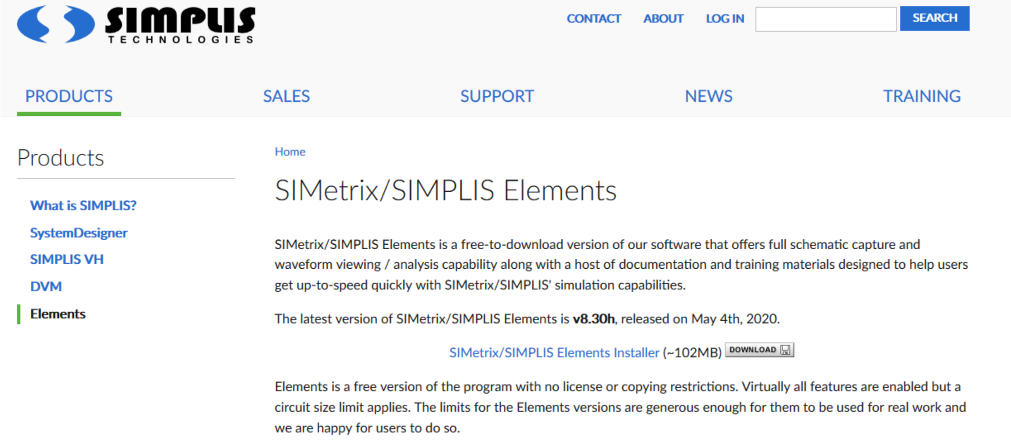
Transfer Functions of Switching Converters

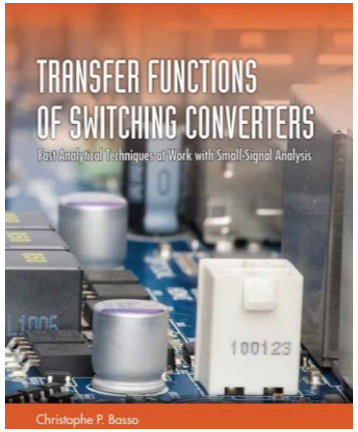
Fast Analytical Techniques at Work with Small-Signal Analysis

Hi everyone, my name is Christophe Basso and I am releasing a new book on small-signal modeling published in June 2021. 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 simulation hours mainly in SIMPLIS® using the free demonstration version Elements. Over the proposed 120+ files, some require the full professional version to operate (such as the PFCs or UC384x-based circuit for instance) the rest are 100% operating on Elements which is an excellent news. You have a tutorial I built on Elements. All application circuits come with an automated calculation window in which you enter the wanted design goals extracted from the power stage response and the program calculates the compensation elements for you. The values are available in the netlist and easily accessed from the development environment. If you are a power supply designer, you can’t miss these ready-made templates for your engineering job. Enjoy these files and let me know what you think of these examples. Thank you – Christophe Basso, May 2020.

