PCB Design 007 *QuietPower* columns

Evaluating Evaluation Boards

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Evaluation boards are very helpful. Manufacturers of complex circuits, for instance DC-DC converters, provide boards with those circuits ready to try out, saving us the time and effort to design the printed circuit board around them. Evaluation boards are supposed to help us to understand the capabilities of the device. But with the very many potential user applications, what should a particular user expect and look for in an evaluation board? We need to know how to properly evaluate an evaluation board.

In early 2013, a QuietPower column showed the LTM4604 evaluation board. In that column the purpose was to discuss different measurement techniques; the subject was not the regulator itself. In this column we look at an LM20143 evaluation board to explain what may matter during the evaluation.

The LM20143 is an adjustable-frequency synchronous buck regulator with current-mode control loop [2]. The input voltage can be anywhere in the 2.95 to 5.5V range, the maximum continuous output current is 3A. The switching frequency is adjustable in the 500 kHz to 1500 kHz range. The default output voltage setting of the evaluation board is 1.2V. The integrated circuit includes the output switching devices. *Figure 1* shows the top view of the evaluation board with no cable attached.

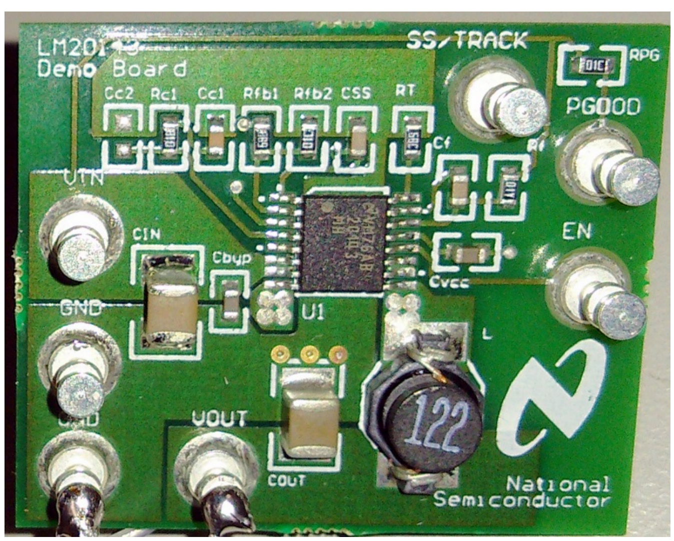

Figure 1: *LM20143 evaluation board, top view. Evaluation module courtesy of Texas Instruments.*

To make the board work, all we have to do is connect a voltage source to the input terminals and pull the Enable pin (labeled 'EN' on the board) to logic high.

The first rule in every test and measurement (also true in simulations, by the way) is "Know what to expect." We measure something because we may want to validate a design or we measure something because we are not sure exactly how the circuit behaves. This latter case, however, is no excuse to ignore the rule: we still should have some idea what we expect as a result. If we don't, it becomes a full-fledged exploration and we need to be extremely careful to make sure that accidental mistakes or measurement errors don't mask the correct signature that we are after. In an evaluation board of a DC-DC converter we can test many different aspects of operation. There are items that require only DC voltage and current meters. This way, for instance, we can check the line and load regulations and efficiency at different input and output voltages and load currents. To test for dynamic parameters, we can use an oscilloscope and transient current source. In the frequency domain, with a Frequency Response Analyzer or Vector Network Analyzer we can test the gain-phase curve or output impedance. These measurements can be done with small-signal excitation or large-signal excitation. As an example, in *Figure 2* we show the output impedance magnitude measured with fixed input and output voltages, with DC load current varied from 0A to 2A. The photo of *Figure 3* shows the measurement setup in my basement lab.

