ISSUE: November 2020

A Quick Way To Determine Power Supply Output Resistance

by Gregory Mirsky, Vitesco Technologies, A Spinoff Of Continental Automotive Systems, Deer Park, Ill.

When dealing with slow-changing dc loads, like solenoids, brushed motors, heaters etc. it is necessary to rapidly define a power supply output resistance in order to correctly assess the power supply load capability and tweak the feedback loop if necessary. There are diverse methods for defining the output impedance of a power supply, but some of these methods involve test instruments that may not always be available and/or produce more information than is needed for the loads in question.

For example, when powering fast changing loads having noticeable reactance, measurements of power supply output impedance taken with a vector network analyzer and specialized adapters enable stability analysis and produce general frequency response plots.[1,2] These sources provide useful information, but that information goes beyond what's required for defining the power supply behavior in the face of a slow-changing dc load.

Another approach only requires measurement of the power supply's output voltage variation at different output current levels. This produces an output resistance value that is sufficient when working with slow dc loads. The presentation in reference 3 shows one way to make these measurements. But even this method of defining the power supply output resistance is pretty complicated and utilizes laboratory equipment that's not always handy.

This article presents a simplified version of the method in reference 3. It needs only a multimeter (which may be a handheld) and a resistor of any resistance close to the load resistance. Its value can be measured with the same multimeter as used for the output voltage measurement. It is presumed that a calculator is handy.

This method is based on measuring the voltage across the nominal load and the voltage across the load when an extra resistor is connected in parallel. After a simple mathematical calculation, based on the measured voltages and known resistors values, the power supply internal resistance (plus that of the external wires) can be defined. Usage of EXCEL might be helpful.

A Simple Test Setup

The two circuit configurations required to implement this test method are shown in Figs. 1 and 2 where the parameters are defined as follows. Vin is the power supply internal voltage, which is a no-load output voltage, but its value does not matter as we will see; R_{out} is the power supply output resistance; V_{out1} and V_{out2} are output voltage, measured at the nominal load resistance R1 and with the (temporary) addition of R2 in parallel, respectively.

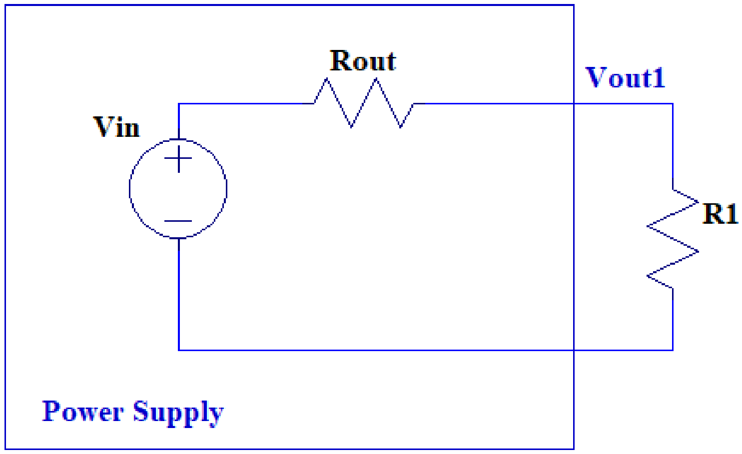

Fig. 1. Power supply under test. At nominal load R1 the output voltage is measured to be V_{out1}.

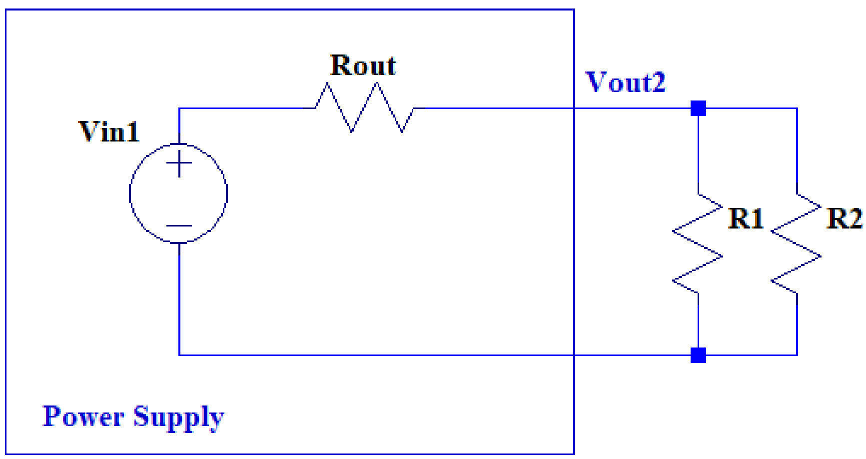

Fig. 2. Connecting external resistor R2 in parallel with R1 reduces the output voltage down to V_{out2}, allowing us to calculate R_{out}.