https://www.simplistechnologies.com/product/elements

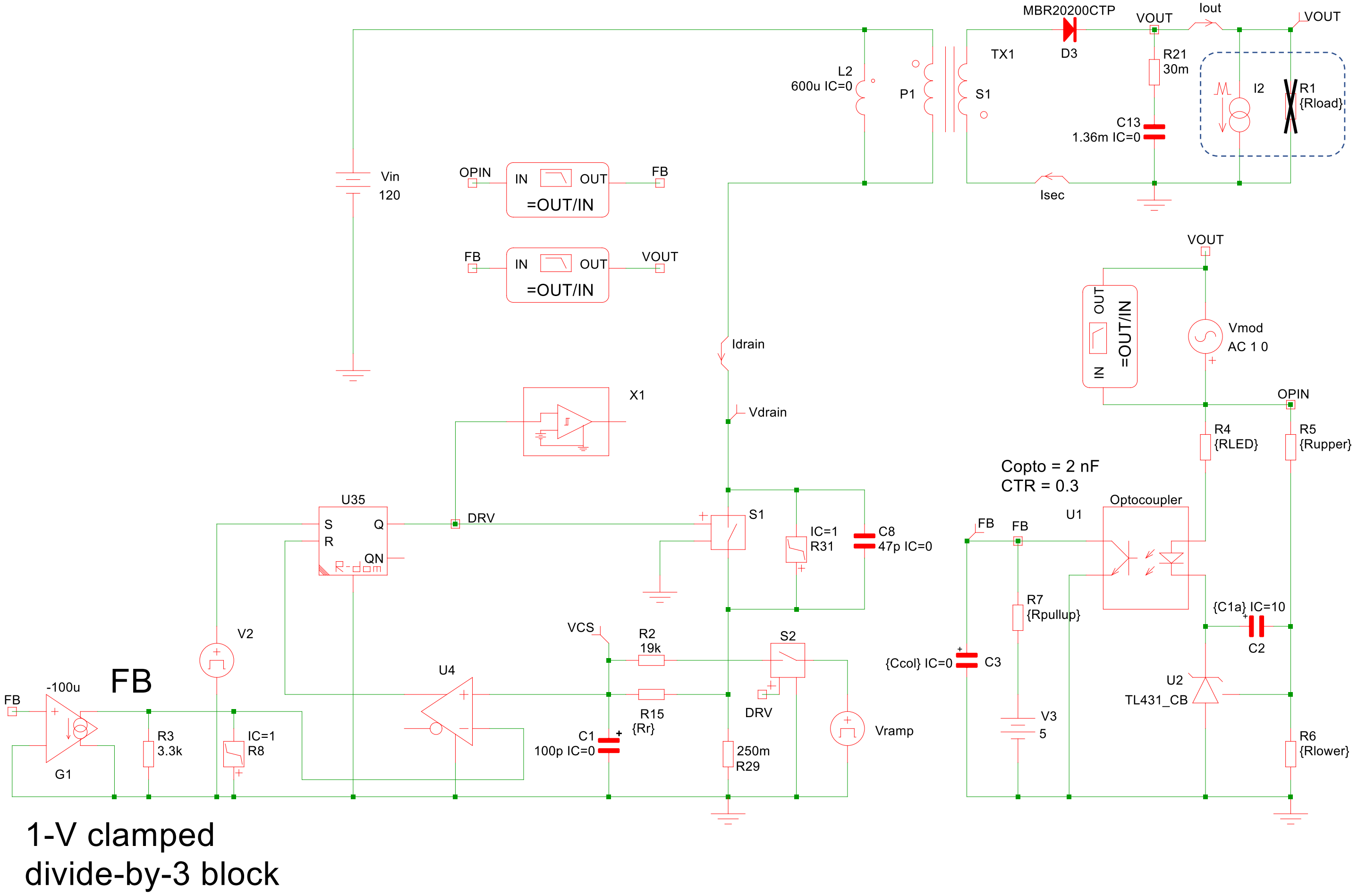


The power supplies templates ZIP is here and the compensators ZIP is available here.



Version 1.43

The Template – it is a ready-to-simulate circuit. Load it, press F9 and there you go:

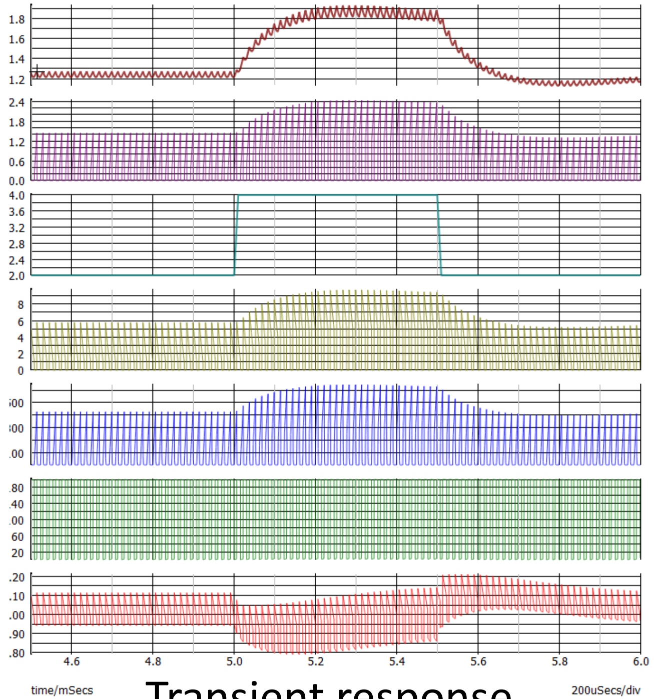


Enable or disable with a right-click.

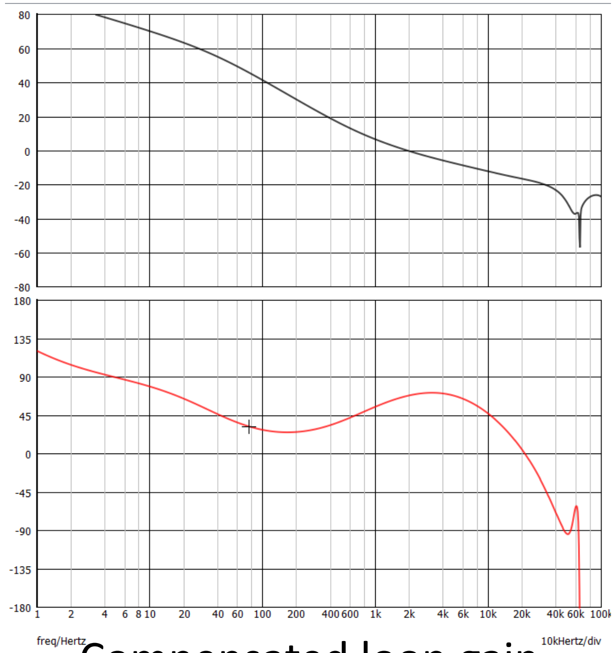
This is a fixed-frequency current-mode-controlled flyback converter delivering 19 V 3 A from a 120-V source. Enable the 6-ohm load for ac analysis and disable the PWL source (right-click after selection) to see the transient response. Check Simulator>Edit Netlist (after preprocess) to see the calculated component values.

