CM-LLC Power Stage Dynamic Response

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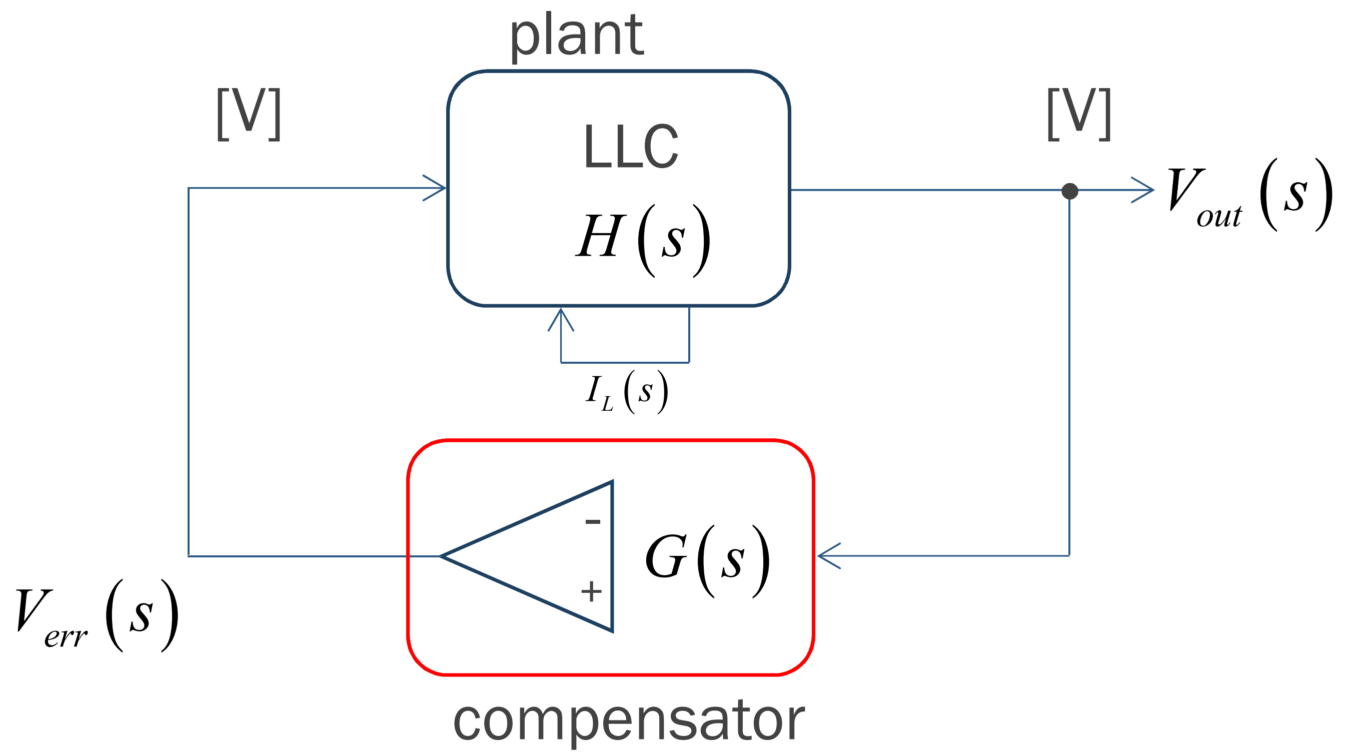
The Basic Blocks of a Closed-Loop CM-LLC Converter

- ❑ Before applying a compensation strategy to any converter, you need its control-to-output transfer function
- ❑ $H(s)$ for a CM-LLC converter cannot be obtained mathematically using a simple model
- ➢ You need to either build a prototype on the bench or use a piece wise linear simulator like SIMPLIS®

The basic blocks assembly for the CM-LLC is as below:



$$T(s) = G(s)H(s)$$

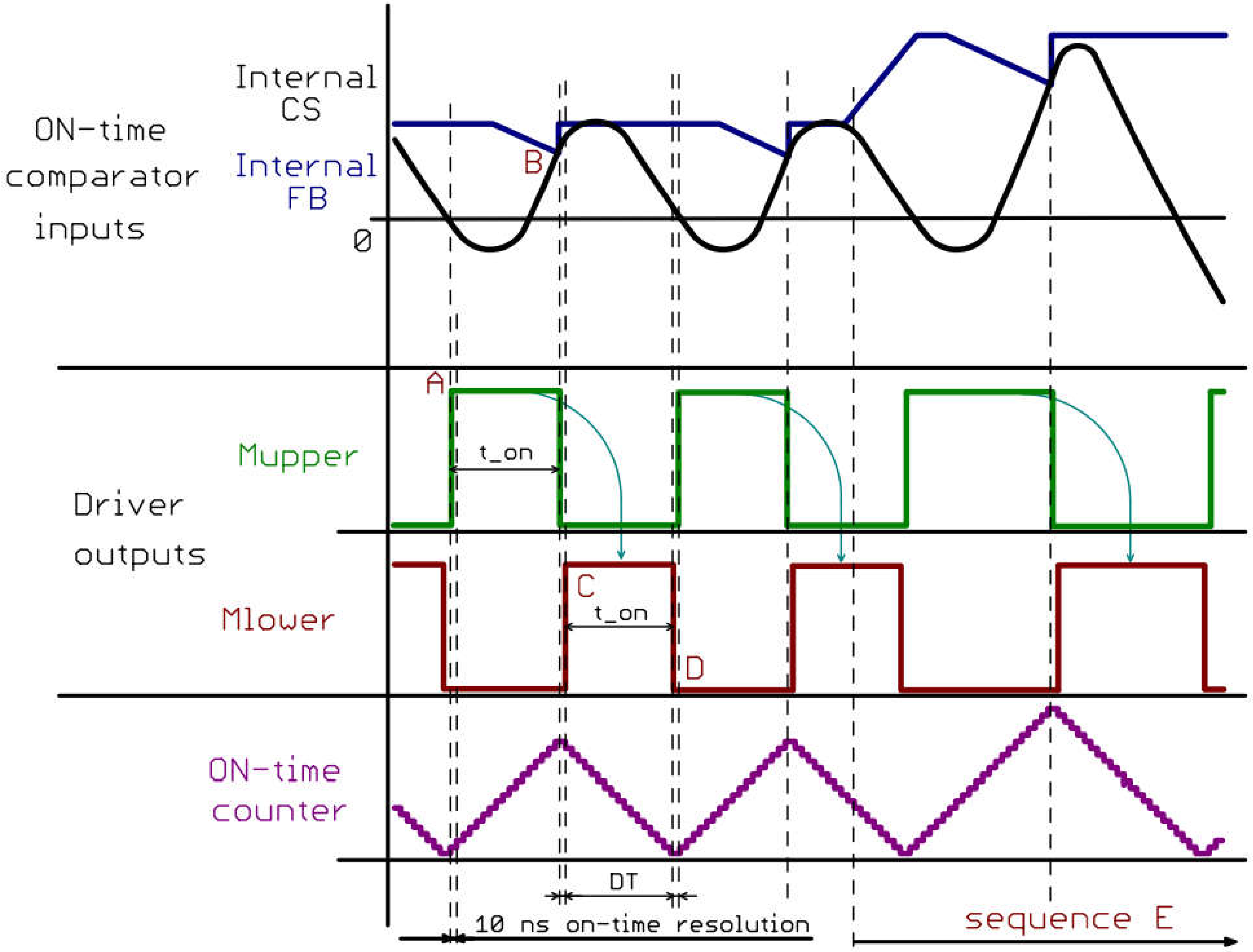
- The compensator delivers a control voltage proportional to input/output operating conditions. The voltage sets the resonating tank current setpoint. It is a current-mode-control type.

- The plant is the LLC power stage, including the resonating elements and the transformer. The power transfer depends on the operating frequency.

