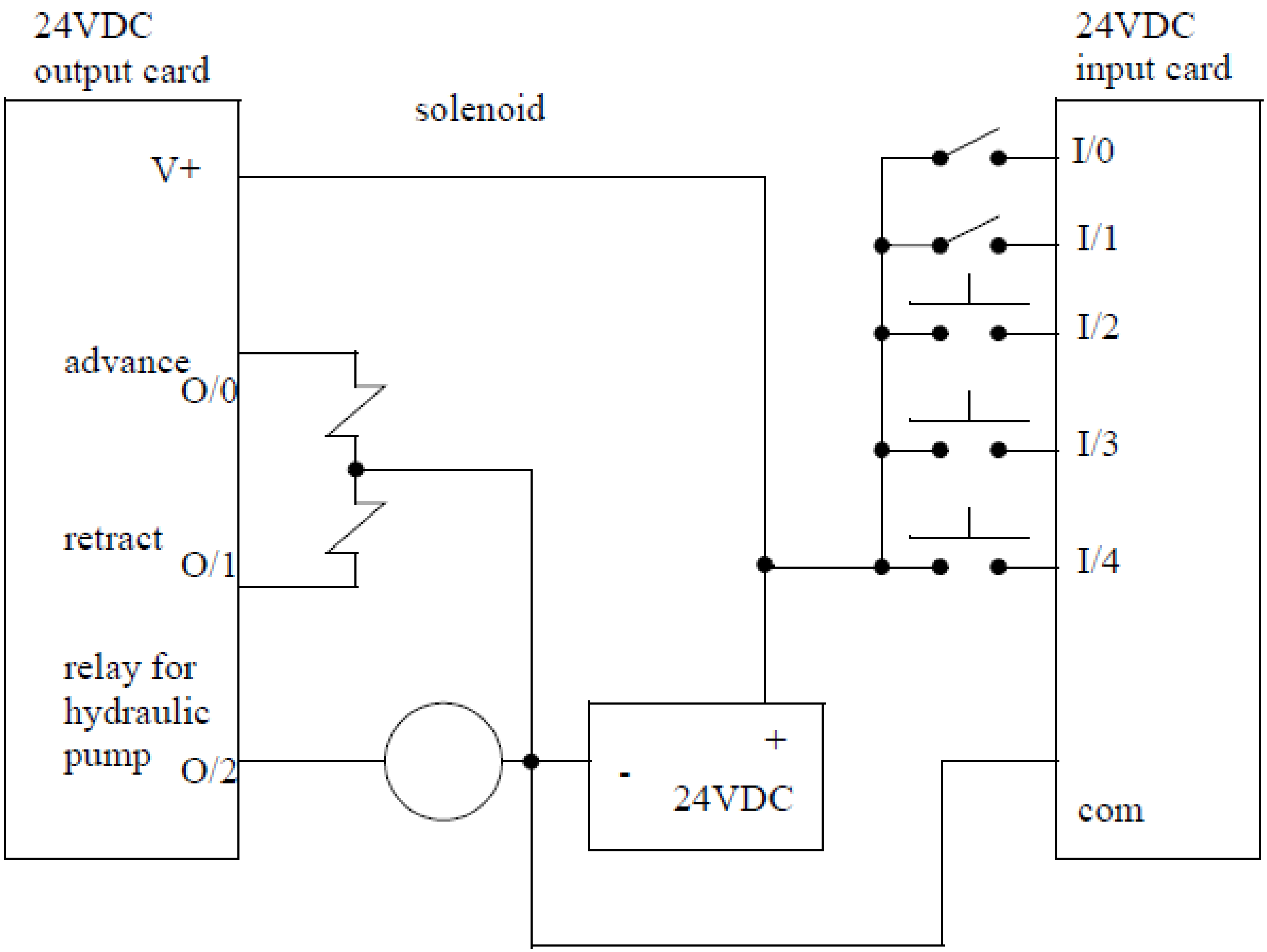
Lecture 5

PLC programming

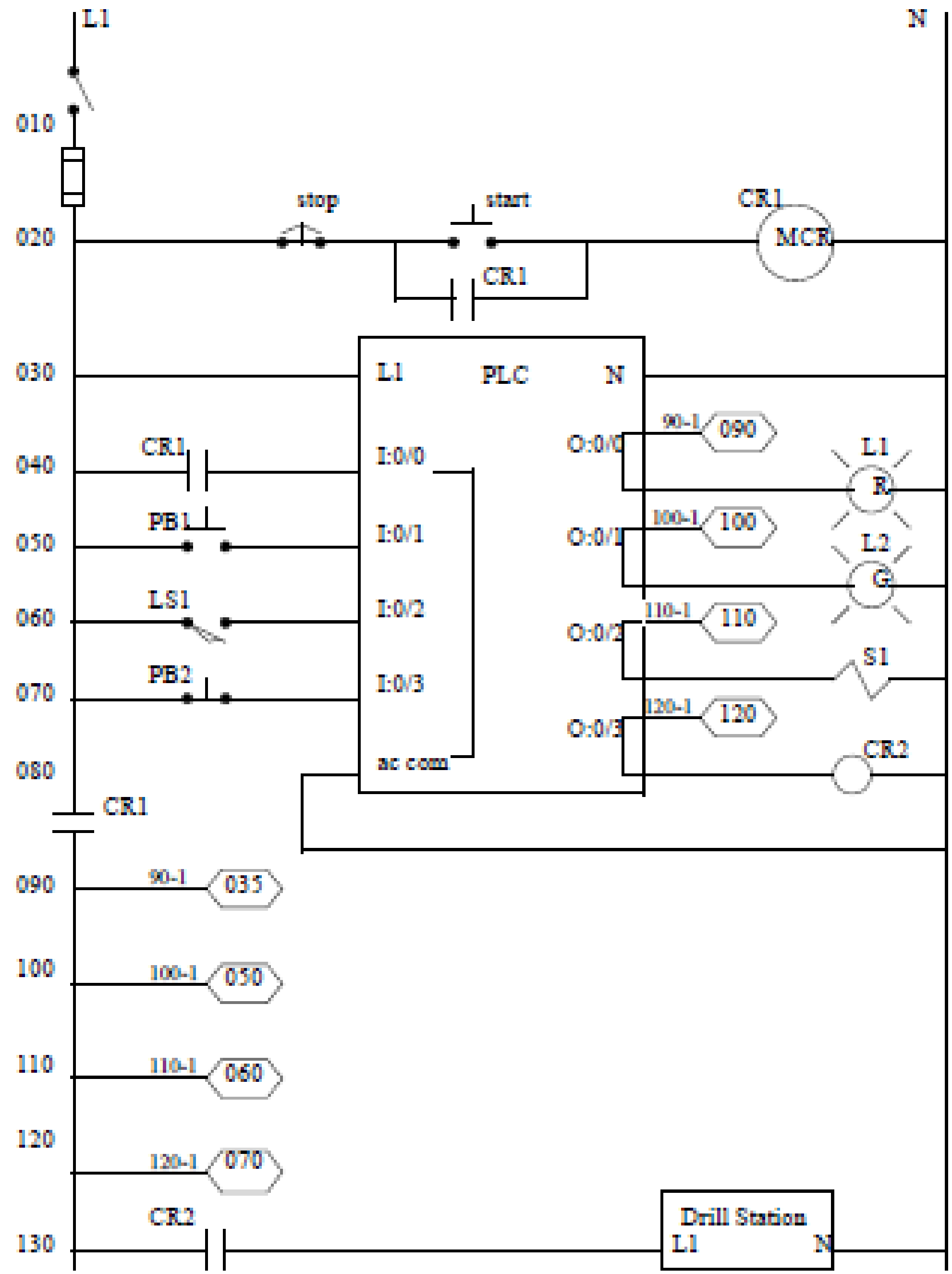
Design of electrical diagrams

Example: An electrical layout is needed for a hydraulic press. The press uses a 24Vdc double actuated solenoid valve to advance and retract the press. This device has a single common and two input wires. Putting 24Vdc on one wire will cause the press to advance, putting 24Vdc on the second wire will cause it to retract. The press is driven by a large hydraulic pump that requires 220Vac rated at 20A, this should be running as long as the press is on. The press is outfitted with three push buttons, one is a NC stop button, the other is a NO manual retract button, and the third is a NO start automatic cycle button. There are limit switches at the top and bottom of the press travels that must also be connected.


