Application Report

SLVA685–June 2015

Designing with the "Advanced" TL431, ATL431

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ABSTRACT

This application note will discuss TI's latest addition to its adjustable shunt regulator family, ATL431. ATL431 offers the lowest minimum cathode current for regulation ($I_{KA(min)}$) and reference current (I_{REF}) of the 431 family of shunt references. Which can equate to much Iq savings on the systems level. Key ATL431 features and the benefits that it presents to common adjustable shunt regulator applications will be discussed along with a comparison with the existing TL431 solution.

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  - $I_{KA(min)}$ = 35 µA (max)
  - I_{REF} = 100 nA (max)
  - I_{OFF} = 200 nA (max)
- Stability
- Improved Absolute Accuracy
  - Low Output Impedance of 0.05 Ω
  - 5mV Temperature Drift
  - Low Voltage Modulation (–400 µV $\Delta V_{REF}/\Delta V_{KA}$)

2 Features

2.1 *Iq --> I_{KA} and I_{REF}*

With shunt regulators contributing little to the overall system BOM cost, they can contribute much to the system's overall power budget, becoming a pain for many designers. Many times the power consumed by these components are compensated by more expensive core devices like DC - DC controllers, data acquisition circuits and MCUs.

ATL431 solves this problem with its lower current consumption from the cathode and reference pins, denoted as I_{KA} and I_{REF}. $I_{KA(min)}$ is the minimum current the active circuitry needs to be biased in the proper operating region to give ATL431 enough gain to regulate. With ATL431 being a bipolar technology, it also needs a base current for the BJTs and this is given by I_{REF}. As shown in the application example below (Figure 1), these can lead to two sources of quiescent current (Iq).

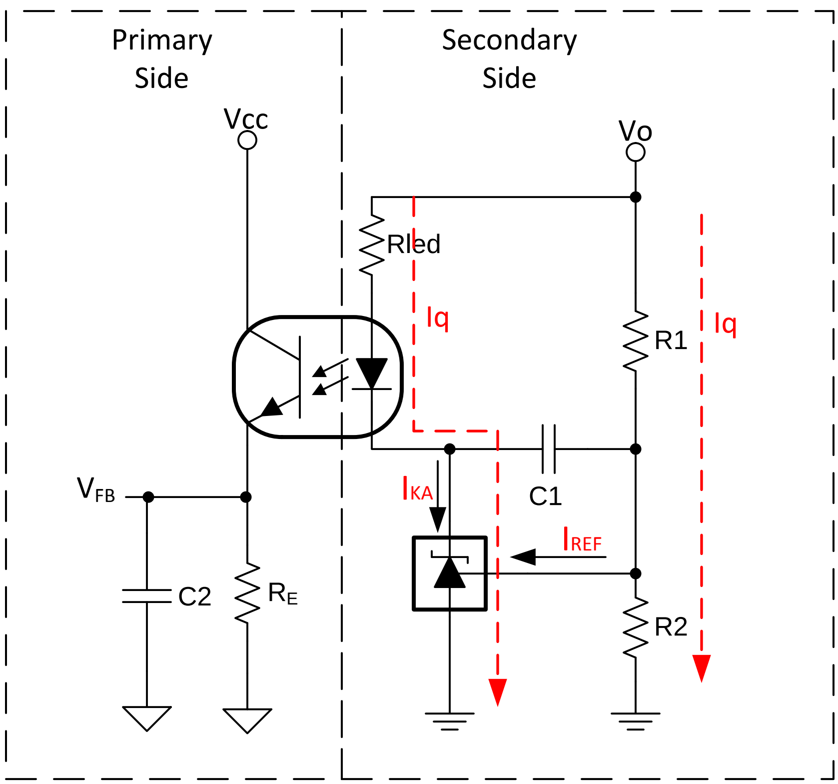


Figure 1. Error Amp Section of Flyback Supply

As shown in Table 1 at least 1 mA of I_{KA} is need to bias TL431 and 35 µA for ATL431 for regulation. These are the maximum values, as it is recommended to use these as a worst case scenario due to process variation. It should also be considered that the $I_{KA(min)}$ spec is the minimum current needed for regulation and not accuracy. This means that the shunt regulator will not be biased to it's full gain potential. Because ATL431 is a shunt regulator, it is most useful to represent this device as a voltage controlled current device or an operational transconductance amplifier (OTA). The gain of an OTA is represented as transconductance ($Gm = \Delta I_{KA} / \Delta V_{KA}$).