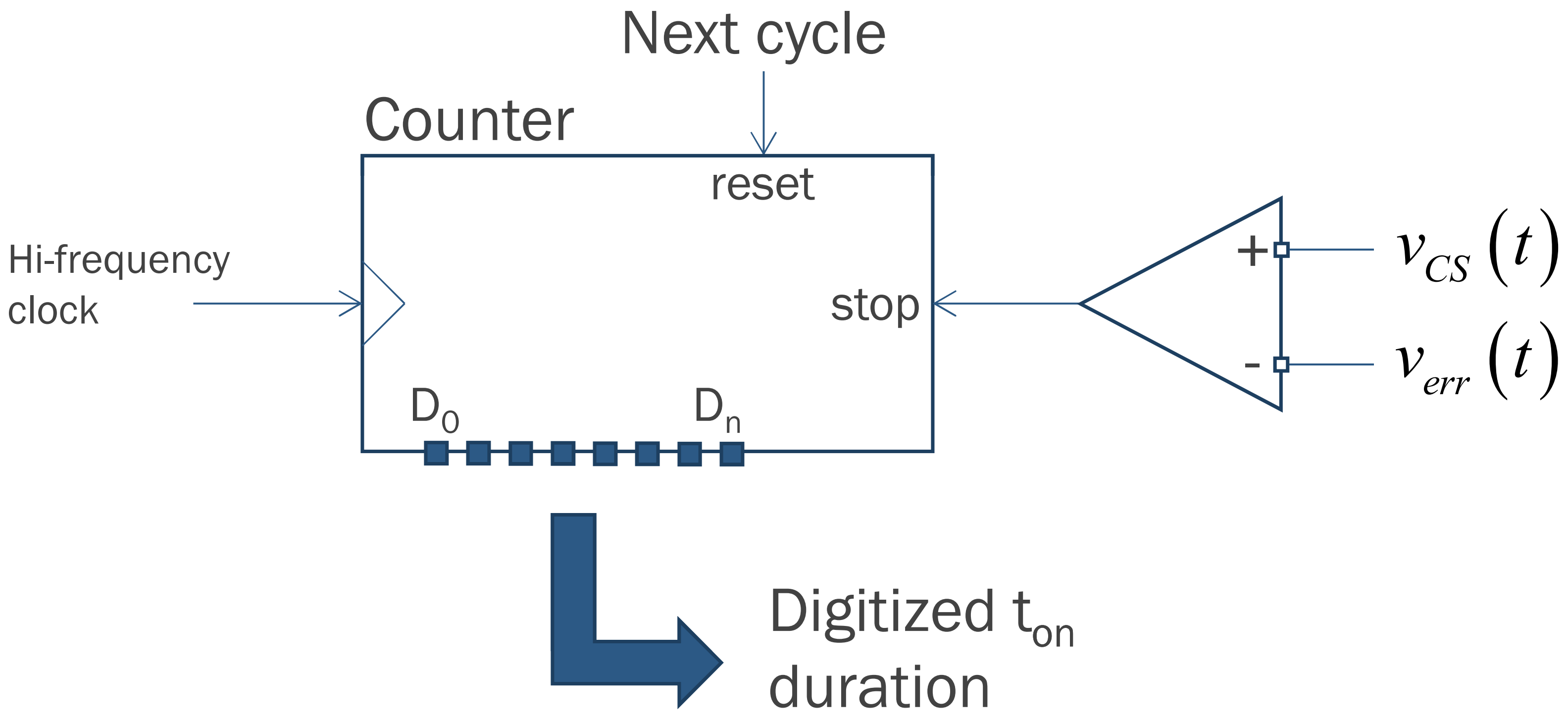
- The compensator is where you apply the compensation strategy to cross over at a certain frequency with a given phase margin.

Basic Principles of Operation of the CM-LLC Converter

- ❑ This CM-LLC operates in a free-running mode: the switching frequency is not internally fixed
- ➢ The on-time is set by the peak current setpoint while the off-time precisely replicates its duration
- ➢ The circuit ensures a 50% duty ratio square wave whose frequency depends on the peak current setpoint.

