



ON Semiconductor®

The TL431 in the Control of Switching Power Supplies

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Product Applications Engineering Director

Agenda

- ❑ Feedback generalities
- ❑ The TL431 in a compensator
- ❑ Small-signal analysis of the return chain
- ❑ A type 1 implementation with the TL431
- ❑ A type 2 implementation with the TL431
- ❑ A type 3 implementation with the TL431
- ❑ Design examples
- ❑ Conclusion



Agenda

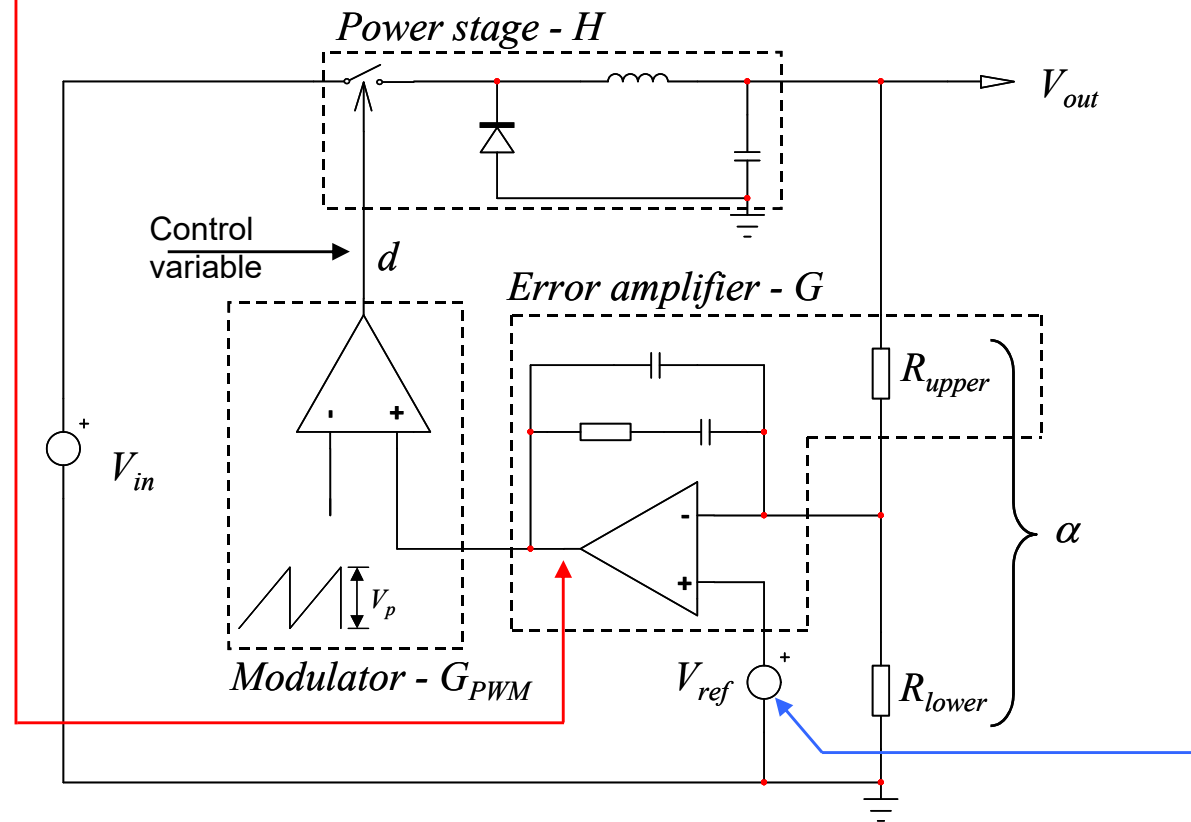
☐ **Feedback generalities**

- ☐ The TL431 in a compensator
- ☐ Small-signal analysis of the return chain
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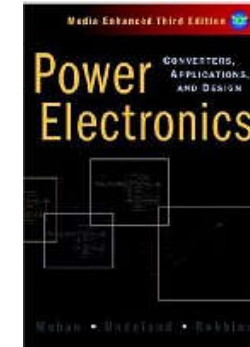
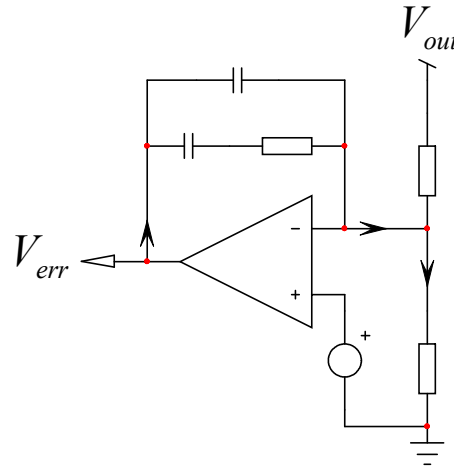
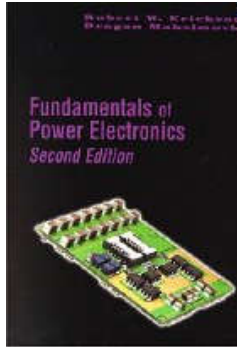
What is a regulated power supply?

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

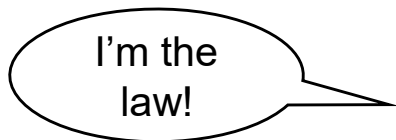


How is regulation performed?

- ❑ Text books only describe op amps in compensators...



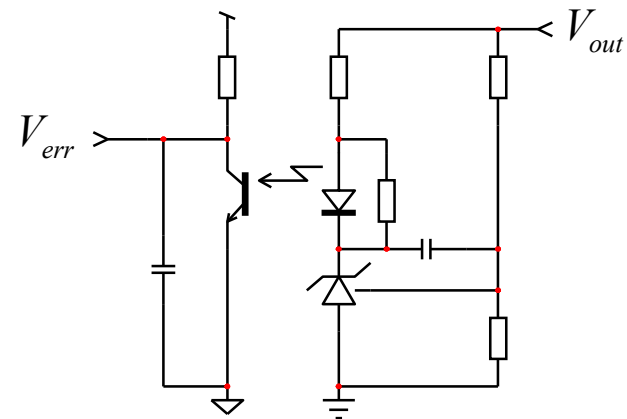
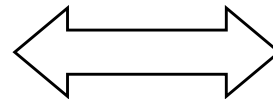
- ❑ The market reality is different: the TL431 rules!



TL431

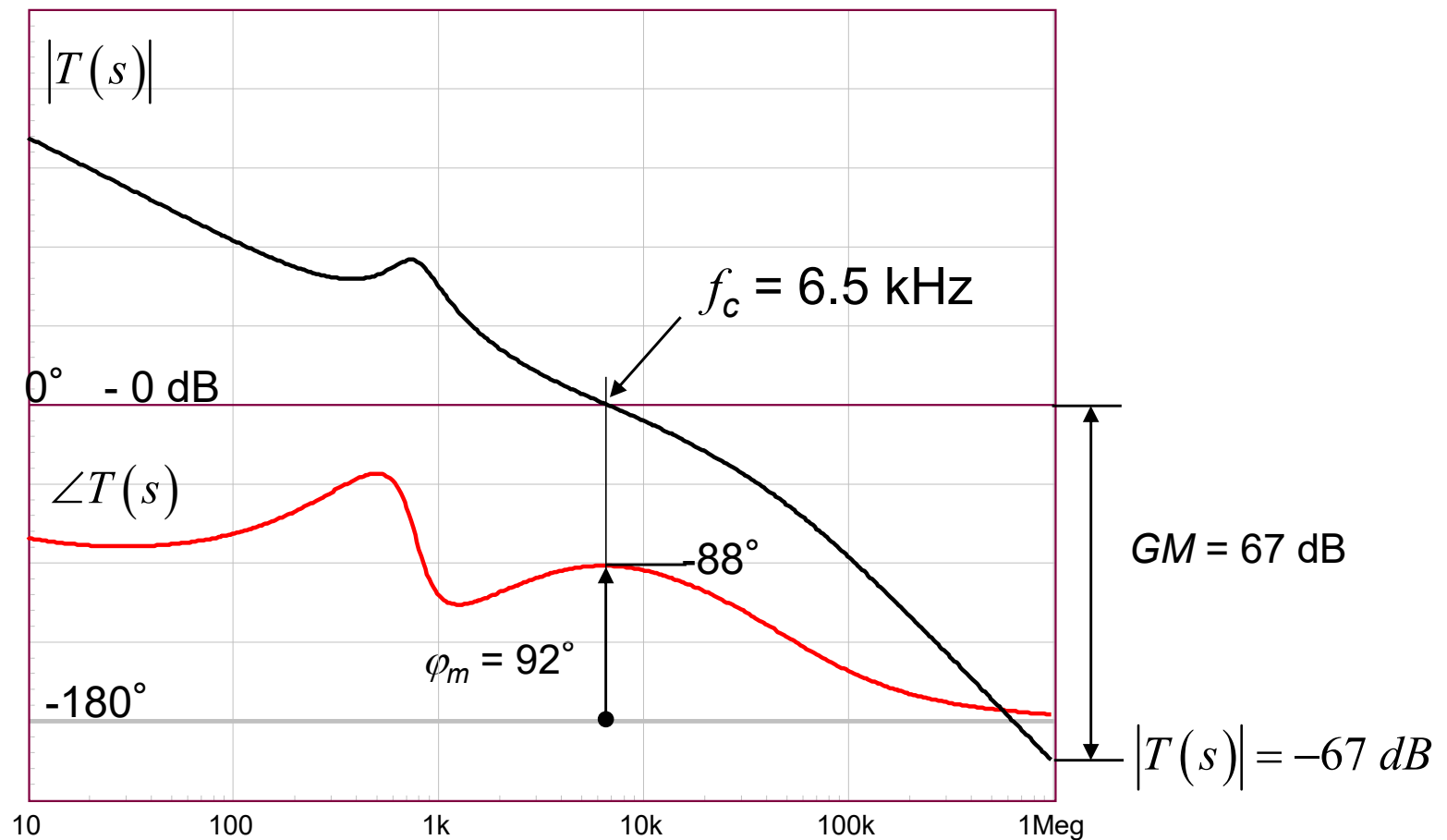


optocoupler



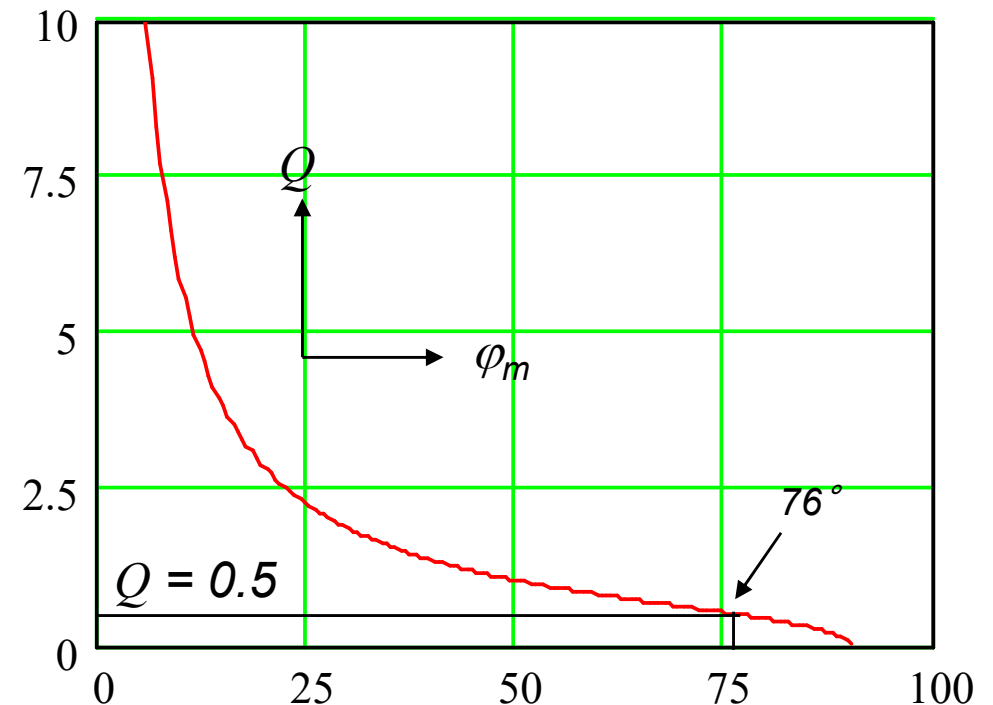
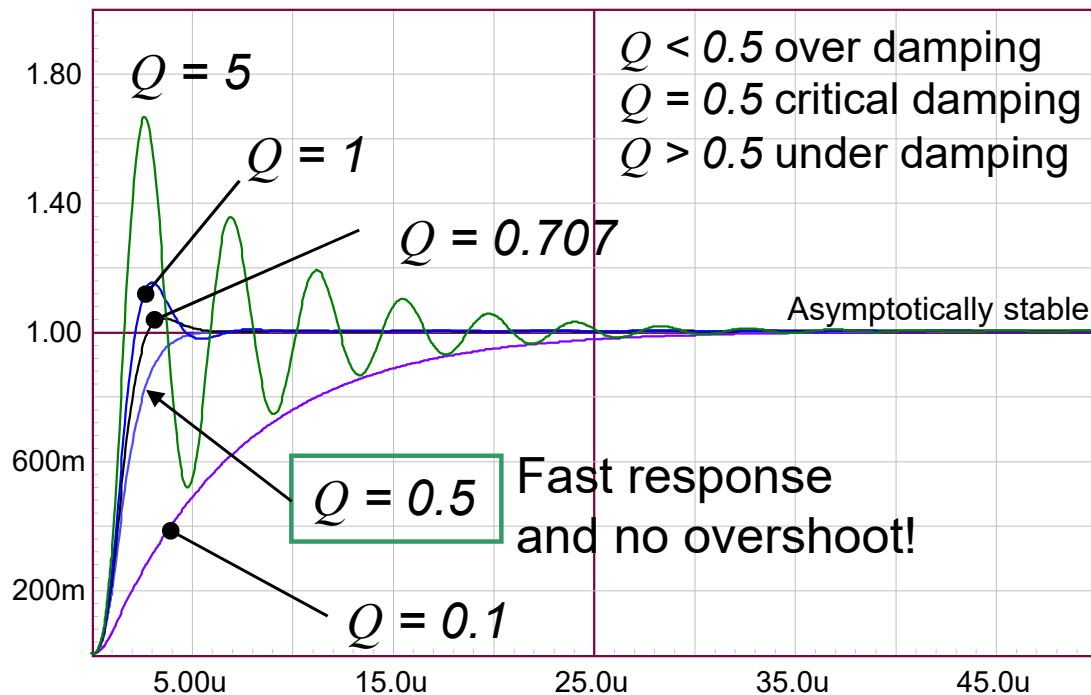
How do we stabilize a converter?

- ❑ We need a high gain at dc for a low static error
- ❑ We want a sufficiently high crossover frequency for response speed
- Shape the compensator $G(s)$ to build phase and gain margins!



How much phase margin to chose?

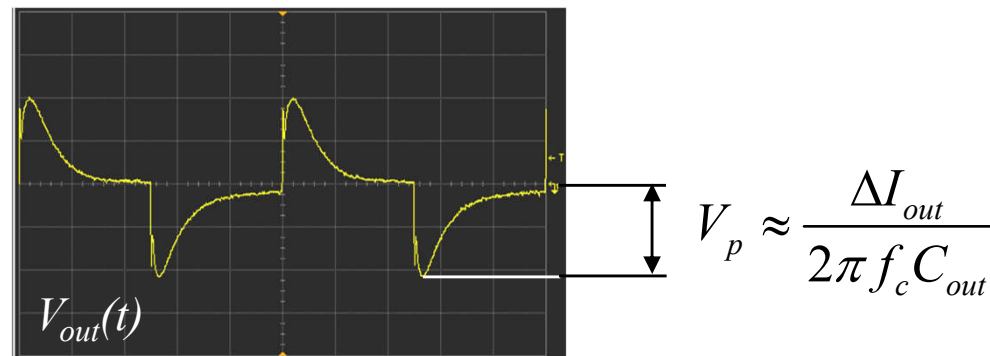
- ❑ a Q factor of 0.5 (critical response) implies a φ_m of 76°
- ❑ a 45° φ_m corresponds to a Q of 1.2: oscillatory response!



- ❑ phase margin depends on the needed response: fast, no overshoot...
- ❑ good practice is to shoot for 60° and make sure φ_m always $> 45^\circ$

Which crossover frequency to select?

