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DC-DC Converters Feedback and Control

Agenda

- ❑ Feedback generalities
- ❑ Conditions for stability
- ❑ Poles and zeros
- ❑ Phase margin and quality coefficient
- ❑ Undershoot and crossover frequency
- ❑ Compensating the converter
- ❑ Compensating with a TL431
- ❑ Watch the optocoupler!
- ❑ Compensating a DCM flyback
- ❑ Compensating a CCM flyback
- ❑ Simulation and bench results
- ❑ Conclusion

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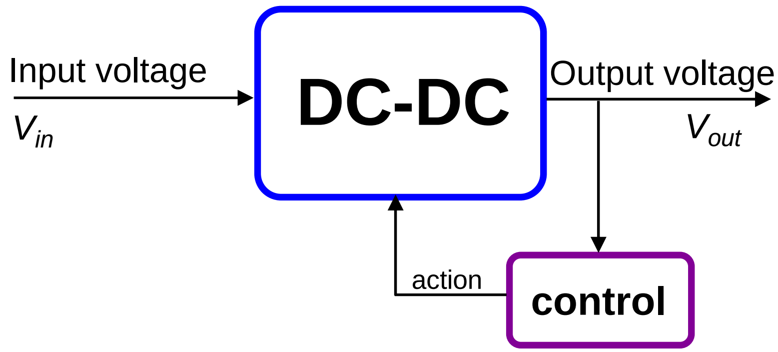
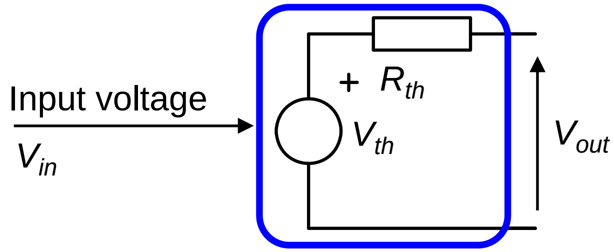
What is Feedback?

- ❑ A target is assigned to one or several state-variables, e.g. V_{out} = 12 V.
- ❑ A circuitry monitors V_{out} deviations related to V_{in}, I_{out}, T° etc.
- ❑ If V_{out} deviates from its target, an error is created and fed-back to the power stage for action.
- ❑ The action is a change in the control variable: duty-cycle (VM), peak current (CM) or the switching frequency.

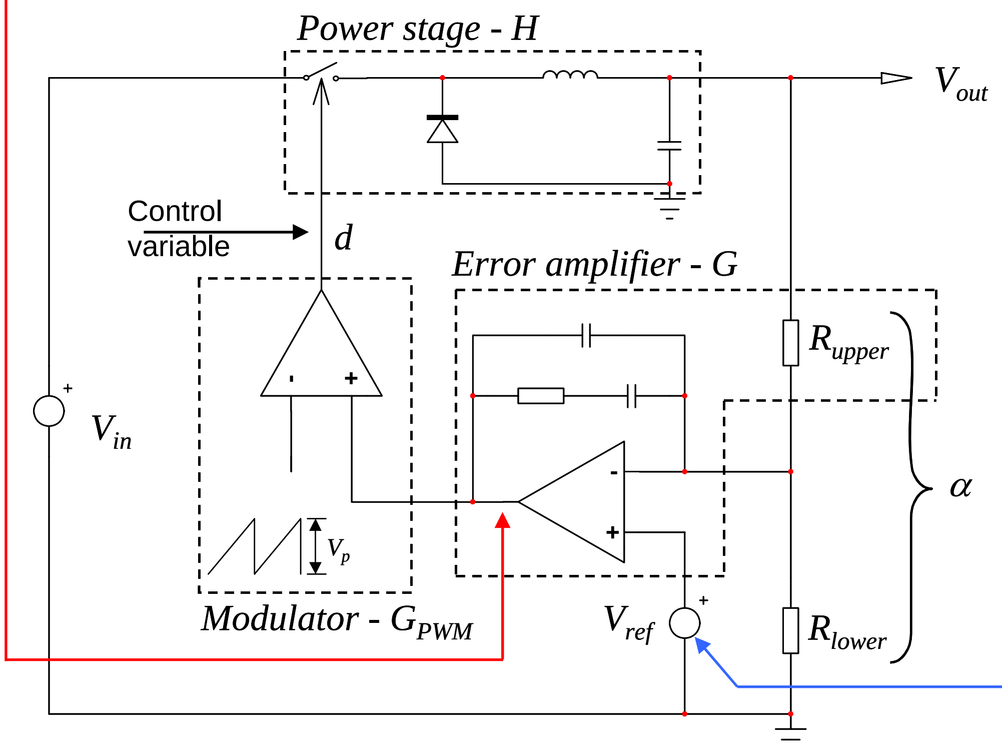
⟹ Compensating for the converter shortcomings!





The Feedback Implementation

- ❑ V_{out} is permanently compared to a reference voltage $\boxed{V_{ref}}$.
- ❑ The reference voltage V_{ref} is precise and stable over temperature.
- ❑ The error, $\boxed{\varepsilon = V_{ref} - \alpha V_{out}}$, is amplified and sent to the control input.
- ❑ The power stage reacts to reduce ε as much as it can.



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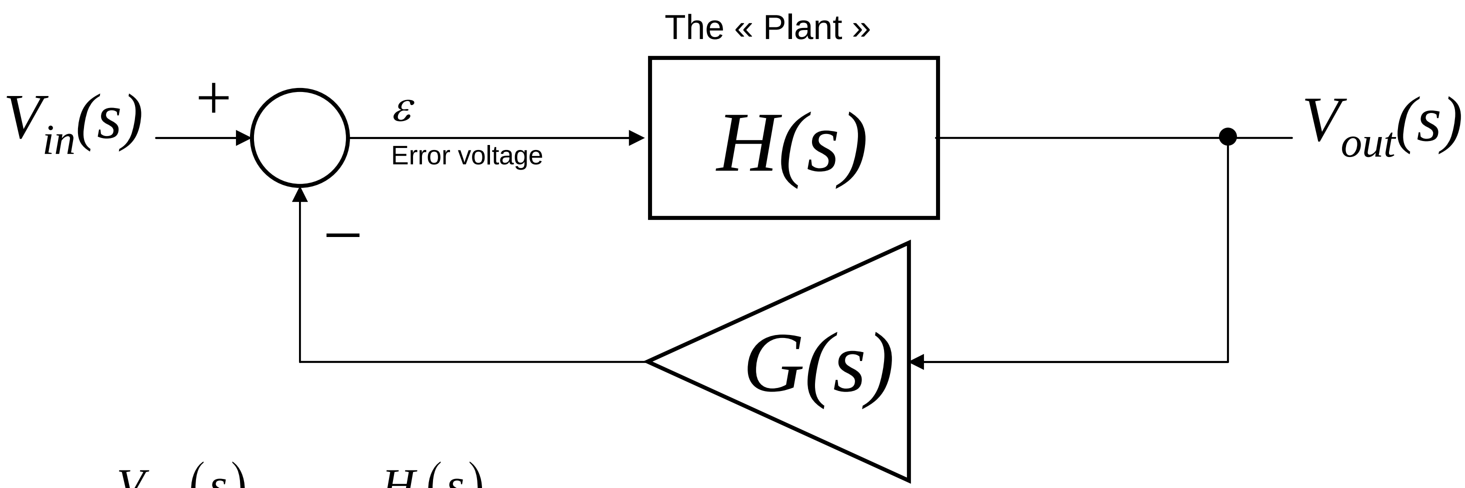
Positive or Negative Feedback?

- ❑ Do we want to build an oscillator?



$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{H(s)}{1+\boxed{H(s)G(s)}}$$

Open-loop gain *T(s)*

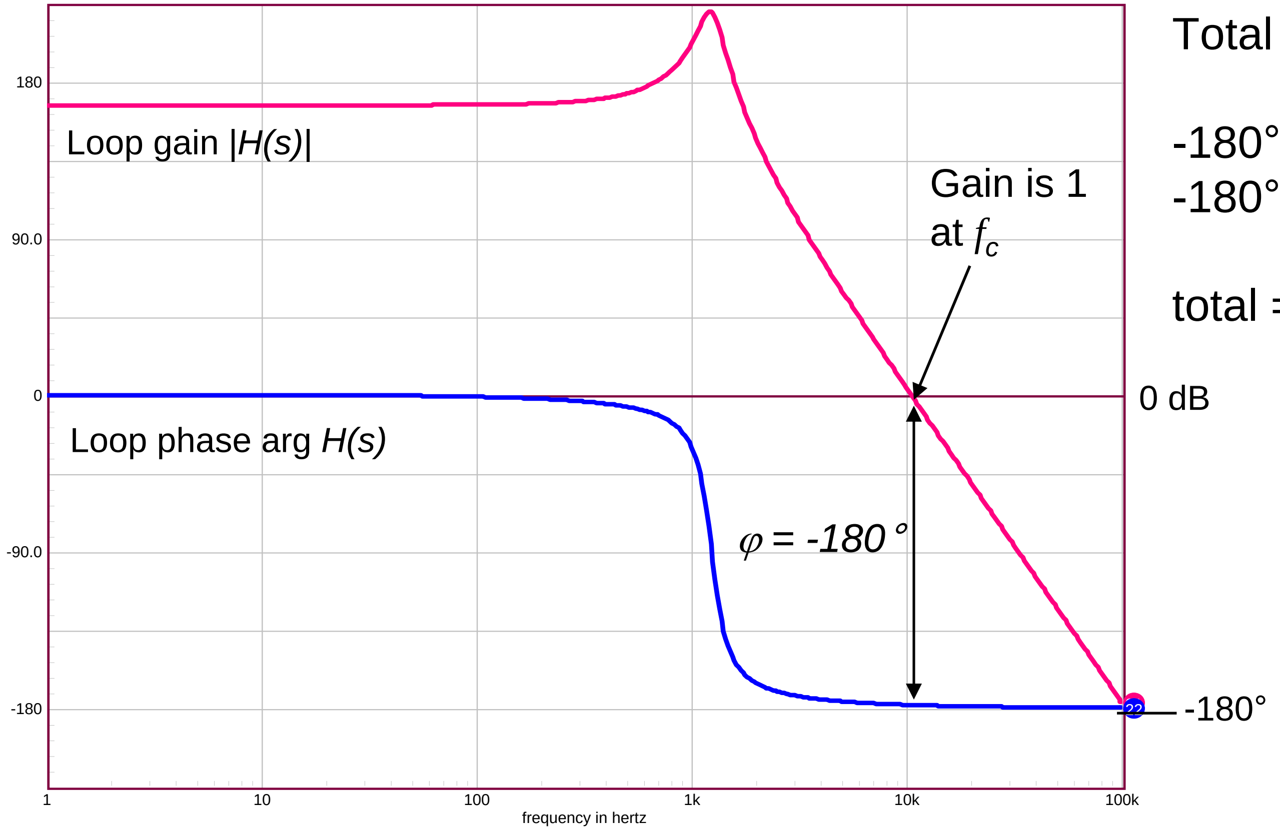
$$V_{out}(s) = \lim_{V_{in}(s)\to 0}\left[\frac{H(s)}{1\boxed{+}\underbrace{G(s)H(s)}_{=1}}V_{in}(s)\right]$$

To sustain self-oscillations, as $V_{in}(s)$ goes to zero, quotient must go infinite

Sign is neg for:
φ = -180°

Conditions for Oscillations

- ❑ when the open-loop gain equals 1 (0 dB) – cross over point
- ❑ total rotation is -360°: -180° for *H(s)* and -180° for *G*(s)
- ➢ we have self-sustaining oscillating conditions



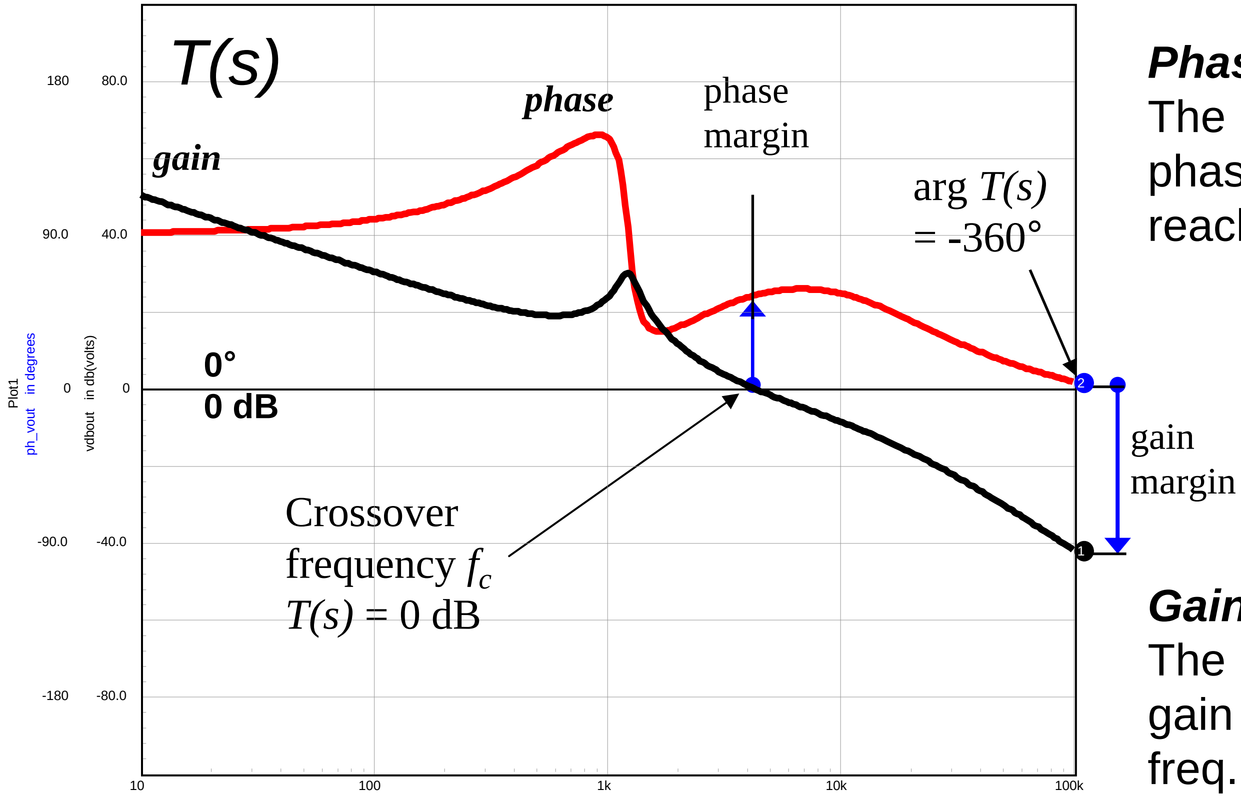
Total phase delay at f_c:

-180° *H(s)* power stage
-180° *G(s)* opamp

total = -360°

The Need for Phase Margin

- ❑ we need phase margin when *T(s)* = 0 dB
- ❑ we need gain margin when arg *T(s)* = -360°



Phase margin:
The margin before the loop phase rotation arg *T(s)* reaches -360° at *T(s)* = 0 dB

Gain margin:
The margin before the loop gain *T(s)* reaches 0 dB at a freq. where arg *T(s)* = -360°

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Poles and Zeros

- A plant (power stage) loop gain is defined by:

$$H(s) = \frac{N(s)}{D(s)} \begin{array}{l} \longrightarrow \text{numerator} \\ \longrightarrow \text{denominator} \end{array}$$

- solving for *N(s)* = 0, the roots are called the **zeros**

- solving for *D(s)* = 0, the roots are called the **poles**

$$H(s) = \frac{(s+5k)(s+30k)}{s+1k}$$

Two zeros

$$\boxed{\begin{aligned} s_{z_1} &= -5k \\ s_{z_2} &= -30k \end{aligned}}$$

$$\boxed{s_{p_1} = -1k}$$

One pole

$$\longrightarrow$$

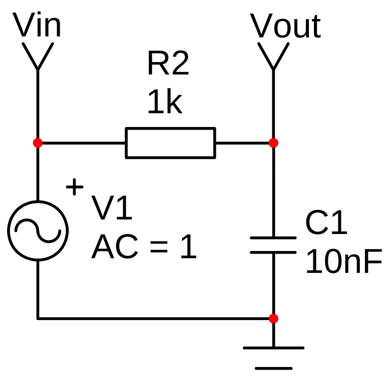
$$f_{z_1} = \frac{5k}{2\pi} = 796\ Hz$$

$$f_{z_2} = \frac{30k}{2\pi} = 4.77\ kHz$$

$$f_{p_1} = \frac{1k}{2\pi} = 159\ Hz$$

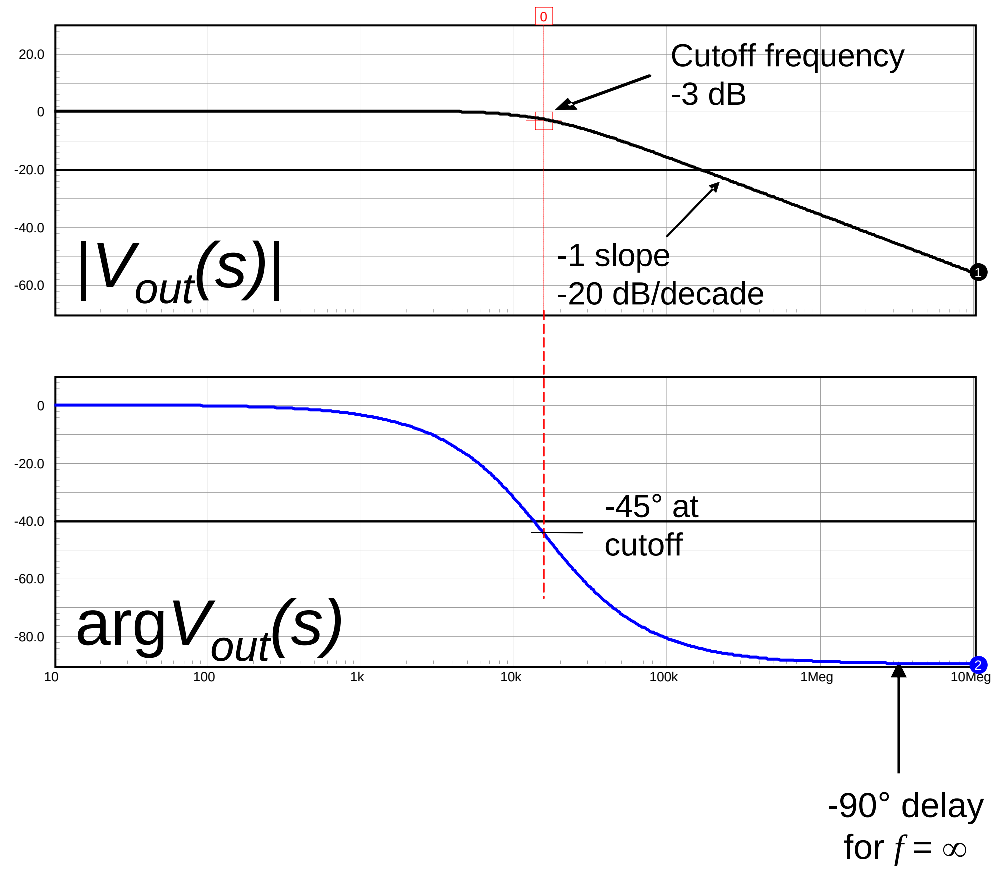
Poles and Zeros

- A pole lags the phase by -45°at its cutoff frequency



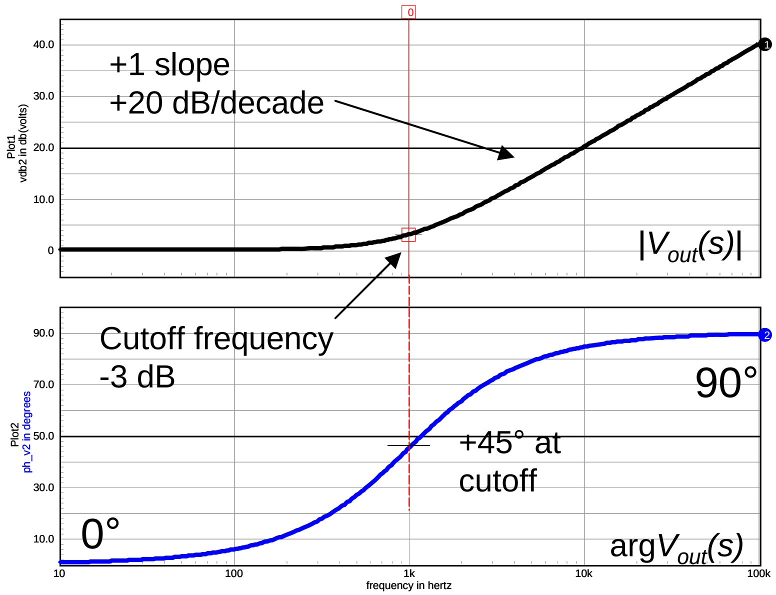
$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{1}{1+sRC} = \frac{1}{1+\frac{s}{\boxed{\omega_0}}}$$

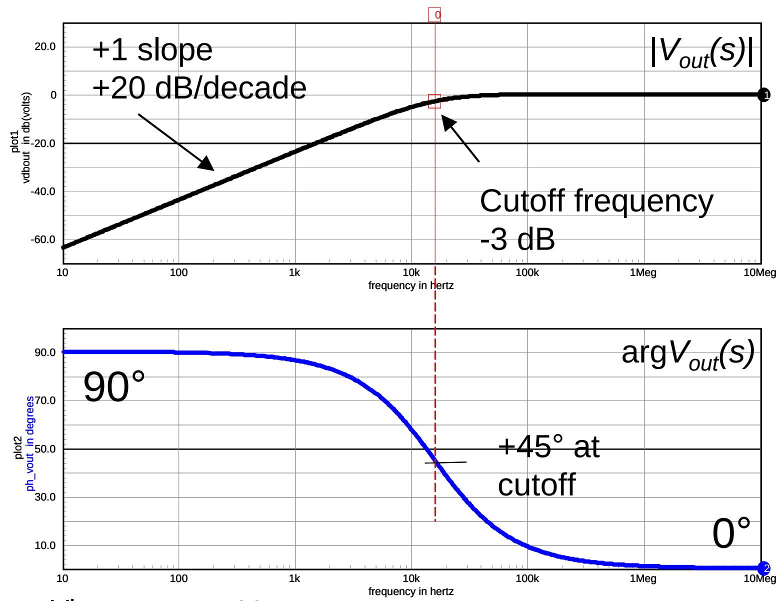
$$\omega_0 = \frac{1}{RC}$$



Poles and Zeros

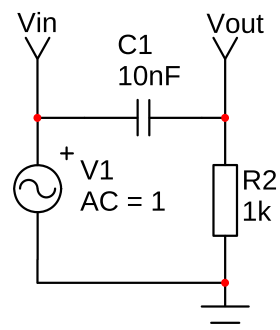
- ❑ A zero <u>boosts</u> the phase by +45°at its cutoff frequency