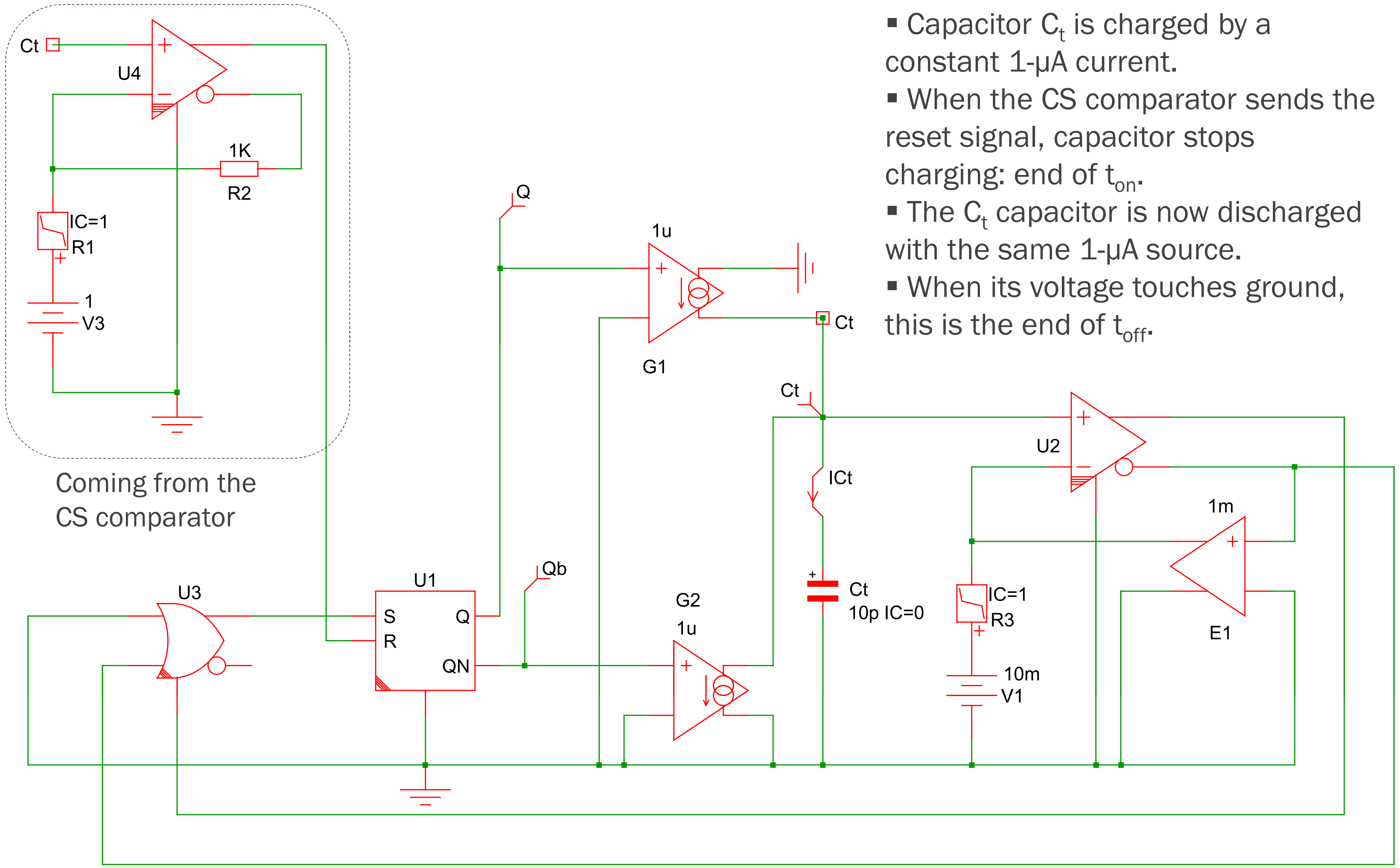


NCP1399 data-sheet

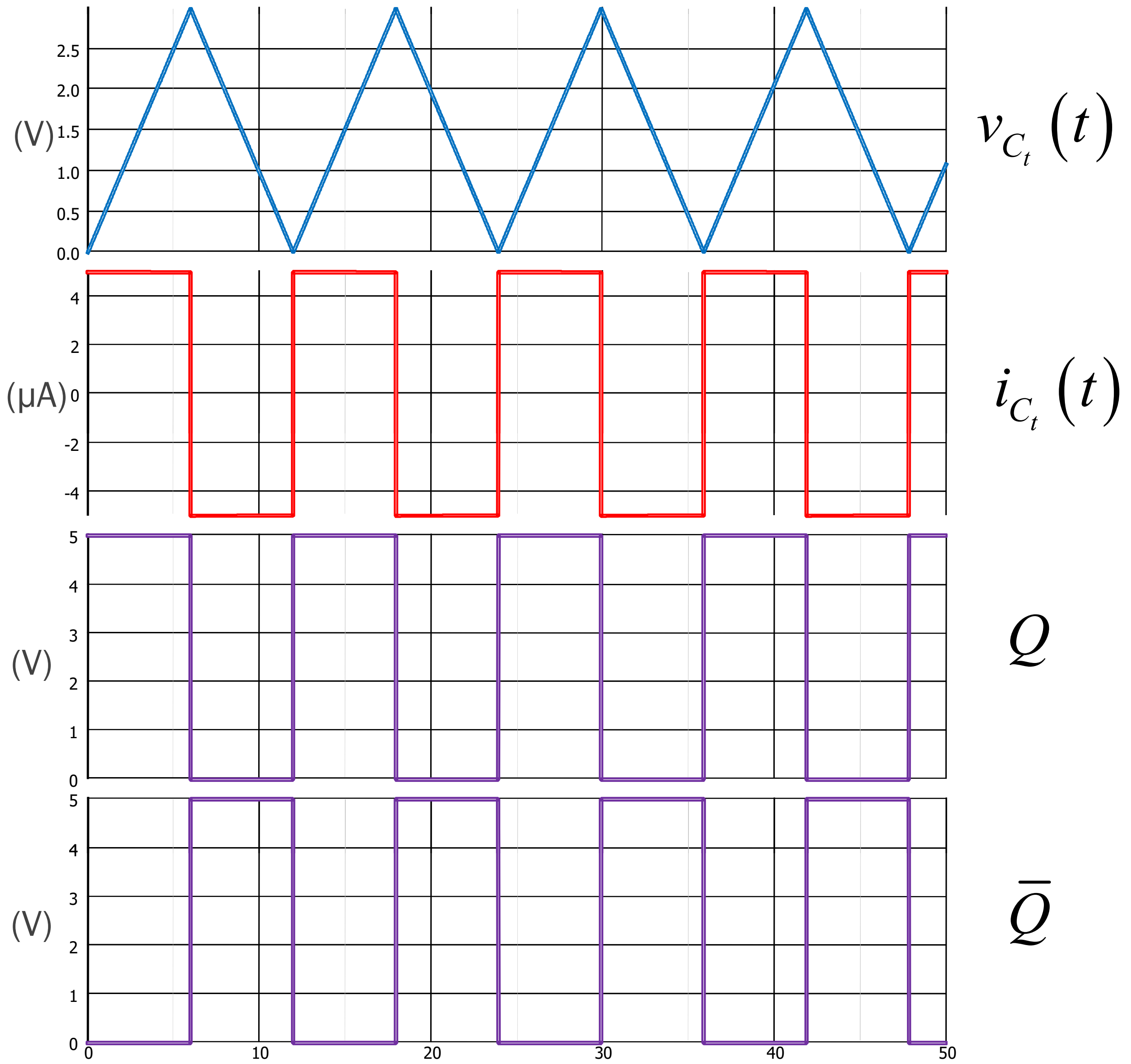


Simplified t_{on} Replication with SIMPLIS®

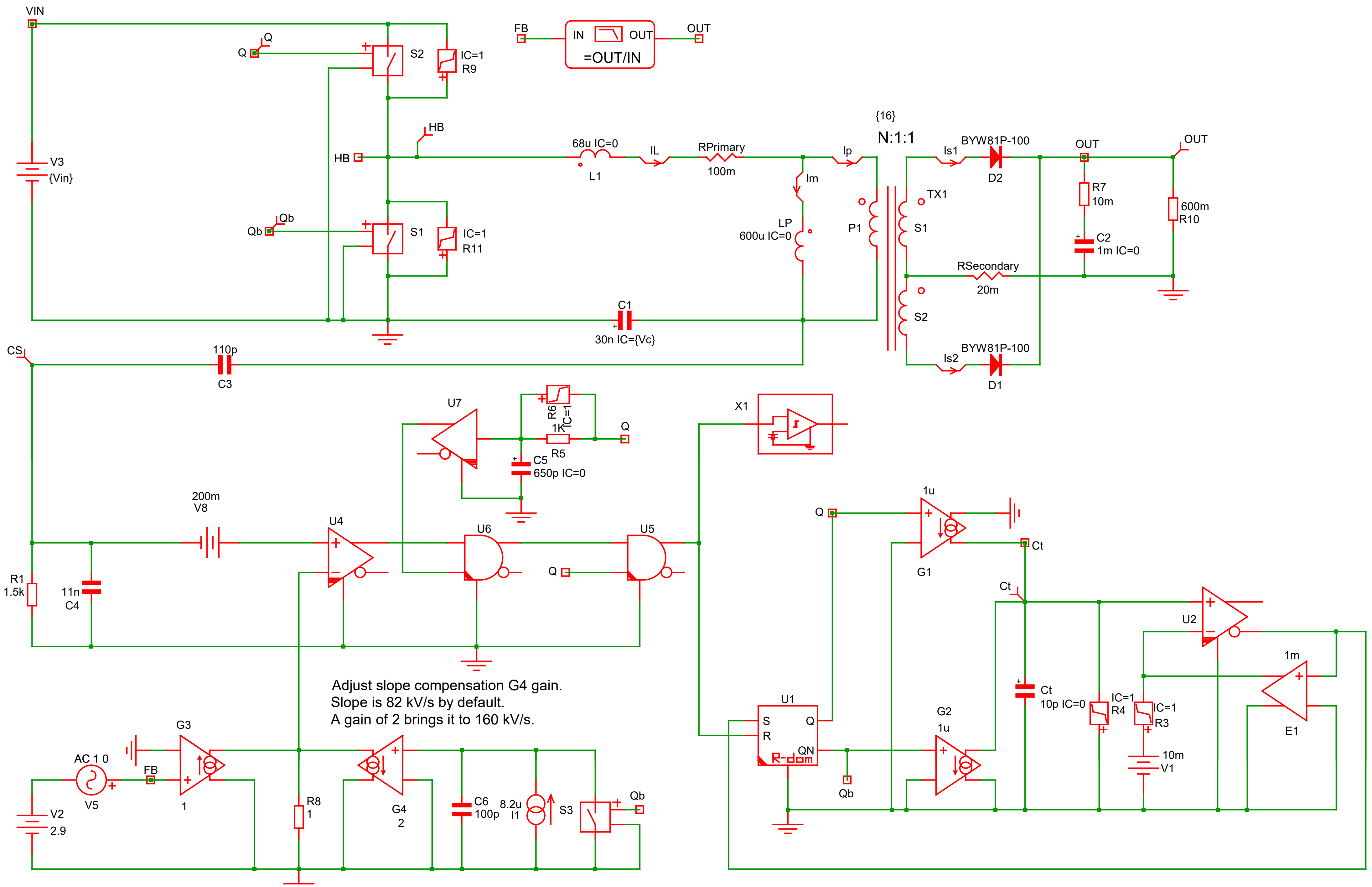
- ❑ Using digital counters with SIMPLIS is not an option if small-signal analysis is wanted
- ➢ A simple capacitor-based circuit does the job quite well and remains fully compatible with POP



- Capacitor C_t is charged by a constant 1-µA current.
- When the CS comparator sends the reset signal, capacitor stops charging: end of t_{on}.
- The C_t capacitor is now discharged with the same 1-µA source.
- When its voltage touches ground, this is the end of t_{off}.