- ❑ crossover frequency selection depends on several factors:
 - *switching frequency*: theoretical limit is $F_{sw}/2$
 - in practice, stay below 1/5 of F_{sw} for noise concerns
 - *output ripple*: if ripple pollutes feedback, «tail chasing» can occur.
 - crossover frequency rolloff is mandatory, e.g. in PFC circuits
 - *presence of a Right-Half Plane Zero (RHPZ)*:
 - you cannot cross over beyond 30% of the lowest RHPZ position
 - *output undershoot specification*:
 - select crossover frequency based on undershoot specs



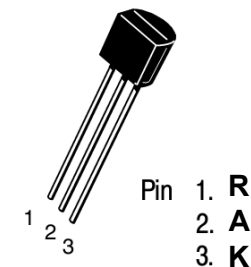
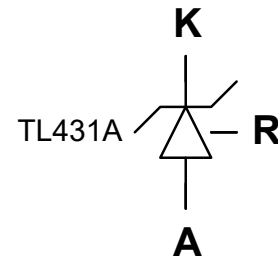
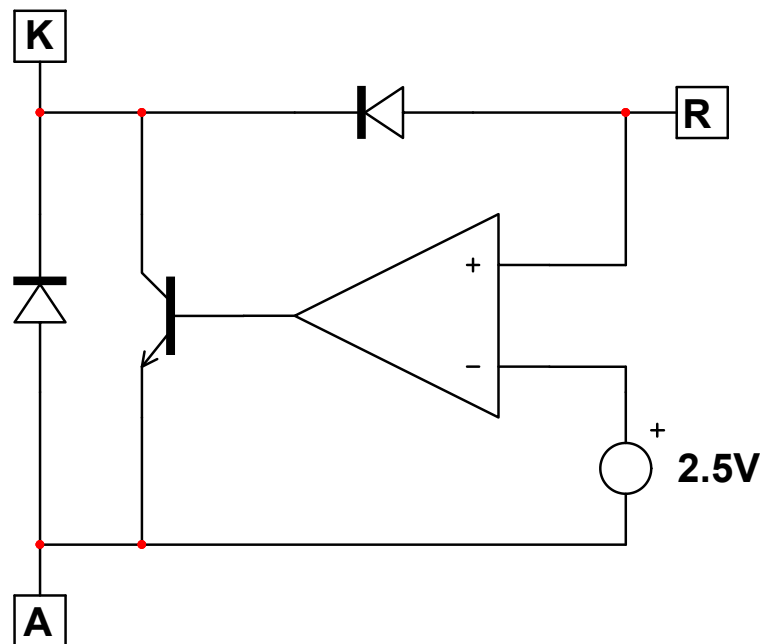
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The TL431 programmable zener

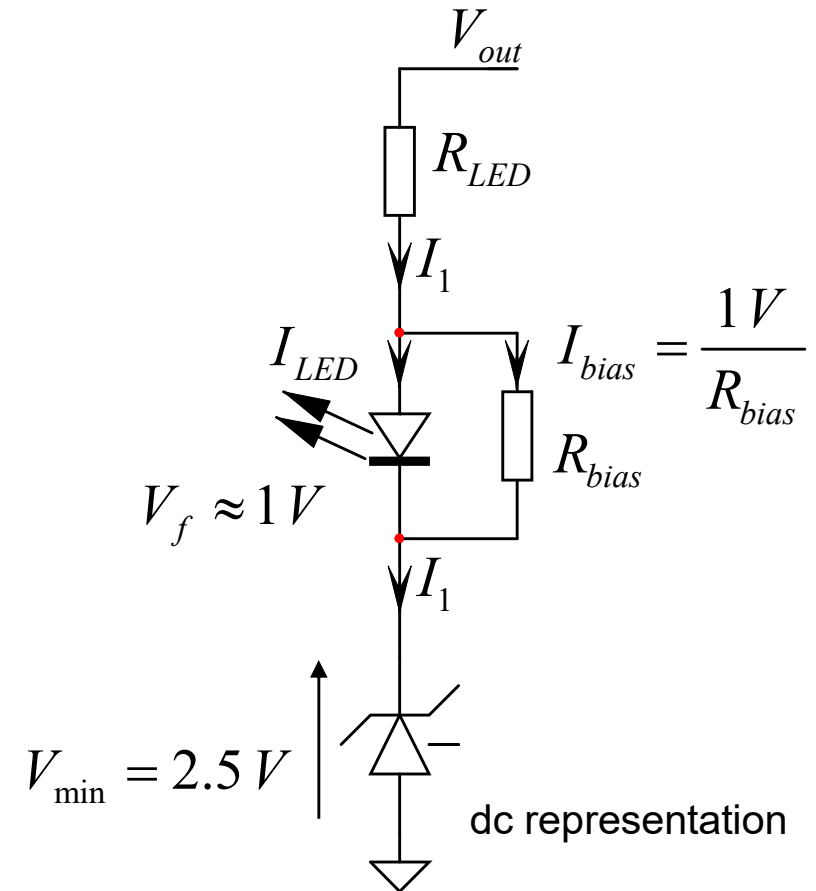
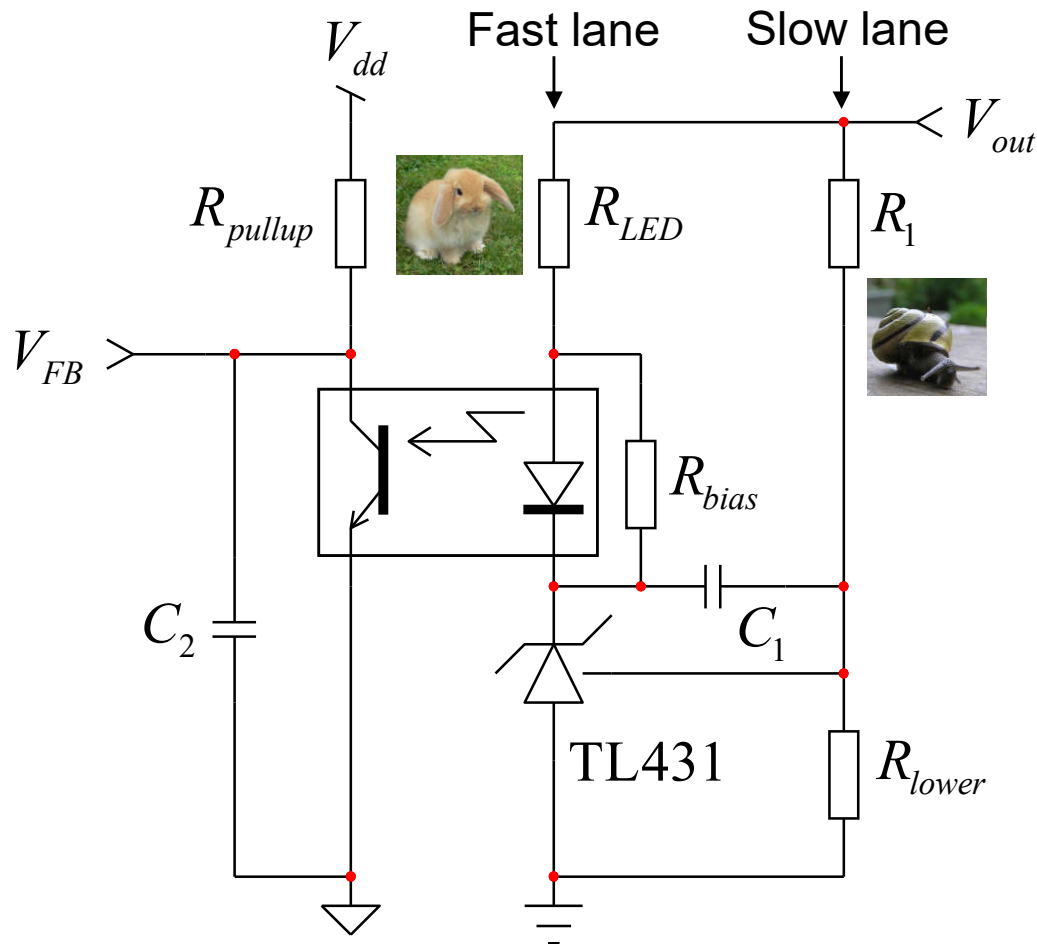
- ❑ The TL431 is the most popular choice in nowadays designs
- ❑ It associates an open-collector op amp and a reference voltage
- ❑ The internal circuitry is self-supplied from the cathode current
- ❑ When the R node exceeds 2.5 V, it sinks current from its cathode



- ❑ The TL431 is a shunt regulator

The TL431 programmable zener

- The TL431 lends itself very well to optocoupler control



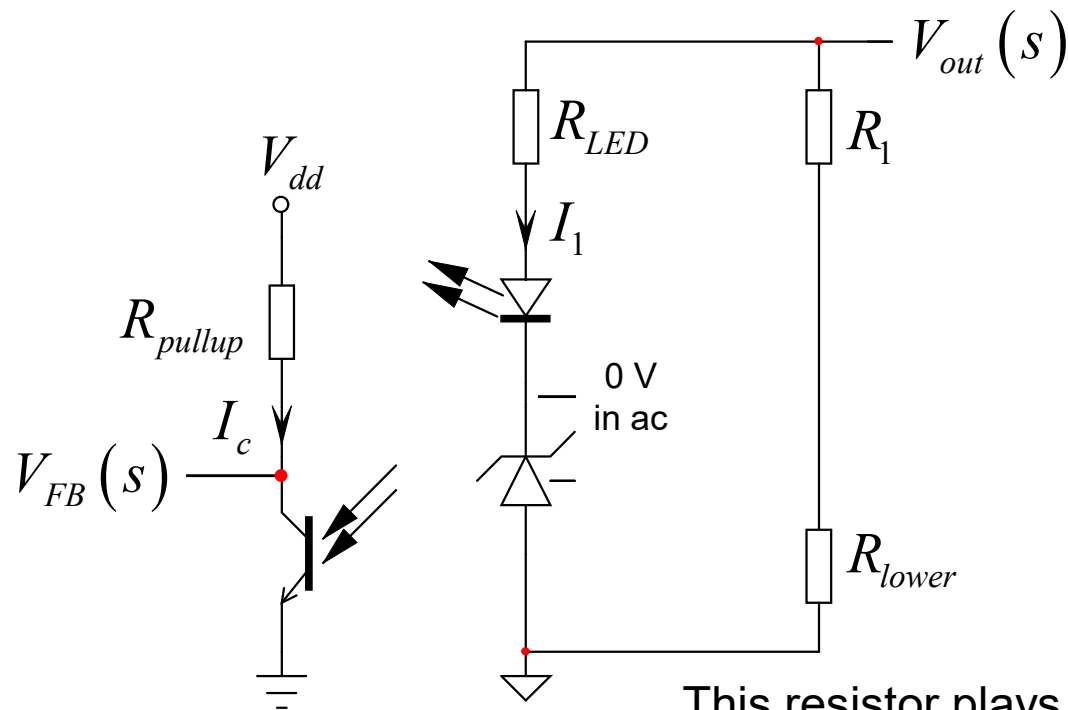
- R_{LED} must leave enough headroom over the TL431: upper limit!

The TL431 programmable zener

□ This LED resistor is a design limiting factor in low output voltages:

$$R_{LED,max} \leq \frac{V_{out} - V_f - V_{TL431,min}}{V_{dd} - V_{CE,sat} + I_{bias} CTR_{min} R_{pullup}} R_{pullup} CTR_{min}$$

□ When the capacitor C_1 is a short-circuit, R_{LED} fixes the fast lane gain



$$V_{FB}(s) = -CTR \cdot R_{pullup} \cdot I_1$$

$$I_1 = \frac{V_{out}(s)}{R_{LED}}$$

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

This resistor plays a role in dc too!

The TL431 – the static gain limit

□ Let us assume the following design:

$$V_{out} = 5\text{ V}$$

$$V_f = 1\text{ V}$$

$$V_{TL431,min} = 2.5\text{ V}$$

$$V_{dd} = 4.8\text{ V}$$

$$V_{CE,sat} = 300\text{ mV}$$

$$I_{bias} = 1\text{ mA}$$

$$CTR_{min} = 0.3$$

$$R_{pullup} = 20\text{ k}\Omega$$

$$R_{LED,max} \leq \frac{5 - 1 - 2.5}{4.8 - 0.3 + 1\text{mA} \times 0.3 \times 20\text{k}} \times 20\text{k} \times 0.3$$



$$R_{LED,max} \leq 857\text{ }\Omega$$



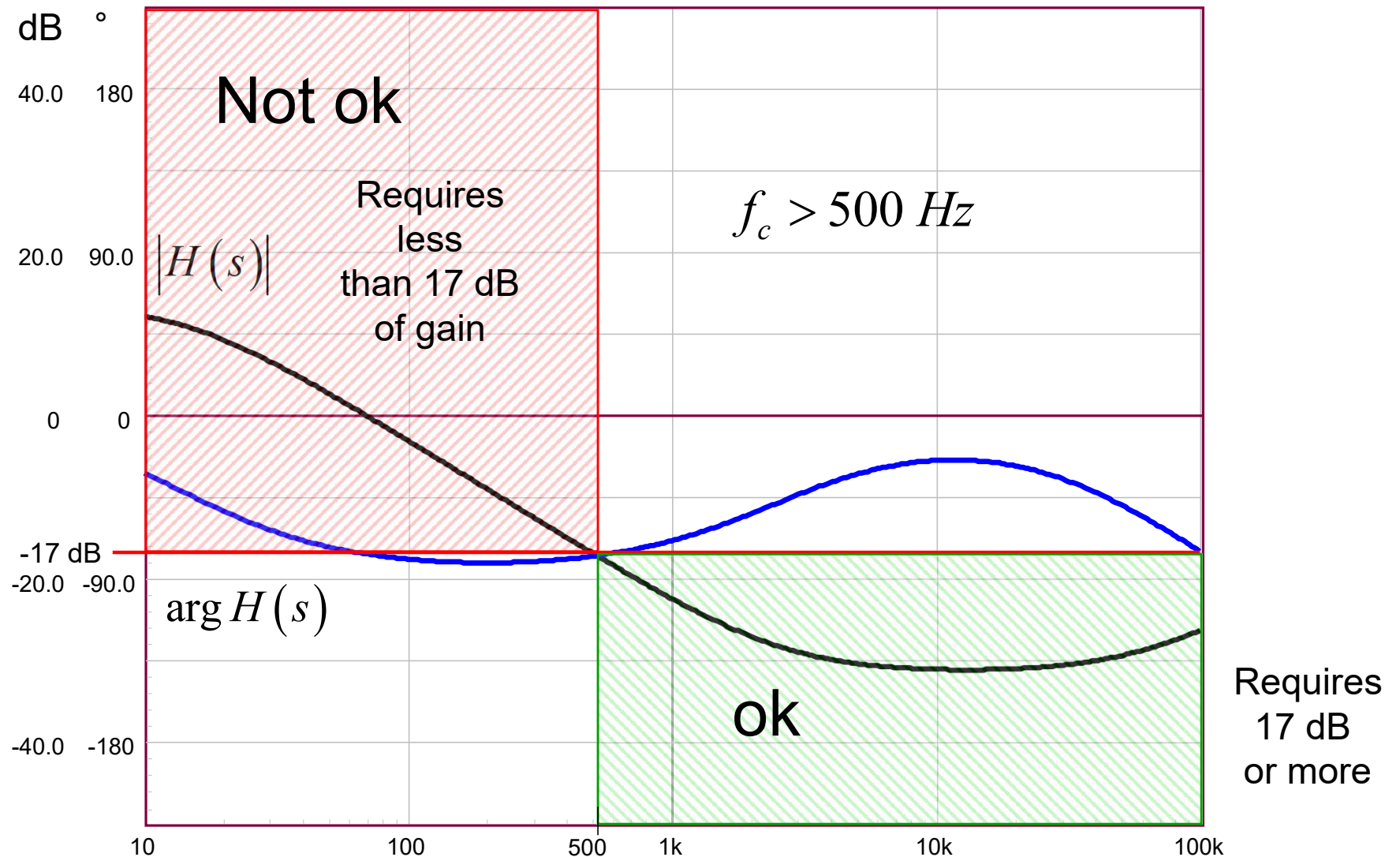
$$G_0 > CTR \frac{R_{pullup}}{R_{LED}} > 0.3 \frac{20}{0.857} > 7 \text{ or } \approx 17\text{ dB}$$

□ In designs where R_{LED} fixes the gain, G_0 cannot be below 17 dB

⇒ You cannot “amplify” by less than 17 dB

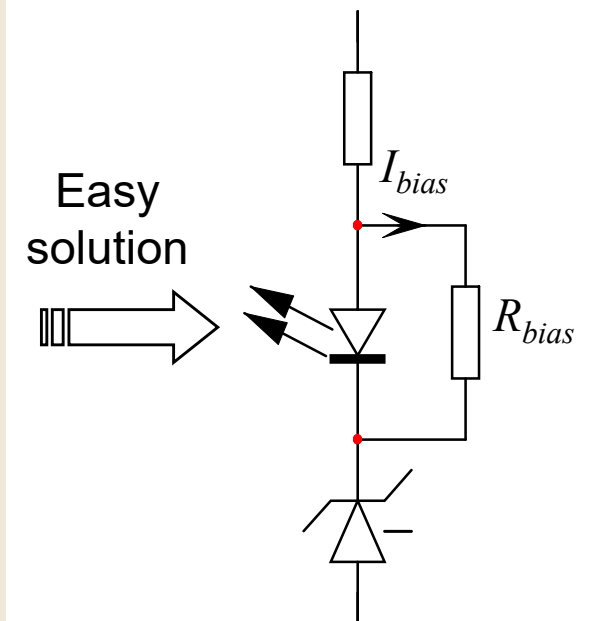
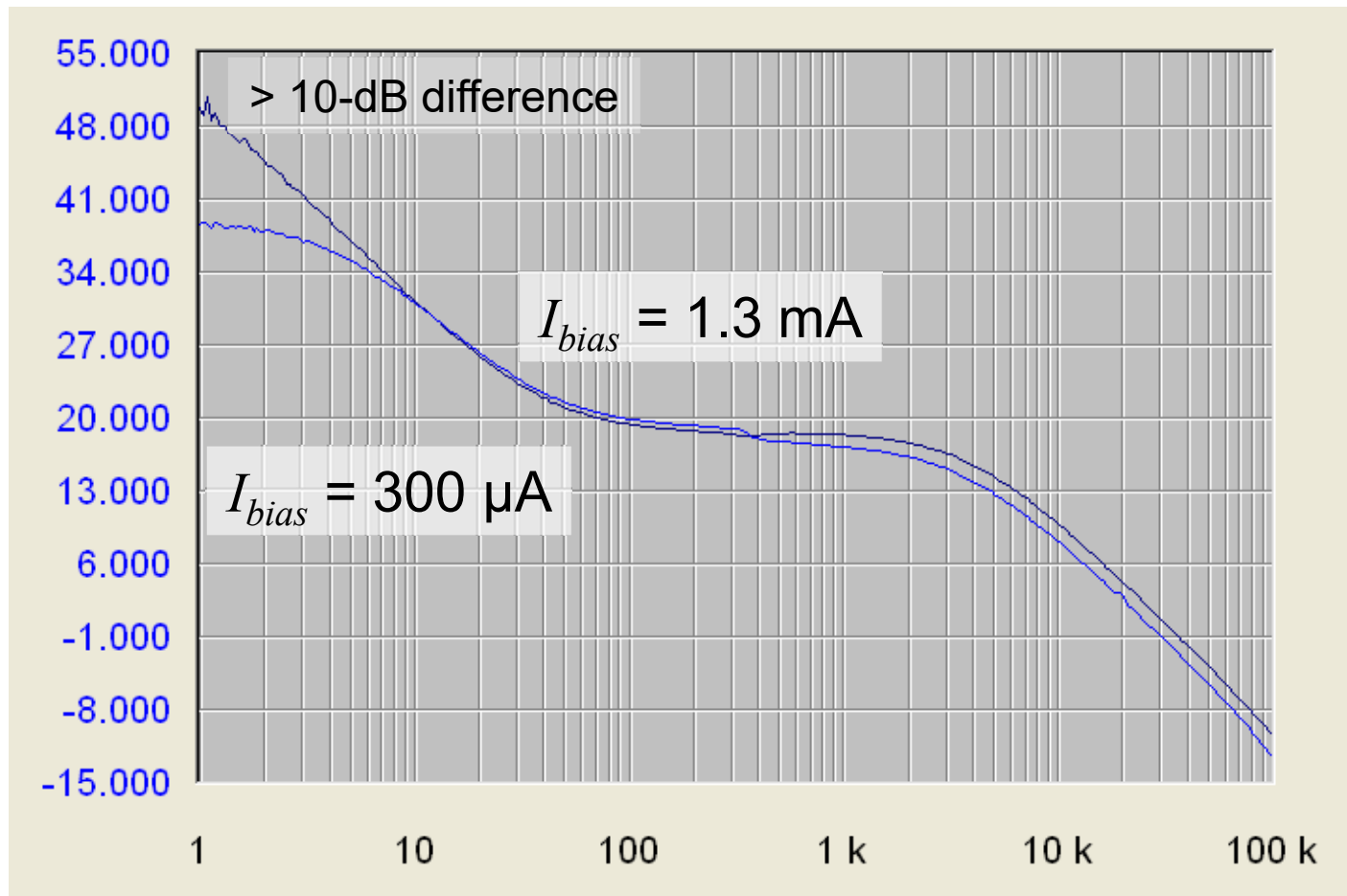
The TL431 – the static gain limit

