Characterizing Passive Components of a DC/DC Buck Converter

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Practical Training using Board *DCDCbuck_Rev10.02*

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Abstract. The passive component RLC lowpass part of a DC/DC buck converter is characterized for understanding physical backgrounds, modeling and optimal control setting.

1 Introduction

1.1 Objectives

Goal of this practical training is the passive component characterization of a mixed analog/digital system using the example of a DC/DC buck converter with a digital control unit.

1.2 Requirements

1.2.1 Hardware

It is assumed that we have the following hardware:

- *DCDCbuck_Rev10*) board, selfmade in electronics lab of OTH Regensburg [1], [2].
- *LoopGain_Rev1.5.4* board, selfmade in electronics lab of OTH Regensburg [3]
- *DE1-SoC* board from *Terasic* [1],
- *Bode 100* network analyzer and *B-WIT 100* injection transformer of *Omicron Lab* [2].

1.2.2 Knowledge

It is assumed that you are familiar with document "Getting Started With *DCDCbuck* Board" [DCDCbuck] available from the author's homepage [Schubert.OTH].

1.3 System Setup

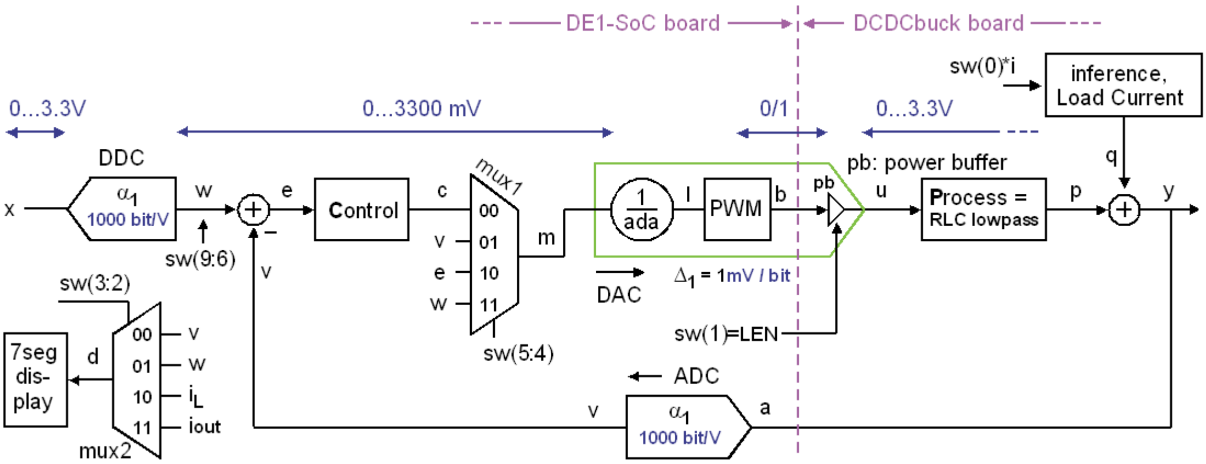


Fig. 1: The DC/DC buck converter setup for first tests.

Fig 1 illustrates the DC/DC step-down conversion system with a digital part on the left hand side of the vertical dashed (pink) line, and an analog part on the right hand side.

The digital part in Fig. 1 is left of the vertical, dashed, pink line is illustrated as block diagram. It is realized with or controlled by *VHDL* [VHDL]. The code is synthesized and downloaded into the *Cyclone V FPGA* [Cyclone-V] on a *DE1-SoC* board [Terasic]. The main blocks of the digital part sketched in Fig. 1 are:

- A controller with control transfer function *CTF(z) = C(z)/E(z)*, whereas capital letters indicate frequency domain notification.
- Analog-to-digital converter (ADC) *LTC2308* [LTC2308] being a part of *DE1-SoC* board.
- A digital-do-analog converter (DAC), which is a selfmade pulse-width modulator (PWM). Factor (1/*ada*) incorporated into the DAC compensates for different amplifications of ADC and DAC, such that ADC and DAC in series deliver an amplification of 1.
- Multiplexer *mux1* allowing to feed different inner signals to the PWM DAC,
- Multiplexer *mux2* feeding different inner signal to the six-digit 7-segment display which is a part of the *DE1-SoC* board.
- The digital-to-digital converter (DDC), which is a hypothetical device for mathematical consideration. It is scaled such that $y = x$ for infinite loop gain.

Due to the division by *ada*, the gain of A/D and D/A converters in series is equal to one.

1.4 Acknowledgements

The author would like to thank *Omicron Lab* [Omicron Lab] for supporting this document with kind support and allowing to use figures from Omicron documentation.