$I_{KA(min)}$ represents the inversion region of the shunt regulator between operable transconductance and optimum transconductance . As shown in Figure 2, there exists four regions of Gm.

1. Minimum Gm
2. Low Gm Region
3. Inversion Region
4. Optimum Gm

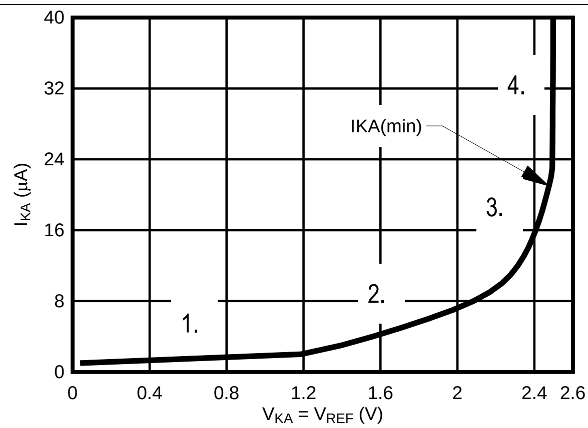


Figure 2. ATL431 Inversion Region

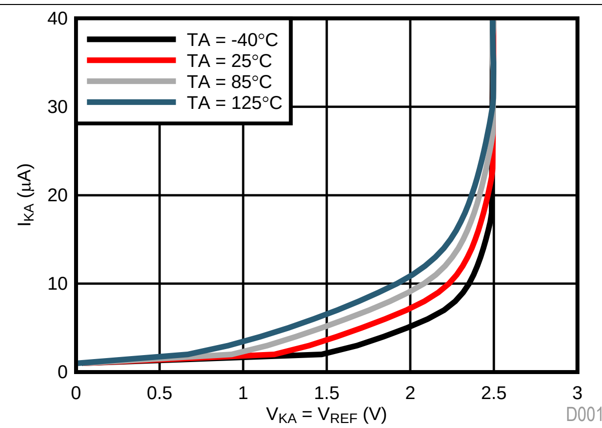


Figure 3. ATL431 Inversion Region vs. Temperature

For ATL431, it is recommended to use a minimum cathode current of 40 µA for optimum gain performance. This value takes in to account the temperature variation of $I_{KA(min)}$ (see Figure 3), process variation and is well within the optimum Gm region.

2.2 Stability

2.2.1 Error Amplifier

The 431' families of shunt regulators were designed to have wide bandwidth while ensuring stability without any external frequency compensation. This makes the device useful in control loop applications and as reference voltage generators without external capacitance. These attributes are also very useful in 431's key application as an error amplifier in a Flyback SMPS system where it is uncommon to place a capacitor between the cathode and anode.

One of the drawbacks of the current TL431 is that it has a unity gain bandwidth of 2 MHz, allowing power supply noise and ripple to be fed back to the controller. The ATL431 has a unity gain bandwidth of 250 kHz as shown in Figure 4. The lower bandwidth of the ATL431 helps to attenuate high frequency ripples on the output of the power supply so they are not fed back to the controller. Whereas designers will add a pole on the output of the high frequency error amplifiers to attenuate ripple.

Another advantage of the ATL431's frequency response in flyback supplies is its flat phase response or low phase shift over typical crossover frequencies from 1 kHz to 100 kHz (see Figure 4). A flat phase response allows designers control of any desired lag or lead with external passive components.

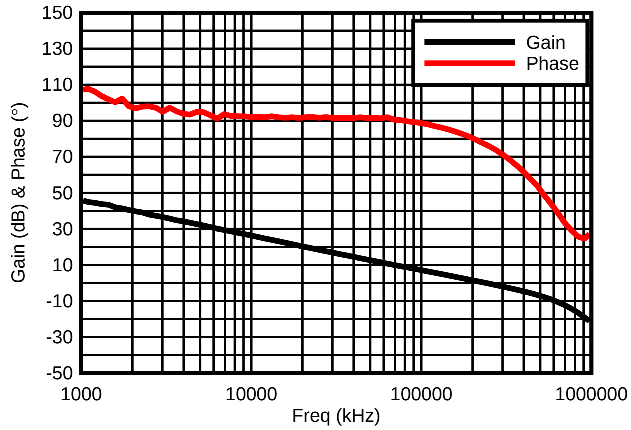
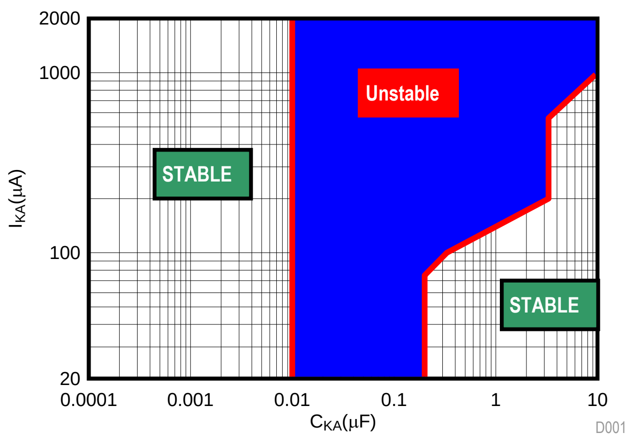


