4

Circuits

This chapter discusses some aspects of electrical circuits utilized with sensors.

4.1 INPUT CIRCUITS

The input circuit for most sensors is mainly for noise immunity, as well as transient immunity. For input noise immunity, typically a capacitor is placed from the supply pin (V_{cc} or V_{dd}) to ground. The noise section discusses this concept in more depth. Additional input circuits may include a small ($< 10\Omega$) resistor in supply line. The purpose of in-line resistor is to reduce transients on the power line, from reaching the circuit. Further, a "ferrite bead" can be placed in-line of the supply line, to suppress transients and radio frequency (RF) noise. The "ferrite bead" is an inductor, and impedance increases with frequency. Thus, at DC, the resistance is low and power flows, but at high frequency, the bead is high impedance to the noise.

4.2 OUTPUT CIRCUITS

This section discusses output circuits, including open collector/open drain, logic interface, 2-wire, linear, and pulse width modulated (PWM).

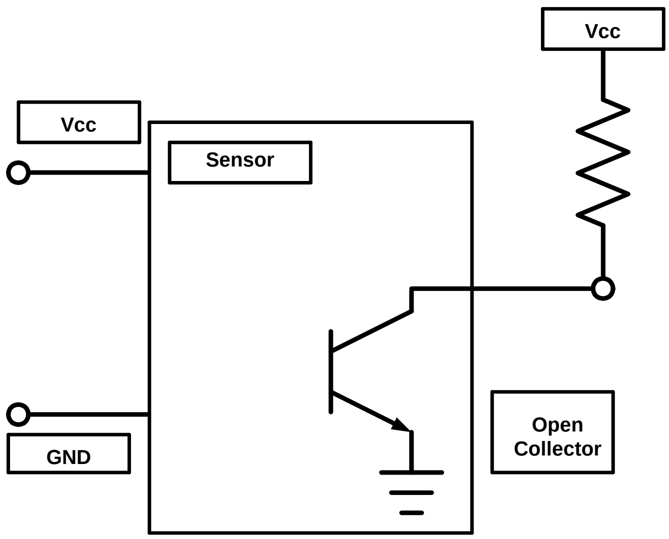

Fig. 4.1 Open Collector Schematic.

4.2.1 Open Collector/Drain

Open collector/open drain is one of the simplest output circuits available, Fig. 4.1. The concept is the sensor is in one of two possible states, logical 0 or 1, and thus the output is either off or on. A subtlety is defining on and off. Is voltage high on? Or, is current flow on? Typically, the voltage at V_{out} defines on and off. With no current flow, V_{out} is equal to the supply voltage (V_{cc}). If the output transistor is on, current flowing, V_{out} is nearly ground. There are two main types of output transistors: bipolar and field effect transistor (FET). A bipolar transistor (typically NPN, open collector) typically has a faster fall time, and handles greater current (typically up to 20mA). The disadvantage of open collector is a higher current requirement, and the voltage across the output transistor, while conducting current (saturation voltage, or V_{sat}), is fairly high, on the order of 0.2V. Also, when not conducting current, bipolar transistors have some unintended current (leakage current), on the order of a few nanoamps, which is heavily temperature dependent. Open drain FET output circuits are best used for driving capacitive load, as opposed to a resistor load. Open drain output requires lower drive current, and V_{sat} is very close to zero (millivolts).

4.2.2 Logic Interface

The Hall Effect Handbook [1] discusses logic interfaces. When that was written, transistor-transistor-logic (TTL) was a popular logic type. TTL logic has the disadvantage of requiring current biasing on the input. More modern logic utilizes CMOS

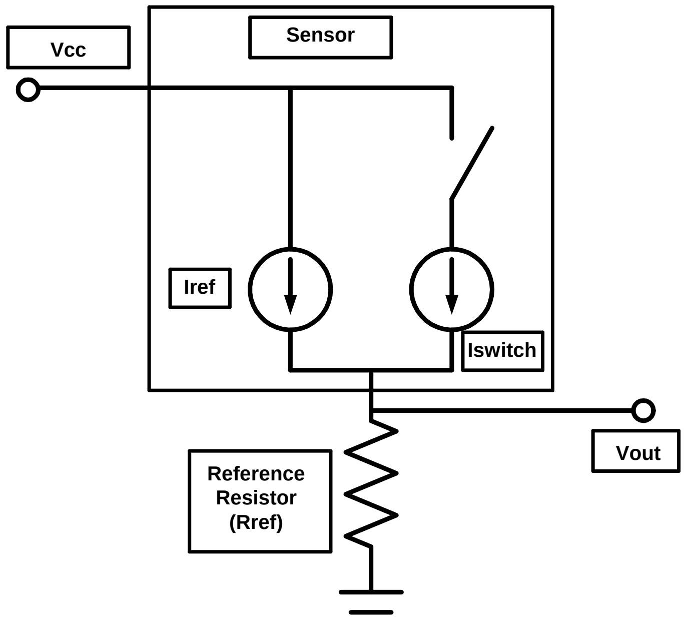

Fig. 4.2 Open Collector Schematic.

input, and requires essentially zero input current, is only voltage driven. Thus, the V_{out} node from open collector/open drain usually can feed directly into logic gates.