1.5 Outline

The organization of this communication is as follows:

Section 1	introduces into this document.
Section 2	makes the student familiar with required tools.
Section 3	characterizes the passive *RLC* lowpass (labeled *Process* in Fig. 1.3) on the isolated *DCDCbuck* daughter board.
Section 4	draws conclusion and
Section 5	offers references.

2 Getting Started with the Tools

This chapter makes you familiar with some basic tools and formulae.

2.1 Fundamental Electronics

2.1.1 Inductor: Extract *L* and series wire resistor *R_w* from *Bode* Diagram

$X_L = sL \xrightarrow{s=j\omega} j\omega L$, consequently $L = \frac{|X_L|}{2\pi f}$

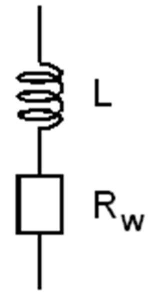


Fig. 2.1.2: *L, R* in series which models a real-world inductor. Example: Fig. 2.8.2.

Inductor with serial wire resistor R_w:

$Z_{RL} = R_w + j\omega L$, consequently

$$L = \frac{\sqrt{|Z_{RL}^2| - R_w^2}}{2\pi f} \qquad (2.1)$$

If $R_w << |X_L|$ negligible: $L = \frac{\sqrt{|Z_{RL}^2| - R_w^2}}{2\pi f} \xrightarrow{|X_L|>>R_w} \frac{|Z_{RL}|}{2\pi f} = \frac{|X_L|}{2\pi f}$ (2.2)

PS: Data sheet note R_w as DC resistor, or *DCR*.

2.1.2 Capacitor: Extract *C* and series resistor *R_C* from *Bode* Diagram

$X_C = \frac{1}{sC} \xrightarrow{s=j\omega} \frac{1}{j\omega C}$, consequently $C = \frac{1}{2\pi f |X_C|}$

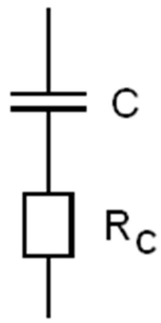


Fig. 2.1.2: *C, R* in series which models a real-world capacitor.

Capacitor with equivalent series resistor R_C:

$Z_{RC} = R_w + \frac{1}{j\omega C}$, consequently

$$C = \frac{1}{2\pi f \sqrt{|Z_{RC}^2| - R_C^2}} \qquad (2.3)$$

If $R_C << |X_C|$ negligible: $C = \frac{1}{2\pi f \sqrt{|Z_{RC}^2| - R_C^2}} \xrightarrow{|X_L|>>R_w} \frac{1}{2\pi f |Z_{RC}|} = \frac{1}{2\pi f |X_C|}$ (2.4)

PS: Data sheets label R_C as *equivalent series resistor*, or *ESR*.

2.1.3 Parallel LRC Oscillator: (*LR*||*C*: Real World Inductor)

Inductor with serial resistor *R* and parallel capacitor *C*:

$$Z_{LRC} = (R+sL) \| \frac{1}{sC} = \frac{R+sL}{1+sRC+s^2LC} \quad (2.5)$$

Using $s = j\omega$ delivers

$$Z_{LRC}(j\omega) = \frac{R+j\omega L}{1-\omega^2 LC + j\omega RC} \quad (2.6)$$

which peaks for small time constants *RC* near

$$\omega_0 = \frac{1}{\sqrt{LC}} \quad \Leftrightarrow \quad f_0 = \frac{1}{2\pi\sqrt{LC}}. \quad (2.7)$$

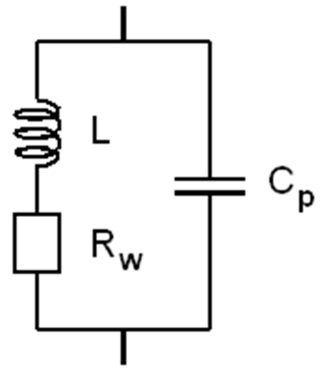


Fig. 2.1.3: LRC parallel, which models a real-world inductor. Example: Fig. 2.8.3 peak up (right).

2.1.4 Series *RLC* Oscillator (Real-World Capacitor)

In series with the capacitor and its resistor R_C we have a series inductor *L*

$$Z_{CRL}(s) = R + sL + \frac{1}{sC} = R_C + \frac{1+s^2LC}{sC} \quad (2.8)$$

and with $s = j\omega$

$$Z_{CRL}(\omega) = R - j\frac{1-\omega^2 LC}{\omega C}. \quad (2.9)$$

At $\omega_0 = \frac{1}{\sqrt{LC}} \Leftrightarrow f_0 = \frac{1}{2\pi\sqrt{LC}}$ we get

$Z_{CRL}(f)$ is minimal (2.10)

and

$$Z_{CRL}(f_0) = R. \quad (2.11)$$

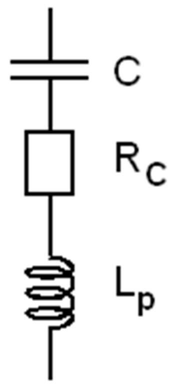
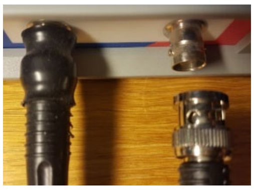


Fig. 2.1.4: LRC parallel oscillator, which models a real-world capacitor. Example: Fig. 2.8.3, peak down (left).

