Steady-State Characteristics of Voltage Regulators

Part II: Switching Regulators

This document will guide you through the measurement of the steady-state characteristics of two switching regulators: a buck converter with 2.5V/2A output and a boost converter with 24V/1.9A output.

The objective of this lab is to extrapolate the following steady-state characteristics of the regulators:

1) Line regulation $\frac{\Delta V_{OUT}}{\Delta V_{IN}}$
2) Load regulation $\frac{\Delta V_{OUT}}{\Delta I_{OUT}}$
3) Efficiency $\eta = \frac{P_{OUT}}{P_{IN}}$

These parameters will be calculated using voltage/current data obtained through a semi-automated testing rig specifically designed to test voltage regulators at different operating conditions.

You will also perform separate steady-state measurements on the converter inductors, evaluating their peak-peak current swing and duty ratio.

1. Devices under test

For this lab experience, we will be using two boards part of the pre-release PMLK (Power Management Lab Kit) from Texas Instruments[1]. Each one of those boards host two different and independent buck and boost converters: we will be using only two of them during this lab, as specified below.

Please follow carefully the instructions given in section 5 and 6 to properly set-up the jumpers and avoid damaging the boards.

1.1. LM3475 buck controller

The TI LM3475 is a hysteretic buck controller with an external PMOS driver. The power stage consists of a Vishay Si2343CDS PMOS and a B120-130-F Schottky rectifier manufactured by Diodes. The inductor is a Coilcraft LPS5030-103M. Please refer to Figure 1 for a partial schematic of this circuit.

1.2. TPS55340 boost controller

The TI TPS55340 is a multi-purpose asynchronous switching controller with integrated NMOS switch. Besides supporting the boost topology (used on this board), this controller can also be used to build SEPIC and isolated flyback converters.

The discrete part of the power stage consists of a B540-13-F Schottky rectifier by Diodes and a MSS1278-103MLB inductor from Coilcraft. A partial schematic is shown in Figure 2.

[1] https://university.ti.com/faculty/teaching-materials-and-classroom-resources/ti-based-teaching-kits-for-analog-and-power-design/power-management-lab-kit-series

2. Test instrumentation

The test rig is composed of an electronic load (Keysight N3300A) and a bench power supply (Keithley 2260B-80-13), both having remote control and measurement capabilities. The instruments are interfaced and controlled by a MATLAB script running on a host computer.

This setup allows you to perform automatic load (output current) and line (input voltage) sweeps. The script stores the input / output voltage and current measurements in a CSV (Comma-Separated Values) file.

In addition to the instrumentation described above, an AC current probe (Tektronix P6022) is used to measure the inductor current waveforms. You can change the current-to-voltage conversion ratio by toggling the switch present on the probe termination. Please notice the polarity of the probe jaw, which is printed on its tip.

3. Measurements to be performed

You will also measure the inductor current waveforms for both converters, but only at two specific operating points for each topology. The waveform characteristics you should note are the peak-peak current ripple and the duty ratio.

3.1. LM3475 buck converter

The buck converter outputs 2.5V and can source up to 2A of current, the supported input range is 5V to 10V; We will test the buck with loads going from 100mA to 2A. Choosing a suitable number of intermediate points is left to the reader. Repeat the load sweeps with V_{IN}=5V and 10V.

Afterwards, you should measure the inductor current waveform at the operating points specified below:

- V_{IN}=5V I_{OUT}=750mA
- V_{IN}=10V I_{OUT}=750mA

Since this buck controller is hysteretic, the switching frequency is not guaranteed to be constant; you are thus advised to perform a single-shot acquisition with the scope and chose one switching period to extract your measurements from.

3.2. TP55340 boost converter

The boost converter is significantly more powerful than the buck: it is nominally rated for 1.9A output at 24V.

The TPS55340 has an internal cycle-by-cycle current limiter that trips when the switch current exceeds 5A: to avoid operating outside of this boundary, we will test the boost with loads ranging from 50mA to 1.25A maximum. Choosing a suitable number of intermediate current steps is left to the reader. Load sweeps should be performed with V_{IN}=7.5V and 12V.

Afterwards, you should measure the inductor current waveform at the operating points specified below:

- V_{IN}=7.5V I_{OUT}=1.25A
- V_{IN}=12V I_{OUT}=1.25A

4. Material checklist

- 1 Power Management Lab Kit (PMLK) buck board.
- 1 Power Management Lab Kit (PMLK) boost board.
- Wires.

