compared to the voltage-mode design that overshoots quite a bit. If we now zoom in on the output voltage for the current-mode design, we can see a negative answer: this is typical of current mode. If we injected more compensation ramp, the current-mode undershoot would increase until it became similar to that of the voltage mode. It would be an overcompensated design.

We can see through this example the good behavior of the k factor with current-mode supplies, mainly first-order systems in the low-frequency portion (before subharmonic poles). In some cases, designers might prefer to manually place the poles and zeros after the crossover frequency has been chosen. This is possible with the type 2 amplifier, and the derivation has been documented in App. 3C. You mainly select your pole and zero locations and calculate the resistor R_2 to generate the right gain at f_c.

3.6.10 The Current-Mode Model and Transient Steps

The current-mode model, in its CCM, DCM, or autotoggling versions, puts a rather heavy burden on the SPICE numerical solver. As a result, simulations can sometimes fail to properly converge when the step occurs in transient runs. The ac analysis does not usually show any problem since the operating point is calculated before the simulation starts. But in transient, some particular modes can lead to trouble. Here is a quick guide to get rid of the convergence issues in transient:

- This is one drawback of the current-mode autotoggling model: if during the transient you transition between the two modes, CCM or DCM, then the resonating capacitor connection or disconnection can lead to convergence issues. The best thing is to then put a star at the beginning of the SPICE code that describes the capacitor expression in the PWMCM subcircuit, as suggested below:

```
* C1 c p C=V(mode) > 0.1 ? {4/((L)*(6.28*Fs)^2)} : 1p ; IsSpice
* XC1 c p mode varicap                             ; PSpice
```

- Increase the transient iteration limit which is the number of trials before a data point is rejected. By default, *ITL4* = 100. Increasing to 300 to 500 helps to solve "Time step too small" errors.
- Relax the relative tolerance *RELTOL* to 0.01.
- If it still fails, relax the absolute current and voltage error tolerance, respectively, *ABSTOL* and *VNTOL*. Values such as 1 µ for *ABSTOL* and 1 m for *VNTOL* usually help a lot.
- Increase *GMIN* to 1 nS or 10 nS. *GMIN* is the minimum conductance in each branch. It helps convergence in deep nonlinear circuits by linearly routing some current out of the nonlinear element.

3.7 FEEDBACK WITH THE TL431

Showing compensation circuits around an op amp is an interesting thing, but the industrial design world differs in reality. The TL431 presence in feedback systems is overwhelming, and few designs still use a true operational amplifier. Why? Because the TL431 already includes a stable and precise reference voltage with an error amplifier. Even if its open-loop gain cannot compete against a true op amp, it is good enough for the vast majority of product definitions. What exactly is a TL431? Figure 3-35a shows the internal arrangement of the device. You can observe a reference voltage of 2.5 V biasing an operational amplifier inverting input.