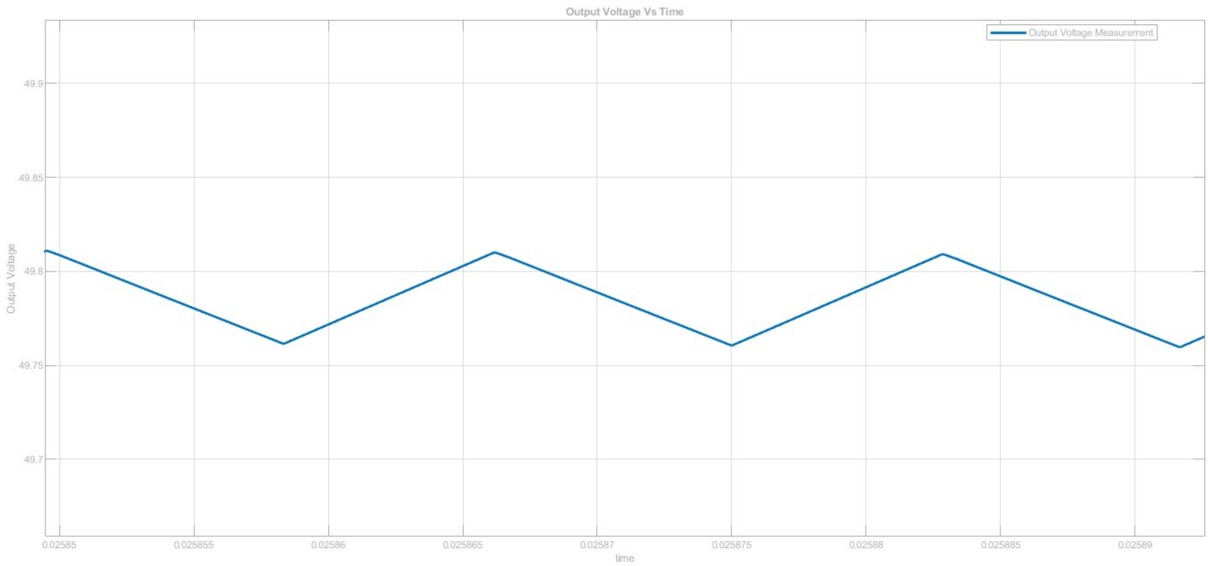


**Figure 4.** Output Voltage of Ideal Condition

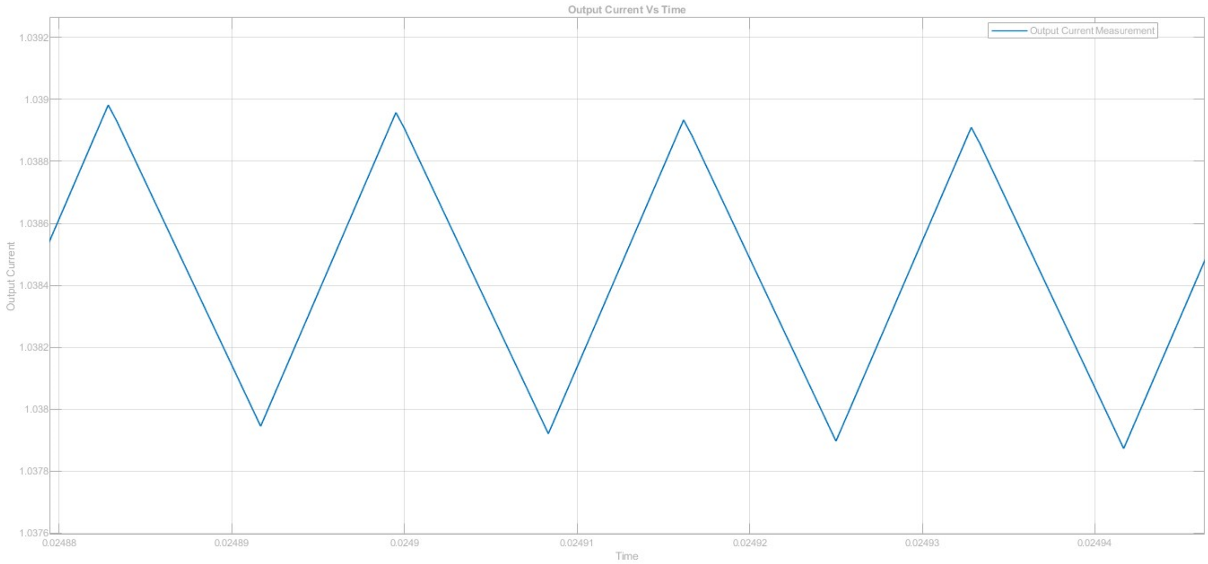


**Figure 5.** Output Current of Ideal Condition

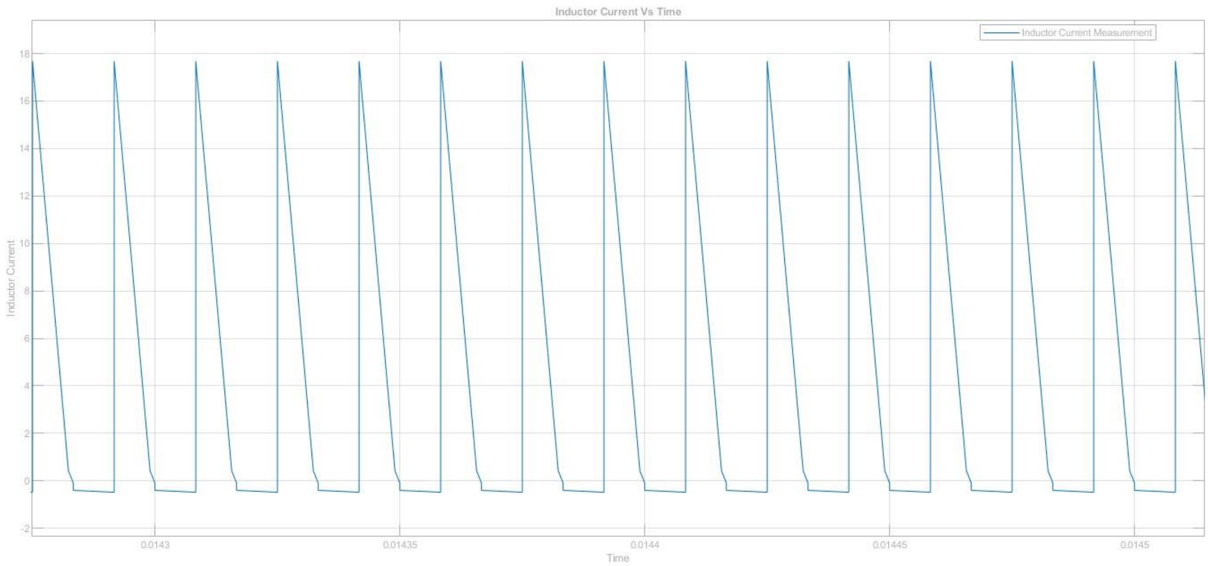


**Figure 6.** Primary Winding Current of Ideal Condition

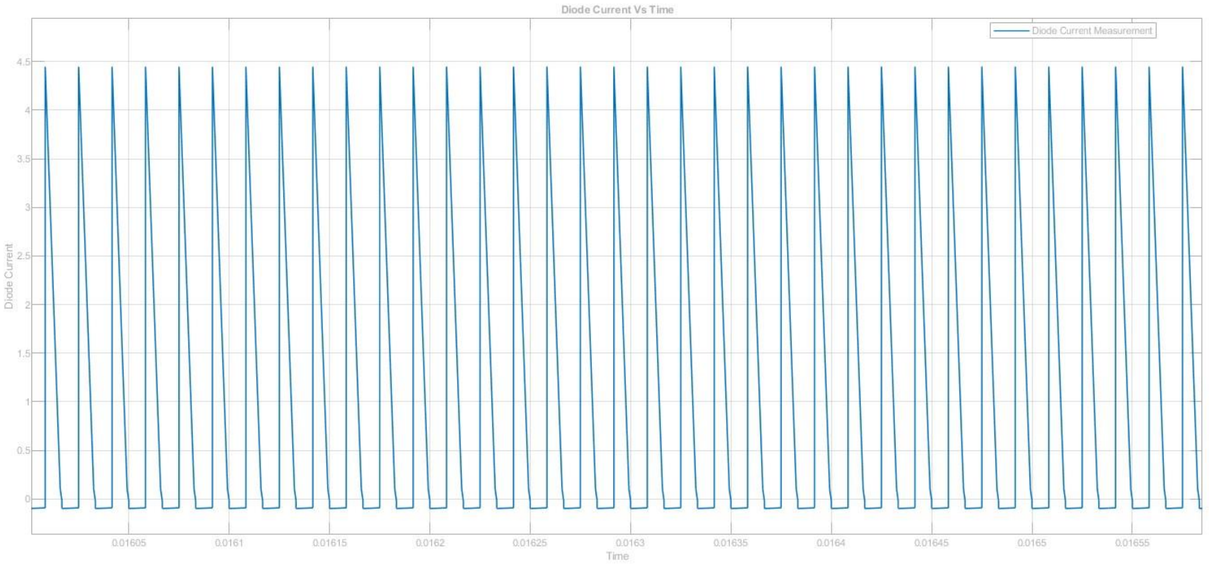


**Figure 7.** Output Diode Current of Ideal Condition

## Efficiency Calculation

$$P_{cond,MOS} = I_p^2 * R_{ds} = 7.26^2 * 0.044 = 2.32W$$

$$P_{sw,MOS} = V_{in} * I * f * \left(t_r + t_f\right) = 18 * 7.26 * 60kHz * (35 + 35)ns = 0.55W$$

$$P_{cond,Diode} = I_s * V_{d(on)} = 3.63 * 0.84 = 3.05W$$

$$P_{core} = 46.32 * 0.2^{1.988} * 60^{1.541} = 1.038\ W$$

$$P_{cu} = 7.26^2 * 2.1 * 10^{-3} + 3.63^2 * 3.67 * 10^{-3} = 159\ mW$$

$$P_{loss} = 2.32 + 0.55 + 3.05 + 1.04 + 0.16 = 7.12W$$

$$P_{in} = P_{out} + P_{loss} = 48 + 7.12 = 55.12W$$

$$\eta = \frac{48}{55.12} = 87.27\%$$

## Simulation of Non-Ideal Circuit

LTSpice program is used to simulate the converter with realistic non-ideal components. IRF1310 MOSFET is used as the equivalent of the MOSFET in the inventory. Appropriate ones from the Spice library were used for Zener and Schottky diodes. It is decided to use TI's UC3843 IC for the switching process. This IC is a current mode pwm controller. LT1243, which is the equivalent of this IC in LTSpice, is used for simulation. The feedback loop in the circuit is established using optocoupler. The op-amp compensation network was set up using the common values and gave the appropriate result. In the course of the project, the working mechanism of the compensation network will be learned and these values will be updated for the most appropriate situation. The snubber circuit was created using TI's Power Stage Designer program. The values of this circuit will also be updated for the optimal case. In the coming period the focus will be on increasing the efficiency of the converter.

