Smart Systems Integrated Solutions Virtual Instrumentation, Testing and Validation course

Hardware in the Loop - Testing and Validation project (2023)

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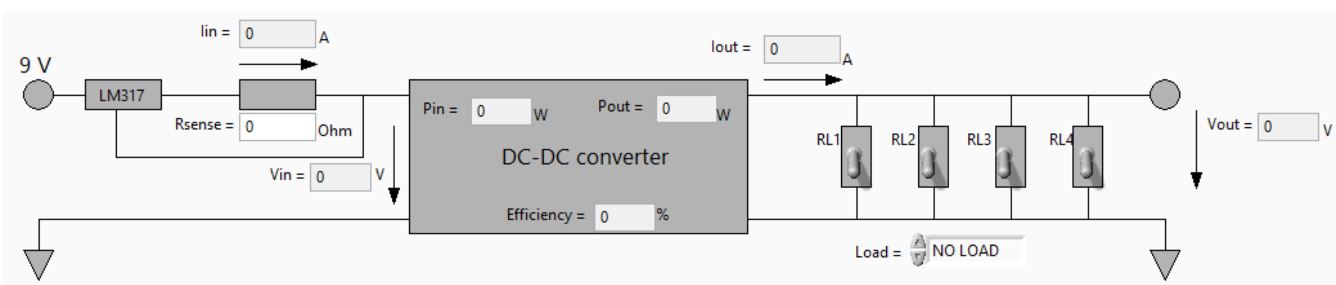
Task Description

The task is to validate the DUT device's performance which is subjected to a series of test loads. The DUT is a DC-DC converter unit (LM2596), operated from 9 VDC and supplying 3.0 VDC at the output. Whilst the DUT's load is changed between 1.3 Ohm and 10 Ohm following the test vector sequence, the following parameters are measured and/or calculated and validated:

- Input voltage
- Input current
- Input power
- Output voltage
- Output current
- Output power
- Efficiency

Pass criterion for the above values are to be defined for each tests based on the expected device performance. The purpose of the test is to identify possible design or construction errors of the DUT.

As depicted below, the load of the DUT is four parallelly connected resistors which can be activated or deactivated programmatically. The input current is limited by the LM317 regulator.



1. Open the schematic of the DUT tester circuit and the datasheet of the DUT. Identify the analog and digital input and output terminals to be used for the measurements. Analog signals of J1 terminal are wired to USB-6001. Make sure that the differential measurement is wired to a differential analog input. Make a block diagram here indicating the wirings and terminals only.

First, the device under test (DUT) was connected to the data acquisition device (DAQ), as shown in fig. 1. The interconnections made have been documented in table 1. The block diagram in fig. 2 shows the connections made between the DUT and the analog and digital terminals of the DAQ.

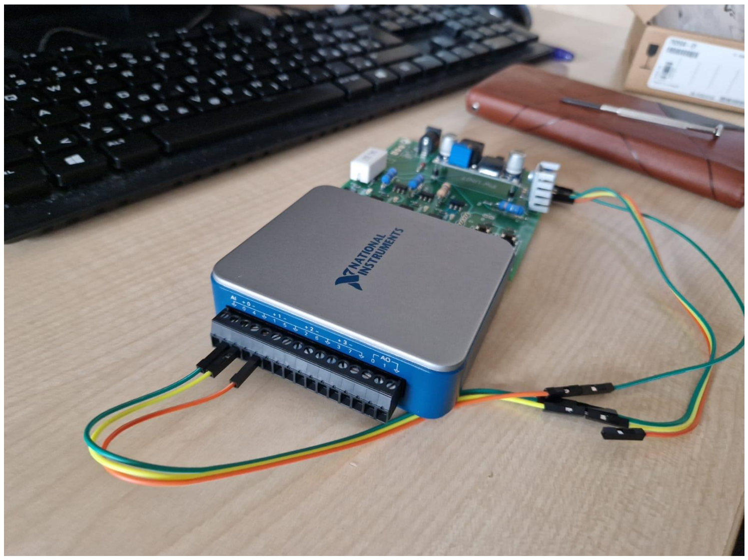


Figure 1. Connections from DUT to DAQ.

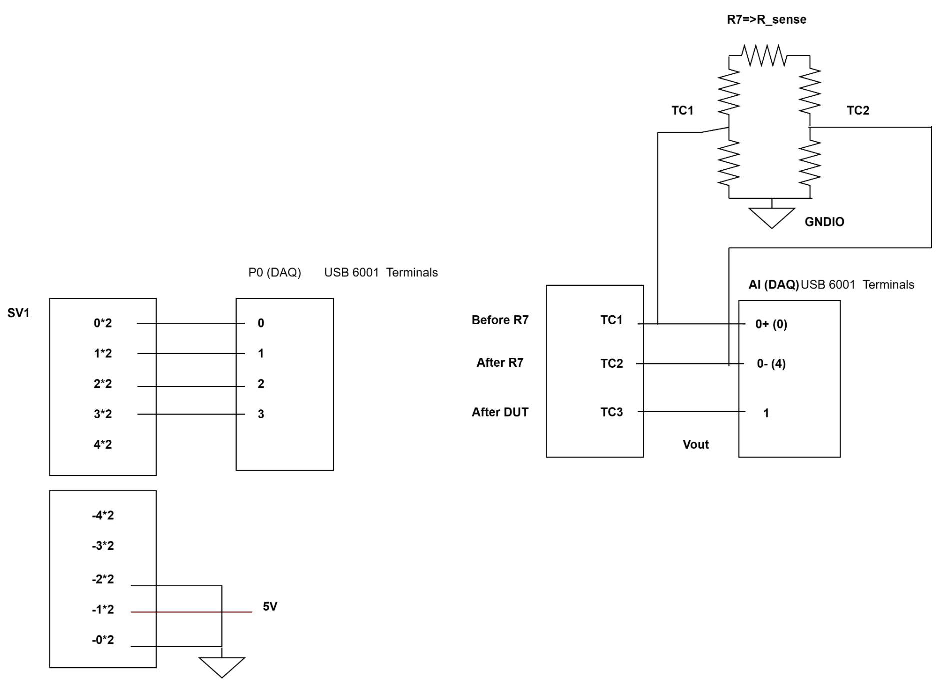


Figure 2. Block diagram

Table 1. Analog signals of J1 terminal are connected to USB 6001. The differential measurements from DUT are wired to the differential analog inputs of the DAQ

Terminal name (Test panel)	Terminal name (USB-6001)	Terminal type (A/line)	Description
SV1.02	P0.0	digital	R8 Resistor
SV1.12	P0.1	digital	R9 Resistor
SV1.22	P0.2	digital	R10 Resistor
SV1.32	P0.3	digital	R11 Resistor
SV1.42	P0.4	digital	-
J1.1	AI.0+	analog ai0	analog input 1 differential
J1.2	AI.4-	analog	analog input 2 differential
J1.3	AI.1	analog	output voltage (TC3)
SV1-1*2	+5V	line	5V
SV1-0*2	DGROUND	line	GND

2. Identify the following elements on the DUT tester panel: Load resistors, FETs for activate the loads, power inlet, signal terminals. Identify the elements with text arrows on the photo below.

Fig. 3 shows the identified elements and resistance values.