Application Circuit Working with Elements

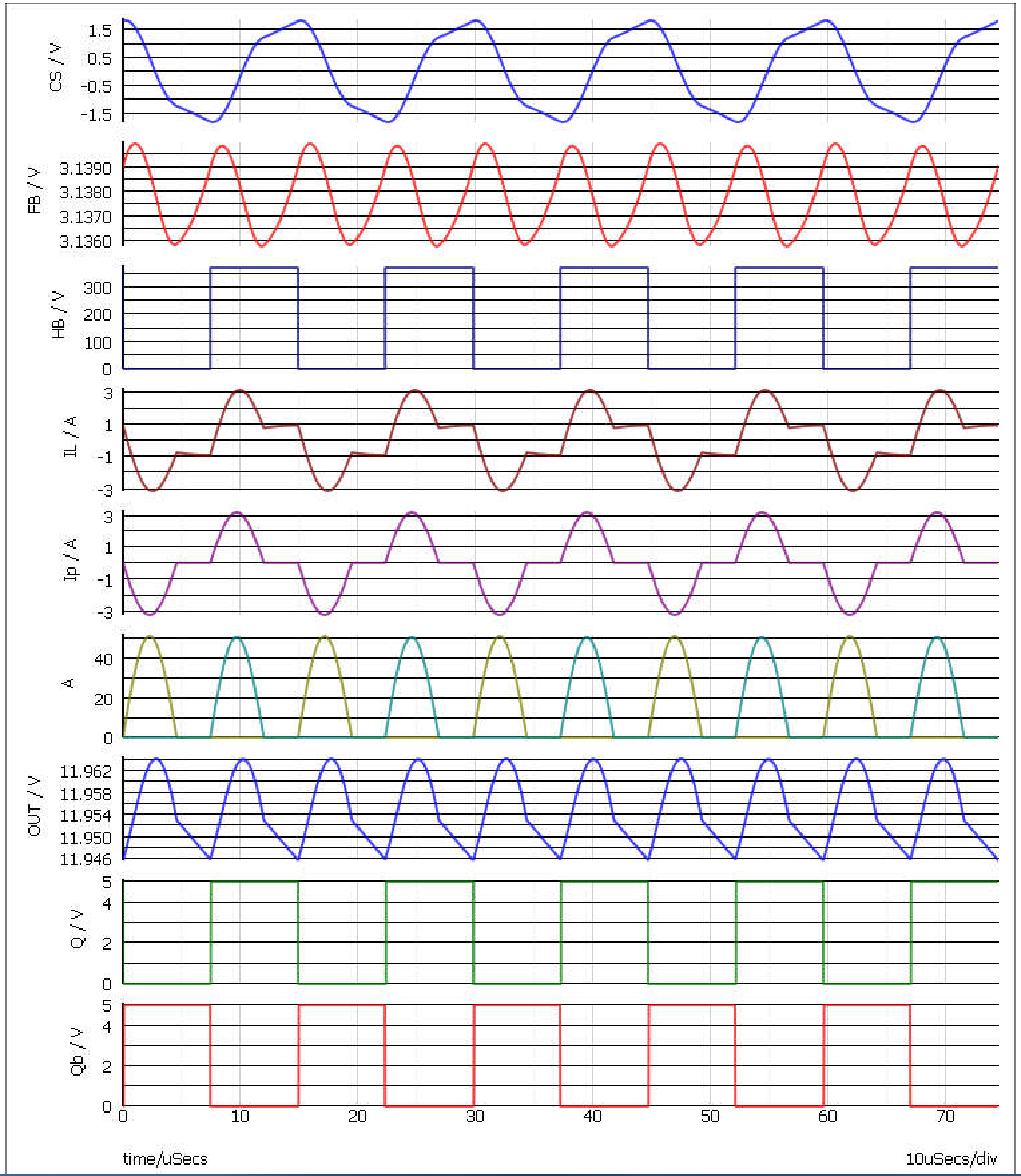


Adjust bias to the desired
Vout level. Here, a 2.9-V
bias gives 12 V/20 A.

- ❑ This is a 12-V/20-A LLC converter as described in the NCP1399 landing page: https://www.onsemi.com/pub/Collateral/EVBUM2342-D.PDF