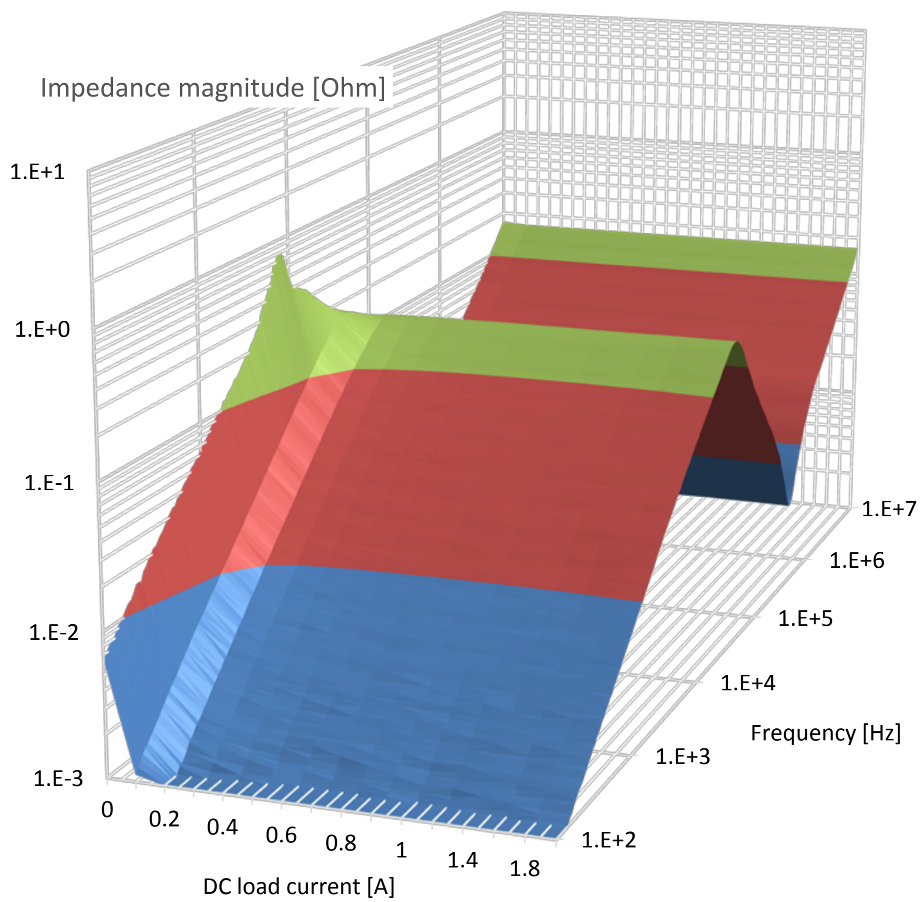

Figure 2*: Output impedance as a function of frequency and DC load current.*

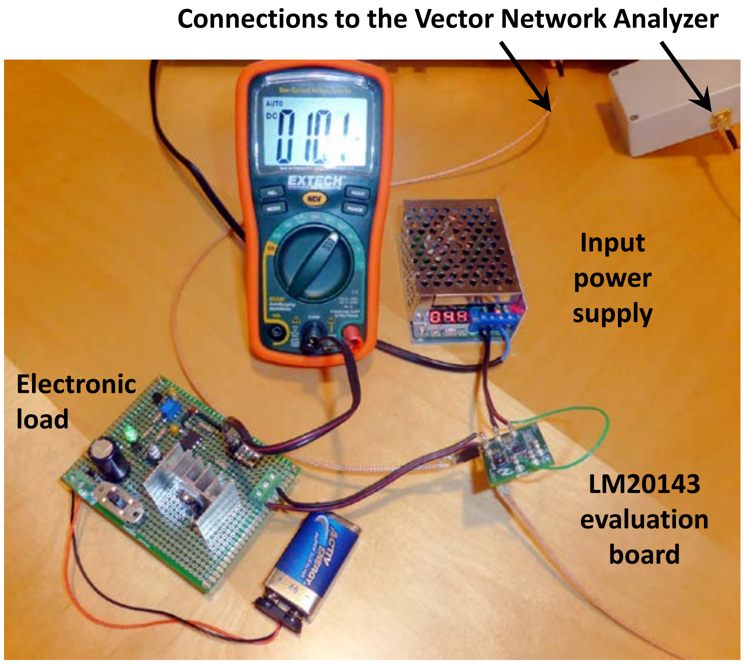

Figure 3: *Test setup with input power supply and electronic load.*

The setup has the LM20143 evaluation board connected to a small AC-DC adjustable power supply, serving as the input source. On the lower left there is a small home-made electronic load circuit, which can draw an adjustable constant current. The voltage, proportional to the DC current is shown on the hand-held digital multimeter. Two cables connect to the Vector Network Analyzer, not shown on this photo.

