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The TL431 in a Modified Type 2 Configuration

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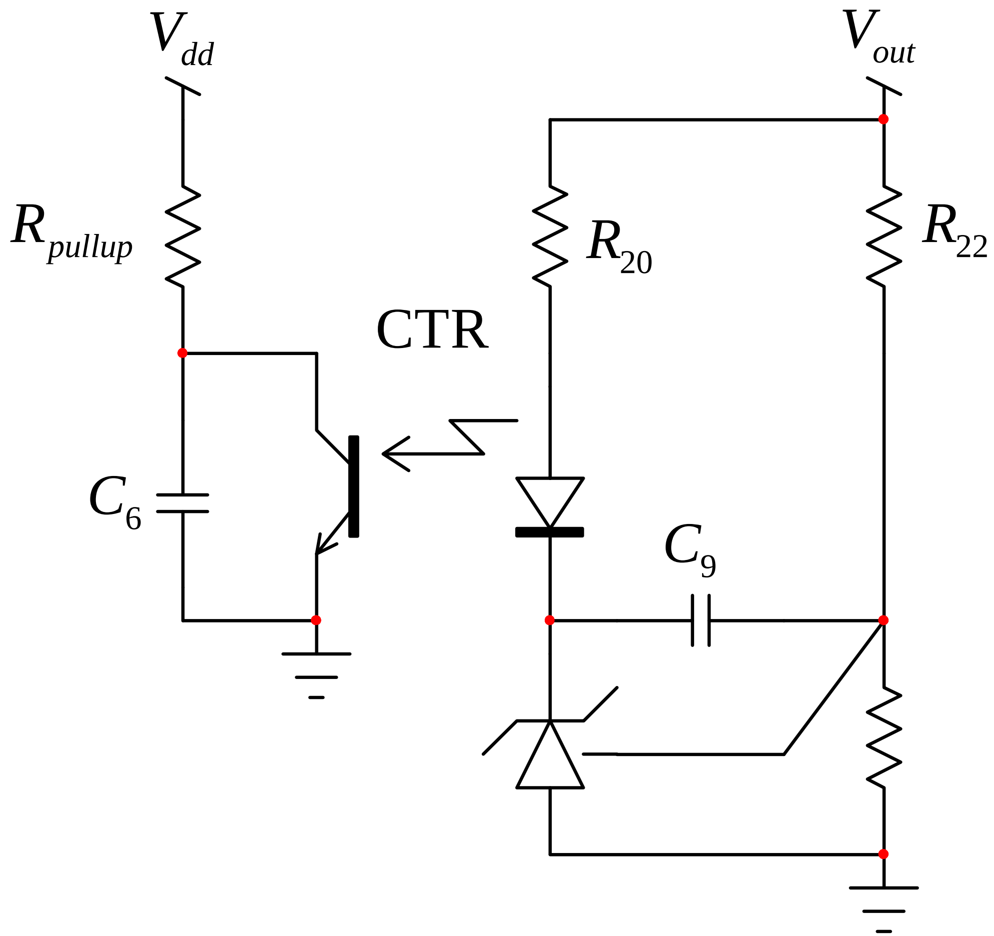
The Type 2 Configuration