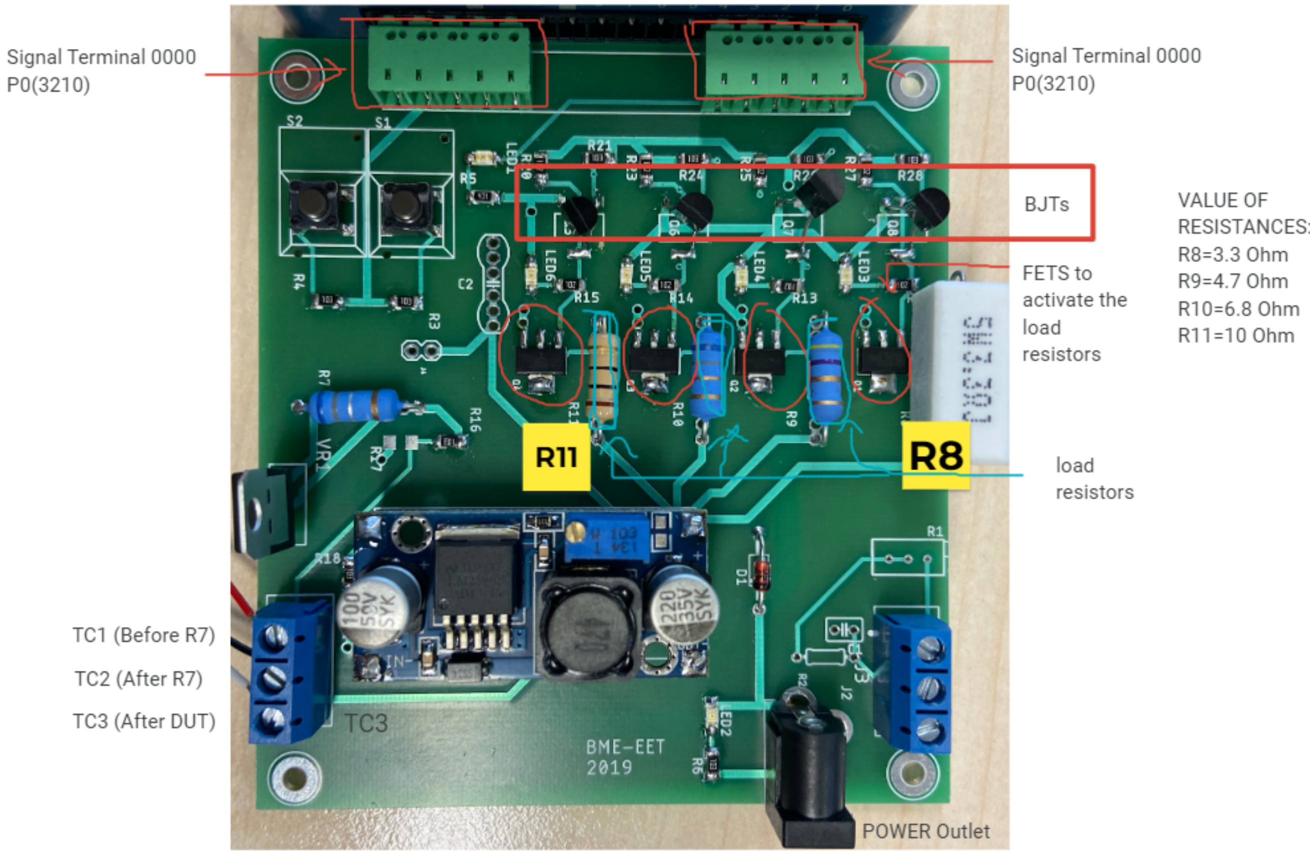


Figure 3. Identifying the components in the DUT.

3. Identify the resistance values of the load resistors.

Table 2 presents a summary of the identified resistance values.

Table 2. Load resistors

R8	**R9**	**R10**	**R11**
3.3	4.7 5%	6.8 5%	10 5%

4. Enumerate 8 out the 16 possible combinations of load resistors and their values. Ensure that the lowest and highest possible load values are included.

Table 3. Load resistors from lowest to highest.

Control	Load value Ohm
P0.3210 Naming convention.	
0000	no load
1000	10
0100	6.8
0010	4.7
0011	4.0
0001	3.3
1100	1.9
1111	1.3

5. The DUT is tested under different loads. Loads can be set digitally through port0/line0:3 by activating or deactivating four resistors installed in the DUT tester. Note, that LEDs on the DUT tester panel are indicating if a resistive load is active and the digital outputs are in open-collector configuration. Draw here the circuit schematic of a single load stage including the open-collector output of USB-6001. Explain how does a load stage work, determine the DC operating points.

If the output is ON, current flows to the Q8 transistor base, therefore, the transistor is open. R27 is connected to ground, no current flows on R12 and the LED. Vgs of Q1 will be below the threshold, thus no conduction. The load is inactive.

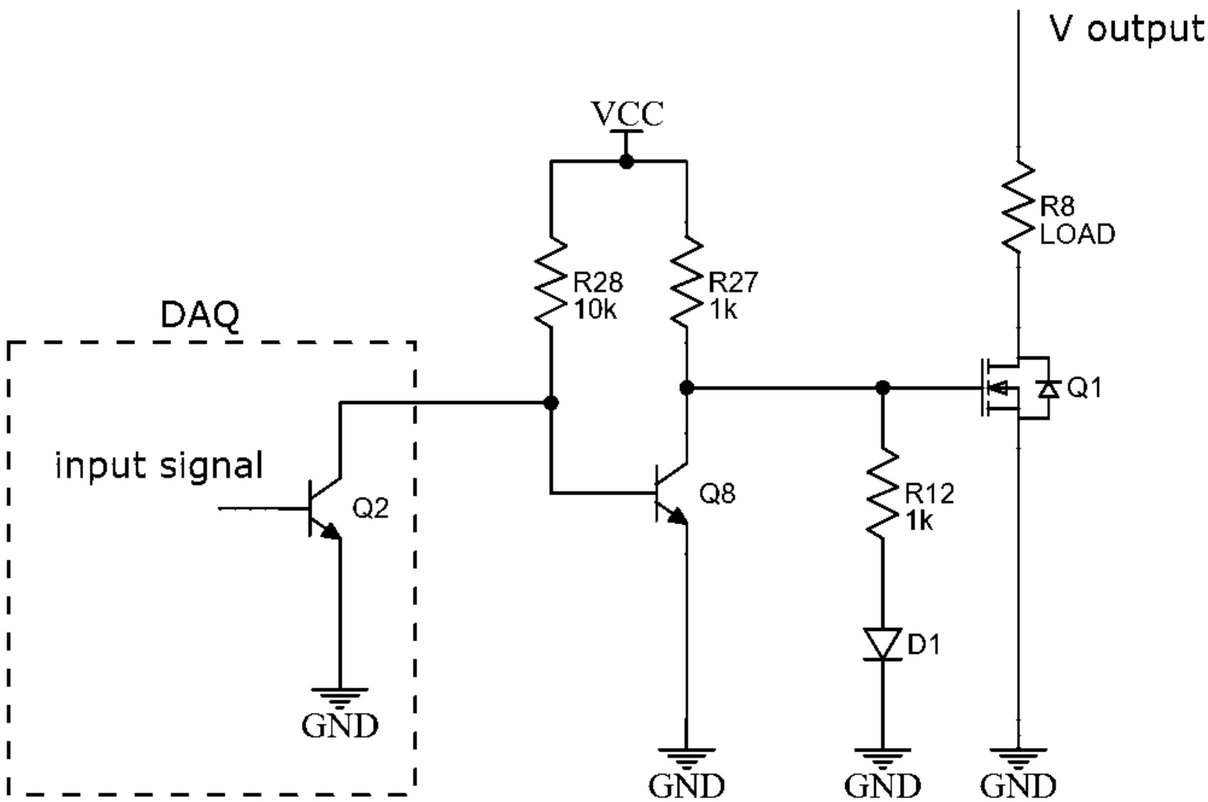


Figure 4. The circuit schematic of a single load stage including the open-collector output of USB-6001.