In summary, at the impedance minimum in the frequency domain we also have phase 0. At this point we can read the series resistor (i.e. R_C of a capacitor) and the resonant frequency f_0.

2.2 Basic Metering

(a) *BNC* plugs



(b) *BNC* ⇔ banana adaptor

(e) multimeter, adaptor and 50Ω

(c) BNC 50Ω

(d) BNC ⇔ pin plugs

Fig. 2.2: Different *BNC* related measurements aids

Most measurements are based on *BNC* and pin cables and plugs as illustrated in Fig. 2.1.

2.3 *Eagle* Layout and Schematic Editor

Download the DCDC converter schematics from the author's homepage > [Schubert.OTH] >…*Edu* > *Labs* > *DE1-SoC Board* > *DCDCbuck* > DCDCbuck board,… Rev.10.02.06: Eagle7.zip, Eagle9.zip . Unpack the *zip* file to get the two files

- *.*brd*: physical board layout
- *.*sch*: board schematic

Opening one of them with *Eagle* [Eagle] software typically opens both.

- Se both layout and schematics view: Click on the  symbol to pop-up the other view
- Understand the layers: brown is top, blue is bottom metal and green is via (connection).
- Activate *View* (German: *Ansicht*) in both windows. Then click on a metal in the *layout window* and observe how the corresponding wire in the *schematic window* is highlighted and vice versa.

2.4 *HM8118 LCR* Bridge for Device Characterization

LCR bridge *HM8118* [HM8118] is available in the electronics lab and suitable to measure components such as capacitors and inductors. Check for the *HM8118 LCR* bridge in the lab and measure some arbitrary inductors and capacitors.

Note that we measure series resistors only, so the *MODE* button must be *AUTO* and/or *SER*. Typically it is enough to press *AUTO* and let the *HM8118* detect the rest.

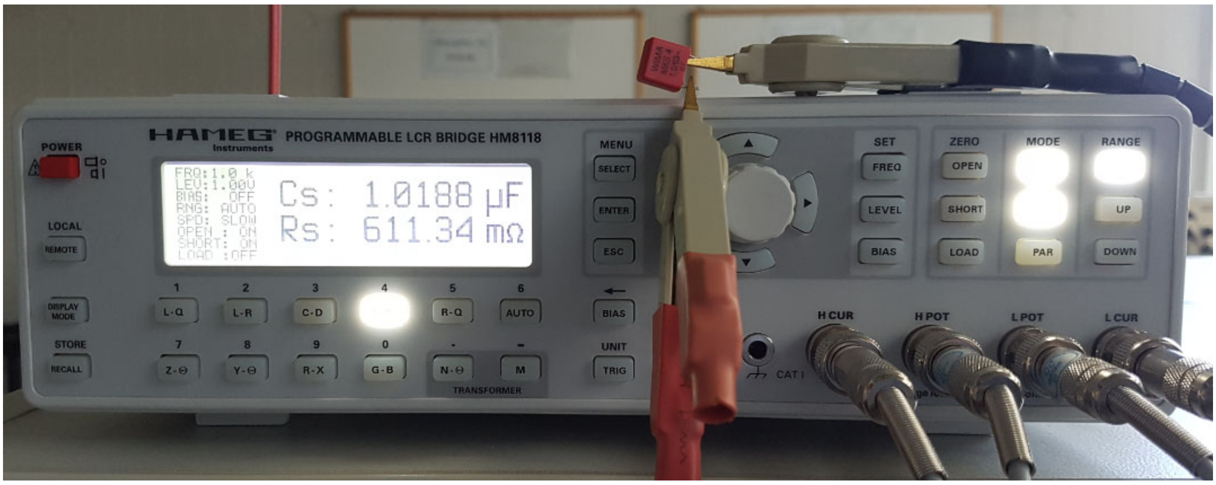


Fig. 2.4: Measuring a capacitor and its equivalent series resistor with HM8118

2.5 Screen Copies with *Microsoft Windows 10*

Screen copies with *MS Windows 10* can be made with the snipping tool: Start menu: → hit keys “*sn*” → (Snipping tool opens)→ *New* → (draw the widow to copy) → *File* → *Save as* → (filename). From the authors experience *Snipping* tool screen copies make smallest file sizes with *PNG* formatted files