With the circuit parameters defined above, we can express V_{out1} and V_{out2} as:

$$V_{out1} = \frac{V_{in}}{R_{out} + R1} \cdot R1 \qquad (1)$$

$$V_{out2} = \frac{V_{in}}{R_{out} + \frac{R1 \cdot R2}{R1 + R2}} \cdot \frac{R1 \cdot R2}{R1 + R2} \qquad (2)$$

Taking the ratio of the two output voltages equations and simplifying we get

$$\frac{V_{out1}}{V_{out2}} = \frac{R1 \cdot R2 + R1 \cdot R_{out} + R2 \cdot R_{out}}{R2 \cdot (R1 + R_{out})} \quad (3)$$

From equation (3) we can then derive an equation for R_{out} which does not include Vin:

$$R_{out} = \frac{R1 \cdot R2 \cdot V_{out1} - R1 \cdot R2 \cdot V_{out2}}{R1 \cdot V_{out2} - R2 \cdot V_{out1} + R2 \cdot V_{out2}} \quad (4)$$

If we designate

$$\alpha = \frac{V_{out1}}{V_{out2}} \quad (5)$$

and

$$\beta = \frac{R2}{R1} \quad (6)$$

then we can obtain an expression for the output resistance in terms of the output voltage and load resistance ratios,

$$R_{out}(\alpha) = \frac{R2 \cdot (\alpha - 1)}{1 + \beta \cdot (1 - \alpha)} \quad (7)$$

We can then plot R_{out} as a function of α as shown in Fig. 3.

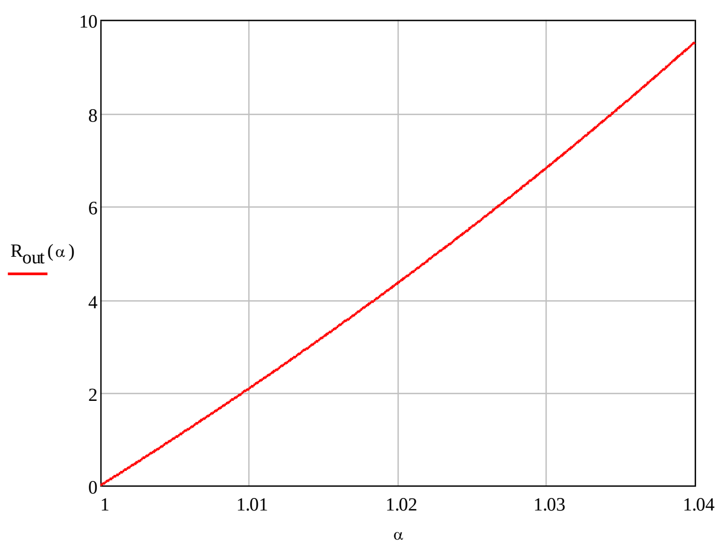

Fig. 3. Knowing the relative variations in V_{out} when adding R2 to the nominal load R1, it is possible to define the power supply output resistance R_{out}. Here α = V_{out1}/V_{out2}.

It is worth noting that expression (7) has limitations for variables α and β since the output resistance cannot be negative.

So, for the reader's convenience we re-write expressions (5), (6) and (7):

$$\alpha = \frac{V_{out1}}{V_{out2}} \tag{5}$$

$$\beta = \frac{R2}{R1} \tag{6}$$

$$R_{out}(\alpha) = \frac{R2 \cdot (\alpha - 1)}{1 + \beta \cdot (1 - \alpha)} \tag{7}$$

Variable α is always more than 1 since adding R2 to R1 will always reduce the output voltage due to an increased voltage drop across the internal resistance. So, $V_{out1} > V_{out2}$.

Expression (7) can be re-written for a specific measured value of V_{out2} as

$$R_{out} = \frac{R2 \cdot (\alpha - 1)}{1 - \beta \cdot (\alpha - 1)} \tag{8}$$

Therefore, to keep R_{out} (α) positive, the following expression should hold true:

$$\beta \cdot (\alpha - 1) < 1 \tag{9}$$

$$\beta < \frac{1}{\alpha - 1} \tag{10}$$

It is recommended to have R2 = R1 and thus

β = 1

α = 1.03

R2 = 200 Ω

So, the steps to define a power supply output impedance are

1. Connect a resistor parallel to the load, whose value is the same as the load (may be defined as output voltage V_{out1} over the output current).

2. Measure the output voltage V_{out1}, define α assuming β = 1.

3. Calculate R_{out} using formula (8).

$$R_{out} = \frac{R2 \cdot (\alpha - 1)}{1 - \beta \cdot (\alpha - 1)} = 7.469\ \Omega$$

A Measurement Example

Let's apply the proposed method to determine the output resistance of an example power supply circuit. In this case, we'll use a simple 5-V to 12-V input dc-dc converter built on Texas Instruments' SN6505B push-pull controller IC and a Wuerth Elektronik transformer having a 1:1.38 turns ratio (Fig. 4). The circuit also incorporates a Schottky bridge rectifier and an LC output filter. The controller has no feedback input, which is why the internal resistance of the converter that we'll measure will be high.