When we give a low, open collector is off, the current goes to ground, so Q8 is closed, therefore current will pass through R12 and the LED is ON and current flowing is

$$I = \frac{V_{in} - V_{LED\ Drop}}{R_{27}+R_{12}} = \frac{9V-2V}{R_{27}-R_{12}} = \frac{7V}{2k} = 3.5mA$$

The voltage for the gate source mosfet is 3.5 V+ 2 V from the drop out voltage of the LED, which is around 5.5 V.
In other words, if P.0 is 0, then Q8 is OFF, MOSFET receives input voltage
If P0 is 1, then current goes from R27 through the transistor Q8 and there is no voltage for the MOSFET.

6. Identify the Rsense resistor which is used to measure the input current of the DUT. Explain how the input current can be measured if the Rsense value is known.

Rsense: R7 *with 5%*

Rsense value: 0.68 Ohm 5%

The LM317 circuit is current limiter configuration

$$Input\ Current\ = \frac{Vr}{Rsense}$$

7. The following parameters are to be measured on the DUT (in the following lab sessions):

a. Input voltage of DUT;
b. Input current of the DUT measured on Rsense
c. Output voltage of the DUT measured
d. Output current, input and output powers, efficiency are calculated based on the measurements.

Identify the test points in the circuit to measure a)-c).

Table 4. Test points

Measured parameter	**Measurement method (RSE or differential)**	**Test points to use**
Input voltage of the DUT	Referenced single ended (RSE)	TC1
Input current of the DUT	Differential measurement	TC1 and TC2
Output voltage of the DUT	Referenced single ended (RSE)	TC3

Provide the formulas for the calculation of the values in d).

Table 5. Formula

Calculated parameter	Formula to calculate
Output current	Output voltage and the load resistance $I_{out} = \frac{V_{out}}{R}$
Input power	Input voltage*input current $P_{in} = V_{in} \cdot I_{in}$
Output power	We don’t have the current V^2/R

	$P_{out} = \frac{V_{out}^2}{R}$
Efficiency	(output power/ input power $\eta = \frac{P_{out}}{P_{in}}*100$

8. The DUT tester circuit consists of a current limiter. Draw here the schematic of the current limiter circuit and calculate the current limit value.

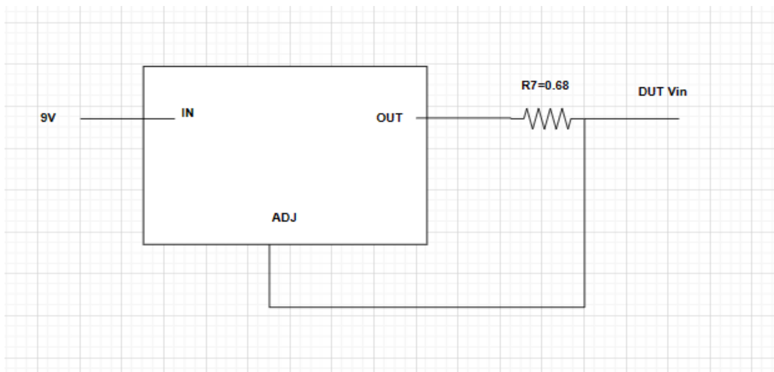


Figure 5. Current limiter circuit.

For the value of voltage drop in the R7 sense.

$$I_{limit} = \frac{V_{ref}}{R_{sense}} = \frac{1.25V}{0.68\,\Omega} = 1.84\,A$$

9. Calculate the expected input and output currents at highest, lowest and two intermittent load cases. The DUT output voltage is set to 3.0 V.

Typical efficiency of LM2596 based on the datasheet: 73%
Typical voltage drop of LM317: 1.2 V
Indicate where the current limiter is active.

Notes: [Calculation]

The dropout voltage changes according to the current flowing at 25°C

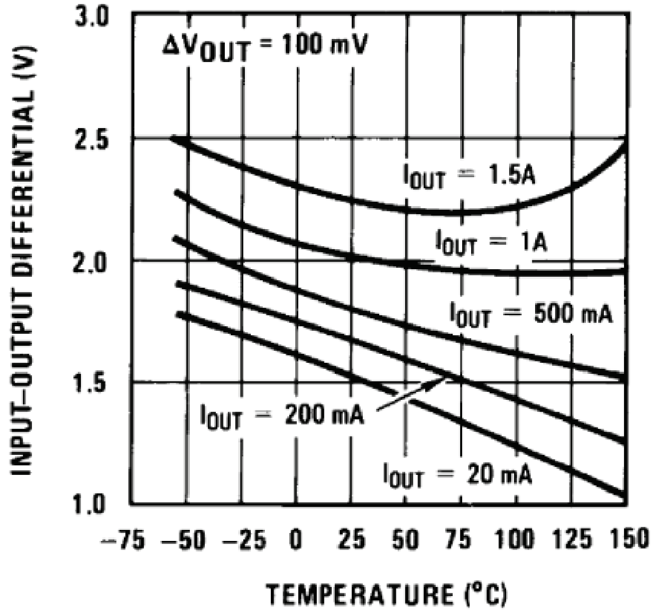


Figure 6. Voltage dropout with different currents for the LM317T.

Table 6. Calculations for different load resistances.

	Load Ohm	Expected output power (3V^2*Load)	Expected output current	Expected efficiency	Expected input power	Expected input current	Current limiter active?
R8+R9+R10+R11	1,3	6,9	2,3	0,73	9,41	1,34	NO
R10+R11	4,0	2,2	0,7	0,73	3,05	0,42	NO
R10	6,8	1,3	0,4	0,73	1,81	0,25	NO
R11	10	0,9	0,3	0,73	1,23	0,16	NO

10. Open `get_volt_meas_set_array.vi`. This VI builds an array of clusters. Each cluster element consists of all the DAQmx task settings required for the measurements. Measurement types are defined in `ctl_volt_meas_modes_enum.ctl`, and later performed on `get_test_output.vi`. You need to define the task parameters for each measurement in constants, which are added as array elements. DAQmx physical channel names are derived by `get_ai_channel_name.vi`. Collect at least 1k samples for one second. Copy here the task description clusters you have made.

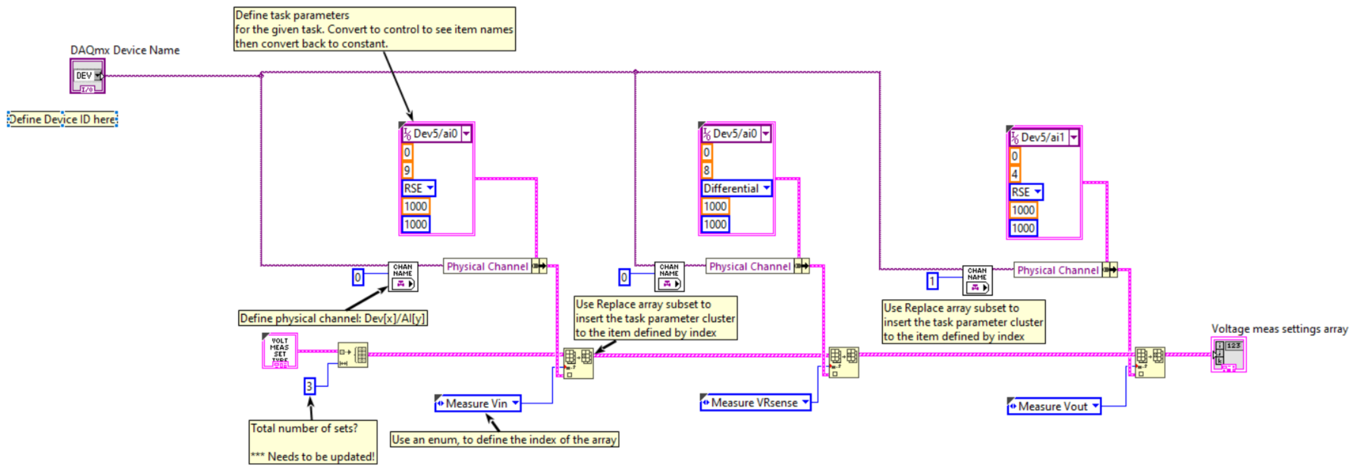


Figure 7. Setting the tasks for volt meas set array,

11. Open `get_test_output.vi` and build up a state machine performing the all the necessary measurements required for the DUT testing. In each state the state machine performs a single measurement using the and functions from the Waveform library as described in the VI documentation. Create here a state transition table.