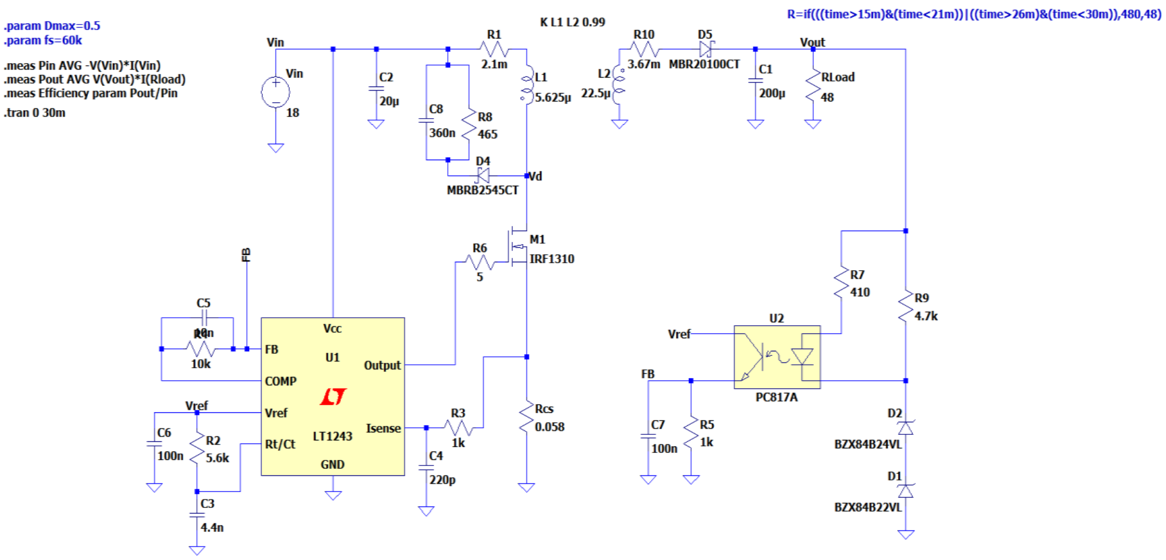


**Figure 8.** Flyback Converter Scheme on LTSpice

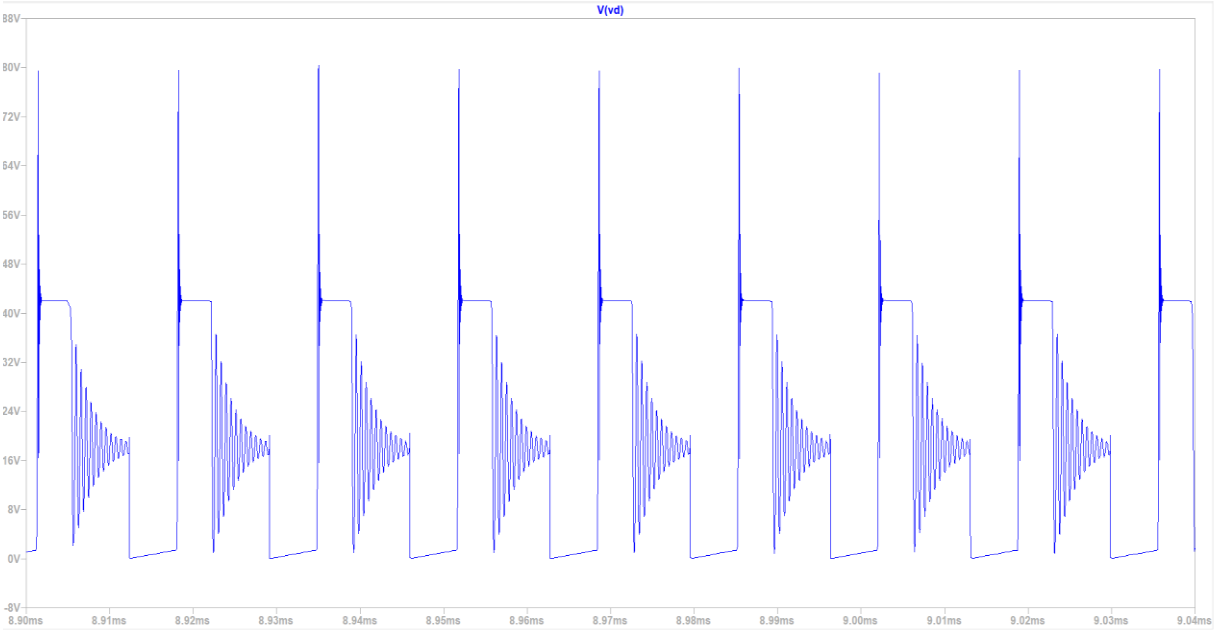


**Figure 9.** MOSFET Drain Voltage with no Snubber

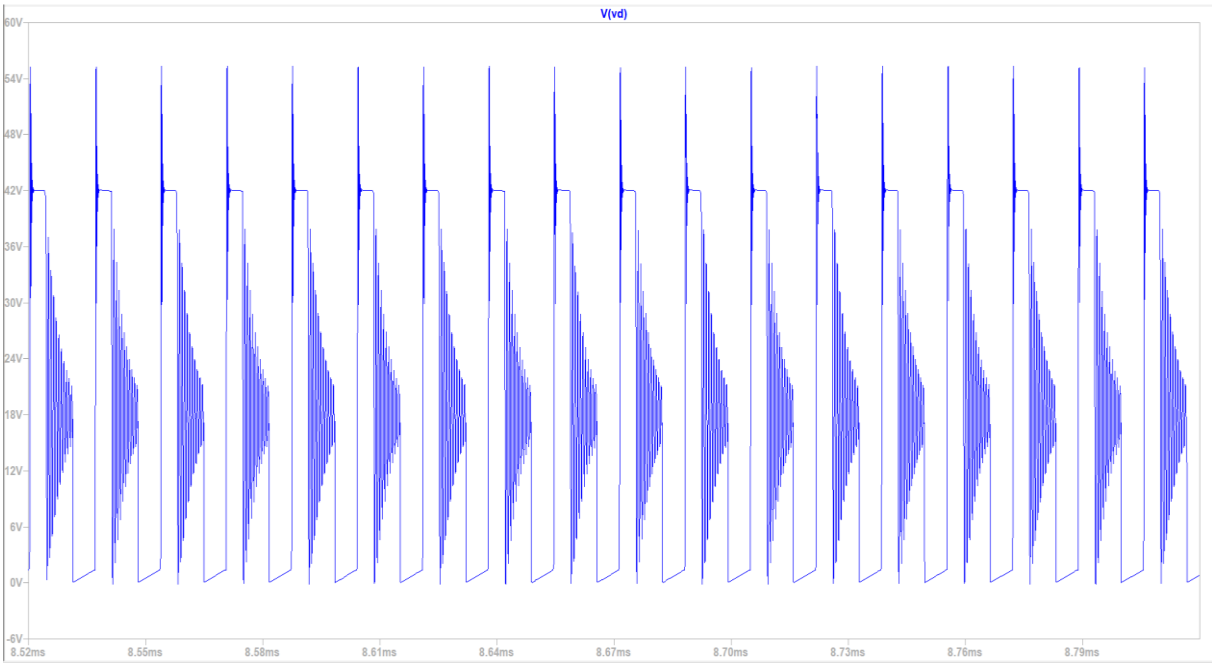


**Figure 10.** MOSFET Drain Voltage with Snubber

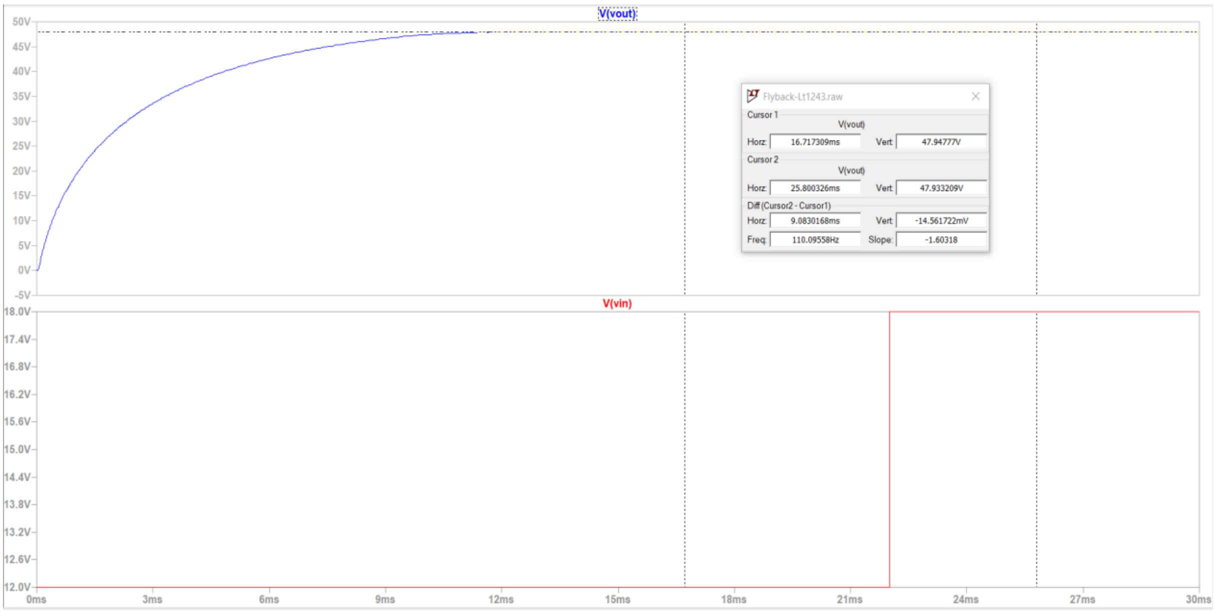


**Figure 11.** Converter's Reaction to Instant Input Voltage Change

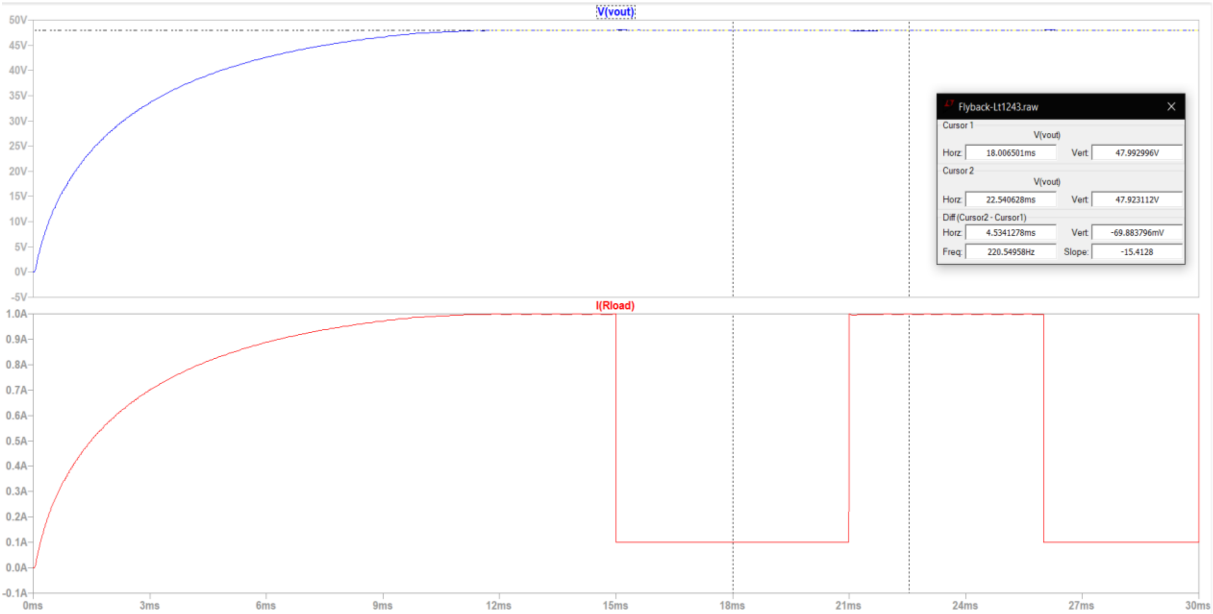