- The below drawing shows a TL431 in a type 2 configuration



$$G(s) = -G_0 \frac{1+\frac{\omega_{z_1}}{s}}{1+\frac{s}{\omega_{p_1}}}$$

$$G_0 = \frac{R_{pullup}}{R_{20}} CTR$$

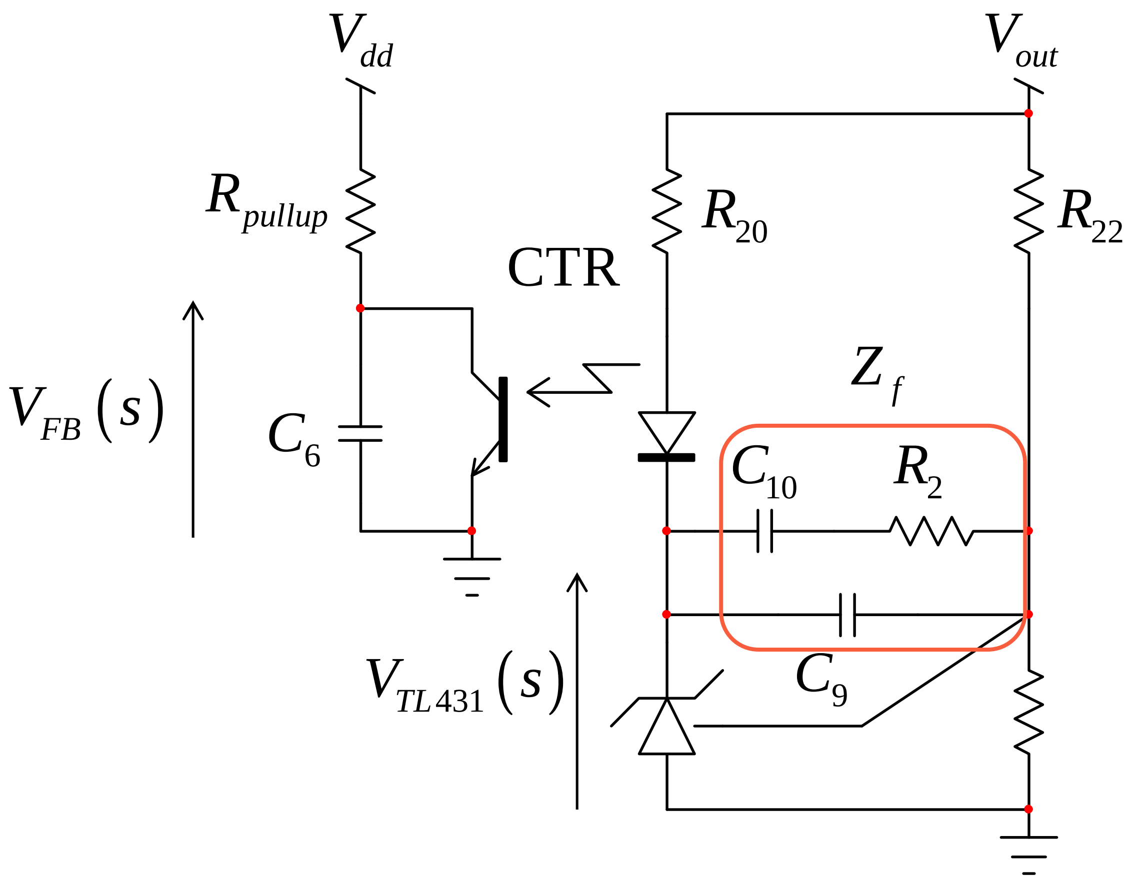
$$\omega_{z_1} = \frac{1}{R_{22} C_9}$$

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

$$C_2 = C_6 \,||\, C_{opto}$$

A Modified Version

- Some designers add an *RC* network as with an op amp



- What is the new transfer function?

Transfer Function Derivation

$$Z_f(s)=\frac{\left(R_2+\frac{1}{sC_{10}}\right)\frac{1}{sC_9}}{\left(R_2+\frac{1}{sC_{10}}\right)+\frac{1}{sC_9}} \qquad I_{LED}(s)=\frac{V_{out}(s)-V_{TL431}(s)}{R_{20}}=\frac{V_{out}(s)}{R_{20}}\left(1+\frac{Z_f(s)}{R_{22}}\right)$$

$$1+\frac{Z_f(s)}{R_{22}}=\frac{C_{10}R_2s+C_9R_{22}s+C_{10}R_{22}s+C_9C_{10}R_2R_{22}s^2+1}{s\left(C_9R_{22}+C_{10}R_{22}\right)\left(1+s\frac{R_2R_{22}C_{10}C_9}{R_{22}\left(C_9+C_{10}\right)}\right)}$$