4.2.3 2-Wire

2-wire output circuits are utilized in a wide range of applications. A major advantage is that less wiring is required. Also, earlier magnetic sensing methods, such as variable reluctance, is inherently 2-wire. Thus, as active devices displace these other sensing methods, the circuit interface (2-wire) is sometimes propagated. The basic concept is shown in Fig. 4.2. A constant current source (I_{ref}), is sent to a reference resistor (R_{ref} or R_{load}), creating a reference voltage. A common current value is 7mA for automobiles, and 4mA for industrial applications. The R_{load} is typically between 100 and 300 Ω for automotive. Care should be taken that the appropriate resistance values are utilized, such that:

$$V_{cc} - (I_{ref} \cdot R_{load}) > V_{min} \tag{4.1}$$

with V_{min} around 3.3 volts. Next, V_{out} goes directly into some detection circuit, such as a comparator, to create a logic level. Typically, the reference resistor is between the sensor and ground, but may be between supply and the sensor.

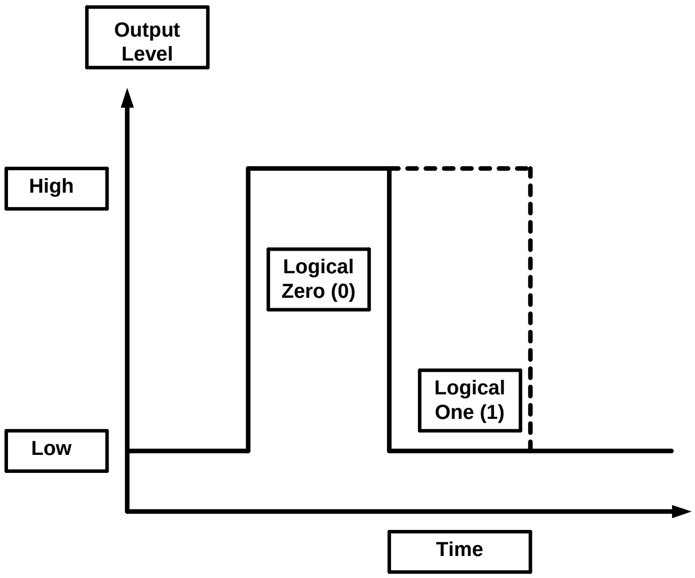

Fig. 4.3 Pulse Width Modulated (PWM) Detection.

4.2.4 Linear

The Hall Effect Handbook covers linear output circuits well. The important concept is driving the load impedance. If the load is 1k Ω, with 5 V supply, the circuit must be able to deliver 5 mA to the load. Also, if the load is from the output of the circuit to ground, the circuit must be able to source the appropriate current. With a load from the output to supply, the circuit must be able to sink the current.

4.2.5 Pulse Width Modulated

A method of transmitting sensor information is pulse width modulated (PWM). PWM may be linear, digital, 2-wire, or the like. Thus, PWM is a communication mode, rather than an output circuit type. A simple digital PWM signal is shown in Fig. 4.3. One common application for PWM is 2-wire wheel speed detection. As the poles of a ring magnet pass the sensor, the output is low-high-low, with a specific time duration. If the magnet rotates the opposite direction, the pulse is still low-high-low, but the pulse width increases, notifying the controller the wheel is going backwards.

4.3 SIGNAL CONDITIONING

A wide range of circuits are utilized in signal conditioning for sensors. Two topics are discussed in the section: amplifiers and comparators.

4.3.1 Amplifier

Amplifiers are one of the main building blocks of analog circuits. An amplifier is an electric circuit which can give a larger signal at the output, than is supplied at the input. An amplifier can shift the level of a signal, as well as a wide range of other useful signal conditioning actions. Several good books exist on the topic, such as Stout and Kaufmann [2]. Also, several useful application notes exist on the internet.

4.3.2 Comparators

As the name suggests, a comparator is a device that compares two signals. With input A higher than input B, the output is high; and input B higher than input A gives a low output (for example). This ability is of great value in circuit design. Some amplifiers can be used as a comparator.

