A Low-Supply Voltage Sensor with an Optical Indicator

Tyler Hamilton
Electrical Engineering Department
California Polytechnic State University, San Luis Obispo
San Luis Obispo, United States of America

***Abstract*—This research investigates a low-supply voltage sensor with an LED alert. The design employs a Zener diode to voltage limiter and a voltage comparator circuit to trigger an LED when the voltage falls below a set point. The focus is on optimizing the Zener diode selection, voltage divider setup, and LED biasing for reliable operation. The experimental results validate the circuit's efficiency in identifying low-voltage situations.**

Keywords—Zener diode, voltage comparator, LED, linear voltage divider, voltage limiter

I. Introduction

A. Zener Diodes

Zener diodes operate similarly to standard diodes under a forward bias (positive anode-to-cathode voltage), typically exhibiting a turn-on voltage of around 0.6V to 0.7V. However, when there is reverse bias, these diodes exhibit a controlled breakdown at a specific voltage. Operating within this breakdown region is permissible as long as the power dissipation stays within the device's limits [1]. This work utilizes a particular Zener diode with a breakdown voltage of 4.3V. It is worth noting that there are a variety of Zener diodes with different breakdown voltages for diverse applications.

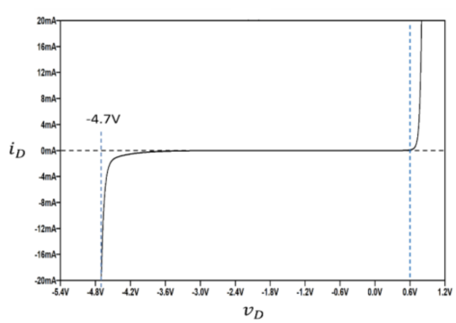

Fig. 1: I-V characteristics of a 4.7 V Zener diode [1].

B. Low Supply Voltage Sensor-Indicator Circuit

Low-supply voltage indicator circuits play a vital role in ensuring the operational integrity of electronic systems. These circuits continuously monitor the voltage level of the power supply. A crucial aspect of monitoring is the establishment of a predetermined threshold voltage. This threshold serves as a critical reference point, and when the supply voltage falls below this level, the indicator is activated.

This design utilizes a voltage comparator to compare the supply voltage established by a Zener diode in the breakdown region. This Zener diode functions as a stable reference, triggering the comparator to switch states when the supply voltage fails below the desired level, as detailed in [1].

When the comparator detects a supply voltage below the threshold established by the Zener diode, its internal switching mechanism triggers a transition in the output voltage level. This transition typically involves a shift from a high state (V_{DD}) to a low state (V_{SS}), which is often referred to as ground.

The comparator's output voltage swing (V_{DD} to V_{SS}) creates a voltage difference across the indicator LED. This potential difference establishes the necessary forward bias condition for the LED, allowing current to flow through the device, which creates the illumination.

Operating electronic systems below the threshold voltage can lead to adverse consequences. In digital circuits, insufficient voltage can cause logic gates to malfunction, resulting in incorrect data processing, or even complete system shutdown. For analog circuits, inadequate voltage supply can distort signal amplitudes and introduce unwanted noise, compromising the system's performance.

Low-supply voltage indicator circuits act as a preventative measure by providing a timely visual alert to the user. This notification allows for corrective actions to be taken before the voltage drop reaches a critical level that could cause permanent damage to some of the electrical components, or data loss within the system.

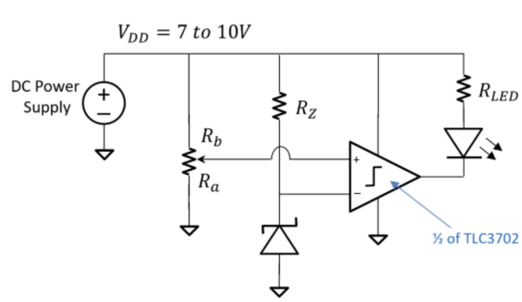

Fig. 2: Schematic of a low supply voltage sensor-indicator circuit [1]

C. Equations

The circuit shown in figure 2 utilizes two voltage dividers to define the equations governing the comparator's threshold voltage detection.

$$V_+ = \frac{R_a}{R_a + R_b} V_{DD} \tag{1}$$

Applying the voltage divider principle, you obtain equation (1). This equation demonstrates that the voltage at terminal V+, denoted as V+, is a scaled-down version of the supply voltage (V_{DD}) determined by the resistor ratio (R_a / R_b).

$$V_{-} \approx V_Z \tag{2}$$

Due to the Zener diode operating in its breakdown region, it exhibits a near-constant voltage at its terminals, denoted as V_Z. Consequently, the voltage at terminal V_- closely approximates V_Z. This relationship is mathematically expressed in (2).