This is a typical converter for an ac-dc notebook adapter.

- Christophe Basso - Transfer Functions of Switching Converters -

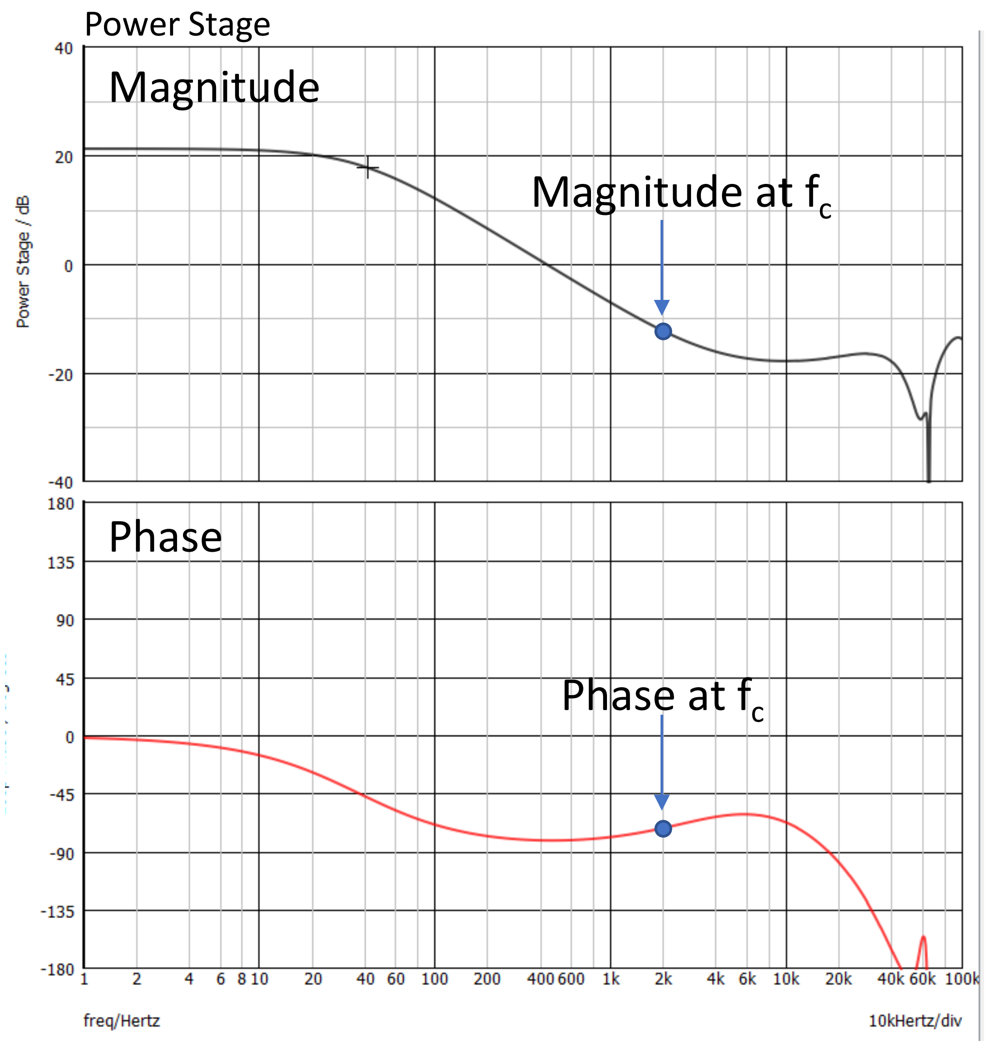


Transient response



Compensated loop gain

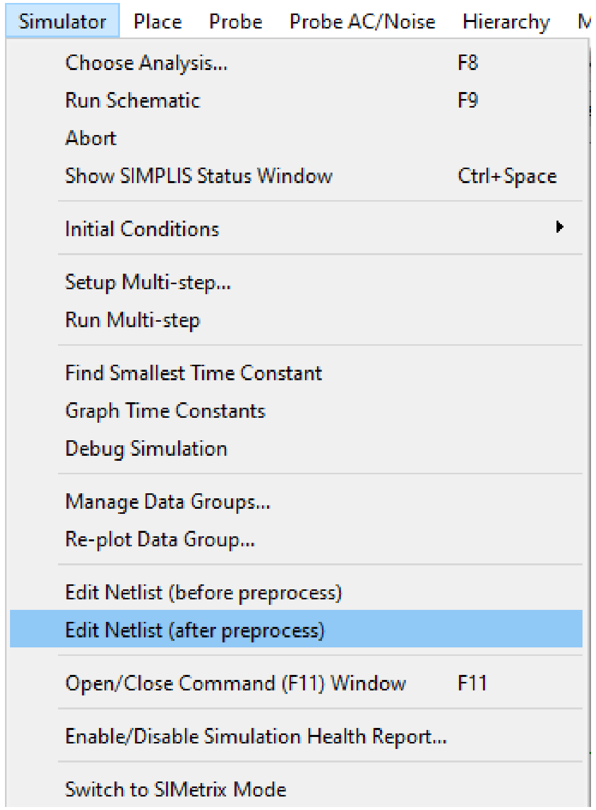
The Compensation – display the power stage response at the selected operating point and extract parameters




```
*
.VAR Vin=120
.VAR Vout=19
.VAR Lp=600u
.VAR Ri=250m
.VAR N=250m
.VAR Rload=6
.VAR Ts=15u * please update clock and ramp generators *
*
.VAR D=Vout/(Vout+N*Vin) * duty ratio calculation *
.VAR mc1=0.818/(1-D) * recommended compensation value for a Q of 1 *
.VAR Sn={(Vin/Lp)*Ri}
.VAR Sramp={2.5/Ts} * 2.5 V over Ts - check your IC specs *
.VAR mc=1.5 * set this value for ramp comp *
.VAR Se={(mc-1)*Sn}
.VAR Rr={(Se/Sramp)*19k+1m}
.VAR fRHPZ={((1-D)^2*Rload/(D*Lp*N^2))/(2*pi)}