Figure 4. ATL431 Frequency Response

2.2.2 Shunt Regulator

Stability is a large concern when designing with shunt regulators. Unless the goal is to design the ATL431 as an oscillator, it is best to operate this device in its stable regions. For use as a reference or linear regulator (closed loop), it is often tempting to apply a capacitor between the cathode and anode of shunt regulators for noise bypassing or stabilizing of legacy devices that aren't very stable with no capacitive load. Because ATL431 is pin to pin compatible with many of these devices, designers need to consider the stability regions of ATL431 in the shunt regulator configuration.

Figure 5 shows one of many stability regions for ATL431 (for more, please see the typical characteristics section in the datasheet). V_{KA} = 2.5 V is the most common use and worst case stability region. To reduce BOM and costs, the ATL431 was designed to be very stable with a 0 pF of load capacitance. As shown in Figure 5, it is very stable with low capacitance with a wide margin of capacitance values (up to 10 nF).



A ESR < 20mΩ

Figure 5. Low I_{KA} (V_{KA} = 2.5 V) Stability Boundary

One key difference in ATL431's stability boundary plots from other shunt regulators is the ESR value denoting. These plots were determined using ceramic capacitors that typically have very low ESR less than 20 mΩ.

To use a larger capacitance that is within the instability region, it is recommended to add additional ESR to the load capacitance or use a high ESR capacitor. Figure 6 through Figure 8show the minimum recommended series resistance to add for desired output capacitance to improve phase margin and make ATL431 stable.