By establishing the condition $V_+ = V_-$, you can combine the derived expressions from equations (1) and (2). This manipulation leads to equation (3), which defines the minimum required supply voltage (V_{DD}) necessary to trigger a state change in the comparator's output.

$$V_{DD(trip)} = \left(1 + \frac{R_b}{R_a}\right) V_Z \tag{3}$$

If the supply voltage is below $V_{DD(trip)}$, then $V_- < V_+$, and the comparator switches, causing the LED to activate.

For proper use, the Zener diode needs to remain in the breakdown [1]. Equation (5) satisfies this requirement.

$$R_Z < \frac{V_{DD(trip)} - V_Z}{I_{Zk}} \tag{4}$$

The threshold current for reliable breakdown in a Zener diode (labeled as I_{ZK}, can vary depending on the specific device, and typically ranges between 0.25mA and 0.50mA [1]. Given that the resistance used for R_Z is below 8kΩ, the Zener diode will remain in its breakdown state.

Additionally, it is crucial to determine the bias resistance for the LED [2], which incorporates $V_{DD(trip)}$. The LED resistance is calculated using equation (5), where the I_{LED} signifies the desired current, and V_{LED} represents the LED's voltage. Equation (6) indicates that the desired current should be lower than both I_F, which denotes the LED's forward current, and I_{OL}, representing the output sink rating of the comparator.

$$R_{LED} < \frac{V_{DD(trip)} - V_{LED}}{I_{LED}} \tag{5}$$

$$I_{LED} < min\{I_F, I_{OL}\} \tag{6}$$

D. Materials Used

This experiment utilizes a 1N5229BTR Zener diode characterized by a breakdown voltage of 4.3V. The WP7113ID LED serves as a low-voltage indicator, Additional components include a TLC3702 voltage comparator integrated circuit (IC), a 50 kΩ trimmer potentiometer, a 2.2 kΩ resistor, and a 1.5 kΩ resistor.

II. Data

A. Zener-Based Voltage Limiter

The first step in building a low-supply voltage sensor is to build a Zener-Based Voltage Limiter.

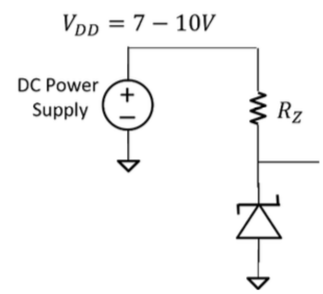

Fig. 3: Zener-Based Voltage Limiter [1]

The experimental setup, as illustrated in figure 3, validates the functionality of a low-supply voltage circuit. The testing procedure involved incrementally varying the supply voltage from 7V to 10V in steps of 0.5V. In each increment, the voltage across the Zener diode was measured.

Table I. Voltage of Zener Regulator vs. Supply Voltage

V_{DD},V	7.0V	7.5V	8.0V	8.5V	9.0V	9.5V	10.0V
V_Z,V	3.401	3.447	3.489	3.527	3.562	3.594	3.624

As expected, V_Z remains relatively constant. For this reason, Zener diodes are used as a voltage regulator.

B. Voltage-Difference Generation Trimming

Calibration of the linear voltage divider was performed to achieve minimal voltage difference at the designated trip voltage of 8V. This process involved applying a constant 8V supply to the circuit while adjusting the potentiometer. The objective was to minimize the voltage differential between the two voltage divider branches. The measured data indicated a state change occurring around 7.9V, which closely aligns with the anticipated threshold for the comparator to switch states.

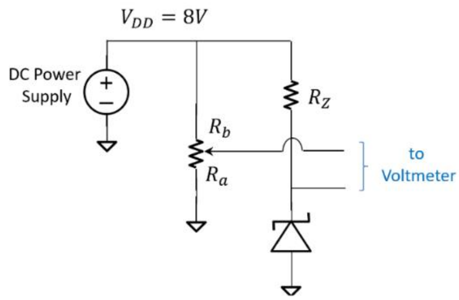

Fig. 4: Linear Voltage Divider to ensure trip voltage [1]