**Figure 12.** Converter's Reaction to Load Change at 12V

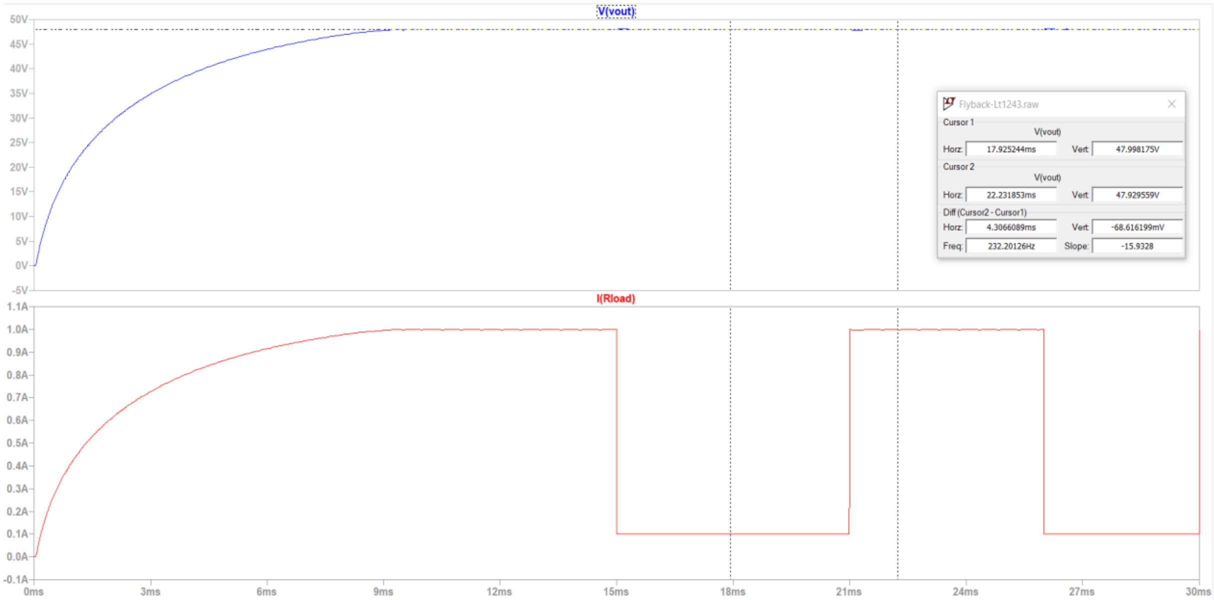


**Figure 13.** Converter's Reaction to Load Change at 18V

## Simulation Cases

### 12V – 25% Load

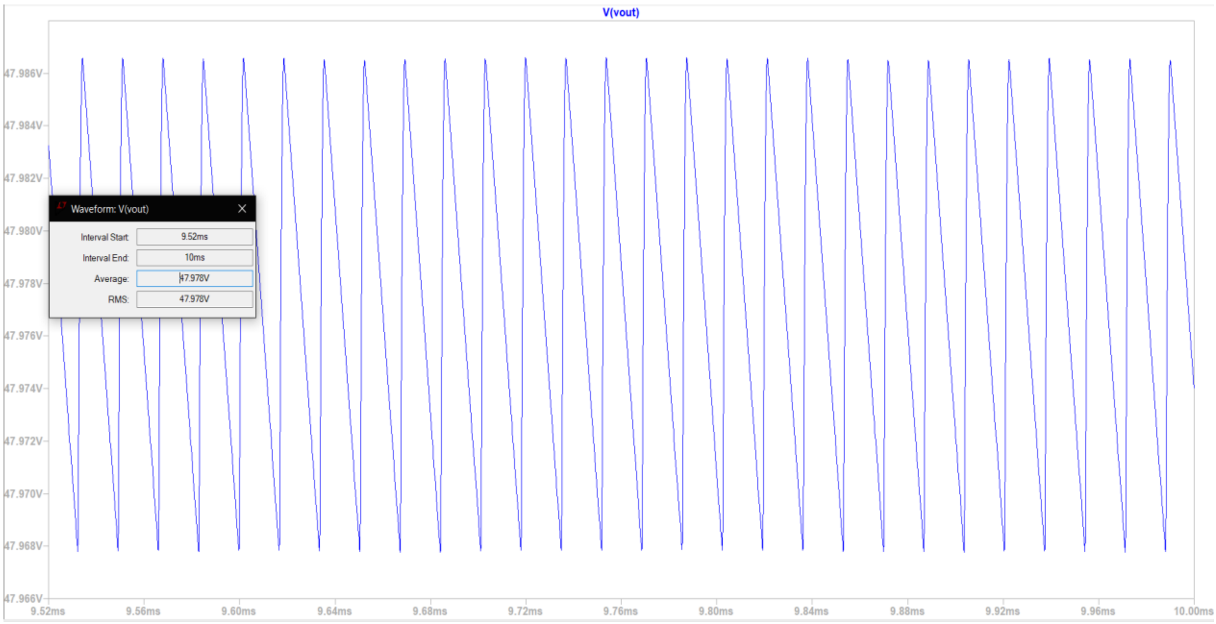


**Figure 14.** Output Voltage at 12V 25% Load

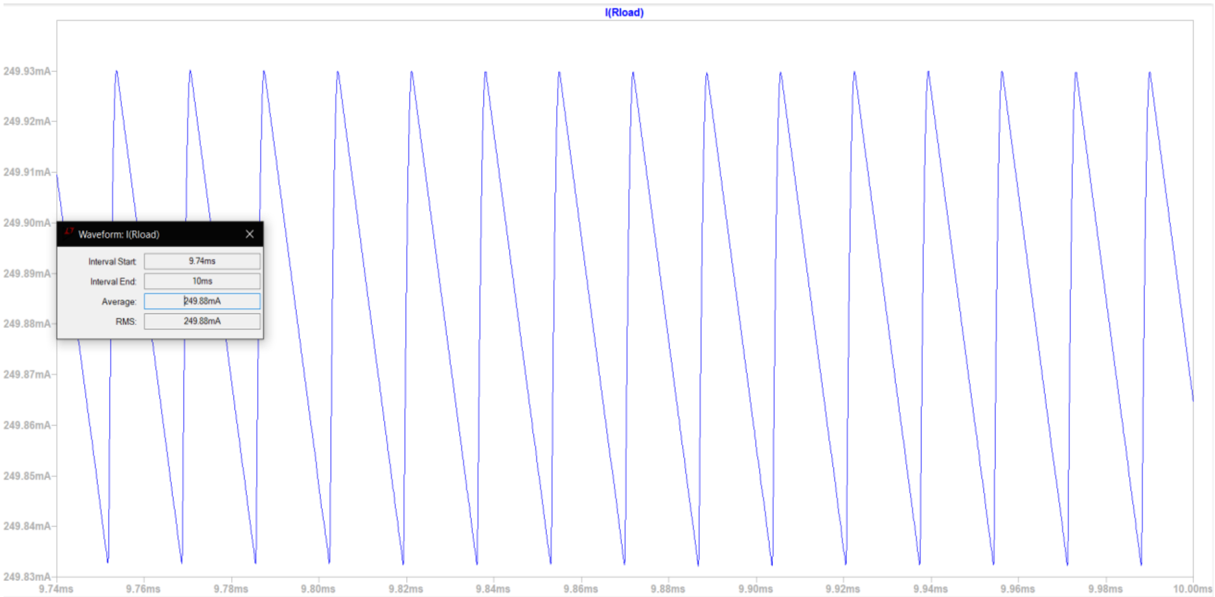


**Figure 15.** Load Current at 12V 25% Load

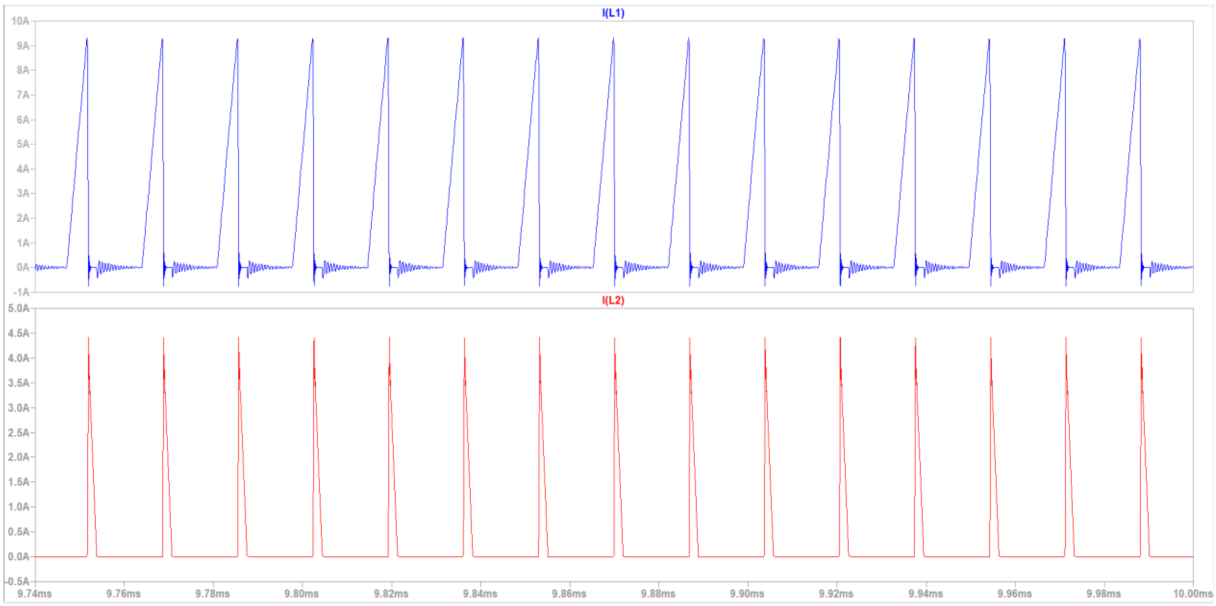


**Figure 16.** Winding Currents at 12V 25% Load

| | |
|---|---|
