Precision Current Sources and Sinks Using Voltage References

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ABSTRACT

Current sources and sinks are common circuits for many applications such as LED drivers and sensor biasing. Popular current references like the LM134 and REF200 are designed to make this choice easier by requiring minimal external components to cover a broad range of applications. However, sometimes the requirements of the project may demand a little more than what these devices can provide or set constraints that make them inconvenient to implement. For these cases, with a voltage reference like the TL431 and a few external components, one can create a simple current bias with high performance that is flexible to fit meet the application requirements. Current sources and sinks have been covered extensively in other Texas Instruments application notes such as SBOA046 and SLYC147, but this application note will cover other common current sources that haven't been previously discussed.

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1   Precision Voltage References

The key component in creating discrete precision current reference is a precision voltage reference. There are two types of voltage reference architectures, shunt and series. Shunt references are similar in functionality to Zener diodes whereas series references are similar to linear regulators. Series references are precision voltage regulators that generally are able to provide a higher accuracy voltage compared to shunt references. Shunt and series references are able to provide different levels of accuracy and architecture to meet most applications due to their internal bandgap with temperature compensation. While an ideal current source can sink and source current to load, a discrete current source is generally set up for either sinking or sourcing. The following application note will discuss how to create current sources and sinks with both shunt and series references..

2 Current Sink with Voltage References

A precision current sink can be created with the combination of a transistor, amplifier, and voltage reference. Figure 1 shows the basic concept of a current sink which consists of an op amp that regulates the voltage across the resistor to create a regulated current sink. In this configuration, V_X represents either a shunt or series voltage reference. The lower the V_X voltage the lower the head room that is required this configuration. This configuration is used in Tips and tricks for designing with voltage references in greater detail. Current sinks are often for applications such as LED driving, battery discharging, thermocouples, and sensor biasing.
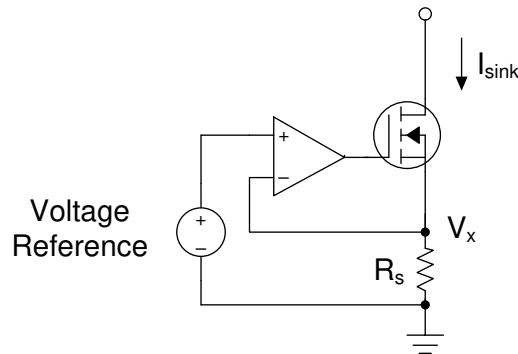

Figure 1. Current Sink Block Diagram

2.1 Current Sink with the Shunt Voltage Reference ATL431LI (TL431 equivalent)

Shunt references come in fixed and adjustable voltage variants. The most common adjustable shunt references are the TL431 and LM4041-N that have similar functionality but different characteristic and functionality that allow them to be preferred in different current source and sink applications. A TL431 regulates the output voltage with the feedback loop from CATHODE and REF. The LM4041-N operated different compared to the TL431 because the LM4041-N feedback loop is between the FB and ANODE.

The schematic in Figure 1 can further simplified by using a TL431 device by taking advantage of the internal error amplifier of the TL431 as it eliminates the need for an additional Op Amp. The TL431 CATHODE to REF feedback loop allows the insertion of a transistor to allow the regulation of V_X to be V_{REF} across R_S. This level of integration with the TL431 will also work for all "431" like products because they share the same architecture as shown in Figure 2.

