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AN-4175

Isolated, Signal Powered, Precision Voltage Detector with Hysteresis

Background

Industrial process control and power supply management applications have a need to accurately monitor and detect specific voltage signals. These monitored voltages are present in electrically noisy environments, shown in Figure 1. The electrical noise can be minimized with passive analog filtering or digital post processing filtering. These two noise reduction techniques often reduce the response time for the detection network. When this is an issue, the common solution is the use of a detector system that includes signal detection hysteresis.

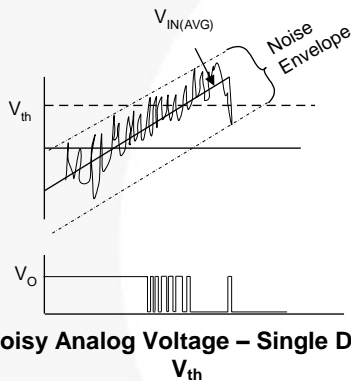


Figure 1. Noisy Analog Voltage – Single DC Threshold,
 V_{th}

Figure 2 illustrates how the noise envelope on the DC voltage signal is rejected by a detector with hysteresis. Note that most of the noise on the signal to be detected is suppressed.

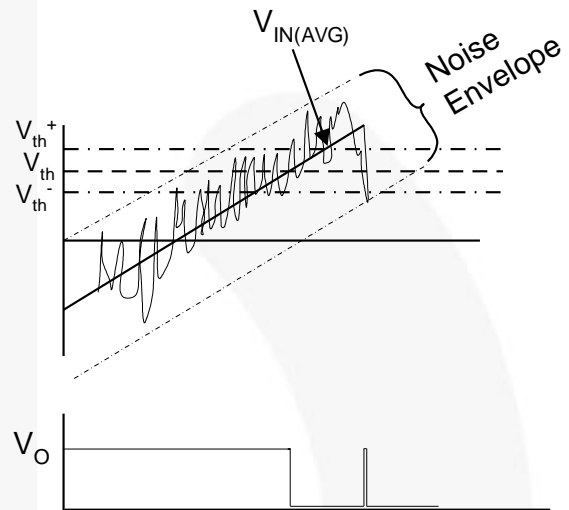


Figure 2. Threshold Detection with Hysteresis

The most common circuit used for introducing hysteresis in a voltage detection system is the Schmitt Trigger. Figure 3 shows the switching progression of a detection system with hysteresis. The X-axis is input voltage, V_{IN} , and the Y-axis output swing of the op-amp comparator. Figure 3a shows the switching at the highest threshold V_{th}^+ , Figure 3b illustrates switching back only when the input is less than the lower threshold V_{th}^- . Figure 3c is the composite of the transfer, the hysteresis voltage V_{HSY} is the difference between V_{th}^+ , and V_{th}^- .