.VAR fcMAX=0.3*fRHPZ
*
* Enter values extracted from the plant Bode plot
*
.VAR Gfc=-13 * magnitude at crossover *
.VAR PS=-80 * phase lag at crossover *
*
* Enter Design Goals Information Here *
*
.VAR fc=2k * targetted crossover *
.VAR PM=60 * choose phase margin at crossover *
*
* Enter the Values for Vout and Bridge Bias Current *
*
.VAR Vout=19
.VAR Ibias=250u
.VAR Vref1=2.5
.VAR Rlower=Vref1/Ibias
.VAR Rupper=(Vout-Vref1)/Ibias
*
* Optocoupler specifications *
*
.GLOBALVAR Rpullup=20k * check with the selected control chip *
.GLOBALVAR Fopto=6k
.GLOBALVAR Copto=1/(2*pi*Fopto*Rpullup)
.GLOBALVAR CTR=0.33
*
.VAR VL=0.2
.VAR VCEsat=0.3
.VAR Vdd=5
```

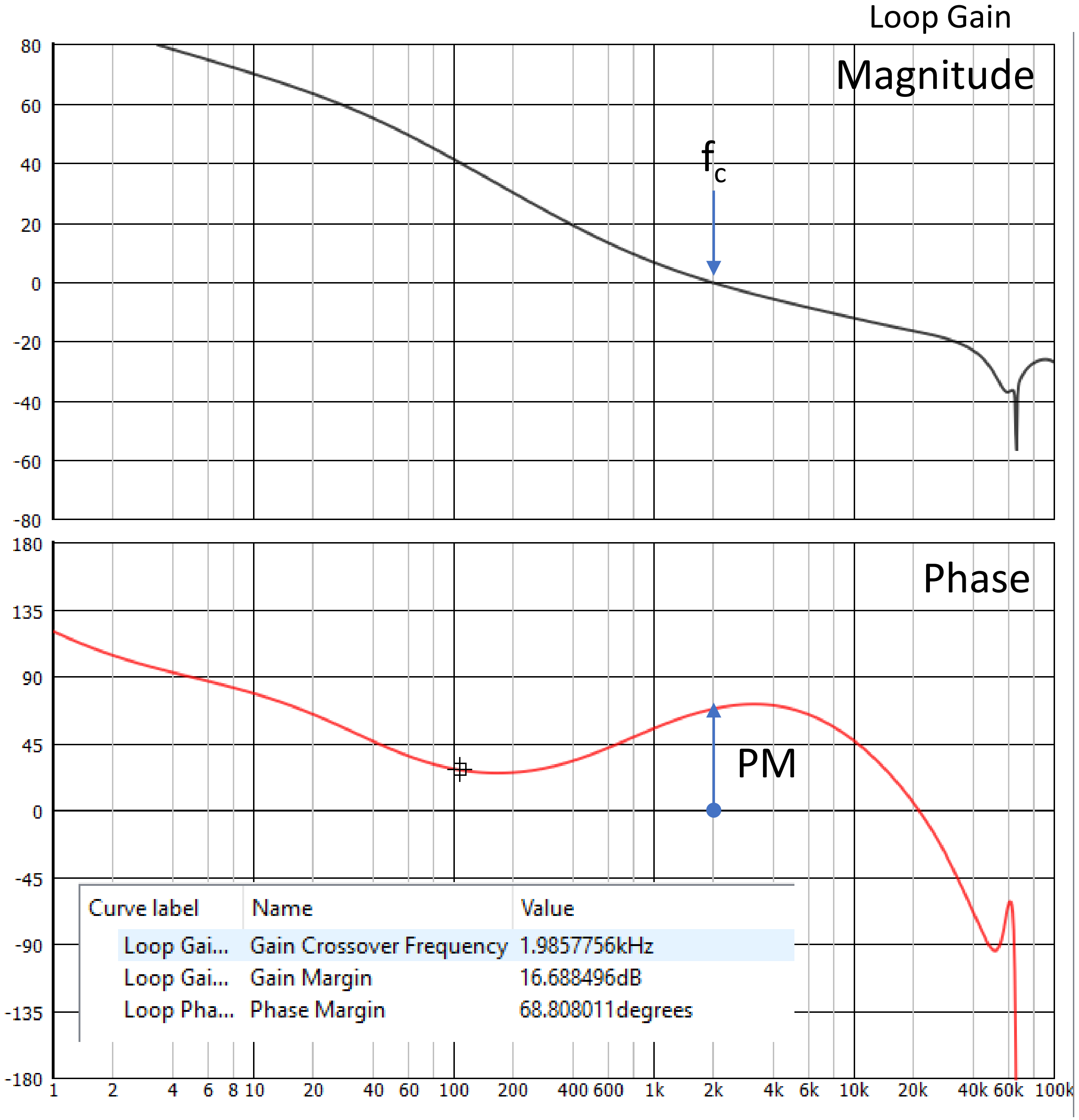
Extract data at the selected crossover frequency.
Here, it is 2 kHz with a 60° phase margin as a goal.