- 1 Bench power supply (Keithley 2260B-80-13).
- 1 Electronic load (Agilent N3300 with N3302A module)

5. Board setup and test circuit for the LM3475

The LM3475 circuit hosted on the PMLK buck board can be identified by the caption printed on the silkscreen; a partial schematic of the circuit is reported in Figure 1.

This schematic only represents the circuit configuration used during this lab experience. In order to set it up properly you need to perform the following adjustments:

- Short jumper J24.

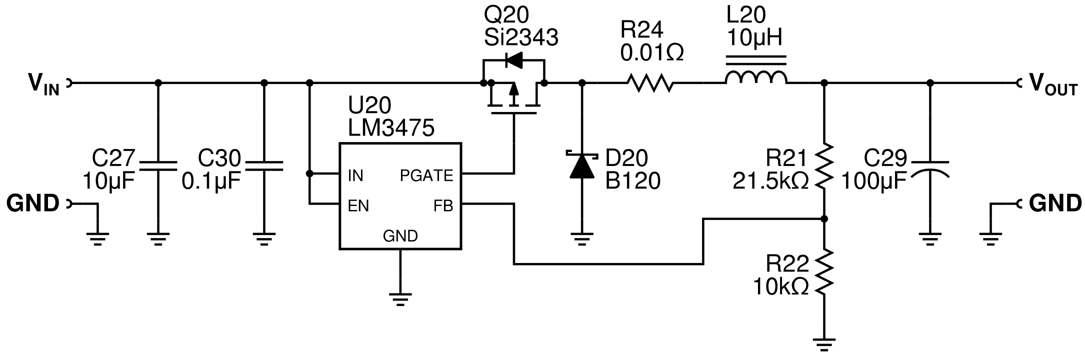

Figure 1. Partial schematic of the LM3475 buck circuit

6. Board setup and test circuit for the TPS55340

The TPS55340 circuit hosted on the PMLK boost board can be identified by the caption printed on the silkscreen; a partial schematic of the circuit is reported in Figure 2.

This schematic only represents the circuit configuration used during this lab experience. In order to set it up properly you need to perform the following adjustments:

- Short pins H6 and H7 using a high-current jumper.
- Short pins H1 and H5 using a high-current jumper.
- Short pins 1 and 2 of header J6.
- Short pins 1 and 2 of header J7.
- Short jumper J8.
- Short pins 1 and 2 of header J17.

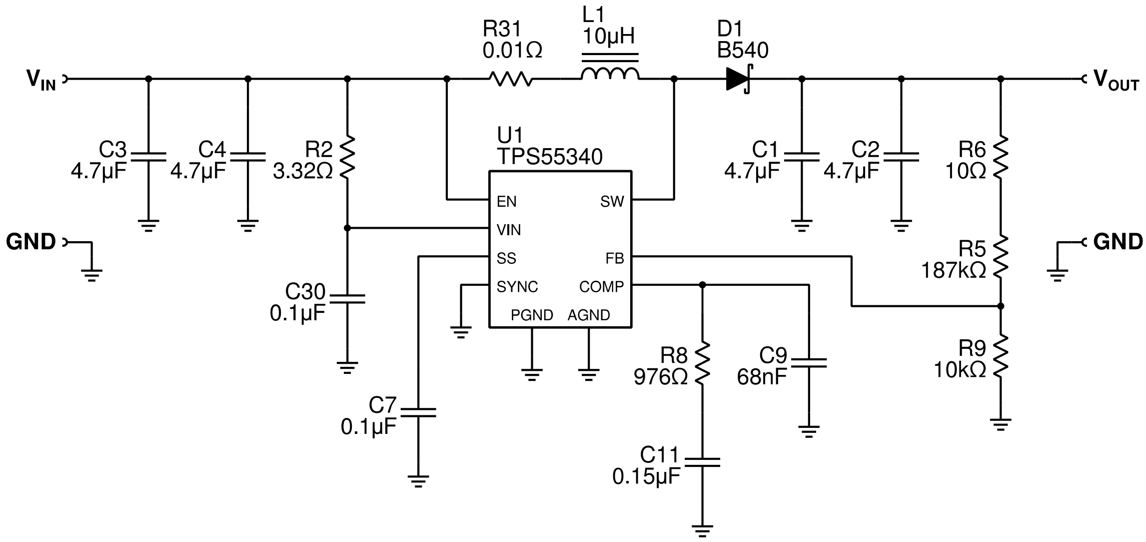

Figure 2. Partial schematic of the TPS55340 boost circuit

7. Test setup

Connect the device under test according to the drawing of Figure 3 (start with the buck). Proceed with the tests as explained in the following section.