The general form of a zero:

$$G(s) = 1 + \frac{s}{\omega_0}$$

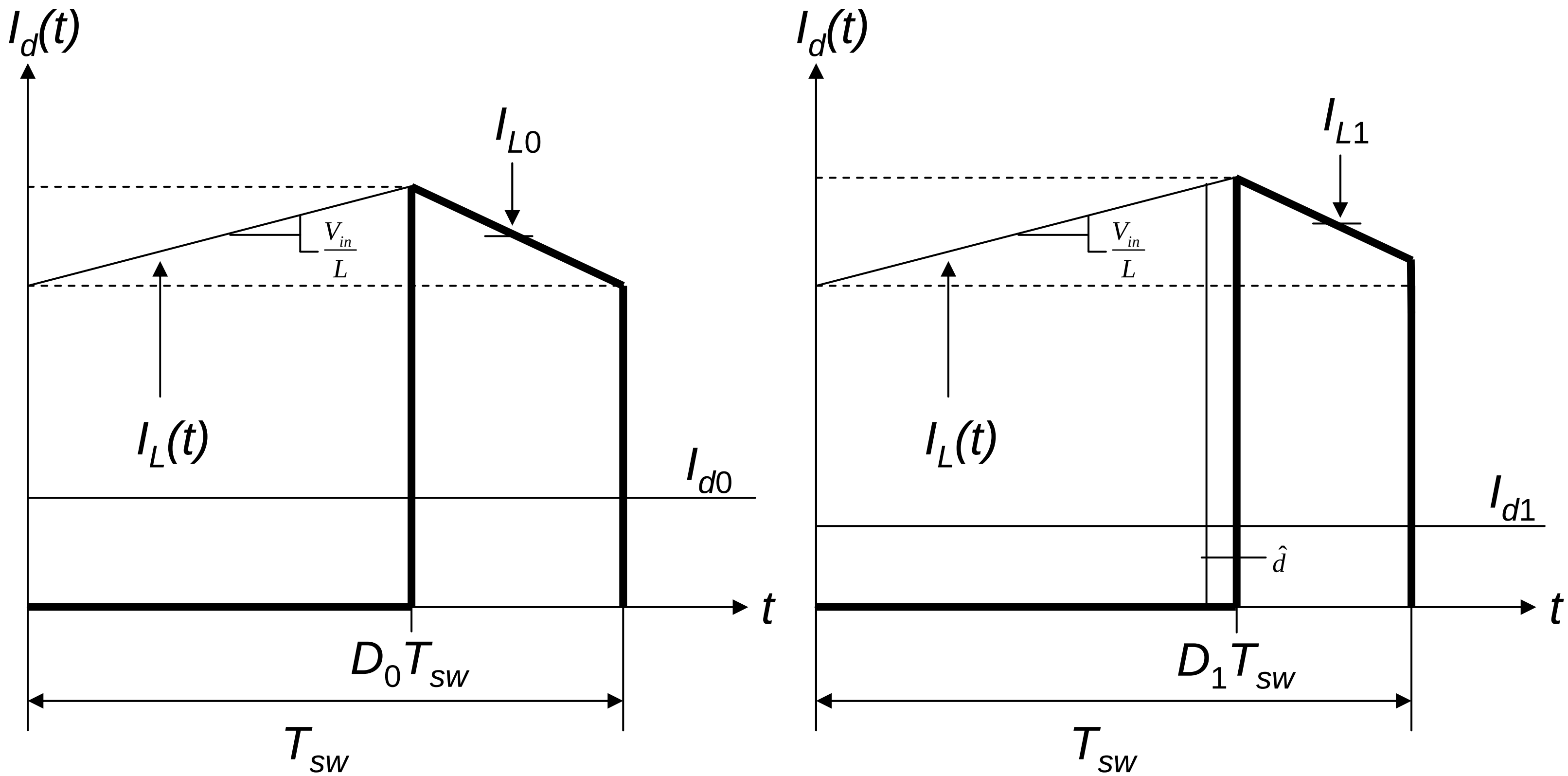


$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{sRC}{1+sRC} = \frac{\frac{s}{\boxed{\omega_0}}}{1+\frac{s}{\boxed{\omega_0}}}$$

$$\omega_0 = \frac{1}{RC}$$

The Right Half-Plane Zero

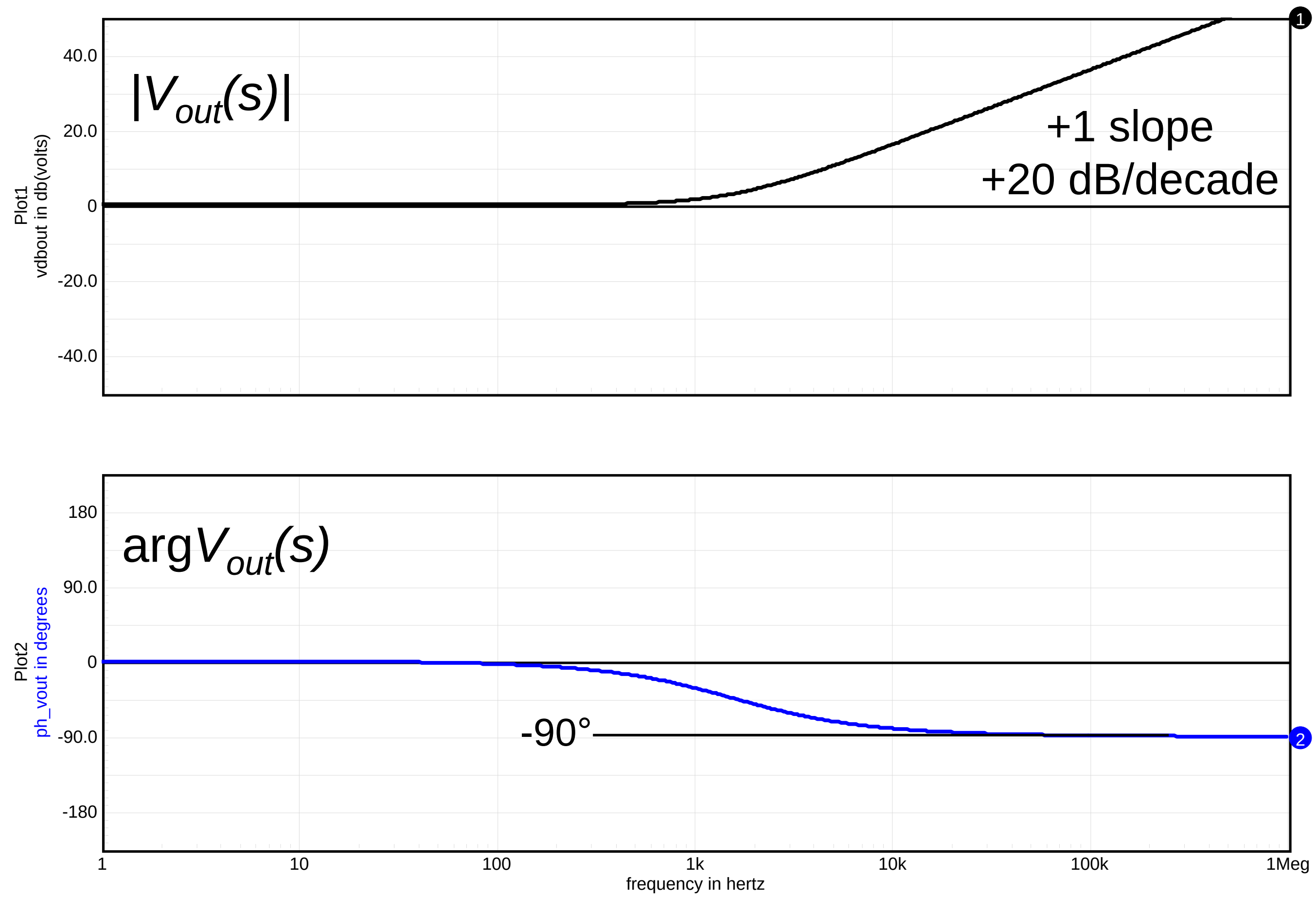
- In a CCM boost, I_{out} is delivered during the off time: $I_{out} = I_d = I_L(1-D)$



- If *D* <u>brutally</u> increases, *D'* reduces and I_{out} drops!
- What matters is the inductor current slew-rate $\longrightarrow \dfrac{d\langle V_L\rangle(t)}{dt}$
- Occurs in flybacks, buck-boost, Cuk etc.

The Right-Half-Plane-Zero

❑ With a RHPZ we have a boost in gain but a lag in phase!



LHPZ

$$G(s) = 1 + \frac{s}{\omega_0}$$

RHPZ

$$G(s) = 1 \boxed{-} \frac{s}{\omega_0}$$

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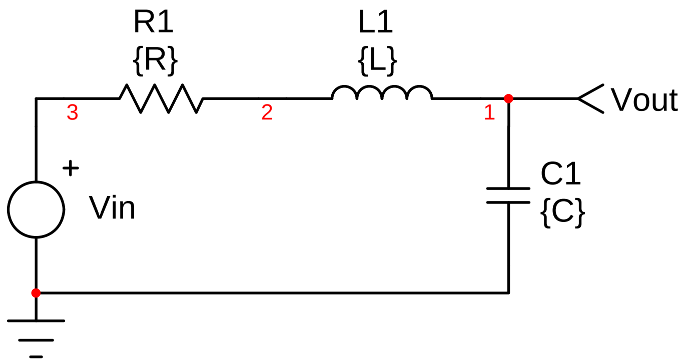
How much Margin? The *RLC* Filter

- let us study an *RLC* low-pass filter, a 2nd order system



parameters

f0=235k
L=10u
C=1/(4*3.14159^2*f0^2*L)
w0=({L}*{C})^-0.5
Q=10
R=1/((({C}/(4*{L}))^0.5)*2*{Q})

$$T(s) = \frac{1}{LCs^2 + RCs + 1}$$

$$T(s) = \frac{1}{\frac{s^2}{\omega_r^2} + 2\zeta\frac{s}{\omega_r} + 1} = \frac{1}{\frac{s^2}{\omega_r^2} + \frac{s}{\omega_r Q} + 1}$$

$$\omega_r = \frac{1}{\sqrt{LC}}$$

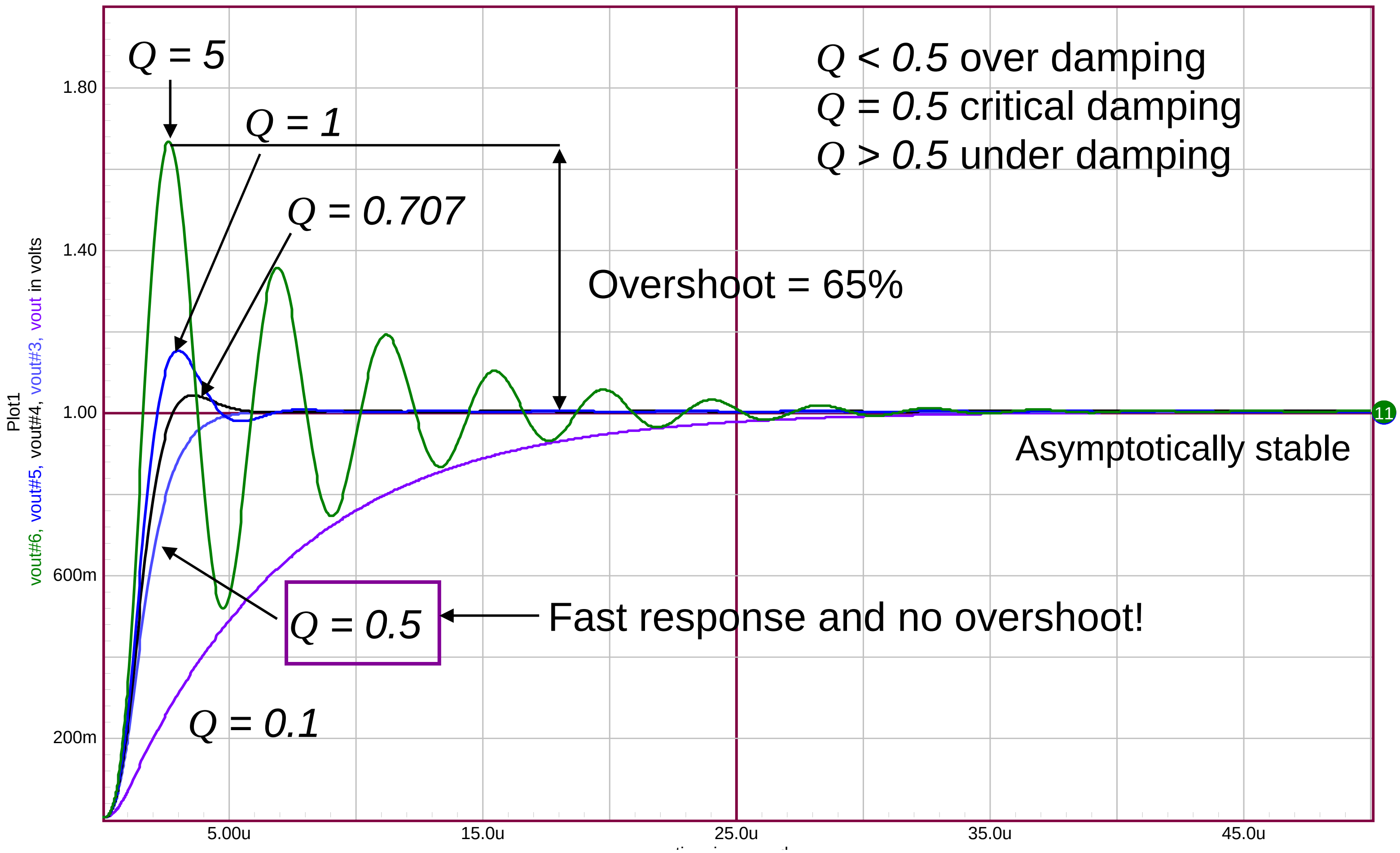
$$\boxed{\zeta} = R\sqrt{\frac{C}{4L}} \qquad Q = \frac{1}{2\zeta}$$

zeta

ω_r resonant freq.
ζ damping factor
Q quality coeff.

The *RLC* Response to an Input Step

- changing Q affects the transient response

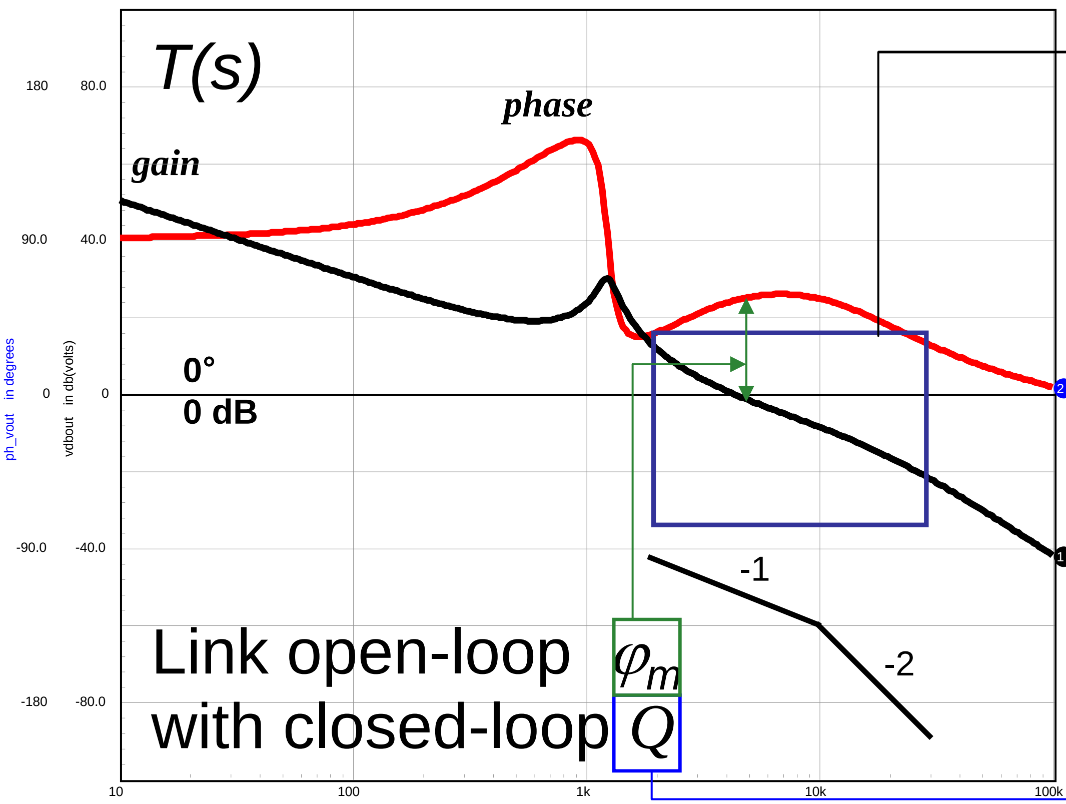


Where is the Analogy with *T(s)*?

❑ in the vicinity of the crossover point, *T(s)* combines:

▪ one pole at the origin, ω_0 and one high frequency pole, ω_2

✓ Link the <u>closed-loop</u> response to the <u>open-loop</u> phase margin:



$$T(s) = \frac{1}{\left(\frac{s}{\omega_0}\right)\left(1+\frac{s}{\omega_2}\right)} \quad \text{(OL)}$$

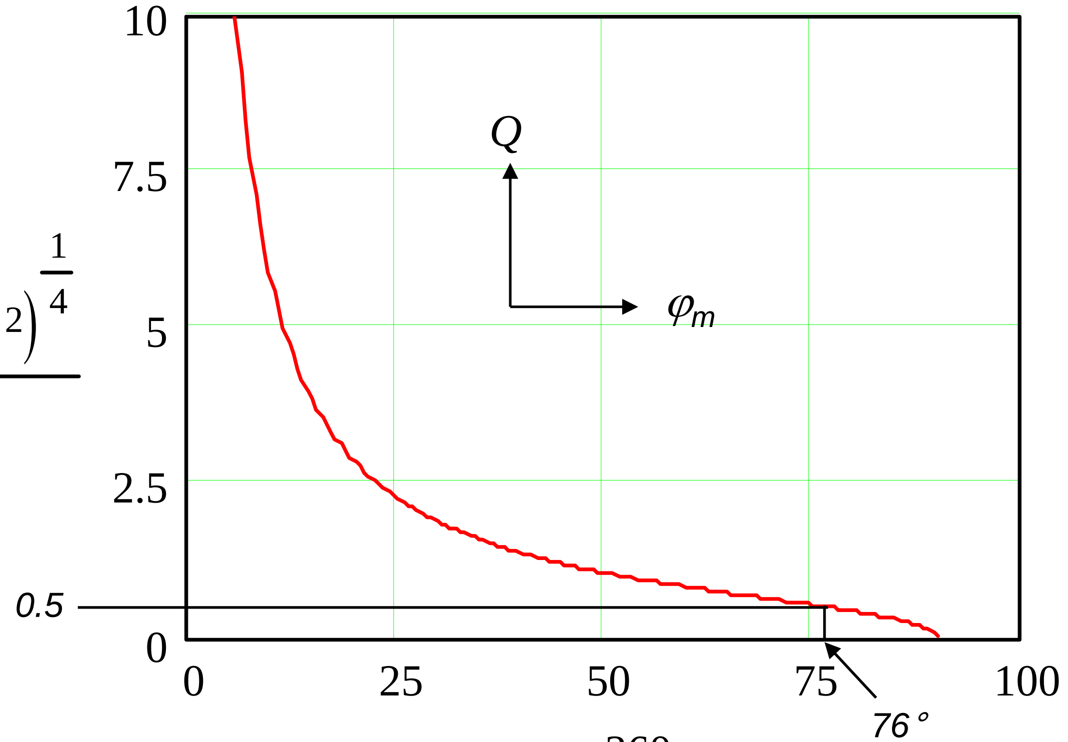
Close the loop

$$\frac{T(s)}{1+T(s)} = \frac{1}{\frac{s^2}{\omega_0\omega_2}+\frac{s}{\omega_0}+1} \quad \text{(CL)}$$

$$\frac{T(s)}{1+T(s)} = \frac{1}{\frac{s^2}{\omega_r^{\ 2}}+\frac{s}{\omega_r \boxed{Q}}+1}$$

Closed-Loop Q Versus Open-Loop φ_m

- a Q factor of 0.5 (critical response) implies a φ_m of 76°
- a 45° φ_m corresponds to a Q of 1.2: oscillatory response!

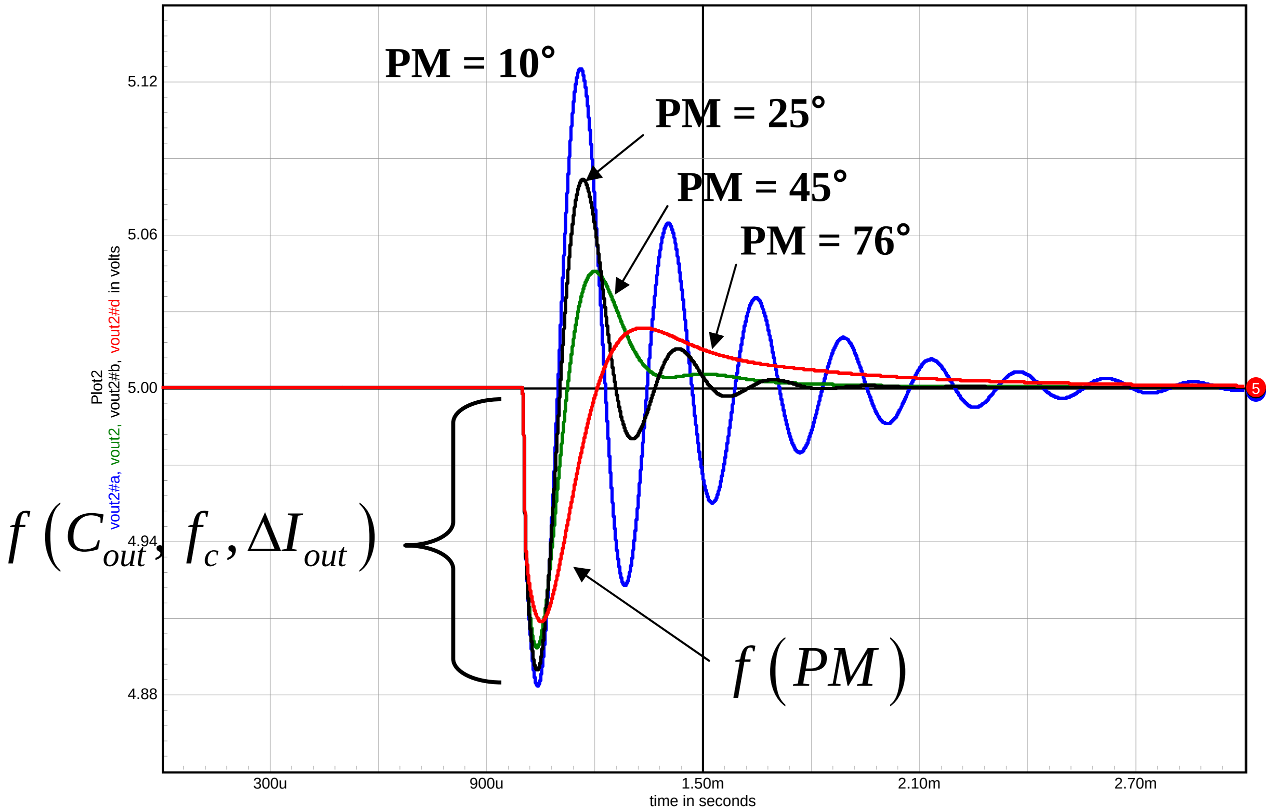


$$\frac{\left(1+\tan(\phi)^2\right)^{\frac{1}{4}}}{\tan(\phi)}$$

$$\phi\cdot\frac{360}{2\cdot\pi}$$

Summary on the Design Criteria

- ❑ compensate the open-loop gain for a phase margin of 70°
- ❑ make sure the open-loop gain margin is better than 15 dB
- ❑ never accept a phase margin lower than 45° in worst case



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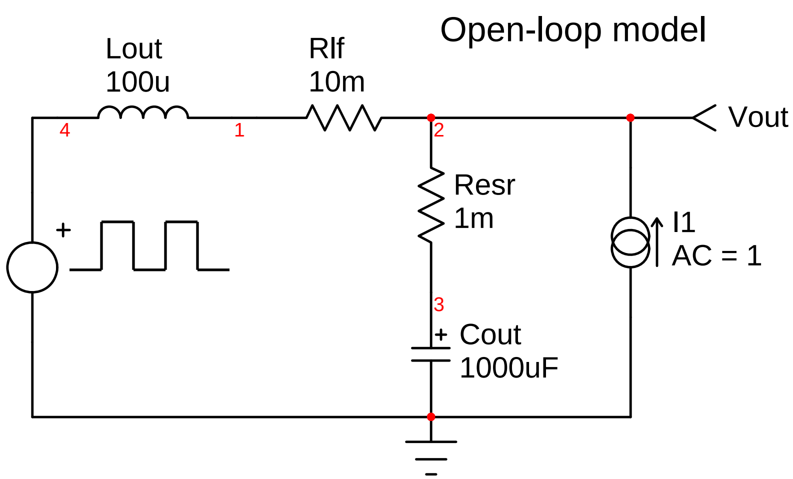
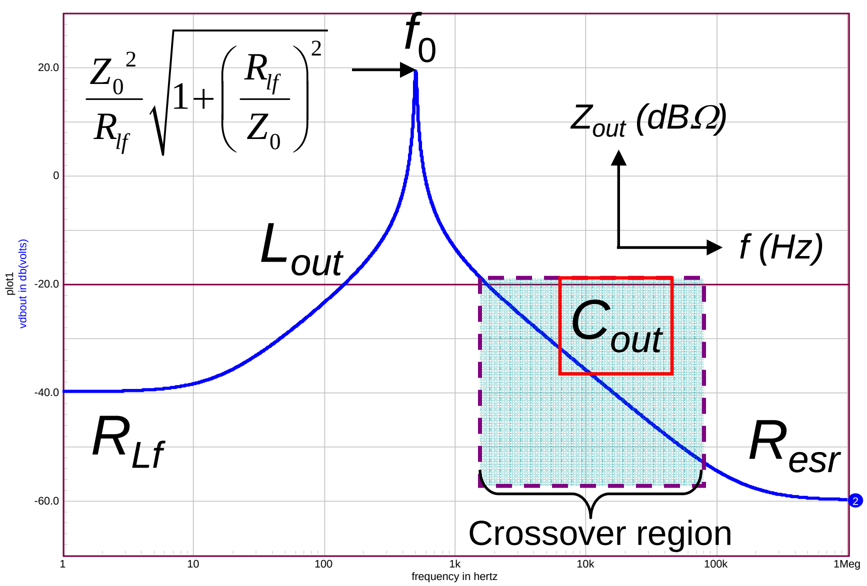
DC-DC Output Impedance

