Transfer Functions of Switching Converters

Fast Analytical Techniques at Work with Small-Signal Analysis

Hi everyone, my name is Christophe Basso and I am releasing a new book on small-signal modeling (now available with Faraday Press). I have derived the control-to-output transfer functions of many converters, starting from simple dc-dc cells (buck, buck-boost or boost) to isolated versions like flyback or forward converters operated in voltage mode (VM), current mode (CM), quasi-resonance (QR), constant on-time (COT), constant off-time (FOT) with various operating modes like continuous conduction (CCM) or discontinuous conduction (DCM) and borderline conduction (BCM or CrM) for power-factor-corrected converters for instance. Many hours of calculus mainly using Mathcad® version 15.

I am releasing a set of 41 files which cover all the examples given in the book. Several files are of particular interest as they automate the compensation of the flyback converter operated in QR and fixed-frequency current-mode control: you select a crossover frequency and poles-zeroes are suggested with responses at high and low-line conditions.

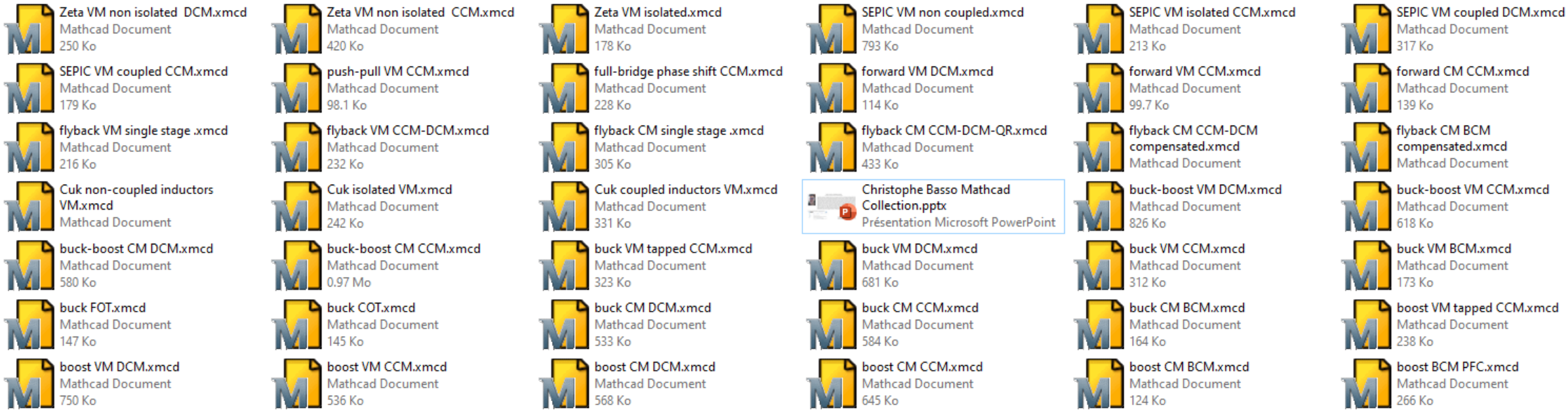
Considering the amount of work put in this study, I am distributing these files for a fixed fee that I will communicate by email: cbasso@wanadoo.fr

If you are a power supply designer, you can't miss these ready-made templates for your engineering job.

Thank you – Christophe Basso, May 2020.

Version 1.0

The Files – there are 41 sheets:



Covered structures:

Buck: CM, VM, DCM/CCM, FOT, COT, QR
Buck-derived: forward, tapped, push-pull, phase-shift full bridge
Boost: CM, VM, DCM/CCM, QR, PFC
Buck-boost: CM, VM, DCM/CCM
Buck-boost-derived: flyback, single-stage PFC
SEPIC, Zeta, Cuk and LLC