The Compensation – find all calculated values in the Edit Netlist submenu



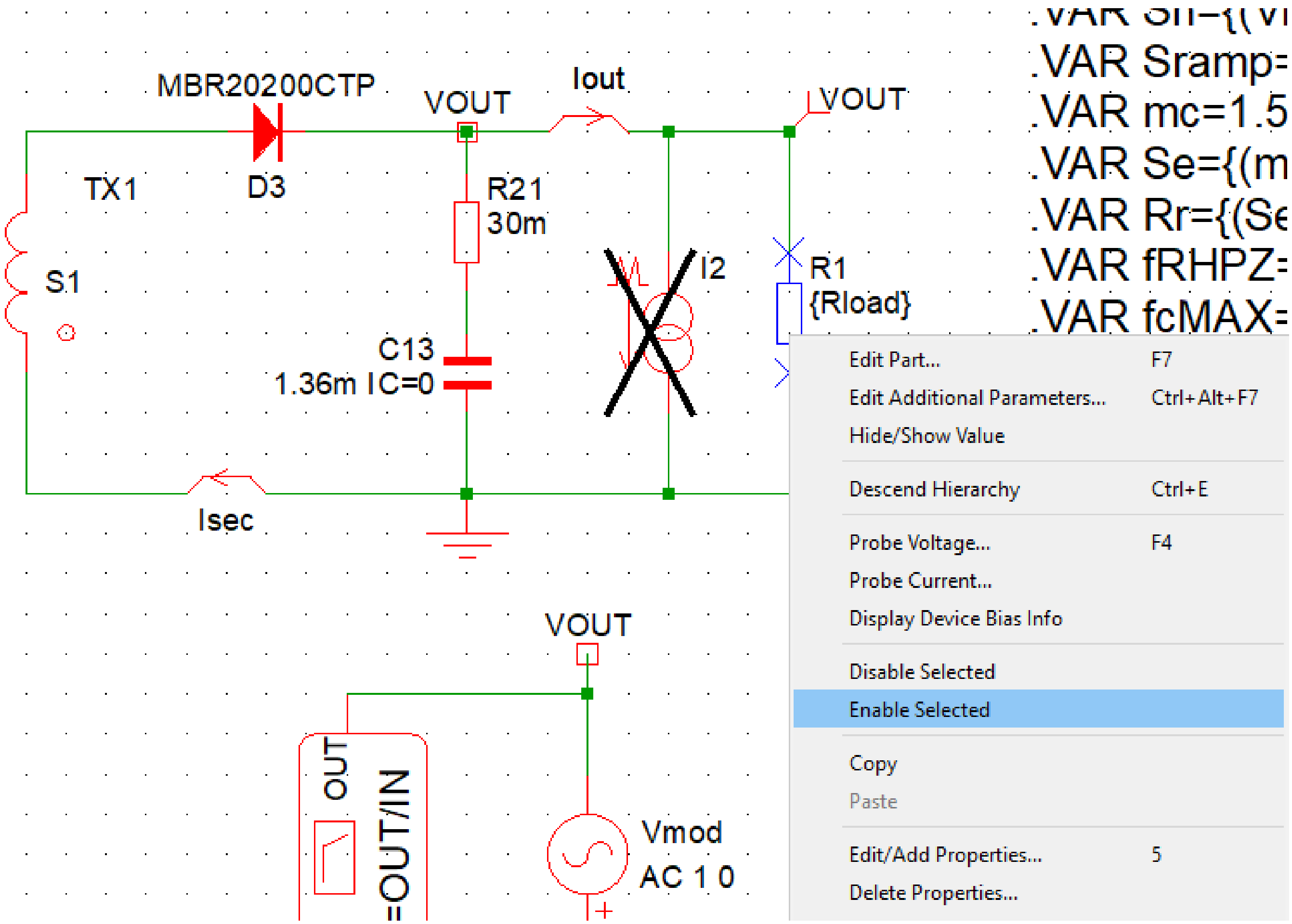

```
*
* Rupper = 66000
* Rlower = 10000
* C2 = 1.44819154804453e-09
* C1 = 3.31268645711794e-09
* Boost = 50
* Fz = 727.940468532405
* Fp = 5494.95483890924
* Sn = 50000
* Se = 25000
* D = 0.387755102040816
* Mc = {mc1}
* Rramp = 2850.001
* Rmax = 24995.7446808511
* FRHPZ = 24616.8762677045
* FcMAX = 7385.06288031136
*
```