24VDC
output card
solenoid
24VDC
input card
V+
I/0
I/1
I/2
I/3
I/4
advance
O/0
retract
O/1
relay for
hydraulic
pump
O/2
+
-
24VDC
com

- The input and output cards were both selected to be 24Vdc so that they may share a single 24Vdc power supply.
- In this case the solenoid valve was wired directly to the output card, while the hydraulic pump was connected indirectly using a relay (only the coil is shown for simplicity).
- This decision was primarily made because the hydraulic pump requires more current than any PLC can handle, but a relay would be relatively easy to purchase and install for that load.
- All of the input switches are connected to the same supply and to the inputs.

A basic wiring diagram is shown. The system is supplied with AC power (120Vac or 220Vac) on the left and right rails. The lines of these diagrams are numbered, and these numbers are typically used to number wires when building the electrical system. The switch before line 010 is a master disconnect for the power to the entire system.

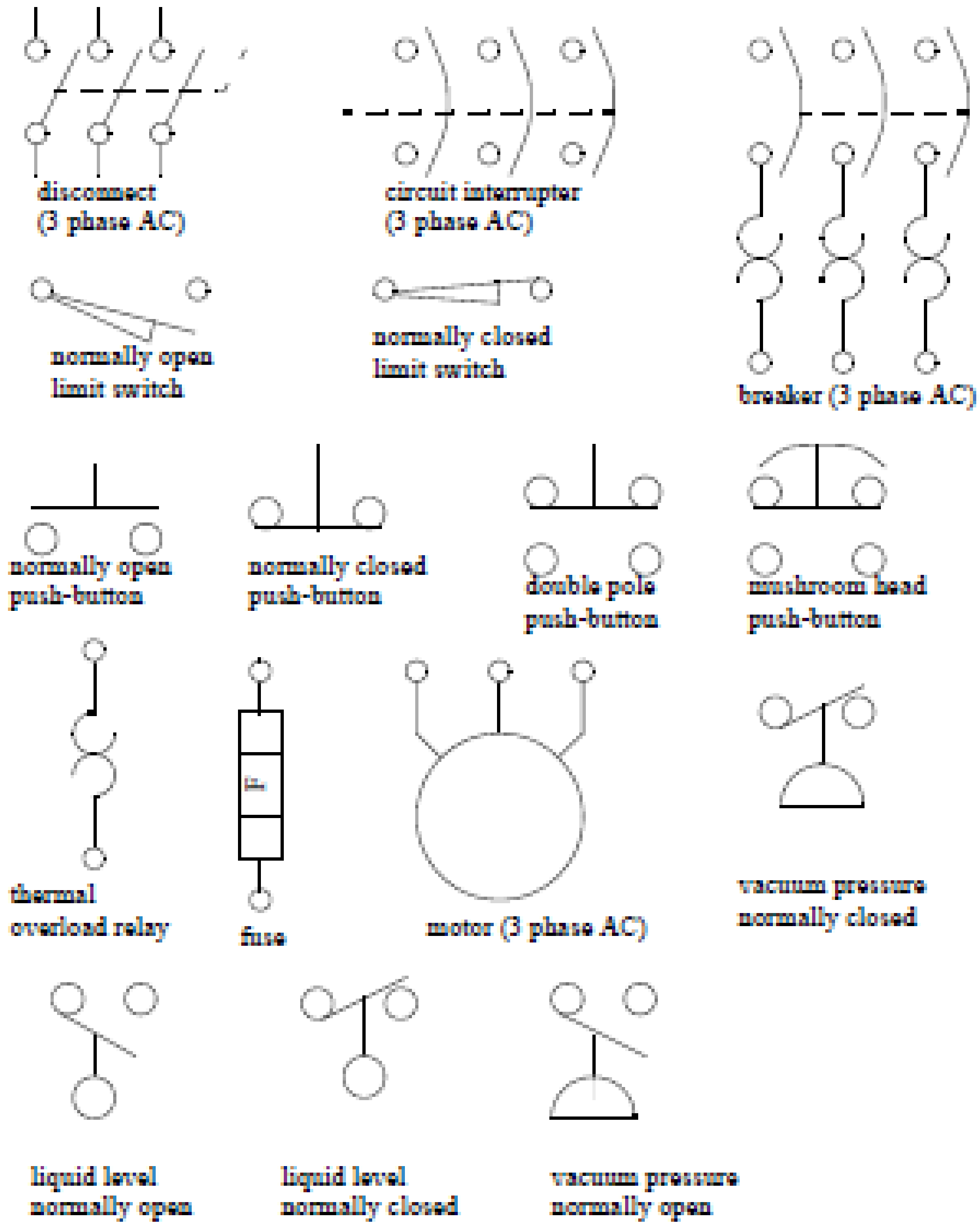


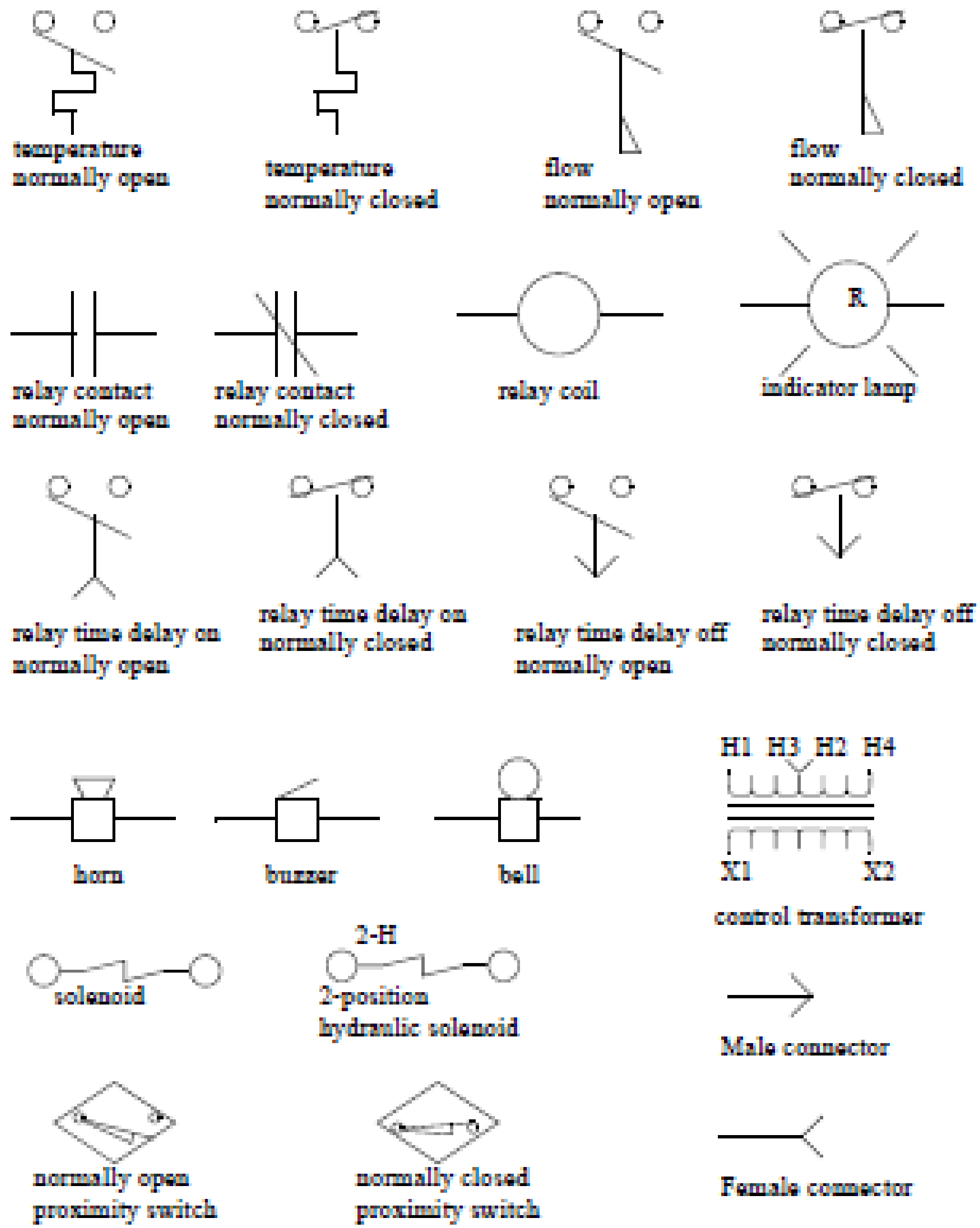
- A fuse is used after the disconnect to limit the maximum current drawn by the system.
- Line 020 of the diagram is used to control power to the outputs of the system.
- The stop button is normally closed, while the start button is normally open. The branch, and output of the rung are CR1, which is a master control relay.
- The PLC receives power on line 30 of the diagram.
- The inputs to the PLC are all AC, and are shown on lines 040 to 070. Notice that Input I:0/0 is a set of contacts on the MCR CR1.