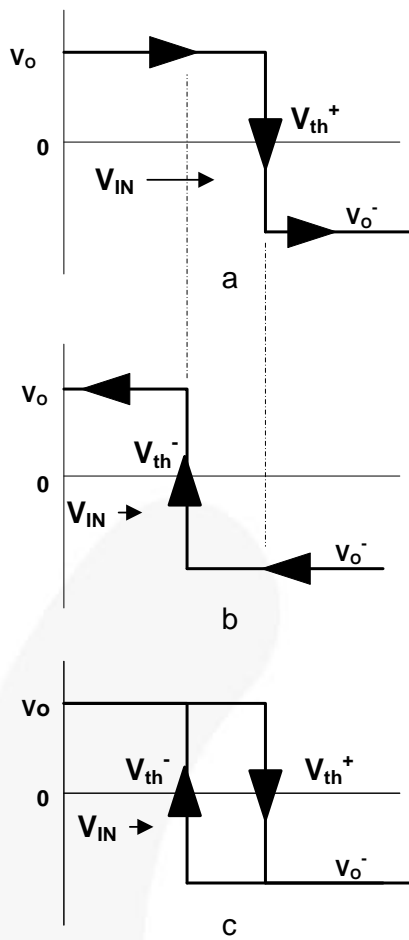


Figure 3. Voltage Detection with Hysteresis

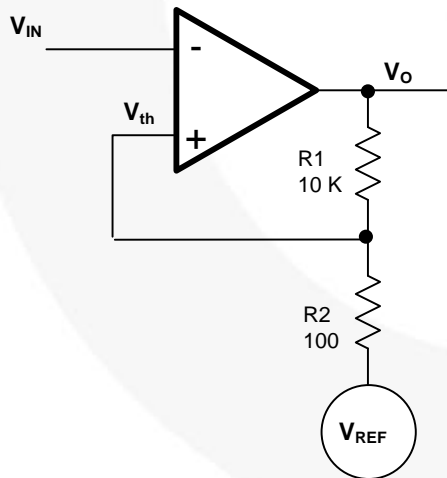


Figure 4. Typical Schmitt Trigger Circuit

Equations (1) and (2) show the fundamental transfer equations for each of the switching levels, V_{th}^+ , and V_{th}^- .

$$\frac{R1 * V_{REF}}{R1 + R2} + \frac{R2 * V_O^+}{R1 + R2} \equiv V_{th}^+ \tag{1}$$

$$\frac{R1 * V_{REF}}{R1 + R2} - \frac{R2 * V_O^-}{R1 + R2} \equiv V_{th}^- \tag{2}$$

Equations (1) and (2) show the threshold voltages (V_{th}^+ ; V_{th}^-), a result of the sum and difference of two scaled voltages. Equation (1) is a reference source, V_{REF} , and the Equation (2) is the output voltage, V_O , of the op-amp/comparator. The equation (2) illustrates one of the main problems using this type of circuit where the power for the op-amp is supplied by the signal being measured. The variation of V_O creates the problem of determining consistent and accurate switching thresholds.

The following describes how to eliminate this operational drawback, by making the threshold setting and hysteresis completely independent of the power supplied to the voltage detection system.

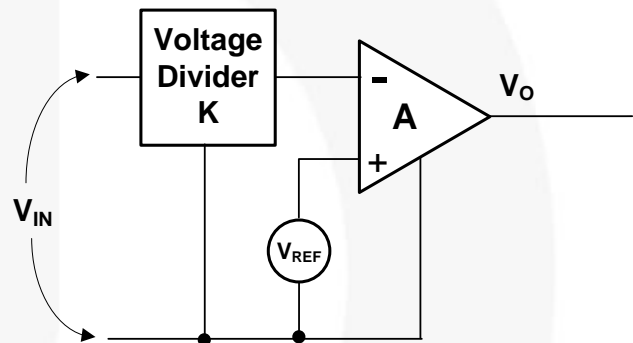


Figure 5. Elements of a Voltage Threshold Detector

The voltage divider is commonly constructed using a pair of resistors. Equation (3) shows the transfer function for the single threshold voltage level detector. For large values of open loop gain, A, the ratio of V_O/A approaches zero.

$$V_O = (V_{REF} - V_{IN} * K) * A \tag{3}$$

$$\frac{V_O}{A} = (V_{REF} - V_{IN} * K) \tag{4}$$

$$0 = (V_{REF} - V_{IN} * K) \tag{5}$$

$$V_{IN} = \frac{V_{REF}}{K} \tag{6}$$

Figure 6 shows the simple network constructed using voltage divider concept.

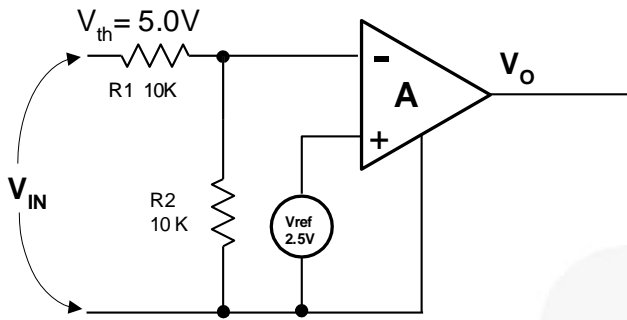


Figure 6. Single Threshold Voltage Detector

The voltage divider K is shown in Equation (7):

$$K = \frac{R2}{R1 + R2} \quad (7)$$

When equation (7) is inserted into equation (6) the result is:

$$V_{IN} = V_{th}^+ = \left(\frac{R1}{R2} + 1 \right) * V_{REF} \quad (8)$$

Hysteresis can be implemented by changing the input switching threshold as a function of the output V_O , rather than its absolute value. The circuit shown in Figure 7 illustrates the concept of the resistor R3 being switched into and out of the voltage divider as a function of the output status of the op-amp comparator.