The File – select the operating parameters and plot the transfer functions

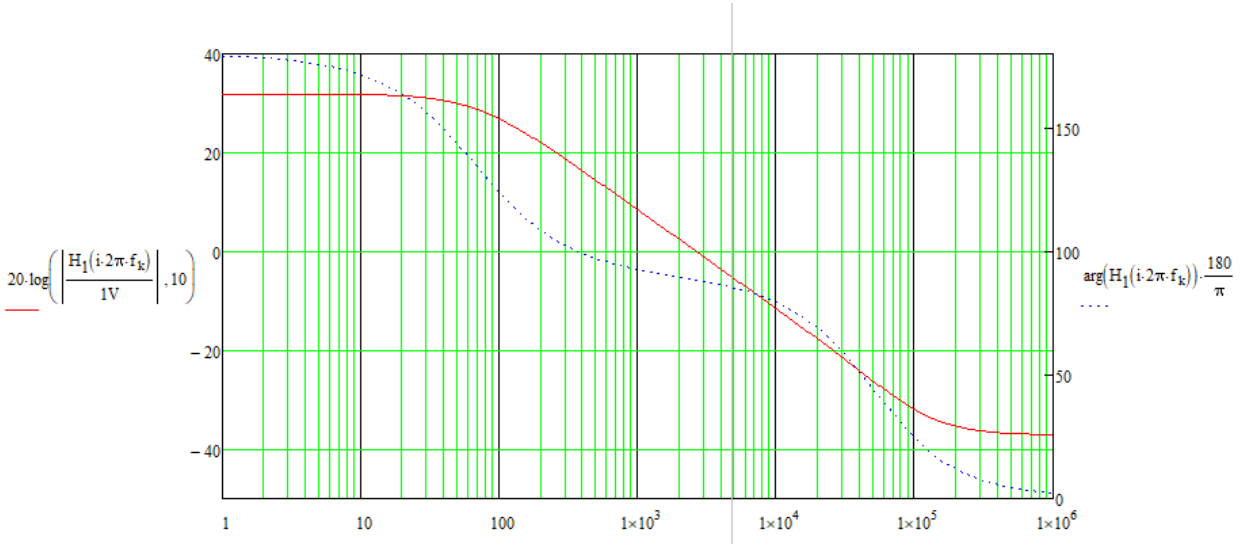
Buck-Boost Converter Fixed Switching Frequency and Voltage Mode - DCM
Christophe Basso - April 2021
Transfer Functions of Switching Converters - Faraday Press

Component values for the DCM boost converter

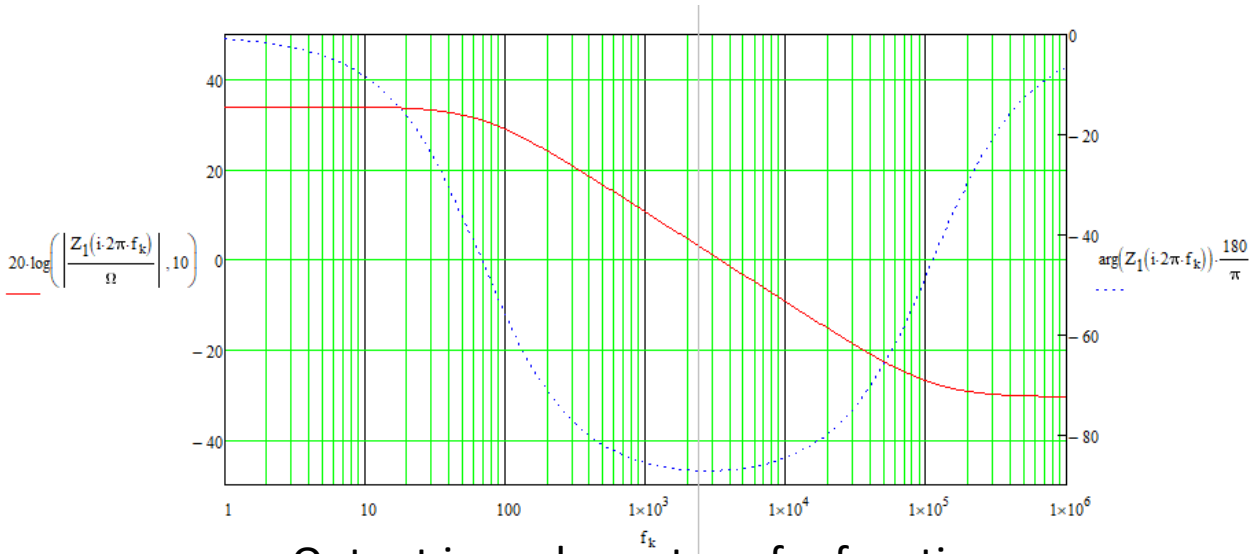
$L_1 := 47\mu H$ $F_{sw} := 100kHz$ $C_2 := 47\mu F$ $V_{in} := 12V$ $r_L := 0.01\Omega$

$\tau_L := \frac{L_1}{R_L} \cdot F_{sw}$ $d_1 := 0.445$ $R_L := 100\Omega$ $r_C := 0.03\Omega$

$\frac{2 \cdot F_{sw} \cdot L_1}{(1 - d_1)^2} = 30.517\,\Omega$ critical load resistance value



Control-to-output transfer function



Output impedance transfer function

Compensated sheets – select a crossover frequency and automate the poles and zeroes placement

Converter Parameters Fixed-Frequency Operation

$V_{in\_min} := 90V$ $V_{in\_max} := 370V$ $N_s := 16$ $R_{sense} := 0.33\Omega$ $C_{out} := 680\mu F$