| **$P_{in}$** | 15.75 W |
| **$P_{out}$** | 11.99 W |
| **Efficiency** | 76.1% |

## 12V – 50% Load

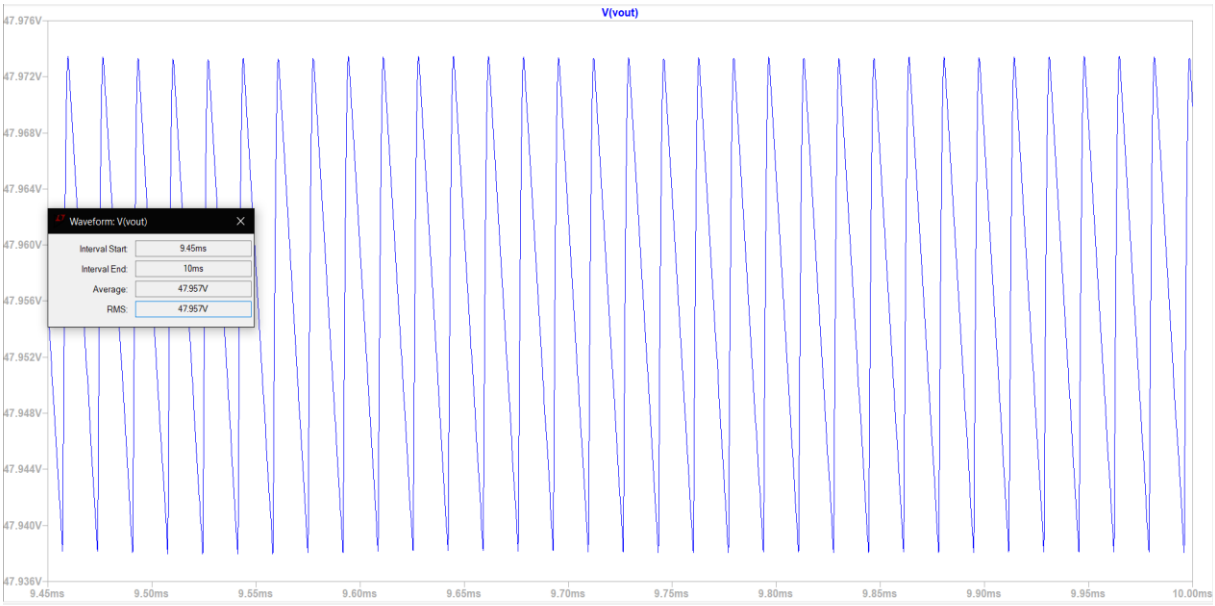


**Figure 17.** Output Voltage at 12V 50% Load

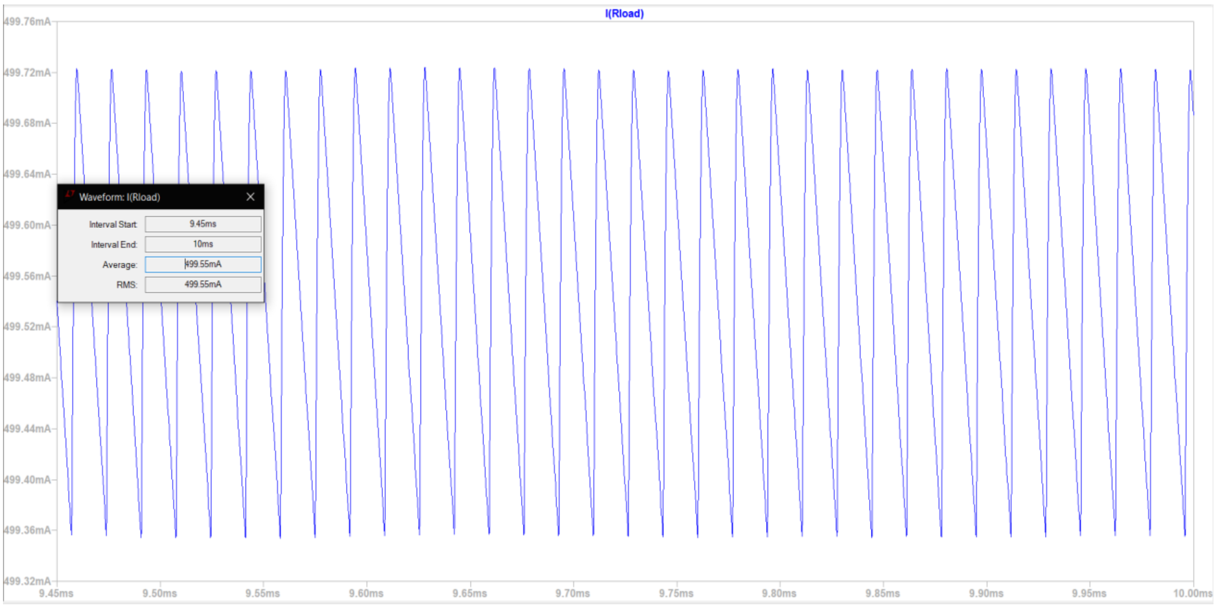


**Figure 18.** Load Current at 12V 50% Load

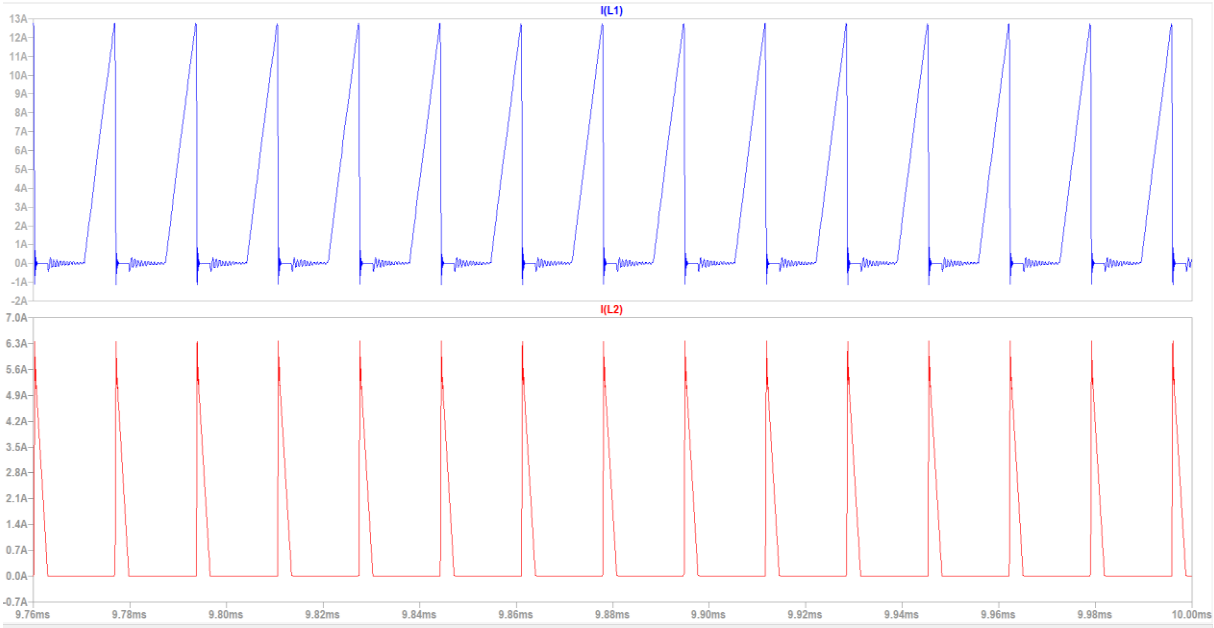


**Figure 19.** Transformer Currents at 12V 50% Load

| | |
|---|---|
| **$P_{in}$** | 29.89 W |
| **$P_{out}$** | 23.96 W |
| **Efficiency** | 80.15% |