When R3 is in circuit, the combination of R2 and R3 reduces the switching threshold. The new threshold is described as V_{th}^- . Equation (8) describes the upper threshold V_{th}^+ , and equation (9) describes the lower threshold, V_{th}^- .

$$V_{th}^- = \left(\frac{R1}{R2 + R3} + 1 \right) * V_{REF} \quad (9)$$

Combining equations (8) and (9) and solving them in terms of R1 results in an equation that describes the ratio of resistors R2 and R3 in terms of the V_{th}^- and the hysteresis voltage. This is shown in equations (10) and (11).

$$\frac{R2}{R3} = \frac{V_{th}^- - V_{REF}}{V_{th}^+ - V_{th}^-} \quad (10)$$

$$\frac{R2}{R3} = \frac{V_{th}^- - V_{REF}}{V_{HYS}} \quad (11)$$

Using equations (8) and (11) allows easy calculation of the resistor values given the thresholds, the desired hysteresis and voltage reference.

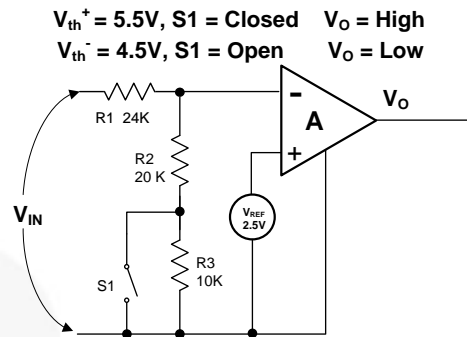


Figure 7. Dual Threshold Controlled by Comparator Output

Figure 7 illustrates a design example with nominal 5 V threshold with 1 V hysteresis. The relatively high input impedance of the op-amp allows the designer flexibility when selecting resistor values.

Controlling the Switch S1

The circuit shown in Figure 8 shows an enhancement mode MOSFET, Q1, functioning as the switch S1. The FDV301N is a low enhancement voltage, milliohm FET that is switched “ON” with a terminal voltage ($V_{IN(+)} - V_{IN(-)}$), lower than the initial threshold V_{th}^+ . Q1 has lower potential than is required to turn-ON the LED found in the optocoupler, U2.

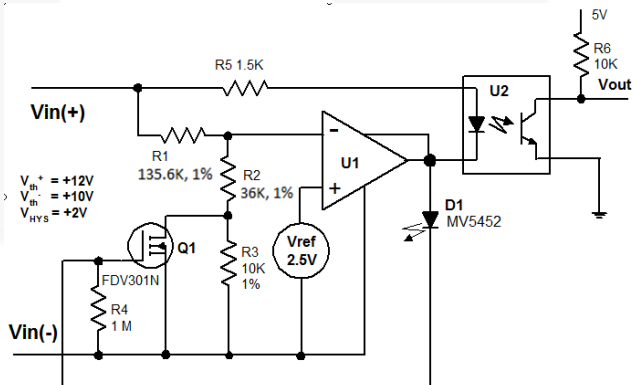


Figure 8. Isolated, Signal Powered, Precision Voltage Detector with Hysteresis

Operational Sequence

Figure 8 is an example of a threshold detector with a nominal threshold of +11 V, and 2 V of voltage hysteresis. This sets the $V_{th}^+ = +12$ V, and the $V_{th}^- = +10$ V. The voltage detection circuit consists of a 2.5 V reference and comparator (V_{REF} , U1), a threshold setting network (R1, R2, R3), switch (Q1, D1, R4), and an output circuit (U2, R5, R6). To get a clear understanding how this circuit functions, first examine the circuit operation as a function of a rising positive voltage between ($V_{IN(+)} - V_{IN(-)}$).