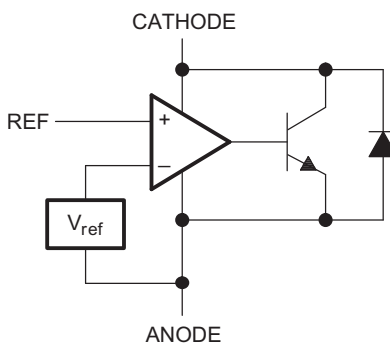**Figure 2. TL431 Functional Block Diagram**

Figure 3 shows the ATL431LI which is a TL431 equivalent with a lower $I_{KA(min)}$ being used in current sink mode. This schematic is common in LED drivers as the level of accuracy and bandwidth allow for a higher level of accuracy with minimal external components.
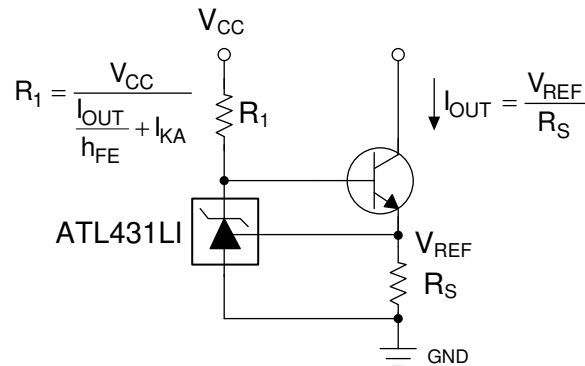
$$R_1 = \frac{V_{CC}}{\frac{I_{OUT}}{h_{FE}} + I_{KA}}$$

$$I_{OUT} = \frac{V_{REF}}{R_S}$$

Figure 3. Current Sink with the ATL431LI

- R_1 = Input bias resistor (Ω)
- R_S = Current sense resistor(Ω)
- I_{OUT} = Output current source (A)
- I_{KA} = Cathode current (A)
- V_{REF} = Internal feedback reference (~2.5V)
- V_{CC} = Input supply voltage (V)
- h_{FE} = Transistor DC current gain

The base of the transistor is controlled by the ATL431LI, which changes the base current in response to the change in voltage across R_S using feedback from the internal op amp. Since the only path for the load current to flow is through R_S, controlling the voltage across R_S controls the current through the load. Stability can be improved in the system with a biasing capacitor between cathode and reference but this will lower the response time of the circuit. The main sources of error in this application will be the ATL431LI and R_S's accuracy and temperature drift. The total error across temperature can be around 1% to 2% depending on ATL431LI accuracy grade variants.

The main benefit of using the ATL431LI is that the value of R_1 can be increased due the lower $I_{KA(min)}$ of the ATL431LI which allows for a lower system I_Q. In this current sink application, the I_{KA} is separate from I_{OUT} which makes the I_{OUT} accuracy not be largely affected by variations on I_{KA} or V_{CC}. The ATL431LI in available an X2SON package which allows for a much smaller footprint compared to a TL431 SOT23-3. A typical application for current sink is LED driving and with a smaller ATL431LI solution size, more LEDs can fit on a given PCB. TLV431 can also be used in place of the ATL431LI in situations where the system needs more head room due to the 1.24V bandgap of the TLV431.

In current sink applications such as Figure 3, the transistor can be interchanged between NPN and NMOS as long as the limitations are understood. NPN's will require a smaller over head voltage compared to a NMOS but NPN's do have higher current sink requirements due to the base current. When using a NPN to sink high amounts of current in the magnitude of 1 A and greater, it can be necessary to use a Darlington pair due to the high base current requirement.

2.2 *Current Sink with Series Reference*

Figure 1 shows that a voltage reference is needed to create a precision current sink and while shunt references can be used in current sinks, they do not provide the high accuracy that a series voltage can provide. The REF4132 is a high precision voltage reference that can be used to create a 0.1% total error voltage reference as shown in Figure 4. This type of topology also has additional benefits in terms of voltage headroom for the load. The amount of headroom based on the type of transistor used as shown in Equation 2 and Equation 3. This headroom is the maximum voltage the load can have while maintaining the regulated current. For example, in certain applications such as LED drivers, the voltage headroom will determine the amount of LEDs in series. When using a 5V rail, it can be difficult to stack 2 red LEDs or a blue LED when the voltage reference is 2.5V. In Figure 4, a voltage divider is used to divide the REF4132 voltage down to 0.5V which allows for more headroom. Equation 1 shows how to calculate the head room and how it is dependent on the output of the REF4132 and the resistor divider.