- ❑ A DC-DC conv. combines an inductor and a capacitor
- ❑ As f is swept, different elements dominate $Z_{out,OL}$



A buck equivalent circuit

$$Z_{out} = \left(sL_{out} + R_{Lf}\right) \| \left(R_{esr} + \frac{1}{sC_{out}}\right)$$

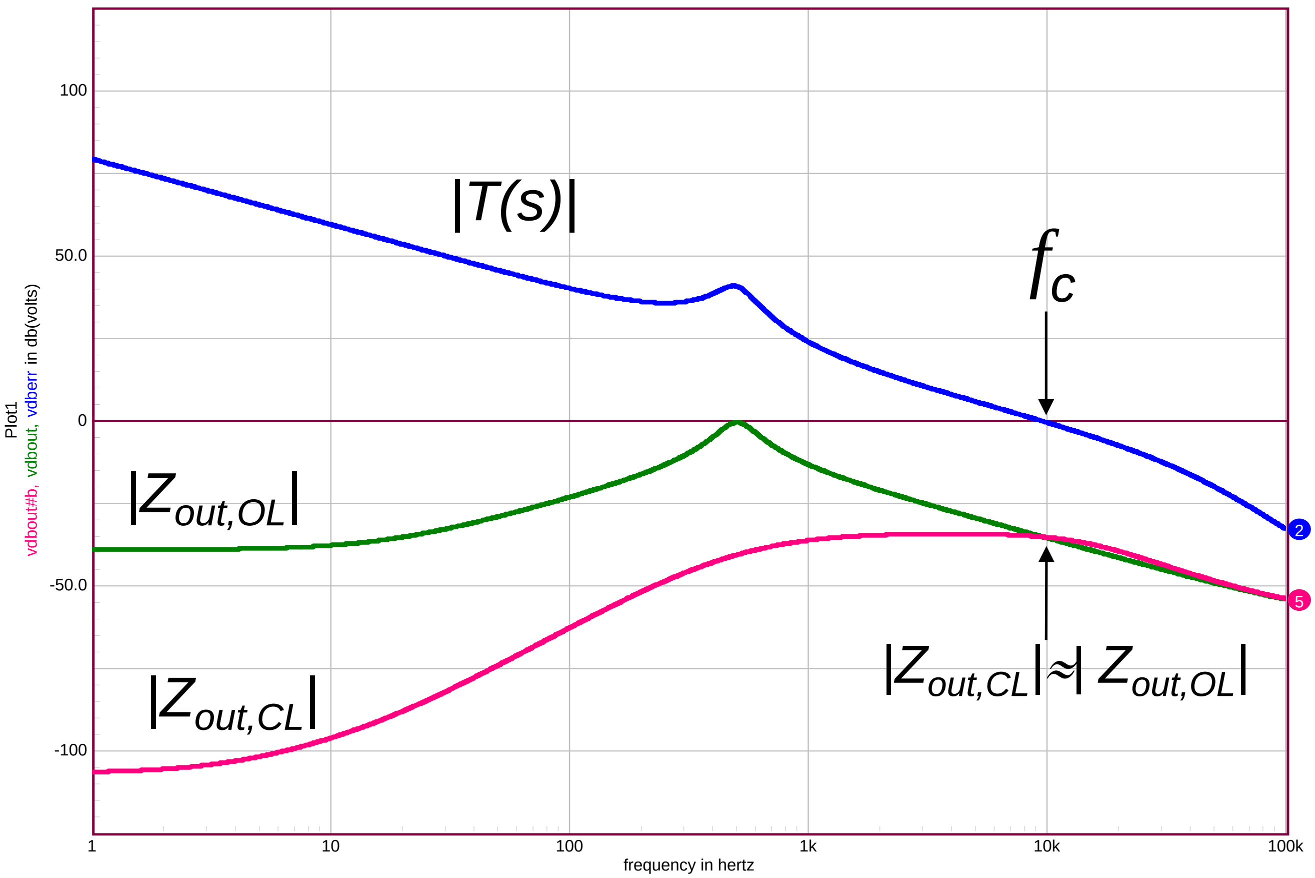


To avoid stability issues,

$f_c >> f_0$

Closing the Loop…

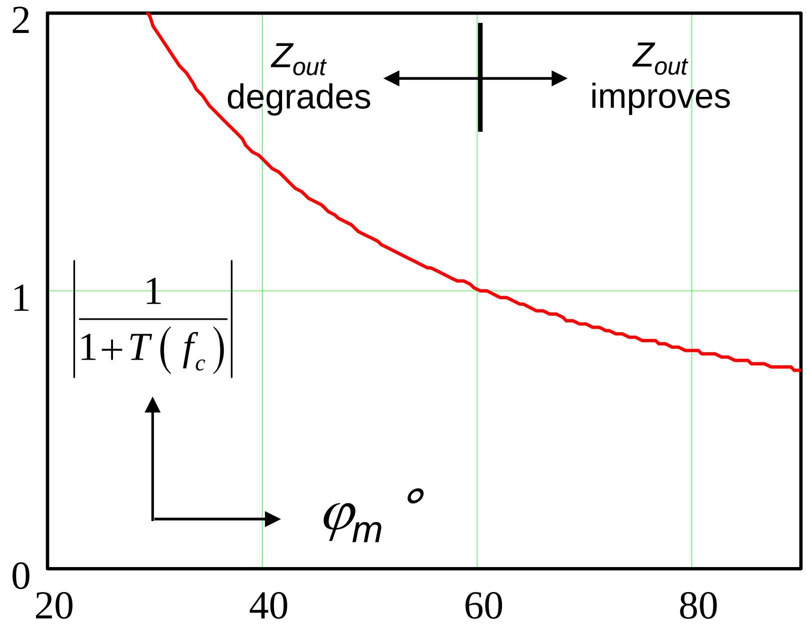
- At the crossover frequency $Z_{out,CL} \approx Z_{out,OL}$



Calculating the Output Impedance

- the closed-loop output impedance is dominated by C_{out}

$$\left|Z_{out,CL}\right| \approx \frac{1}{2\pi f_c C_{out}}\left|\frac{1}{1+T(s)}\right| \approx \frac{1}{2\pi f_c C_{out}}\frac{1}{\sqrt{2-2\cos(\varphi_m)}}$$



Open-loop phase margin affects the closed-loop output impedance

An Example with a Buck

- Let's assume an output capacitor of 1 mF
- The spec states a 80 mV undershoot for a 2 A step
- How to select the crossover frequency?

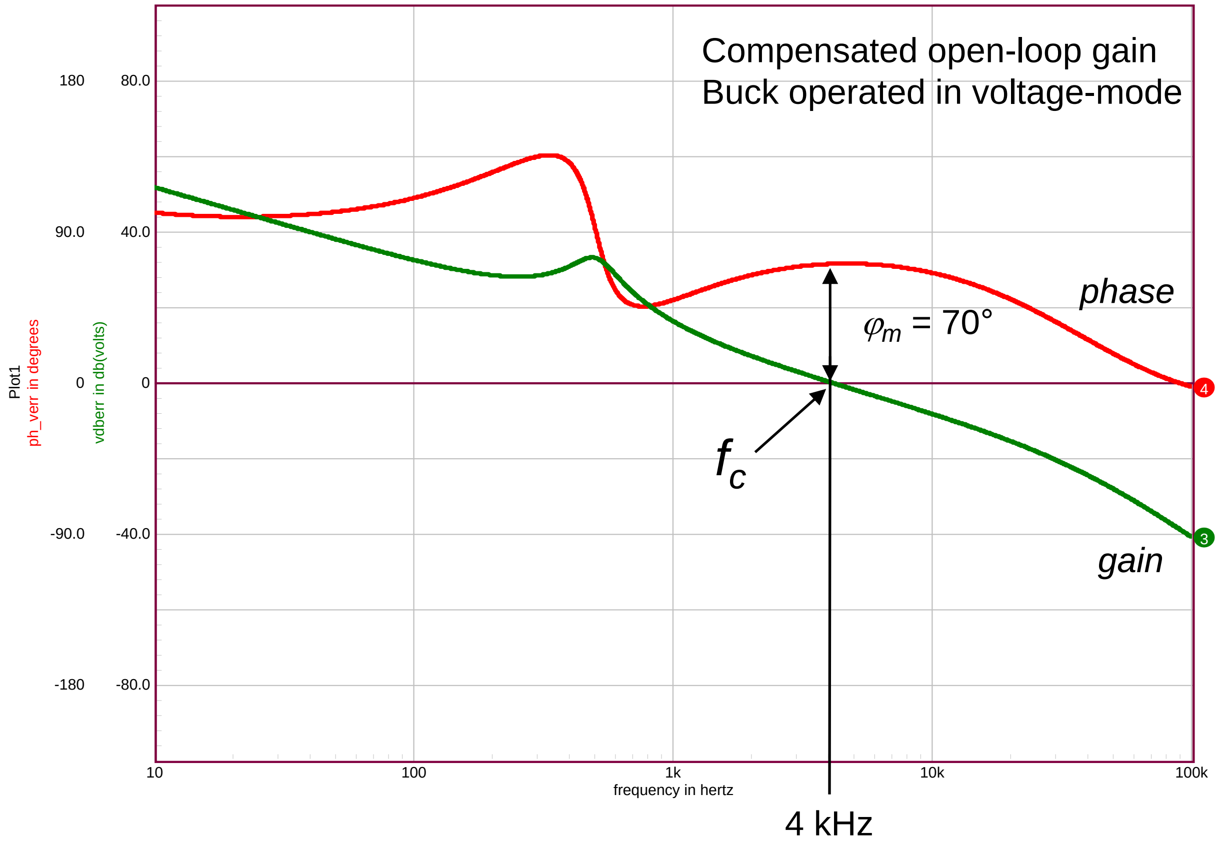
$$\Delta V_{out} \approx \frac{\Delta I_{out}}{2\pi f_c C_{out}} \longrightarrow f_c \approx \frac{\Delta I_{out}}{\Delta V_{out} C_{out} 2\pi}$$

$$f_c \approx \frac{2}{80m \times 1m \times 2\pi} = \boxed{4\ kHz} \qquad Z_{C_{out}} @ 4\ kHz = \frac{1}{2\pi \times 4k \times 1m} = 40\ m\Omega$$

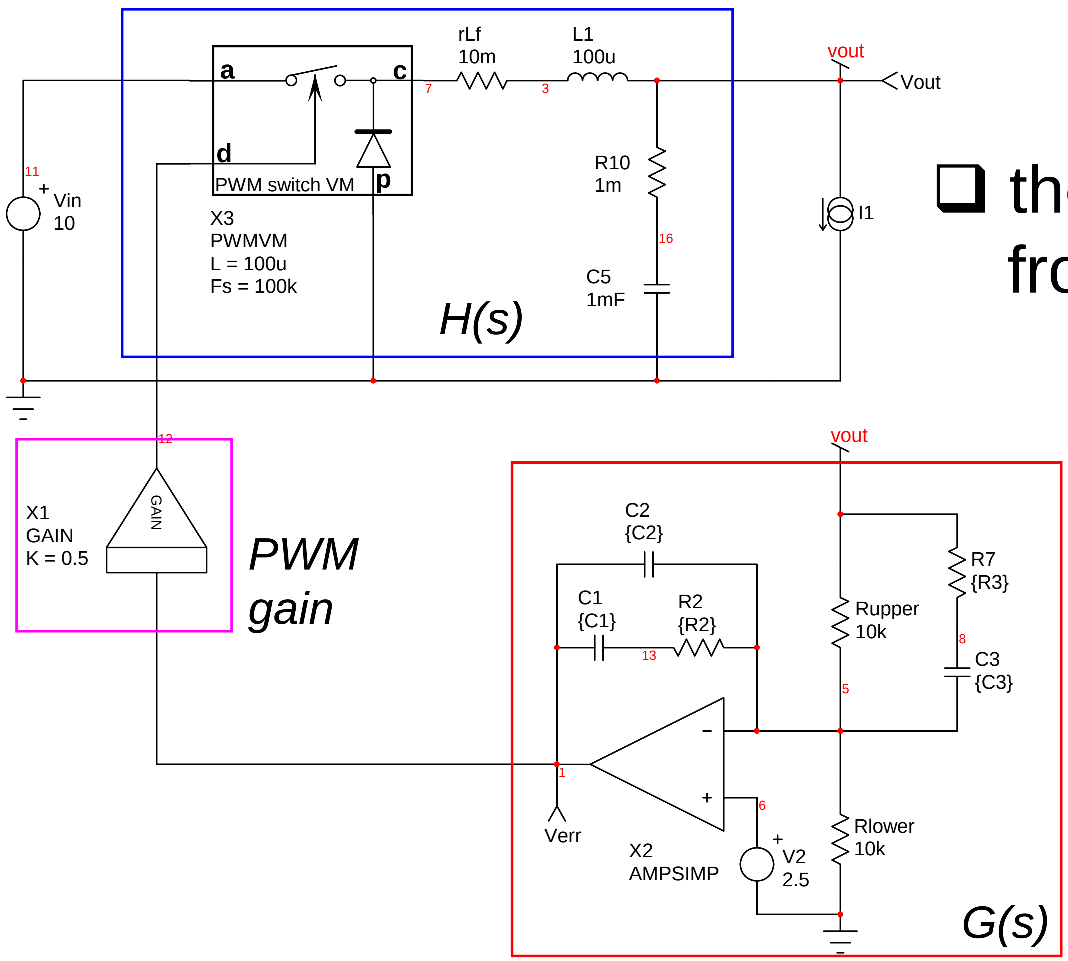
Select a 1000-µF capacitor featuring less than a 40-mΩ ESR

Setting the Right Crossover Frequency

- Compensate the converter for a 4 kHz f_c

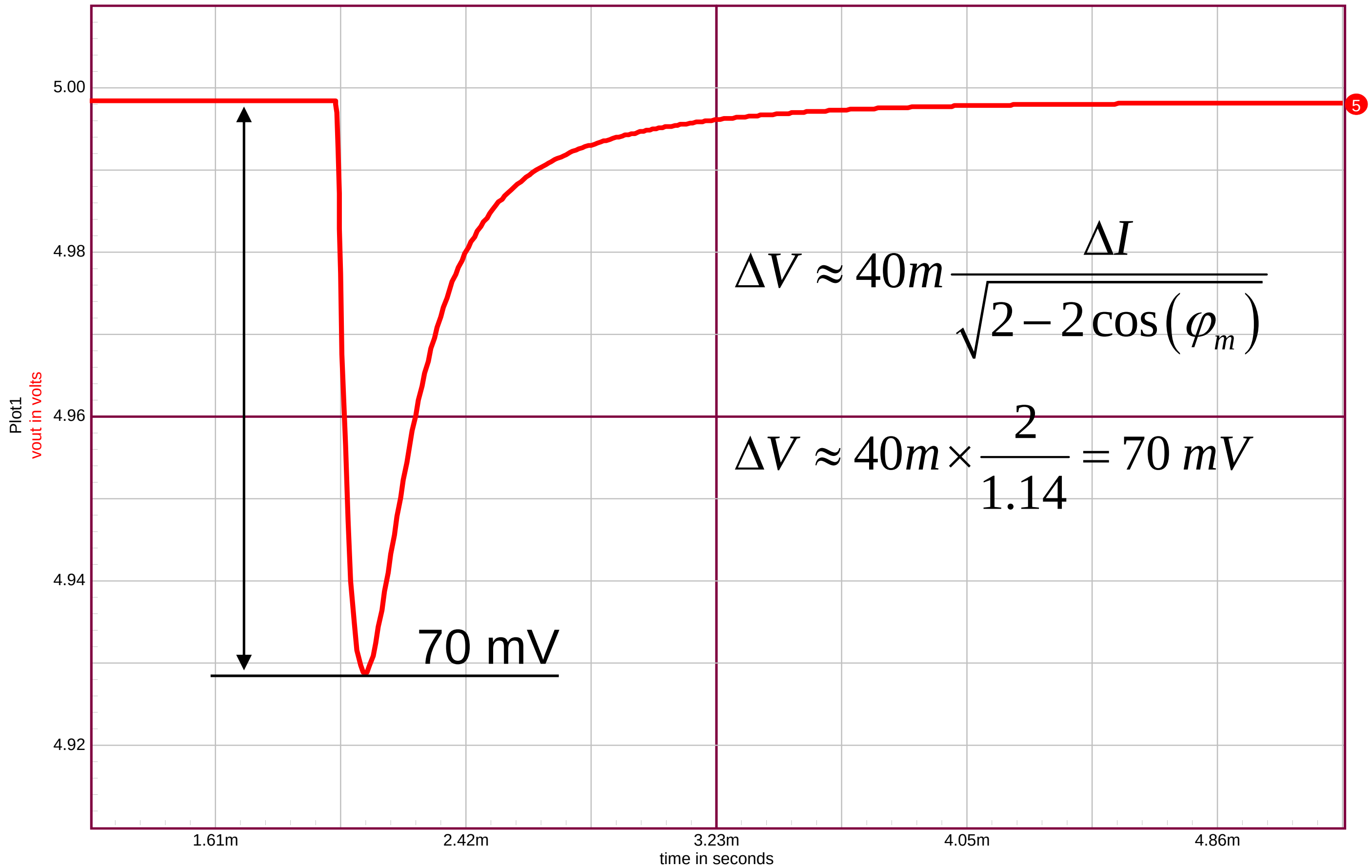


Step Load the Output



- the load varies from 100 mA to 2.1 A

Measure the Obtained Undershoot



$$\Delta V \approx 40m \frac{\Delta I}{\sqrt{2-2\cos(\varphi_m)}}$$

$$\Delta V \approx 40m \times \frac{2}{1.14} = 70\ mV$$

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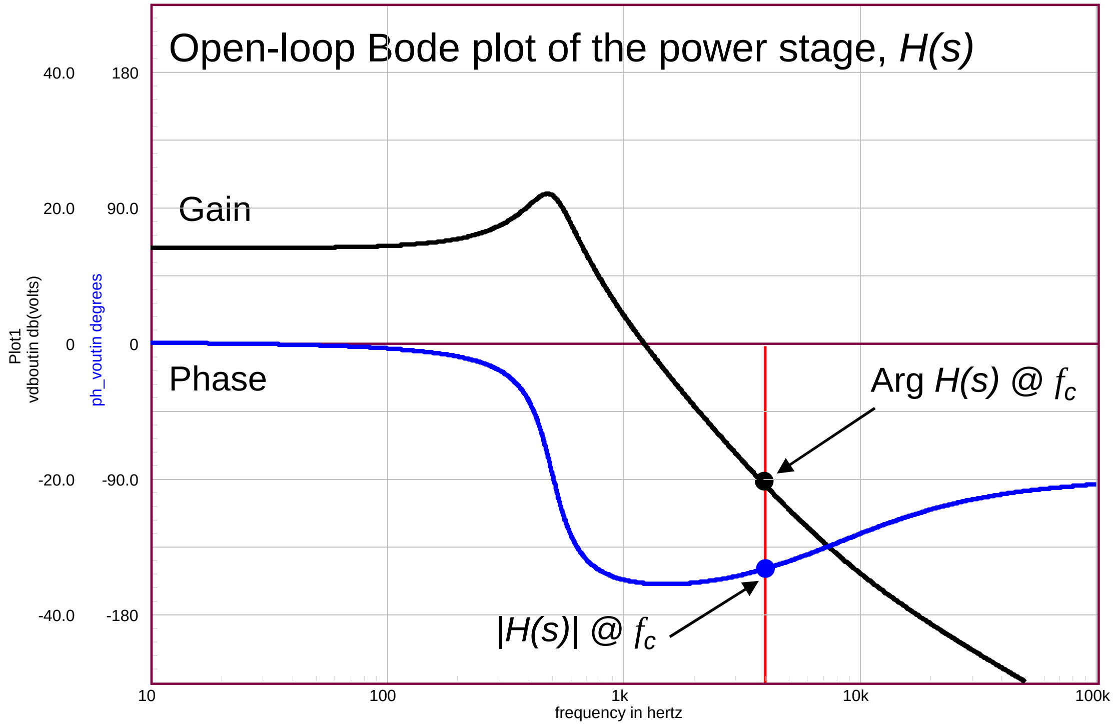
How do we Stabilize the Converter?

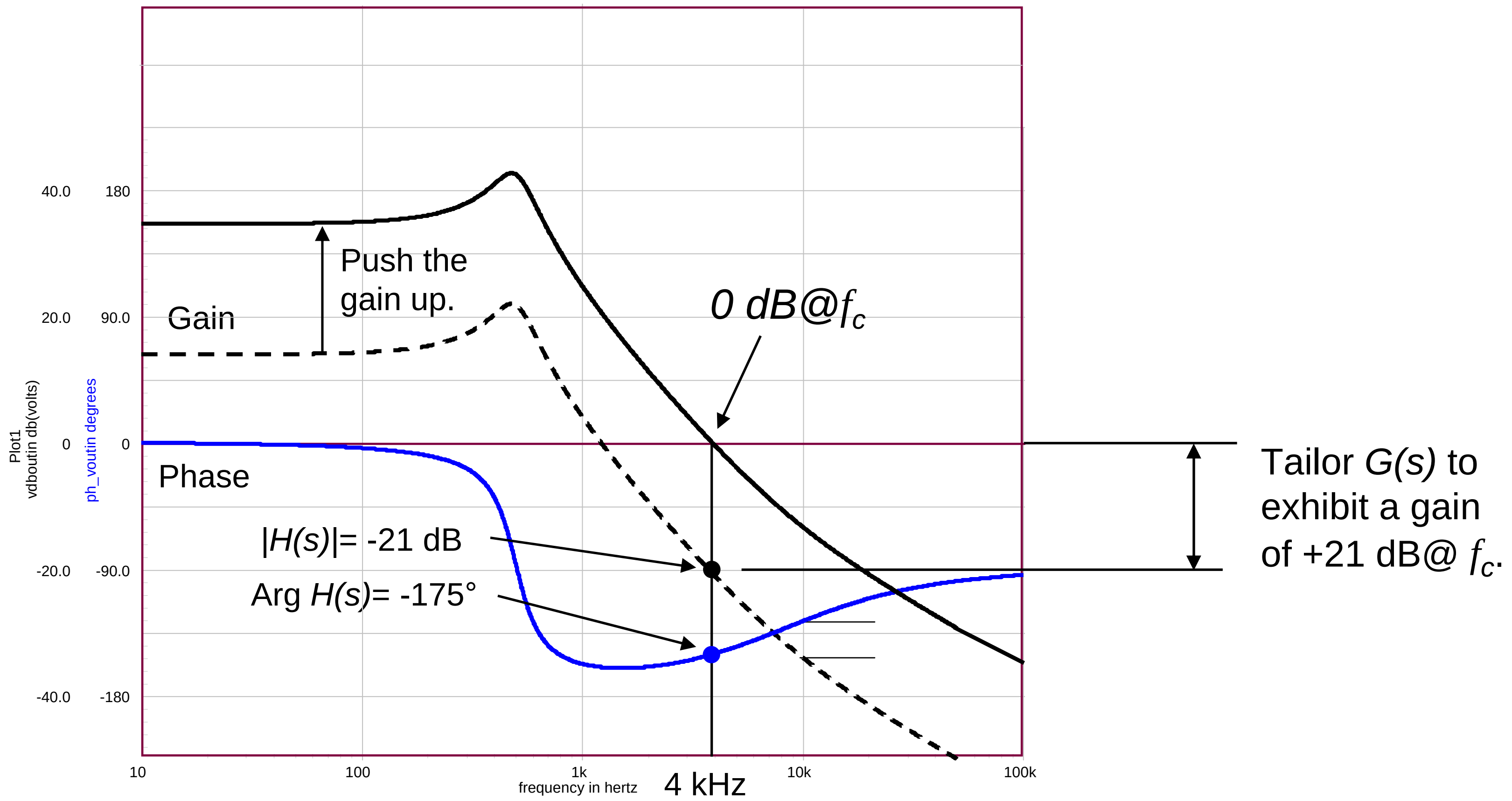
1. Select the crossover frequency f_c (assume 4 kHz)
2. Provide a high dc gain for a low static error and good input rejection
3. Shoot for a 70° phase margin at f_c
4. Evaluate the needed phase boost at f_c to meet (3)
5. Shape the *G(s)* path to comply with 1, 2 and 3