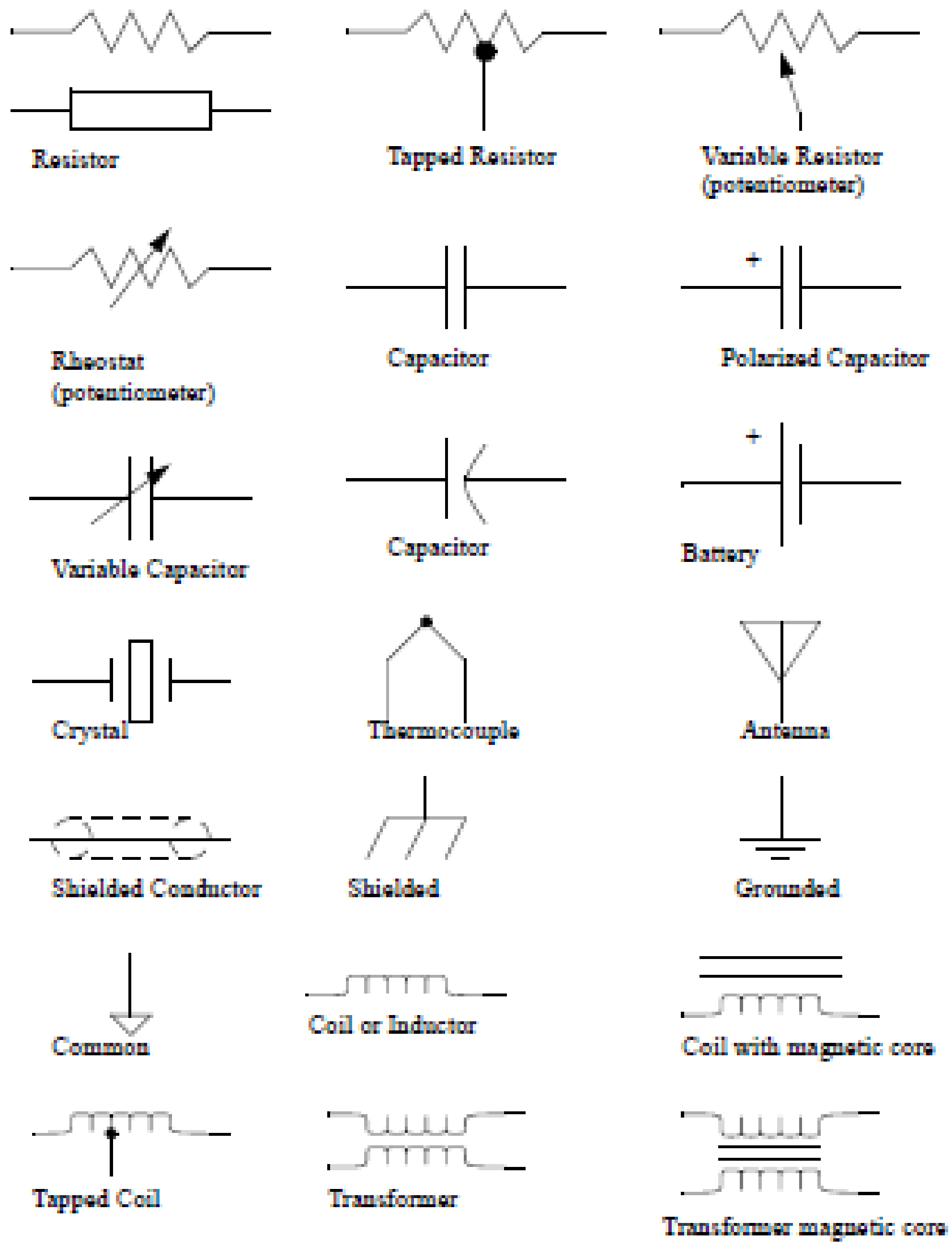
- The other 3 inputs are a normally open push button (line 050), a limit switch (060) and a normally closed push button (070).
- After line 080 the MCR CR1 can apply power to the outputs.
- These power the relay outputs of the PLC to control a red indicator light (040), a green indicator light (050), a solenoid (060), and another relay (080).
- The relay on line 080 switches a relay that turn on another device drill station.
- In the wiring diagram the choice of a normally close stop button and a normally open start button are **international**.
- All buttons that stop a system should be normally closed, while all buttons that start a system should be normally open.

JIC Wiring Symbols

:To standardize electrical schematics, the Joint International Committee (JIC) symbols were developed, these are shown below.




temperature normally open
temperature normally closed
flow normally open
flow normally closed
relay contact normally open
relay contact normally closed
relay coil
R
indicator lamp
relay time delay on normally open
relay time delay on normally closed
relay time delay off normally open
relay time delay off normally closed
horn
buzzer
bell
H1 H3 H2 H4
X1 X2
control transformer
solenoid
2-H
2-position hydraulic solenoid
Male connector
normally open proximity switch
normally closed proximity switch
Female connector


Resistor
Tapped Resistor
Variable Resistor (potentiometer)
Rheostat (potentiometer)
Capacitor
+
Polarized Capacitor
Variable Capacitor
Capacitor
+
Battery
Crystal
Thermocouple
Antenna
Shielded Conductor
Shielded
Grounded
Common
Coil or Inductor
Coil with magnetic core
Tapped Coil
Transformer
Transformer magnetic core

LOGICAL SENSORS

Topics:

- Sensor wiring, switches, TTL, sourcing, sinking
- Proximity detection, contact switches, photo-optics, capacitive, inductive and ultrasonic

Objectives:

- Understand different types of sensor outputs.
- Know basic sensor types and understand application issues.

Sensors allow a PLC to detect the state of a process. Logical sensors can only detect a state that is either **true** or **false**. Examples of physical phenomena that are typically detected are listed below.

- inductive proximity - is a metal object nearby?
- capacitive proximity - is a dielectric object nearby?
- optical presence - is an object breaking a light beam or reflecting light?
- mechanical contact - is an object touching a switch?

- Recently, the cost of sensors has dropped and they have become commodity items, typically between $50 and $100.
- They are available in many forms from multiple vendors such as Allen Bradley, Omron, Hyde Park, Ifm and Turck.
- In applications sensors are interchangeable between PLC vendors, but each sensor will have specific interface requirements.