- ❑ You must identify the areas where compensation is possible



TL431 – injection bias current

- ❑ Make sure enough current always biases the TL431
- ❑ If not, its open-loop suffers – a 10-dB difference can be observed!



$$R_{bias} = \frac{1}{1m} = 1 \text{ k}\Omega$$

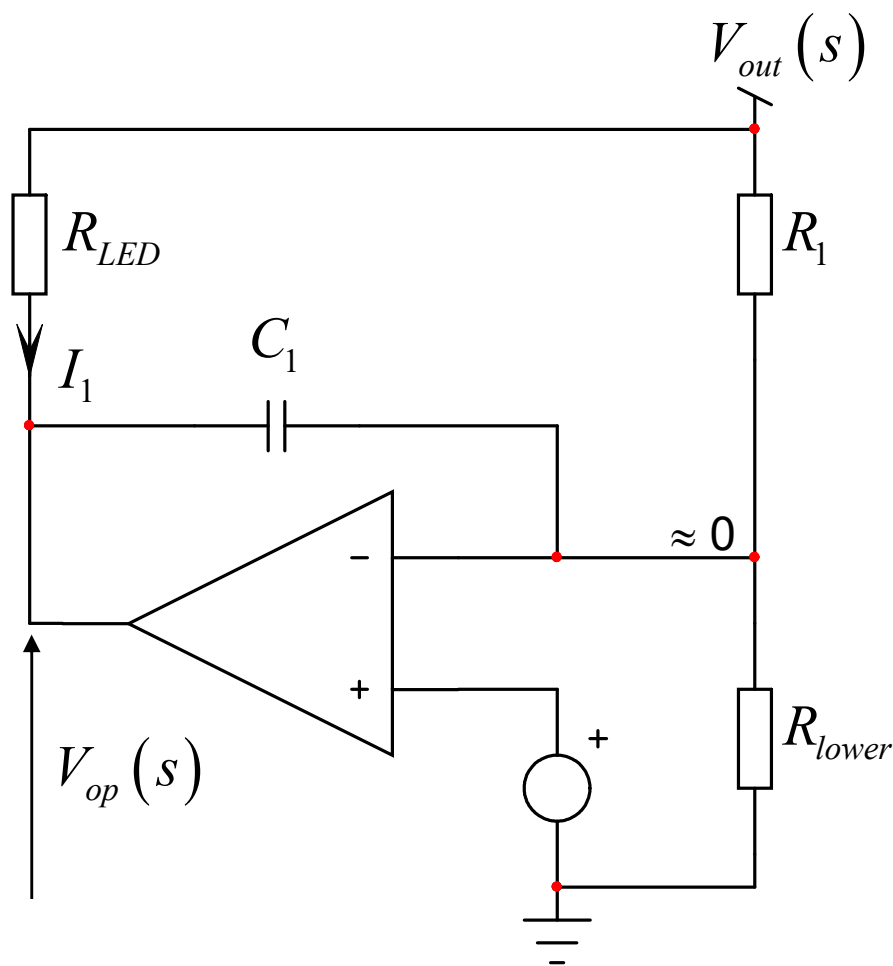
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TL431 – small-signal analysis

- ❑ The TL431 is an open-collector op amp with a reference voltage
- ❑ Neglecting the LED dynamic resistance, we have:



$$I_1(s) = \frac{V_{out}(s) - V_{op}(s)}{R_{LED} \cdot 1}$$

$$V_{op}(s) = -V_{out}(s) \frac{sC_1}{R_{upper}} = -V_{out}(s) \frac{1}{sR_{upper}C_1}$$

$$I_1(s) = V_{out}(s) \frac{1}{R_{LED}} \left[1 + \frac{1}{sR_{upper}C_1} \right]$$

We know that: $V_{FB}(s) = -CTR \cdot R_{pullup} \cdot I_1$

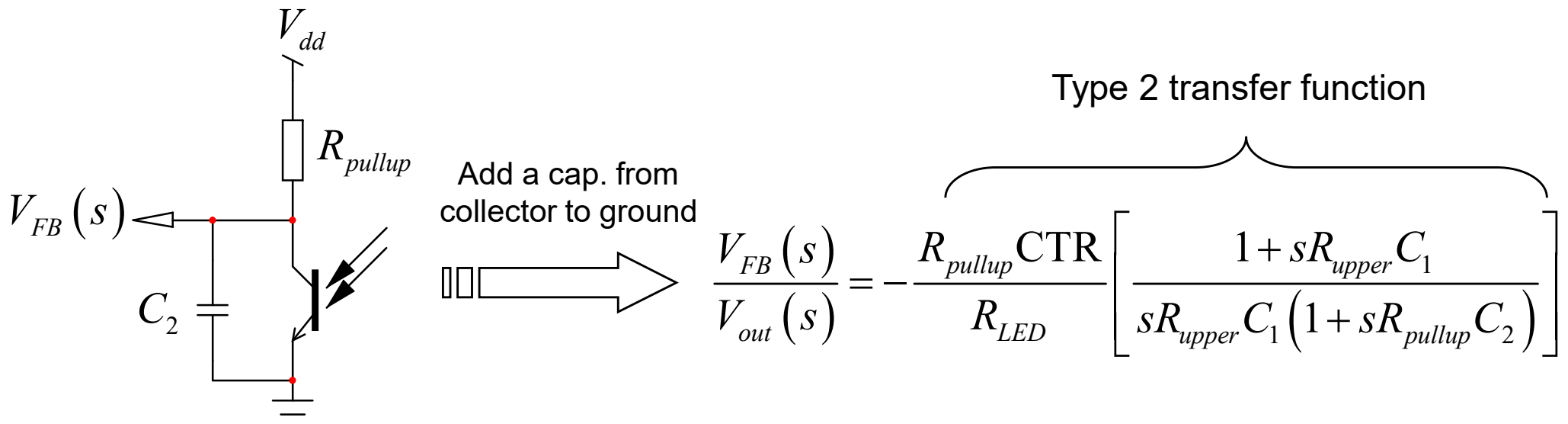
$$\frac{V_{FB}(s)}{V_{out}(s)} = -\frac{R_{pullup} CTR}{R_{LED}} \left[\frac{1 + sR_{upper}C_1}{sR_{upper}C_1} \right]$$

TL431 – small-signal analysis

□ In the previous equation we have:

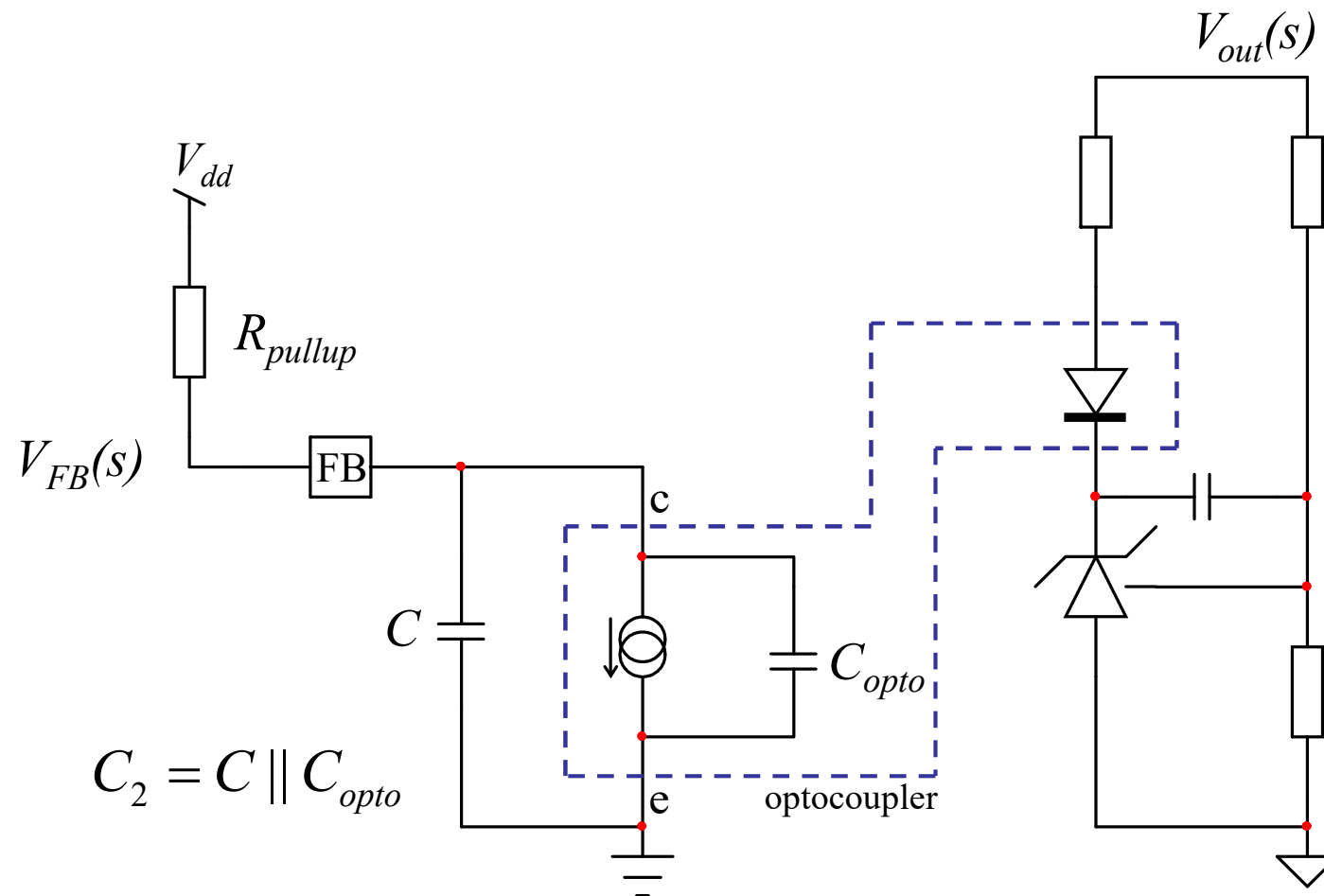
- ✓ a static gain $G_0 = \text{CTR} \frac{R_{\text{pullup}}}{R_{\text{LED}}}$
- ✓ a 0-dB origin pole frequency $\omega_{po} = \frac{1}{C_1 R_{\text{upper}}}$
- ✓ a zero $\omega_{z_1} = \frac{1}{R_{\text{upper}} C_1}$

□ We are missing a pole for the type 2!



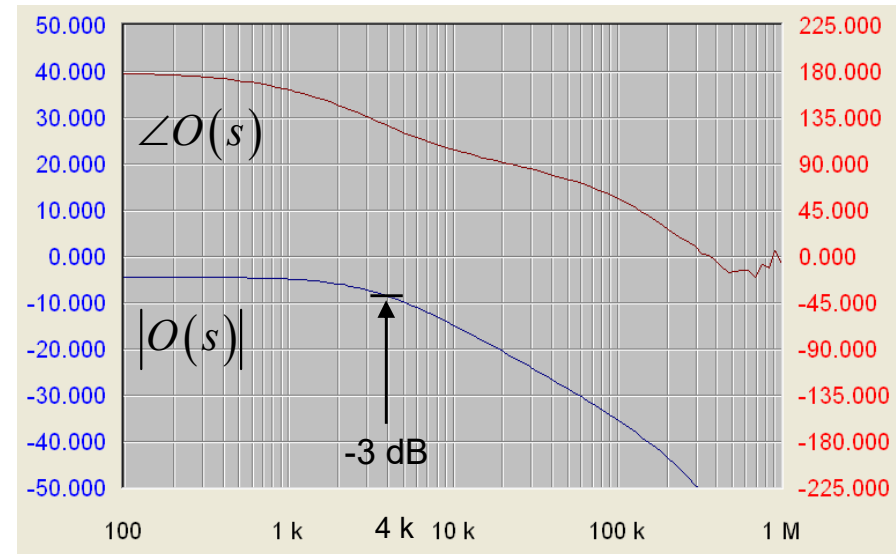
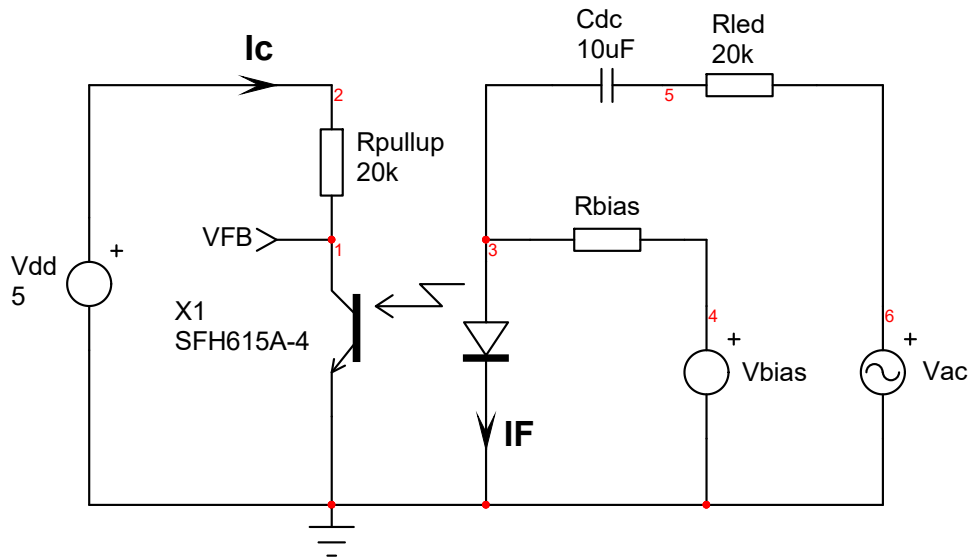
TL431 – small-signal analysis

- ❑ The optocoupler also features a parasitic capacitor
 - it comes in parallel with C_2 and must be accounted for



TL431 – small-signal analysis

- The optocoupler must be characterized to know where its pole is



- Adjust V_{bias} to have V_{FB} at 2-3 V to be in linear region, then ac sweep
- The pole in this example is found at 4 kHz

$$C_{opto} = \frac{1}{2\pi R_{pullup} f_{pole}} = \frac{1}{6.28 \times 20k \times 4k} \approx 2 \text{ nF}$$

⇒ Another design constraint!

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The TL431 in a type 1 compensator

- To make a type 1 (origin pole only) neutralize the zero and the pole

$$\frac{V_{FB}(s)}{V_{out}(s)} = -\frac{R_{pullup} CTR}{R_{LED}} \left[\frac{1 + sR_{upper}C_1}{sR_{upper}C_1 (1 + sR_{pullup}C_2)} \right]$$

$$sR_{upper}C_1 = sR_{pullup}C_2 \implies C_1 = \frac{R_{pullup}}{R_{upper}}C_2 \xrightarrow{\text{substitute}} \omega_{po} = \frac{1}{\frac{R_{upper}R_{LED}}{R_{pullup}CTR}C_1}$$

$$\omega_{po} = \frac{CTR}{C_2R_{LED}} \implies C_2 = \frac{CTR}{2\pi f_{po}R_{LED}}$$

- Once neutralized, you are left with an integrator

$$G(s) = \frac{1}{s} \xrightarrow{\omega_{po}} |G(f_c)| = \frac{f_{po}}{f_c} \rightarrow f_{po} = G_{f_c} f_c \implies C_2 = \frac{CTR}{2\pi G_{f_c} f_c R_{LED}}$$

TL431 type 1 design example

□ We want a 5-dB gain at 5 kHz to stabilize the 5-V converter

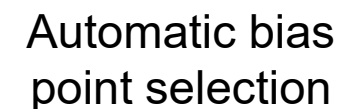
$$\begin{array}{l}
 V_{out} = 5\text{ V} \\
 V_f = 1\text{ V} \\
 V_{TL431,min} = 2.5\text{ V} \\
 V_{dd} = 4.8\text{ V} \\
 V_{CE,sat} = 300\text{ mV} \\
 I_{bias} = 1\text{ mA} \\
 CTR_{min} = 0.3 \\
 R_{pullup} = 20\text{ k}\Omega
 \end{array}
 \left\{
 \begin{array}{l}
 R_{LED,max} \leq 857\ \Omega \xrightarrow{\text{Apply 15\% margin}} R_{LED} = 728\ \Omega
 \end{array}
 \right.$$

$$\begin{array}{l}
 G_{fc} = 10^{\frac{5}{20}} = 1.77 \\
 f_c = 10\text{ kHz}
 \end{array}
 \left\{
 \begin{array}{l}
 C_2 = \frac{CTR}{2\pi G_{fc} f_c R_{LED}} = \frac{0.3}{6.28 \times 1.77 \times 5k \times 728} \approx 7.4\text{ nF}
 \end{array}
 \right.$$

$$\begin{array}{l}
 C_{opto} = 2\text{ nF} \\
 \Rightarrow C = 7.4\text{ n} - 2\text{ n} = 5.4\text{ nF} \quad C_1 = \frac{R_{pullup}}{R_{upper}} C_2 \approx 14.7\text{ nF}
 \end{array}$$

❑ SPICE can simulate the design – automate elements calculations...

Fopto=4k
Copto=1/(2*pi*Fopto*Rpullup)
CTR = 0.3



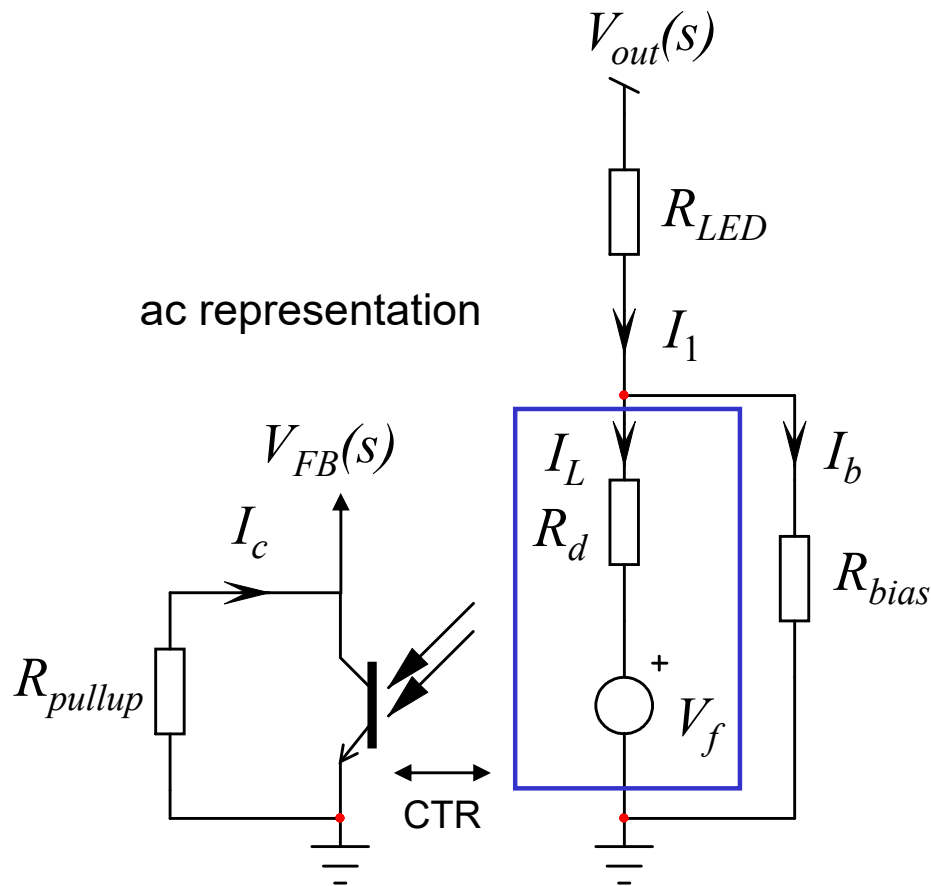
TL431 type 1 design example

□ We have a type 1 but 1.3 dB of gain is missing? 🙄 Hu?