$$1+\frac{Z_f(s)}{R_{22}}=\frac{1+s\left(C_{10}R_2+C_9R_{22}+C_{10}R_{22}\right)+s^2C_9C_{10}R_2R_{22}}{sR_{22}\left(C_9+C_{10}\right)\left(1+s\frac{R_2R_{22}C_{10}C_9}{R_{22}\left(C_9+C_{10}\right)}\right)}=\frac{1+\frac{s}{\omega_0Q}+\left(\frac{s}{\omega_0}\right)^2}{\frac{s}{\omega_{po}}\left(1+\frac{s}{\omega_{p_1}}\right)}$$

$$\omega_0=\frac{1}{\sqrt{C_9C_{10}R_{22}R_2}} \qquad Q=\frac{\sqrt{C_9C_{10}R_2R_{22}}}{R_{22}\left(C_9+C_{10}\right)+C_{10}R_2} \qquad \omega_{po}=\frac{1}{R_{22}\left(C_9+C_{10}\right)} \qquad \omega_{p_1}=\frac{C_9+C_{10}}{R_2C_{10}C_9}$$

Transfer Function Derivation

- The feedback voltage is defined by

$$V_{FB}(s) = -I_{LED}(s)\,\mathrm{CTR}\,\frac{R_{pullup}}{1+\dfrac{s}{\omega_{p_2}}}$$

- The complete transfer function becomes

$$\frac{V_{FB}(s)}{V_{out}(s)} = -G_0 \frac{1+\dfrac{s}{\omega_0 Q}+\left(\dfrac{s}{\omega_0}\right)^2}{\dfrac{s}{\omega_{po}}\left(1+\dfrac{s}{\omega_{p_1}}\right)} \frac{1}{1+\dfrac{s}{\omega_{p_2}}} \qquad G_0 = \frac{R_{pullup}}{R_{20}}\mathrm{CTR}$$

- If Q is weak

$$\frac{V_{FB}(s)}{V_{out}(s)} \approx -G_0 \frac{\left(1+\dfrac{s}{\omega_{z_1}}\right)\left(1+\dfrac{s}{\omega_{z_2}}\right)}{\dfrac{s}{\omega_{po}}\left(1+\dfrac{s}{\omega_{p_1}}\right)} \frac{1}{1+\dfrac{s}{\omega_{p_2}}}$$

2 zeros
2 poles
1 origin pole

Transfer Function Derivation

- The circuit creates an additional pole/zero pair
- However, usually, C_9 is smaller than C_{10}

$$\omega_{po} = \frac{1}{R_{22}\left(C_9 + C_{10}\right)} \approx \frac{1}{R_{22}C_{10}} \qquad \omega_{p_1} = \frac{R_{22}\left(C_9 + C_{10}\right)}{R_2 R_{22} C_{10} C_9} \approx \frac{1}{R_2 C_9} \longleftarrow$$

C_9 is small
hi freq. pole

- The double zero splits into a lo and hi-frequency zeros
- You find them by solving:

$$1 + \frac{s}{\omega_0 Q} + \left(\frac{s}{\omega_0}\right)^2 = 0 \longrightarrow s_1, s_2 = \frac{\omega_0}{Q}\frac{1 \pm \sqrt{1 - 4Q^2}}{2} \longrightarrow \left(1 + x\right)^n \approx 1 + nx$$

$$s_1 = \frac{\omega_0}{Q}\frac{1 + \sqrt{1 - 4Q^2}}{2} \approx -\frac{\omega_0}{Q}\left(Q^2 - 1\right) \approx \frac{\omega_0}{Q} \qquad s_2 = \frac{\omega_0}{Q}\frac{1 - \sqrt{1 - 4Q^2}}{2} \approx \frac{\omega_0}{Q}\frac{1 - \left(1 - 2Q^2\right)}{2} \approx Q\omega_0$$

$$\omega_{z_1} \approx \frac{1}{C_{10}R_2} + \frac{R_2 + R_{22}}{C_9 R_2 R_{22}}$$ Hi freq. zero