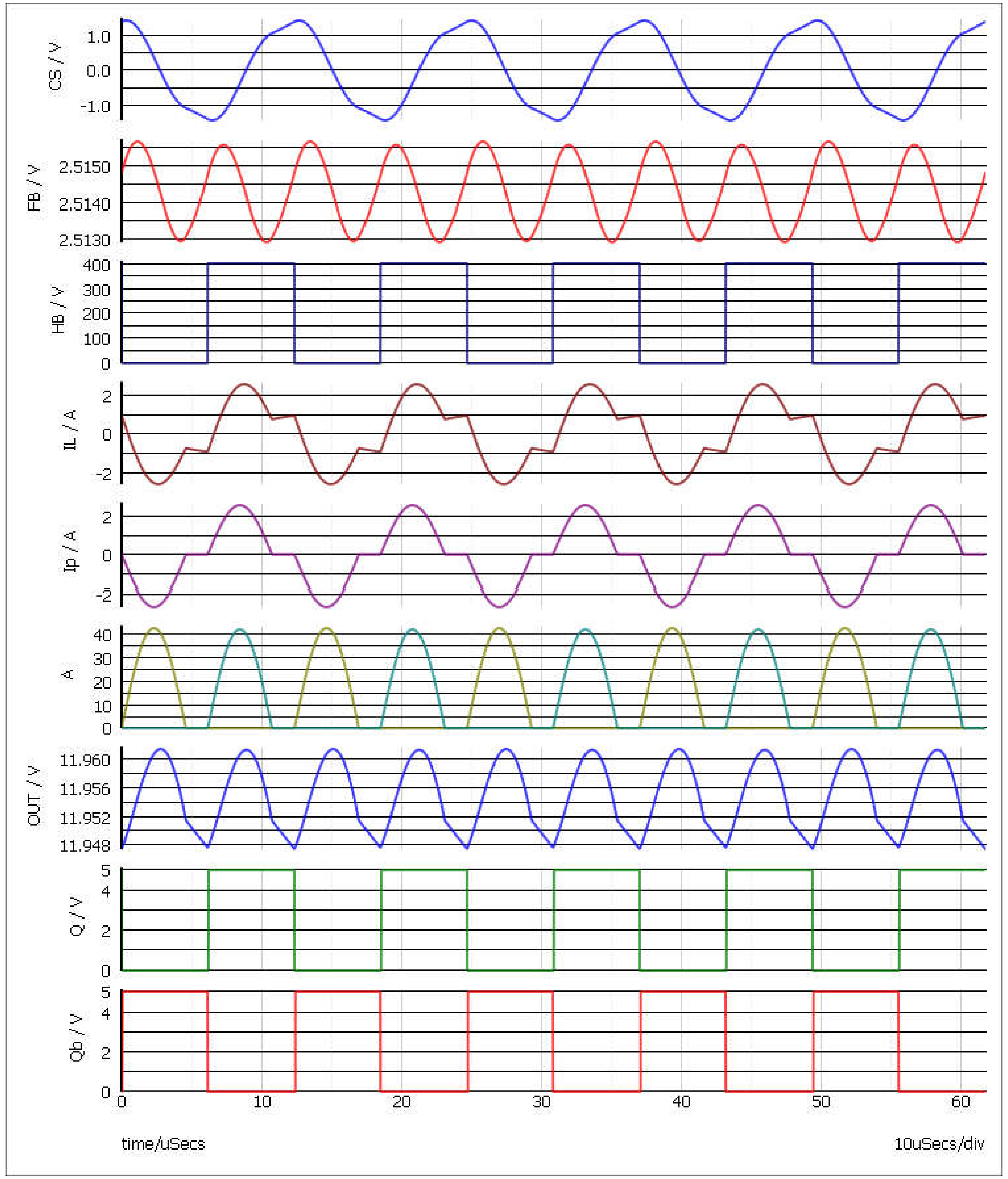
Ok with demo version

Obtaining Steady-State Waveforms



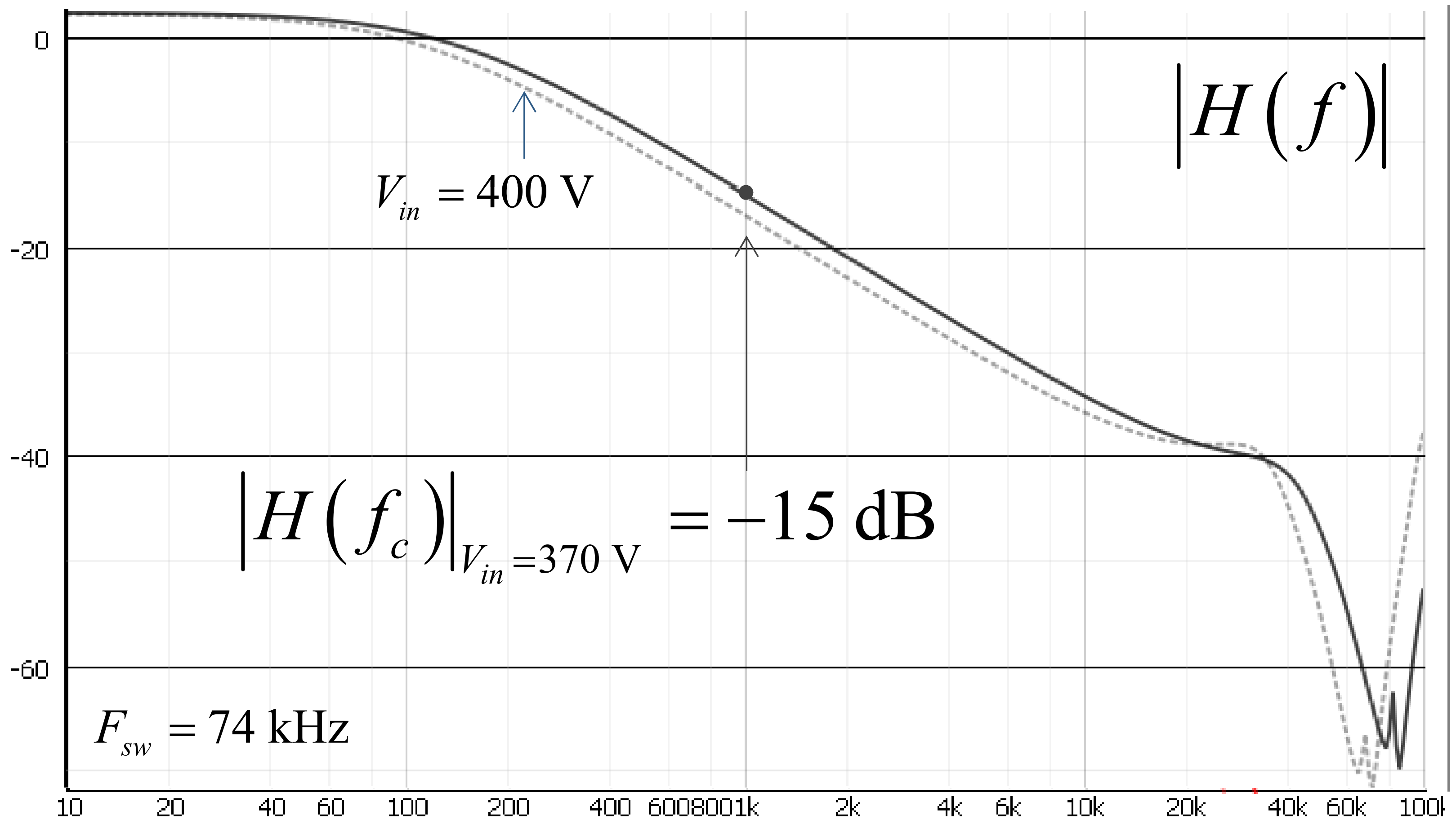
$V_{in} = 370\ \mathrm{V}$

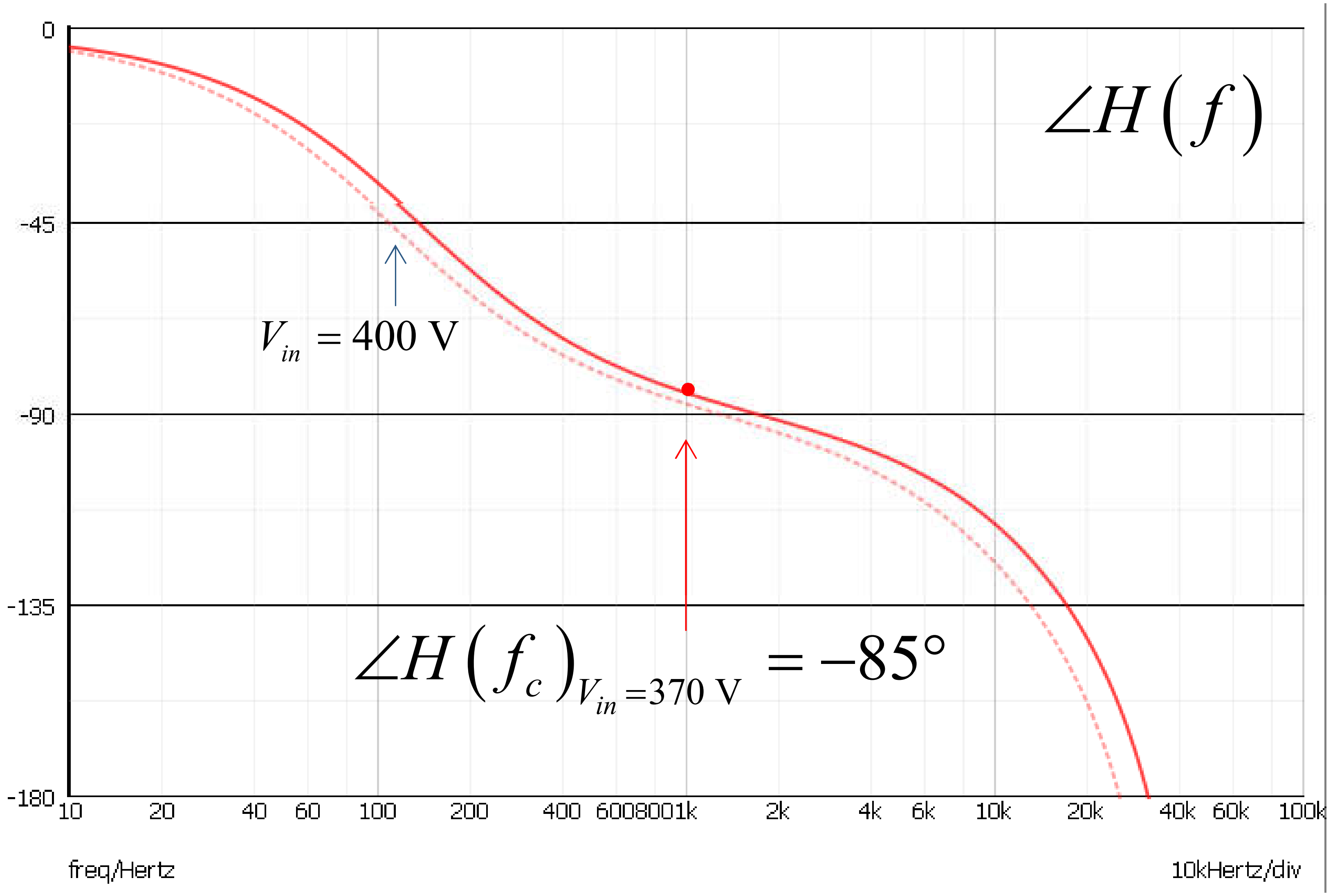
$V_{in} = 400\ \mathrm{V}$



- You can check the waveforms at steady-state operation and assess peak and rms values.