TL431 type 1 design example

- ❑ The 1-kΩ resistor in parallel with the LED is an easy bias
- ❑ However, as it appears in the loop, does it affect the gain?



$$V_{FB} = I_c R_{pullup} = I_L R_{pullup} \text{CTR}$$

$$I_L = I_1 \frac{R_{bias}}{R_{bias} + R_d}$$

$$I_L = \frac{V_{out}}{R_{LED} + R_{bias} \parallel R_d} \frac{R_{bias}}{R_{bias} + R_d}$$

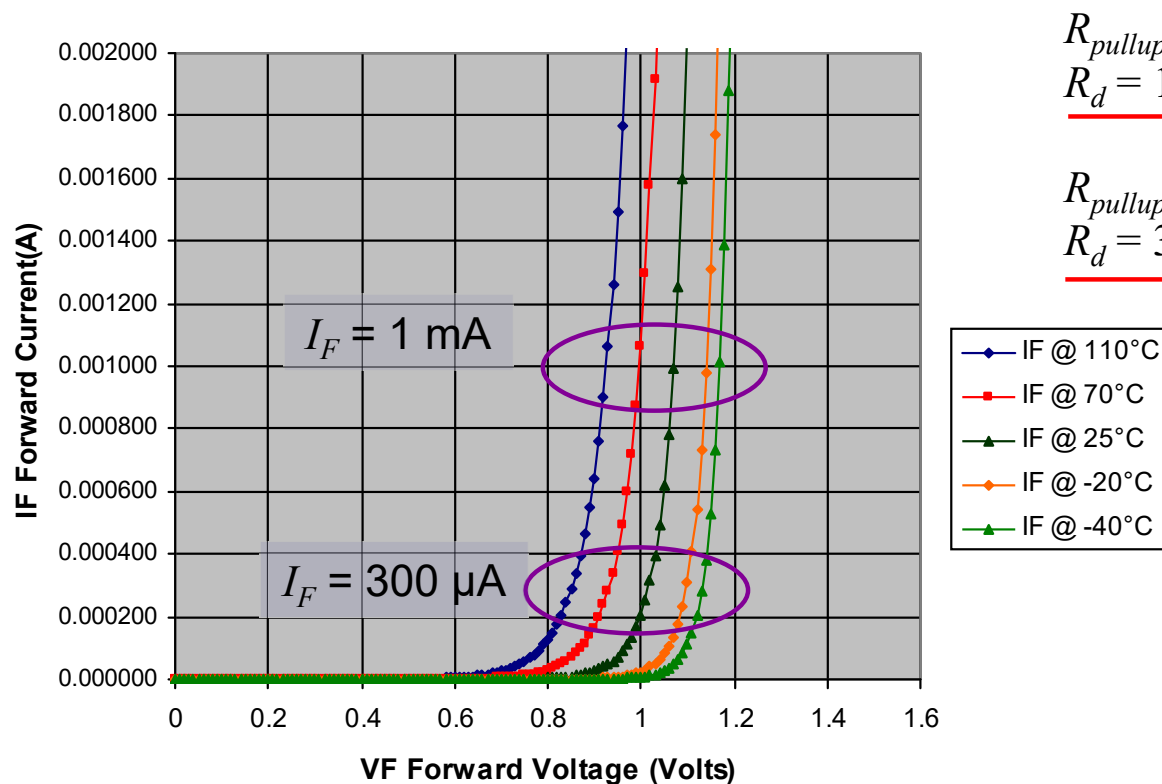
$$\left. \frac{V_{FB}}{V_{out}} \right|_{s=0} = \frac{R_{pullup} \text{CTR}}{R_{LED} + R_{bias} \parallel R_d} \frac{R_{bias}}{R_{bias} + R_d}$$

- ❑ Both bias and dynamic resistances have a role in the gain expression

TL431 type 1 design example

- ❑ A low operating current increases the dynamic resistor

SFH615A-2 -FORWARD CHARACTERISTICS



$$R_{pullup} = 20 \text{ k}\Omega, I_F = 300 \text{ } \mu\text{A} \text{ (CTR} = 0.3)$$

$$\underline{R_d = 158 \text{ } \Omega}$$

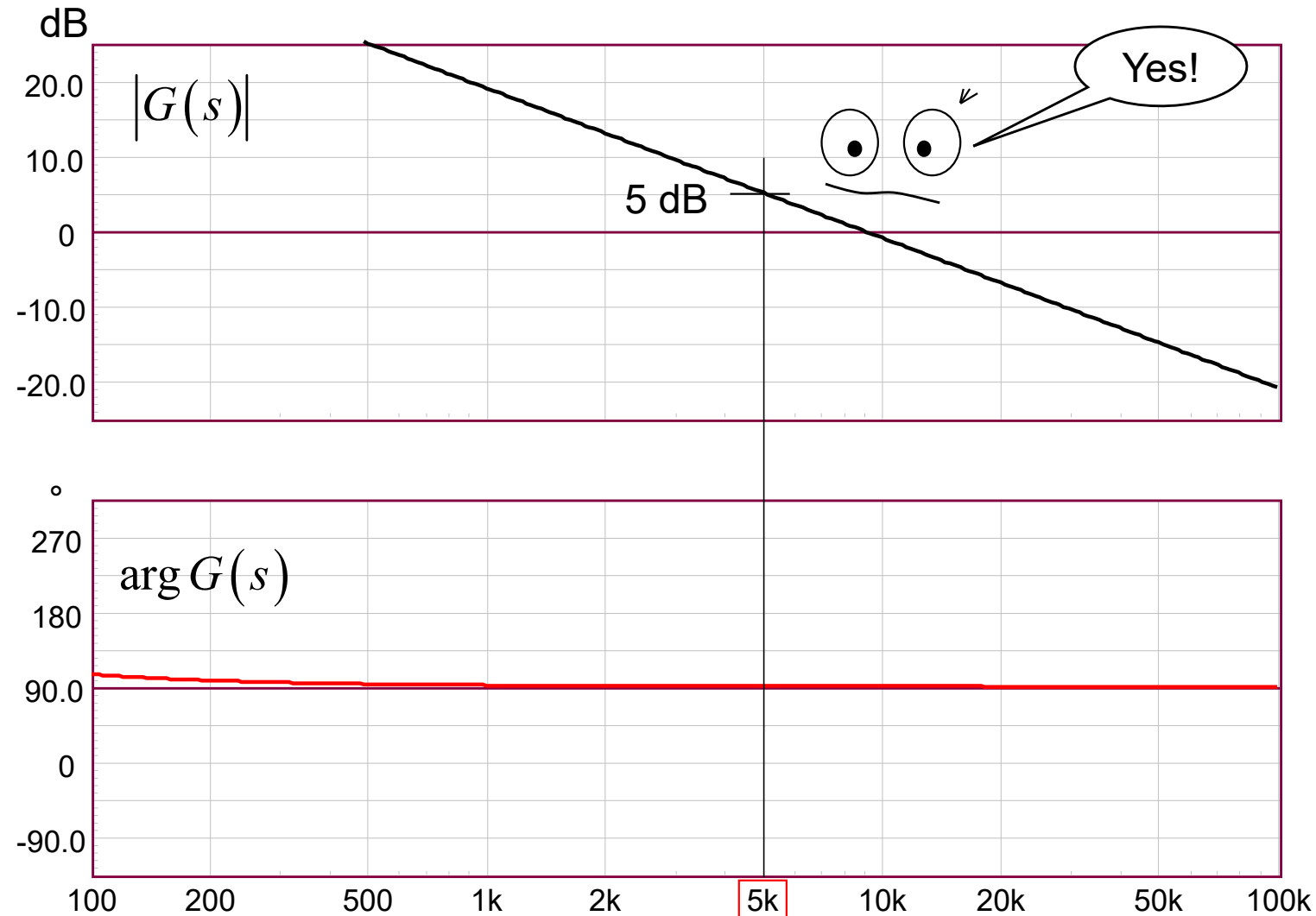
$$R_{pullup} = 1 \text{ k}\Omega, I_F = 1 \text{ mA (CTR} = 1)$$

$$\underline{R_d = 38 \text{ } \Omega}$$

- ❑ Make sure you have enough LED current to reduce its resistance

TL431 type 1 design example

- The pullup resistor is 1 k Ω and the target now reaches 5 dB



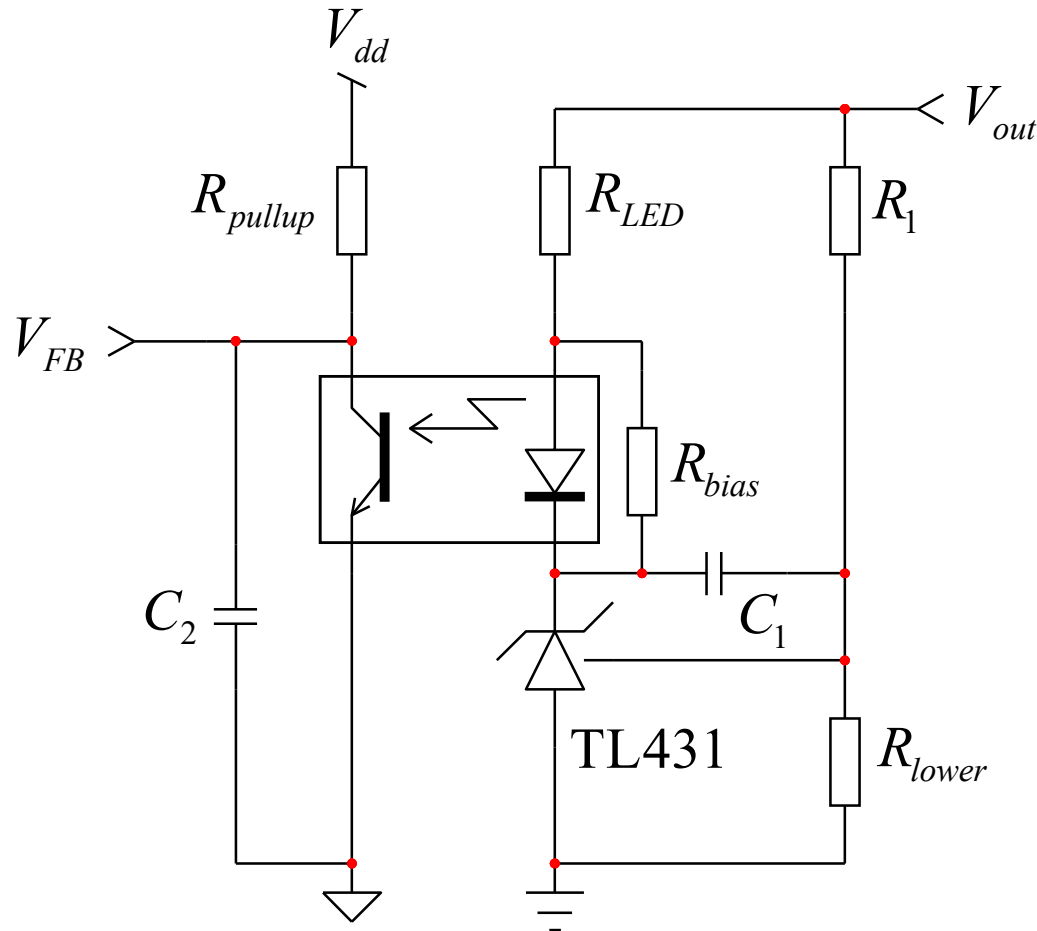
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The TL431 in a type 2 compensator

□ Our first equation was already a type 2 definition, we are all set!



$$G_0 = CTR \frac{R_{pullup}}{R_{LED}}$$

$$\omega_{z_1} = \frac{1}{R_1 C_1}$$

$$\omega_{p_1} = \frac{1}{R_{pullup} C_2}$$

□ Just make sure the optocoupler contribution is involved...

TL431 type 2 design example

- ❑ You need to provide a 15-dB gain at 5 kHz with a 50° boost

$$f_p = \left[\tan(\text{boost}) + \sqrt{\tan^2(\text{boost}) + 1} \right] f_c = 2.74 \times 5k = 13.7 \text{ kHz}$$

$$f_z = f_c^2 / f_p = 25k / 13.7k \approx 1.8 \text{ kHz} \quad G_0 = \text{CTR} \frac{R_{\text{pullup}}}{R_{\text{LED}}} = 10^{15/20} = 5.62$$

- ❑ With a 250-μA bridge current, the divider resistor is made of:

$$R_{\text{lower}} = 2.5 / 250\mu = 10 \text{ k}\Omega \quad R_1 = (12 - 2.5) / 250\mu = 38 \text{ k}\Omega$$

- ❑ The pole and zero respectively depend on R_{pullup} and R_1 :

$$C_2 = 1 / 2\pi f_p R_{\text{pullup}} = 581 \text{ pF} \quad C_1 = 1 / 2\pi f_z R_1 = 2.3 \text{ nF}$$

- ❑ The LED resistor depends on the needed mid-band gain:

$$R_{\text{LED}} = \frac{R_{\text{pullup}} \text{CTR}}{G_0} = 1.06 \text{ k}\Omega \xrightarrow{\text{ok}} R_{\text{LED,max}} \leq 4.85 \text{ k}\Omega$$



TL431 type 2 design example

- ❑ The optocoupler is still at a 4-kHz frequency:

$$C_{pole} \approx 2 \text{ nF} \xrightarrow{\text{Already above!}}$$

- ❑ Type 2 pole capacitor calculation requires a 581-pF cap.!

➡ The bandwidth cannot be reached, reduce f_c !

- ❑ For noise purposes, we want a minimum of 100 pF for C
- ❑ With a total capacitance of 2.1 nF, the highest pole can be:

$$f_{pole} = \frac{1}{2\pi R_{pullup} C} = \frac{1}{6.28 \times 20k \times 2.1n} = 3.8 \text{ kHz}$$

- ❑ For a 50° phase boost and a 3.8-kHz pole, the crossover must be:

$$f_c = \frac{f_p}{\tan(\text{boost}) + \sqrt{\tan^2(\text{boost}) + 1}} \approx 1.4 \text{ kHz}$$

TL431 type 2 design example

- The zero is then simply obtained:

$$f_z = \frac{f_c^2}{f_p} = 516 \text{ Hz}$$

- We can re-derive the component values and check they are ok

$$C_2 = 1/2\pi f_p R_{pullup} = 2.1 \text{ nF} \quad C_1 = 1/2\pi f_z R_1 = 8.1 \text{ nF}$$

- Given the 2-nF optocoupler capacitor, we just add 100 pF

- In this example, $R_{LED,max}$ is 4.85 kΩ

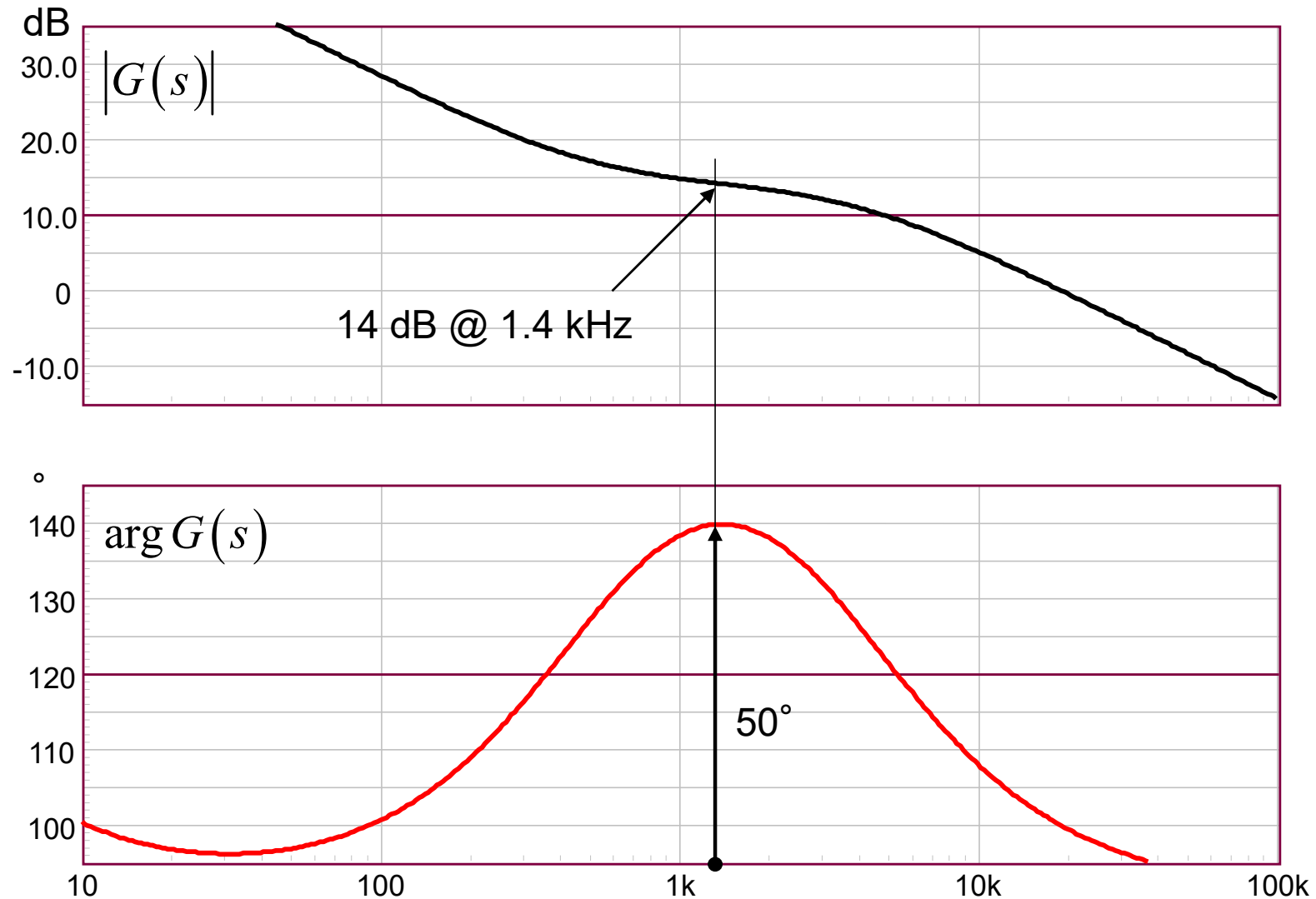
$$G_0 > \text{CTR} \frac{R_{pullup}}{R_{LED}} > 0.3 \frac{20}{4.85} > 1.2 \text{ or } \approx 1.8 \text{ dB}$$

- You cannot use this type 2 if an attenuation is required at f_c !