When we look at the data on *Figure 2*, we have to answer the question: is this close to what we expected? What would be warning signs that something is wrong with our measurement or the evaluation board may not meet our expectations? We can start with items that we know. In case of evaluation boards, we get a schematics and BOM as well, reproduced in *Figure 4* from [3].

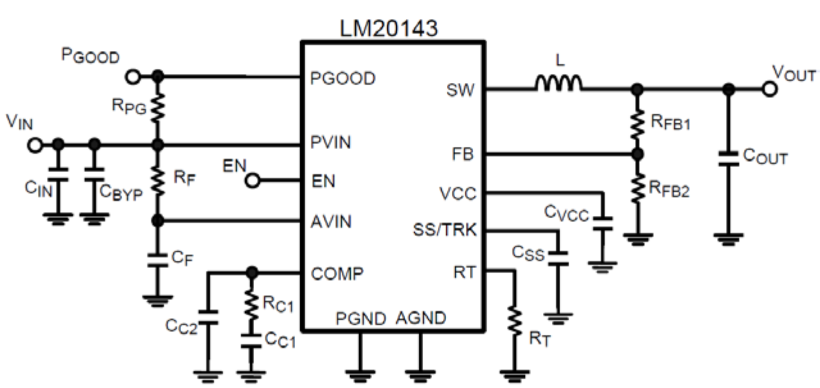

Figure 4a: *Schematics of the LM20143 evaluation board, from [3].*

Designator	Description	Part Number	Qty	Manufacturer
U1	Synchronous Buck Regulator	LM20143	1	Texas Instruments
C_{IN}	47 µF, 1210, X5R, 6.3 V	GRM32ER60J476ME20	1	Murata
C_{BYP}	1 µF, 0603, X5R, 6.3 V	GRM188R60J105KA01	1	Murata
C_{OUT}	47 µF, 1210, X5R, 6.3 V	GRM32ER60J476ME20	1	Murata
L	1.2 µH, 17 mΩ	DO1813H-122ML	1	Coilcraft
R_F	1Ω, 0603	CRCW06031R0J-e3	1	Vishay-Dale
C_F	100 nF, 0603, X7R, 16 V	GRM188R71C104KA01	1	Murata
CV_{CC}	1 µF, 0603, X5R, 6.3 V	GRM188R60J105KA01	1	Murata
R_{PG}	10 kΩ, 0603	CRCW06031002F-e3	1	Vishay-Dale
R_{C1}	1 kΩ, 0603	CRCW06031001F-e3	1	Vishay-Dale
C_{C1}	4.7 nF, 0603, X7R, 25 V	VJ0603Y472KXXA	1	Vishay-Vitramon
C_{C2}	OPEN	OPEN	0	N/A
C_{SS}	33 nF, 0603, X7R, 25 V	VJ0603Y333KXXA	1	Vishay-Vitramon
R_{FB1}	4.99 kΩ, 0603	CRCW06034991F-e3	1	Vishay-Dale
R_{FB2}	10 kΩ, 0603	CRCW06031002F-e3	1	Vishay-Dale
R_T	49.9 kΩ, 0603	CRCW06034992F-e3	1	Vishay-Dale
Test Points	Test Points	160-1026-02-01-00	7	Cambion