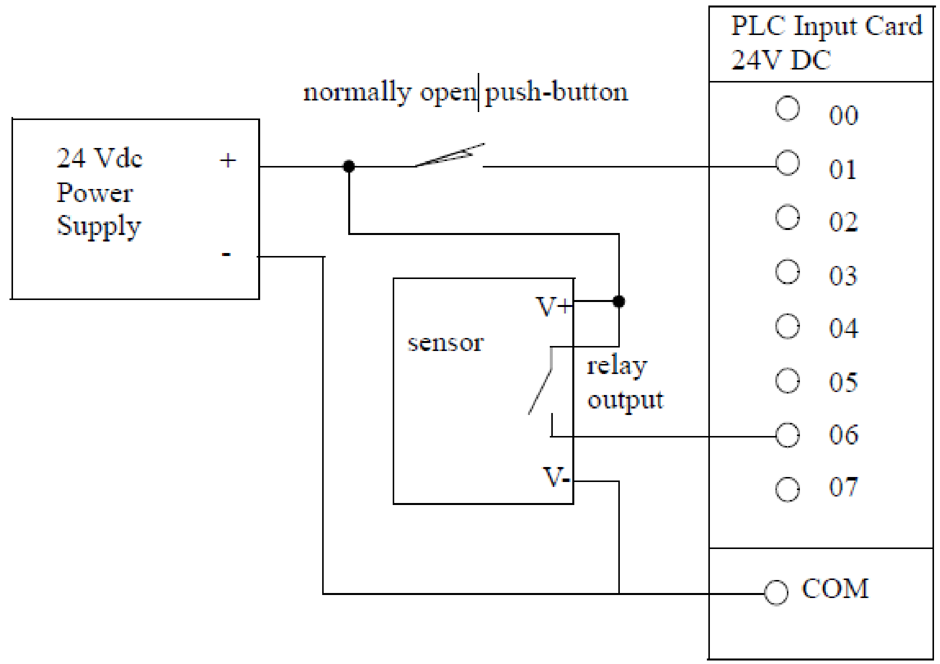
SENSOR WIRING

When a sensor detects a logical change it must signal that change to the PLC. This is typically done by switching a voltage or current on or off. In some cases the output of the sensor is used to switch a load directly, completely eliminating the PLC. Typical outputs from sensors (and inputs to PLCs) are listed below in relative popularity.

- Sinking/Sourcing - Switches current on or off.
- Plain Switches - Switches voltage on or off.
- Solid State Relays - Switch AC outputs.
- TTL (Transistor Transistor Logic) - Uses 0V and 5V to indicate logic levels.

Switches

The simplest example of sensor outputs are switches and relays. A simple example is shown below.

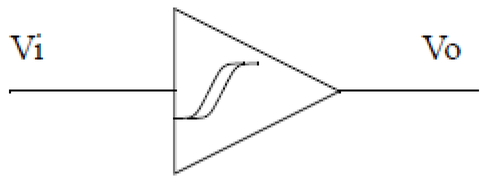


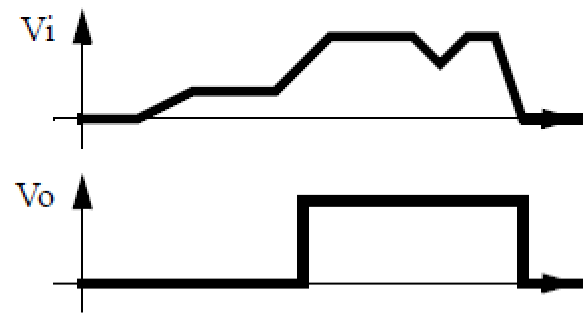
A NO contact switch is connected to input 01. A sensor with a relay output is also shown. The sensor must be powered separately, therefore the V+ and V- terminals are connected to the power supply. The output of the sensor will become active when a phenomenon has been detected.

the internal switch (relay) will be closed allowing current to flow and the positive voltage will be applied to input 06.

Transistor Transistor Logic (TTL)

- Transistor-Transistor Logic (TTL) is based on two voltage levels, 0V for false and 5V for true.
- This method is very susceptible to electrical noise on the factory floor, and should only be used when necessary.
- TTL outputs are common on electronic devices and computers, and will be necessary sometimes.
- When connecting to other devices simple circuits can be used to improve the signal, such as the Schmitt trigger shown below.



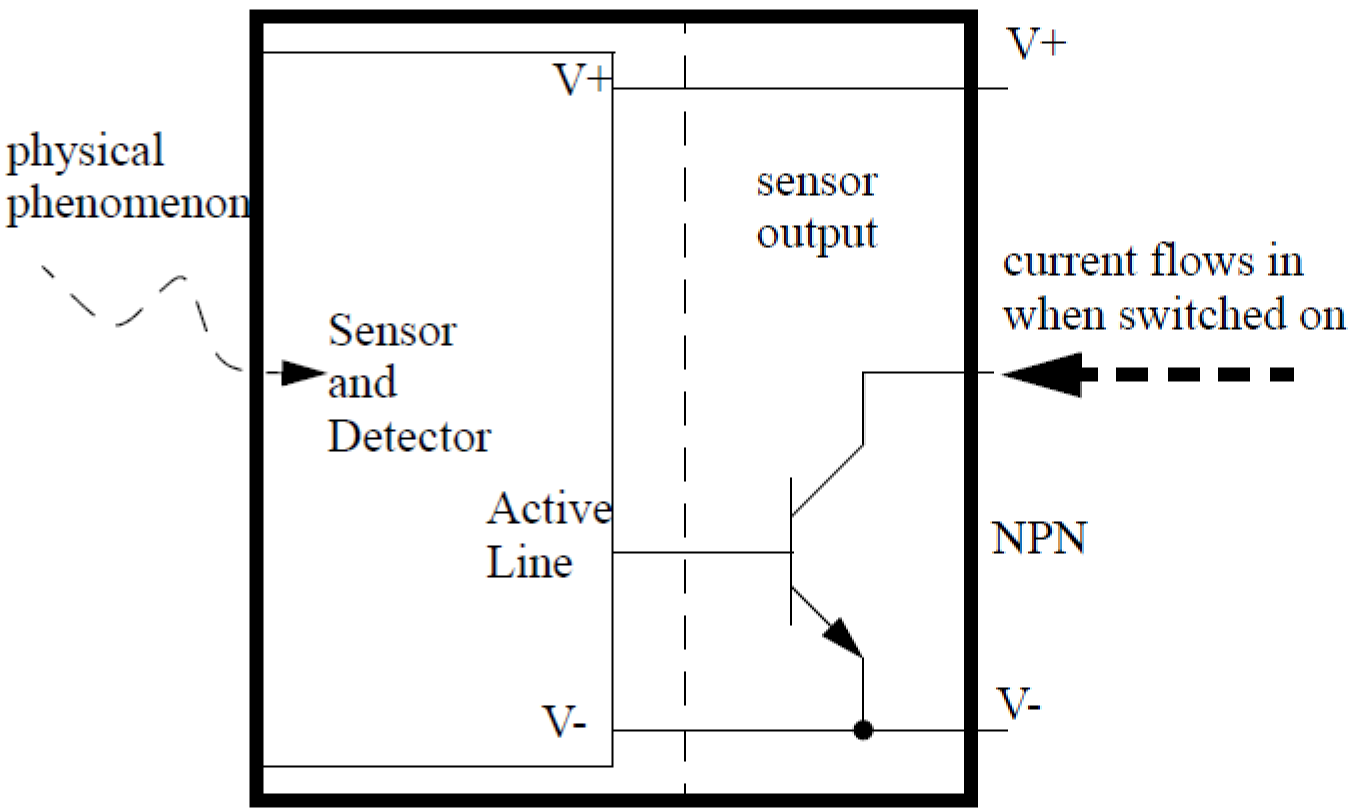


- A Schmitt trigger will receive an input voltage between 0-5V and convert it to 0V or 5V.
- If the voltage is in an ambiguous range, about 1.5-3.5V it will be ignored.
- If a sensor has a TTL output the PLC must use a TTL input card to read the values.
- If the TTL sensor is being used for other applications it should be noted that the maximum current output is normally about 20mA.