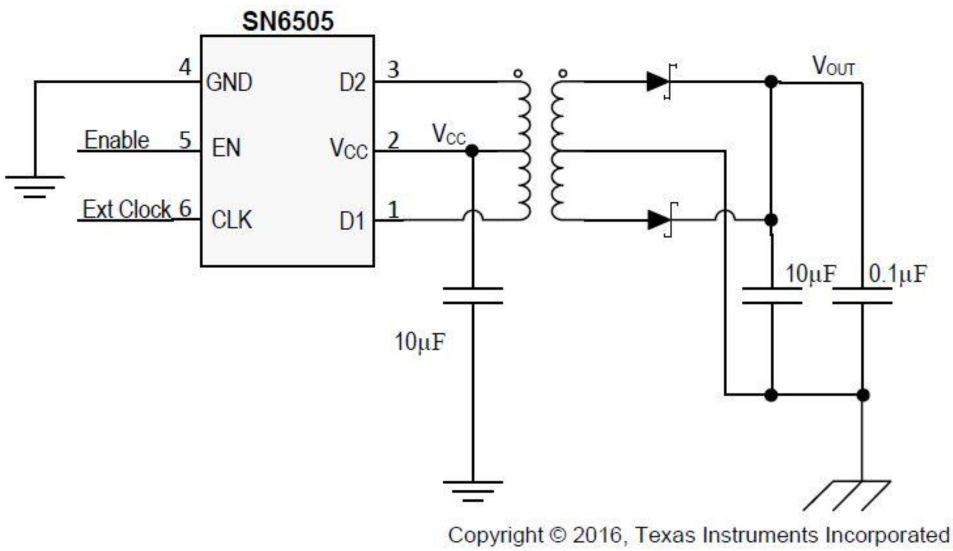

Fig. 4. Simplified application schematic for isolated power supply based on the SN6505 transformer driver. (Diagram courtesy of Texas Instruments)

In this example, the load resistor values are

R1 = 50 Ω

R2 = 200 Ω

which results in output voltage measurements of

V_{out1} = 10.3 V

V_{out2} = 9.94 V

Recalling our voltage and resistance ratios of

$$\alpha = \frac{V_{out1}}{V_{out2}}$$

$$\beta = \frac{R2}{R1}$$

We can use our example values above to calculate

$$\alpha_0 = \frac{V_{out1}}{V_{out2}} = 1.036$$

$$\beta = \frac{R2}{R1} = 4$$

and plug these into our resistance formula:

$$R_{out}(\alpha) = \frac{R2 \cdot (\alpha - 1)}{1 + \beta \cdot (1 - \alpha)}$$

$$R_{out}(\alpha_0) = 8.471\ \Omega$$

It is worth mentioning that this method does not use the no-load output voltage value and utilizes just relative variations of the load resistance and output voltage. This avoids a potential problem as the output of an improperly designed power supply may go out of regulation under the no-load condition.

References

1. "Characterizing and Selecting the VRM" by Steven M. Sandler, presentation for DesignCon 2017.

2. "Traditional and Non-Invasive Stability Measurements, Using the Bode 100 and Picotest J2111A Current Injector," Bode 100 Application note from Omicron Lab, by Florian Hammerle, Steve Sandler and Tobias Schuster, 2017.

3. "Output Impedance of a Bench Power Supply," YouTube video by Paul Wesley Lewis, July 25, 2013.

About The Author

Gregory Mirsky, is a senior electrical engineer with Vitesco Technologies, a spinoff of Continental Automotive Systems, in Deer Park, Ill., which he joined in March 2015. In his current role, Gregory performs design verification on various projects, designs and implements new methods of electronic circuit analysis, and runs workshops on MathCAD 15 usage for circuit design and verification.

He obtained a Ph.D. degree in physics and mathematics from the Moscow State Pedagogical University, Russia. During his graduate work, Gregory designed hardware for the high-resolution spectrometer for research of highly compensated semiconductors and high-temperature superconductors. He also holds an MS degree from the Baltic State Technical University, St. Petersburg, Russia where he majored in missile and aircraft electronic systems.

Gregory holds numerous patents and publications in technical and scientific magazines in Great Britain, Russia and the United States. Outside of work, Gregory's hobby is traveling, which is associated with his wife's business as a tour operator, and he publishes movies and pictures about his travels online.

For further reading on measuring power supply parameters, see the How2Power Design Guide, locate the Design Area category and select "Test and Measurement".