$$V_{Rs} = V_{REF} \times (\frac{R_2}{R_1 + R_2})$$

(1)

$$V_{headroom} = V_{DD} - V_{Rs} - V_{CE}$$

(2)

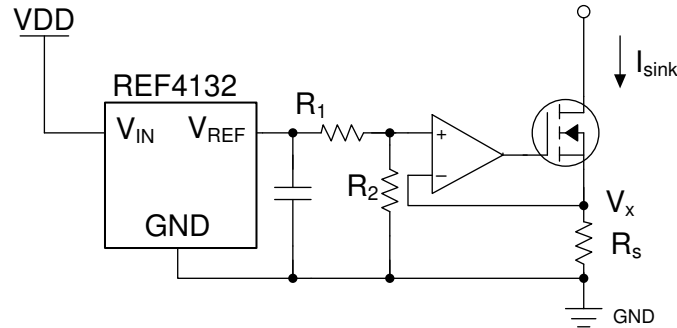$$V_{headroom} = V_{DD} - V_{Rs} - V_{DS}$$

(3)

Figure 4. Current Sink Using REF4132 with a Voltage Divider

2.3 *Current Sink with REF3425*

Force and sense output voltage references such as the REF3425 can be used as single active device solutions to current sink applications. This is due to the nature of a force and sense connection. in a typical series voltage reference, the output buffer and its feedback is all internal for regulation. This causes issues when the voltage reference is far away from the ADC and there is IR drop from the output of the reference. The REF3425 has a force and sense output that combine to form the feedback path of the output buffer with the "force" being the output of the amplifier and the "sense" being the input negative terminal of the output buffer. The force and sense of the REF34 family allows a NPN to added in the feedback loop and be controlled and regulated by the REF3425 such as in Figure 5. In this application the REF3425 must be sourced with a voltage higher than V_{OUT} (2.5V) + V_{BE} (0.7V) for proper regulation.
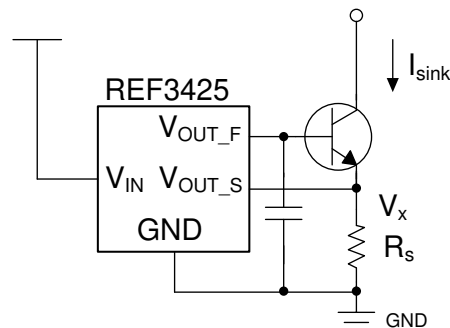

Figure 5. Current Sink Using the REF3425

3 Current Source with Voltage References

A precision currents source can be created with a similar structure as a currents sink. The main difference the current source will source current to the load to ground which allows support for different kind of applications. Current sources can be used to charge batteries, LED driving, temperature sensor biasing, and multimeters. Current sources have the benefit of having the load referenced connected directly to an independent ground. A direct connection for the load to ground allows the load voltage to be compared directly to ground for voltage and current measurement for sensors.
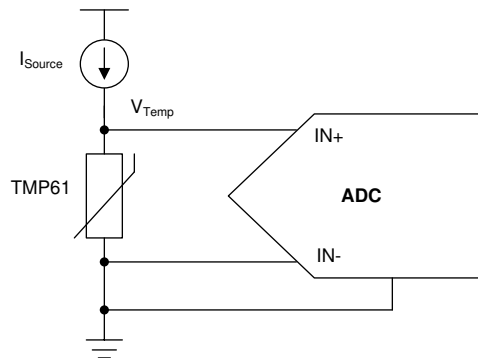
Figure 6. Temp Sensor with Current Source