Table 7. State machine

State name	Description	Next state
get input V	Use the voltage measurement VI, to get Vin value, and calculate RMS and update output cluster	get output V
get output V	Measure the output voltage and update Output V ampl in Outputs cluster by getting the RMS value of the measured vector. Use Ampliutude and Levels waveform fN to get and update Output V ampl in Outputs Use Rload_value Ohm from Meas environment cluster to calculate the Output current and update its value in Outputs cluster Use voltage_measurement.vi to perfrom measurement Use the appropriate element of Meas Set Array Measure the output voltage, use VOLT MEAS to perform the measurement, and get the amplitude and RMS value. Later, use an index array for getting the value itself, and then dividing Rload and RMS to the the output current. Finally updating the cluster output	get input current
get input current	Measure the differential voltage fall on Rsense resistor and update Input Current in Outputs cluster by getting the RMS value of the measured vector and Rsense_value_Ohm value from the Meas environment cluster. Update Rsense voltage drop in Output cluster. Use voltage_measurement.vi to perfrom measurement Use the appropriate element of Meas Set Array Measure differential voltage of Rsense resistor and obtain the RMS value. Later, divide the RMS with the Rsens to get the input current, and update the cluster output. Also, registering the Rsense Vdrop	calculate efficiency

calculate efficiency	get the input V, input I, output V, output I values from the output cluster, use multiply to calculate and write the values for input P and output P, use divide and multiply by 100 to calculate and write the efficiency value to the output cluster	disable loads
disable loads	write false to all loads by running set_loads.vi, pass the output cluster data	end
end	passes the output cluster data and error cluster, write true to the loop stop condition.	

voltage_measurement.vi:

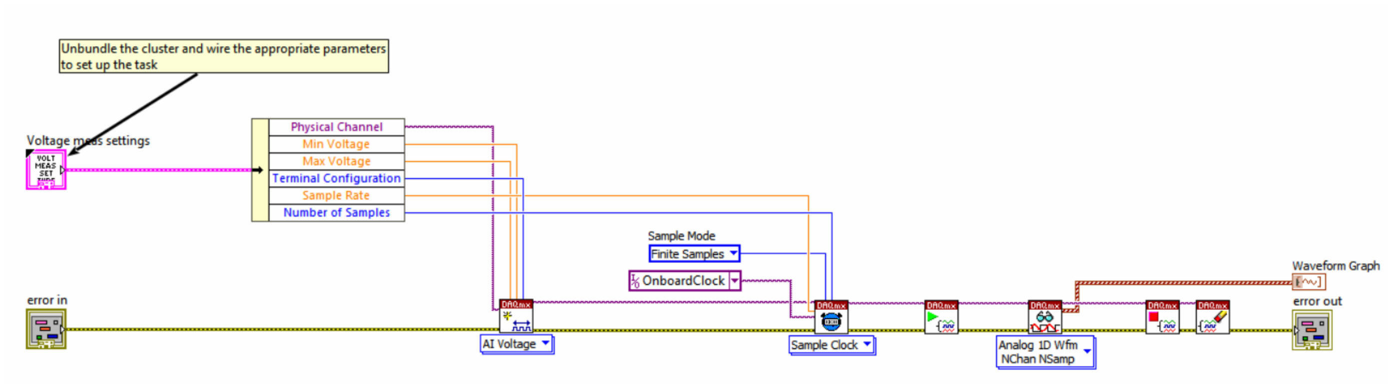


Figure 8. Creation of channel, sampling, reading and release of system resources.

12. Open the `ctl_loads_enum.ctl`. Calculate the possible resistive load combinations of the DUT and name them after the nominal resistance values e.g. "2.2 Ohm". Add the items to the enum control typedef. Preserve an enum for NO LOAD. List here the enumerated items. It is possible to right click and open definition.

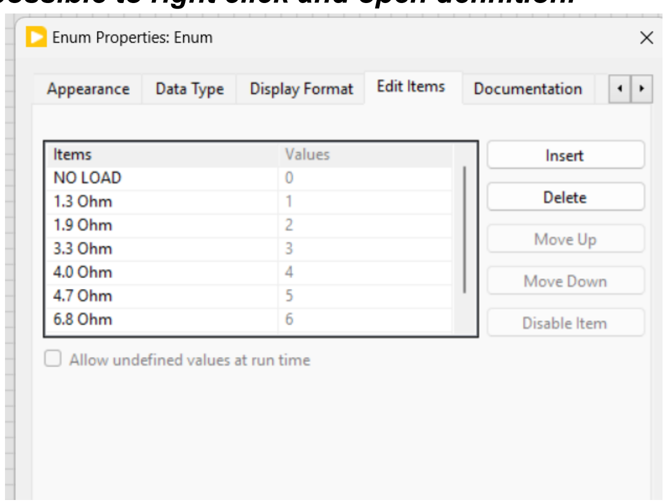
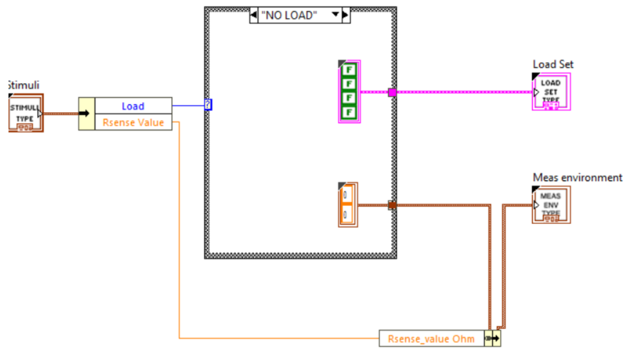
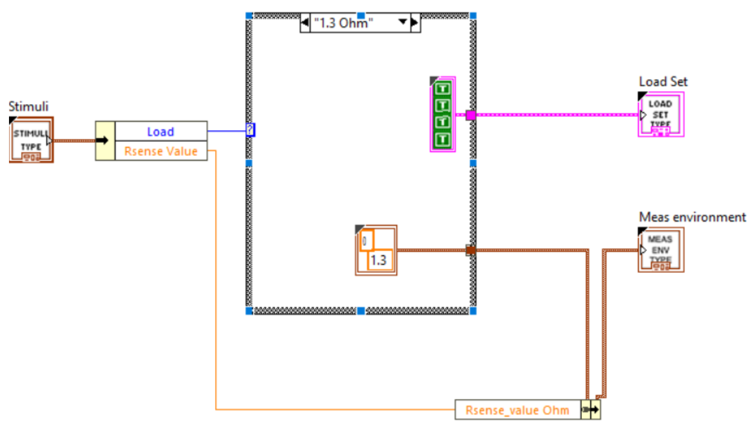


figure 8. Resistance loads

13. Open `get_meas_env.vi`. Use `Stimuli.Load` enum control to a case structure. Update the `Load Set` indicator by the appropriate combination of resistive loads, as

well as the `Meas environment` cluster. Note that `Meas environment.Rsense_value` Ohm value comes from the `Stimuli` cluster. Copy the cases of NO LOAD, minimal load and maximal load here.





