Signal Conditioning

6.1 What is “Signal Conditioning”?

There are many factors which may prevent a signal produced by one device or circuit from being usable by another device or circuit, requiring some intermediate circuitry to bridge the gap. This kind of “bridging” function is doing what I call “signal conditioning”.

6.2 Type of Signal Conditioning

Signal conditioning may be divided into 4 types:

1. *analog*; analog signal in, analog signal out
2. *digital*; digital signal in, digital signal out
3. *either*; either kind of signal in; same type out
4. *interface*; involves both analog and digital signals in some way

6.2.1 Analog Signal Conditioning

- *amplification* or *attenuation*
- *level shifting*
- *filtering*
- *impedance changing*

All of the above functions can be performed by operational amplifier circuits. A couple of additional functions are

- *clipping*
- *clamping*

Clipping

Often it's necessary to ensure that a signal does not exceed a certain voltage in order to avoid harming circuitry which follows. For instance, a sensor inside the engine of a car may pick up electrical noise of hundreds of volts occasionally which could destroy a microprocessor. To avoid this, the signal may be **clipped** so that it never goes above a fixed voltage. This can be done using a Zener diode as shown in Figure 6.1.

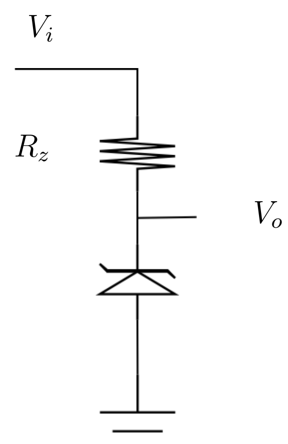

Figure 6.1: Clipping a Signal

Since the Zener diode will conduct once the voltage exceeds the Zener voltage, V_Z, the output voltage will follow the input until the input exceeds V_Z, and from then on the output will not increase. The resistor should be chosen so that the maximum current through the diode is within the specified limits.

Clamping

It may sometimes be necessary to ensure that a signal does not become negative. Again, using the car sensor example, a negative voltage due to noise could destroy a microprocessor. To avoid this, the signal may be **clamped** so that it never goes below zero. This can be done using a diode as shown in Figure 6.2.

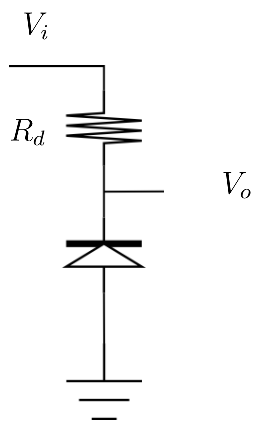

Figure 6.2: Clamping a Signal

Since the diode will conduct once it is forward biased, the output voltage will follow the input until the input goes below about $-0.7V$, and from then on the output will not decrease. (This slight negative voltage will not be a problem for most electronics.) The resistor should be chosen so that the maximum current through the diode is within the specified limits.

6.2.2 Digital

Sometimes digital signals in a system need to be *cleaned up*. This can be in order to do one or both of:

- remove noise from the signal
- change the duration of the signal

These two cases will now be discussed.

Removing Noise

Detecting the state of a digital signal can be difficult if the signal contains noise. A **Schmitt trigger** is a gate which uses *hysteresis* to remove noise from a signal. The effect of a Schmitt trigger is shown in Figure 6.3. In contrast to an ordinary gate, where the output changes state as the input passes some unknown voltage between the manufacturer's specified $V_{il_{max}}$ and $V_{ih_{min}}$, for a Schmitt trigger, there are two separate voltages. When the output is low, the input has to go above V_{on} before the output will go high, and when the output is high, the input has to go below V_{off} before the output will go low. The farther apart V_{on} and V_{off} are, the more *noise immunity* is provided. (For a normal gate, is it as though V_{on} and V_{off} are the same.)

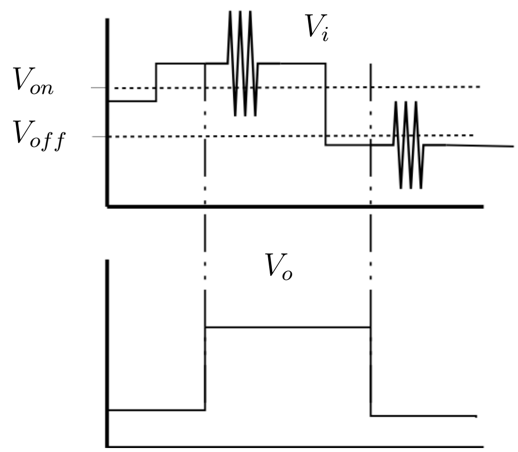

Figure 6.3: Removing Noise from a Digital Signal using a Schmitt Trigger

Changing Pulse Width

A common situation occurs when a signal needs to be extended in time so that it will be detected by a microprocessor. This can be accomplished by the use of a **one shot**. When a **trigger pulse** (ie. the signal) is received by a one shot, its output will produce a pulse of a fixed length. There are two types of one shots:

- *retriggerable*
- *non-retriggerable*

With a retriggerable one shot, if a second trigger pulse occurs while the output is active (ie. during a pulse created by a previous trigger pulse), the output will be extended for a further period. In this way a pulse can be extended indefinitely. With a non-retriggerable one shot, any trigger pulses occurring while the output is active, (ie. during a pulse created by a previous trigger pulse), will be ignored. In other words, the output pulse is always the same length.

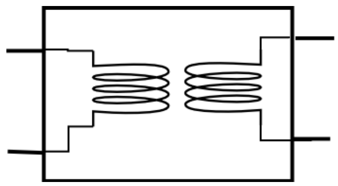

Figure 6.4: Inductive Isolation of a Signal

6.2.3 Either

Isolation

The purpose of **isolation** is to remove large DC offsets from a signal. (Of course it could be to add a DC offset instead.) An op-amp can be used to remove small DC offsets, of the same order of voltage as the supply voltage, but sometimes hundreds or thousands of volts must be removed. (For instance, inside a car engine, the ignition system produces sparks of thousands of volts, while the electronics runs on normal logic levels. The spark plug voltages could not be directly sensed by the microprocessor. At least more than once.....)

- *inductive* using a transformer
  - cannot transmit DC (ie. steady-state) values
  - 2 way
  - can transmit power
  - the above two conditions mean that care must be taken as voltage spikes at the *input* end can be transmitted to the *input* end and vice versa

  Inductive isolation is shown in Figure 6.4. Keep in mind that different numbers of windings in the two coils allow the input signal to be increased or decreased while any DC offset is removed.

- *optical* using an LED and a phototransistor or photodiode
  - can transmit DC (ie. steady-state values)
  - only one way

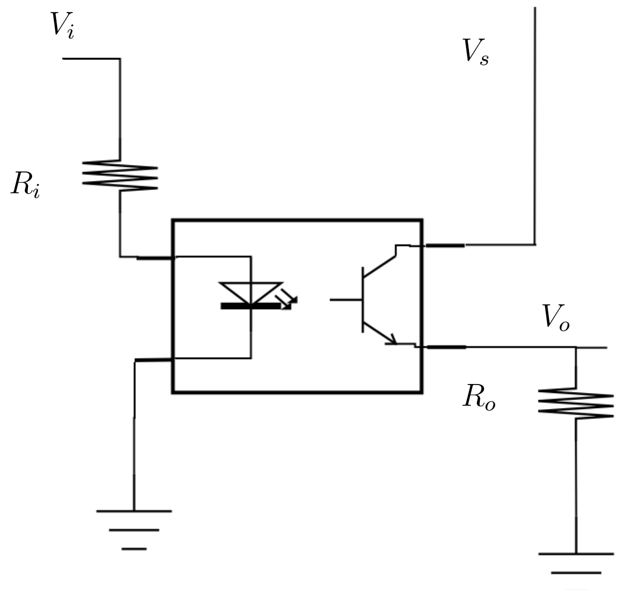

Figure 6.5: Optical Isolation of a Signal

- cannot transmit power
- the above two conditions mean that there is no danger of voltage spikes as there is with inductive isolation

An **optoisolator** is shown in Figure 6.5. The resistors are used because effectively the LED and the phototransistor are *current* devices, and usually signals are processed as voltages. The values chosen for the resistors should be consistent with the current specifications for the device. The amount of DC isolation provided by an optoisolator is usually in the range of kV. At some point the insulation will break down and arcs can occur.

Whenever sensors are in a place where it is *possible* for high voltages to be induced, optical isolation should be used to protect electronic devices which follow.

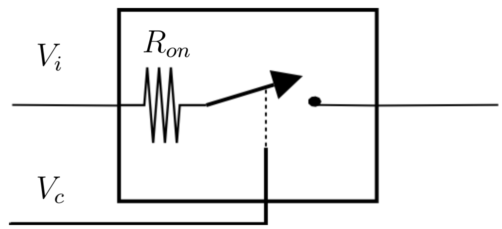

Figure 6.6: Single Pole single Throw Analog Switch

6.2.4 Interface

Analog Comparators

Two analog voltages can be compared with an analog **comparator**. This device is basically an operational amplifier with a digital output, so that the output indicates which of the inputs is higher.