$$A_{sc,CL}(s) = \frac{A_{sc,OL}(s)}{1+T(s)}$$

First, Provide Mid-Band Gain at Crossover

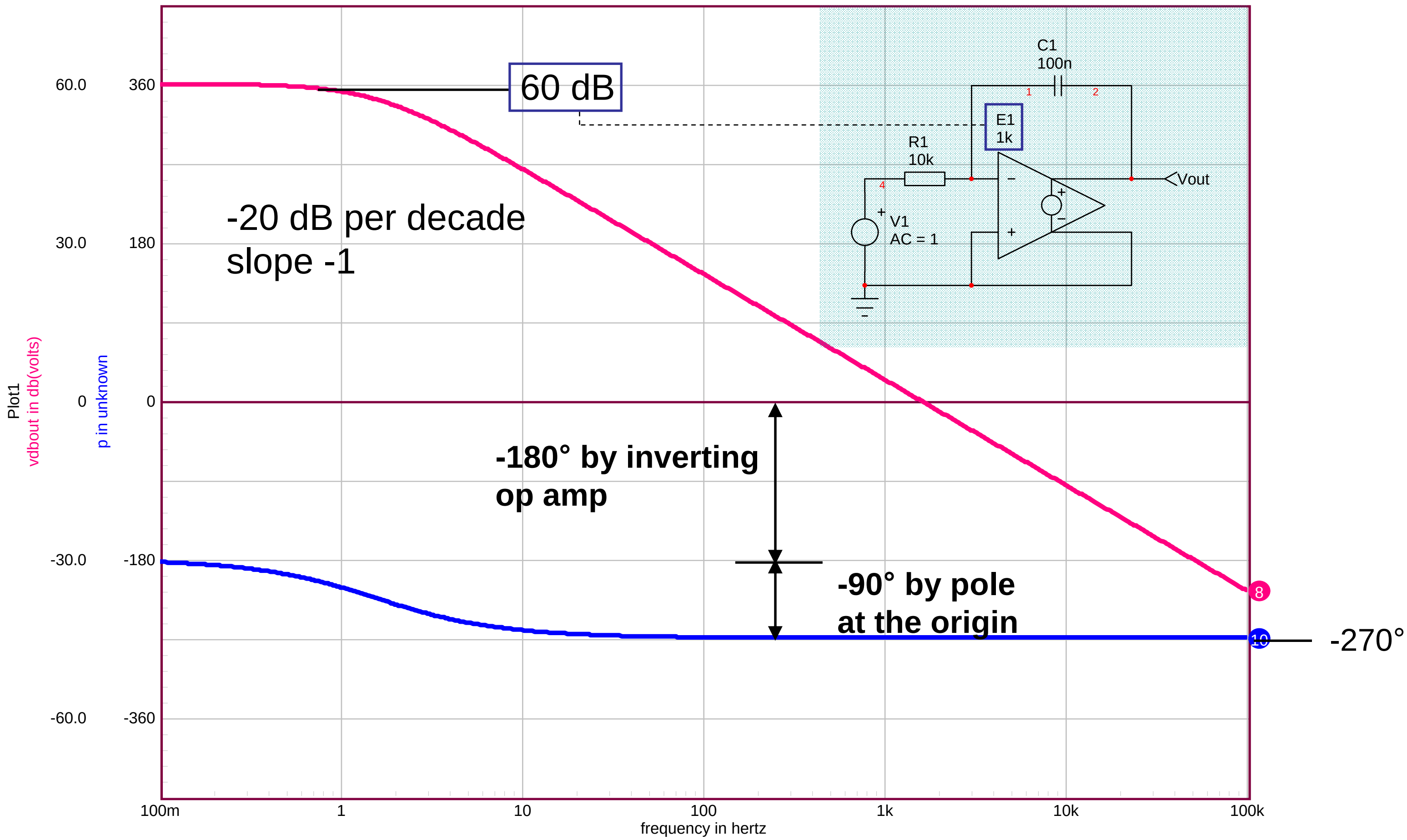
1. Adjust *G(s)* to boost the gain by +21 dB at crossover
➢ Create the so-called mid-band gain



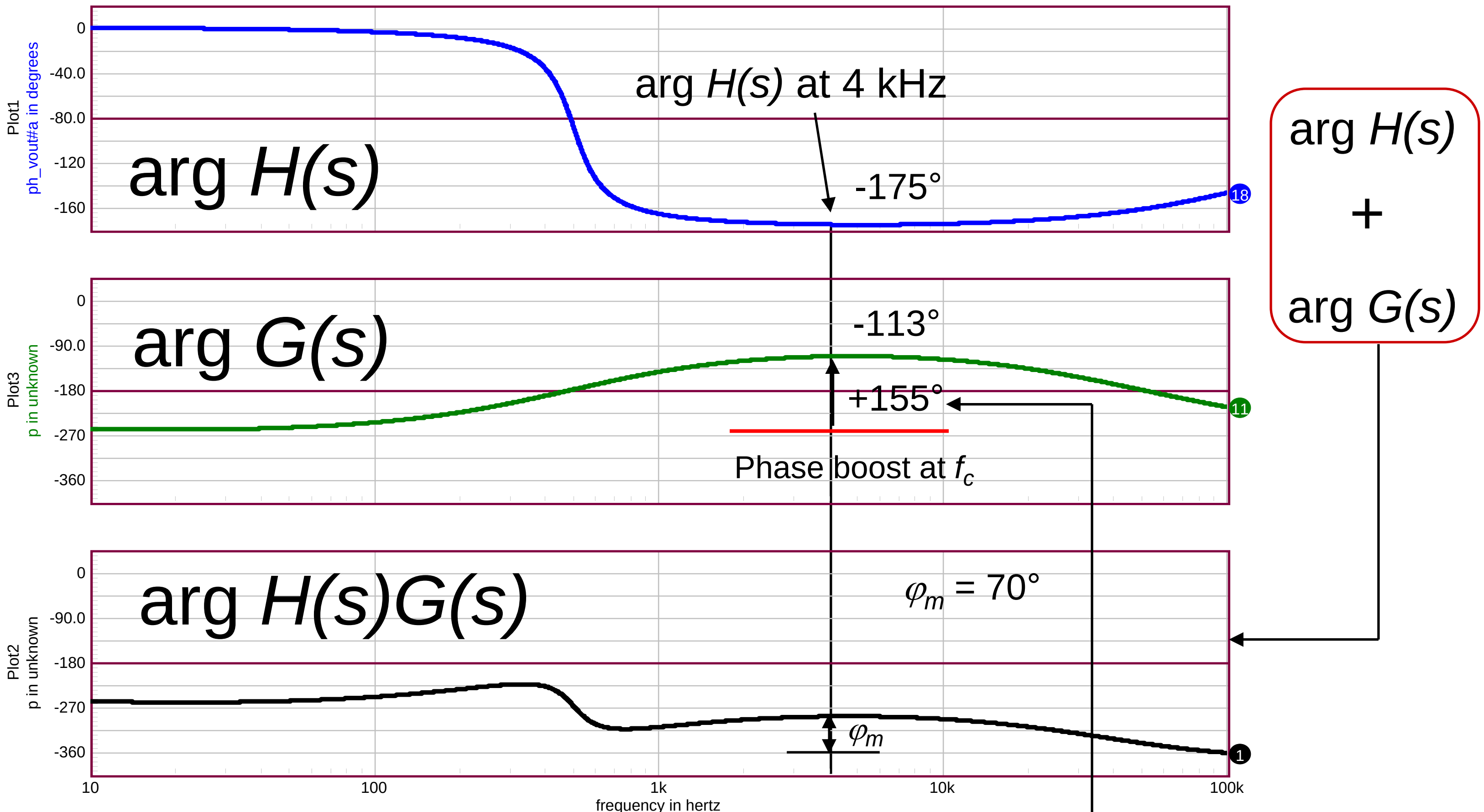
Second, Provide High Gain in DC

2. An integrator provides a high dc gain but rotates by -270°

➢ This is the origin pole



Third, Evaluate the Phase Boost at f_c



$$\arg H(f_c) - 270° + BOOST - \varphi_m = -360°$$

$$BOOST = \varphi_m - \arg H(f_c) - 90° = 70° + 175 - 90 = \boxed{155°}$$

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How do We Boost the Phase at f_c?

- The phase boost is created by combining zeros and poles

$$G(j\omega) = \frac{\left(1 + j\frac{\omega}{\omega_{z1}}\right)}{\left(1 + j\frac{\omega}{\omega_{p1}}\right)} \qquad \arg G(j\omega) = boost = \arg \frac{\left(1 + j\frac{\omega}{\omega_{z1}}\right)}{\left(1 + j\frac{\omega}{\omega_{p1}}\right)}$$

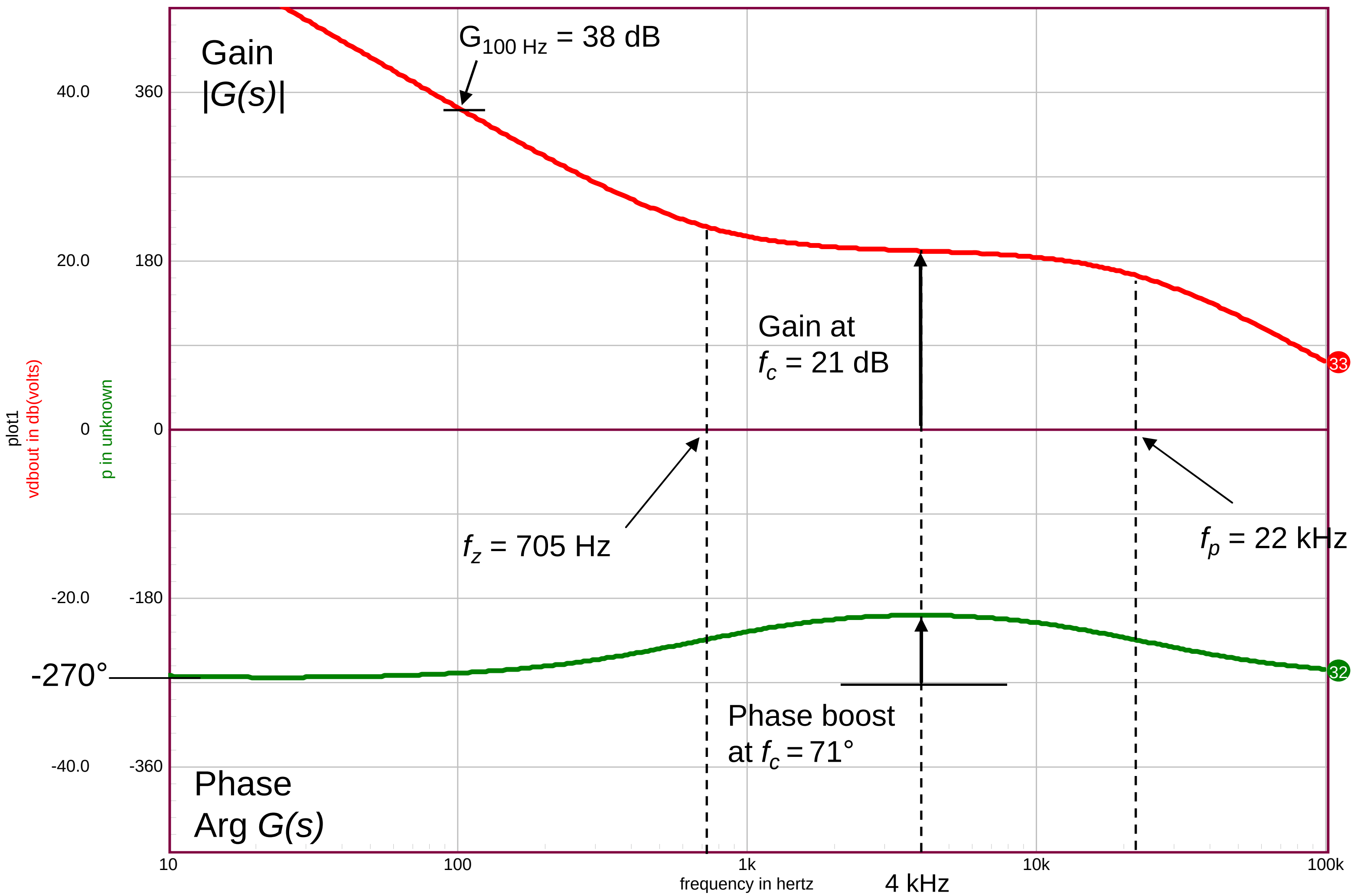
$$\arg G(f_c) = \arctan\left(\frac{f_c}{f_{z1}}\right) - \arctan\left(\frac{f_c}{f_{p1}}\right)$$

Assume 1 zero placed at 705 Hz, 1 pole at 22 kHz and a 4-kHz crossover frequency:

$$\arg G(4\,kHz) = \arctan\left(\frac{4k}{705}\right) - \arctan\left(\frac{4k}{22k}\right) = 80 - 10.3 \approx 70°$$

- If poles and zeros are coincident, no phase boost!

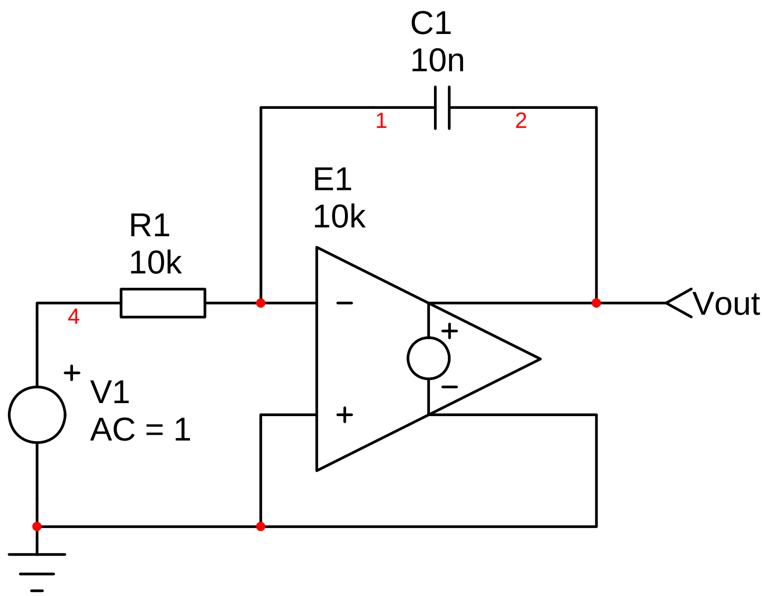
How do We Boost the Phase at f_c?



Type 2

How do We Boost the Phase at f_c?

- The type 1 configuration
- No phase boost, pure integral term
- Permanent phase lag of -270°
- Ok if arg$H(f_c)$ < -45° for a φ_m of 45°



$$G(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{1}{sR_1C_1} = \frac{1}{\frac{s}{\omega_0}}$$

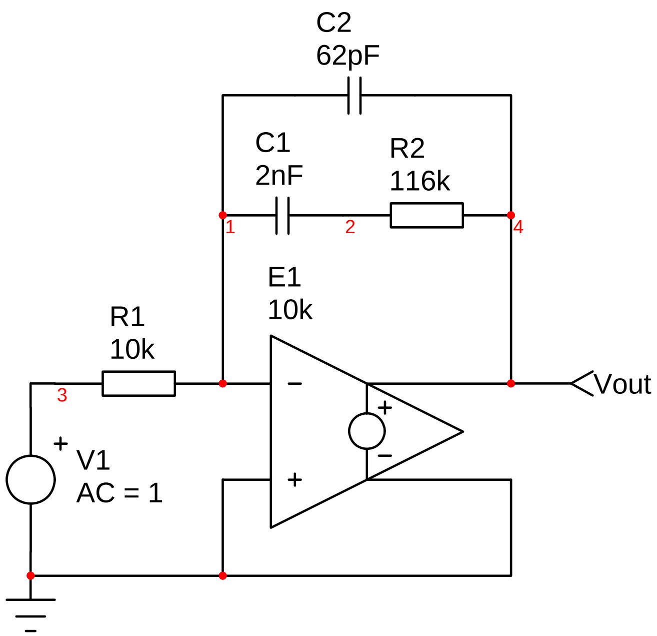
$$\omega_{p1} = \frac{1}{R_1C_1}$$

1 pole at the origin

Type 1

How do We Boost the Phase at f_c?

- The type 2 configuration
- Phase boost up to 90°
- Ok if arg$H(f_c)$ < -90°



$$G(s) = -\frac{1+sR_2C_1}{sR_1(C_1+C_2)\left(1+sR_2\left[\frac{C_1C_2}{C_1+C_2}\right]\right)}$$

If $C_2 << C_1$

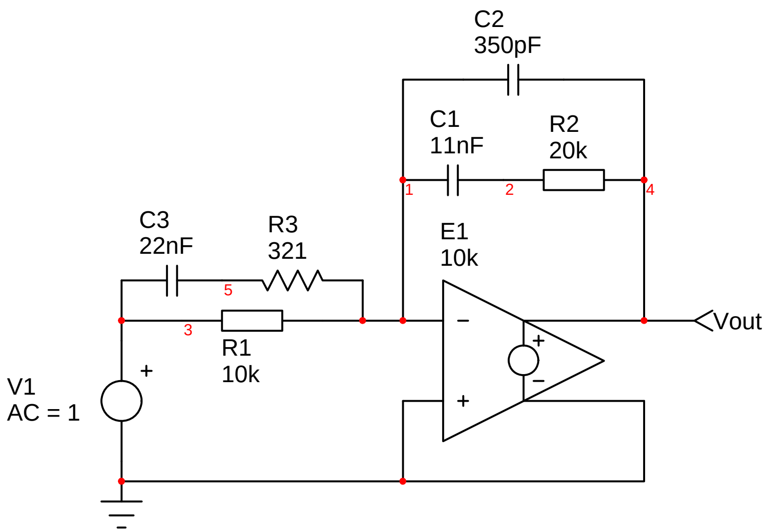
$$\omega_{po} = \frac{1}{R_1C_1} \quad \omega_{p1} = \frac{1}{R_2C_2} \quad \omega_{z1} = \frac{1}{R_2C_1}$$

1 pole at the origin
1 zero
1 pole

Type 2

How do We Boost the Phase at f_c?

- The type 3 configuration
- Phase boost up to 180°
- Ok if arg$H(fc)$ < -180°



$$G(s) = -\frac{sR_2C_1+1}{sR_1(C_1+C_2)\left(1+sR_2\frac{C_1C_2}{C_1+C_2}\right)}\frac{sC_3(R_1+R_3)+1}{(sR_3C_3+1)}$$

If $C_2 \ll C_1$ and $R_3 \ll R_1$

$$\omega_{z1} = \frac{1}{R_2C_1} \quad \omega_{z2} = \frac{1}{R_1C_3} \quad \omega_{po} = \frac{1}{R_1C_1}$$

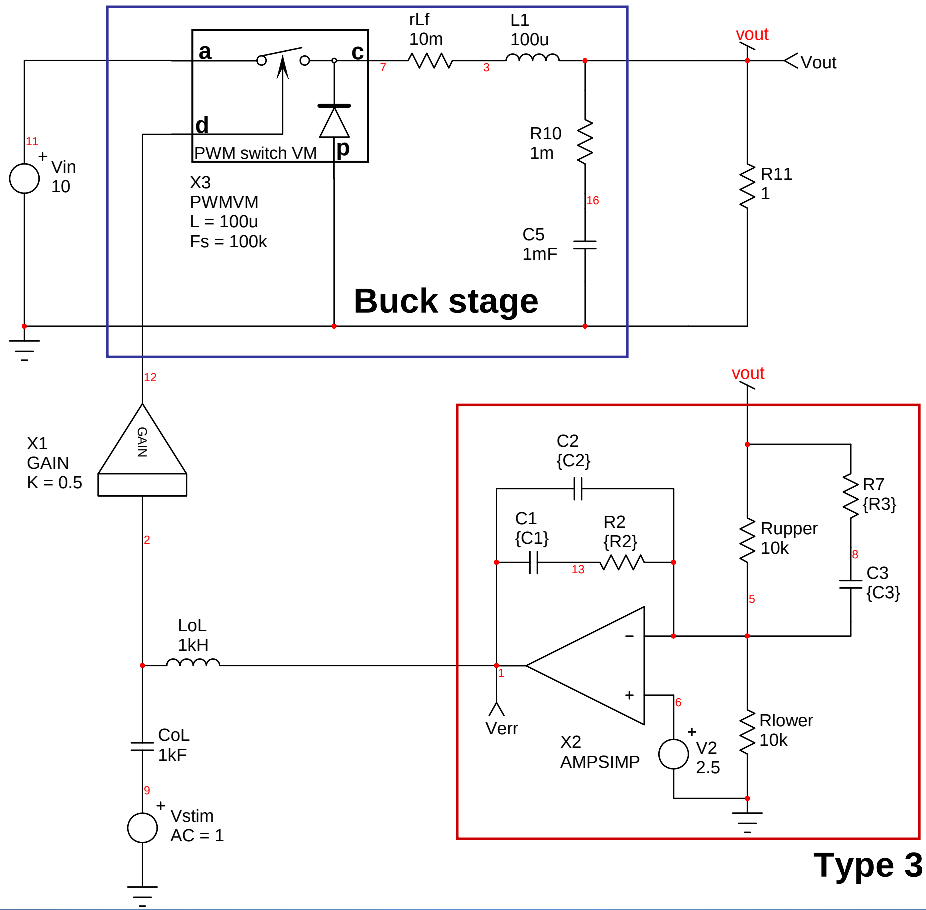
$$\omega_{p1} = \frac{1}{R_3C_3} \quad \omega_{p2} = \frac{1}{R_2C_2}$$

1 pole at the origin
2 zeros
2 poles

Type 3

Finally, We Test the Open-Loop Gain

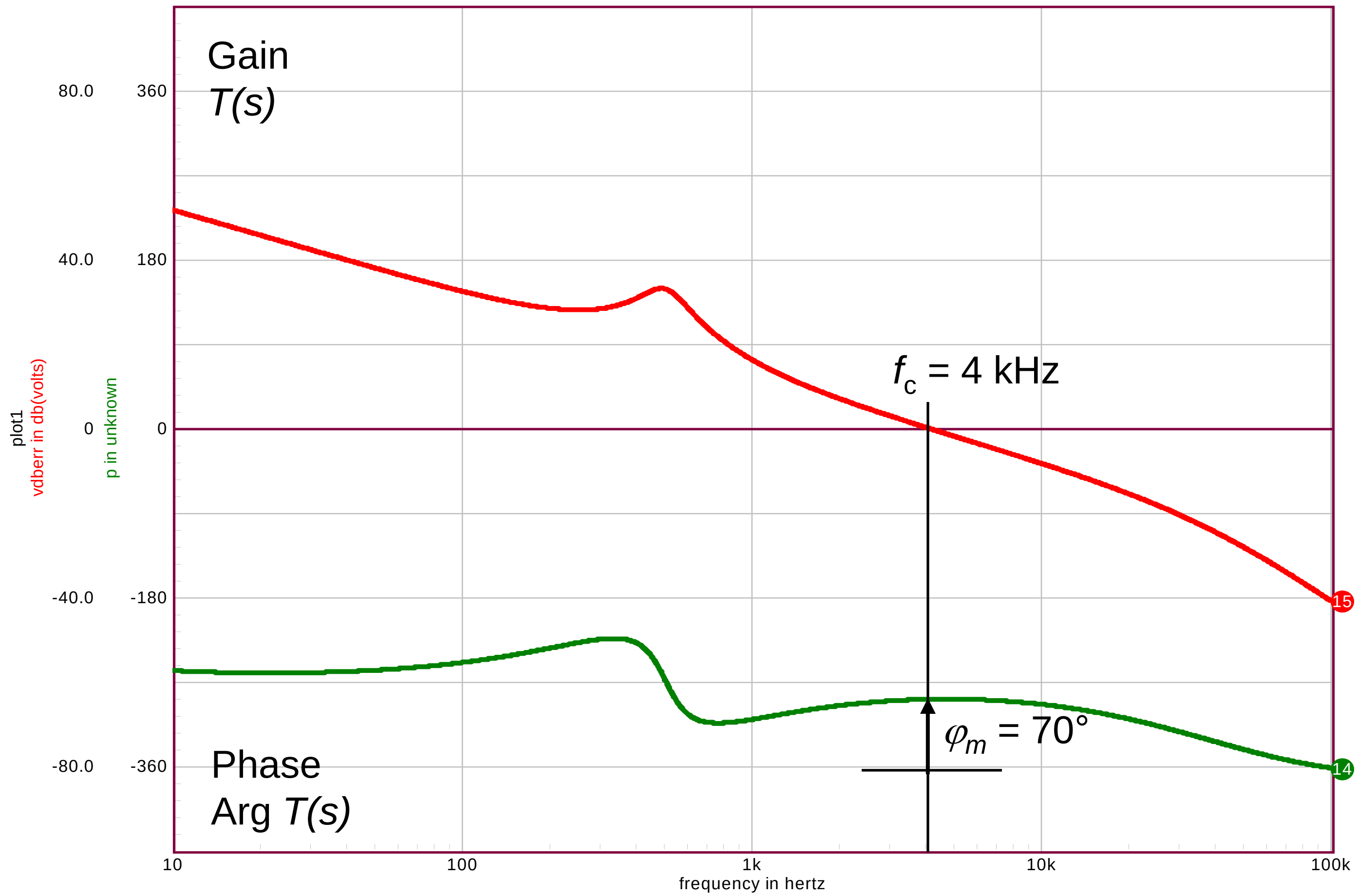
5. Given the necessary boost of 155°, we select a type-3 amplifier
6. A SPICE simulation can give us the whole picture!