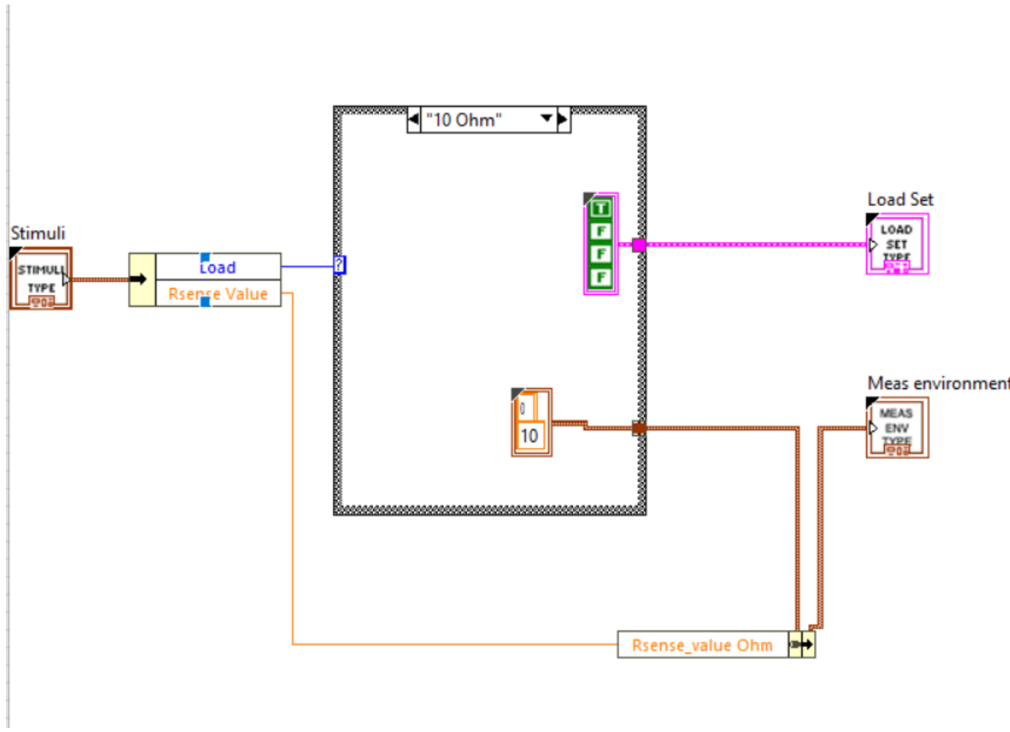
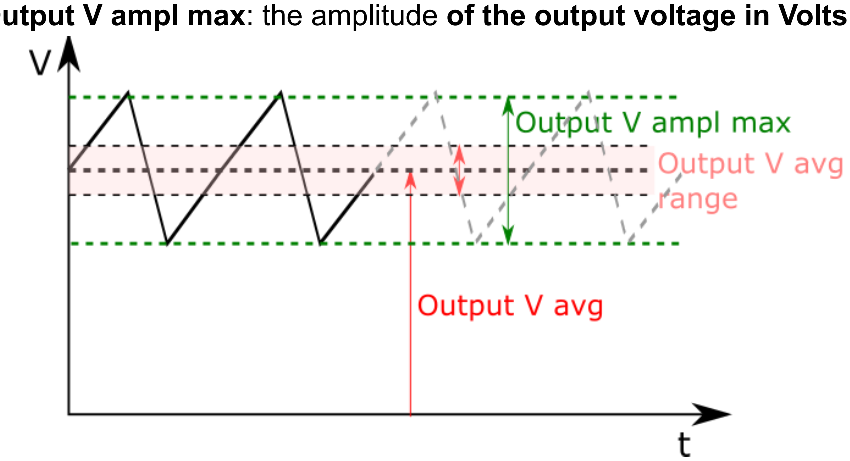


figure 9. Set loads

Pass criterion

Measurement data and calculated parameters undergo an assessment of fulfilling pass criterion as follows

e. **Input V min**: the v**alue of the minimal required input voltage in Volts**
f. **Output V avg and range**: the value of the r**equired output voltage average** and its range
g. **Output V ampl max**: the amplitude **of the output voltage in Volts**



h. Efficiency min: the minimum required efficiency

14. Open `run_test_item.vi`. You have to make a code to evaluate the measured values against the pass conditions defined in `Test item` cluster. `Efficiency` is OK (TRUE) if the measured efficiency is higher than the pass limit. `Input voltage` (Input V min) is

OK, if the measured input voltage is higher than the pass limit. `Output voltage` is OK, if the measured output voltage is within the defined pass range (`Output V avg range`) AND the noise level (`Output V ampl max`) is lower than the ripple in the pass range.

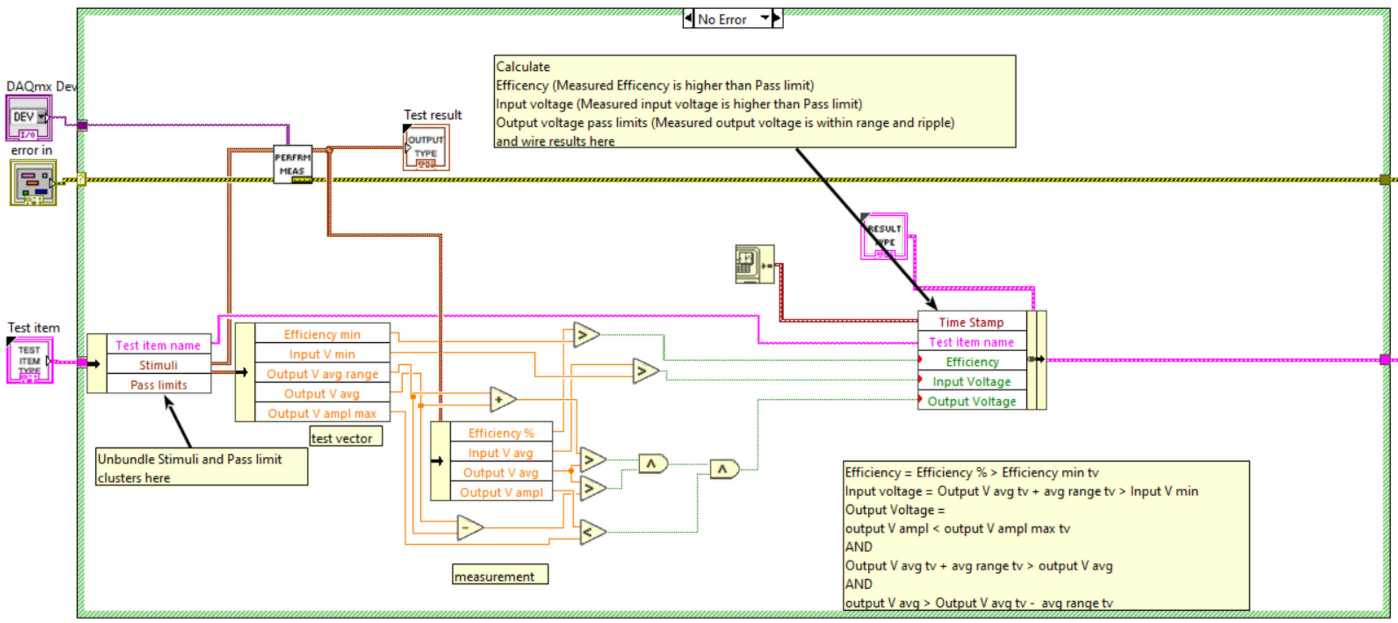


figure 10. test vector definition and comparison with the measured data that comes from the perform MEAS.