Under the initial conditions, when $V_{IN} = 0$ V, all circuits elements are OFF or non-conducting. As the terminal voltage increases the output of U1, V_O , follows the input voltage. When the terminal voltage exceeds 2.5 V, the comparator and reference are active. The output voltage, V_O ,

of U1 continues to be high, tracking the input voltage. At this point the voltage difference between $V_{IN(+)}$ and the V_O is too small to force a current through the optocoupler's LED, thus the output of the optocoupler is also high, $V_{OUT} = 5\text{ V}$. When it reaches a potential of approximately 3 V, the transistor, Q1, is turned ON, shunting the resistor, R3. This 3 V potential is required to satisfy the combination of the barrier voltage of the visible LED, D1, and the threshold voltage, V_{GS} , of the FET. With Q1 ON, the threshold setting network consists of R1 and R2 resulting in a $V_{th+} = 12\text{ V}$. When the input reaches this level the comparator switches from $V_O = V_{IN+}$ to a output voltage, $V_O = 2.5\text{ V}$. This output level is below the required voltage to keep Q1 conducting, thus shunting action of Q1 on R3 stops. Now the threshold setting elements include R1, R2, and R3. This set the new threshold level at V_{th-} or 10 V. With the comparator's output in the low state, current can now flow through R5 and the LED, thus forcing the optocoupler's output into the low state.

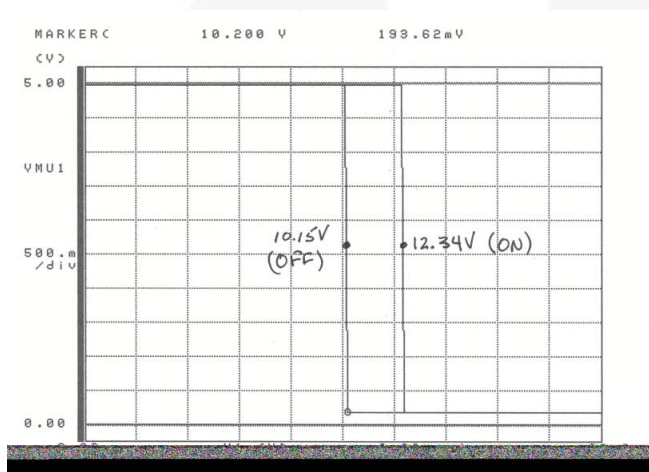


Figure 9. Voltage Transfer Function

The input signal must fall below the new threshold, V_{th-} , or +10 V for the comparator to switch back to its original high state. When back in the high state, the LED is forced off, and coupler's output goes high. Figure 9 shows the typical voltage transfer operation hysteresis for the circuit shown in Figure 8. The speed and accuracy of this circuit is dependent on the reference/ comparator and the optocoupler used.

Circuit Implementation

The circuit shown in Figure 8 can be realized with a wide variety of op-amp/comparators and bandgap references. One of the highest volume and least expensive is the programmable shunt regulator, eg. KA431 and LM431 Series. As shown in Figure 10, the symbol for this circuit is a programmable Zener diode. Unique to this device is the fact that the output connection (cathode) is also the supply for the op-amp/comparator. These programmable shunt regulators are available with either a 2.5 or 1.25 V reference.

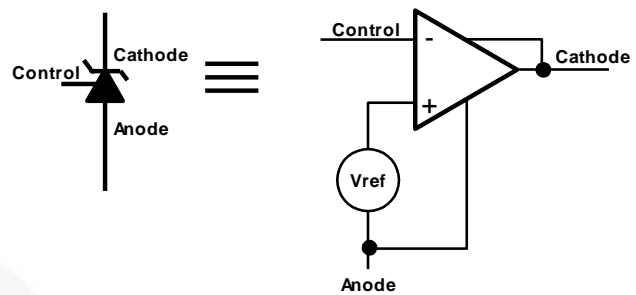


Figure 10. Programmable Shunt Regulator – Equivalent Circuit

Fairchild's FOD2741 Series offers a combination of optocoupler and comparator-reference in one package making the construction of this circuit easier.

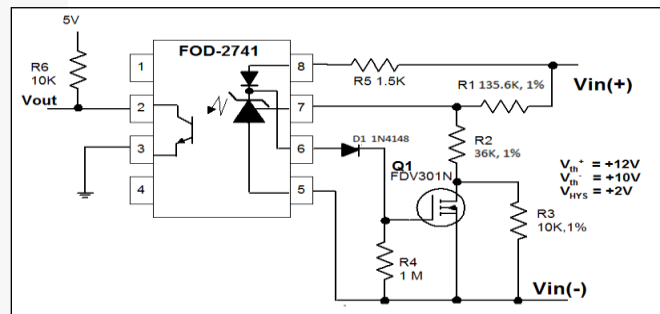


Figure 11. Precision Voltage Detector using FOD2741

Figure 11 shows the implementation of the precision voltage detector using the FOD2741 Series. This device offers 1% reference accuracy and low Zener current operation. The burden on the voltage being monitored is minimized by using a low-current high-gain optocoupler. The burden current versus input voltage for Figure 9 is shown in Figure 12.