1 pole at the origin
2 zeros at 500 Hz
2 poles at 50 kHz

Finally, We Test the Open-Loop Gain

An ac simulation gives us the open-loop Bode plot



Agenda

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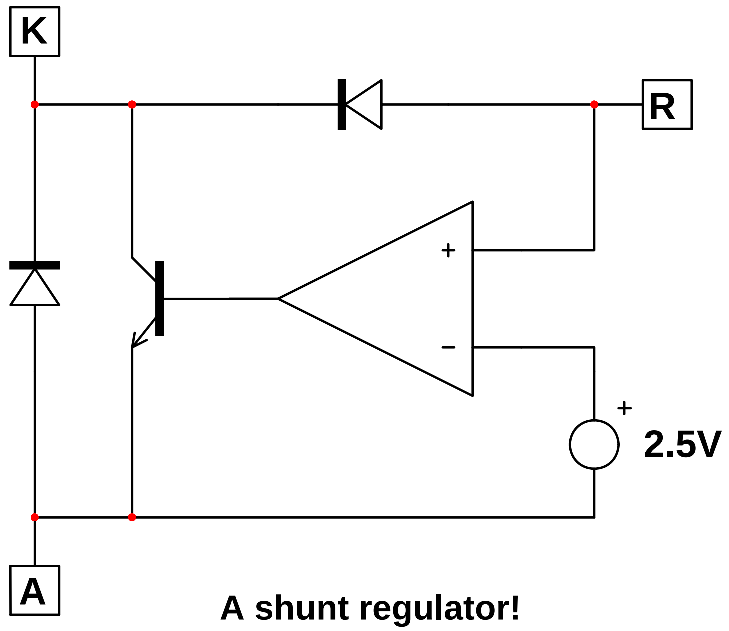
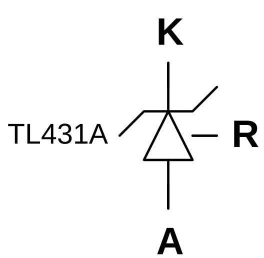
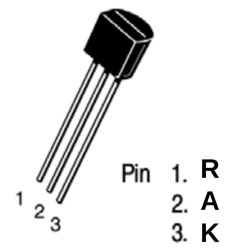
Type 2 with a TL431

- ❑ Litterature examples use op amps to close the loop.
- ❑ Reality differs as the TL431 is widely implemented.
- ❑ How to convert a type 2 to a TL431 circuit?



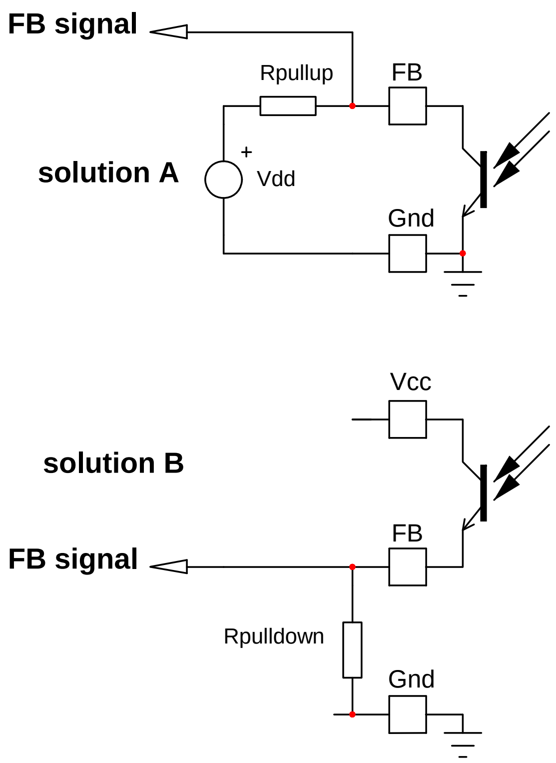
A shunt regulator!

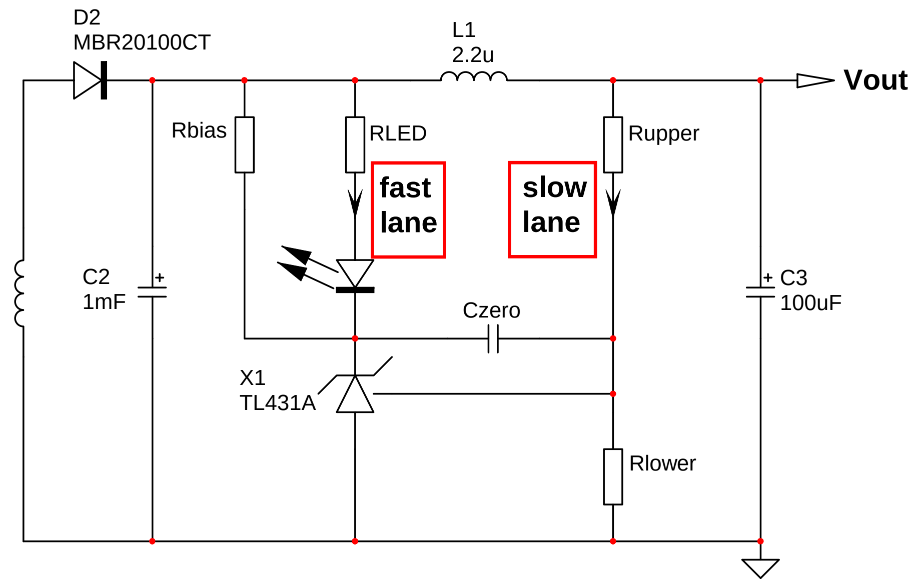




Type 2 with a TL431

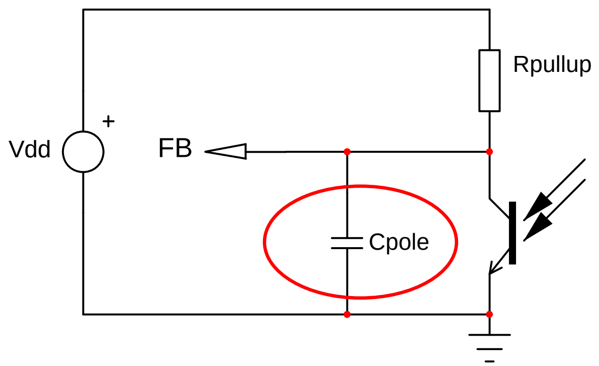
- ❑ A TL431 implements a two-loop configuration

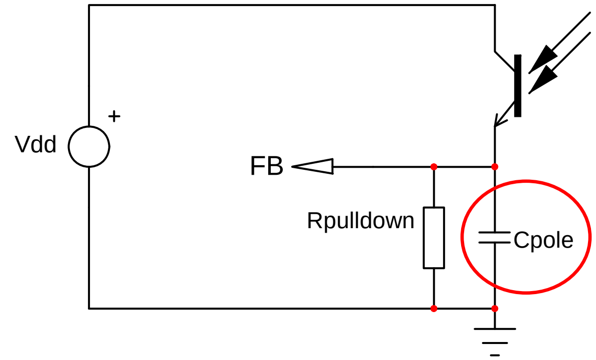




Adding a Pole for a Type 2 Circuit

- The pole is a simple capacitor on the collector





Or on the emitter

$$G(s)=\frac{V_{FB}(s)}{V_{out}(s)}=-\left(\frac{sR_{upper}C_{zero}+1}{sR_{upper}C_{zero}}\right)\left(\frac{1}{1+sR_{pullup}C_{pole}}\right)\frac{R_{pullup}}{R_{LED}}\mathrm{CTR}$$

$$f_{po}=\frac{1}{2\pi R_{upper}C_{zero}}$$

Pole at the origin

$$f_z=\frac{1}{2\pi R_{upper}C_{zero}}$$

Low frequency zero

$$G=\frac{R_{pullup}}{R_{LED}}\mathrm{CTR}$$

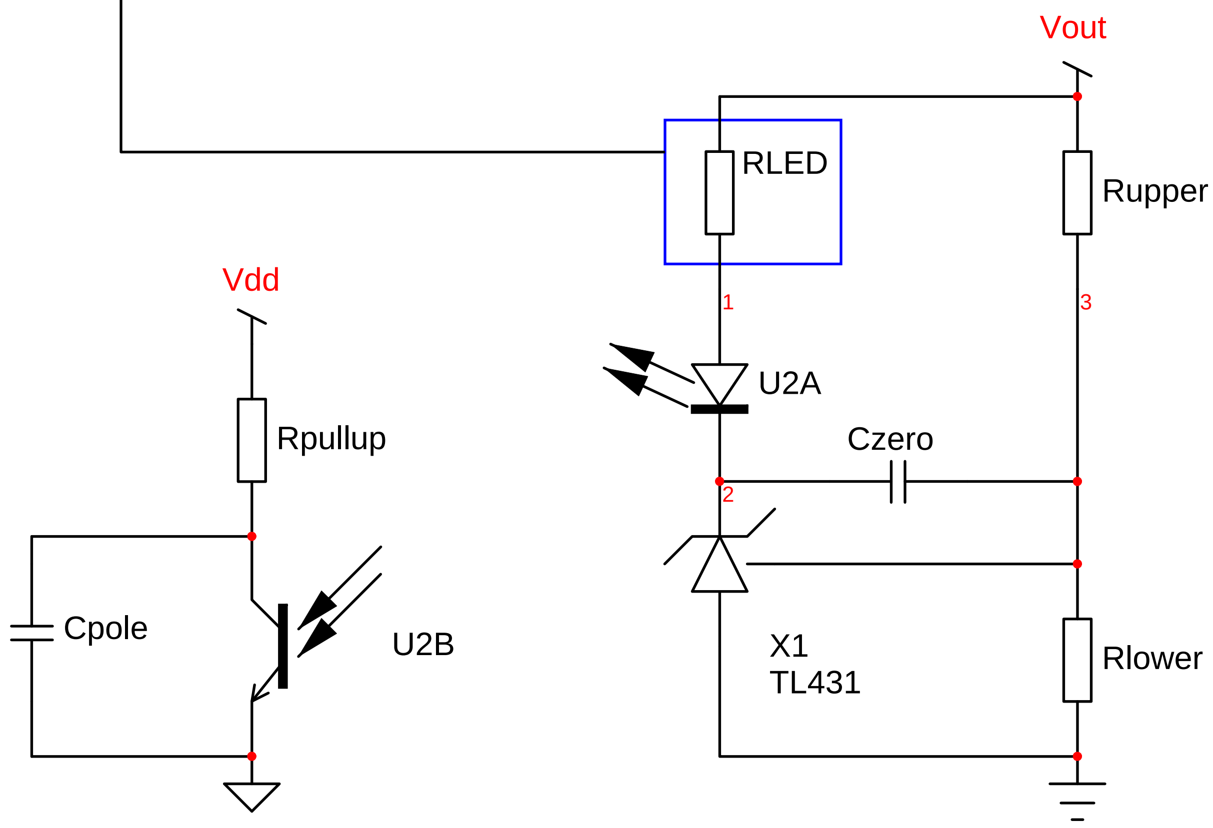
Mid-band gain

$$f_p=\frac{1}{2\pi R_{pullup}C_{pole}}$$

High frequency pole

The Type 2 Final Implementation

- The LED resistor fixes the mid-band gain



What TL431?

❑ The TL431 is available under several grades

- TL431AI, 2.495 V, ± 2.2% T_A = -25 °C to +85 °C
- TL431AC, 2.495 V, ± 1.6% T_A = -25 °C to +85 °C
- TL431BI, 2.495 V, ± 0.8% T_A = -25 °C to +85 °C
- BV = 37 V, $I_{K,max}$ = 100 mA and $I_{K,min}$ = $\boxed{1\text{ mA}}$

❑ The TLV431 can regulate to a lower output

- TLV431A, 1.24 V, ± 2% T_A = -25 °C to +85 °C
- TLV431B, 1.24 V, ± 1% T_A = -25 °C to +85 °C
- BV = 18 V, $I_{K,max}$ = 20 mA and $I_{K,min}$ = $\boxed{100\ \mu\text{A}}$

→ NCP100 down to 0.9 V

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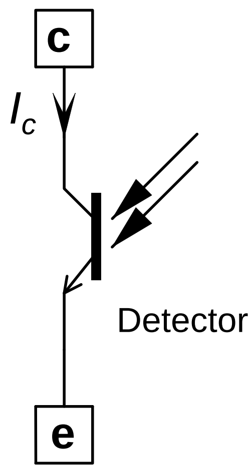
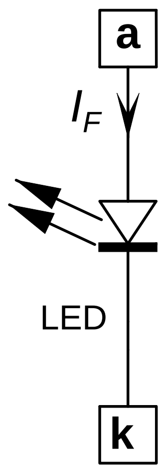
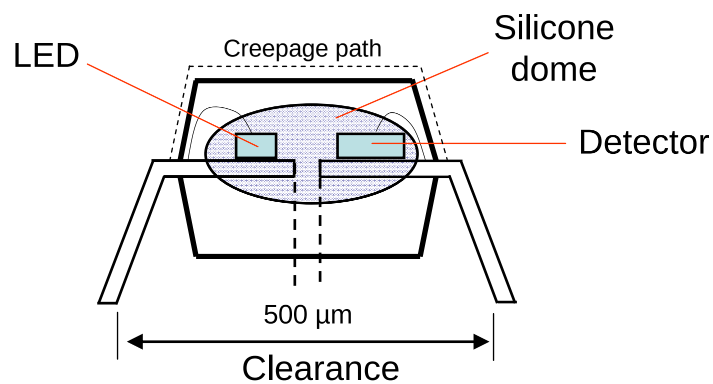
The Optocoupler is the Treator Here!

- ❑ You need galvanic isolation between the prim. and the sec.
- ❑ An optocoupler transmits light only, no electrical link





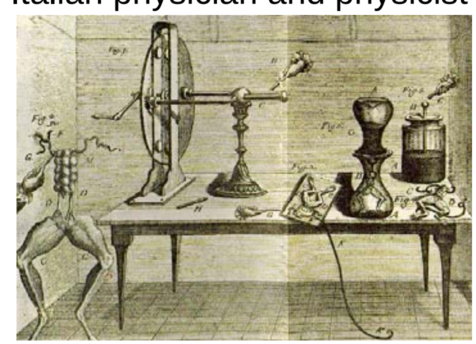


$$\mathrm{CTR} = \frac{I_c}{I_F} \times 100$$

Current Transfer Ratio

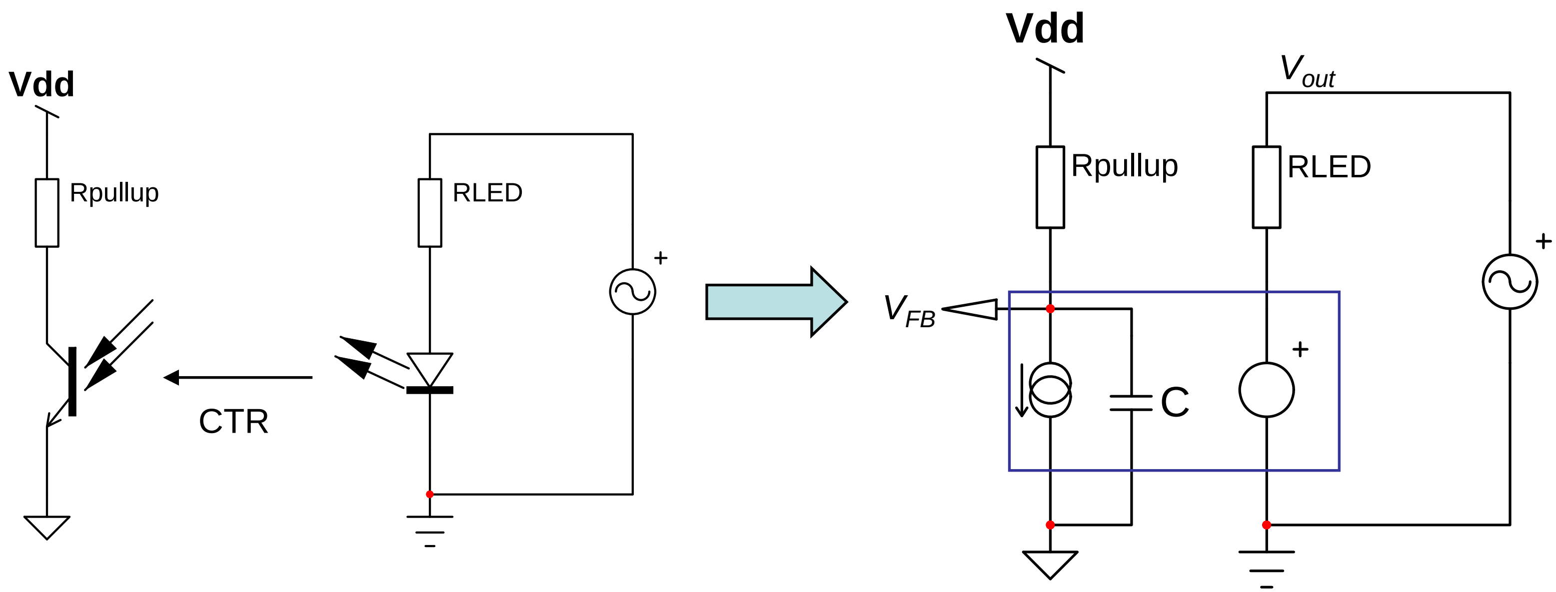
French specimen

Luigi Galvani, 1737-1798
Italian physician and physicist



The Internal Pole should be Known

- The photons are collected by a collector-base area.
- This area offers a large parasitic capacitance: opto pole!



$$\frac{V_{FB}(s)}{V_{out}(s)} = -\frac{R_{pullup}\mathrm{CTR}}{R_{LED}} \frac{1}{1+sR_{pullup}C} \longrightarrow$$

If f_p is above 5 times f_c, its effect is negligible
If f_p is close to f_c, phase margin degradation

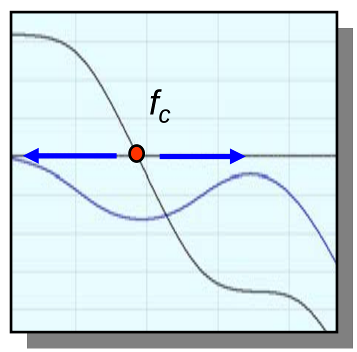
Assess the CTR Variations

- ❑ CTR changes with the operating current!
- ❑ Try to select collector bias currents around 2-5 mA

Current Transfer Ratio (I_C/I_F at V_{CE}=5.0 V) **and Collector-emitter Leakage Current**

Parameter	**-1**	**-2**	**-3**	**-4**	**-12**	**-23**	**-34**	**-13**	**-24**	**-14**	**Unit**
I_C/I_F (I_F=10 mA)	40–80	63–125	100–200	160–320	40–125	63–200	100–320	40–200	63–320	40–320	%
I_C/I_F (I_F=1.0 mA)	30(>13)	45(>22)	70(>34)	90(>56)	30(>13)	45(>22)	70(>34)	30(>13)	45(>22)	30(>13)	
Collector-Emitter Leakage Current, I_{CEO}, V_{CE}=10 V	2.0(≤50)	2.0(≤50)	5.0(≤100)	5.0(≤100)	2.0(≤50)	5.0(≤100)	5.0(≤100)	5.0(≤100)	5.0(≤100)	5.0(≤100)	nA

CTR between 0.63 and 1.25
Normalized to 1 (0 dB)
0.63 gives –4 dB
1.25 gives +2 dB

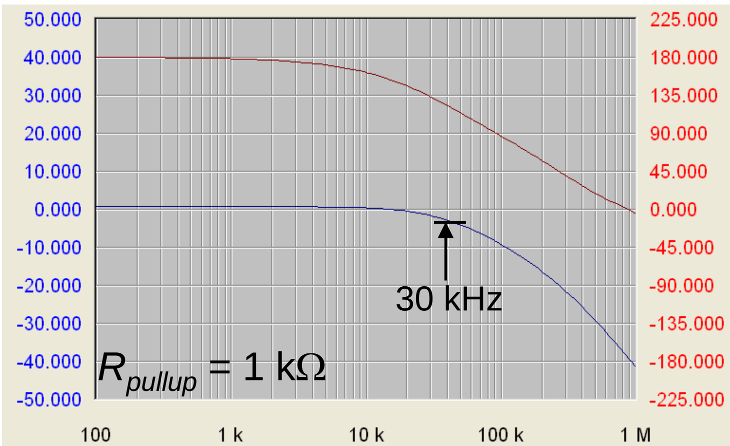


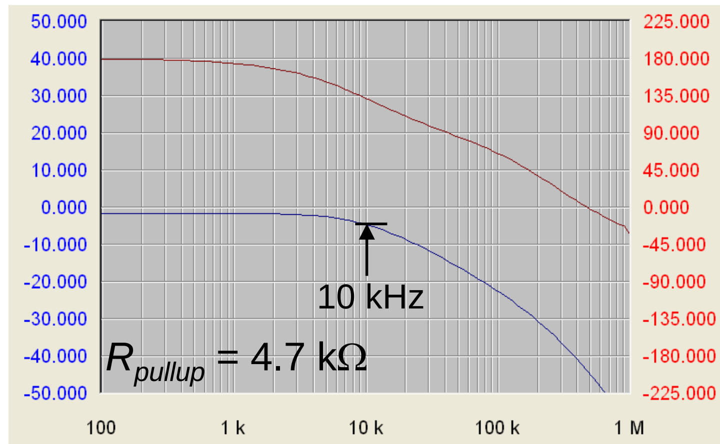
Watch out for crossover frequency changes and phase margin at CTR extremes!

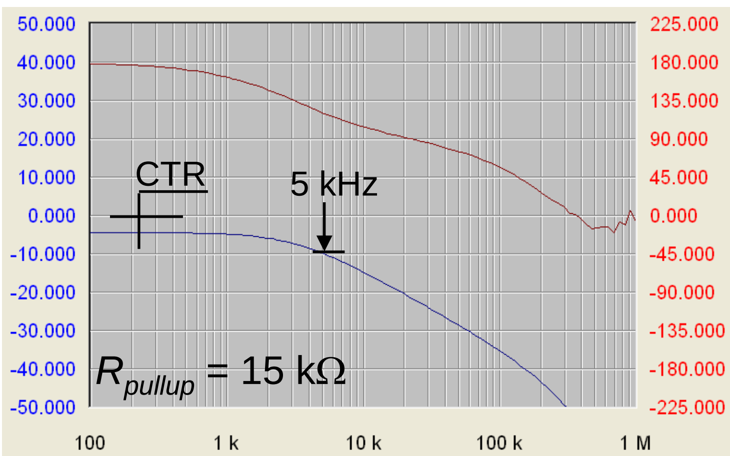
SFH-615

Changing the Pullup Affects the Pole Position

- ❑ A low pullup resistor offers better bandwidth!







- ❑ Changing the bias point affects the CTR

$$\frac{V_{FB}(s)}{V_{out}(s)} = -\frac{R_{pullup}}{R_{LED}}\mathrm{CTR}$$

- ❑ If $R_{pullup} = R_{LED}$, then $|G_0|$ = 0 dB…?