Test the hardware

15. Run `interactive_tester` to validate your measurements in 3 test cases. Use a digital multimeter to validate the measured values, compare the measured and displayed results here.

The 3 cases are:

- Case 1: no load

- Case 2: only R8 is active

- Case 3: only R11 is active

Table 8. Measurement of voltages with multimeter and labview

Case	**Testpoint**	**Measured**	**Displayed in LabVIEW**	**Difference**
No load	Vin	7.51	7.50	All differences below ±0.01
	Vout	2.99	2.98	-
R 4ohm Active	vin	6.9	6.89	-
	vout	2.91	2.91	-
R 10 ohm	vin	7.3	7.3	-
	vout	2.95	2.96	-

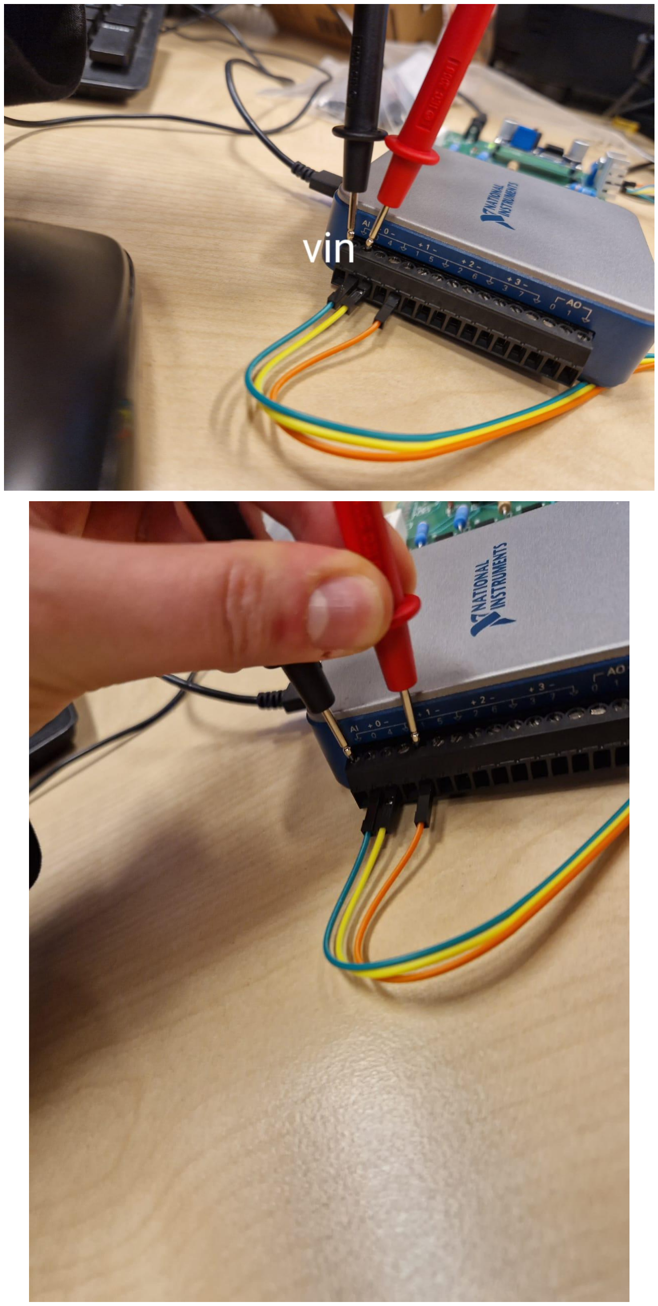


Fig. 11. Measurement of voltage in the USB 6001 with the digital multimeter

Create a test vector
16. Run `edit_test_vectors.vi`, and create a test vector. The vector should cover a range of test loads, you need to define the appropriate pass ranges for each measurement. Create a summary table here with the test cases you created.
ftest_vector_7 used

Table 9. defined test vector.

Case No	Load settings	Pass criterion				
		Input V min	Output V avg	Out. Volt. range …	output v amplitu de max.	effic. min.
0	10	7	3	0.2	0.5	60
1	6.8	7	3	0.2	0.5	60
2	4.0	7	3	0.2	0.5	60
3	1.3	7	3	0.2	0.5	60
4	no	7	3	0.2	0.5	60

Report and analyse the results

Note that a log file is automatically generated using the **`write_to_logfile.vi`*****. Import this file into Excel to analyse the contents.***

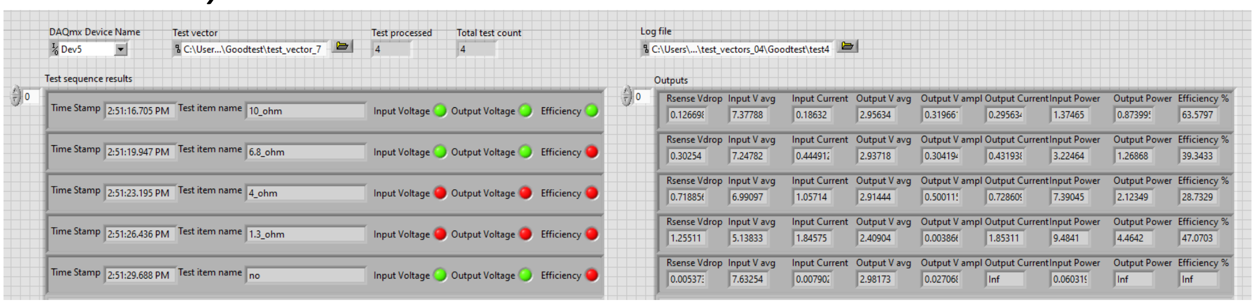


Fig. 12. Results

Fig. 12. Test results

17. Create one or more well formatted graphs to display the results.

Comparison of input and output current:

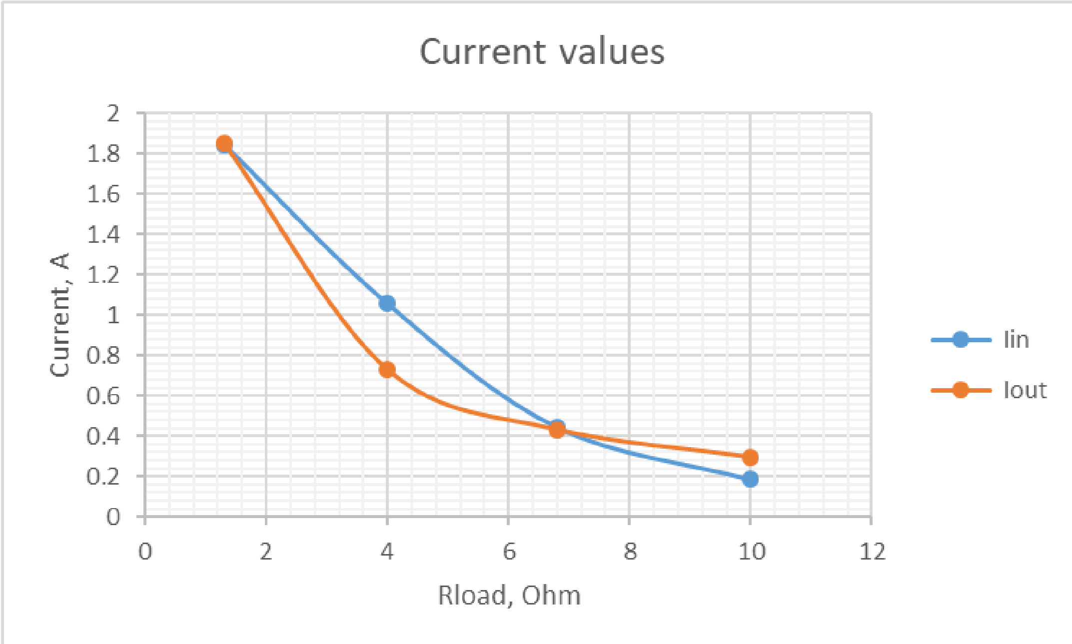


Fig. 13. Rload vs current for input and output.