3.1 *Current Source with the ATL431LI (TL431 Equivalent)*

The ATL431LI can also current source by connecting the load on the GND side. The main drawback of current sourcing the ATL431LI is that the accuracy of the current will be a combination the ATL431LI bias current and the current through the transistor. For a more accurate current sink the I_{Rs} should be significantly larger than I_{KA} bias current.
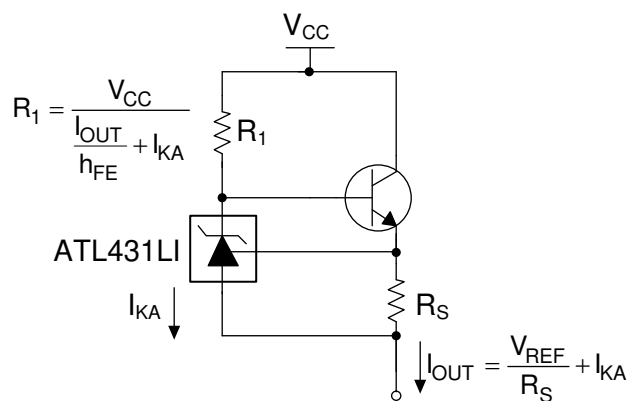

$$R_1 = \frac{V_{CC}}{\frac{I_{OUT}}{h_{FE}} + I_{KA}}$$

$$I_{OUT} = \frac{V_{REF}}{R_S} + I_{KA}$$

Figure 7. Current Sourcing with the ATL431LI

This application circuit is explored in greater detail in SLYT768 with a stronger focus on the TLVH431 but the application concepts will also apply to the ATL431LI and TL431.

3.2 *Current Sourcing with the LM4041-N*

TI's LM4041-N ADJ is an ideal solution in current sourcing because its feedback voltage on FB is with respect to CATHODE unlike the ATL431LI. This allows the LM4041-N ADJ in current source configuration to have the I_{OUT} be independent of I_{KA}. The benefit of the LM4041-N ADJ over the ATL431LI is the higher accuracy and simplified schematic.
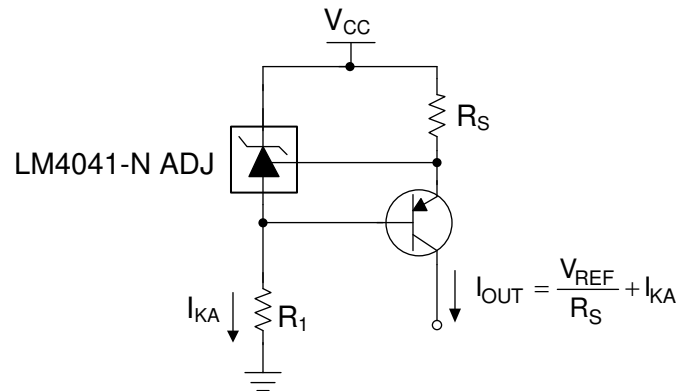
Figure 8. Current Sourcing with the LM4041-N ADJ

- R_1 = Input bias resistor (Ω)
- R_S = Current sense resistor(Ω)
- I_{OUT} = Output current source (A)
- I_{KA} = Cathode current (A)
- V_{REF} = Internal feedback reference (~1.2V)
- V_{REF} = Internal feedback reference (~1.2V)
- h_{FE} = Transistor DC current gain

The current supplied to the load is controlled by the R_s resistor and the LM4041-N enforcing a 1.2 volt drop across it. The PNP transistor will regulate the current through the load based on the feedback from the LM4041-N. If current supplied to the load decreases, the internal op amp of the LM4041 will readjust the correct voltage across Rs by draining more current from the base of the transistor.

3.3 Current Source with Series Voltage Reference

A series voltage reference can be used to increase the accuracy of a current source. In SBVA001 and SBOA046 demonstrates the use of a REF102 as a current source and sink. The REF102 current source application can be expanded other series voltage references.

4 References

- IMPLEMENTATION AND APPLICATIONS OF CURRENT SOURCES AND CURRENT RECEIVERS SBOA046
- Tips and tricks for designing with voltage references SLYC147
- High-side current sources for industrial applications SLYT768

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