In current-mode control, S_n is the on-slope inductor current – it sometimes needs to be scaled by the transformer turns ratio 1:N in isolated buck-derived structures – m_c is defined as $m_c = S_e/S_n + 1$ as per R. Ridley notation in his thesis and S_e is the external or artificial ramp used for slope compensation. $m_c = 1$ implies no compensation ($S_e = 0$), $m_c = 1.5$ means a 50% compensation.

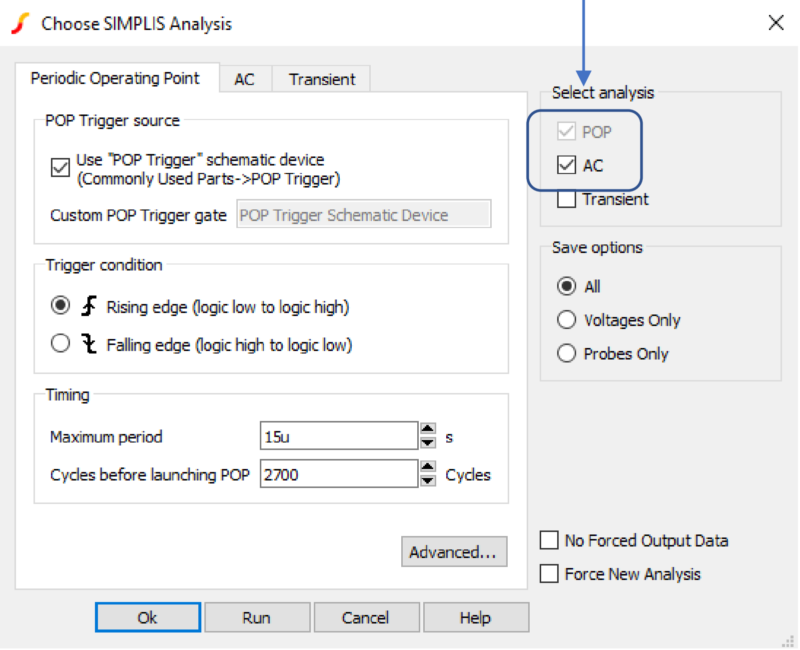


Compensated loop gain

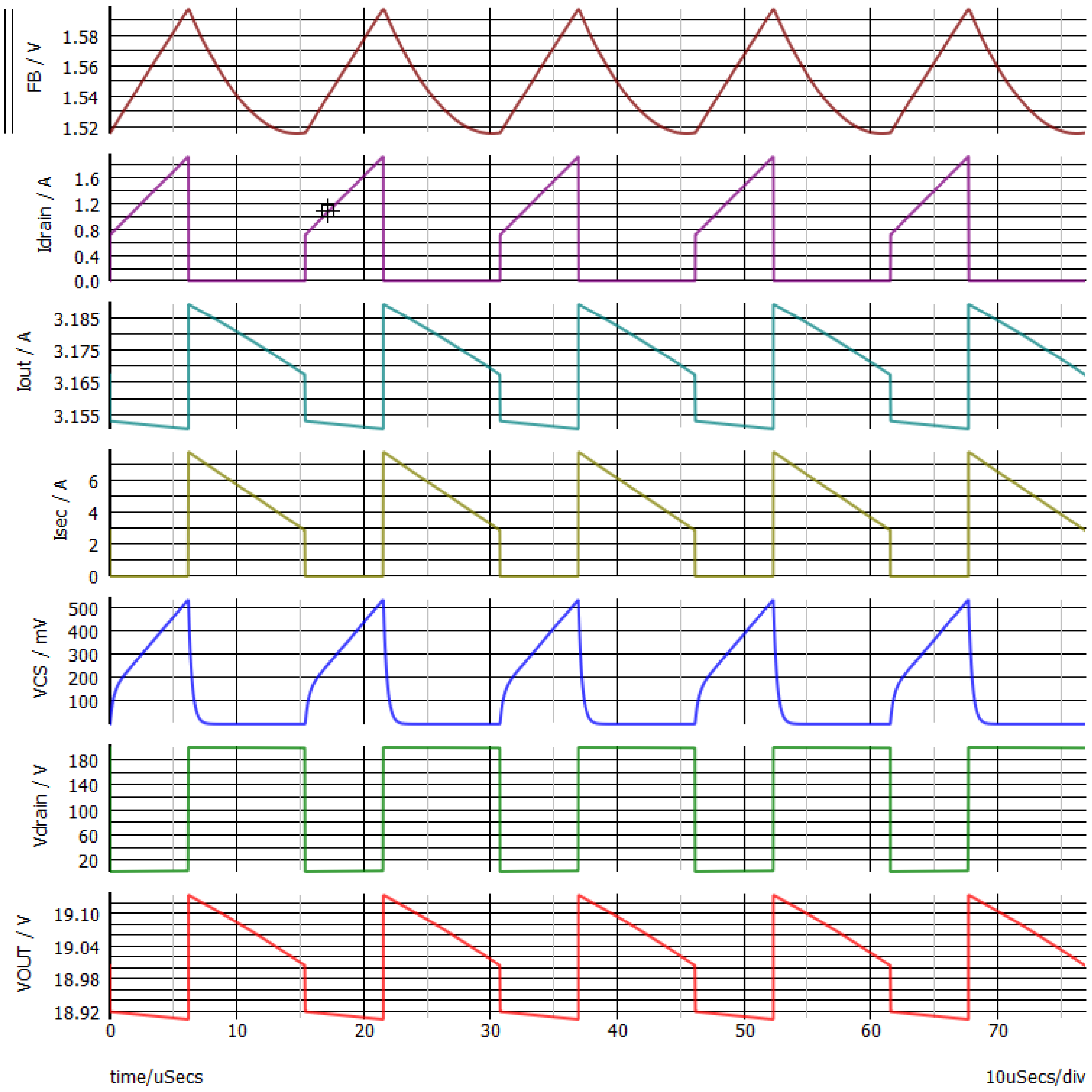
The Template – change the load from a fixed resistance to a current source for the step load response