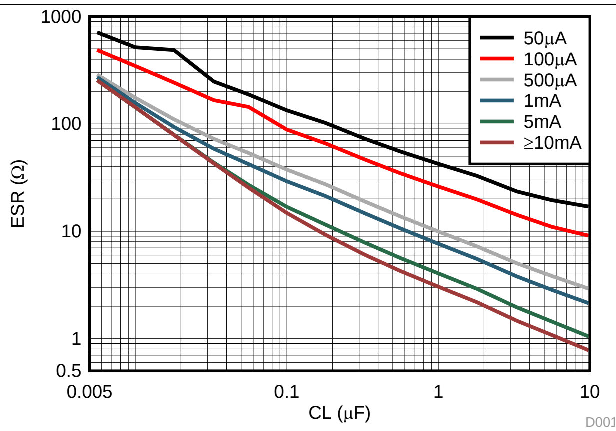


Figure 6. ESRs at V_{KA} = 2.5 V

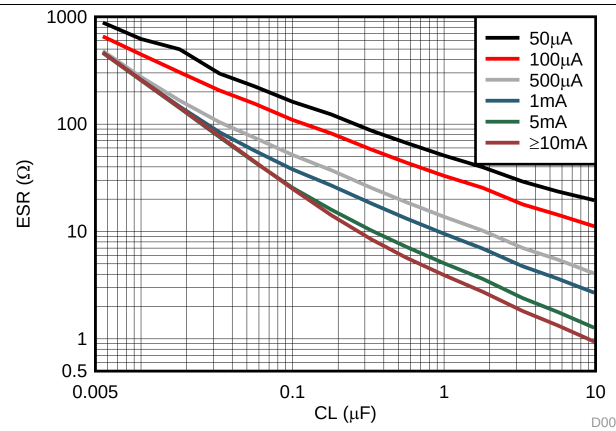


Figure 7. ESRs at V_{KA} = 5.0V

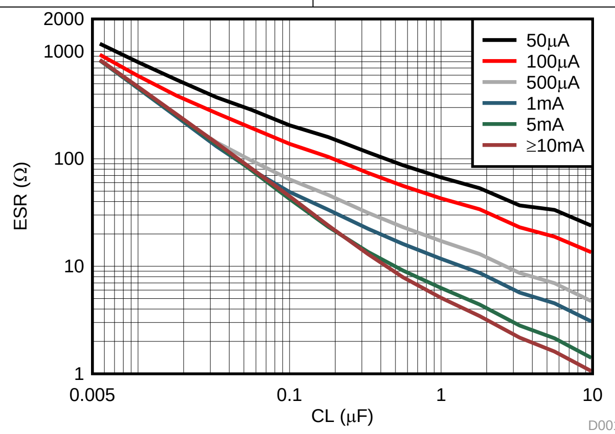


Figure 8. ESRs at V_{KA} = 10.0 V

2.3 Improved Absolute Accuracy

Though shunt regulators and voltage references are specified for an initial accuracy (i.e. 0.5%), once output impedance, reference current, programmed V_{KA} and temperature are taken in to account, the overall accuracy may decrease. This can be deduced by the below expressions and Table 1 where it is easily seen that most of the specifications that relate to overall system accuracy are at least an order of magnitude lower.

Total V_{REF} error = initial accuracy + output impedance error + programmed V_{KA} error + V_{REF} temperature deviation – Iref error ≈ V_{REF}(min/max) + I_{KA} x Z_{KA} + (V_{KA} – V_{REF}) x $\Delta V_{REF}/\Delta V_{KA}$+ $V_{I(dev)}$- R1 × I_{REF}

Table 1. ATL431 vs. TL431

Parameter	ATL431B	TL431B
V_{REF}	2.5V (±0.5%)	2.495V (±0.5%)
$I_{KA(min)}$	35 µA	1 mA
I_{REF}	150 nA	4 µA
$V_{I(dev)}$(–40°C to 85°C)	5 mV	14 mV
$\Delta V_{REF}/\Delta V_{KA}$	–0.4 mV/V	–1.4 mV/V
Z_{KA}	0.05 Ω	0.2 Ω

Table 1 and datasheet electrical characteristics offers the majority of the specifications at room temperature. A closer look at the typical characteristics plots for each part will show even better performance of ATL431 over temperature. Where a much flatter V_{REF} curvature can be observed.