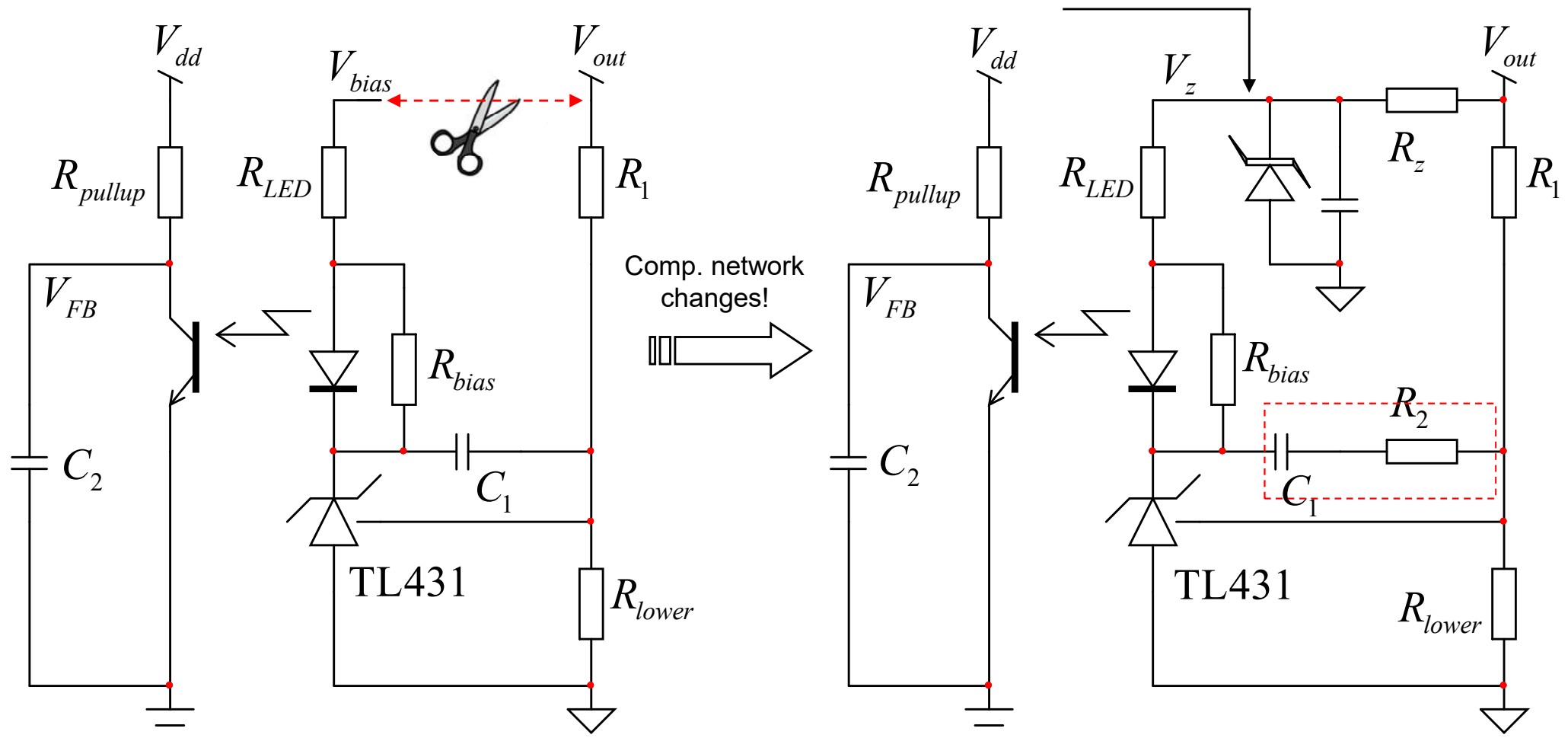
TL431 type 2 design example

- The 1-dB gain difference is linked to R_d and the bias current



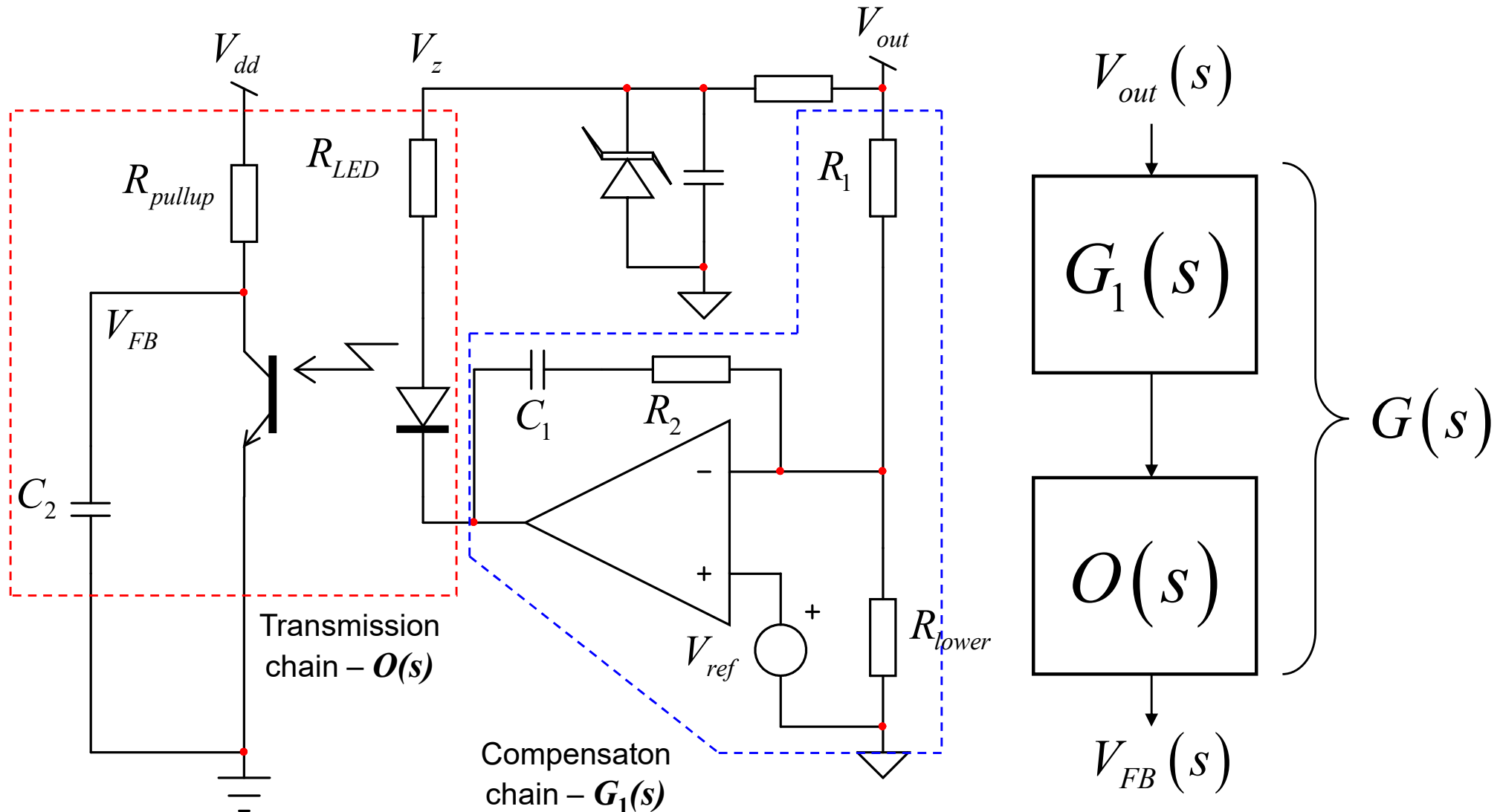
TL431 – suppressing the fast lane

- ❑ The gain limit problem comes from the fast lane presence
- ❑ Its connection to V_{out} creates a parallel input
- The solution is to hook the LED resistor to a fixed bias



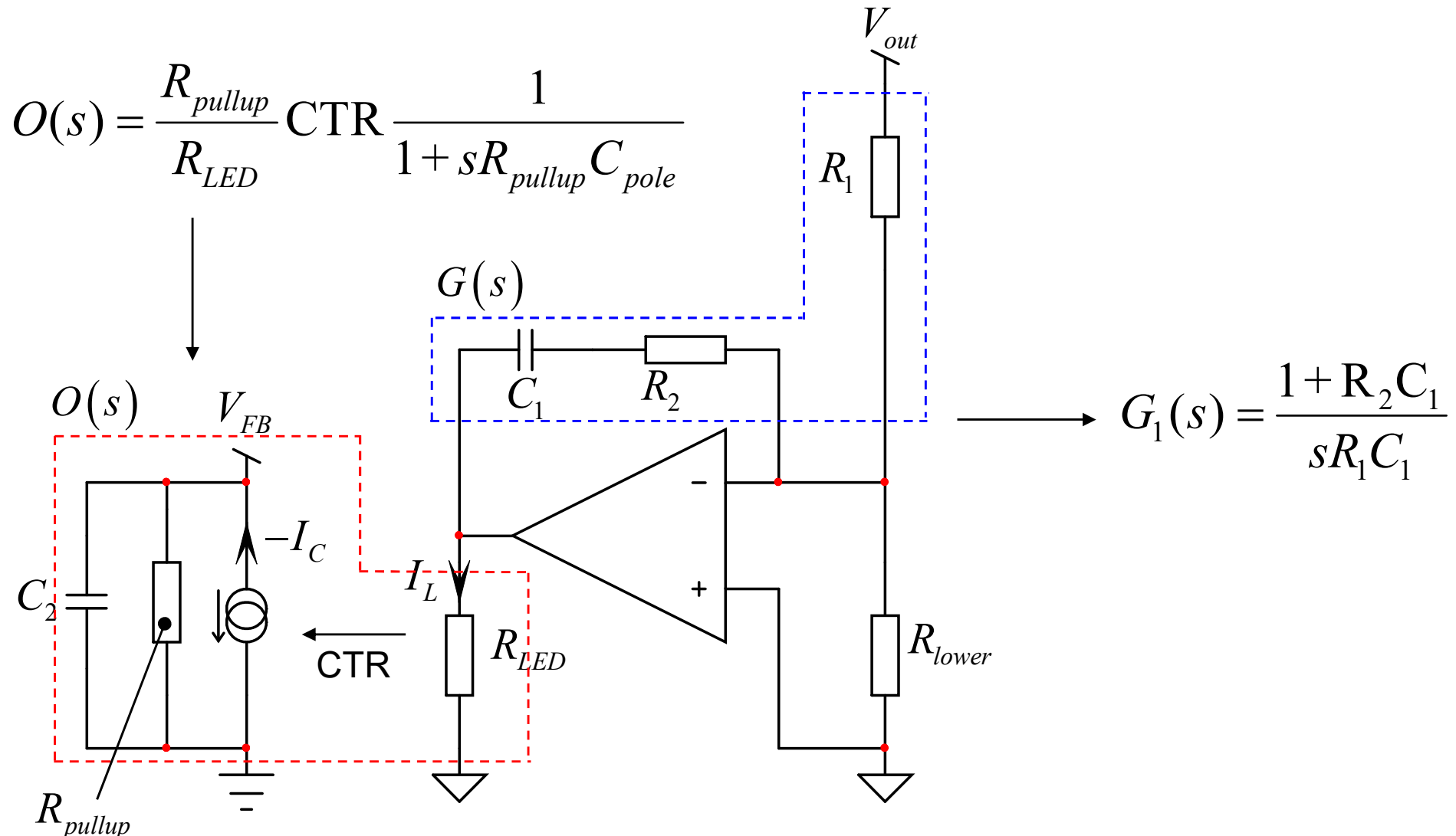
TL431 – suppressing the fast lane

- The equivalent schematic becomes an open-collector op amp



TL431 – suppressing the fast lane

- The small-signal ac representation puts all sources to 0



TL431 – suppressing the fast lane

- ❑ The op amp can now be wired in any configuration!
- ❑ Just keep in mind the optocoupler transmission chain

$$O(s) = \frac{R_{pullup}}{R_{LED}} \text{CTR} \frac{1}{1 + sR_{pullup}C_{pole}}$$

- ❑ Wire the op amp in type 2A version (no high frequency pole)

$$G_1(s) = \frac{1 + R_2C_1}{sR_1C_1}$$

- ❑ When cascaded, you obtain a type 2 with an extra gain term

$$G(s) = \underbrace{\frac{R_{pullup}}{R_{LED}} \text{CTR}}_{G_2} \frac{1 + R_2C_1}{sR_1C_1 (1 + sR_{pullup}C_{pole})}$$

TL431 type 2 design example – no fast lane

- We still have a constraint on R_{LED} but only for dc bias purposes

$$R_{LED,max} \leq \frac{V_z - V_f - V_{TL431,min}}{V_{dd} - V_{CE,sat} + I_{bias} CTR_{min} R_{pullup}} R_{pullup} CTR_{min}$$

- You need to attenuate by -10-dB at 1.4 kHz with a 50° boost
- The poles and zero position are that of the previous design

$$\left. \begin{array}{l} V_z = 6.2 V \\ V_f = 1 V \\ V_{TL431,min} = 2.5 V \\ V_{dd} = 4.8 V \\ V_{CE,sat} = 300 mV \\ I_{bias} = 1 mA \\ CTR_{min} = 0.3 \\ R_{pullup} = 20 k\Omega \end{array} \right\} R_{LED,max} \leq 1.5 k\Omega \xrightarrow{\text{Apply 15\% margin}} R_{LED} = 1.27 k\Omega$$
$$f_z = 516 Hz \quad f_p = 3.8 kHz$$

TL431 type 2 design example – no fast lane

- We need to account for the extra gain term:

$$G_2 = \frac{R_{pullup}}{R_{LED}} CTR = \frac{20k}{1.27k} 0.3 = 4.72$$

- The required total mid-band attenuation at 1.4 kHz is -10 dB

$$G_{f_c} = 10^{-10/20} = 0.316$$

- The mid-band gain from the type 2A is therefore:

$$G_1 = \frac{G_0}{G_2} = \frac{0.316}{4.72} = 0.067 \text{ or } -23.5 \text{ dB}$$

- Calculate R_2 for this attenuation:

$$R_2 = G_1 R_1 \frac{\sqrt{\left(\frac{f_c}{f_p}\right)^2 + 1}}{\sqrt{\left(\frac{f_z}{f_c}\right)^2 + 1}} = 2.6 \text{ k}\Omega$$

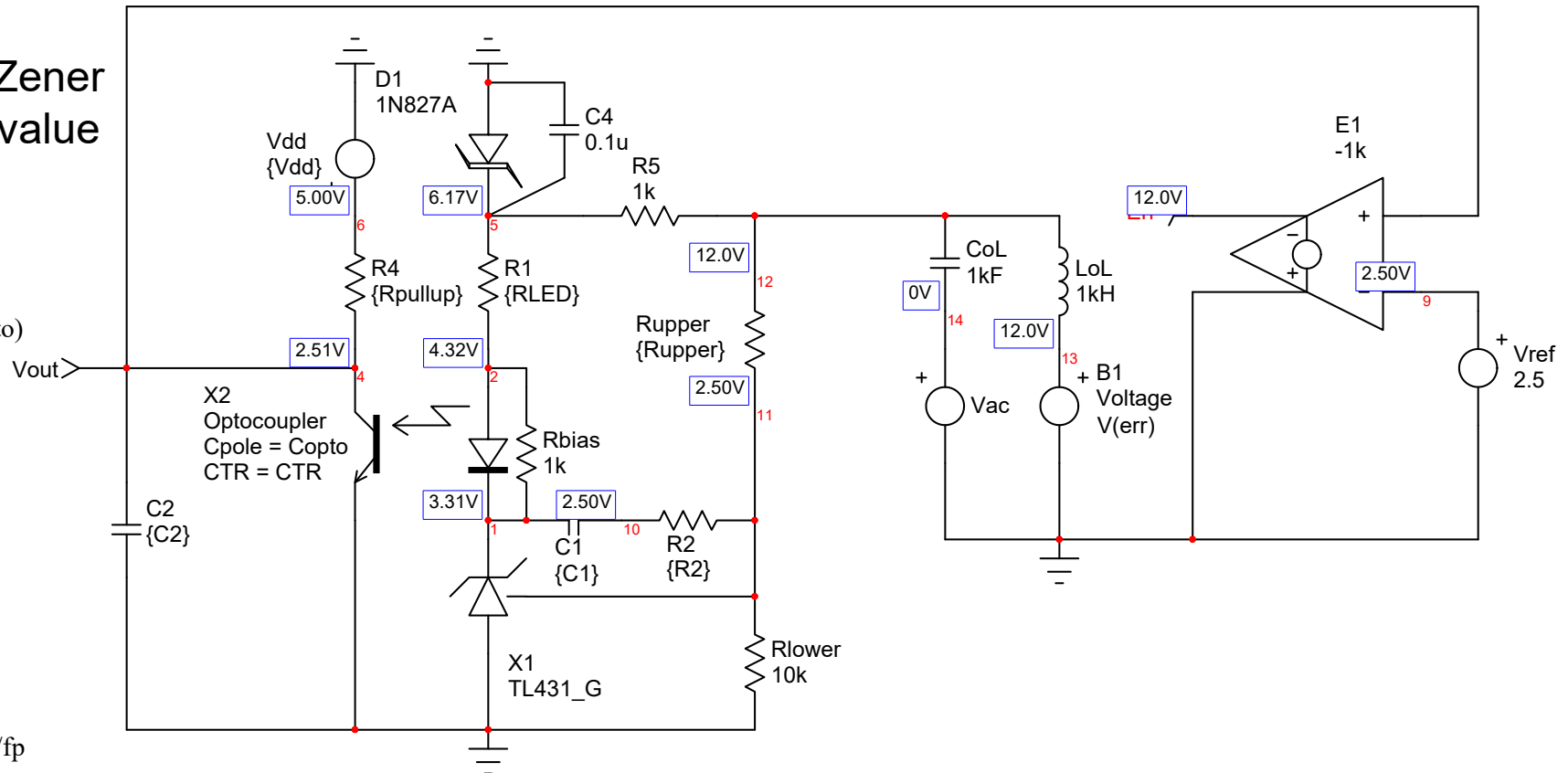
TL431 type 2 design example – no fast lane