Sinking/Sourcing

- Sinking sensors allow current to flow into the sensor to the voltage common.
- sourcing sensors allow current to flow out of the sensor from a positive source.
- For both of these methods the emphasis is on current flow, not voltage. By using current flow, instead of voltage, many of the electrical noise problems are reduced.
- In sourcing and sinking processes, the output of the sensor is acting like a switch. In fact the output of the sensor is normally a transistor, that will act like a switch (with some voltage loss).

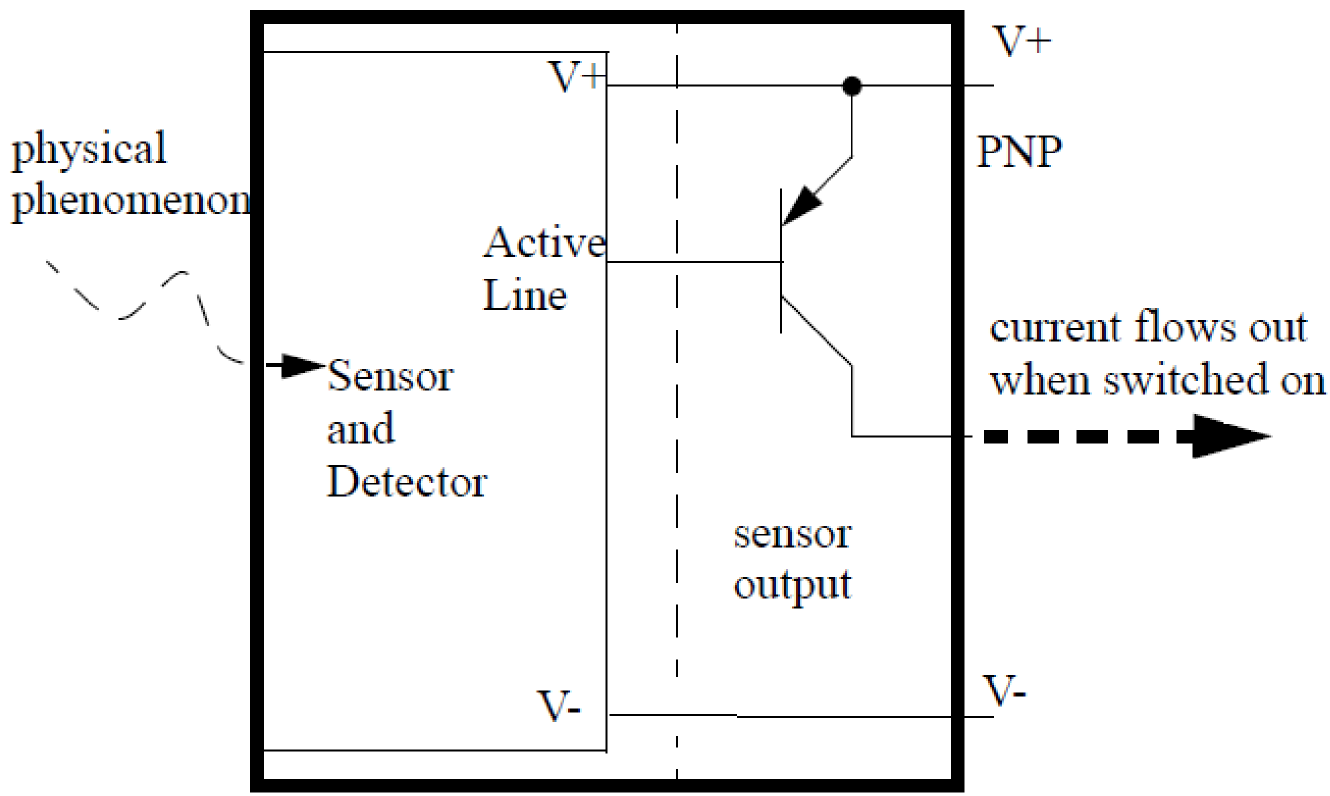
A PNP transistor is used for the sourcing output, and an NPN transistor is used for the sinking input. When discussing these sensors the term sourcing is often interchanged with PNP, and sinking with NPN. A **sinking** output sensor is shown below.



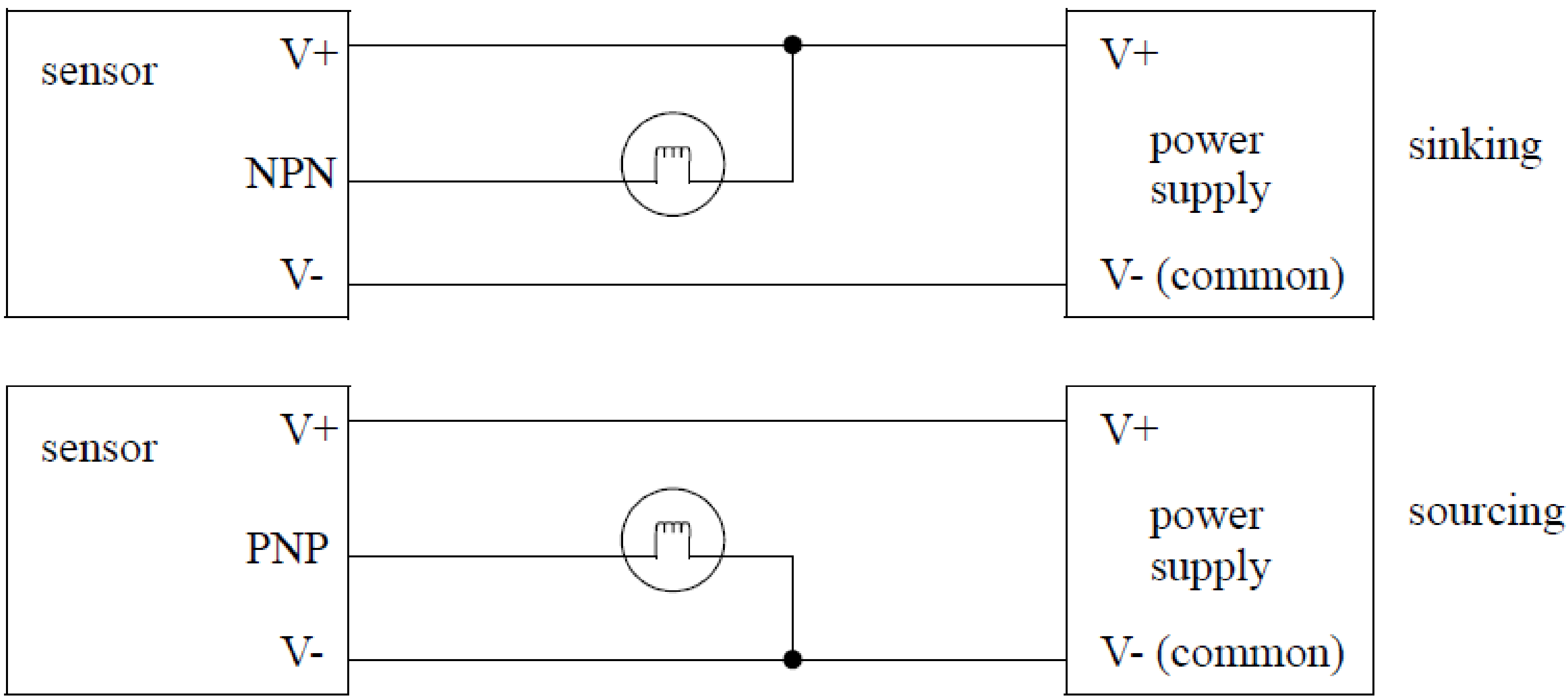
- The sensor will have some part that deals with detection, this is on the left.
- The sensor needs a voltage supply to operate, so a voltage supply is needed for the sensor.
- If the sensor has detected some phenomenon then it will trigger the active line. The active line is directly connected to an NPN transistor.
- If the voltage to the transistor on the active line is 0V, then the transistor will not allow current to flow into the sensor.
- If the voltage on the active line becomes larger (12V) then the transistor will switch on and allow current to flow into the sensor to the common.

Sourcing sensors are the complement to sinking sensors. The sourcing sensors use a PNP transistor, as shown below. When the sensor is inactive the active line stays at the V+ value, and the transistor stays switched off.