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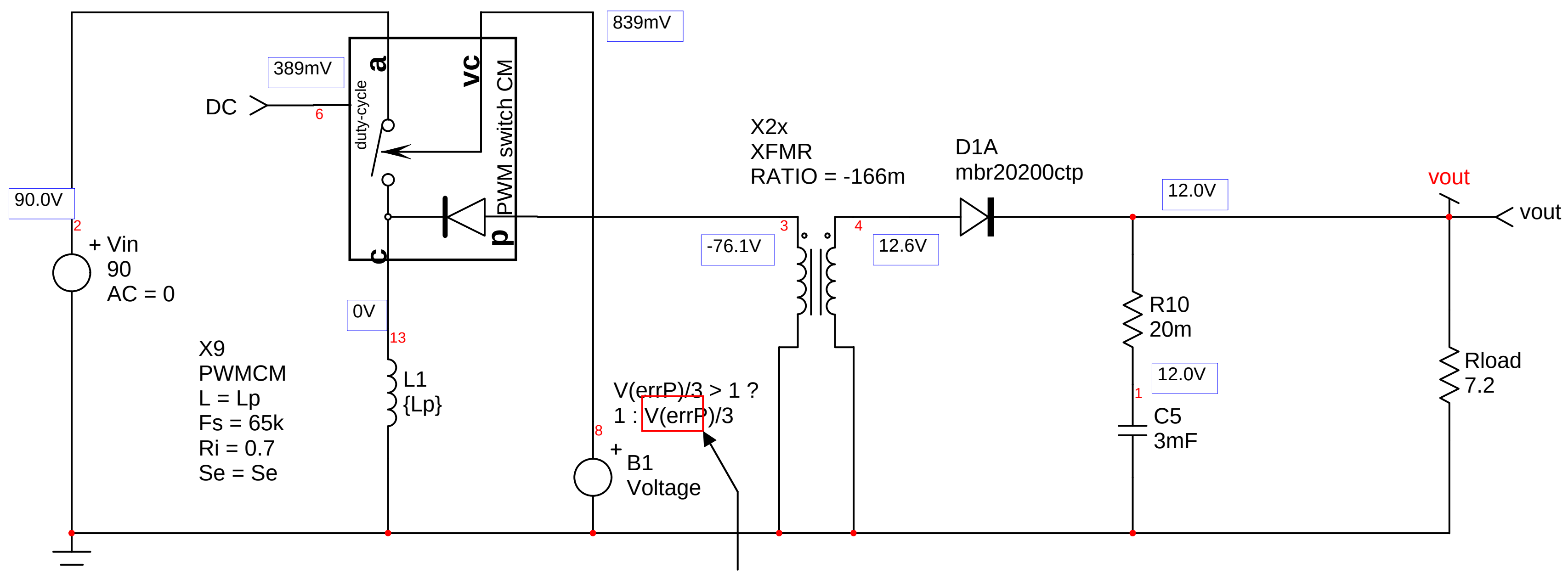
Stabilizing a DCM Flyback Converter

- We want to stabilize a 20 W DCM adapter
- V_{in} = 85 to 265 Vrms
- V_{out} = 12 V/1.7 A
- F_{sw} = 60 kHz
- Selected controller: NCP1216

1. Obtain a power stage open-loop Bode plot, *H(s)*
2. Look for gain and phase values at cross over
3. Compensate gain and build phase at cross over, *G(s)*
4. Run a loop gain analysis to check for margins, *T(s)*
5. Test transient responses in various conditions

Stabilizing a DCM Flyback Converter

- Capture a SPICE schematic with an averaged model

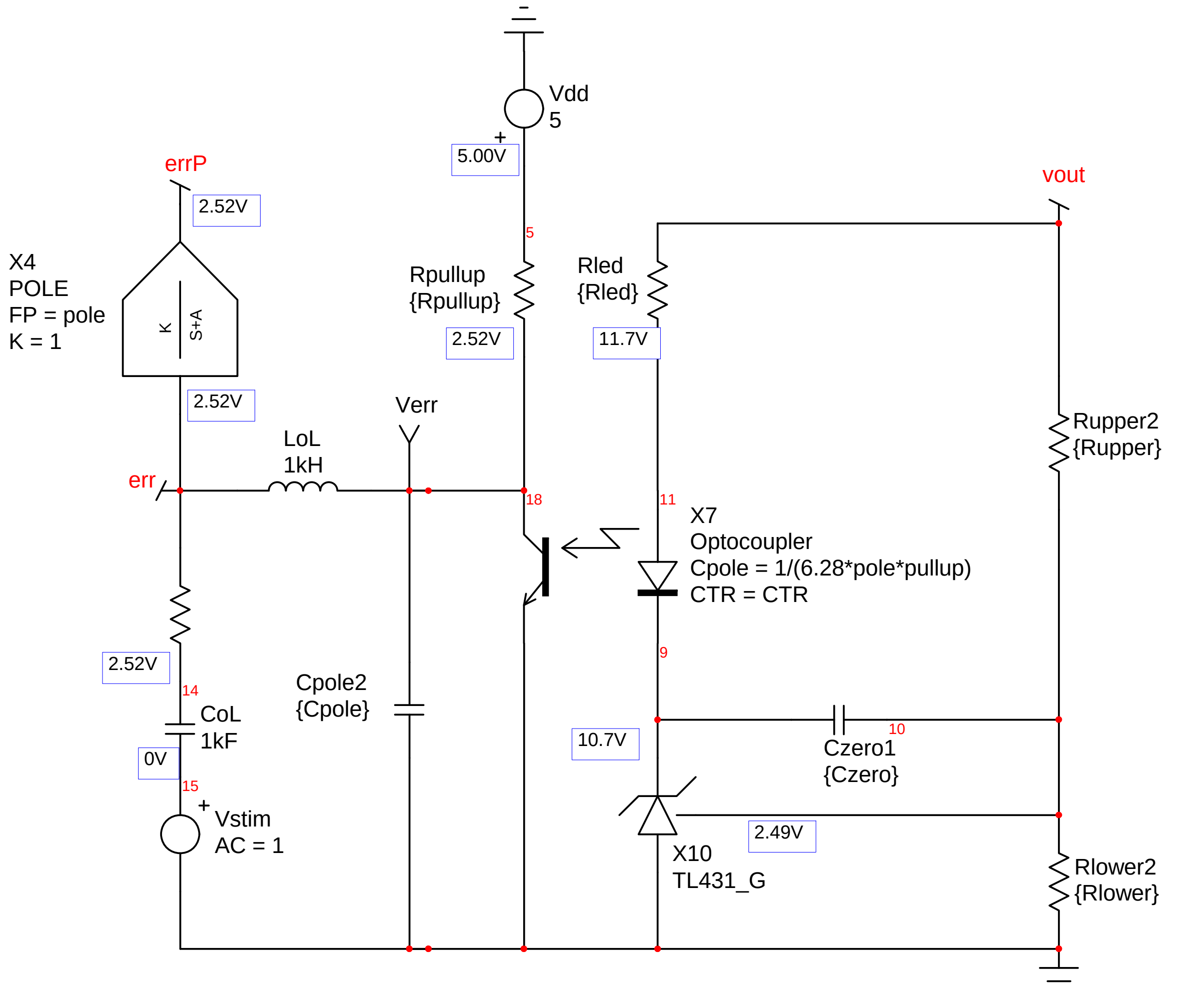


Coming from FB

- Look for the bias points values: V_{out} = 12 V, ok

Stabilizing a DCM Flyback Converter

- The feedback portion includes the optocoupler pole



parameters

Vout=12
Ibridge=250u
Rlower=2.5/Ibridge
Rupper=(Vout-2.5)/Ibridge
Lp=450u
Se=100m
fc=1k
pm=60
Gfc=-24
pfc=-77

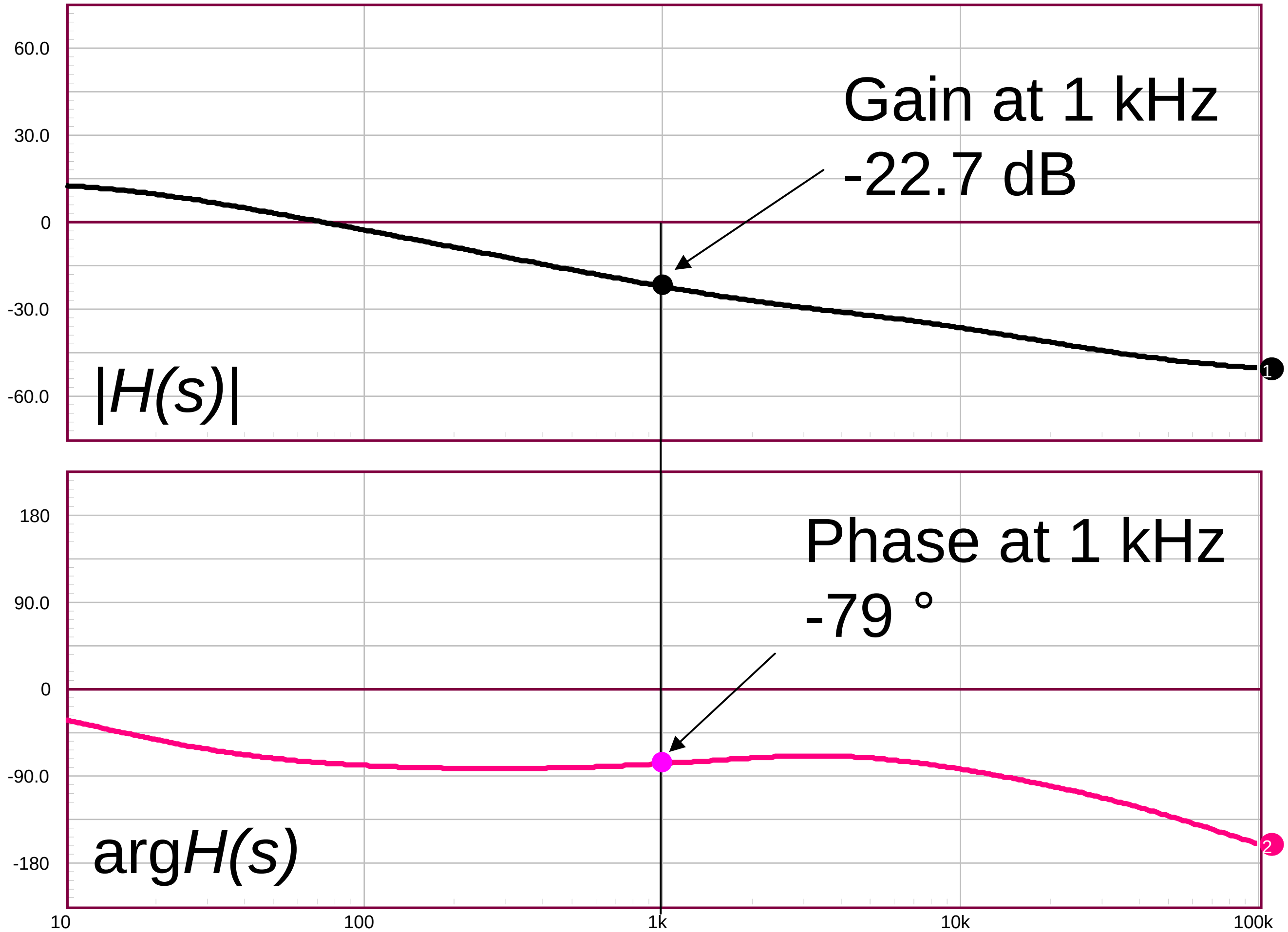
from Bode

G=10^(-Gfc/20)
boost=pm-(pfc)-90
pi=3.14159
K=tan((boost/2+45)*pi/180)
Fzero=fc/k
Fpole=k*fc
Rpullup=20k
RLED=CTR*Rpullup/G
Czero=1/(2*pi*Fzero*Rupper)
Cpole=1/(2*pi*Fpole*Rpullup)
CTR=1.5
Pole=6k

Automated compensation

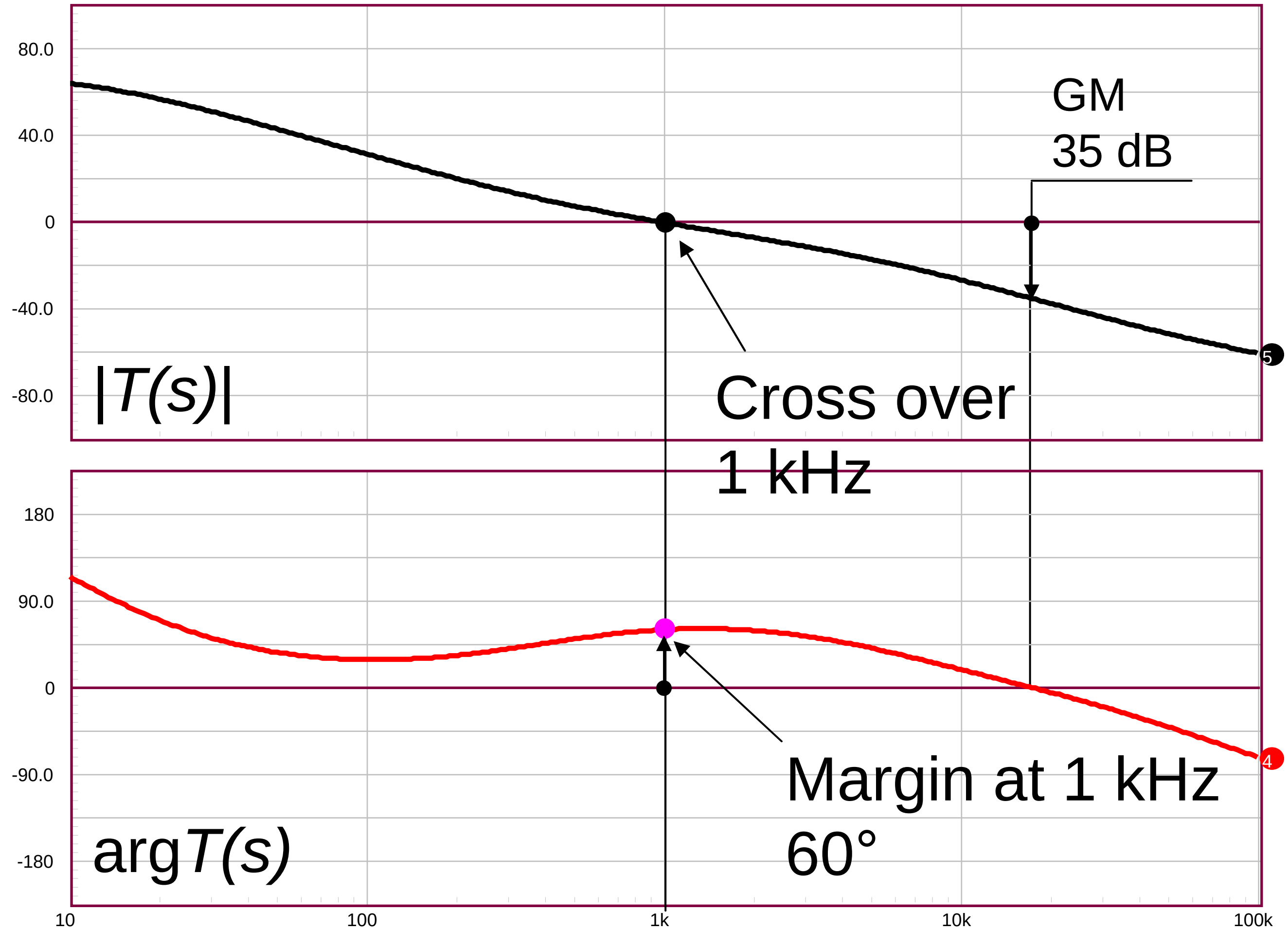
Stabilizing a DCM Flyback Converter

- Get the open-loop power stage transfer function, *H(s)*



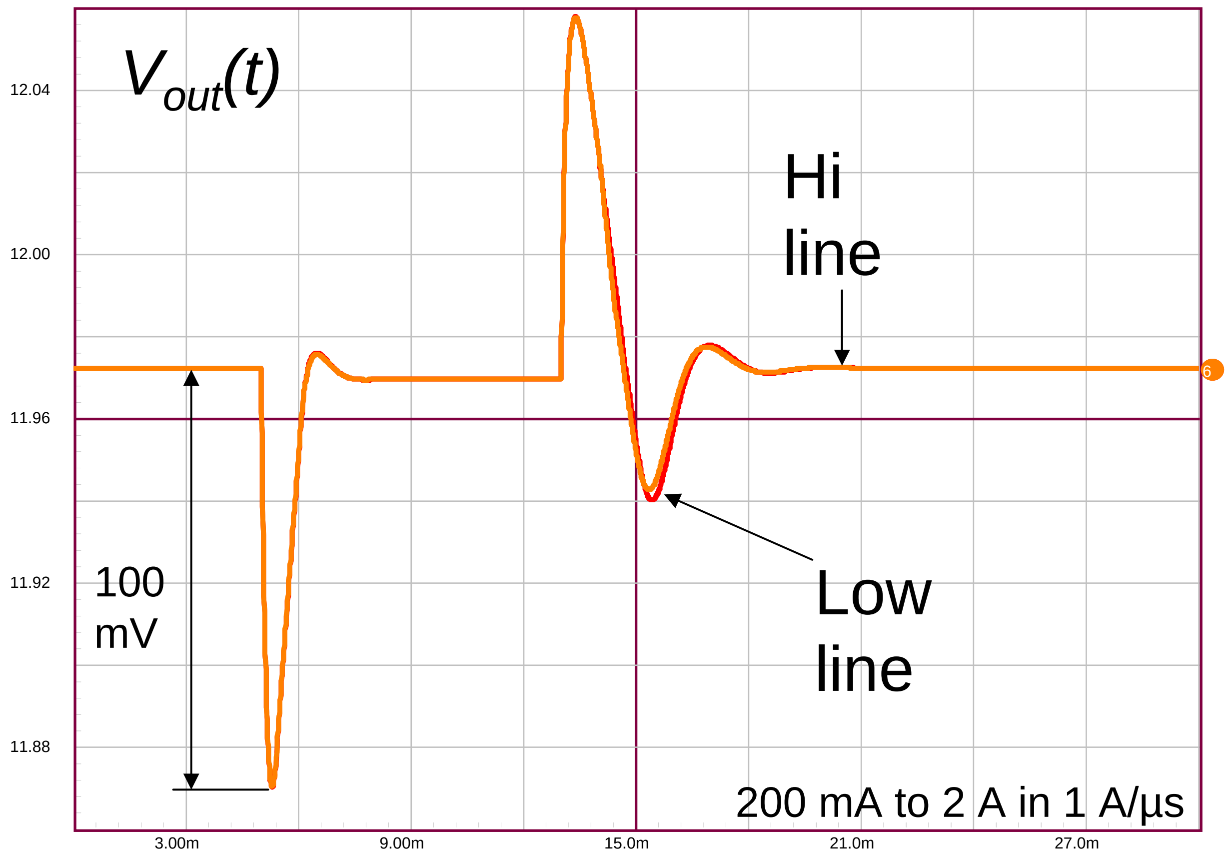
Stabilizing a DCM Flyback Converter

- Boost the gain by +22 dB, boost the phase at f_c



Stabilizing a DCM Flyback Converter

- Test the response at both input levels, 90 and 265 Vrms
- Sweep ESR values and check margins again



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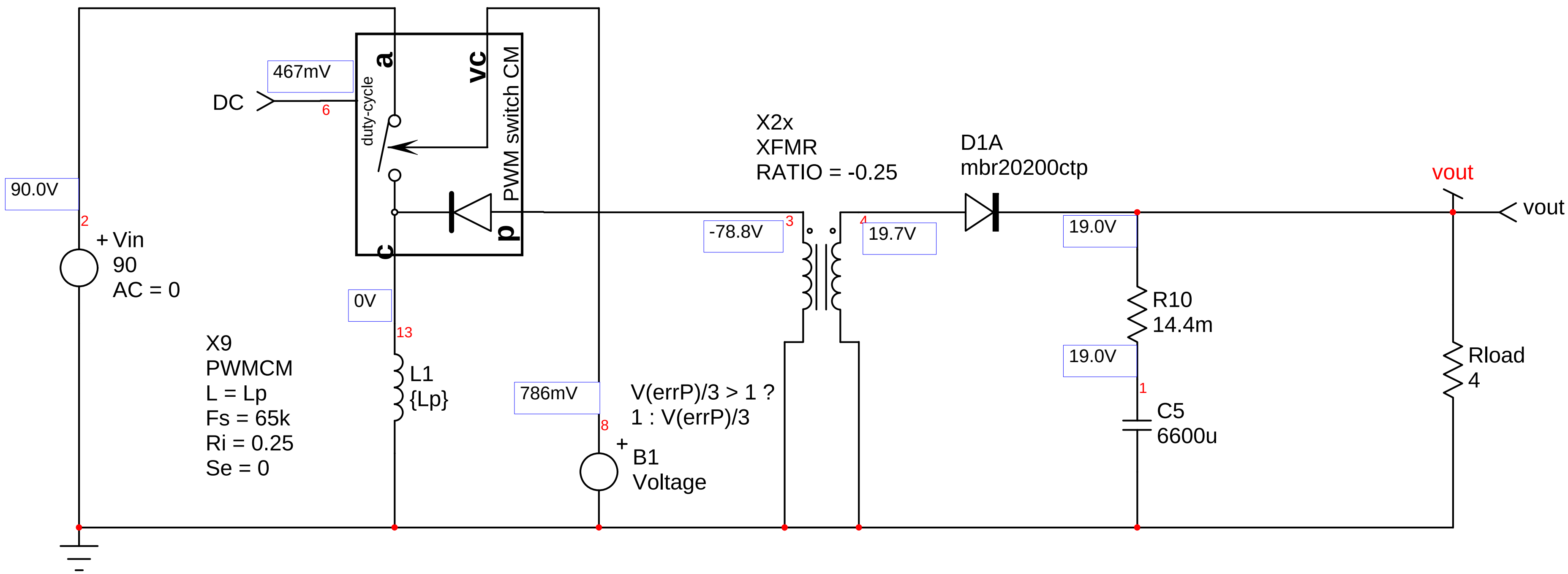
Stabilizing a CCM Flyback Converter

- We want to stabilize a 90 W CCM adapter
- V_{in} = 85 to 265 Vrms
- V_{out} = 19 V/4.8 A
- F_{sw} = 60 kHz
- Selected controller: NCP1230

1. Obtain a power stage open-loop Bode plot, *H(s)*
2. Look for gain and phase values at cross over
3. Compensate gain and build phase at cross over, *G(s)*
4. Run a loop gain analysis to check for margins, *T(s)*
5. Test transient responses in various conditions

Stabilizing a CCM Flyback Converter

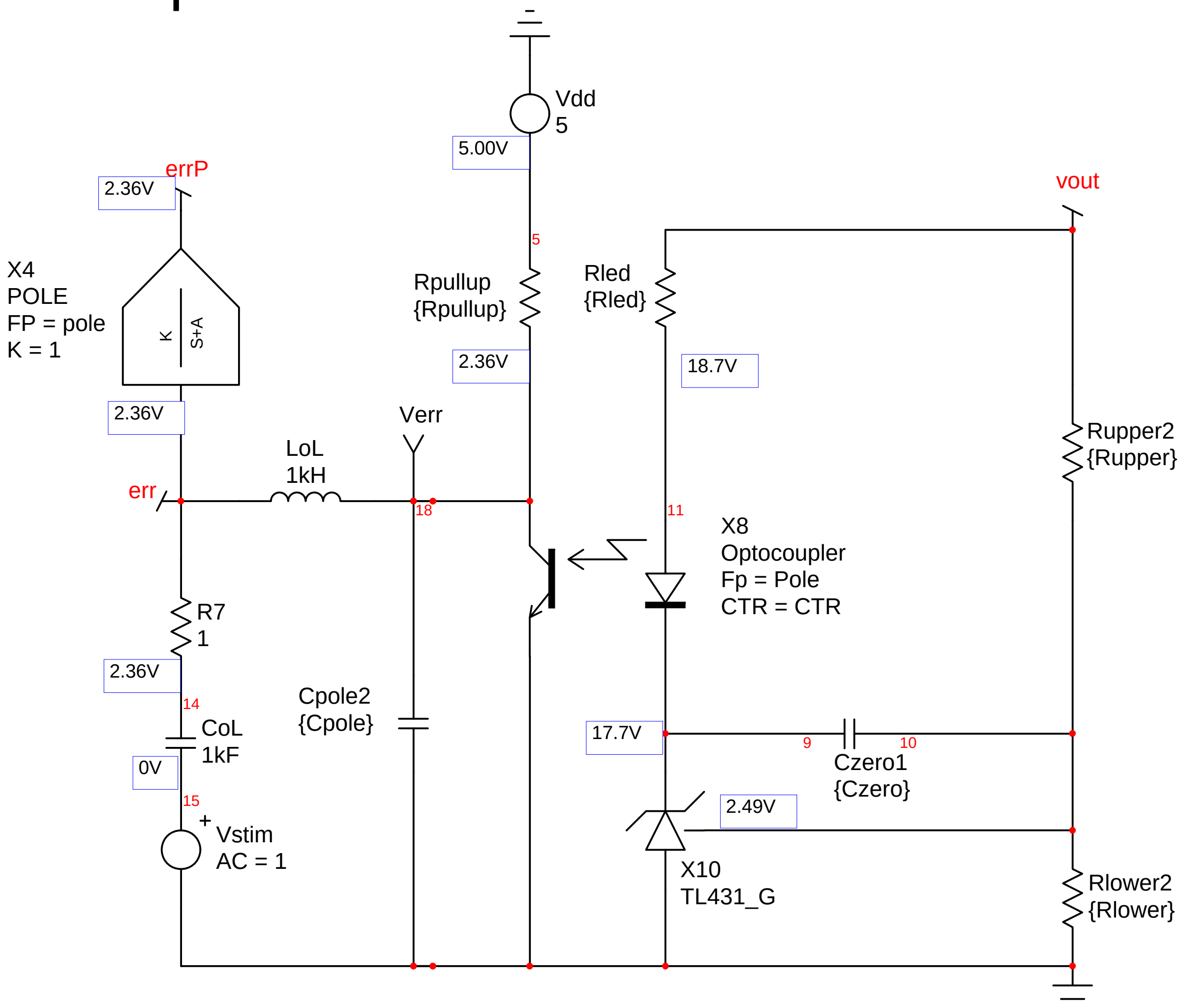
- ❑ Capture a SPICE schematic with an averaged model