Analog Switches and Multiplexers

An **analog switch** works just like a mechanical switch in allowing an analog signal to flow between two points in a circuit when it is closed, and preventing the flow when it is open. The difference with an analog switch is that the control of the opening and closing of the switch is provided by a digital signal. Like mechanical switches, there are a variety of switch types, such as SPST, SPDT, DPDT, and so on. A simple SPST analog switch is shown in Figure 6.6. The resistor R_{on} is to indicate a finite resistance between the input and output when the switch is closed. The value of R_{on} should be in the device specifications.

An **analog multiplexer** is similar to a digital multiplexer in that a set of digital signals controls which *analog* signal is passed through to the output. Since the internal construction is similar to that of an analog switch, there is an on resistance as before.

6.3 Current Amplification

Operational amplifiers make good *voltage* amplifiers, but usually their current output is very limited. *Current amplification* is a job more suited to transistors.

6.3.1 Basic BJT Operation

The BJT operates as a current amplifier. In the common emitter configuration, controlling the current to the base results in change to the collector current. Since

$$\beta = \frac{I_c}{I_b} \approx 100 \rightarrow 500$$

then a substantial increase in current is possible. A few choices of how to do this in a circuit follow. (NPN transistors will be assumed. It's easy to change to PNP after you understand the principles.)

Darlington Transistors

If a very great current gain is desired, ie. up to $\approx 1000\times$, a **Darlington** configuration may be used. This has the emitter of one transistor fed directly into the base of another, with the collectors in common. In this way the two β values get multiplied, so a much greater gain is possible. *Darlington transistors* are devices which are connected this way internally, so they look like an ordinary transistor from the outside.

6.3.2 Grounded Load

In this configuration, the load , shown as a resistance R_l, is placed between the emitter of the transistor and ground. It is often useful to have one end of the load grounded. For a transistor to be "on", the base–emitter junction must be forward biased so

$$V_{be} \geq 0.7V$$

This means that the base of the transistor must be able to go *above* the highest load voltage desired.

6.3.3 Floating Load

If the base voltage cannot easily be raised above the desired load voltage, it is possible to place the load between the *collector* of the transistor and the supply voltage, and then ground the emitter of the transistor.

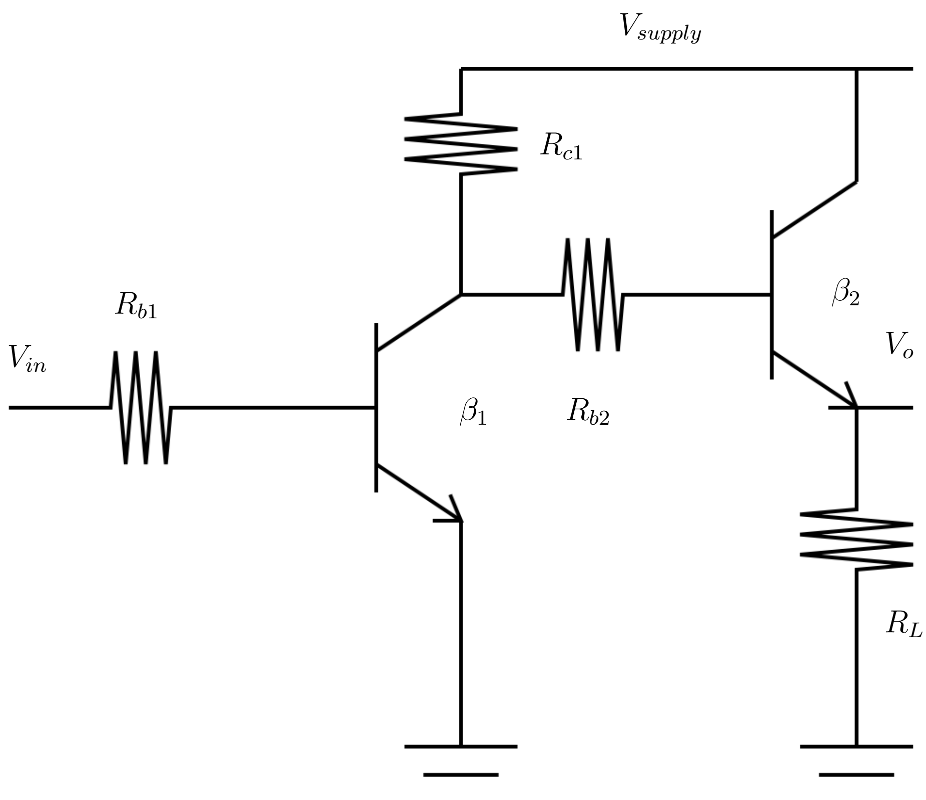

Figure 6.7: Grounded load current amplification (inverted)