# Maximize the bandwidth for optocoupler signal transfer with current mirror receiver circuit

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Opto coupler based isolated compensator is widely used to provide output regulation in isolation converter while maintaining galvanic isolation. Controller structure as shown in Fig. 1 is the most commonly used design for this purpose.

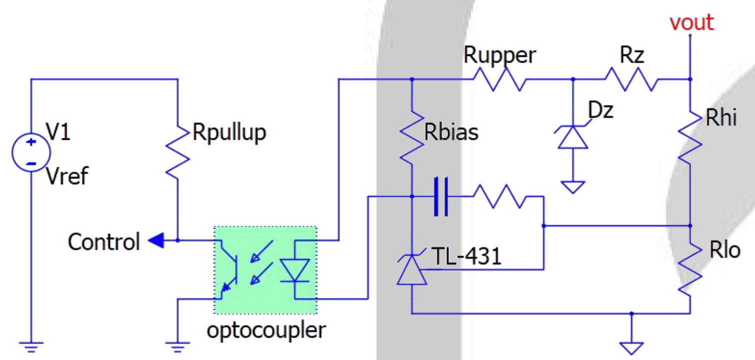


**Figure 1. Common configuration for opto-isolated compensator based on TL-431 regulator.**

While this design is very ubiquitous and has worked well for millions of product on the market. However, this design has a drawback of being only suitable for low control loop bandwidth design due to the limitation imposed by the "receiver side" of the signal isolation.

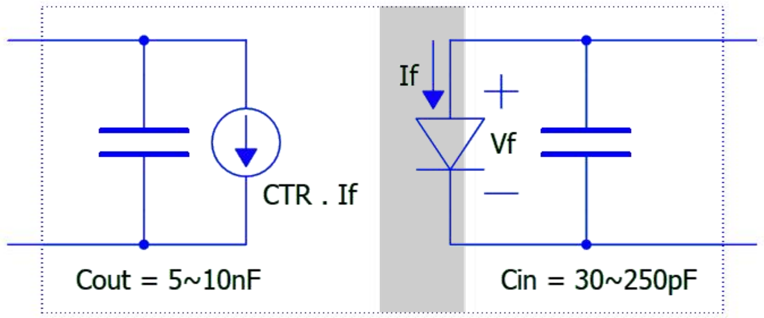


**Figure 2. Equivalent simplified circuit model of an optocoupler**

I took note and estimate the value from PC-817 and a few other for the $C_{out}$ and $C_{in}$ though it may not be written as so.

From Fig. 2, we can see that an optocoupler is typically modeled as a simple diode on the input side with a small < 500pF input capacitance and a dependent current source and a relatively large output capacitor. The reason for this large output capacitance is primarily to increase the current transfer ratio (CTR) by having large light receiving surface. Unfortunately, this optocoupler internal design optimization when used for circuit in Fig. 1 the combination of $R_{pullup}$ and $C_{out}$ will then form a pole that is often placed in very low frequency (around 1~3kHz) for a given common value of Rpullup (5k ~ 30kΩ). Meanwhile, the $C_{in}$ effect on the frequency response is considerably negligible due to its small value and also the negligible voltage swing of $V_f$ during forward bias of the LED side.

$$f_{-3dB} = \frac{1}{2\pi} \cdot R_{pullup} \cdot C_{out} \qquad (1)$$

We can now simulate the frequency response from between optocoupler LED input to the "Control" node from according to the common receiver side circuit in Qspice as shown in Fig. 3. From the simulation, we can evaluate that -3dB bandwidth is found to be at 1.77 kHz which is exactly matched with the theoretical calculation in (1). Such low pole frequency is caused by the charge-discharge of the $C_{out}$. This low pole frequency is what typically limits the overall circuit crossover frequency and thus transient response of a controller with such structure.