Check Response at Different Input Voltages

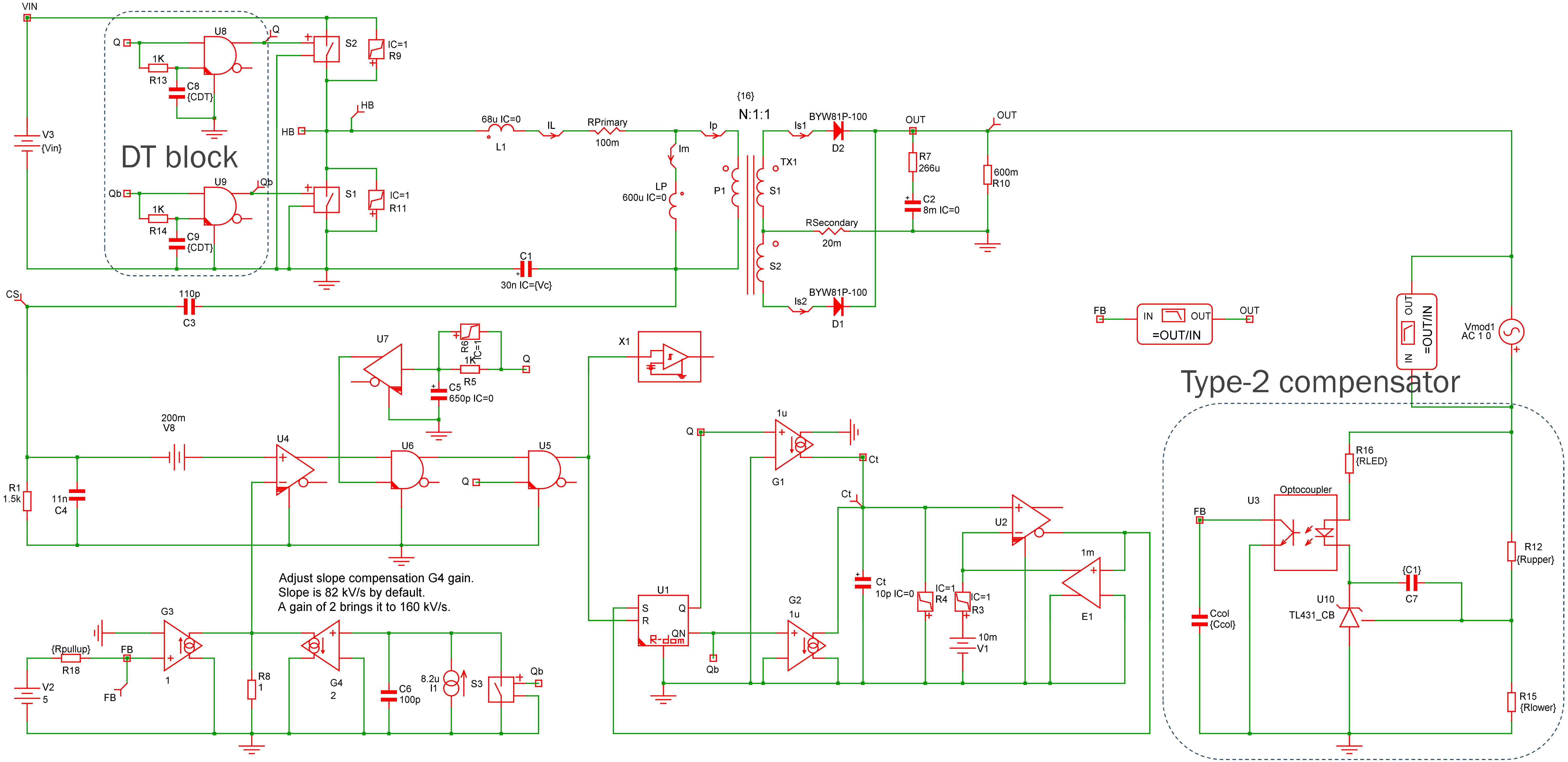




- One benefit of the CM operation is the 1st-order response.
- The control-to-output transfer function remains the same from 370 V dc to 400 V dc.

For a 1-kHz crossover frequency, a simple type-2 compensator will do!

Now Include Dead Time and Loop with Full Version



Public Information

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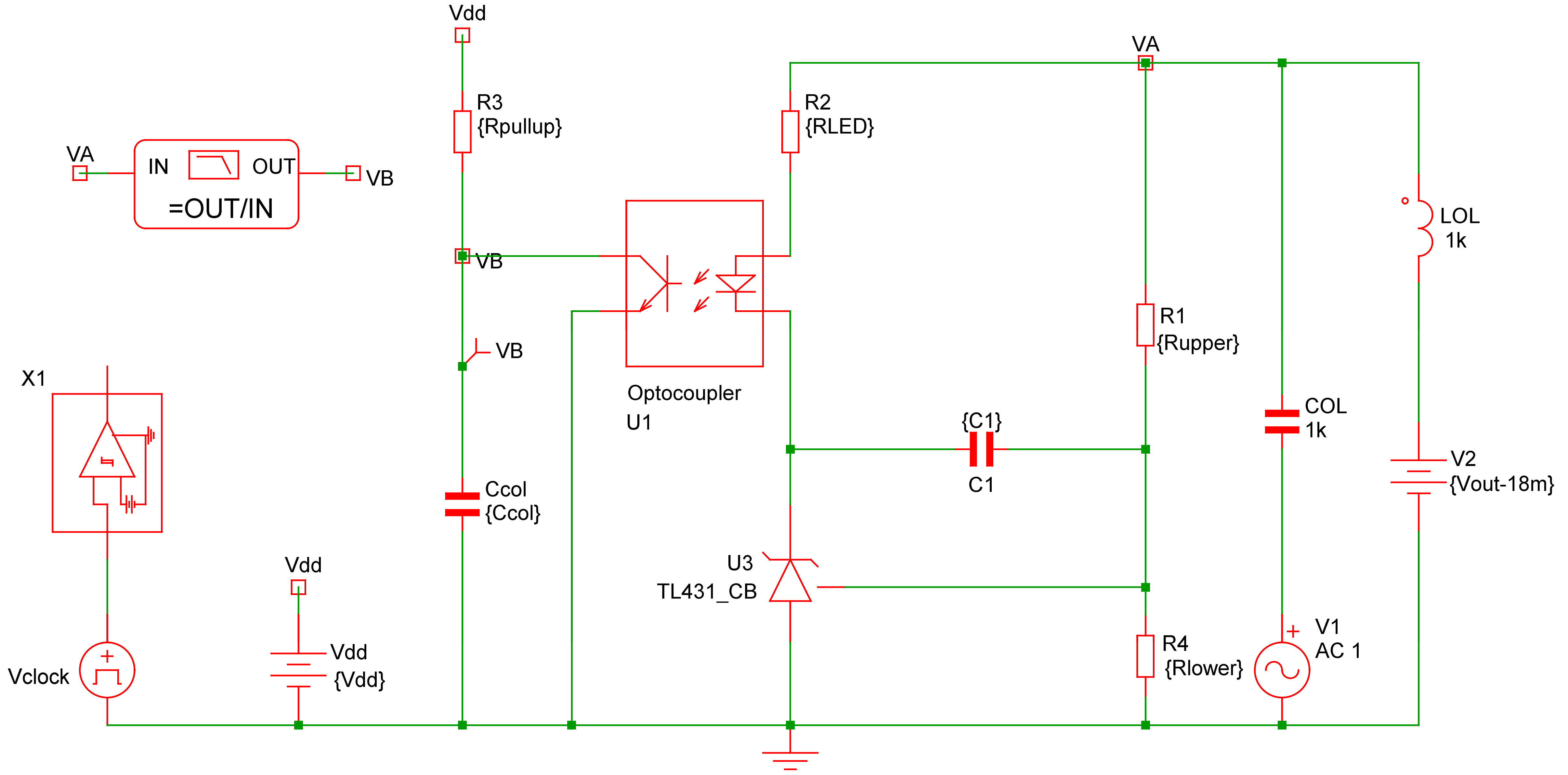
Type 2 Compensator with Optocoupler

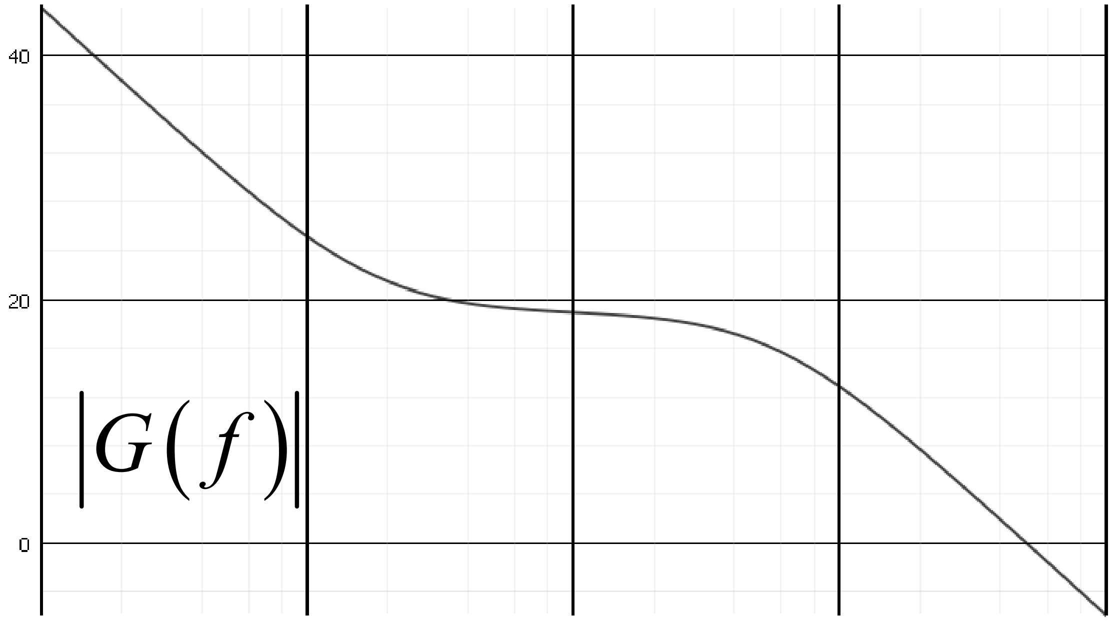
- ❑ The component values are calculated by SIMPLIS® to meet the needed gain and phase boost