Figure 4b: *Bill of Materials (BOM) of the LM20143 evaluation board, from [3].*

The schematics and BOM show that on the evaluation board the main inductor has 1.2 uH inductance and 17 mOhm DC resistance. There is a single capacitor on the output, a 1210-size 47uF 6.3V X5R ceramic capacitor. With or without this knowledge about the component values, we can take the measured output impedance and fit to it a simple model. The plot in *Figure 5* shows the result of a very quick curve fitting we can do in a spreadsheet in seconds. The measured data is the blue trace, using the data at 1A DC load current from *Figure 2*. The red line, almost completely behind the blue trace, is the result of a simple three-capacitor model, where the third capacitor is fit around the impedance minimum at 0.5 MHz. The values to get this match come at as C_3 = 38uF, R_3 = 3.5mOhm, L_3 = 3nH. Are these values reasonable? The 38uF capacitance is 80% of the nominal 47uF value. Considering the 20% initial tolerance rating on the part, plus the additional few percent for DC bias effect and the expected 20-30% capacitance drop due to AC bias effects [4], the 38uF is way within the expected range. Many capacitors from major component manufacturers also have various models available, from which we can get the typical ESR values. In case this data is not available and we may suspect that the ESR value we got from curve fitting might be wrong, we can continue the testing and collect more data. If we want to check the parameters of the same exact capacitor that we have on the evaluation board, we can for instance measure the output impedance with the converter turned OFF, so that across the output terminals we have only the output capacitor. If we do this, we may need to apply a DC bias we have during normal operation, so that we measure the part with the correct DC operating point. To remove any potential contribution from the evaluation board, we can desolder the capacitor and measure it in a fixture. Ultimately we can obtain samples of the same capacitor model and measure several of them to see how different or how identical their data looks. As an example, in *Figure 6* the combined plot of the evaluation board is shown with and without input power. We can see that around 0.5MHz, where the output capacitor's ESR matters, the agreement is quite good, namely the impedance in that frequency range even with the converter running is primarily dictated by the output capacitor. From all the above we can conclude that the ESR of the output capacitor is around 2 to 2.5 mOhms, assuming that the plane resistance on the evaluation board between the location of the output capacitor and the point where we measure the output impedance is in the range of one to one and half mOhms. Finally, we can confirm this by measuring the part in a fixture with the fixture deembedded.

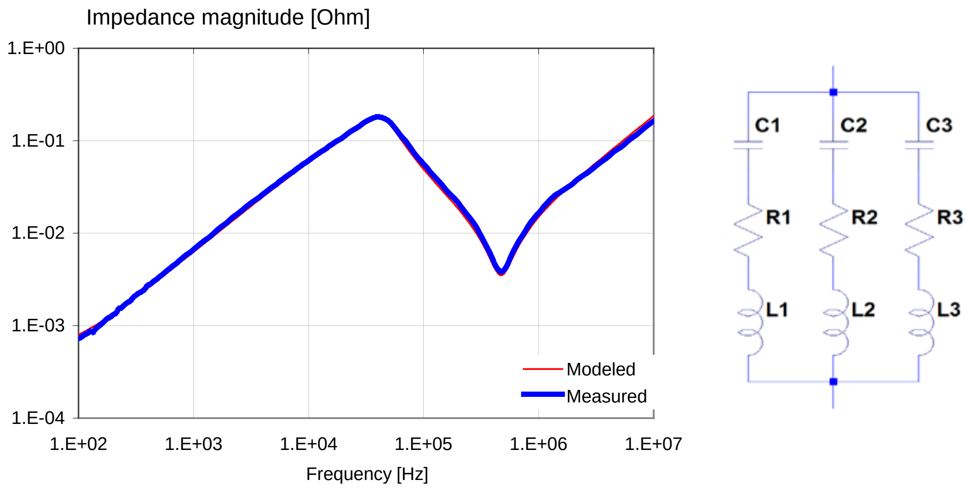

Figure 5: *Correlation of measured output impedance to a three-capacitor model at 4.5V input voltage, 1.2V output voltage and 1A DC load current.*