## 12V – 75% Load

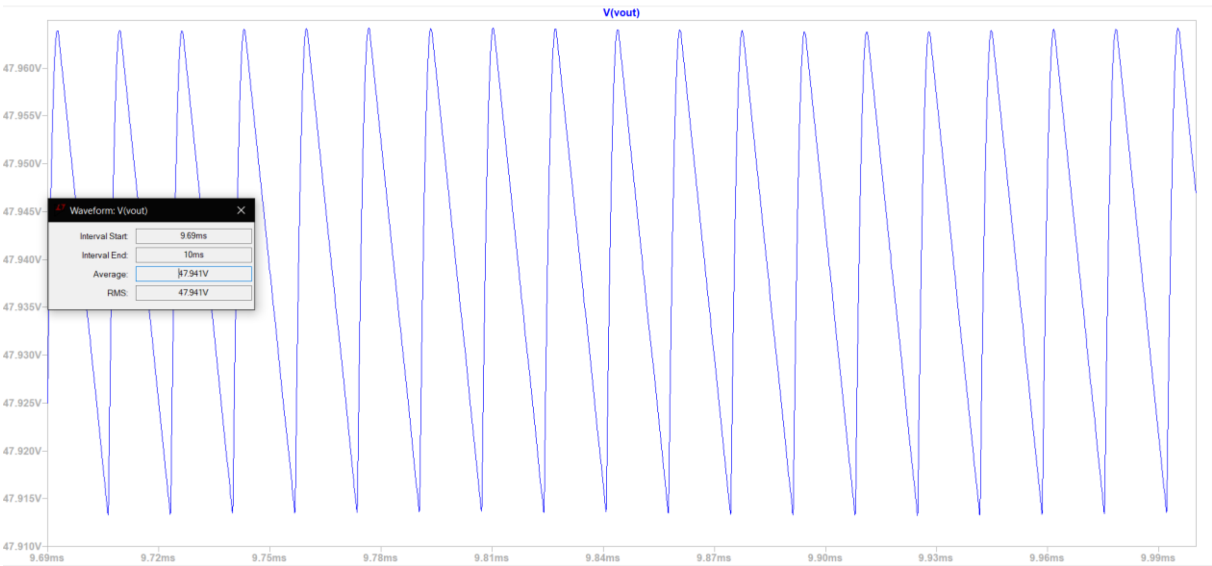


**Figure 20.** Output Voltage at 12V 75% Load

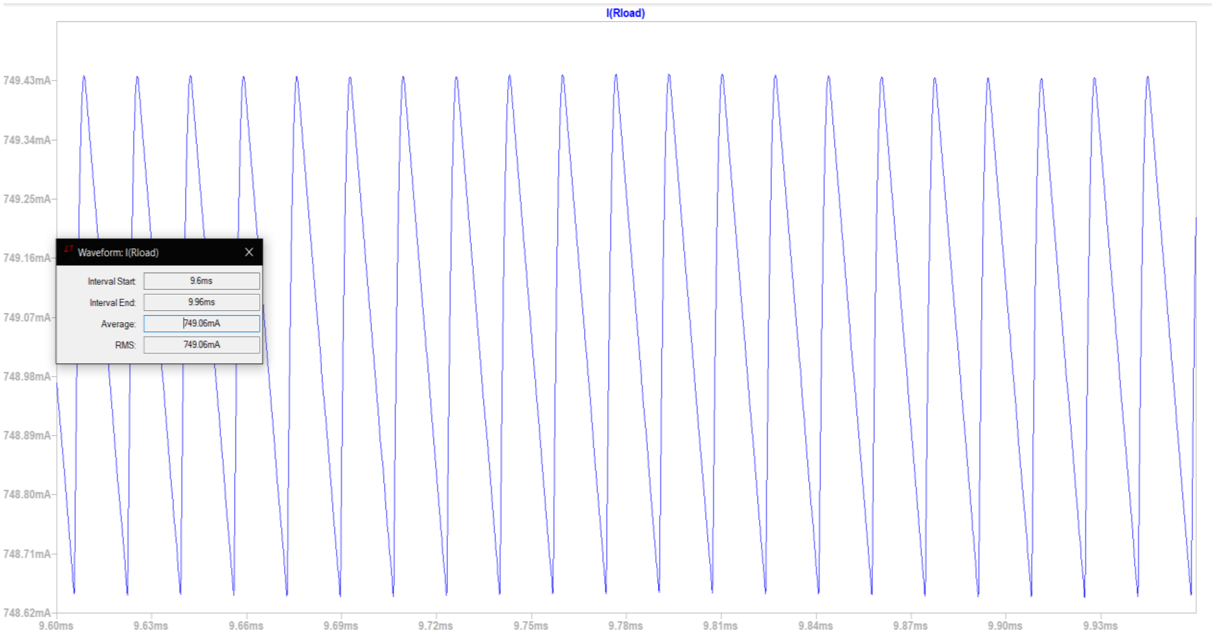


**Figure 21.** Load Current at 12V 75% Load

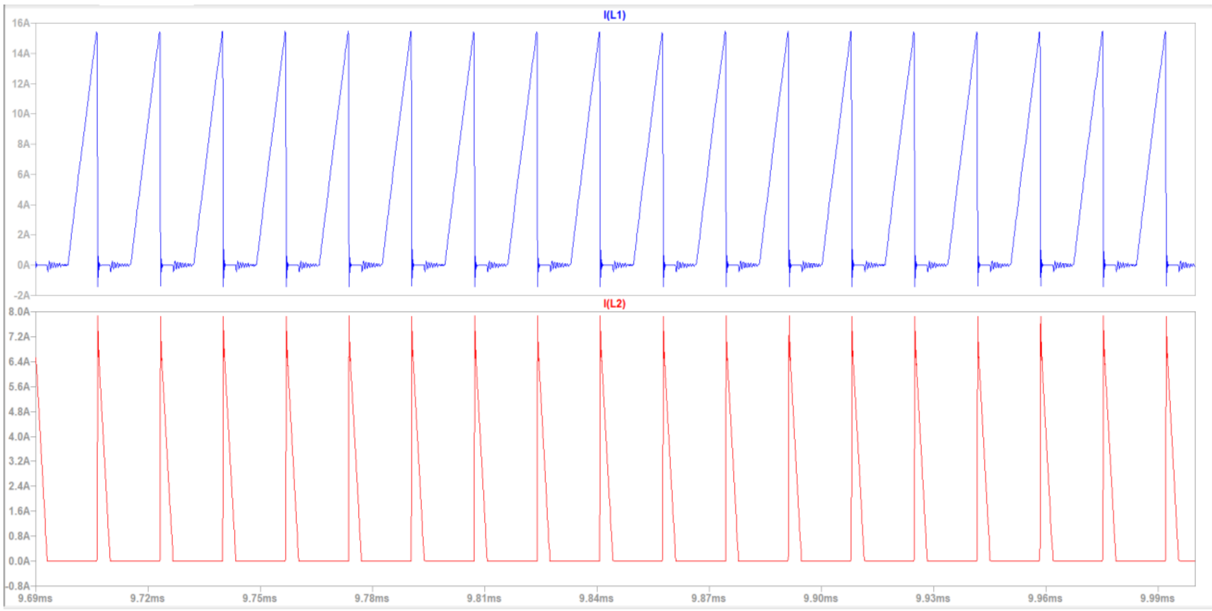


**Figure 22.** Transformer Winding Currents at 12V 75% Load

| | |
|---|---|
| **$P_{in}$** | 44.23 W |
| **$P_{out}$** | 35.91 W |
| **Efficiency** | 81.18% |