Note that the input and output current at 1.3 ohms is the same, this because the regulator is operating at that particular point.

Output voltage and output voltage change amplitude:

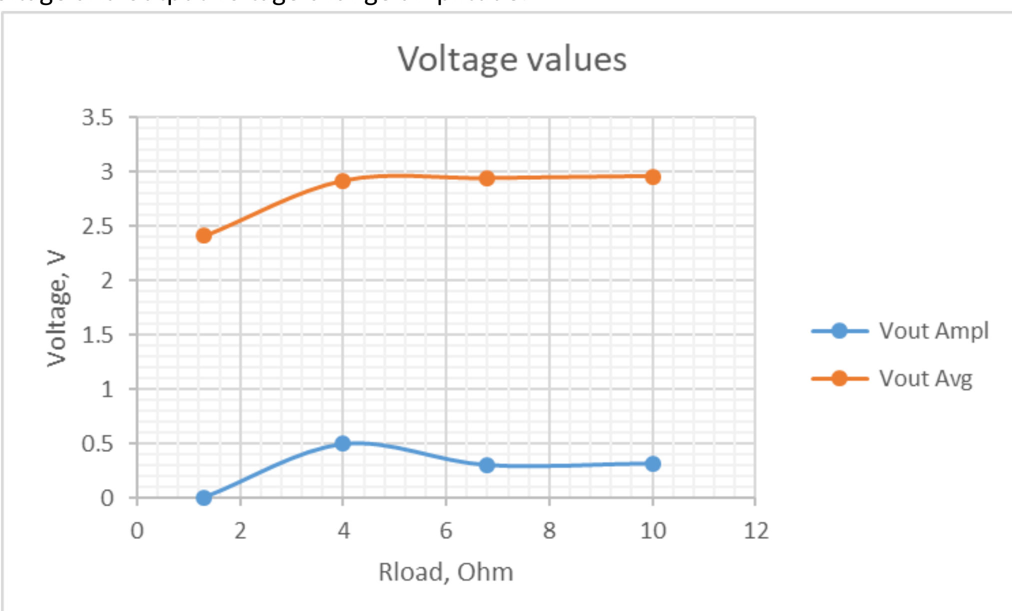


Fig. 13. Voltage output average and also amplitude voltage for each resistance load.

Efficiency as a function of load :

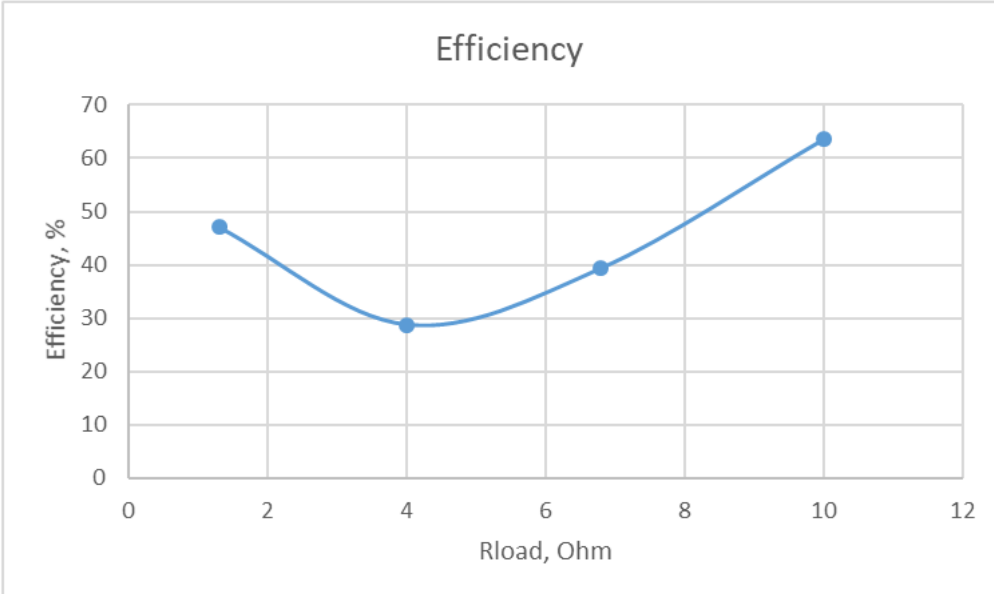


Fig. 14. Rload vs efficiency measured

18. Compare the results to the expected values provided in Task 9. Explain the differences if any – at low currents, at high currents.

The values of output power coincide quite well for loads for 4ohm and above, for 1.3 ohm the measured output power is lower largely because the current regulator has decreased the input power. In other words, the LM317 reduces the input voltage of the DUT. Expected efficiency is lower for all cases than expected from the datasheet. This is reasonable because of the different input voltages, defects on the fabrication or physical circuit that can affect the efficiency. Besides, the DUT is mass manufactured and general purpose which can definitely affect the overall performance.

input power is higher than expected in almost all cases because efficiency is lower. For 1.3 ohm, the power is similar because the current limiter is activated with that resistance load. The only test passed was the 4 ohm and 10 ohms in the efficiency aspect.

Input current is higher for the same reasons as the input power. For 1.3 ohms it is actually 1.8 A, which is the cutoff of the LM317 regulator. It is exactly the same value of current as calculated. 1.85 theoretical vs 1.84 calculated.

19. Considering efficiency, what is the optimal operating point of the DUT with the given loads?

Based on the obtained results, the higher efficiency is at **10 ohms**, which is the lowest resistance load. Larger currents will result in a decrease in efficiency.

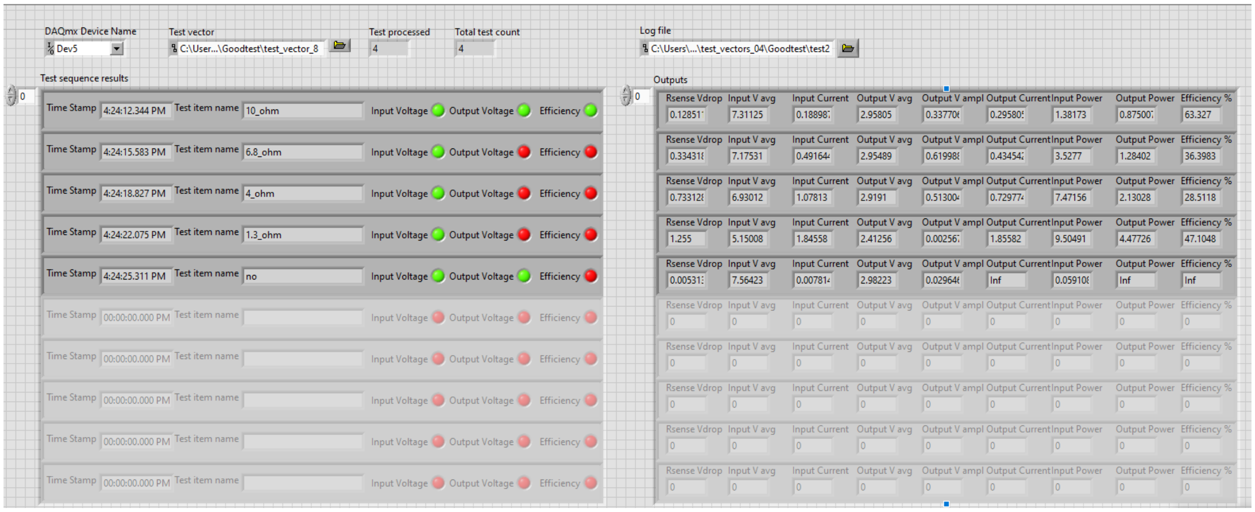
20. Identify those loads where the current limiter actively limits the input current.