□ An automated simulation helps to test the calculation results

parameters

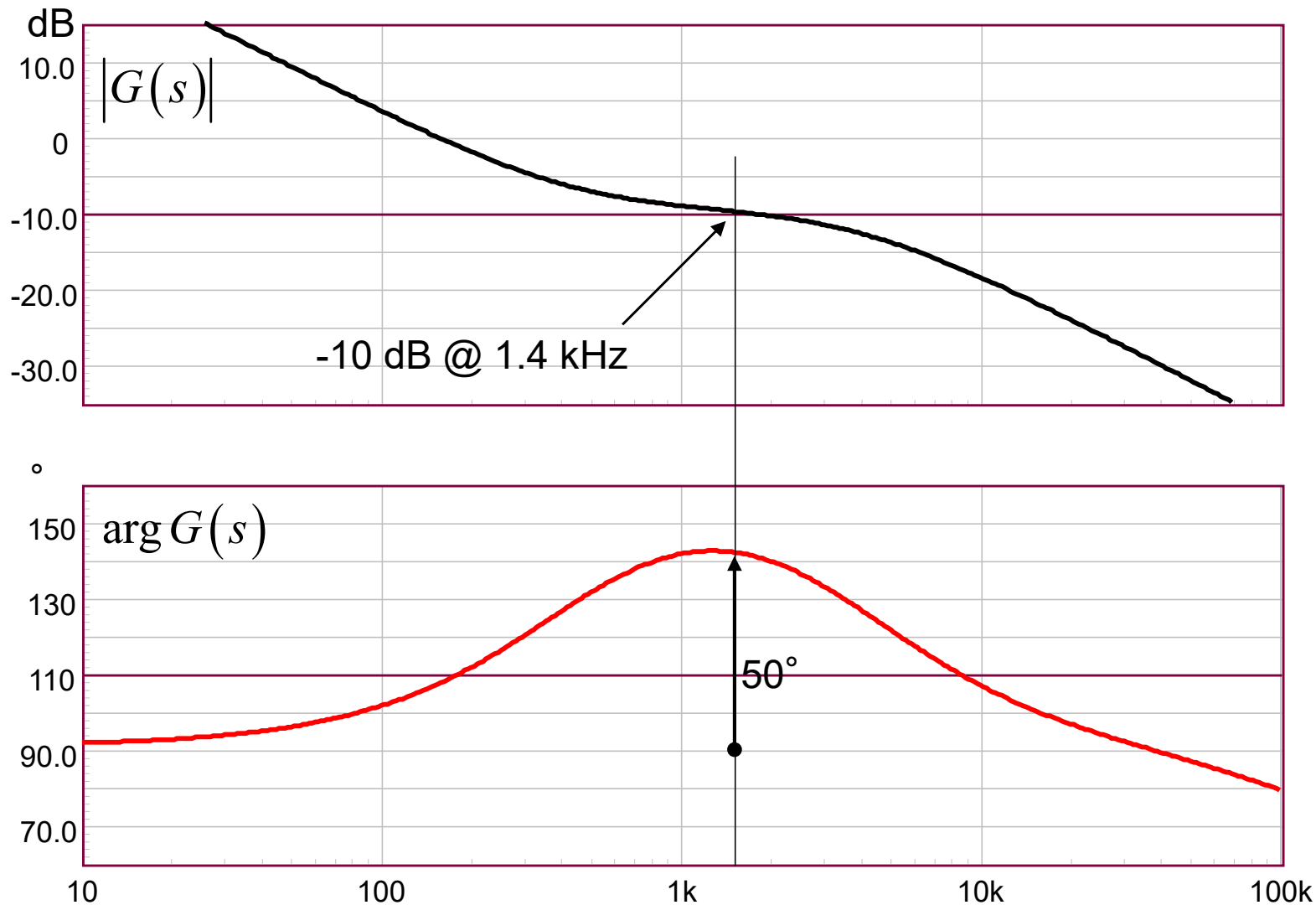
$V_{out}=12$
 $R_{upper}=(V_{out}-2.5)/250\mu$
 $f_c=1.4k$
 $G_{fc}=10$
 $V_f=1$
 $I_{bias}=1m$
 $V_{ref}=2.5$
 $V_{CEsat}=300m$
 $V_{dd}=5$
 $V_z=6.2$
 $R_{pullup}=20k$
 $F_{opto}=4k$
 $C_{opto}=1/(2*\pi*R_{pullup}*F_{opto})$
 $CTR=0.3$
 $G_1=R_{pullup}*CTR/R_{LED}$
 $G_2=10^{(-G_{fc}/20)}$
 $G=G_2/G_1$
 $\pi=3.14159$
 $f_z=516$
 $f_p=3.8k$
 $C_1=1/(2*\pi*f_z*R_2)$
 $C_{pole2}=1/(2*\pi*f_p*R_{pullup})$
 $C_2=C_{pole2}-C_{opto}$
 $a=(f_z^2+f_c^2)*(f_p^2+f_c^2)$
 $c=(f_z^2+f_c^2)$
 $R_2=(\sqrt{a}/c)*G*f_c*R_{upper}/f_p$
 $R_{max1}=(V_z-V_f-V_{ref})$
 $R_{max2}=(V_{dd}-V_{CEsat}+I_{bias}*(R_{pullup}*CTR))$
 $R_{LED}=(R_{max1}/R_{max2})*R_{pullup}*CTR*0.85$

Zener value



TL431 type 2 design example – no fast lane

- The simulation results confirm the calculations are ok



TL431

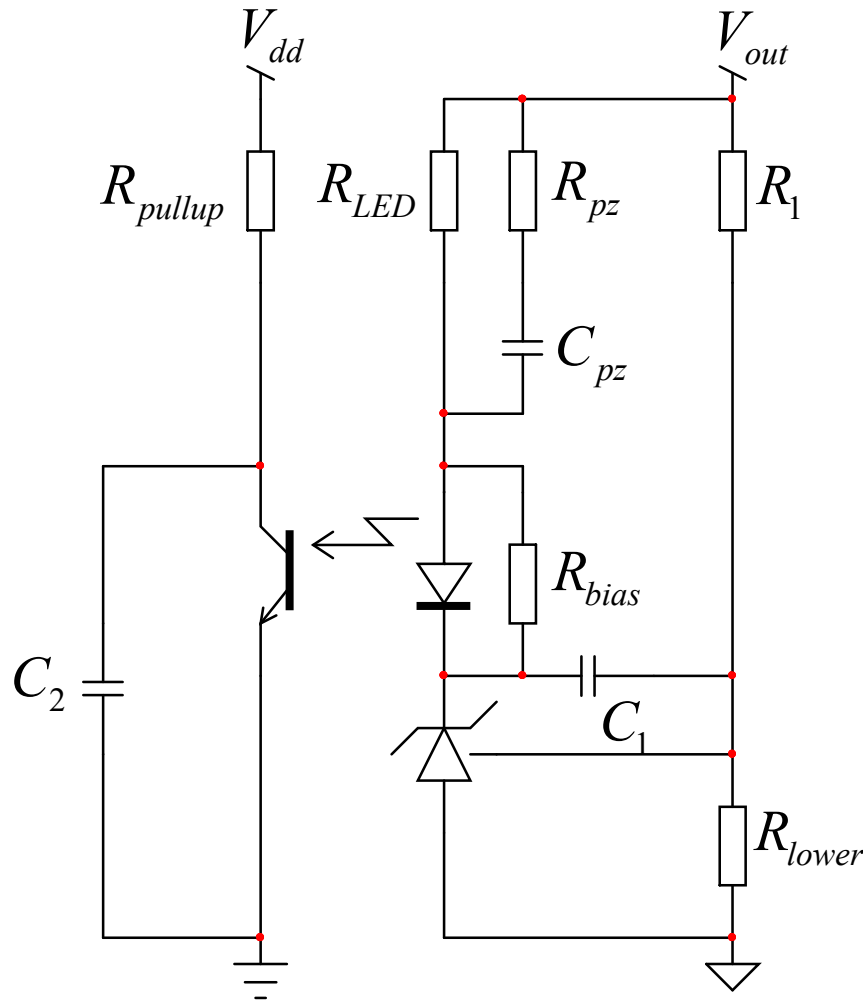
Agenda

- ❑ Feedback generalities
- ❑ The TL431 in a compensator
- ❑ Small-signal analysis of the return chain
- ❑ A type 1 implementation with the TL431
- ❑ A type 2 implementation with the TL431
- ❑ **A type 3 implementation with the TL431**
- ❑ Design examples
- ❑ Conclusion



The TL431 in a type 3 compensator

- The type 3 with a TL431 is difficult to put in practice



$$f_{z_1} = \frac{1}{2\pi R_1 C_1}$$

$$f_{z_2} = \frac{1}{2\pi (R_{LED} + R_{pz}) C_{pz}}$$

$$f_{p_1} = \frac{1}{2\pi R_{pz} C_{pz}}$$

$$f_{p_2} = \frac{1}{2\pi R_{pullup} (C_2 \parallel C_{opto})}$$

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

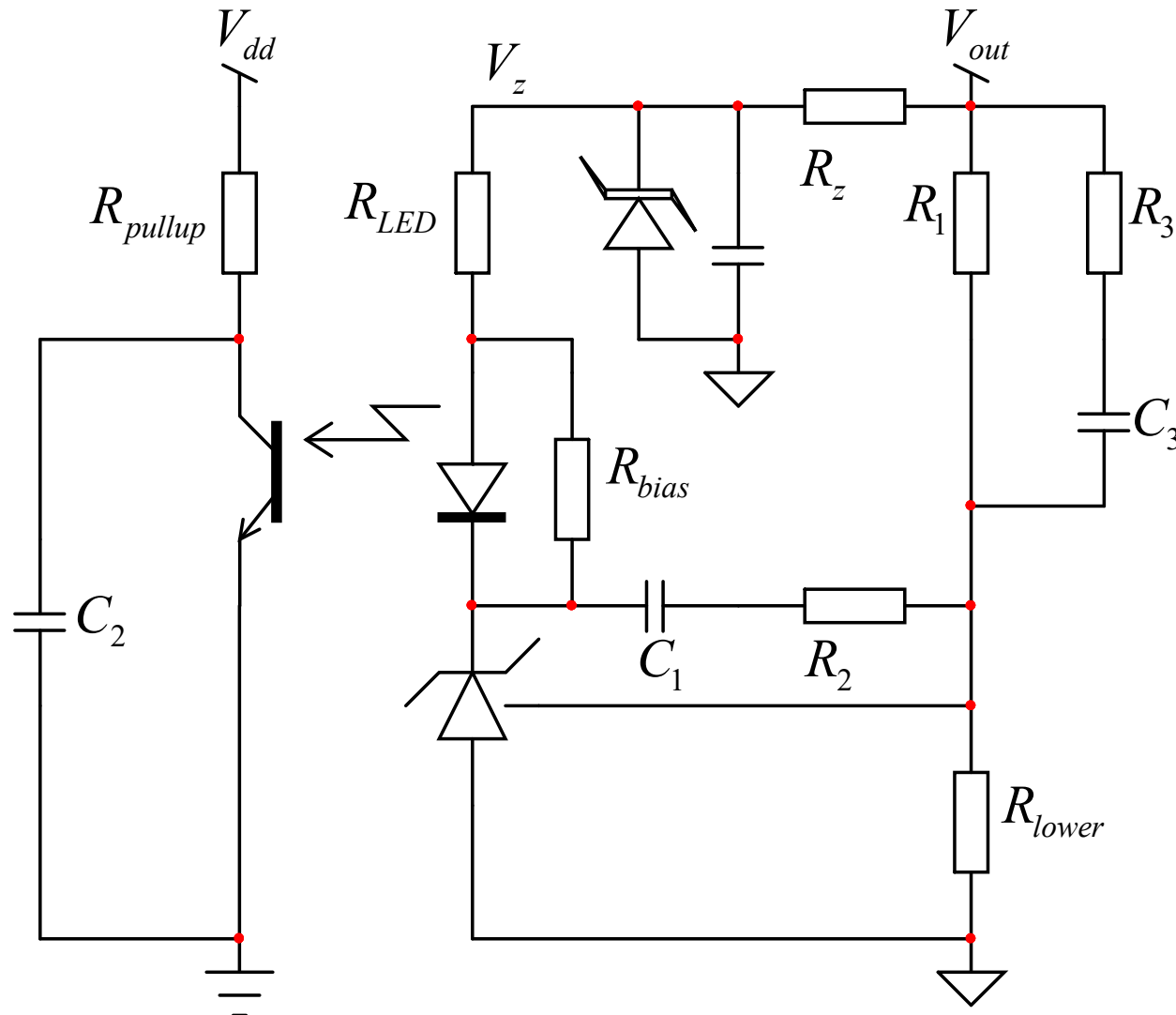
R_{LED} fixes the gain and a zero position

- Suppress the fast lane for an easier implementation!

TL431

The TL431 in a type 3 compensator

- Once the fast lane is removed, you have a classical configuration



$$f_{z_1} = \frac{1}{2\pi R_2 C_1}$$

$$f_{z_2} = \frac{1}{2\pi R_1 C_3}$$

$$f_{p_1} = \frac{1}{2\pi R_3 C_3}$$

$$f_{p_2} = \frac{1}{2\pi R_{pullup} (C_2 \parallel C_{opto})}$$

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

TL431

TL431 type 3 design example – no fast lane

- ❑ We want to provide a 10-dB attenuation at 1 kHz
- ❑ The phase boost needs to be of 120°
- place the double pole at 3.7 kHz and the double zero at 268 Hz
- ❑ Calculate the maximum LED resistor you can accept, apply margin

$$R_{LED,max} \leq \frac{V_z - V_f - V_{TL431,min}}{V_{dd} - V_{CE,sat} + I_{bias} CTR_{min} R_{pullup}} R_{pullup} CTR_{min} \leq 1.5 k\Omega \xrightarrow{\times 0.85} 1.3 k\Omega$$

- ❑ We need to account for the extra gain term:

$$G_2 = \frac{R_{pullup}}{R_{LED}} CTR = \frac{20k}{1.3k} 0.3 = 4.6$$

- ❑ The required total mid-band attenuation at 1 kHz is -10 dB

$$G_{f_c} = 10^{-10/20} = 0.316$$

TL431



TL431 type 3 design example – no fast lane

- The mid-band gain from the type 3 is therefore:

$$G_1 = \frac{G_0}{G_2} = \frac{0.316}{4.6} = 0.068 \text{ or } -23.3 \text{ dB}$$

- Calculate R_2 for this attenuation:

$$R_2 = \frac{G_1 R_1 f_{p1}}{f_{p1} - f_{z1}} \frac{\sqrt{1 + \left(\frac{f_c}{f_{p1}}\right)^2} \sqrt{1 + \left(\frac{f_c}{f_{p2}}\right)^2}}{\sqrt{1 + \left(\frac{f_{z1}}{f_c}\right)^2} \sqrt{1 + \left(\frac{f_c}{f_{z2}}\right)^2}} = 744 \Omega$$

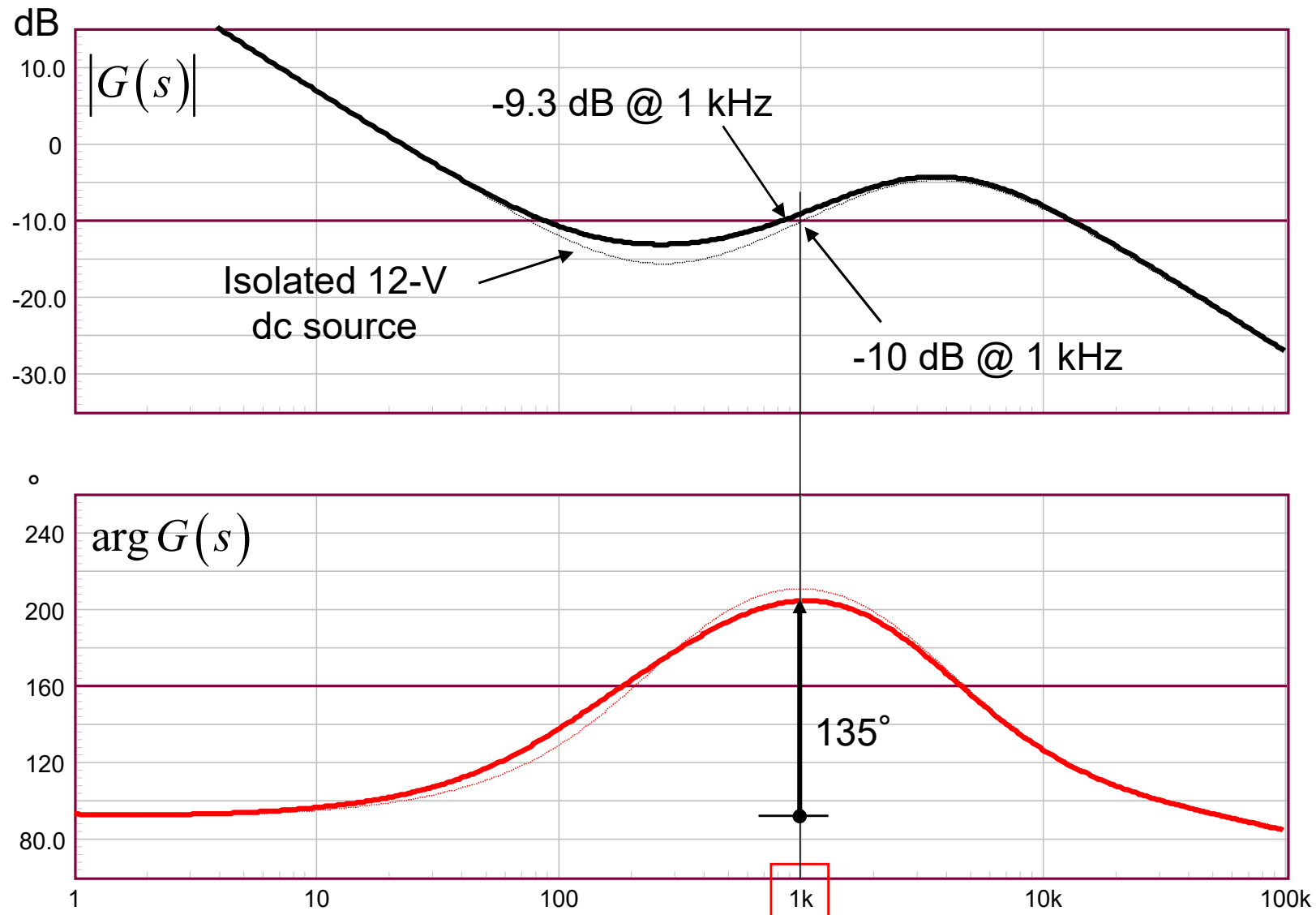
$$C_1 = 800 \text{ nF} \quad C_2 = 148 \text{ pF} \quad C_3 = 14.5 \text{ nF} \quad C_{opto} = 2 \text{ nF}$$

- The optocoupler pole limits the upper double pole position
- The maximum boost therefore depends on the crossover frequency