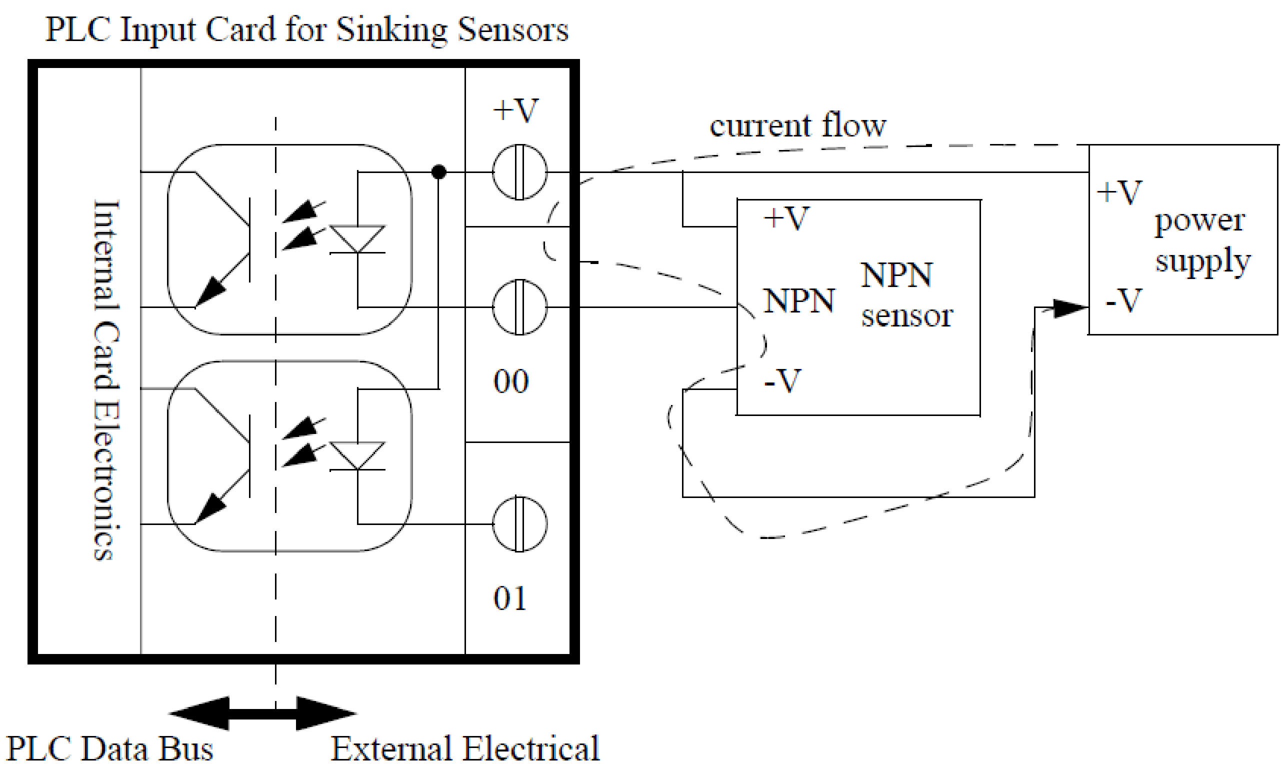
When the sensor becomes active the active line will be made 0V, and the transistor will allow current to flow out of the sensor.



- Most NPN/PNP sensors are capable of handling currents up to a few amps, and they can be used to switch loads directly. (Always check the documentation for rated voltages and currents.)
- An example using sourcing and sinking sensors to control lights is shown below (motion detector that turns on lights in dark hallways.)

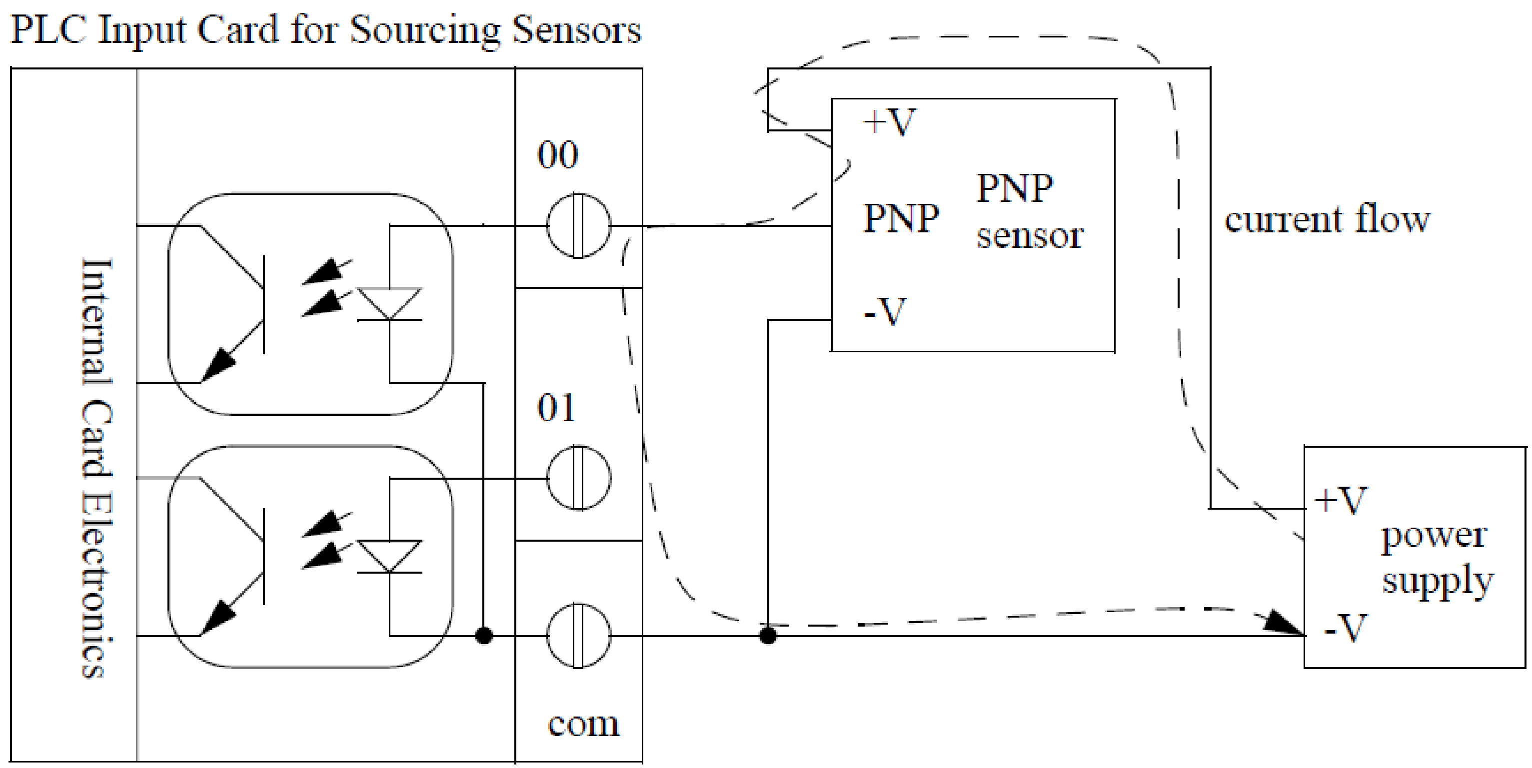


The output of a sensor will be an input for a PLC. There are two viable approaches for connecting sensors to PLCs. The first is to always use PNP sensors and normal voltage input cards. The second option is to purchase input cards specifically designed for sourcing or sinking sensors. An example of a PLC card for sinking sensors is shown below.