## 12V – 100% Load

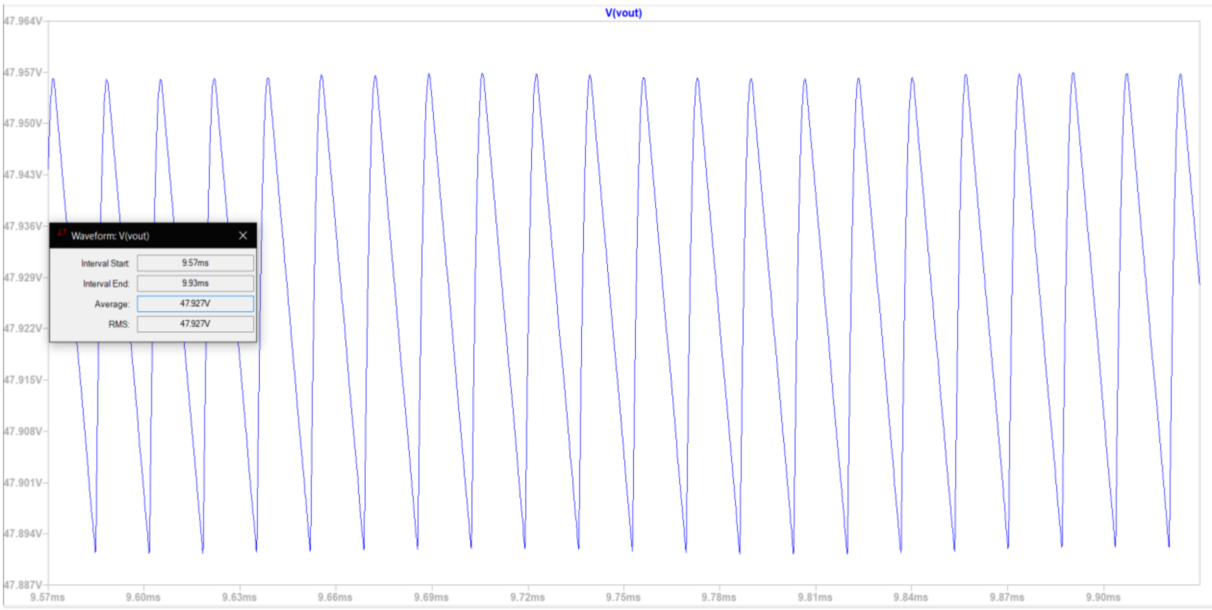


**Figure 23.** Output Voltage at 12V 100% Load

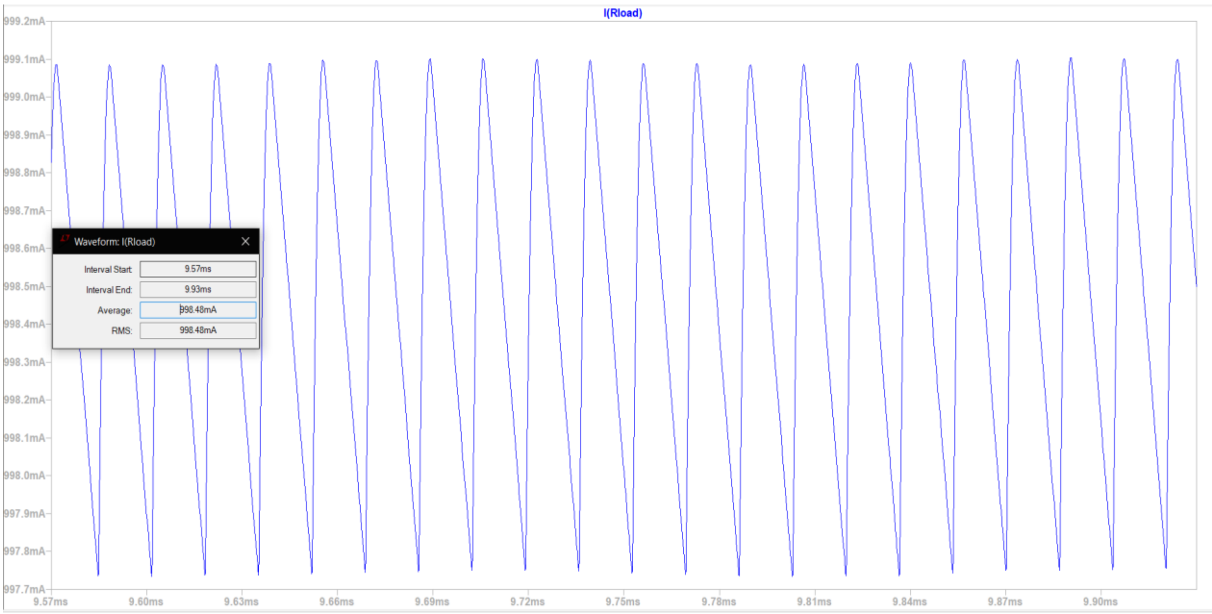


**Figure 24.** Load Current at 12V 100% Load

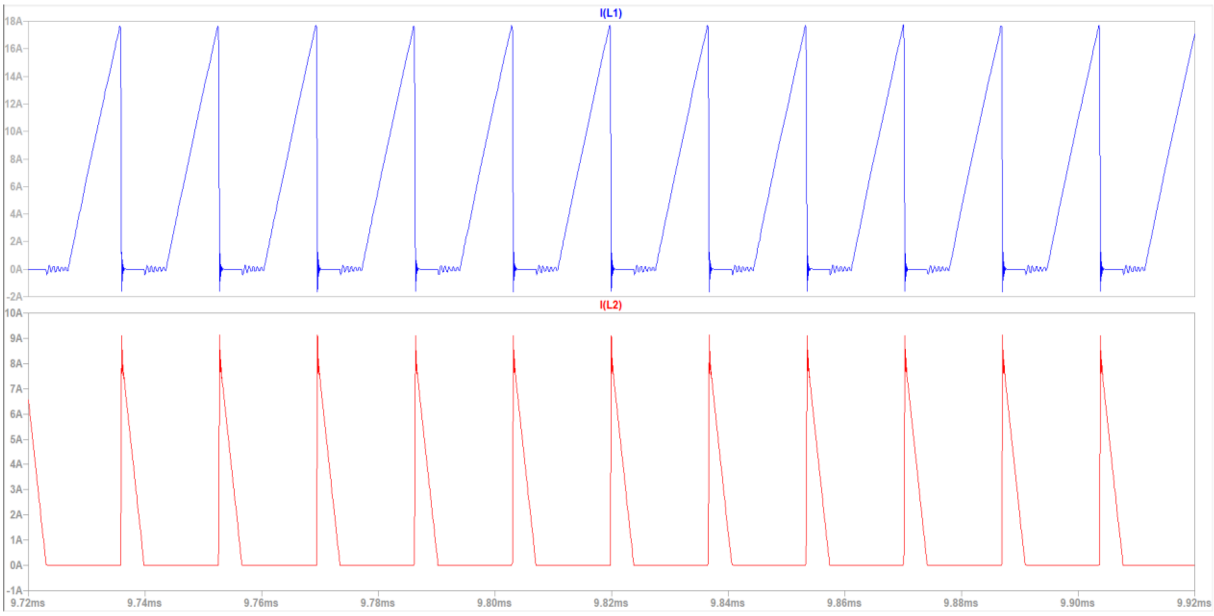


**Figure 25.** Transformer Winding Currents at 12V 100% Load

| | |
|---|---|
| **$P_{in}$** | 58.76 W |
| **$P_{out}$** | 47.85 W |
| **Efficiency** | 81.43% |

## 18V – 25% Load

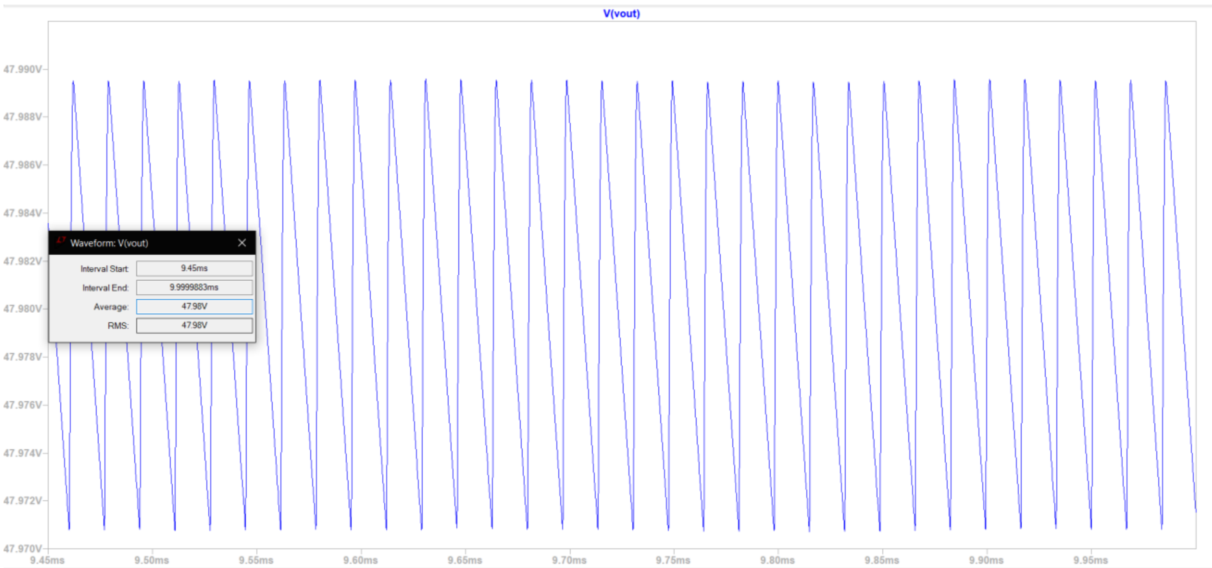


**Figure 26.** Output Voltage at 18V 25% Load

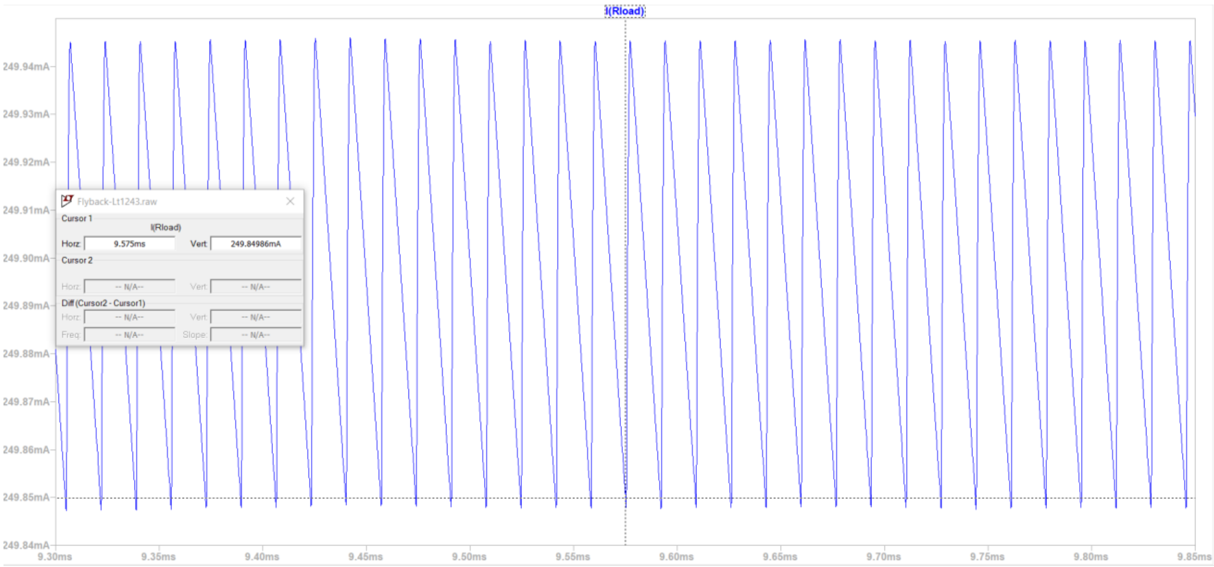


**Figure 27.** Load Current at 18V 25% Load

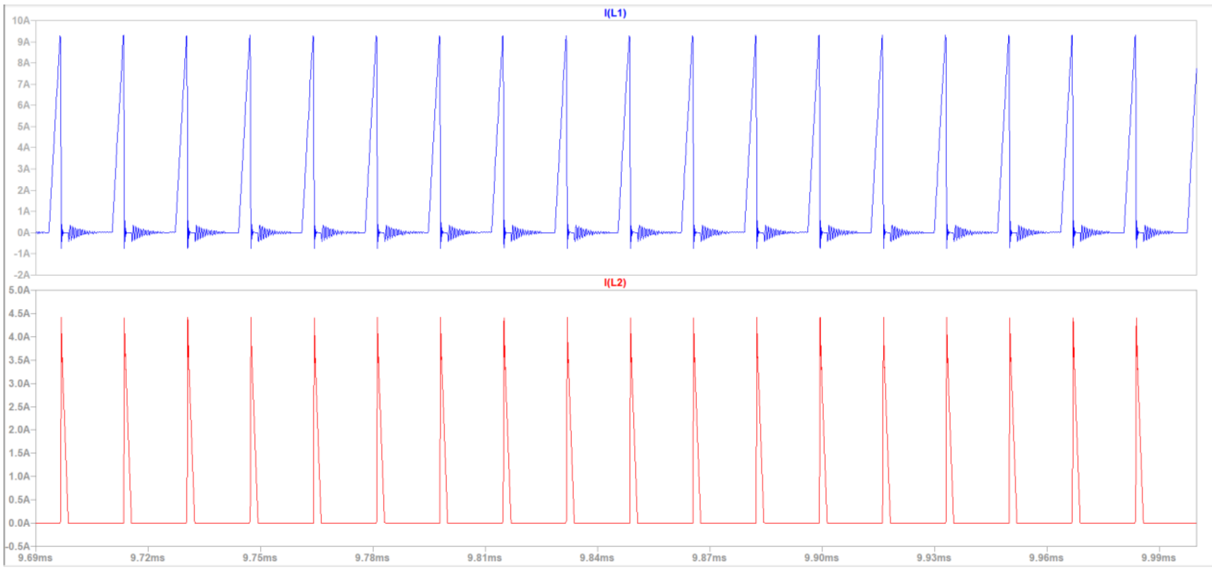


**Figure 28.** Winding Currents at 18V 25% Load

| | |
|---|---|
| $\mathbf{P_{in}}$ | 15.91 W |
| $\mathbf{P_{out}}$ | 11.99 W |
| **Efficiency** | 75.36% |

