Reference	V_{ref}	$I_{bias,min}$	Precision	Max. voltage	Max. current
TL431I	2.495 V	1 mA	± 2% @ 25 °C	36 V	100 mA
TL431A	2.495 V	1 mA	± 1% @ 25 °C	36 V	100 mA
TL431B	2.495 V	1 mA	± 0.4% @25 °C	36 V	100 mA
TLV431A	1.24 V	100 µA	± 1% @25 °C	1 V	20 mA
TLV431B	1.24 V	100 µA	± 0.5% @25 °C	1 V	20 mA

Appendix 3B describes the SPICE models of a behavioral TL431, which we extensively used in all the book examples. This model can work on *IsSpice* or *PSpice* and has proved to properly reflect reality.

In Fig. 3-35b, the resistive network $R_{upper} - R_{lower}$ senses the output voltage and biases the TL431 reference pin. When the output is above the reference, the TL431 reduces its cathode voltage and increases the LED current. This, in turn, reduces the feedback set point, and the converter delivers less power. On the contrary, when the output is below the target, the TL431 almost leaves the cathode open and stops pumping current into the LED. As a result, the primary feedback allows for more output power, pushing the converter to increase the output voltage until the TL431 detects the target is reached. The converter can accept two different optocoupler configurations, described as solutions A and B:

- *Solution A*: This is a common emitter configuration as found on popular controllers such as ON Semiconductor's NCP1200 series. Bringing the FB pin down reduces the peak current in this current-mode controller. This solution also exists on UC384X-based designs where the collector can directly drive the output of the internal op amp.
- *Solution B*: In this common collector configuration, the emitter pulls high the FB pin to reduce the duty cycle or the peak current set point. This option usually requires an inverting amplifier inside the controller.

As you can see in Fig. 3-35b, the LED branch is called the "fast lane" whereas the divider network is tagged "slow lane." The slow lane uses the internal op amp to drive the TL431 output transistor and fixes the dc operating point via the resistive network divider $R_{upper} - R_{lower}$. Thanks to the presence of the capacitor C_{zero}, it is possible to introduce an origin pole and thus roll off the gain as a standard type 1 amplifier would do. Alas! Above a certain frequency range, because C_{zero} has completely rolled off the gain, the shunt regulator no longer behaves as a controlled zener diode. The internal op amp still fixes the dc bias point but no longer ac controls the shunt regulator as its gain has gone to a low value via the impedance of C_{zero}. The sketch thus simplifies to Fig. 3-36 (with solution A, for instance) where the TL431 becomes a simple zener diode. For the small-signal study, we can replace this diode by a fixed voltage in series with its internal impedance, the LED undergoing the same translation. However, as the sum of these dynamic resistors remains small compared to R_{LED}, we can easily neglect them in the final calculation.

From Kirchhoff's law,

$$V_{FB}(s) = -I_1 R_{pullup} \text{CTR} \tag{3-53}$$

where CTR represents the optocoupler current transfer ratio, a gain linking the quantity of photons collected by the transistor base and the collector current they engender: $I_c = I_1\text{CTR}$. Considering constant the LED voltage drop and the zener voltage, their derivative terms are zero in the small-signal analysis, therefore:

$$I_1 = \frac{V_{out}(s)}{R_{LED}} \tag{3-54}$$

Substituting Eq. (3-54) into Eq. (3-53) gives

$$\frac{V_{FB}(s)}{V_{out}(s)} = -\frac{R_{pullup}}{R_{LED}}\text{CTR} \tag{3-55}$$