1. Right click on the resistance
2. Enable it - *Enable Selected*
3. Right click on the current source
4. Disable it – *Disable Selected*
5. Press F8
6. Choose ac analysis



- *Step load*: disable the loading resistance, press F8 then check transient
- *Ac sweep or steady-state*: disable the current source, press F8 then check ac analysis. The POP delivers the ac response and the operating waveforms.



SIMPLIS® starts the ac analysis when the so-called periodic operating point or POP is found. The engine finds the exact point at which the converter is in a stable operating point also called steady-state operation. In this mode, the average current in any capacitor is extremely small (0 A in theory) while the average voltage across any inductor is also an extremely small value (0 V in theory). It happens that SIMPLIS® cannot find its POP and you have to help him converge. It can happen if you have selected a wrong target for a crossover frequency, a too aggressive phase margin or the converter can simply not be stabilized. Check the computed elements in the netlist to make sure there are no negative values. This is generally a sign of a wrong goal set for instance or a bad position of the double zeroes in the type 3 compensator. Running a transient analysis with a load resistance usually helps identify what is wrong.

- TMP
- Tom
- Book Collection.zip
- Boost 2 Phase CM compensated.wxsch
- Boost 2 Phase VM compensated AC.wxsch
- Boost 2 Phase VM compensated TRAN.wxsch
- Boost average CM PFC Ac I_loop.sxsch
- Boost average CM PFC Ac V_loop.sxsch
- Boost average CM PFC Step.sxsch
- Boost average CM PFC TRAN.sxsch
- Boost BCM CM.wxsch
- Boost CCM Average Mode PFC 1854.sxsch
- Boost CCM Var toff PFC ac analysis.sxsch
- Boost CCM Var toff PFC load step.sxsch
- Boost CCM Var toff PFC tran 1.3 kW - demo Po...
- Boost CCM Var toff PFC tran 1.3 kW - demo Po...
- Boost CCM Var toff PFC tran 1.3 kW - demo.sx...
- Boost CCM Var toff PFC tran 1.3 kW - interleav...
- Boost CCM Var toff PFC tran CT.sxsch
- Boost CCM Var toff PFC tran.sxsch
- Boost CM - UC3843.sxsch
- Boost CM PFC ac tran demo.wxsch
- Boost CM PFC sine full version.wxsch
- Boost CM.wxsch
- Boost PFC 1-Phase 3-Level CCM Mul.sxsch
- Boost PFC 1-Phase 3-Level Interleaved CCM M...
- Boost PFC 1-Phase 3-Level Interleaved CCM Va...
- Boost PFC 3-Phase 6-switch MUL - PoP.sxsch
- Boost PFC 3-Phase 6-switch OCC - PoP.sxsch
- Boost PFC NCP1654 AC.sxsch
- Boost PFC NCP1654 TRAN Step.sxsch
- Boost PFC NCP1654 TRAN.sxsch
- Boost TPPFC BCM.sxsch
- Boost TPPFC CCM 3-Level T-type Var toff.sxsch
- Boost TPPFC CCM Var toff tran.sxsch
- Boost VM compensated AC.sxsch
- Boost VM compensated TRAN.wxsch
- Boost VM PFC ac tran demo.wxsch
- Boost VM PFC sine full version.wxsch
- Buck 2 Phase CM.wxsch
- Buck 2 Phase VM.wxsch
- Buck Ac-Ac Converter - demo.sxsch
- Buck Ac-Ac Converter - full version.sxsch
- Buck BCM.wxsch
- Buck Class D.sxsch
- Buck CM PoE.sxsch
- Buck CM Synchro.sxsch
- Buck CM with OTA.sxsch
- Buck CM.sxsch
- Buck COT.wxsch
- Buck FOT.wxsch
- Buck Hysteretic.sxsch
- Buck VM CCM - UC3843.sxsch
- Buck VM Monte Carlo.sxsch
- Buck VM PID analog.sxsch