TL431 type 3 design example – no fast lane

- The decoupling between V_{out} and V_{bias} affects the curves



TL431

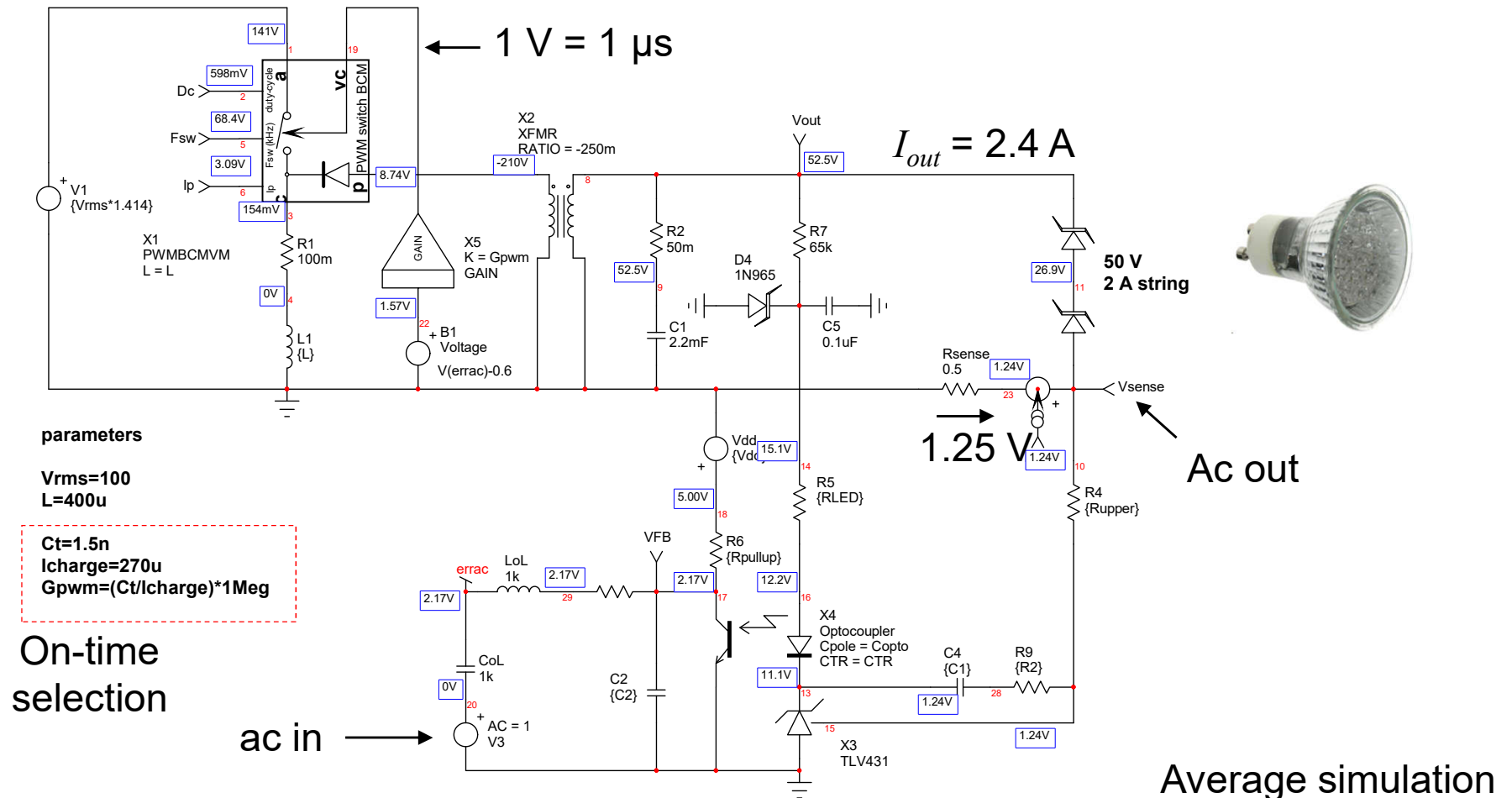
Agenda

- ☐ Feedback generalities
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- ☐ Conclusion



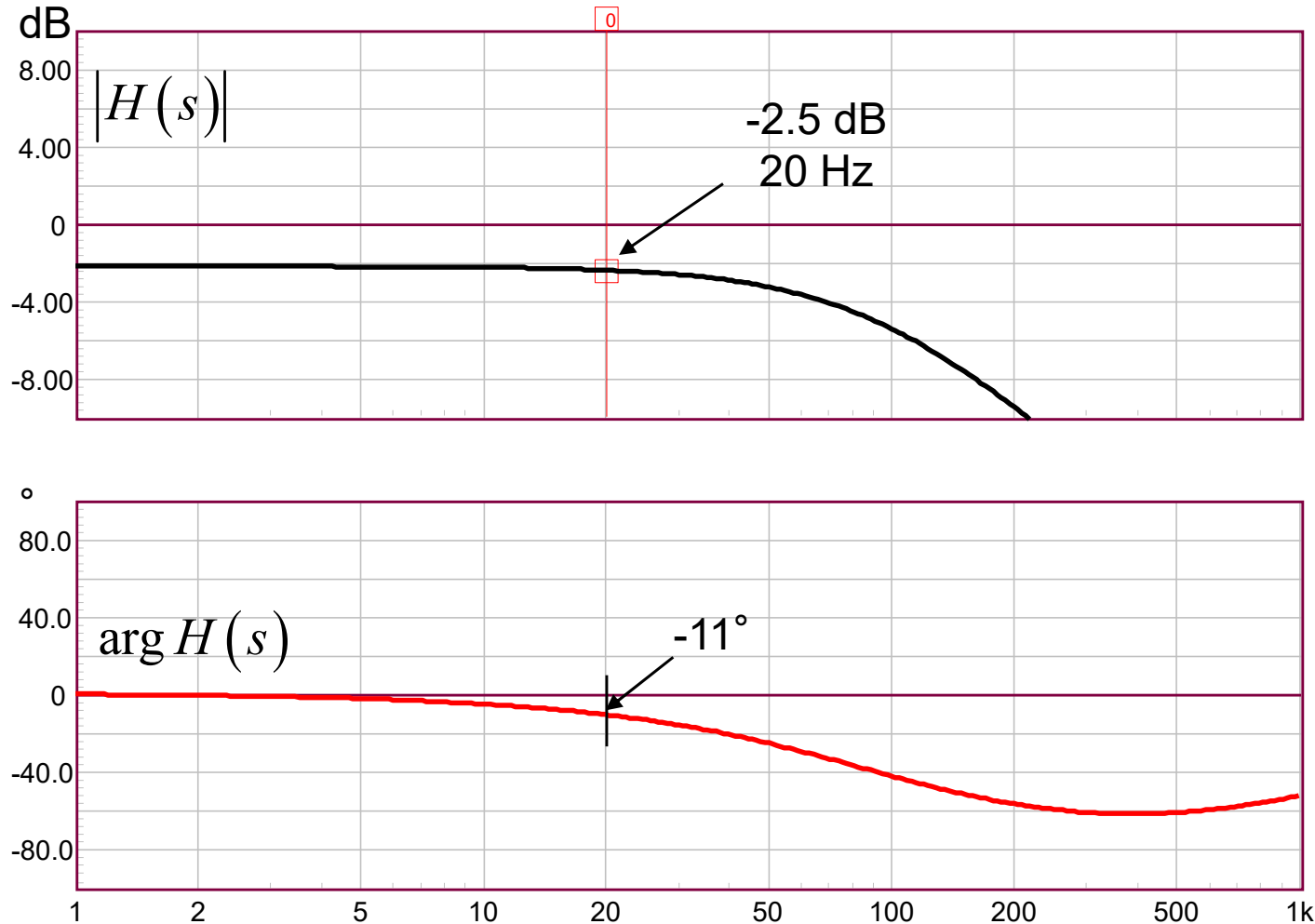
Design Example 1 – a single-stage PFC

- ❑ The single-stage PFC is often used in LED applications
- ❑ It combines isolation, current-regulation and power factor correction
- ❑ Here, a constant on-time BCM controller, the **NCP1608**, is used



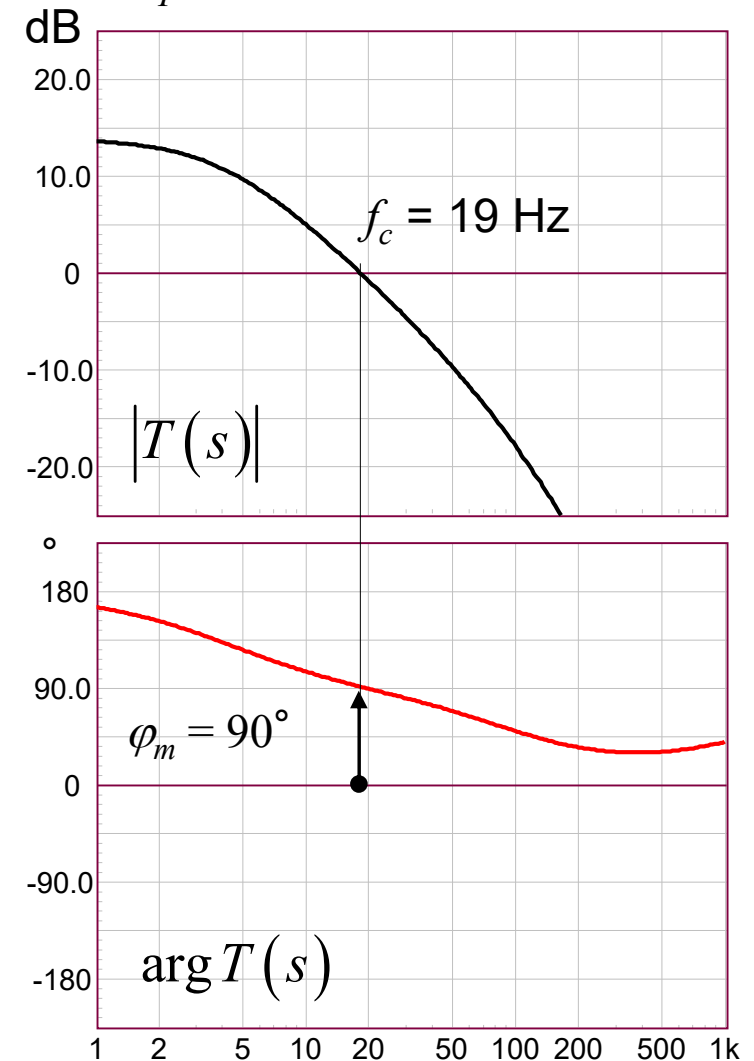
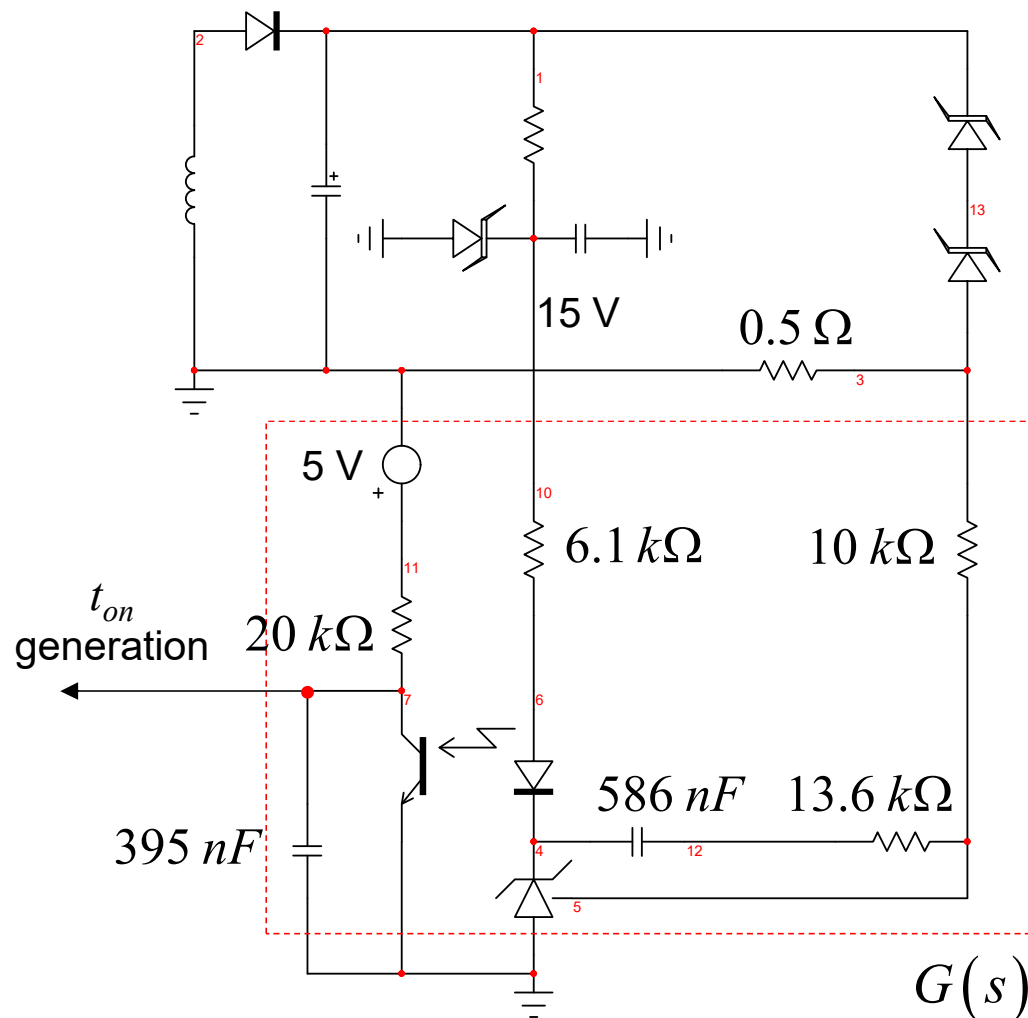
Design Example 1 – a single-stage PFC

- Once the converter elements are known, ac-sweep the circuit
- Select a crossover low enough to reject the ripple, e.g. 20 Hz



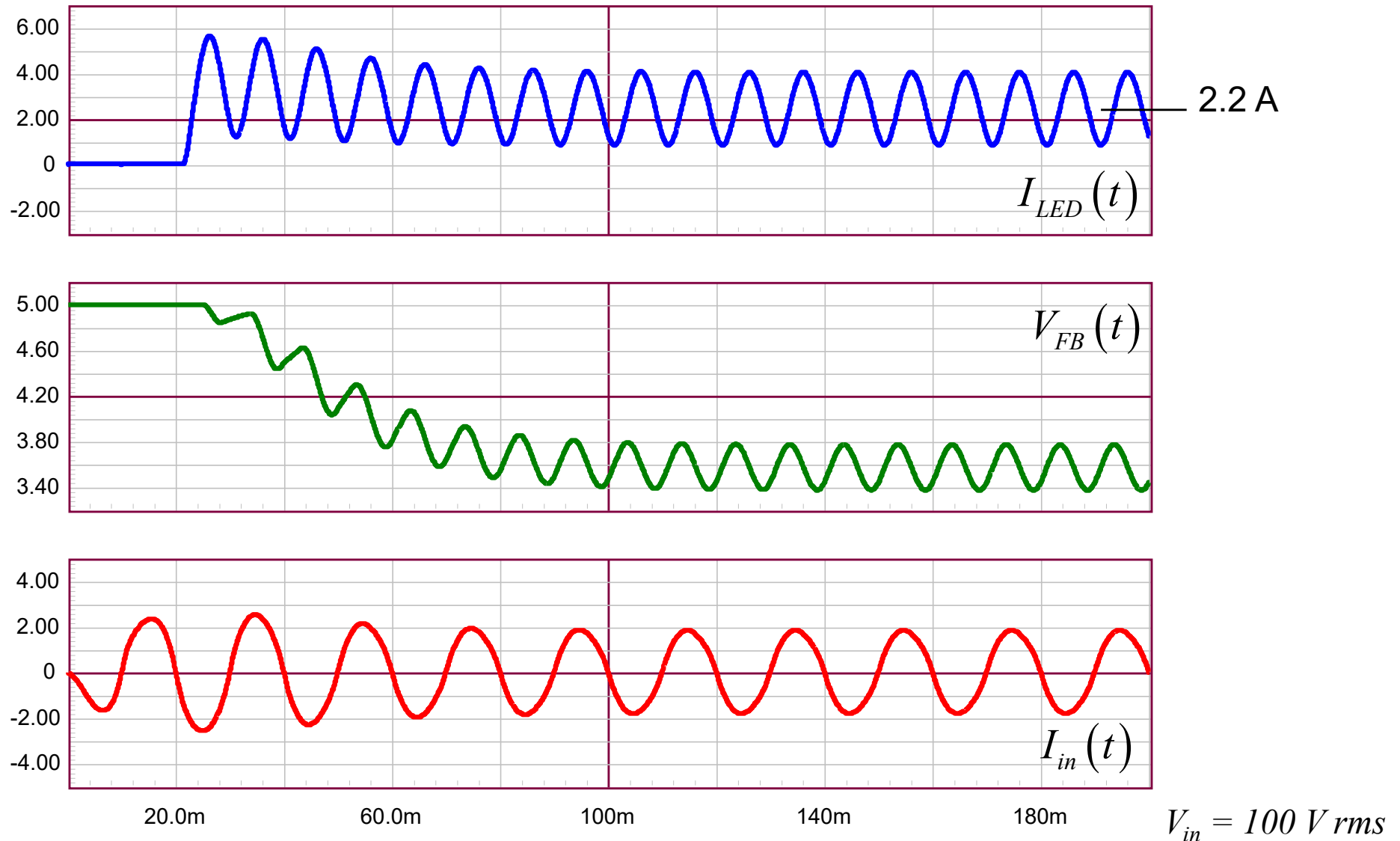
Design Example 1 – a single-stage PFC

- Given the low phase lag, a type 1 can be chosen
- Use the type 2 with fast lane removal where f_p and f_z are coincident