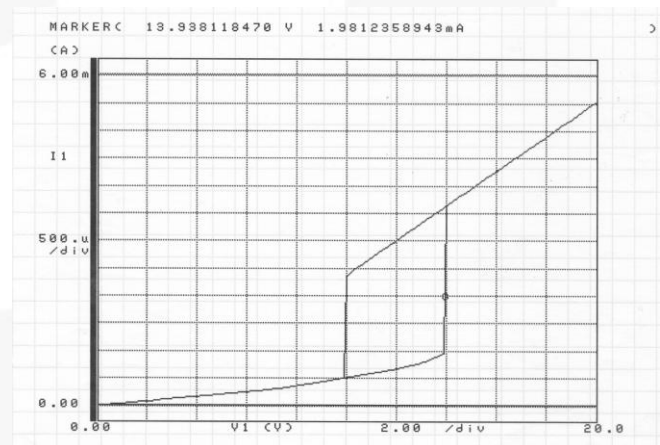


Figure 12. Burden Current vs. Input Voltage

Note that the burden current below the threshold is between 500 μA and 1 mA. The majority of this current below switching is the shunt regulator's "Zener" current. The current after threshold is the current supplied to the LED. The use of lower input current optocouplers reduces the slope of this line greatly.

Switching Time

This signal detector speed is a combination of the switching time of the comparator, and of the optocoupler. When using higher speed optocouplers, eg. FODM453, the delay time can be as short as 500 ns. By using faster comparators and higher speed optocouplers, this time can be reduced to fewer than 100 ns. These faster circuits offer a significantly higher power burden on the voltage being evaluated.

Lower Voltage Detection

The application circuit discussed so far works best at threshold voltages at or above 5 V. The circuit uses a series connection of the LED between the input and output of the comparator. Lower voltage less than or equal 2 V can be monitored by modifying the circuit. First, use a lower voltage reference, eg. LV431 or RC431 offers a 1.25 V reference. The second major change is to shunt drive the LED instead of the series drive shown earlier. Figure 13 illustrates an isolated, signal powered, precision voltage detector using a shunt driven LED.

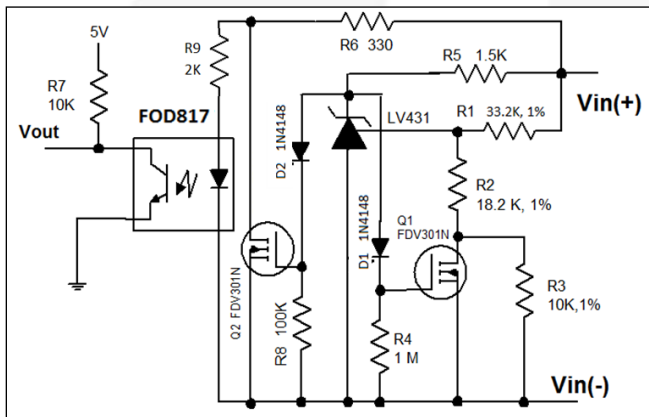


Figure 13. Isolated, Signal Powered, Precision Voltage Detector with Hysteresis - LED Shunt Driven

The LED of the optocoupler is enabled when the comparator of the LV431 switches to the low state. This occurs when V_{th}^+ is detected. The drop in V_O eliminates the gate voltage on the shunt transistor, Q2, thus turning it off. With Q2 off, the current flowing through R6 now is directed to the LED of the optocouplers. The diode D2 insures that Q2 stays off when the LV431 output is low. The circuit shown above is designed for $V_{th}^- = +2.7$ V, and $V_{th}^+ = +3.5$ V ($V_{HSY} = 0.8$ V).

Conclusion

These circuits offer an accurate voltage threshold and hysteresis which is independent of the supply voltage powering the comparator. This is a major improvement over the classical “Schmitt Trigger”. The solution is elegant in its simplicity. It uses inexpensive parts. The result is an accurate, stable, signal powered, and fast responding voltage detector that is used in industrial and power management applications.

Related Datasheets

[FOD2741](#)

[FODM453](#)

[FDV301N](#)

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