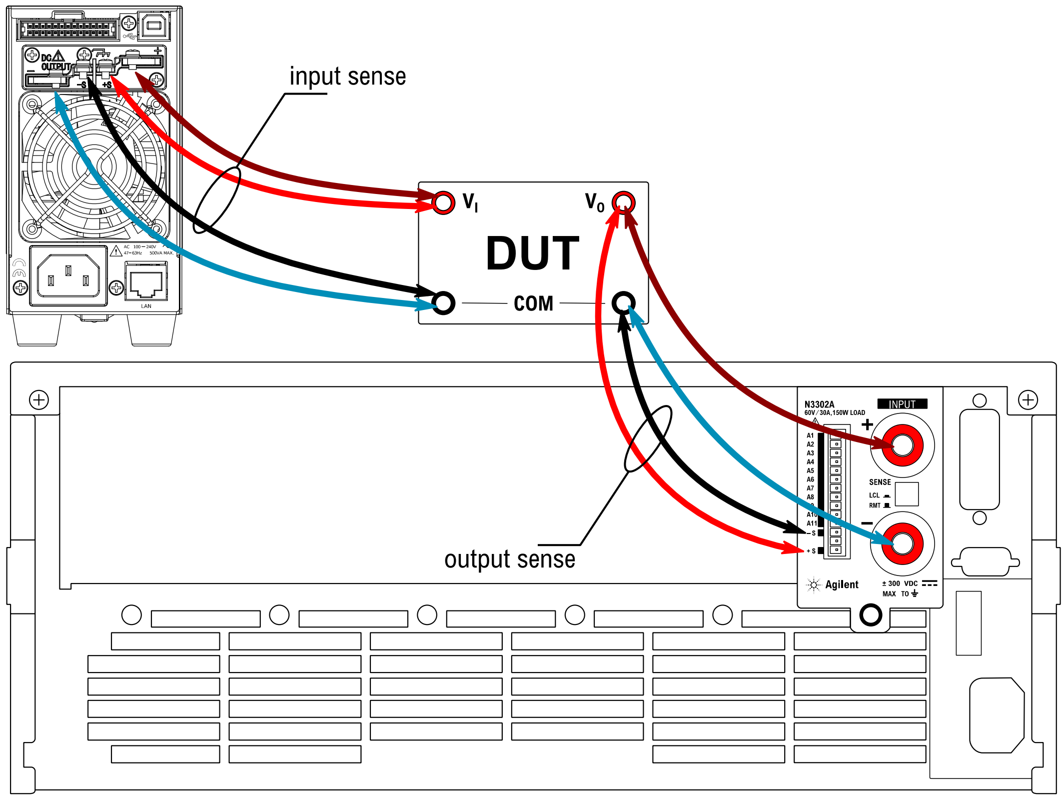

Figure 3. Measurement setup connections

During this lab experience, you will also need to use the AC current probe to measure the inductor current of both converters. Both boards provide an inductor current testpoint in the form of bare element resistors (R24 for the buck and R11 for the boost): simply clamp the current probe to the metal bar to start measuring the current. Make sure the jaw of the current probe is fully closed before starting the measurement.

8. Test procedure

Switch on the electronic load and the power supply.

Launch the MATLAB script and follow the on screen instructions. The script will ask the user for a list of input voltages and load currents in the form of a CSV file. Please have this file ready before starting the measurements.

The software will prompt you to save the data when the measurements are done. Remember to use meaningful filenames!

Perform all the measurements stated in section 3.1 for the LM3475.

After testing the first converter disconnect the circuit and attach the other one the same way. If the control script was interrupted mid-run, you should manually disable the electronic load first, before disabling the power supply. After you have connected the new device you can execute the script again.

Perform all the measurements stated in section 3.2 for the TPS55340.

9. Laboratory report

The report concerning this laboratory unit will be graded and is due at <*a currently unknown date*>. Such report should cover at least the following points:

Your lab report should cover at least the following points:

- Brief summary of the laboratory exercise.
- Line regulation, load regulation and efficiency plots for both devices, calculated from the measurements.
- Analysis of the results and explanation of how they were obtained.
- Comparison between the measured and theoretical duty ratios.
- Comparison between the measured and theoretical inductor ripple currents.
- Analysis of the results.

Please refer to the course teacher or teaching assistants for further information