Design Example 1 – a single-stage PFC

- A transient simulation helps to test the system stability

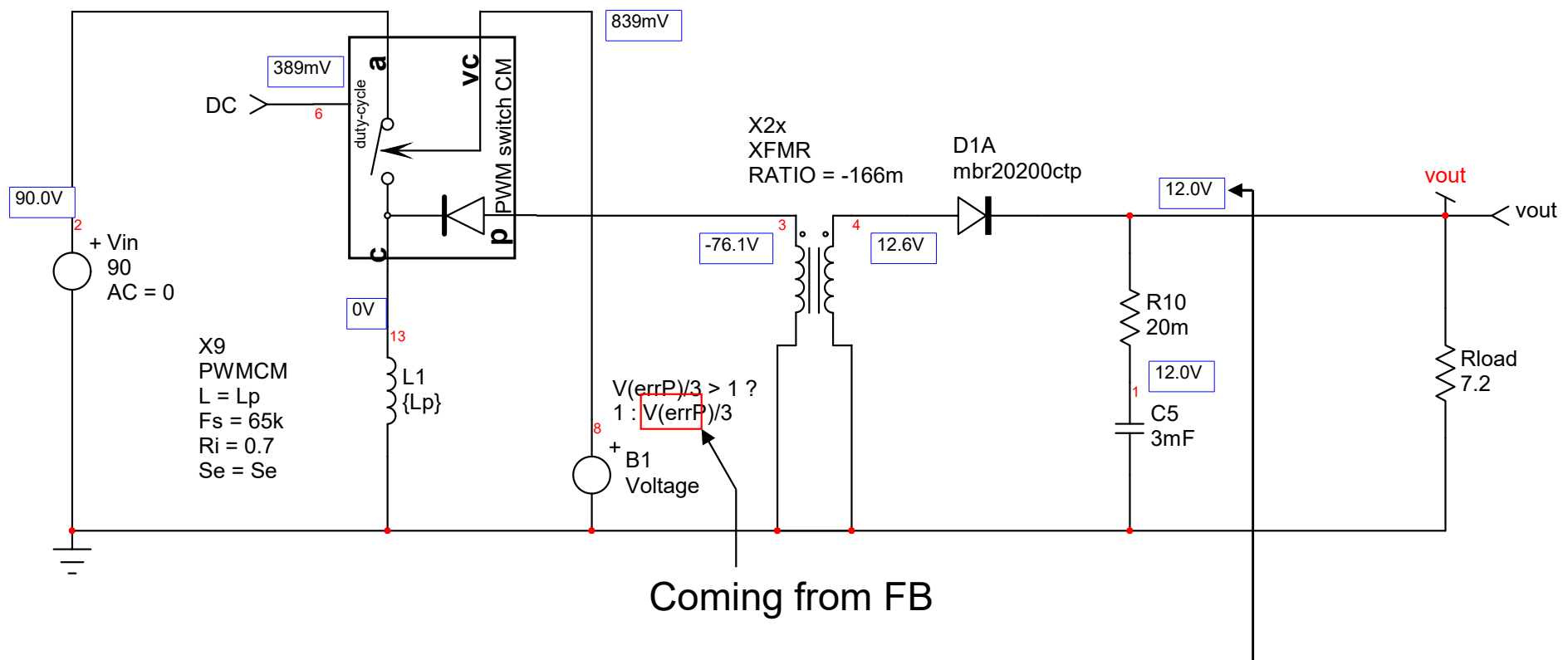


Design example 2: a DCM flyback converter

- ❑ We want to stabilize a 20-W DCM adapter
 - ❑ $V_{in} = 85$ to 265 V rms, $V_{out} = 12$ V/1.7 A
 - ❑ $F_{sw} = 65$ kHz, $R_{pullup} = 20$ k Ω
 - ❑ Optocoupler is SFH-615A, pole is at 6 kHz
 - ❑ Cross over target is 1 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



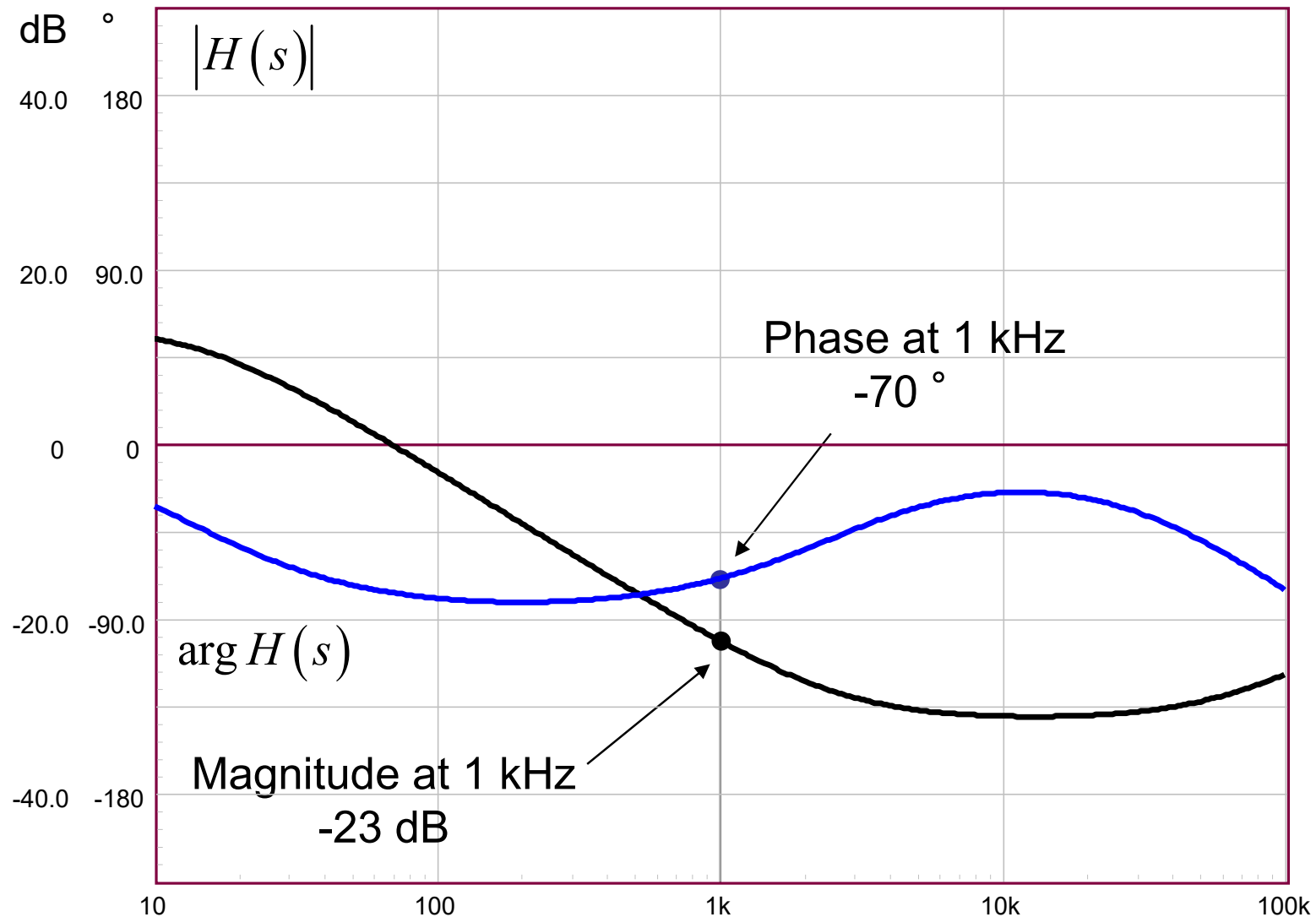
- ❑ Capture a SPICE schematic with an averaged model



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

Design example 2: a DCM flyback converter

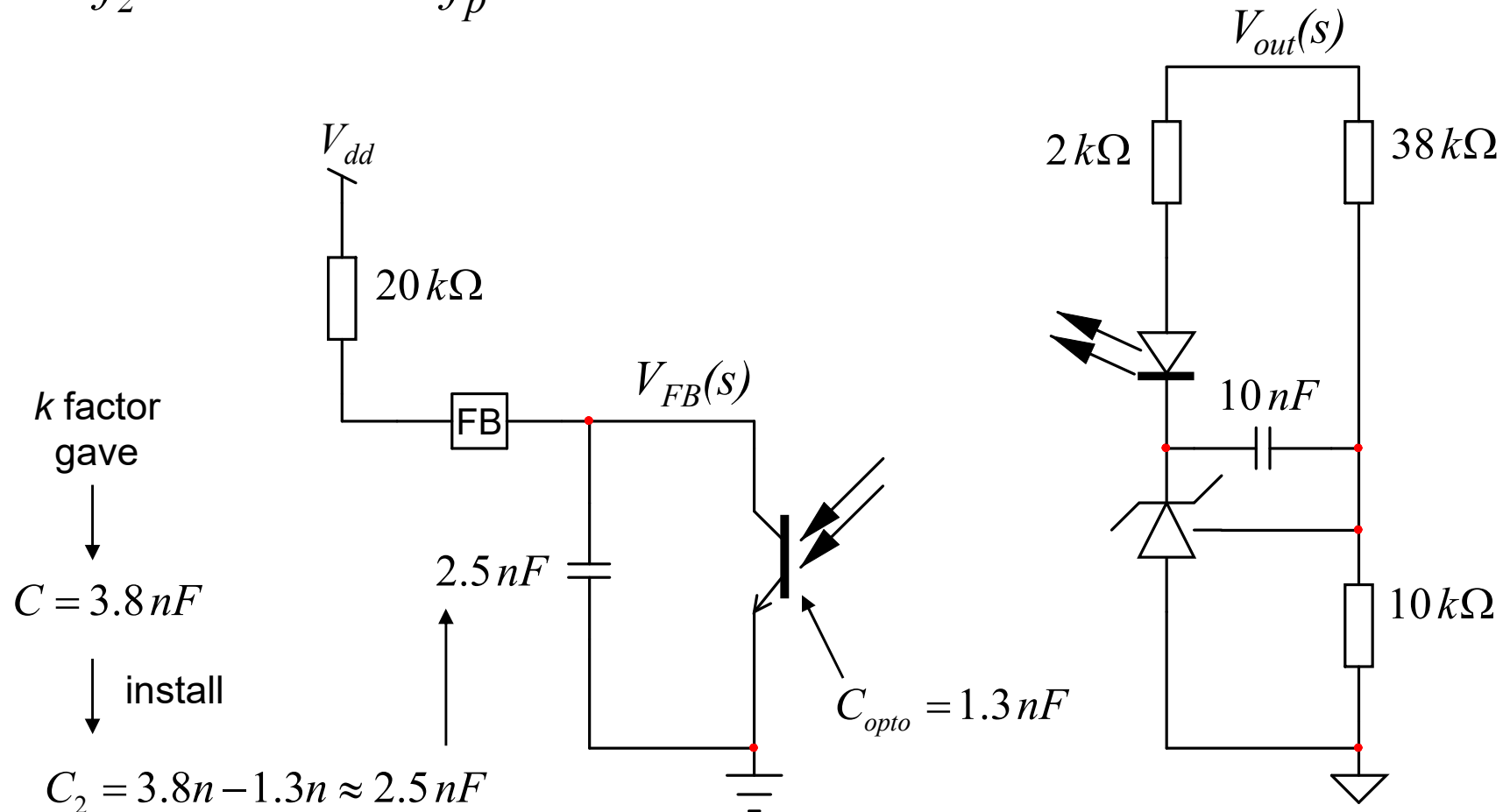
- Observe the open-loop Bode plot and select f_c : 1 kHz



Design example 2: a DCM flyback converter

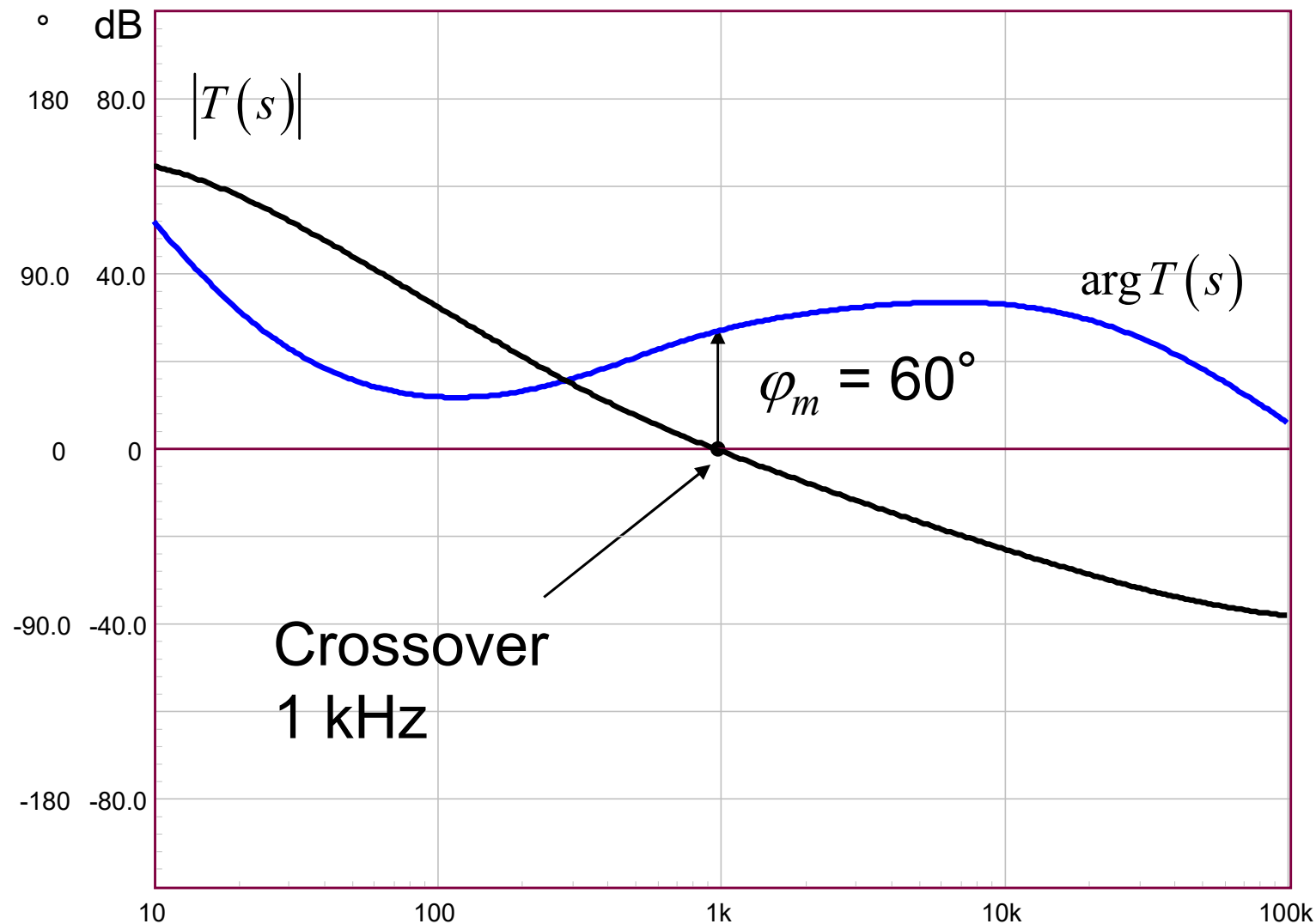
□ Apply k factor or other method, get f_z and f_p

➤ $f_z = 3.5 \text{ kHz}$ $f_p = 4.5 \text{ kHz}$



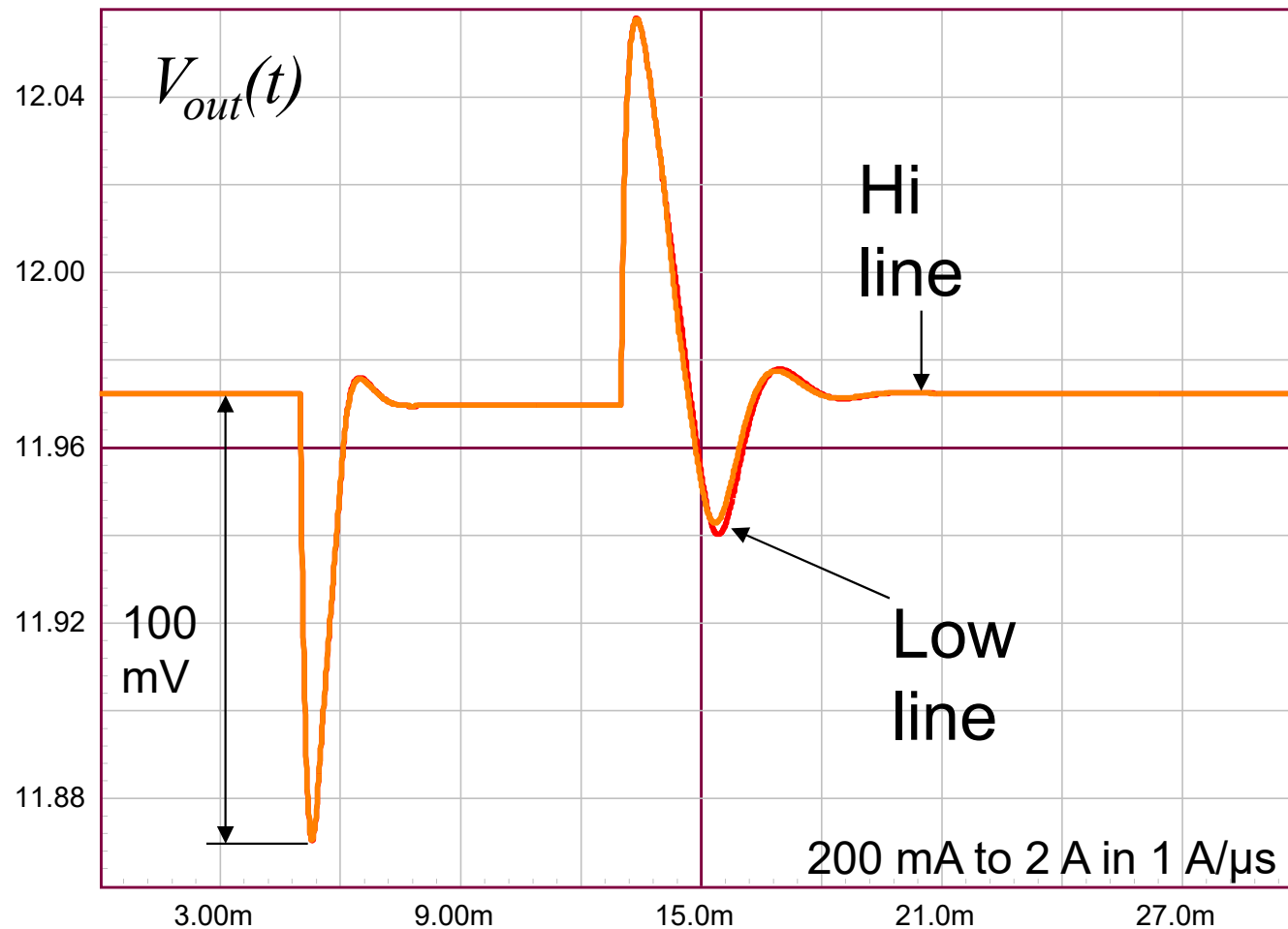
Design example 2: a DCM flyback converter

- Check loop gain and watch phase margin at f_c



Design example 2: a DCM flyback converter

- Sweep ESR values and check margins again



Excellent!



Conclusion

- ❑ Classical loop control theory describes op amps in compensators
- ❑ Engineers cannot apply their knowledge to the TL431
- ❑ Examples show that the TL431 with an optocoupler have limits
- ❑ Once these limits are understood, the TL431 is simple to use
- ❑ All three compensator types have been covered
- ❑ Design examples showed the power of averaged models
- ❑ Use them to extensively reproduce parameter dispersions
- ❑ Applying these recipes is key to design success!



Merci !
Thank you!
Xiè-xie!