- Buck VM Synchro.sxsch
- Buck VM with OTA.sxsch
- Buck VM Zin.sxsch
- Buck VM Zout.sxsch
- Buck VM.sxsch
- Buck-Boost CM.wxsch
- Buck-Boost VM compensated AC.wxsch
- Buck-Boost VM compensated TRAN.wxsch
- Christophe Basso SIMPLIS Collection.pptx
- CUK CM coupled.sxsch
- CUK CM isolated.sxsch
- CUK VM coupled.sxsch
- CUK VM isolated.sxsch
- CUK VM uncoupled.sxsch
- DAB converter closed loop.sxsch
- Flyback 2SW CM isolated gate drive.wxsch
- Flyback 2SW CM isolated.wxsch
- Flyback active clamp CM isolated and compen...
- Flyback active clamp CM non-isolated - demo ...
- Flyback active clamp CM non-isolated - demo....
- Flyback CM Isolated ac input - UC384x.sxsch
- Flyback CM isolated ac sine input.wxsch
- Flyback CM Isolated dc input - UC384x.sxsch
- Flyback CM isolated leakage.wxsch
- Flyback CM isolated Zener diode.sxsch
- Flyback CM isolated.wxsch
- Flyback CM non isolated - UC384x.sxsch
- Flyback CM QR isolated ac sine input.wxsch
- Flyback CM QR isolated.wxsch
- Flyback CM QR open-loop.wxsch
- Flyback CM QR Prim Reg 2 Outputs.sxsch
- Flyback CM QR Weighted Reg 2 Outputs.sxsch
- Flyback CM single stage non iso MC33262 ac si...
- Flyback CM single stage non iso MC33262 dc ...
- Flyback VM non-isolated compensated 12-24 ...
- Flyback VM non-isolated compensated AC Zin...
- Flyback VM non-isolated compensated AC.wx...
- Flyback VM non-isolated TRAN.wxsch
- Flyback VM QR single stage ac.wxsch
- Flyback VM QR single stage sine.wxsch
- Flyback VM single stage non iso NCP1608 ac si...
- Flyback VM single stage non iso NCP1608 dc O...
- Forward 2SW CM isolated.wxsch
- Forward 2SW CM non iso.wxsch
- Forward 2SW VM FF non iso.wxsch
- Forward 2SW VM non iso.wxsch
- Forward active clamp CM non-isolated - demo...
- Forward active clamp VM non-isolated - demo...
- Forward active clamp VM non-isolated with SR...
- Forward active clamp VM non-isolated.wxsch
- Forward CM isolated - UC384x.sxsch
- Forward CM isolated.wxsch
- Forward CM non iso.wxsch
- Forward VM isolated.wxsch
- Forward VM non iso PSRR OL.wxsch
- Forward VM non iso.wxsch
- Full Bridge 3-Level Ac Inverter.sxsch
- Full bridge CM isolated - full version.wxsch
- Full bridge CM isolated Zener.wxsch
- Full bridge phase shift CM isolated - full versio...
- Full bridge phase shift CM isolated Zener.wxsch
- Full bridge phase shift VM isolated with DT and...
- Full bridge phase shift VM isolated.wxsch
- Full bridge phase shift VM nonisolated with op...
- Half bridge VM isolated - full version.wxsch
- Half bridge VM isolated Zener.wxsch
- Half bridge VM non iso.wxsch
- LLC Bang Bang Charge Control demo.wxsch
- LLC Charge Control with Type 2.sxsch
- LLC CM Demo.sxsch
- LLC CM Full Opto 500 W.sxsch
- LLC open loop demo.wxsch
- LLC open loop full bridge.sxsch
- LLC VM demo.wxsch
- LLC VM type 2.sxsch
- OPSIMP.sxcmp
- OPTOPARAM.sxcmp
- Pushpull CM isolated.wxsch
- Pushpull CM non iso.wxsch
- Pushpull VM isolated.wxsch
- Pushpull VM non iso.wxsch
- SEPIC Coupled CM.wxsch
- Tapped Boost VM.wxsch
- Tapped Buck VM.wxsch
- TL431_CB.sxcmp

You have 130+ ready-to-simulate switching converters to play with and many of them work with the free demo!

April 2024