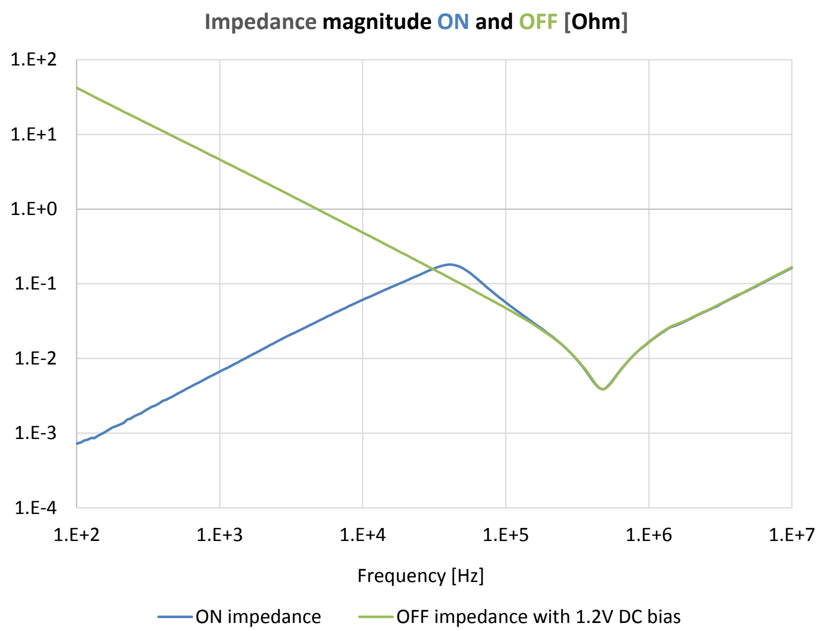

Figure 6: *Output impedance of the evaluation board with no input power (green trace) and with input power (blue trace) applied.*

Once we feel comfortable with the basic results, we can look further and ask again: what did we expect or what are we looking for in the test results? One qualitative feature that we may want to see, especially if we want to use the measured impedance to create simple equivalent circuits for simulations, is the consistency of the impedance plots across the different input parameters, such as load current, input voltage and possibly ambient temperature. Output voltage should also be considered for the list if we plan on using the same device with different output voltage settings. To get a sense of how consistent is the small-signal impedance performance of the converter, *Figure 7* shows the impedance surfaces at three different input voltages. We can see that the primary variation is along the frequency axis, but there is very minimal change with input voltage and load current, especially above 0.2A DC load.

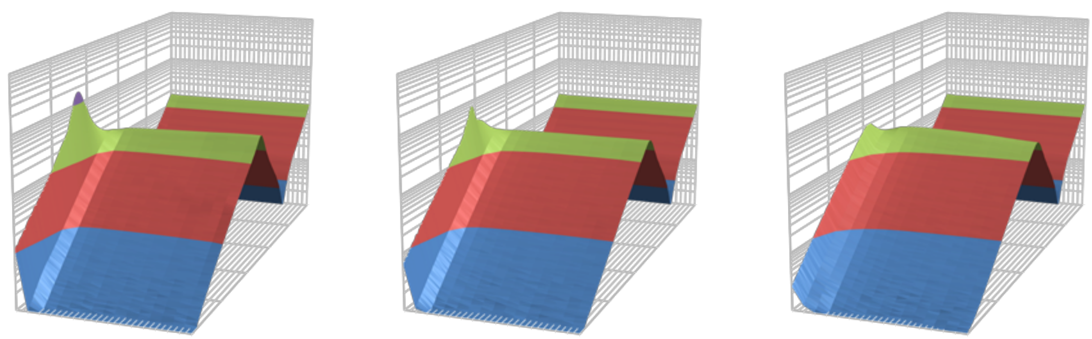

Figure 7: *Variation of impedance surface as a function of input voltage. Left plot: 3.5V, middle plot: 4.5V, right plot: 5.5V DC input voltage. For sake of simplicity, axis labels and titles are not shown, but are the same as in Figure 2.*

There are many other parameters we may want to test. In the frequency domain we could check the Gain-phase plot to assess the stability margin of the converter. In the time domain we can measure the output ripple, high-frequency burst noise and transient response. And finally we could tie all that data back to simulations to see how good correlation we get. We will address some of those items in future columns, and also things that don't make sense to check on evaluation boards.

So next time when you evaluate an evaluation board, be prepared to know what to expect. Double checking the test data always helps to avoid wrong and potentially misleading conclusions.

References:

[1] "Do not measure PDN noise across capacitors!" Quietpower column, http://www.electrical-integrity.com/Quietpower_files/Quietpower-23.pdf

[2] LM20143 data sheet, http://www.ti.com/general/docs/lit/

[3] AN-1691 LM20143 Evaluation Board, http://www.ti.com/general/docs/lit/

[4] "DC and AC Bias Dependence of Capacitors Including Temperature Dependence," http://www.electrical-integrity.com/Paper_download_files/DCE11_200.pdf