4.4 POWER CONDITIONING: REGULATION

Sensor performance is dramatically effected by the power applied. For example, excessive voltage may destroy the device. Thus, care is required to protect the sensor, and provide the required voltage and current. This function is performed by the power conditioning circuit (regulator). Regulators may be external devices (such as 78XX series), or included on the sensor (such as a bandgap regulator [3]). For external regulators (78XX series), replace the XX by the voltage required, thus a 7805 is a 5 volt regulator. A few points of interest, to make an external regulator successful. First, capacitors are often required on the input and output. A larger capacitor ($\sim 10\mu$F) is on the input, and a small capacitor ($\sim 0.1\mu$F) on the V_{out} side, to minimize electrical ripple. Second, typically a load is required for proper performance, ie. do not connect the regulator, without a load, and expect the regulated 5 volts at the output. Next, take caution to use the proper voltage and current required by the regulator. For example, if the regulator is capable of supplying 100 mA, do not apply a load requiring 1 A. Also, there is some voltage lost required. In a simple regulator, there is a “dropout” voltage, across the regulator. If 5 volts is the output voltage, typically the requirements are 2 volts higher than the output, thus 7V is the minimum at the input.

4.5 NOISE

Noise is important for many electronic systems, such as communications and sensors. The capabilities of electrical systems are ultimately limited by the noise in the system. Noise may be defined as any undesired signal in a system. Noise may be offset of a bridge, or reception of a radio station. Noise may be in two main categories: correlated and fundamental. Correlated noise is a result of the system creating or absorbing noise from a known source, such as turning on a vacuum cleaner

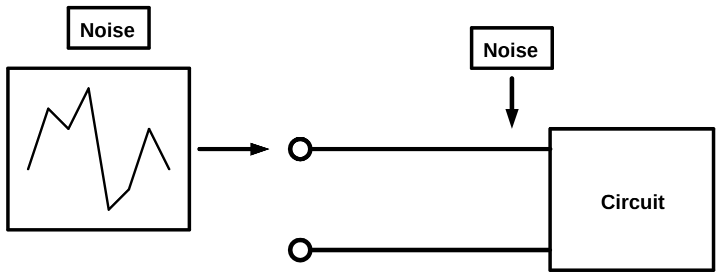

Fig. 4.4 Noise on Power Lines.

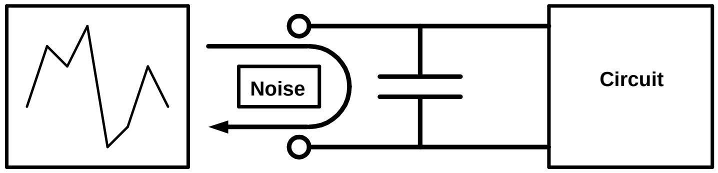

Fig. 4.5 Noise Reduction from Capacitor.

messing up radio reception. One can improve correlated noise, such as turn off the vacuum cleaner. Fundamental noise is due to the discrete electron structure of atoms. Fundamental noise is always in a system, but may be optimized by the designer. Correlated noise is often more difficult to resolve. The book by Ott [4] covers the topics of noise quite well. Additionally, Aldert van der Ziel is widely known as one, if not the, leading expert on noise [5]. Noise is often called noise because if amplified, and put through a speaker, it sounds like hissing.

4.5.1 Power Supply Noise

This subsection very briefly discusses power supply noise. Noise may arrive at the sensor along the power lines, Fig. 4.4. Then, a capacitor is added from the power line to ground. A capacitor has an impedance which is proportional to the inverse of the frequency (1/f), thus at higher frequencies, the capacitor appears as a short, and the noise bypasses the sensor, Fig. 4.5.

4.5.2 Magnetic Noise

As discussed in the introduction, magnetism is created at the subatomic level. In many ferromagnetic materials, the structure is polycrystalline, with a (at least initially) random magnetization. In other words, the small interacting particles group together on an intermediate atomic type level. A grouping of interrelated small particles is referred to as a domain. As the applied field is varied, a different grouping of particles is seen. The energy associated with the domains may be release with different applied field configurations, and is seen as noise. This type of noise is known as Barkhausen noise. Permalloy "chirp" may be considered a Barkhausen noise phenomena.

4.5.3 Metallic (Faraday) Cage

One technique to improve electrical noise is the use of a metallic (Faraday) cage. An electrical circuit, placed in metal box, is nearly impervious to external electrical noise. The noise may be considered to be shorted past the circuit. One obvious question would be, "How do you power a circuit in a cage?" If the power is entered through the cage, there is a concern noise will be introduced on the power lines. Another possibility is to battery power the circuit in the cage. A battery is a low noise power supply.

4.5.4 Mu Metal Cage

A technique similar to a Faraday cage, but concerned with magnetic noise (such as from electric motors), is the so called "Mu Metal" cage, where the Mu is for high permeability (μ). The circuit will be mostly shielded from external magnetic fields. This may be of value for Permalloy sensors.

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