## 18V – 50% Load

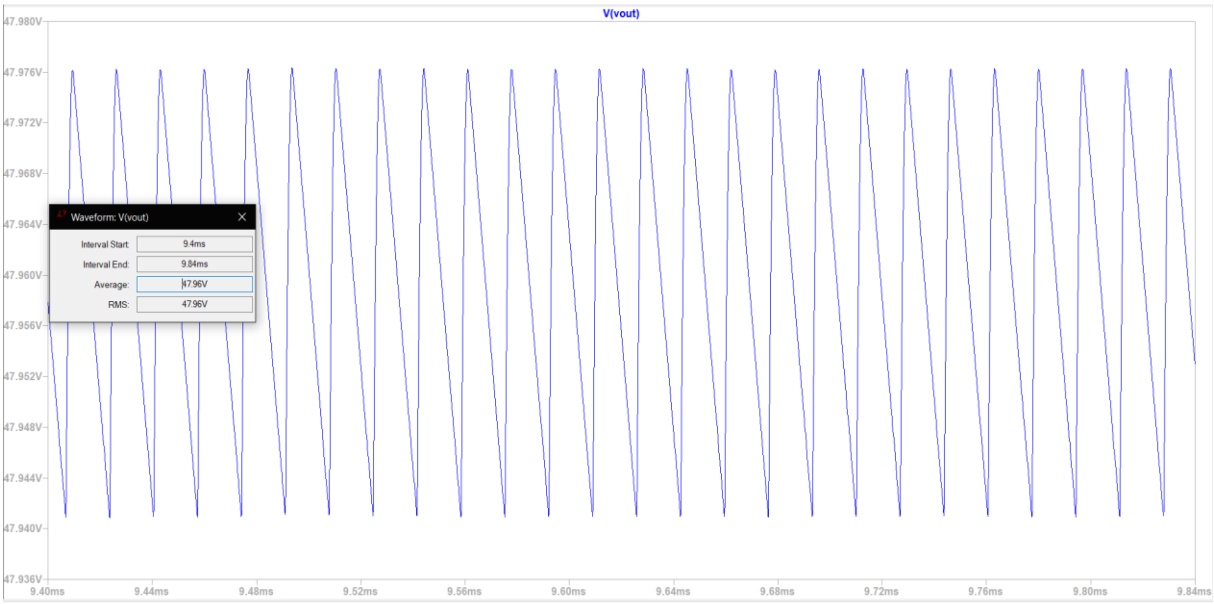


**Figure 29.** Output Voltage at 18V 50% Load

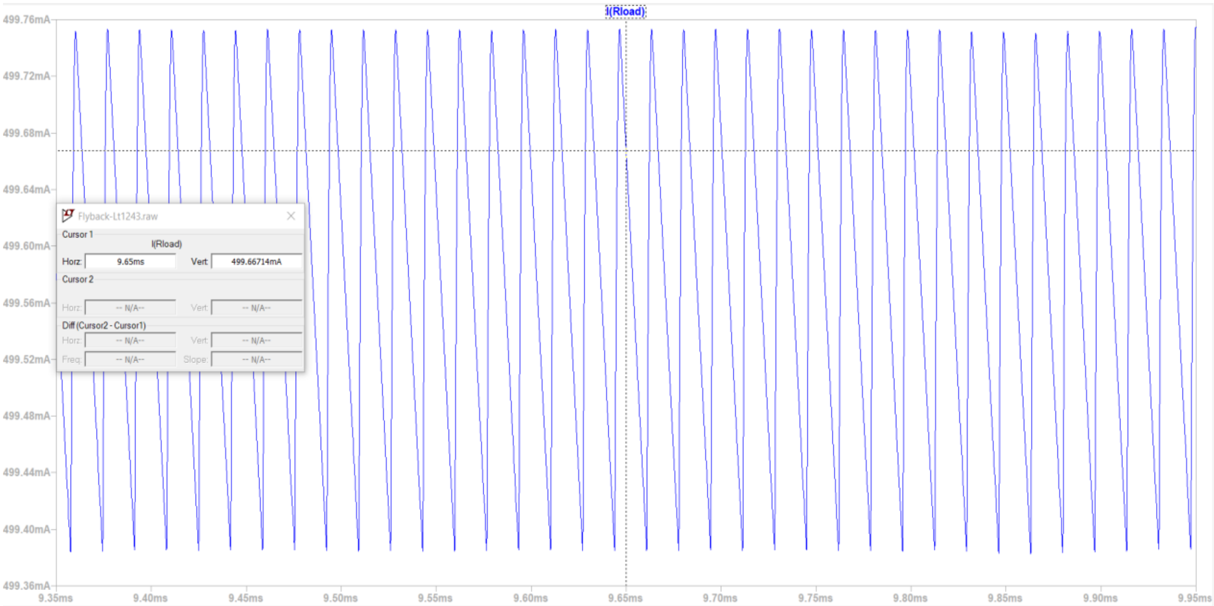


**Figure 30.** Load Current at 18V 50% Load

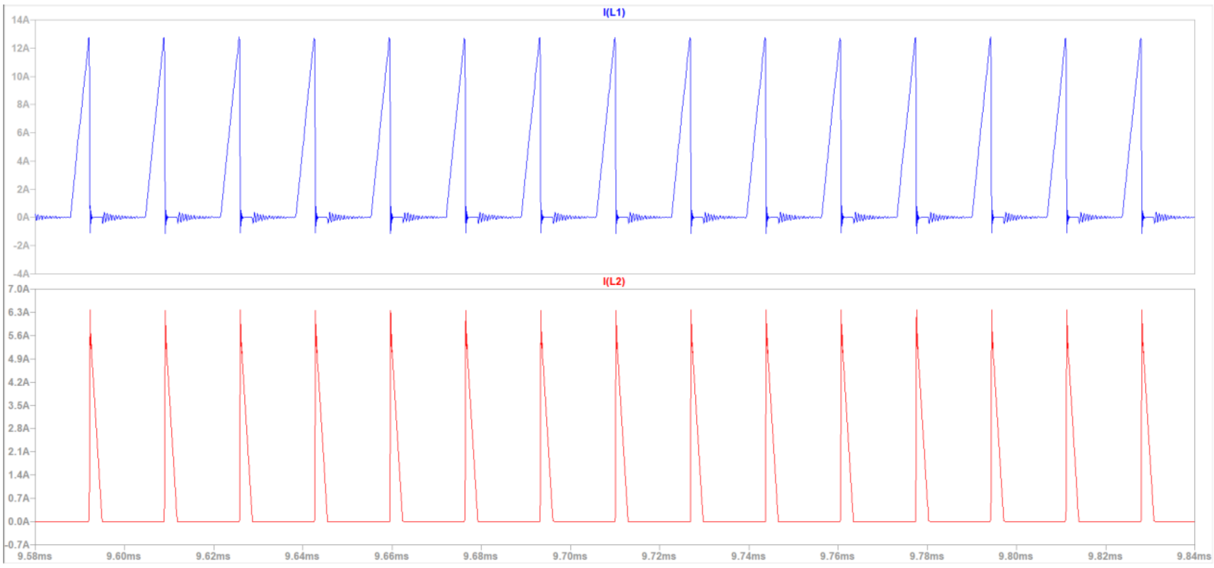


**Figure 31.** Transformer Winding Currents at 18V 50% Load

| | |
|---|---|
| **$P_{in}$** | 29.73 W |
| **$P_{out}$** | 23.96 W |
| **Efficiency** | 80.60% |