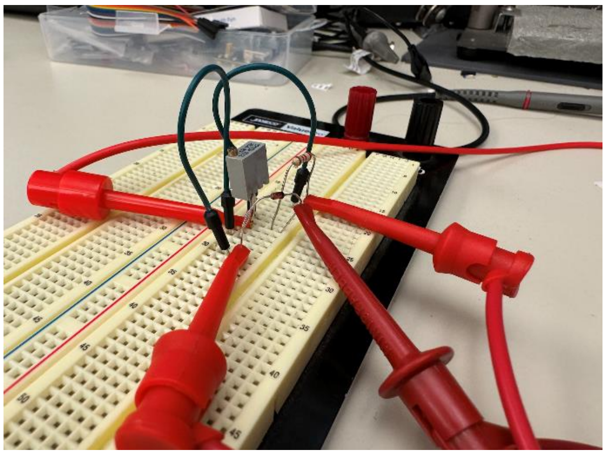

Fig. 5: Circuit Representation of Linear Voltage Divider

C. Comparator Assembly and Test

The circuit depicted in figure 6 serves as the foundation for the task. In order to do this, you have to go through a meticulous process, which consists of deactivating one of the TLC3702 comparators. Subsequently, you have to adjust the supply voltage over a specified range and then monitor the output voltage of the comparator, as shown in figure 6. Now, you record the V_{DD} value at which the output voltage of the comparator changes its state (approximately 8V). The data recovered from this investigation coincides with the expected output for the state change, as it changed states at about 7.9V.

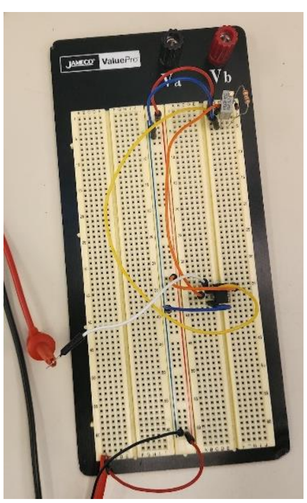

Fig. 6: Circuit Assembly of the Comparator

D. Adding the LED

As shown in figure 6, there is no LED. To add the LED, you must mimic the circuit shown in figure 6 and add a couple of other wires to make sure everything operates correctly. When adding a voltage source to this circuit, you must be careful of reverse-basing the LED because this could result in permanently damaging the LED. Figures 7 and 8 depict us supplying a voltage exceeding the trip voltage and supplying a voltage below the trip voltage.

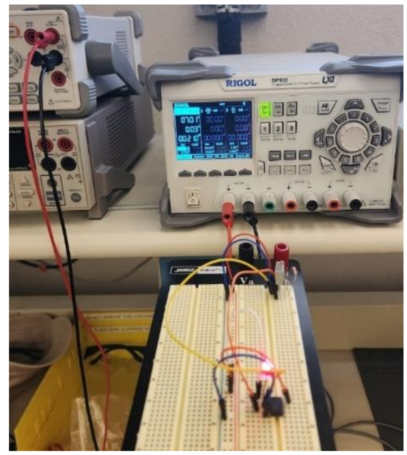

Fig. 7: Circuit Below the Trip Voltage

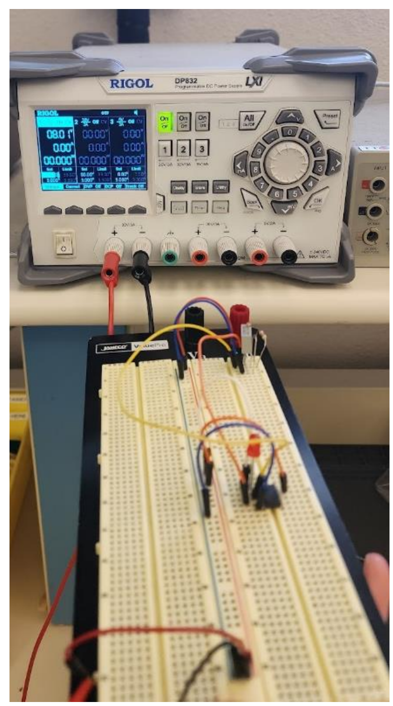

Fig. 8: Circuit Exceeding the Trip Voltage

III. Conclusion

The circuits in this lab successfully tested a low-supply voltage sensor with an LED indicator, demonstrating a practical application of the zener diodes in monitoring and alerting on changes in voltage. The use of a zener diode voltage limiter, combined with a voltage comparator-based circuit, allows for precise control and activation of the LED indicator when the supply voltage dropps below a predetermined threshold. Through rigourous experimentation, validation of the circuit's effectiveness in identifying low-voltage situations ensures the integrity of electronic systems.

References

[1] Week 7: A Low-Supply Voltage Sensor with an Optical Indicator Lab Manual https://canvas.calpoly.edu/courses/116649/files/12332349?module_item_id=3401680

[2] Edman, Lenore. "Basics: Picking Resistors for LEDs." Evil Mad Scientist Laboratories, 29 Aug. 2012, www.evilmadscientist.com/2012/resistors-for-leds/.