$V_{out} := 19V$ $L_p := 600\mu H$ $N_p := 100$ $\eta := 85\%$ $R_{esr} := 0.05\Omega$

$P_{out} := 70W$ $V_f := 0.5V$ $N_1 := \frac{N_s}{N_p} = 0.16$ $R_{load} := \frac{V_{out}^2}{P_{out}} = 5.157\,\Omega$

Controller Parameters

$F_{sw} := 65kHz$ $S_e := 0\frac{kV}{s}$ $Div := 3$ $T_{sw} := \frac{1}{F_{sw}} = 15.385\cdot\mu s$

Operating points calculations - Vin_min

Operating points calculations - Vin_max

Logarithmic graph

Mode detection CCM or DCM for Vin_min:

Mode detection CCM or DCM for Vin_max:

Small signal Analysis Poles Zeros Positions - CCM operation - Vin_min

Small signal Analysis Poles Zeros Positions - DCM operation - Vin_min

Small signal Analysis Poles Zeros Positions - CCM operation - Vin_max

Small signal Analysis Poles Zeros Positions - DCM operation - Vin_max

Complete transfer function CCM and DCM - Vin min and max

Final result check LL

$f_{cLL} := 1kHz$

$f_{cLL} := root\left(\left|T_{OL\_LL}\left(i\cdot 2\cdot\pi\cdot f_{cLL}, S_e\right)\right| - 1, f_{cLL}\right)$

$f_{cLL} = 0.998\cdot kHz$ crossover frequency

$\arg\left(T_{OL\_LL}\left(i\cdot 2\cdot\pi\cdot f_{cLL}, S_e\right)\right) = 68.761\cdot°$ Phase margin

$f_{gLL} := 20kHz$

$f_{gLL} := root\left(\arg\left(T_{OL\_LL}\left(i\cdot 2\cdot\pi\cdot f_{gLL}, S_e\right)\right), f_{gLL}\right)$

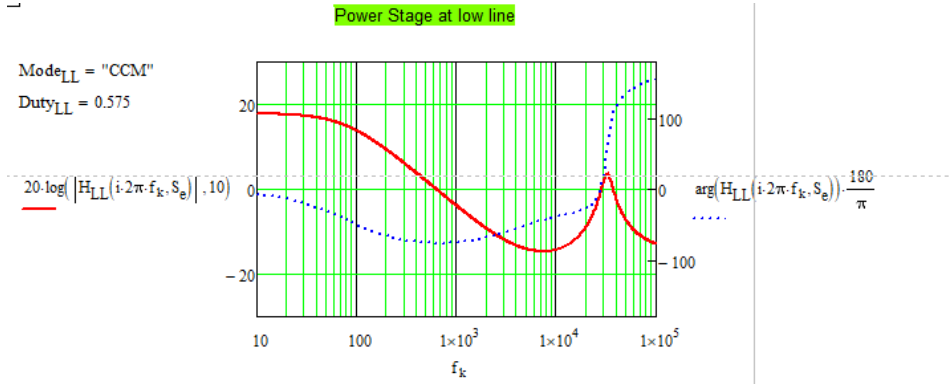
$f_{gLL} = 23.953\cdot kHz$ f(pi)

$20\cdot\log\left(\left|T_{OL\_LL}\left(i\cdot 2\cdot\pi\cdot f_{gLL}, S_e\right)\right|, 10\right) = -23.953$ Gain margin

Power Stage at low line

$Mode_{LL} = "CCM"$

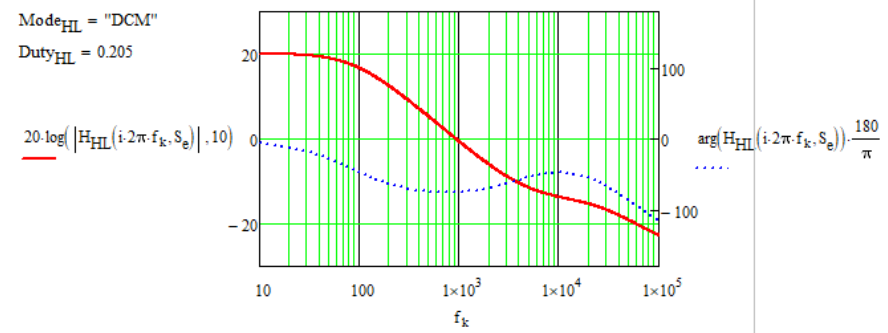
$Duty_{LL} = 0.575$



Power Stage at high line

$Mode_{HL} = "DCM"$

$Duty_{HL} = 0.205$



Compensated Converter Bode - Low line

$T_{OL\_LL}(s, S_e) := -\left(H_{LL}(s, S_e)\cdot G_1(s)\right)$