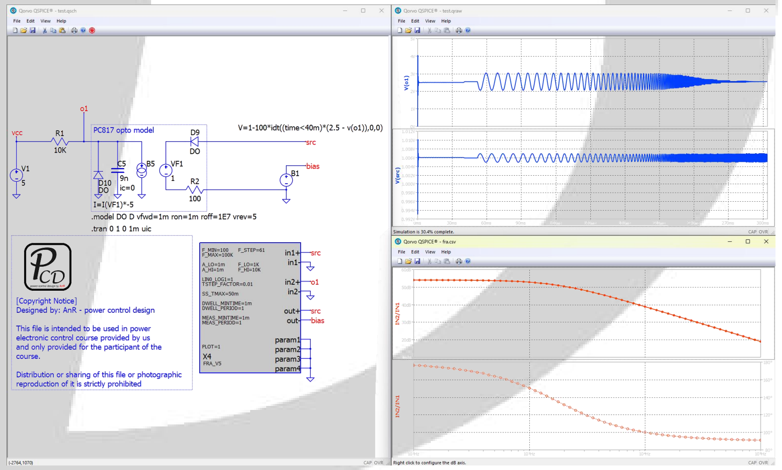

**Figure 3. Simulated frequency response of common optocoupler based circuit.**

To improve the signal isolation bandwidth, the initial design instinct might be to reduce the value of $R_{pullup}$ (or $C_{out}$, though its not possible since its intrinsic to the optocoupler). However, such option is often not feasible since the smaller Rpullup will cause (1) increased controller bias current consumption, and (2) increase the $V_{ce,sat}$ of the optocoupler. Additionally, the $R_{pullup}$ is very often already included in controller IC to minimize BOM count which makes changing its value not always possible.

So, instead what we can do is to make the $C_{out}$ to be invisible to the receiver side of the optocoupler. How?

The trick is to ensure that the optocoupler's $V_{ce}$ to be constant which eliminates the charge-discharge of $C_{out}$. While, at the same time we somehow can extract the current information from the photo receiver. For this, we can employ a current mirror circuit, Fig. 4, that can mirror the reference current on the control leg ($I_{C,Q1}$) to the controlled leg ($I_{C,Q2}$). With this circuit, the voltage across the resistor is will be constant as Vcc - $V_{be,Q1}$ with $V_{be,Q1}$ = 0.6 ~ 0.7V, and thus the reference current can be easily calculated accordingly.

Then, we can employ the current mirror to utilize its constant Vbe on the control leg to provide constant reverse bias voltage on the phototransistor then use it to provide the reference current. Lastly, we use the controlled leg on the current mirror with $R_{pullup}$ to provide the control signal.

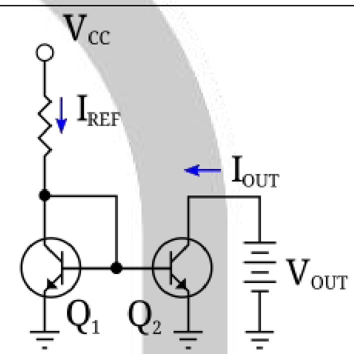


**Figure 4. NPN-based current mirror.**
https://en.wikipedia.org/wiki/Current_mirror

In Fig. 5, we can now see the simulation of the circuit simulation with current mirror. From the transient waveform, the V(supply,opto) is now only have very small voltage swing at ~11mVpp which means only tiny amount of the photodetector's current is used to charge-discharge the $C_{out}$ and thus removing the effect of $C_{out}$ to almost negligible. The circuit output is then observed from $R_{pullup}$ with the controlled leg that has nearly flat magnitude on the frequency response with $f_{-3dB}$ at > 100kHz. It then allows the flexible placement of the controller pole when implementing Type-2 controller which allows for higher system crossover frequency. Another advantage of this circuit is that it maintain the inverted input to output relationship as with the traditional circuit, which allow it to be used with the common TL-431 based compensator.

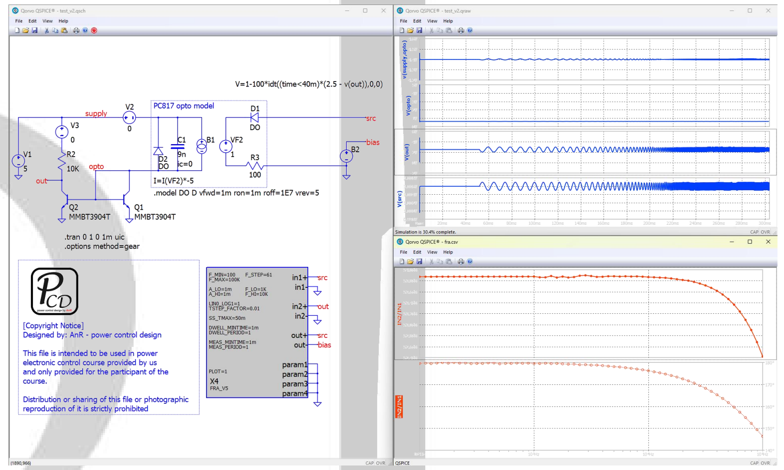

**Figure 5. Simulated frequency response of optocoupler with current mirror**

Note that, this simulation only consider a simplistic model of optocoupler, thus on practical circuit, a more moderate $f_{-3dB}$ may be expected though improvement of > 10x compared to the conventional circuit is still realistic.

Ref:
[1] https://www.ednasia.com/current-mirror-boosts-pwm-regulators-performance/
[2] https://www.ti.com/lit/ds/symlink/ucc256403.pdf
[3] https://www.analog.com/media/en/technical-documentation/data-sheets/4430fd.pdf