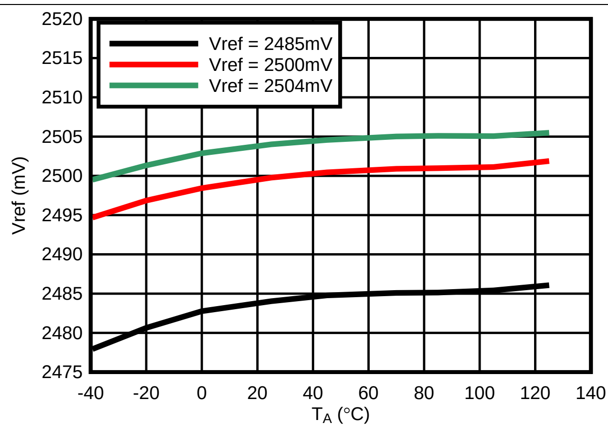


Figure 9. ATL431 V_{REF} vs. Temperature

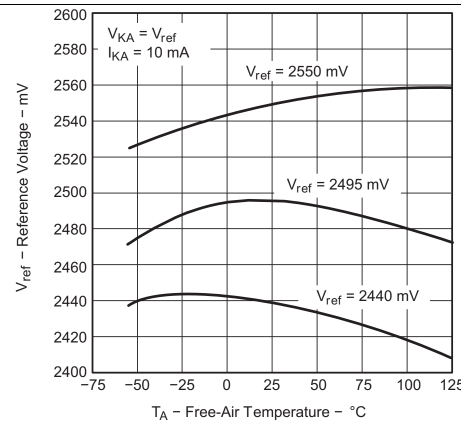


Figure 10. TL431 V_{REF} vs. Temperature

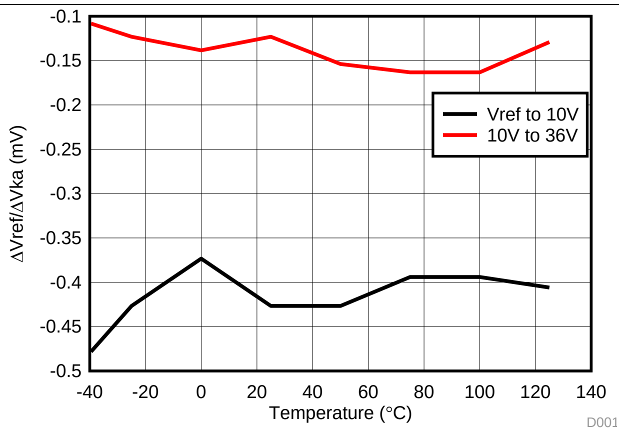


Figure 11. ATL431 $\Delta V_{REF}/\Delta V_{KA}$ vs. Temperature

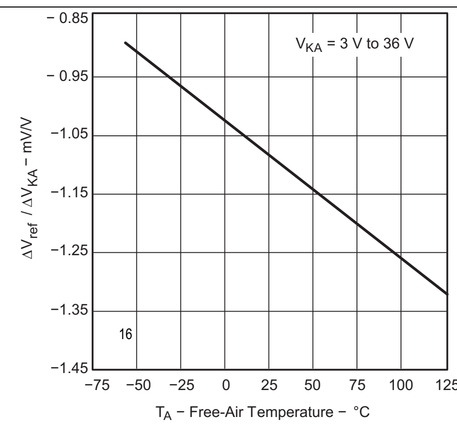


Figure 12. TL431 $\Delta V_{REF}/\Delta V_{KA}$ vs. Temperature

3 Application Considerations

3.1 Isolated Switched Mode Power Supply

Many Isolated supplies are used in very high voltage environments that are susceptible to large ground shifts and EOS on the primary side. The transformer coil and optocoupler ideally act as barriers for EOS between the primary and secondary side. However, these devices have ESD/EOS limits that can cause a breakdown of that barrier, with the optocoupler being the weakest link. Once the optocoupler is breached, the overstress has two paths depending on where the bias resistor (R_B) is placed. It will travel to the output capacitor (C_O) to ground or the shunt regulator (ATL431).

The breached current from the ESD event will travel in the path of least resistance, meaning the path that does not have R_B in it. In the case of Figure 13, the EOS will flow in to the output capacitor. This is good because the capacitor will tolerate much higher ESD energies than the shunt regulator can survive.

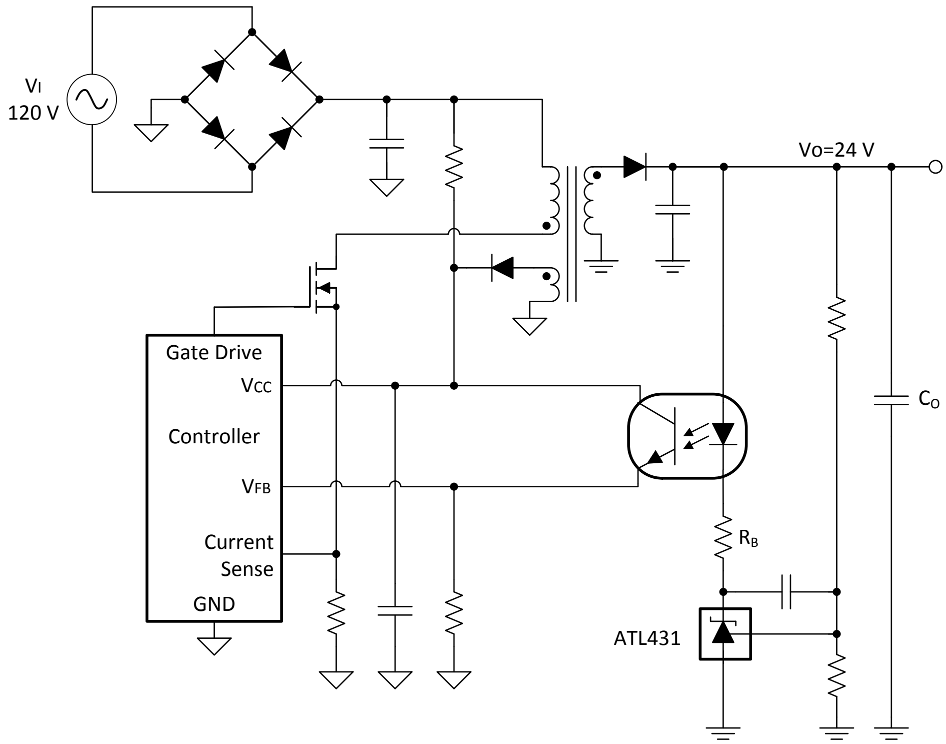


Figure 13. Isolated SMPS

4 Conclusion

As discussed in this document, ATL431 is a big improvement upon the existing TL431 solution. With the lower operating current making this device a good choice in applications that need better power efficiency and the improved overall accuracy helping users to have more precision in their system.

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