Other Useful Digital Electronic Devices

This lecture briefly reviews some basic circuit theory and describes some devices other than logic ICs that are useful in digital control applications.

Basic Circuit Theory

- The sum of the voltages around any loop in a circuit is zero (*Kirchhoff's Voltage Law*).
- The sum of the currents into any node in a circuit is zero (*Kirchhoff's Current Law*).
- The voltage drop across a resistor is: $V = IR$, where I is the current and R is the resistance (*Ohm's Law*).
- The power dissipated in a circuit element is given by the equation $P = VI$.

Resistors

Resistors are one of the most common circuit elements. They are used to limit current flows and provide voltage drops. The most important specification of a transistor is, of course, its resistance. Other important specifications for a resistor are power dissipation and tolerance.

The I-V characteristic of a resistor is:

Diodes

A diode is a two-terminal device that allows current to flow in only one direction. When the diode is forward biased the voltage across is is about 0.7 V. The I-V characteristic of such a diode is:

LED's

Light Emitting Diodes (LED's) are devices with the same electrical characteristics as diodes, but they have the additional property that they generate light when forward-biased. They are often used for displays and can be arranged in multi-segment matrices to form numeric or (less often) alphanumeric displays. The forward-biased voltage drop is about 2 volts and typical supply currents are 2 to 10 mA. LED's can usually be driven from a 5-volt TTL logic output if a current-limiting resistor is used.

The schematic symbol for an LED is:

Phototransistor

A phototransistor (or photodiode) is a transistor where the collector-emitter current is controlled by the amount of light falling on a portion (the base) of the transistor. This allows the device to be controlled by a light source.

Optocouplers

An optocoupler is a device that combines an LED and a phototransistor in the same case. The LED shines on the phototransistor and turns on the phototransistor when the LED turned on. The advantage of an optocoupler is that the only coupling between the input (LED) and output stages is with light. The two stages are thus completely isolated and need not share a common reference voltage.

Relays

A relay is an electromechanical device consisting of an coil forming an electromagnet and one or more moving contacts. When current flows through the coil the magnetic force brings the contacts together and closes or opens electric circuits. When the relay is driven by semiconductor devices a protection diode must be used to bypass the temporary reverse voltage pulse generated when the current is switched off.

In many power-control applications relays have been replaced by solid state devices such as transistors, optocouplers, SCRs and TRIACS (other types of solid-state control devices).

Operational Amplifiers

Operational amplifiers (op-amps for short) are a basic building block for many analog circuits. Op-amps are available as inexpensive integrated circuits, often with two or four amplifiers on the same chip. Op-amps are often used to interface between a digital controller and analog devices.

Properties of Ideal Op-Amps

An op-amp is a differential amplifier. That is, its output is proportional to the difference between two inputs. If the voltage at one terminal, the non-inverting input, is v_+ and the input at another input, the inverting input, is v_- then the output is equal to $v_{\text{out}} = A(v_+ - v_-)$ where A is the op-amp's gain.

An ideal op-amp has two important properties: (1) nearly-infinite gain (A typically $> 10^5$) and (2) nearly-infinite input impedance. The consequence of the first property is that in normal operation the difference between the input pins must be very small and is usually assumed to be zero. The effect of the second property is that we can assume that there is zero current into the input terminals of the op-amp. These two properties make it easy to analyze op-amp circuits.

The symbol used in schematic diagrams for an op-amp is:

Inverting Amplifier

The following circuit is an amplifier with gain given by the ratio $-R_f/R_1$.

We can derive this result using the ideal op-amp properties. Since the sum of currents flowing into the inverting input must be zero, the currents through the two resistors must be equal and opposite. Since the difference in voltage between the input pins must be zero, the inverting pin must also be at ground level (0 V) and so we can compute these currents and from this obtain the amplifier's gain:

$$V_{\text{out}}/R_f = -V_{\text{in}}/R_1 \tag{1}$$

$$V_{\text{out}}/V_{\text{in}} = -R_f/R_1 \tag{2}$$

Summing Amplifier

If we add additional input branches we can repeat the analysis and find that the following circuit sums up the input voltages so that

$$V_{\text{out}} = -\frac{1}{R_f}(R_1 v_1 + R_2 v_2 + R_3 v_3) \tag{3}$$

Voltage Follower

The following circuit can be used as a buffer between two parts of a circuit because it has very high input impedance (so that it doesn't load the driving circuit) and a low output impedance (so that it's output voltage doesn't vary as a function of the output current).

Practical Considerations

Op-amps must usually be supplied with both positive and negative power supplies (typically $\pm$ 12 or $\pm$ 15 volts). The output voltage must be kept several volts less than these voltages (e.g. $\pm$ 10V) for the op-amp to operate properly.

Typical op-amps can only supply very limited amounts of power (100 mW or so) although (expensive) high-power devices are available.

Op-amps are also limited in their frequency response (how quickly their outputs can respond to changes in the input). Typical op-amps are limited to frequencies under about 100 kHz although higher-frequency devices are also available.