- ❑ Look for the bias points values: V_{out} = 19 V, ok
- ❑ $V_{setpoint}$ < 1 V, enough margin on current sense

Stabilizing a CCM Flyback Converter

- Capture a SPICE schematic with an averaged model



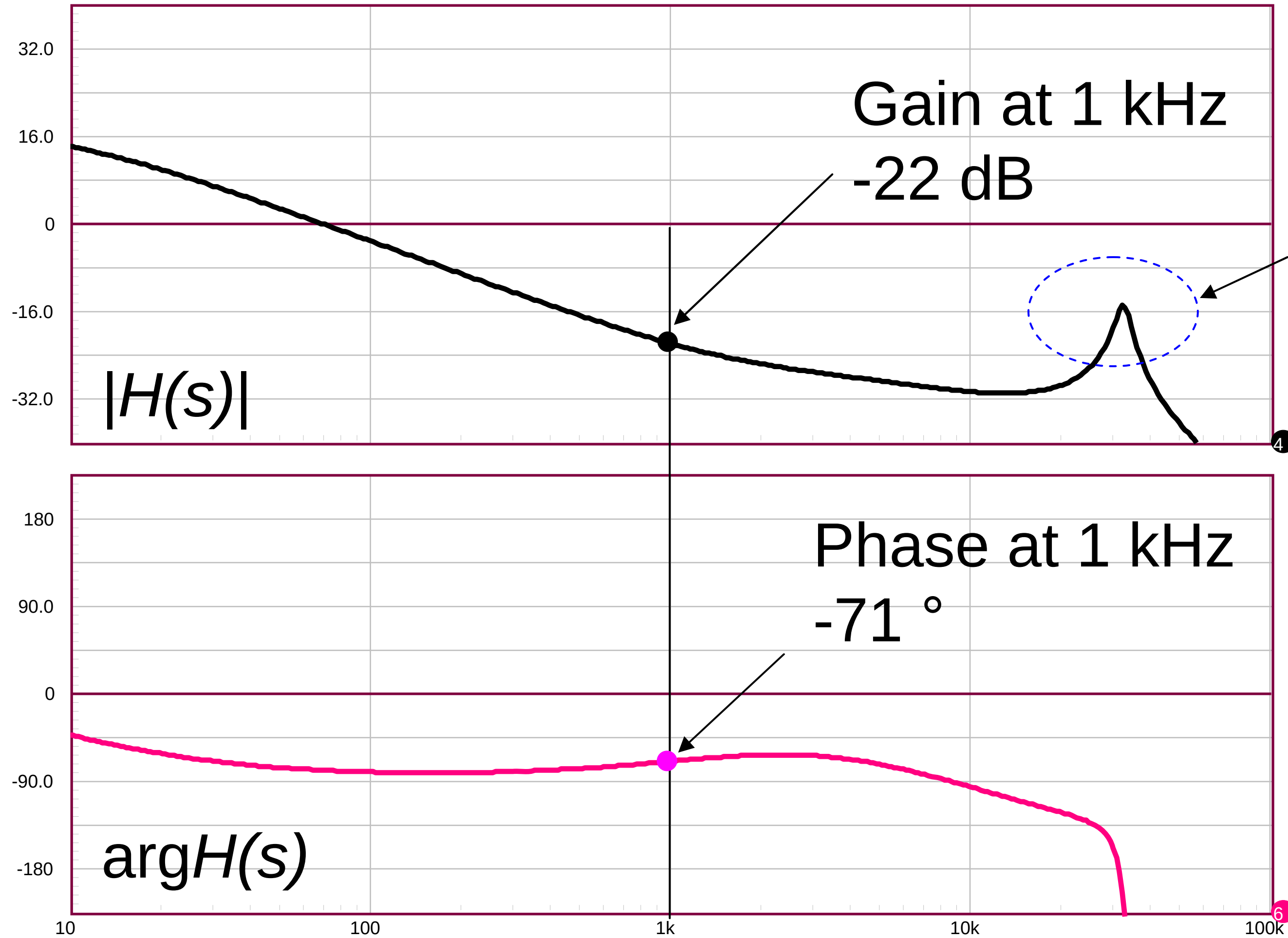
parameters

Vout=19
Ibridge=250u
Rlower=2.5/Ibridge
Rupper=(Vout-2.5)/Ibridge
Lp=350u
Se=20k
fc=1k
pm=60
Gfc=-22
pfc=-71
G=10^(-Gfc/20)
boost=pm-(pfc)-90
pi=3.14159
K=tan((boost/2+45)*pi/180)
Fzero=fc/k
Fpole=k*fc
Rpullup=20k
RLED=CTR*Rpullup/G
Czero=1/(2*pi*Fzero*Rupper)
Cpole=1/(2*pi*Fpole*Rpullup)
CTR=1.5
Pole=6k

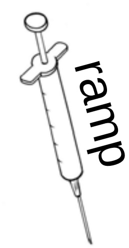
from Bode

Stabilizing a CCM Flyback Converter

- Capture a SPICE schematic with an averaged model



Sub harmonic poles



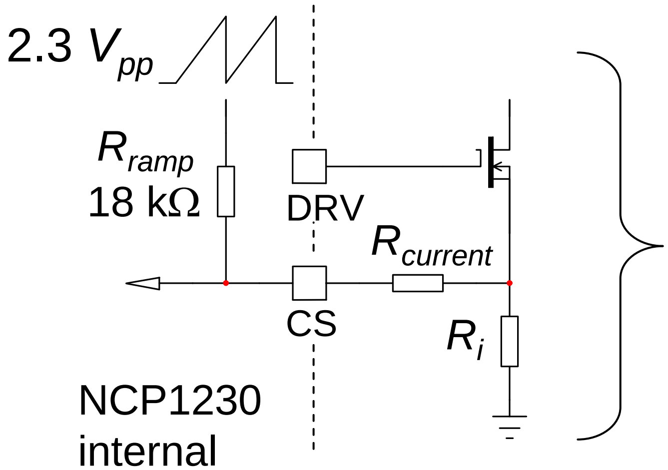
Inject ramp compensation

Stabilizing a CCM Flyback Converter

- The easiest way to damp the poles:
- Calculate the equivalent quality coefficient at $F_{sw}/2$
- Calculate the external ramp to make Q less than 1

$$Q=\frac{1}{\pi\left(D'\frac{S_e}{S_n}+\frac{1}{2}-D\right)}=\frac{1}{3.14\times(0.5-0.46)}=8$$

$$S_e=\frac{S_n}{D'}\left(\frac{1}{\pi}-0.5+D\right)=\frac{V_{in}R_i}{L_pD'}\left(\frac{1}{\pi}-0.5+D\right)=\frac{90\times 0.25}{320u\times(1-0.46)}\left(\frac{1}{3.14}-0.5+0.46\right)=36\,kV/s$$



$$M_r=\frac{S_e}{S_n}=\frac{36k}{70k}=51\%$$

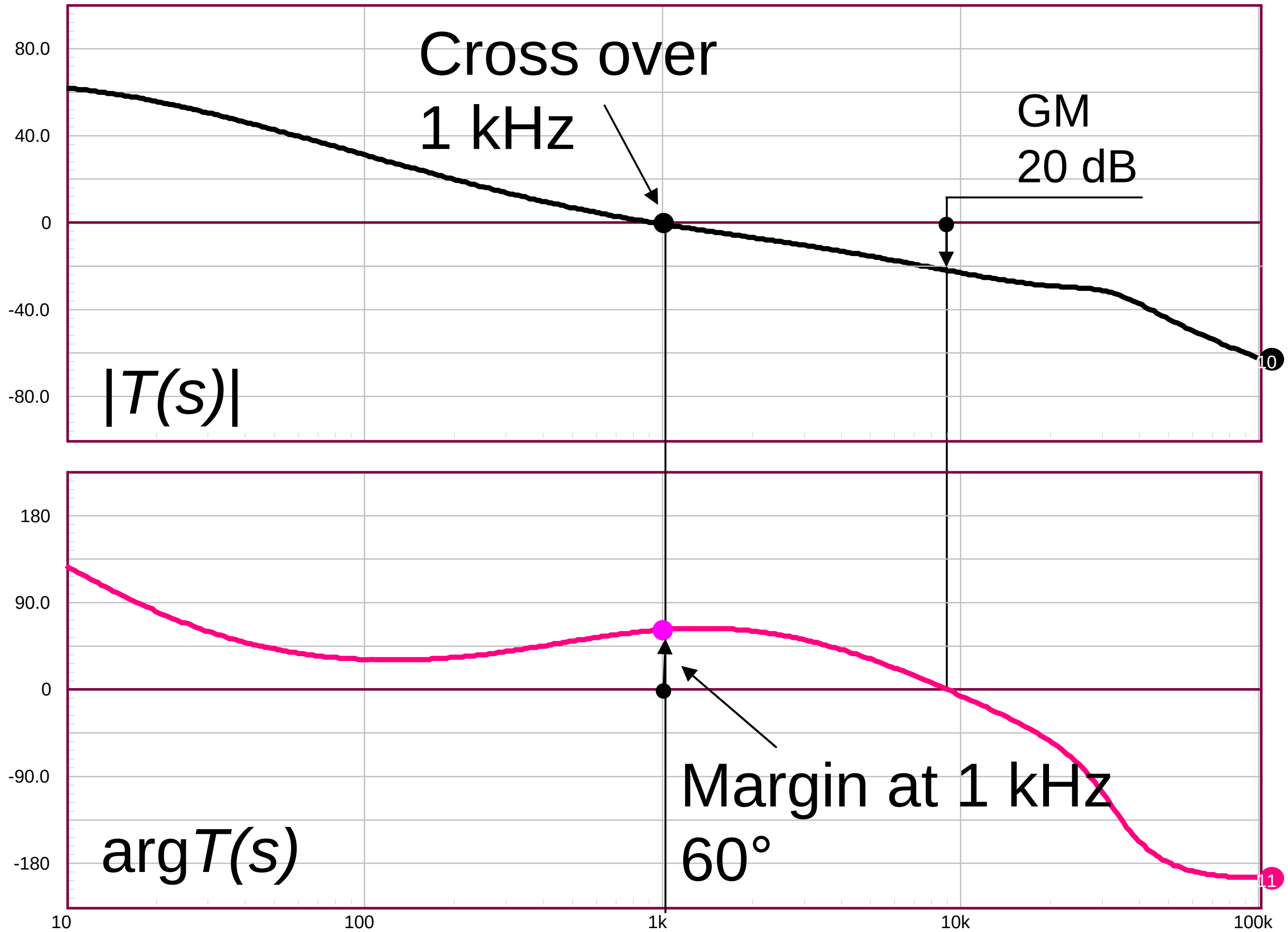
On-time slope $\frac{V_{in}R_i}{L_p}$

$$S_{ramp}=\frac{2.3}{15u}=153\,kV/s$$

$$R_{current}=\frac{M_rS_nR_{ramp}}{S_{ramp}}=\frac{0.51\times 70k\times 18k}{153k}=4.1\,k\Omega$$

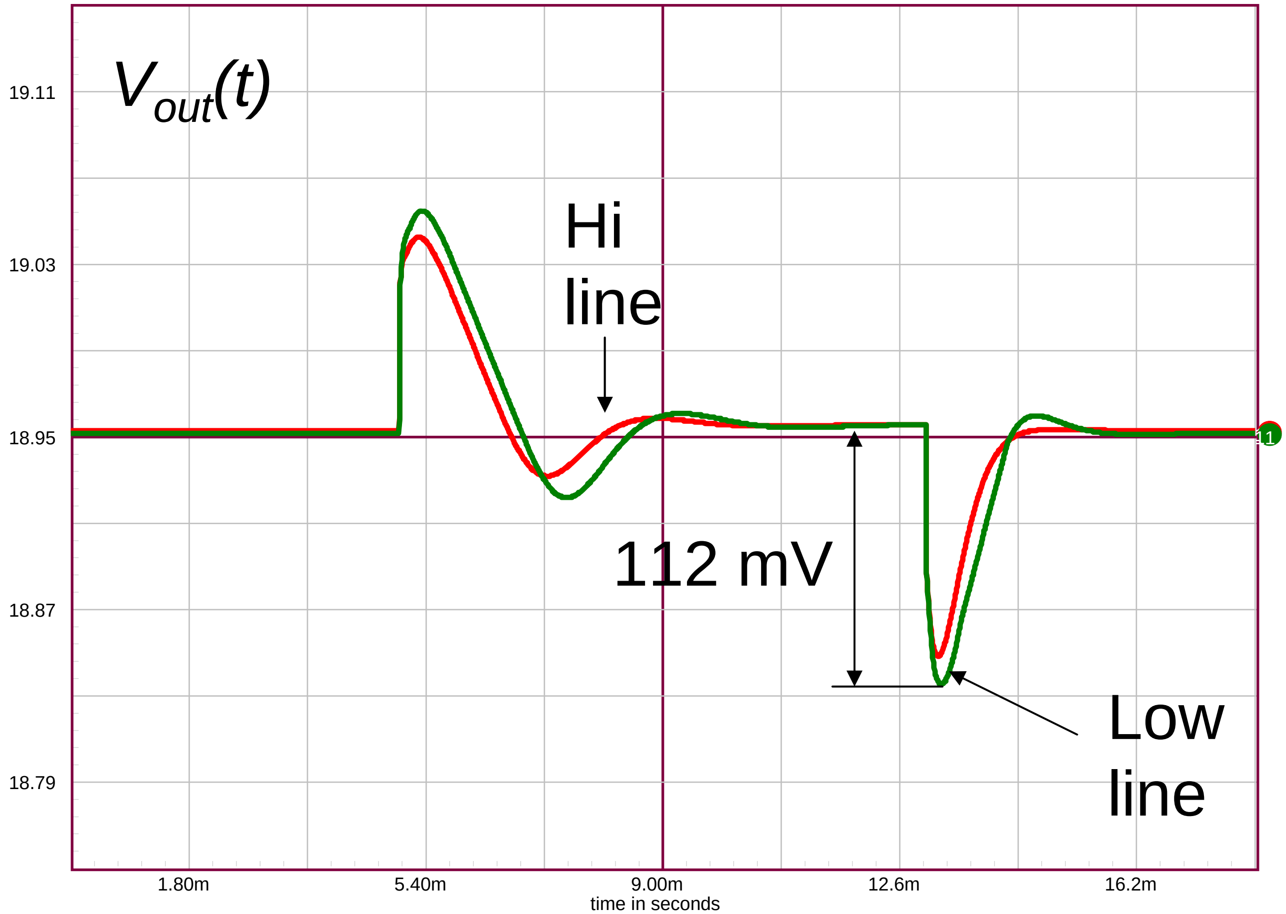
Stabilizing a CCM Flyback Converter

- Boost the gain by +22 dB, boost the phase at f_c



Stabilizing a CCM Flyback Converter

- Test the response at both input levels, 90 and 265 Vrms
- Sweep ESR values and check margins again



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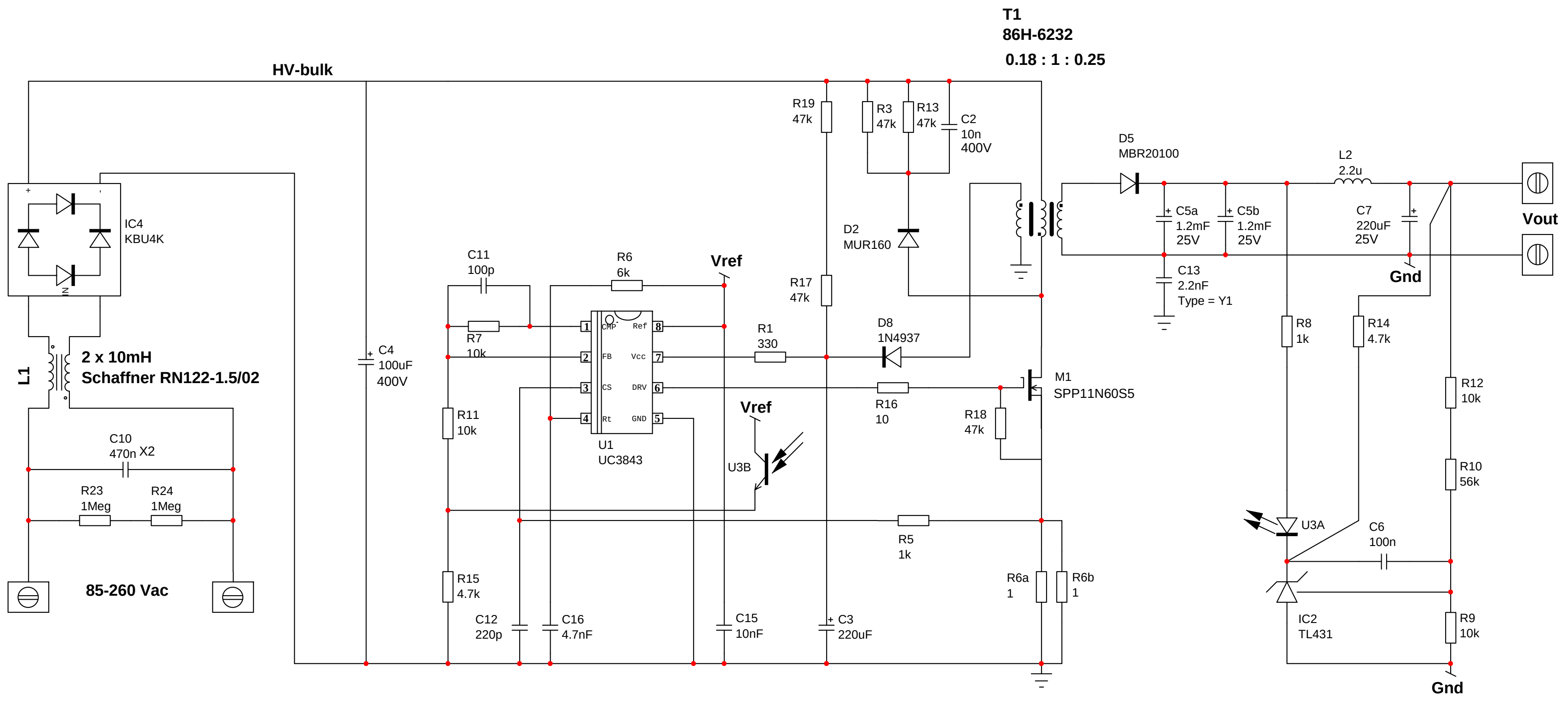
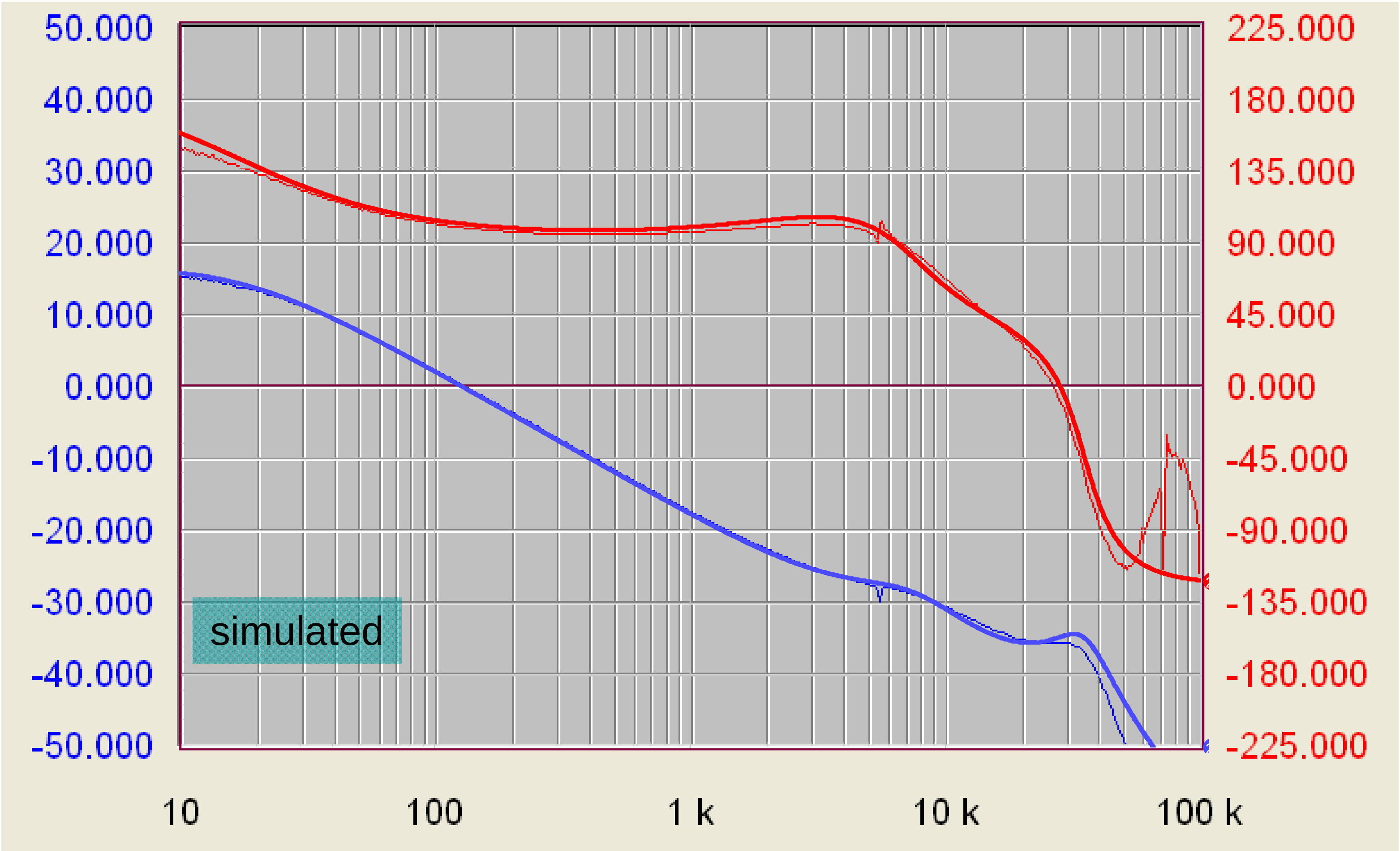
Testing a UC3843 Converter

- A 19 V/3 A converter is built around an UC3843
- The converter operates in CCM or DCM