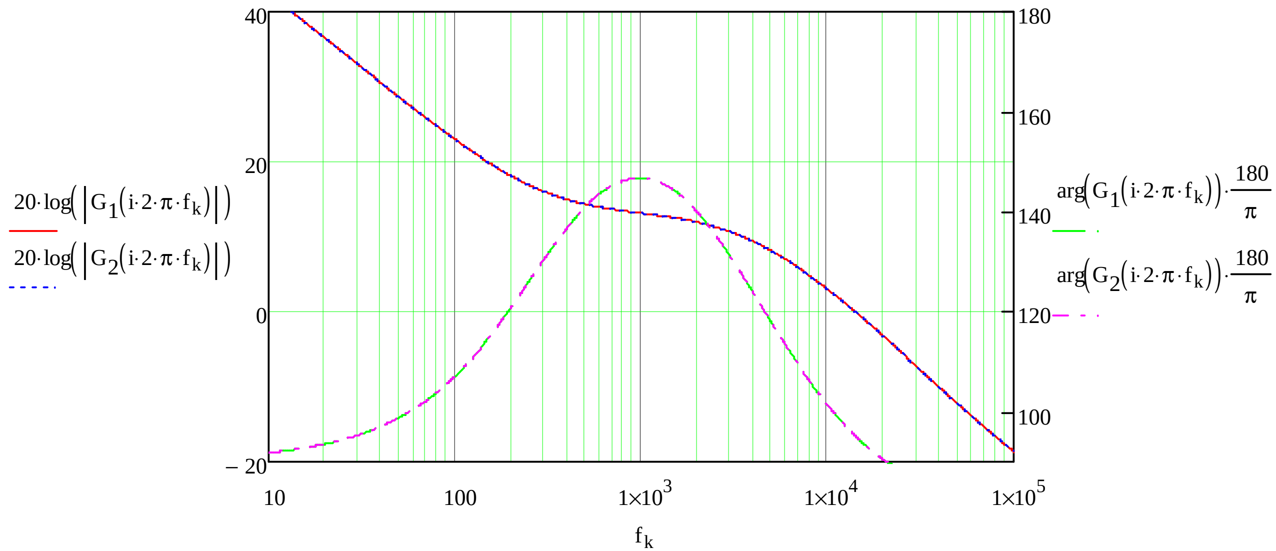
Lo freq. zero $$\omega_{z_2} \approx \frac{1}{R_{22}\left(C_9 + C_{10}\right) + C_{10}R_2}$$

Transfer Function Derivation

❑ The high-frequency pole and zero are close to each other

➢ They cancel and the whole network can be rewritten as:

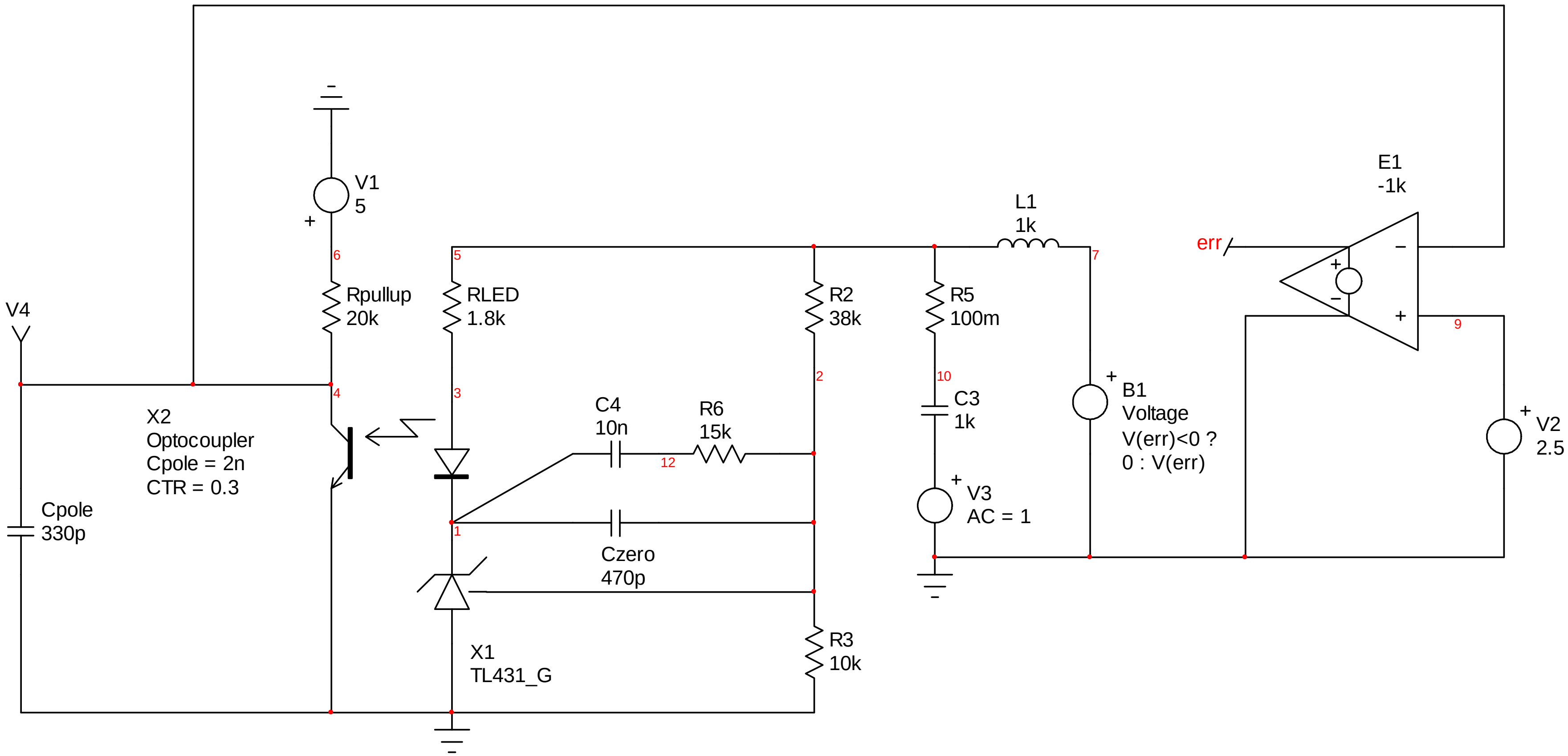
$$\frac{V_{FB}(s)}{V_{out}(s)} \approx -G_0 \frac{\left(1+\frac{s}{\omega_{z_1}}\right)\left(1+\frac{s}{\omega_{z_2}}\right)}{\frac{s}{\omega_{po}}\left(1+\frac{s}{\omega_{p_1}}\right)} \frac{1}{1+\frac{s}{\omega_{p_2}}} \approx -G_0 \frac{\left(1+\frac{s}{\omega_{z_2}}\right)}{\frac{s}{\omega_{po}}\left(1+\frac{s}{\omega_{p_2}}\right)}$$



Classical Type 2 response!