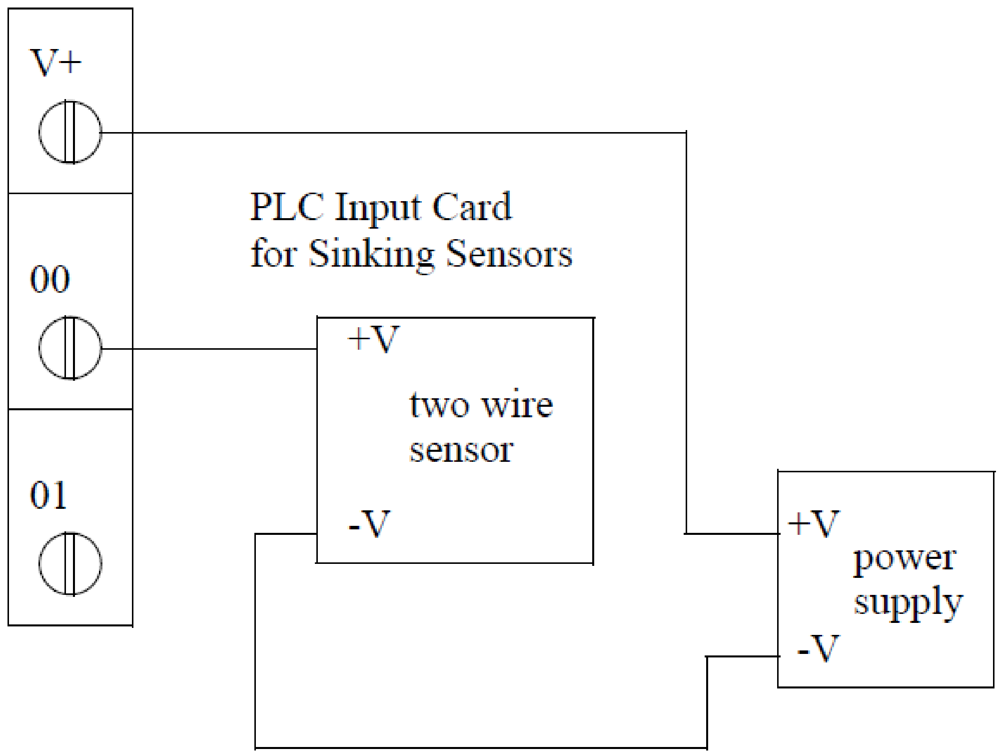
- This card is shown with 2 optocouplers (one for each output). Inside these devices the is an LED and a phototransistor, but no electrical connection. These devices are used to isolate two different electrical systems. In this case they protect the 5V digital levels of the PLC computer from the various external voltages and currents.
- The dashed line represents the current flow path when the sensor is active. It enters the PLC input card first at a V+ terminal and leaves the card at input 00 and passes through the sensor to V-. When the sensor is inactive the current will not flow, and the light in the optocoupler will be off.

- The input cards for PNP sensors are similar to the NPN cards, as shown.

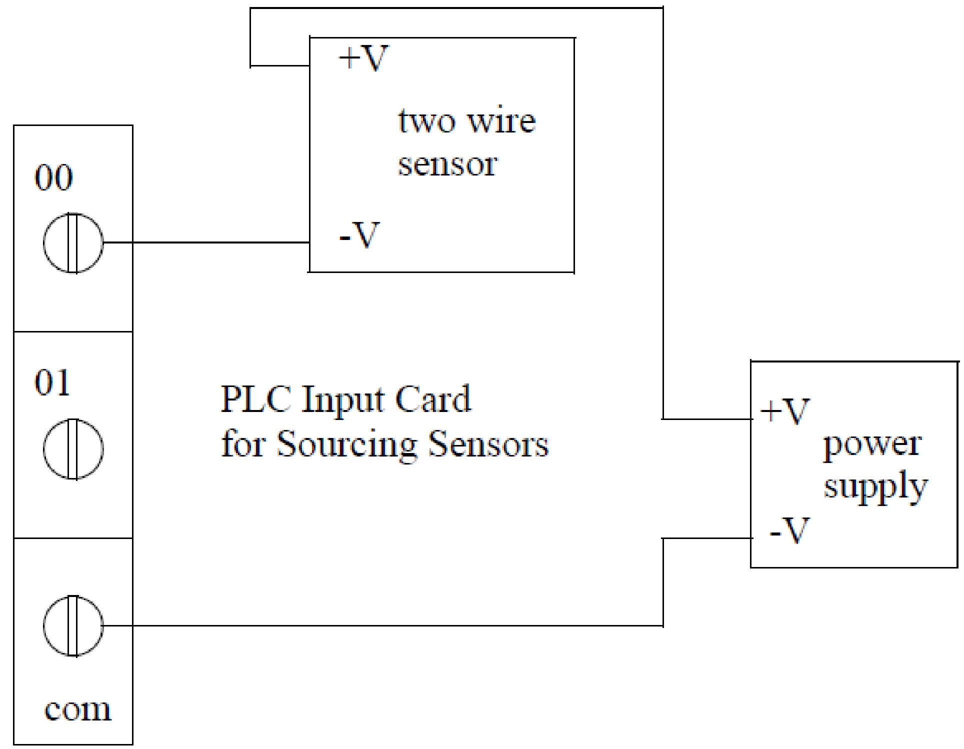


- The current flow is shown with a dashed line. It begins at the V+, passes through the sensor, in the input 00, through the optocoupler, out the common and to the V-.

Wiring is a major concern with PLC applications, so to reduce the total number of wires, two wire sensors have become popular. (couple the power supply and sensing functions into one). Two wire sensors are shown below.



- A two wire sensor can be used as either a sourcing or sinking input.
- In both cases, the sensor will require a small amount of current to power the sensor, but when active it will allow more current to flow.
- This requires input cards that will allow a small amount of current to flow (called the leakage current).

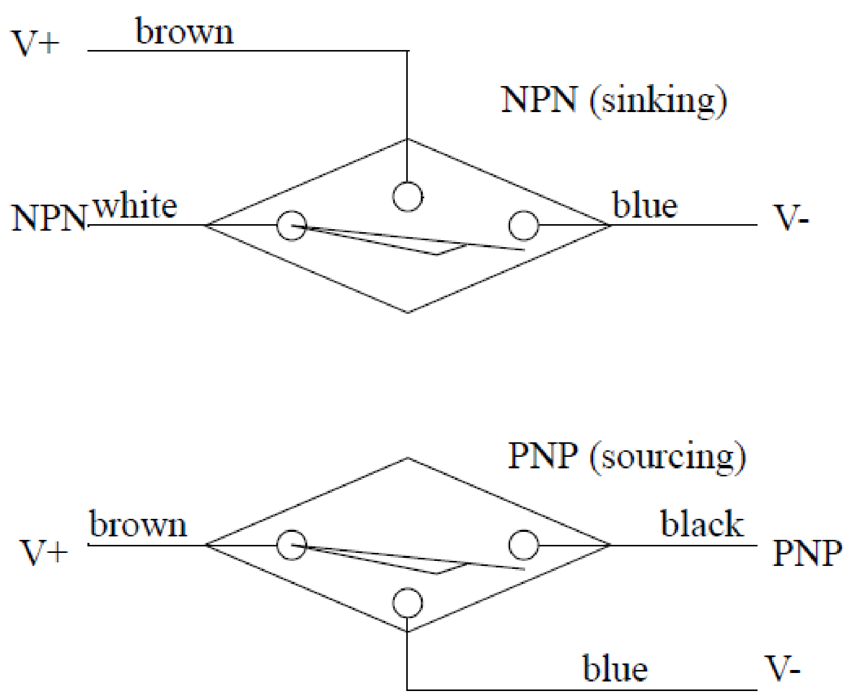


- It have to be able to detect when the current has exceeded a given value.

Important considerations about sensors and input cards

- Most modern sensors have both PNP and NPN outputs, although if the choice is not available, PNP is the more popular choice.
- PLC cards can be confusing to buy, as each vendor refers to the cards differently.
- To avoid problems, look to see if the card is specifically for sinking or sourcing sensors, or look for a V+ (sinking) or COM (sourcing).
- Some vendors also sell cards that will allow you to have NPN and PNP inputs mixed on the same card.