## 18V – 75% Load

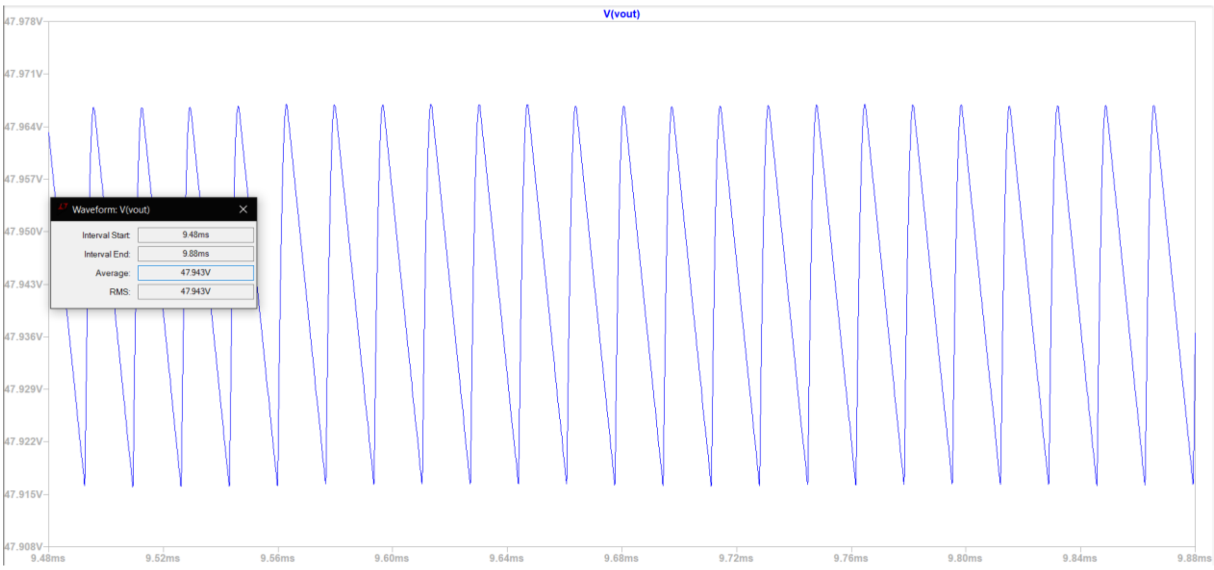


**Figure 32.** Output Voltage at 18V 75% Load

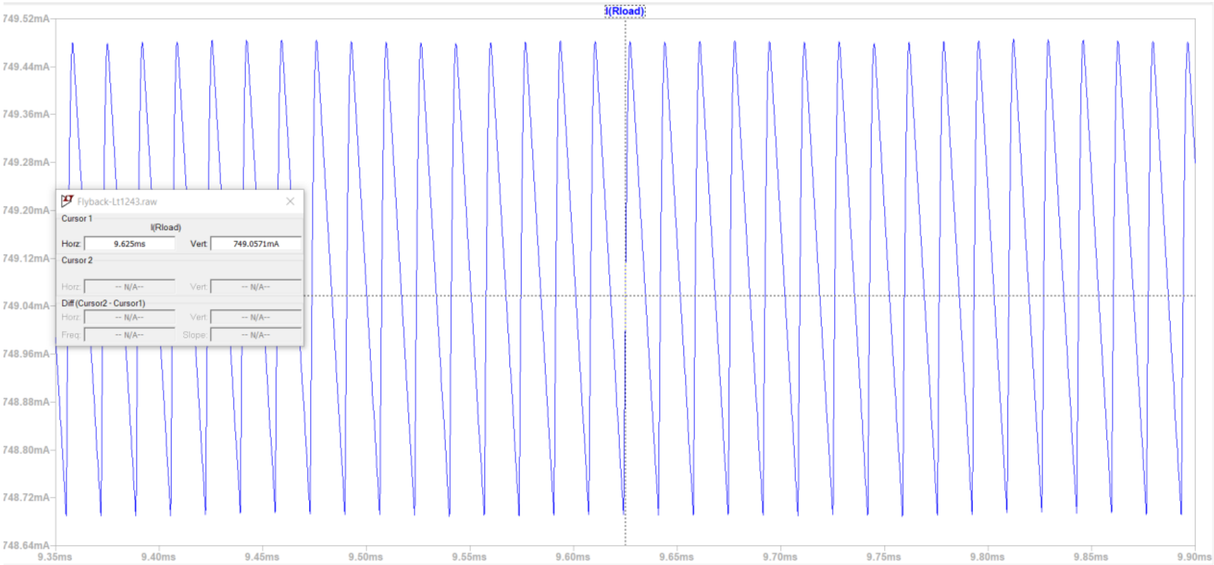


**Figure 33.** Load Current at 18V 75% Load

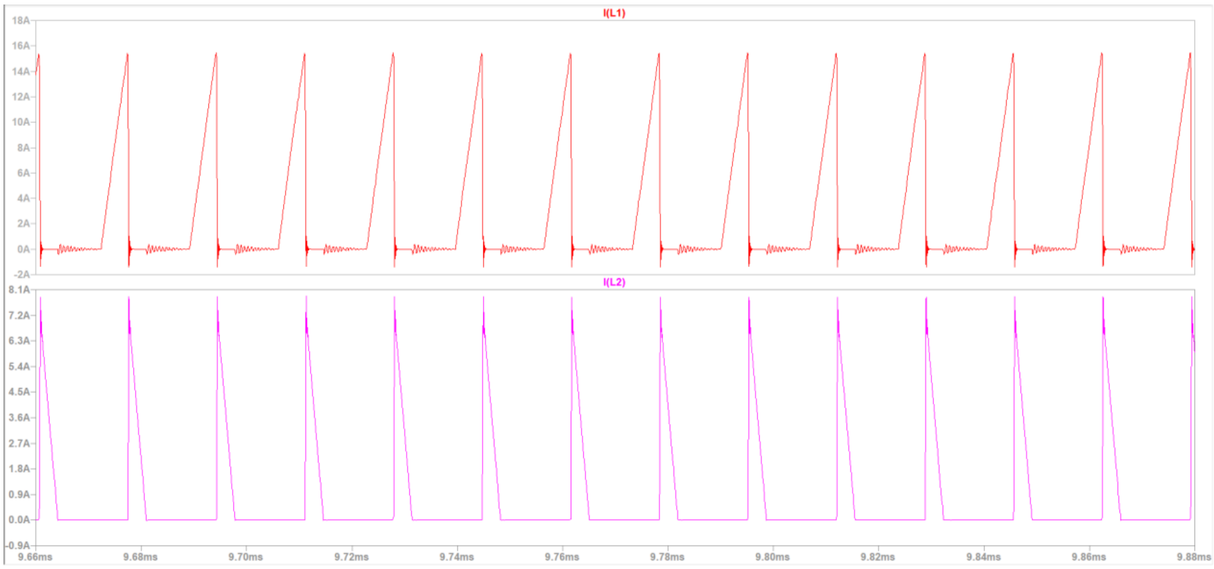


**Figure 34.** Transformer Winding Currents at 18V 75% Load

| | |
|---|---|
| **$P_{in}$** | 43.57 W |
| **$P_{out}$** | 35.91 W |
| **Efficiency** | 82.43% |

## 18V – 100% Load


**Figure 35.** Output Voltage at 18V 100% Load

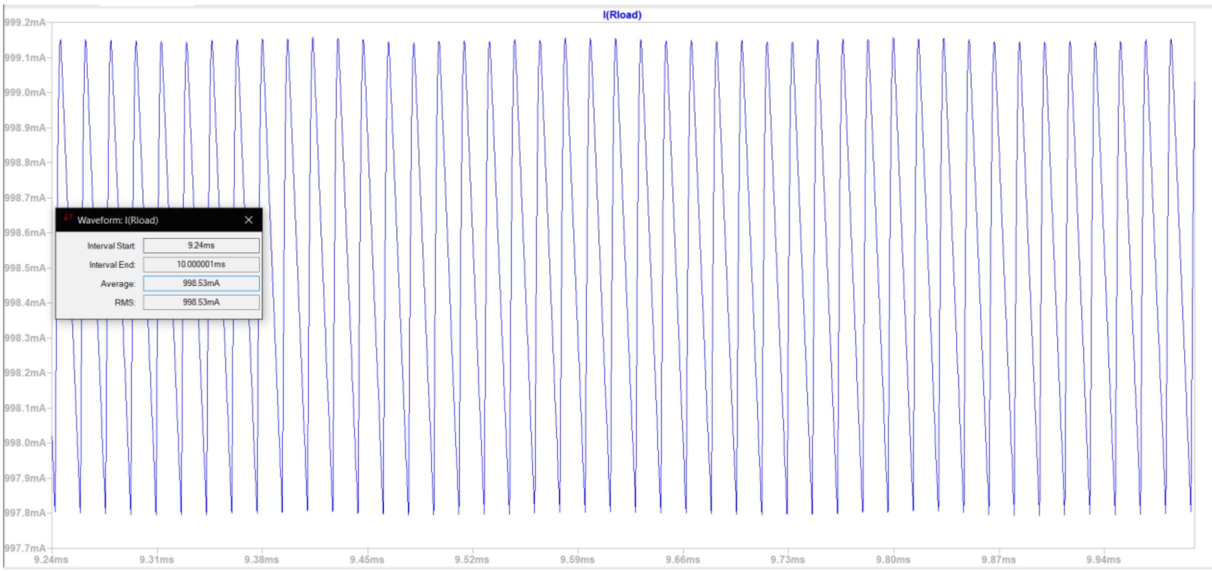


**Figure 36.** Load Current at 18V 100% Load

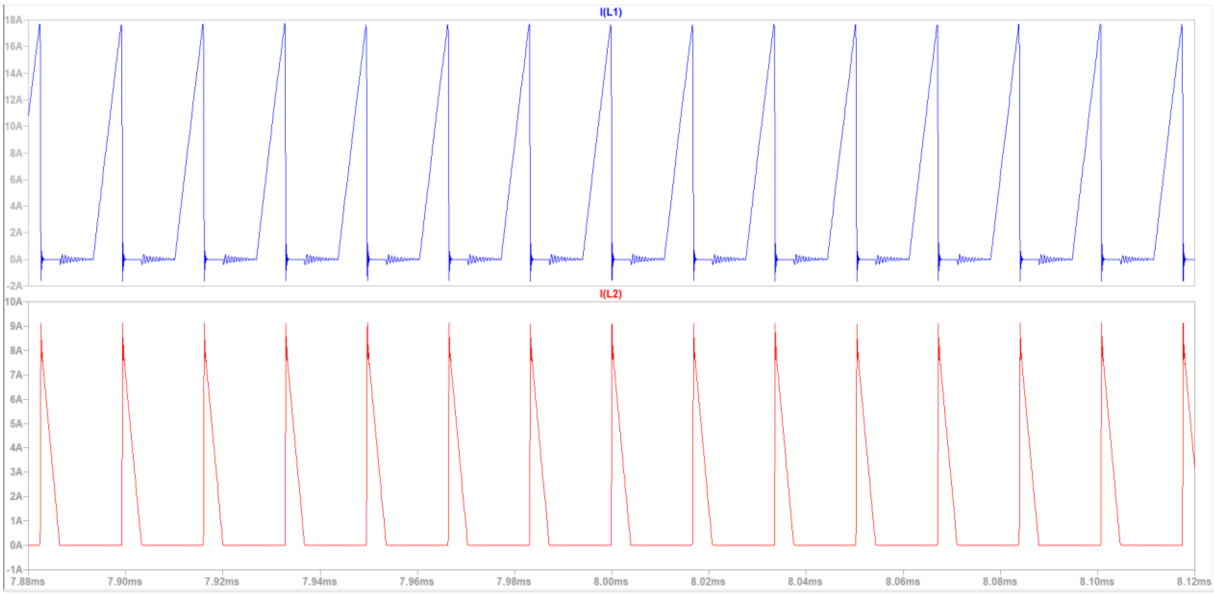


**Figure 37.** Transformer Winding Currents at 18V 100% Load

| | |
|---|---|
| **$P_{in}$** | 57.44 W |
| **$P_{out}$** | 47.86 W |
| **Efficiency** | 83.31% |