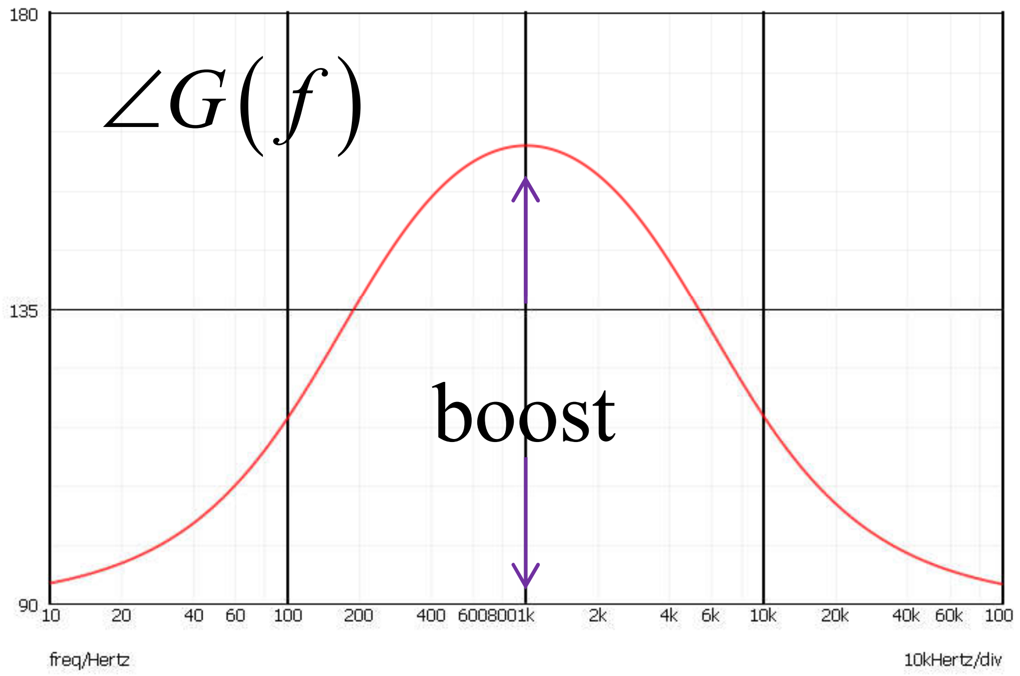


Component Calculations for the Type 2

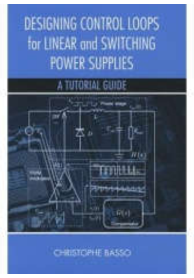
```
.GLOBALVAR Vin=370 * the input source voltage *
.GLOBALVAR Vc=Vin/2 * pre-charged resonating capacitor *
.GLOBALVAR DT=50n * select HB deadtime *
.GLOBALVAR CDT=DT/(1k*0.693) * calculate DT capacitor *

.GLOBALVAR Gfc=-18 * magnitude at crossover *
.GLOBALVAR PFC=-87 *plant phase at crossover *
.GLOBALVAR PM=70 * phase margin goal *
.GLOBALVAR boost=pm-(pfc)-90 * required boost *
*
* Enter Design Goals Information Here *
*
.GLOBALVAR fc=1k * targetted crossover *
*
* Pole-zero calculations *
*
.GLOBALVAR k=tan((boost/2+45)*pi/180)
.GLOBALVAR fp=k*fc
.GLOBALVAR fz=fc/k
*
* Enter the Values for Vout and Bridge Bias Current *
*
.GLOBALVAR Vout=12
.GLOBALVAR Ibias=250u
.GLOBALVAR Vref1=2.5
.GLOBALVAR Rlower=Vref1/Ibias
.GLOBALVAR Rupper=(Vout-Vref1)/Ibias
.GLOBALVAR Rpullup=18k
*
* Optocoupler specifications *
*
.GLOBALVAR Fopto=15k
.GLOBALVAR Copto=1/(2*pi*Fopto*Rpullup)
.GLOBALVAR CTR=0.3
*
.GLOBALVAR VL=0.2
.GLOBALVAR VCEsat=0.3
.GLOBALVAR Vdd=5
.GLOBALVAR Vf=1
.GLOBALVAR A=Vout-Vf-VL
.GLOBALVAR B=Vdd-VCEsat
.GLOBALVAR Rmax=(A/B)*Rpullup*CTR
*
* Do not edit the below lines *
*
.GLOBALVAR G=10^(-Gfc/20)
.GLOBALVAR RLED=CTR*Rpullup/G * watch for internal LED rd contribution for low RLED *
.GLOBALVAR C1=1/(2*pi*fz*Rupper)
.GLOBALVAR C2=1/(2*pi*fp*Rpullup)
.GLOBALVAR Ccol=C2-Copto
*

.simulator DEFAULT
```