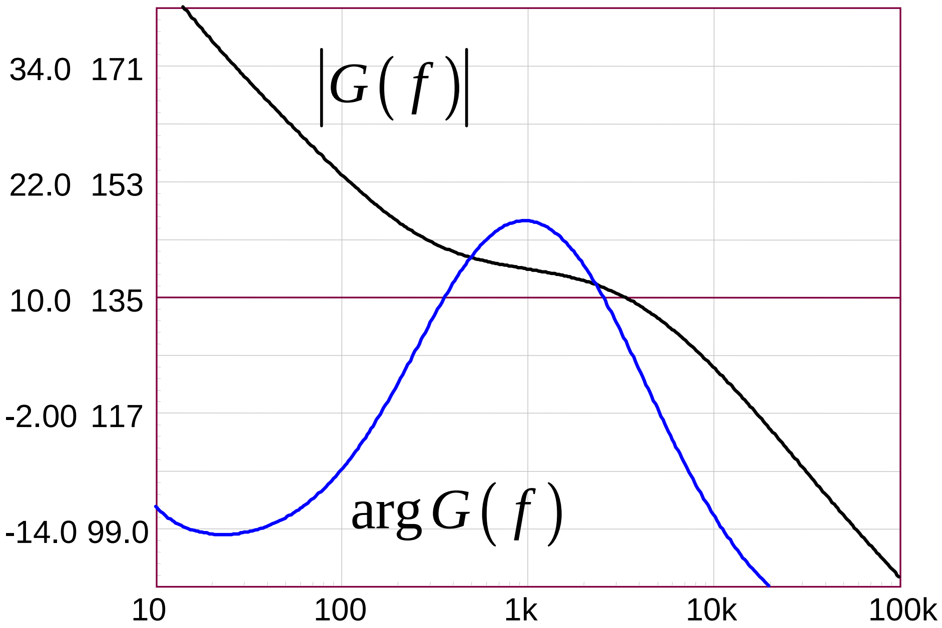
SPICE Check

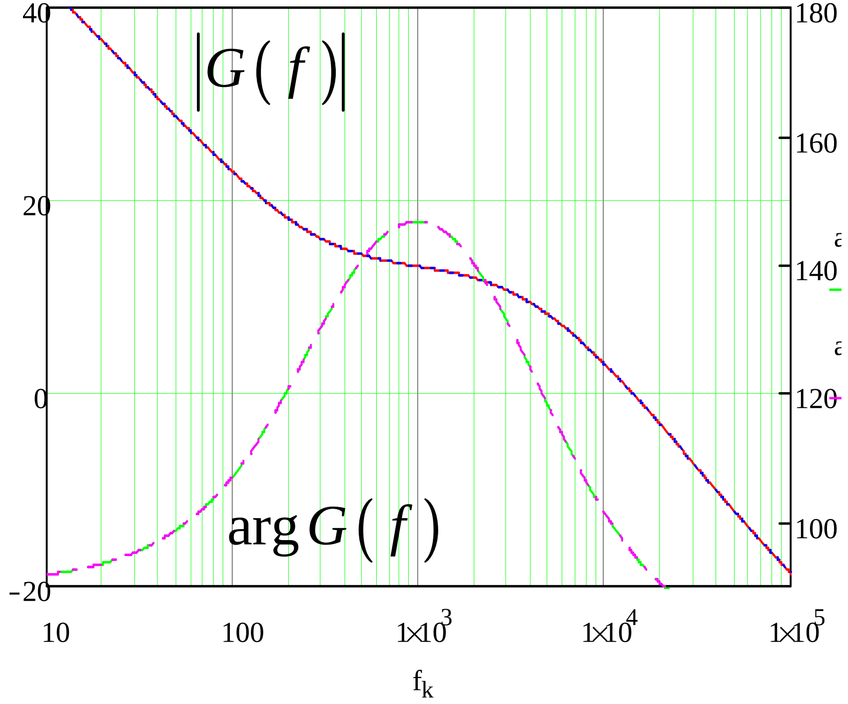
- ❑ A self-biased circuit can help verify the derivations



SPICE Check

- ❑ The curves are similar in amplitude and phase





- ❑ The derivation is correct

Conclusion

- ❑ The TL431 type 2 requires a single capacitor in the return path
- ❑ When an RC network is inserted instead, it complicates the equations
- ❑ However, results show that the response is still that of a type 2
- ❑ As a recommendation, keep the capacitor alone!