Strictly speaking, it starts working between 4 and 1.3 ohms the LM317. The value of current for the lowest load was 1.855 A

Submit this part before the final evaluation.

Annex

Changing from 7 to 3.8



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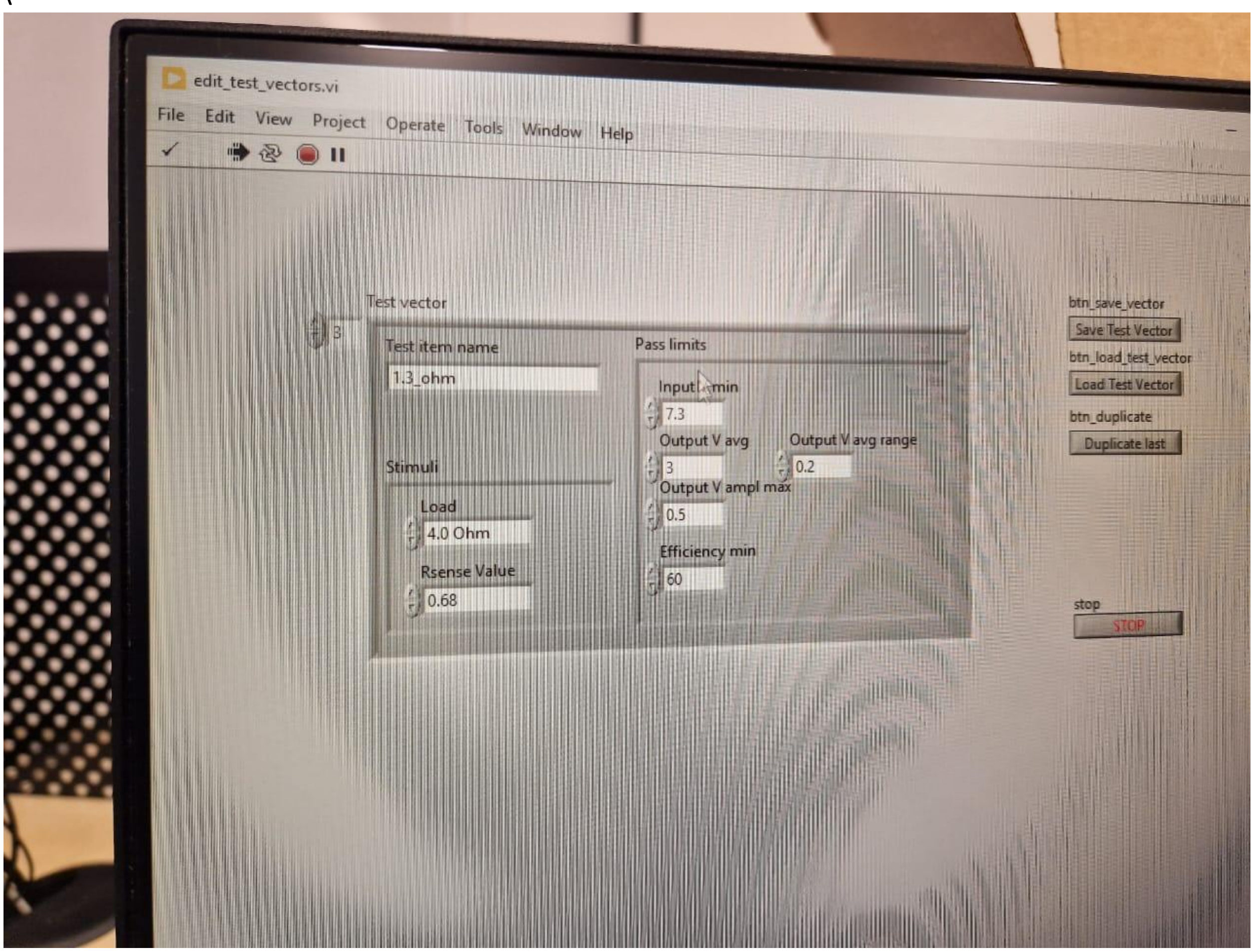
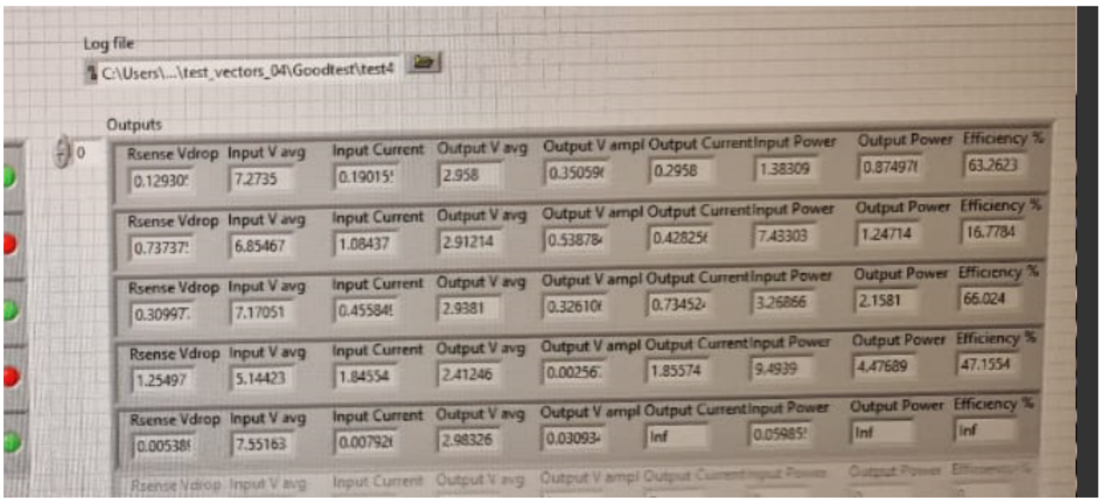


Table 6. Calculations for different load resistances.

	Load Ohm	Expected output power (3V^2*Load)	Expected output current	Expected efficiency	Expected input power	Expected input current	Current limiter active?
R8+R9+R10+R11	1,3	6,9	2,3	0,73	9,41	1,34	NO
R10+R11	4,0	2,2	0,7	0,73	3,05	0,42	NO
R10	6,8	1,3	0,4	0,73	1,81	0,25	NO
R11	10	0,9	0,3	0,73	1,23	0,16	NO



Rload	Input V OK	Out V OK	Eff OK	Vout Avg	Vout Amp	Iin	Iout	Eff
10	1	1	1	2.956	0.32	0.186	0.296	63.58
6.8	1	1	0	2.937	0.304	0.445	0.432	39.343
4	0	0	0	2.914	0.5	1.057	0.729	28.733
1.3	0	0	0	2.409	0.004	1.846	1.853	47.07
0	1	1	0	2.982	0.027	0.008	Inf	Inf