Power stage magnitude at f_c
Power stage phase at f_c
Wanted phase margin



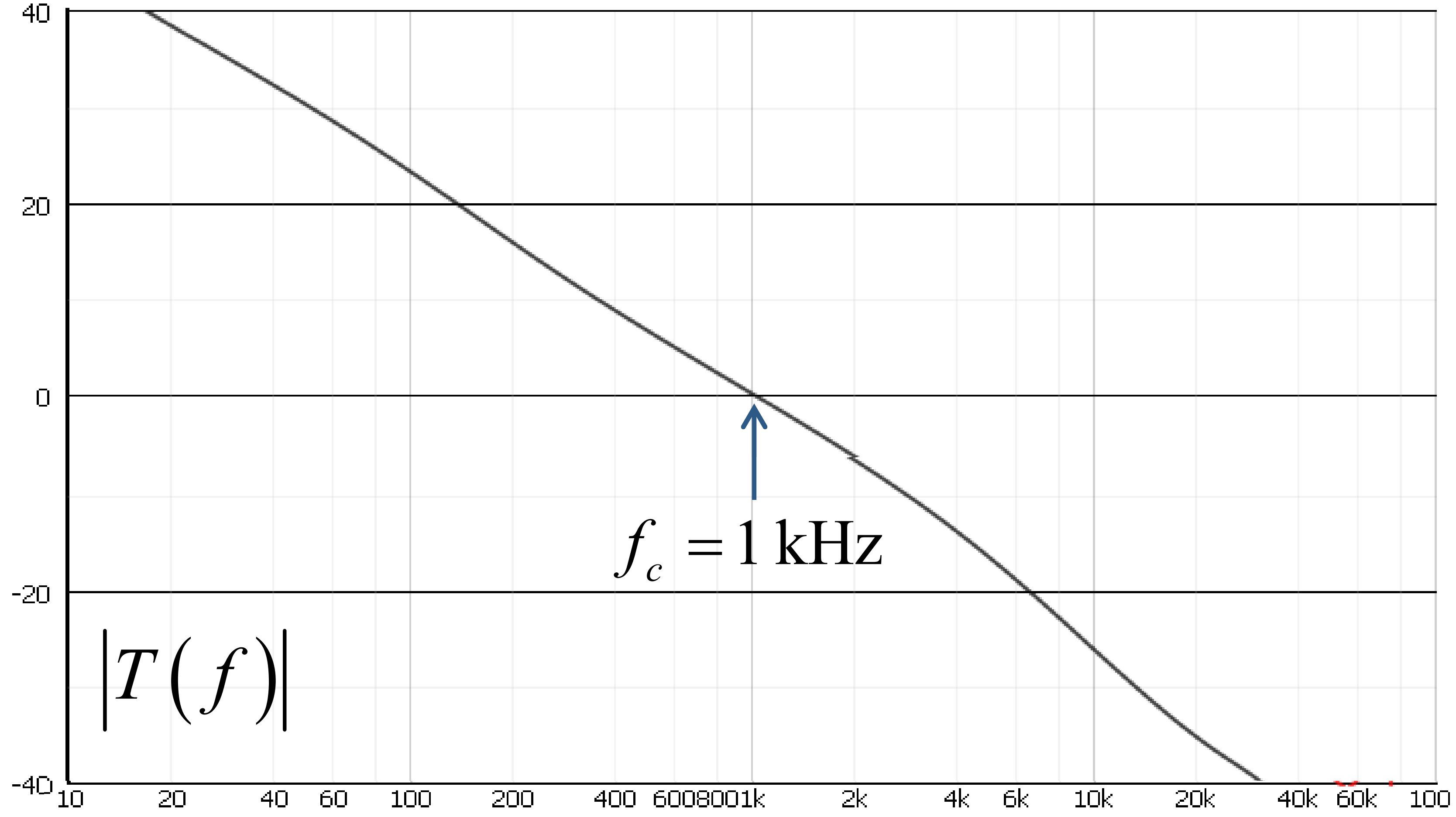


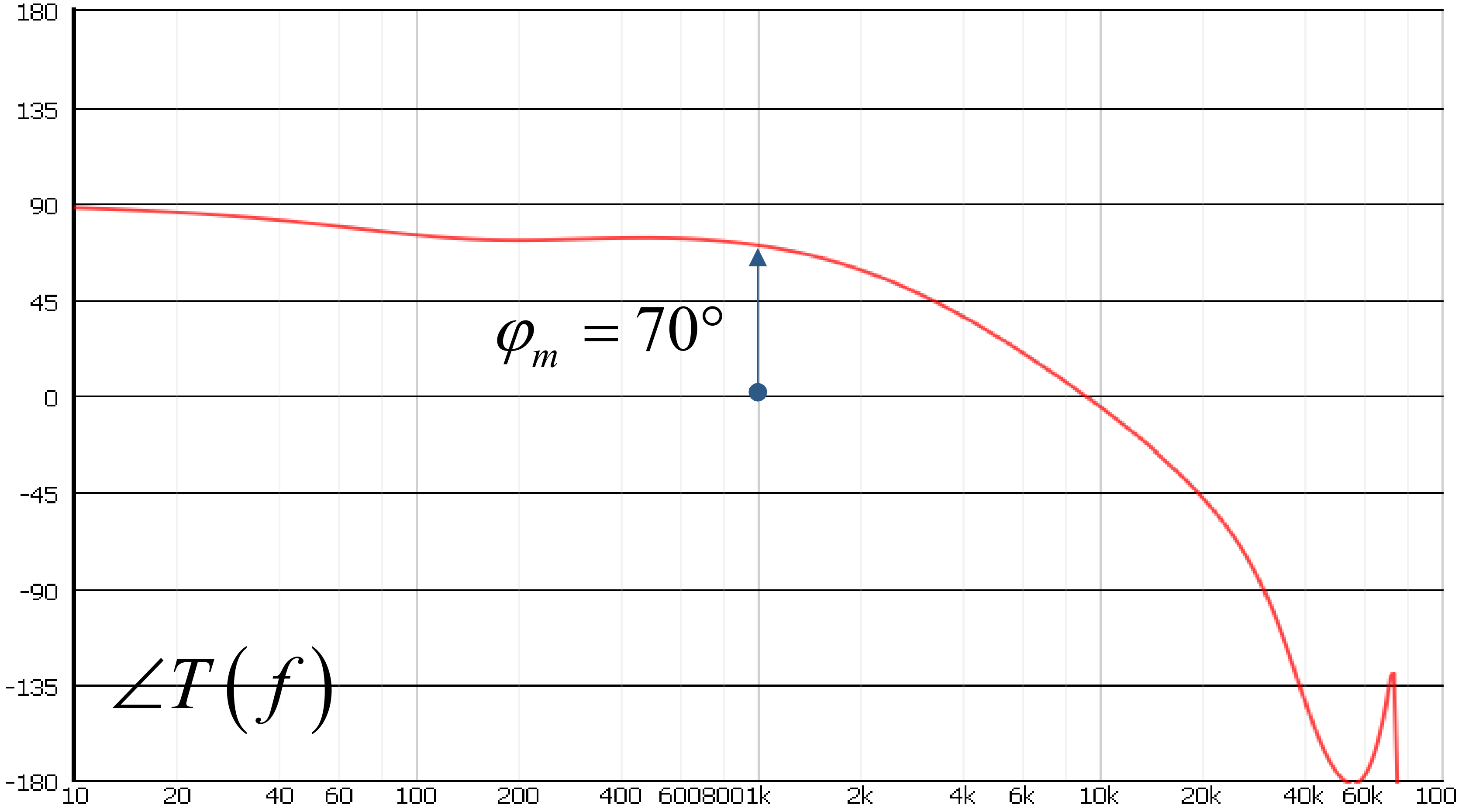
Type 1, 2 and 3 design details can be found in C. Basso, *Designing Control Loops for Linear and Switching Power Supplies*, Artech House 2012



Compensated Loop Gain

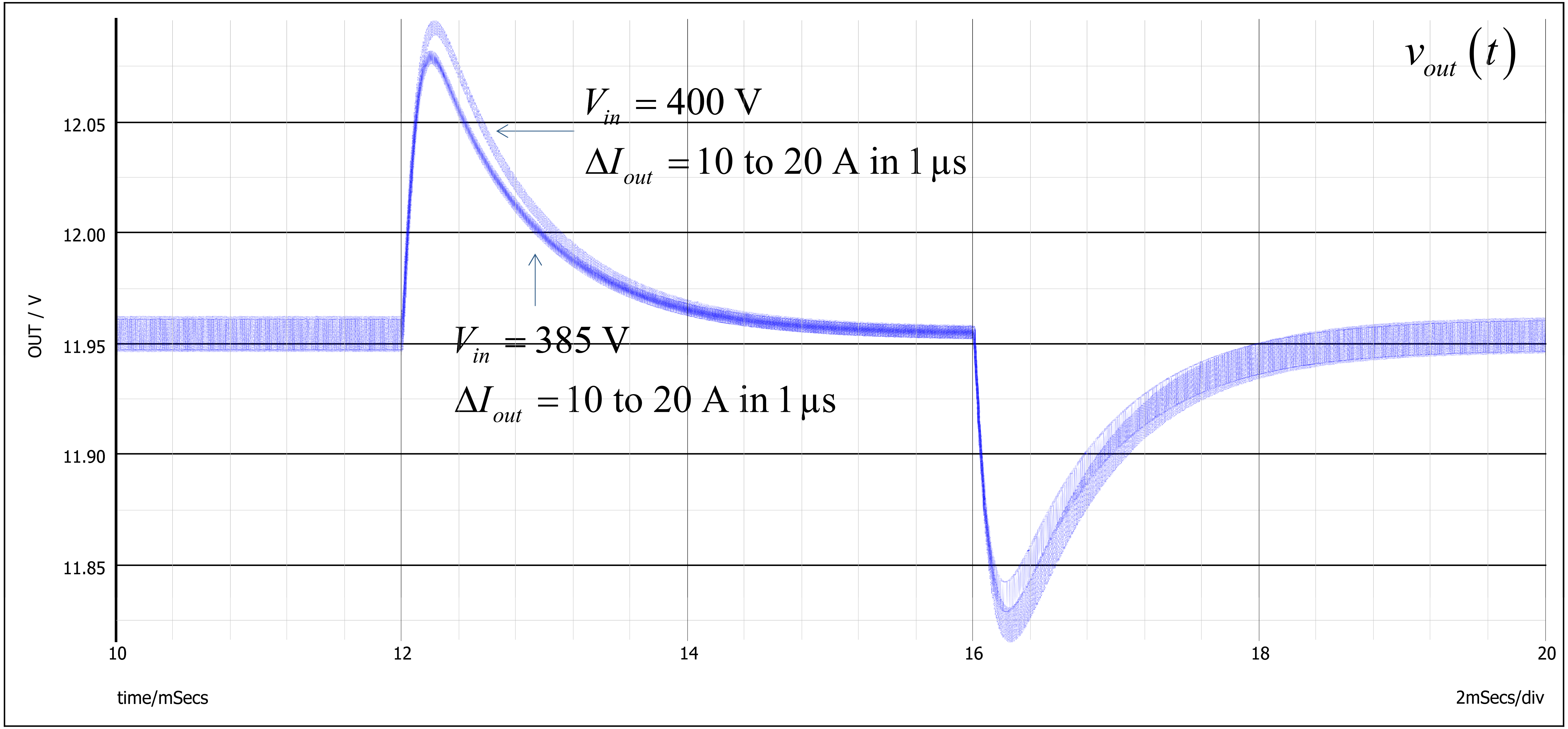
- Plot the loop gain to check crossover frequency and phase margin at this point





A 1-kHz crossover frequency is obtained with a 70° phase margin.

Compensated Transient Response



Conclusion

- The compensation of a CM-LLC-based power converter is done via a few steps

1. Determine the control-to-output transfer function with SIMPLIS®
2. Extract the magnitude and phase at the selected crossover frequency
3. Build a type-2 compensator with an op-amp or a TL431 and an optocoupler
4. Make sure the optocoupler is well characterized for its CTR and lo-freq. pole
5. Check the complete loop gain $T(s)$ at different operating conditions
6. Sweep all parasitics (ESRs, capacitor etc.) and check there is always a sufficiently-high phase margin
7. Check load-step response is within design goals in all conditions