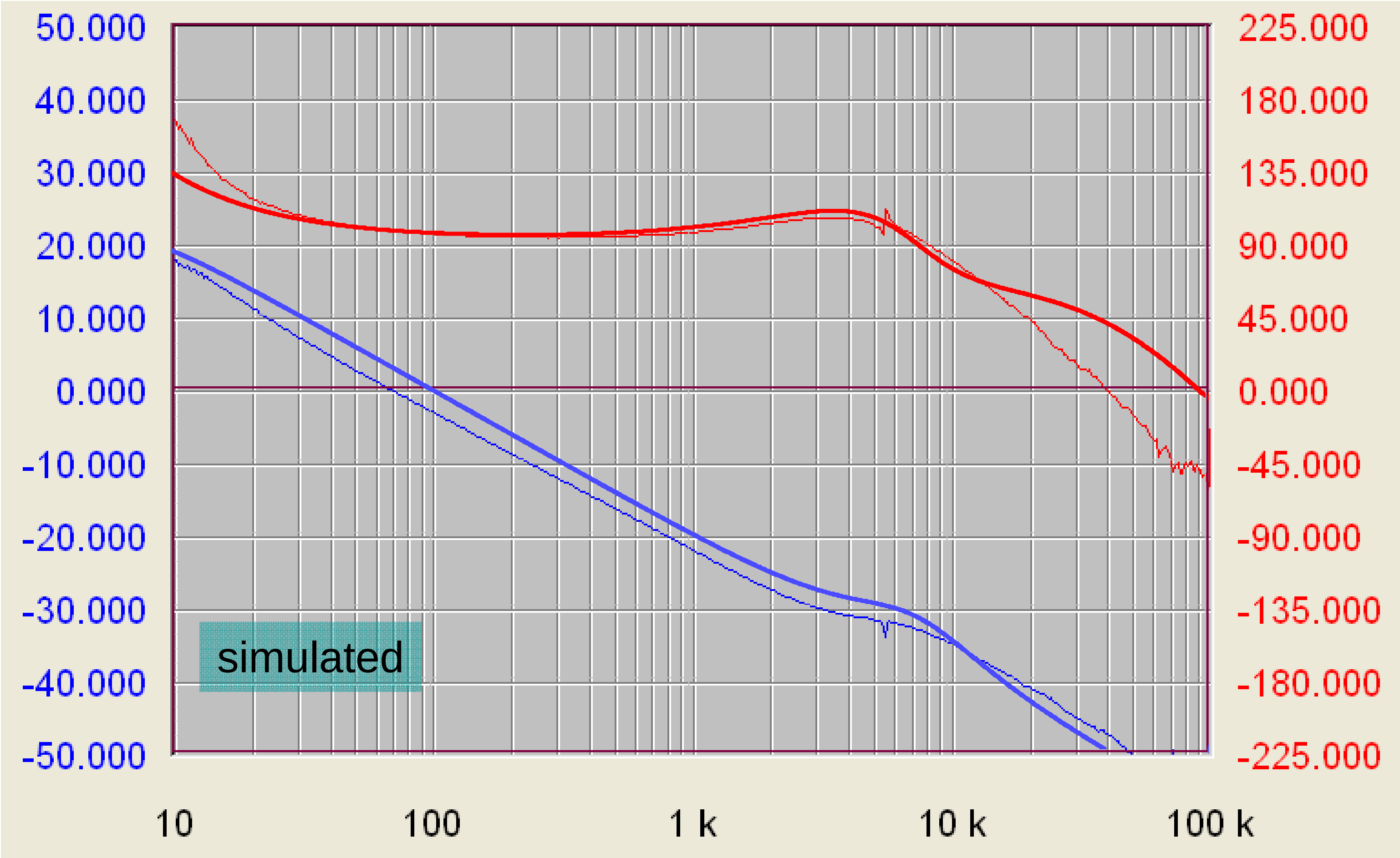


Full Load Leads to CCM Operation



CCM operation, R_{load} = 6.3 Ω

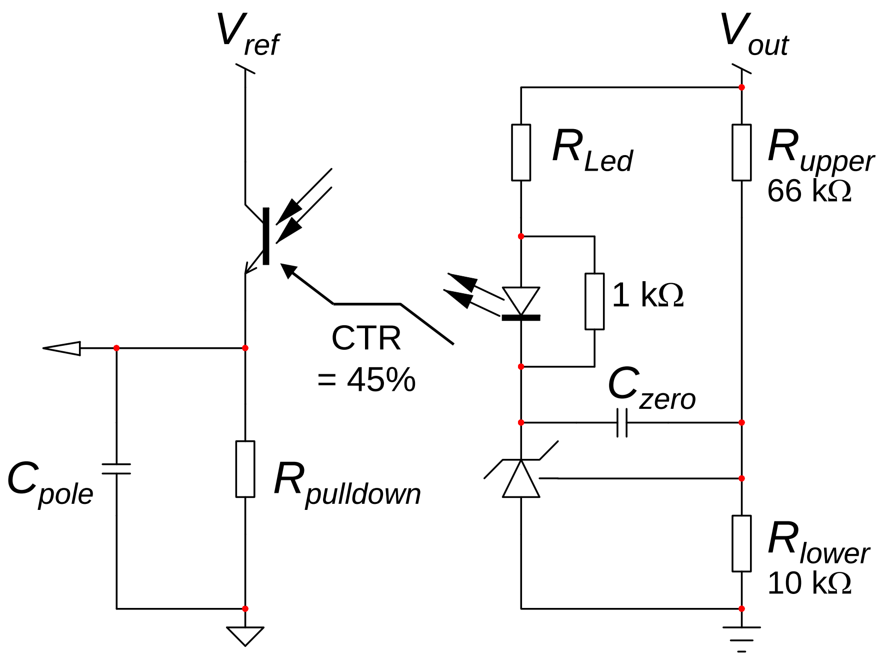
Reduce the Load to Enter in DCM



DCM operation, R_{load} = 20 Ω

From the Open-Loop Bode Plot, Compensate

- The TL431 is tailored to pass a 1 kHz bandwidth



Calculate mid-band gain: +18 dB

$$R_{LED} = \frac{R_{pullup}\mathrm{CTR}}{10^{\frac{18}{20}}} = \frac{4.7k \times 0.45}{7.94} = 266\ \Omega$$

We place a zero at 300 Hz:

$$C_{zero} = \frac{1}{2\pi f_{zero} R_{upper}} = \frac{1}{6.28 \times 300 \times 66k} = 8\ nF$$

We place a pole at 3.3 kHz:

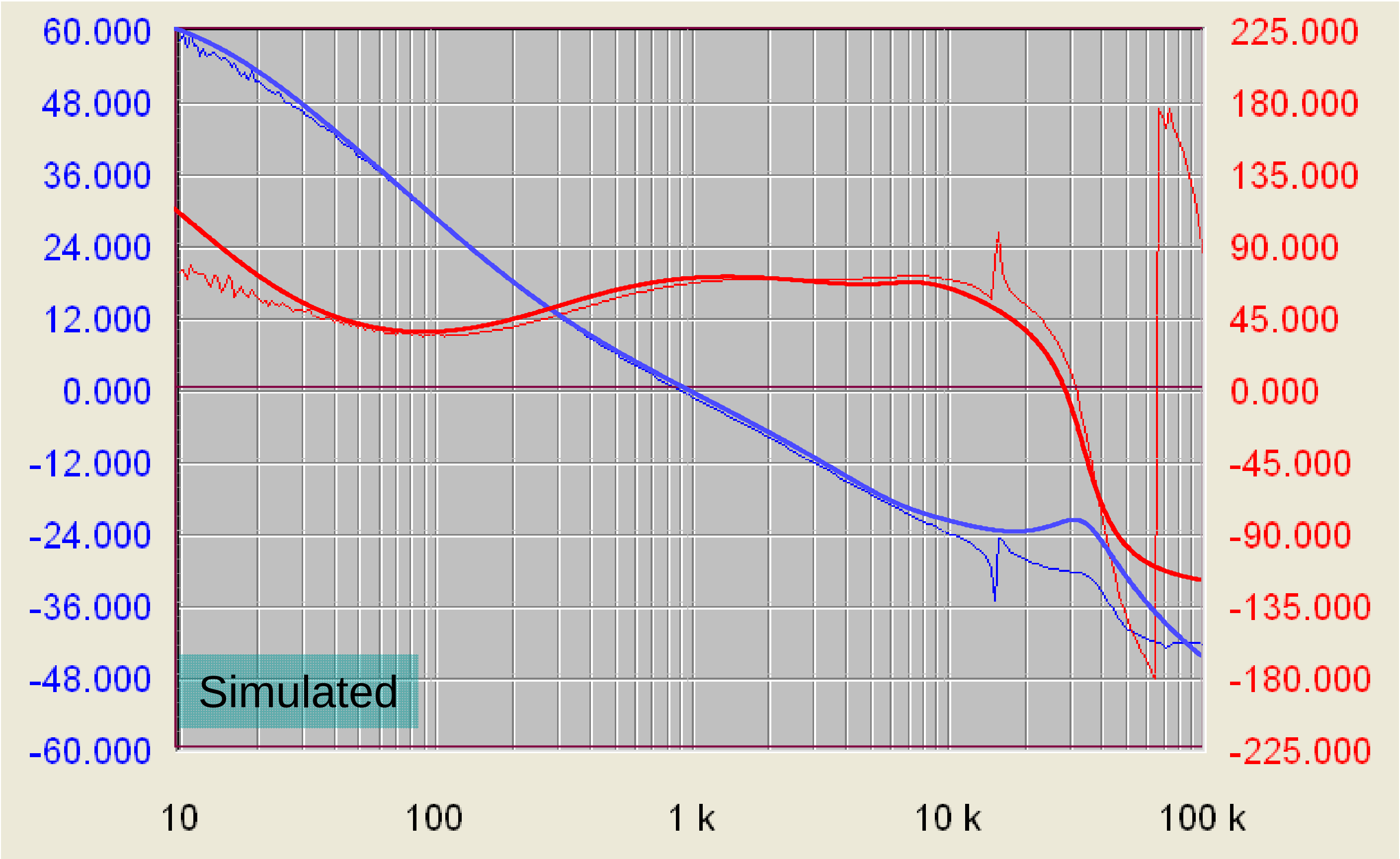
$$C_{pole} = \frac{1}{2\pi f_{pole} R_{pulldown}} = \frac{1}{6.28 \times 3.3k \times 4.7k} = 10\ nF$$

k factor method

“Switch-Mode Power Supplies: SPICE Simulations and Practical Designs”, McGraw-Hill

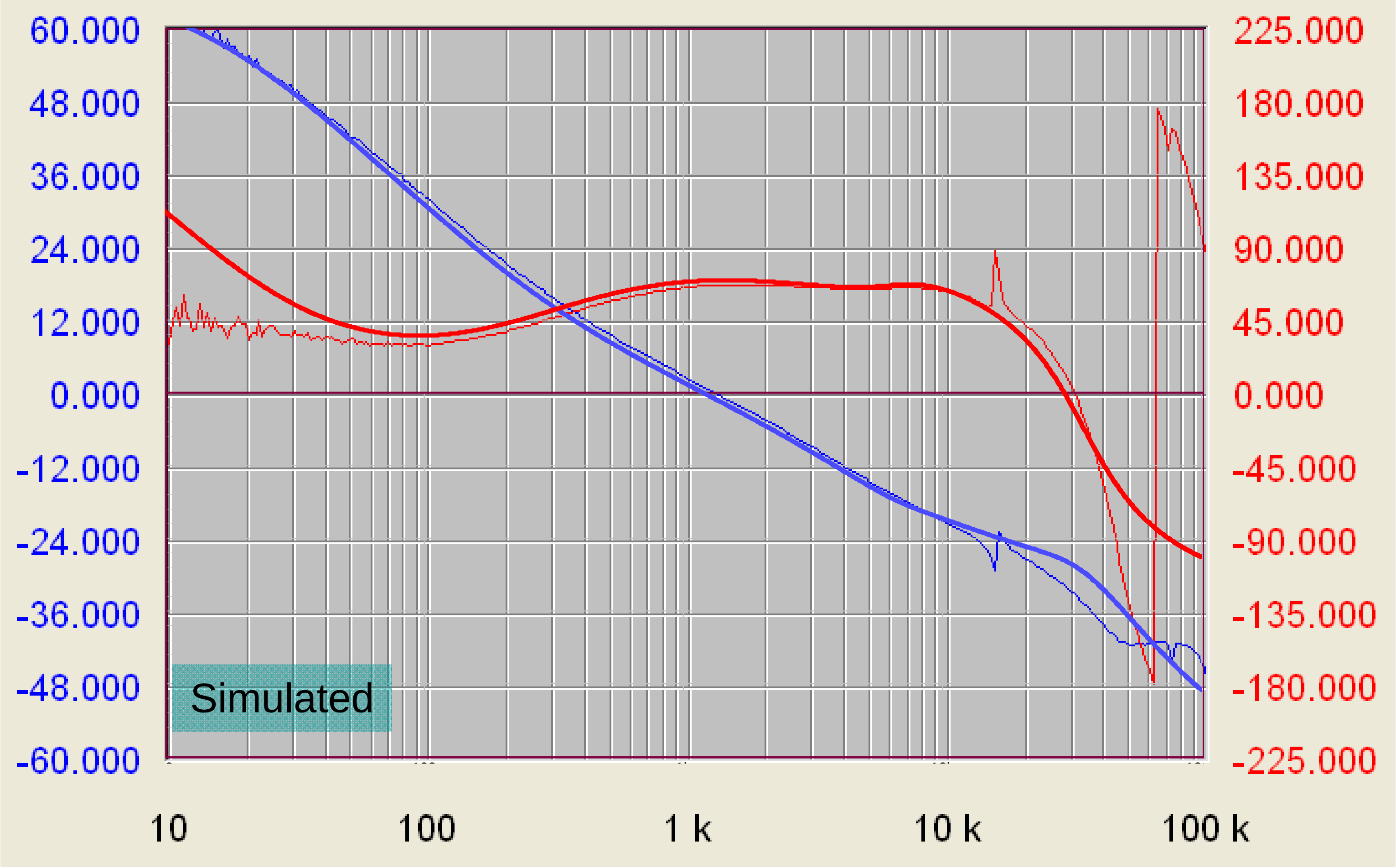
Verify in the Lab. the Open-Loop Gain

- Sweep extreme voltages and loads as well!



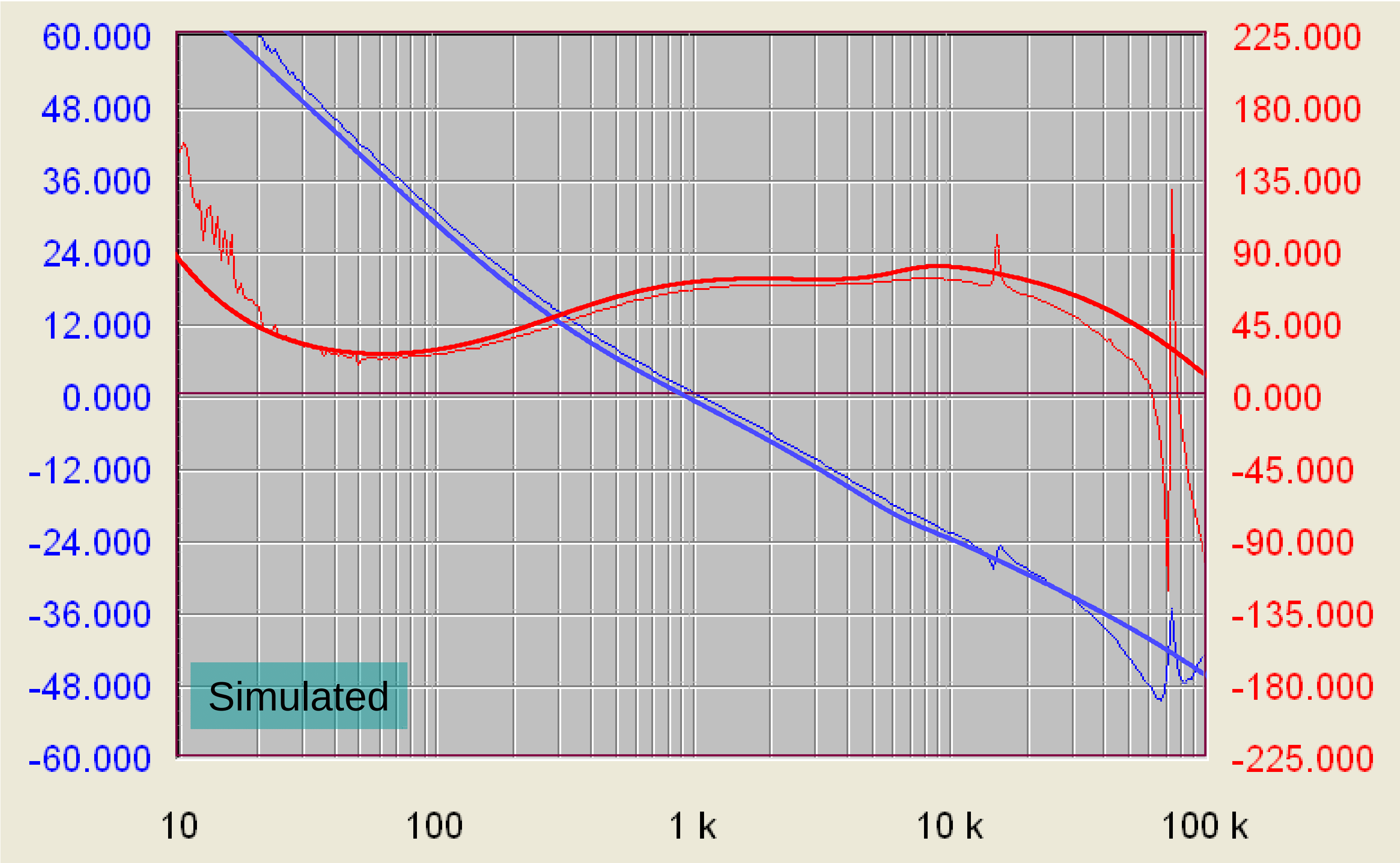
CCM operation, R_{load} = 6.3 Ω, V_{in} = 150 Vdc

Verify in the Lab. the Open-Loop Gain



CCM operation, R_{load} = 6.3 Ω, V_{in} = 330 Vdc

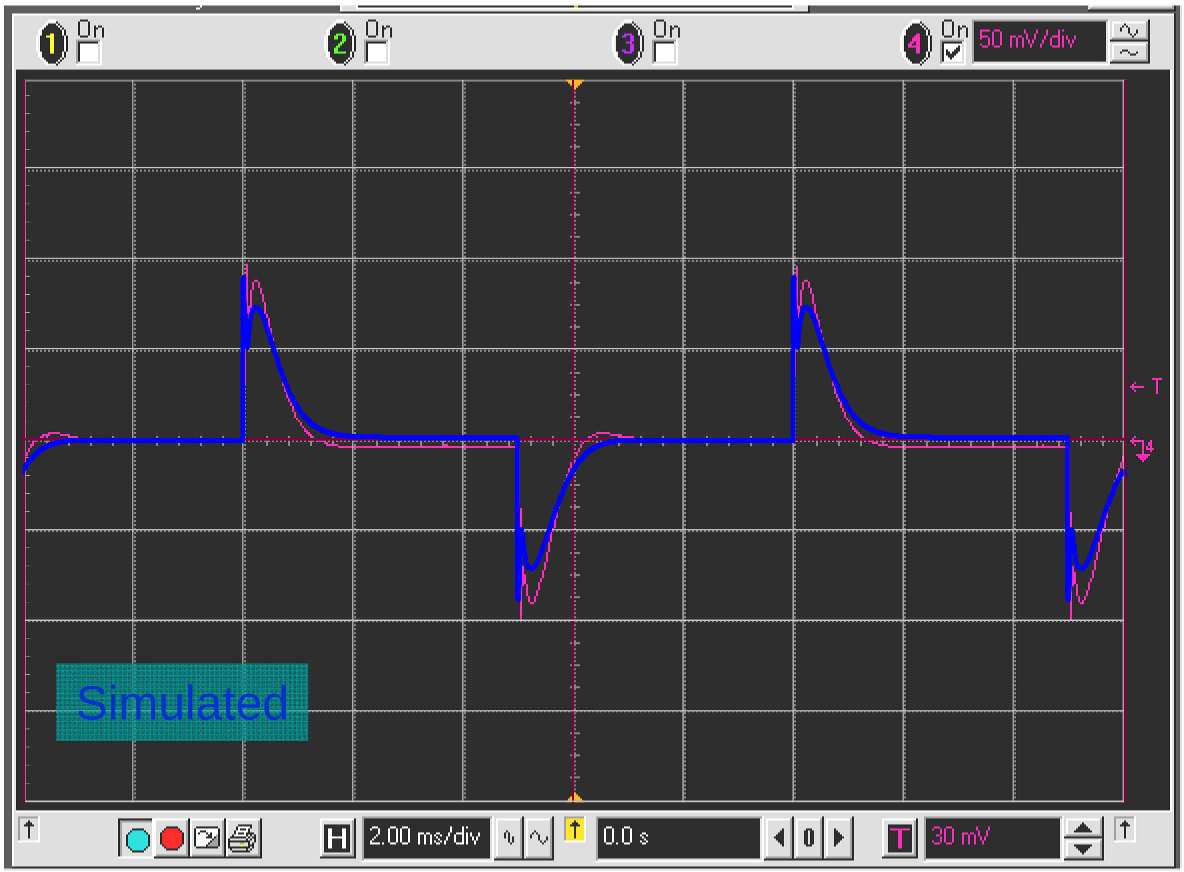
Verify in the Lab. the Open-Loop Gain



DCM operation, R_{load} = 20 Ω, V_{in} = 330 Vdc

As a Final Test, Step Load the Output

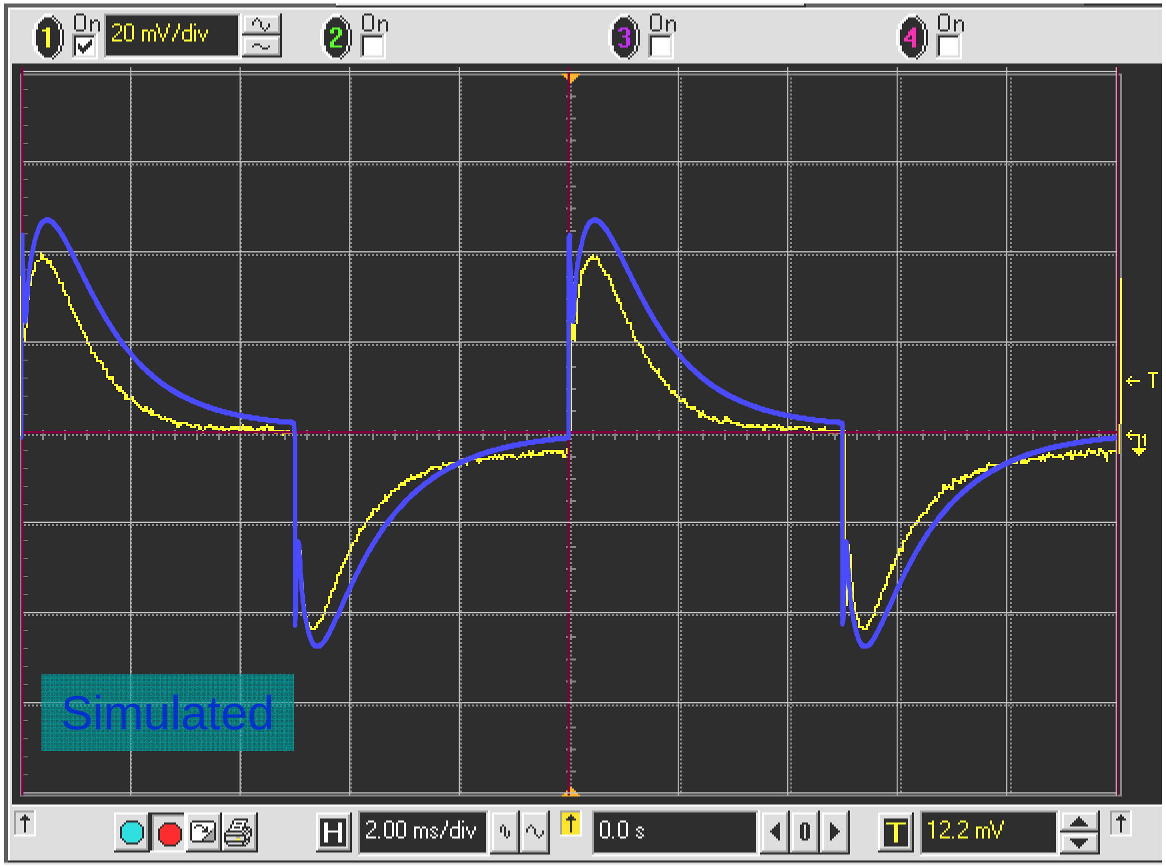
- ❑ Good agreement between curves!



V_{in} = 150 V
CCM
2 to 3 A
1 A/µs

As a final test, Step Load the Output

- ❑ DCM operation at high line is also stable



V_{in} = 330 V
DCM
0.5 to 1 A
1 A/µs

Conclusion

- DC-DC loop compensation cannot be overlooked
- It is important to understand the impact of phase margin
- The crossover frequency affects the output impedance
- Current mode CCM or DCM is ok with a TL431-based type 2
- Make sure the optocoupler is characterized, watch the pole!
- Use SPICE before going to the bench: NO trial and error!
- Once the simulation is stable, build the prototype
- Simulations and laboratory debug: the success recipe!

For More Information

- View the extensive portfolio of power management products from ON Semiconductor at www.onsemi.com
- View reference designs, design notes, and other material supporting the design of highly efficient power supplies at www.onsemi.com/powersupplies