- When drawing wiring diagrams the symbols shown below are used for sinking and sourcing proximity sensors.
- In the sinking sensor when the switch closes (moves up to the terminal) it contacts the common.
- Closing the switch in the sourcing sensor connects the output to the V+.



- On the physical sensor the wires are color coded as indicated in the diagram.
- The brown wire is positive, the blue wire is negative and the output is white for sinking and black for sourcing.
- The outside shape of the sensor may change for other devices, such as photo sensors which are often shown as round circles.

Solid State Relays

- Solid state relays switch AC currents.
- These are relatively inexpensive and are available for large loads.
- Some sensors and devices are available with these as outputs.

PRESENCE DETECTION

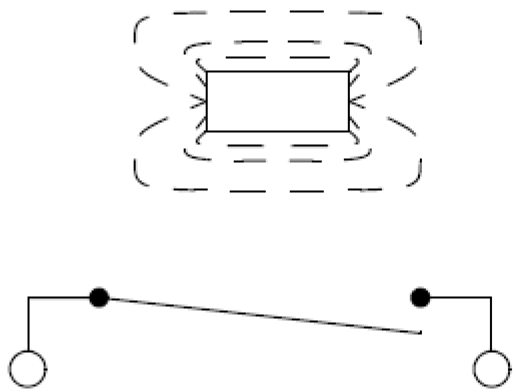
- There are two basic ways to detect object presence (contact and proximity).
- Contact implies that there is mechanical contact and a resulting force between the sensor and the object.
- Proximity indicates that the object is near, but contact is not required.
- These sensors account for a majority of the sensors used in applications.

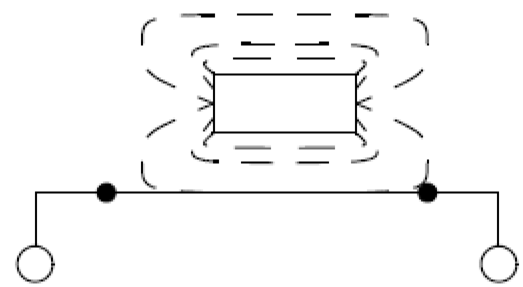
Contact Switches

- Contact switches are available as normally open and normally closed.
- Their housing are reinforced so that they can take repeated mechanical forces.
- These often have rollers and wear pads for the point of contact.
- Lightweight contact switches can be purchased for less than a dollar, but heavy duty contact switches will have much higher costs.
- Examples of applications include motion limit switches and part present detectors.

Reed Switches

Reed switches are very similar to relays, except a permanent magnet is used instead of a wire coil. When the magnet is far away the switch is open, but when the magnet is brought near the switch is closed as shown below. They are commonly used for safety screens and doors because they are harder to trick than other sensors.

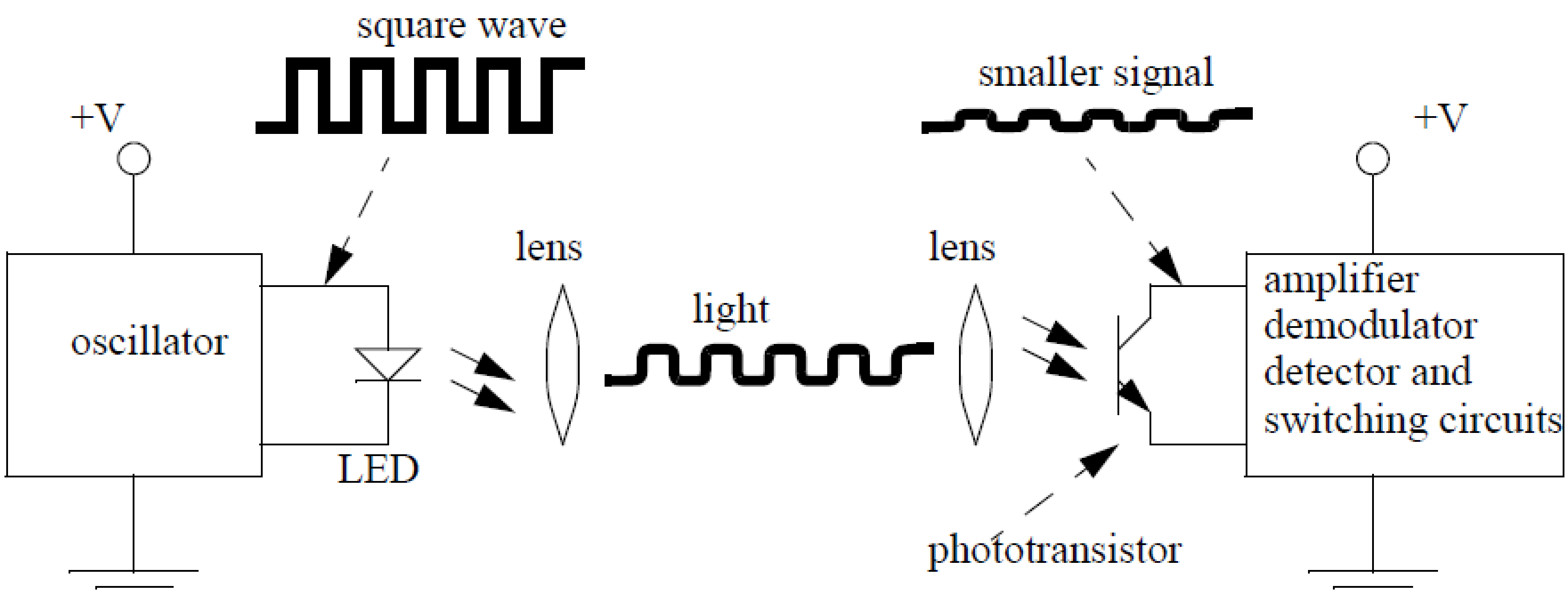


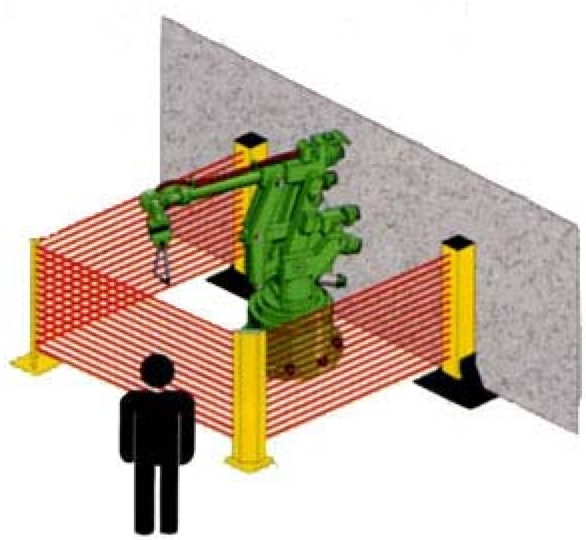


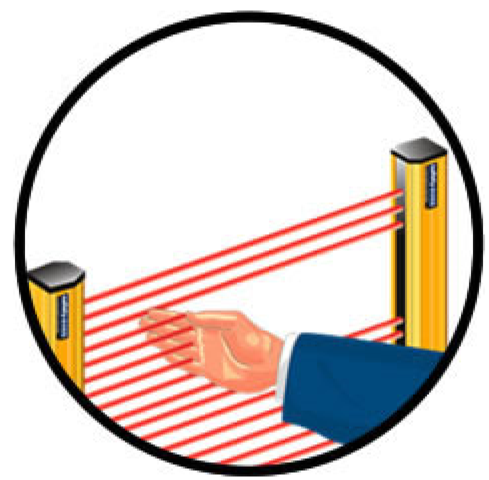
As the magnet gets closer the switch will close. This allows proximity detection without contact, but requires that a separate magnet be attached to a moving part.

Optical (Photoelectric) Sensors

- Light sensors have been used for almost a century - originally photocells were used for applications such as reading audio tracks on motion pictures.
- Modern optical sensors are much more sophisticated. Optical sensors require both a light source (emitter) and detector.
- Emitters will produce light beams in the visible and invisible spectrums using LEDs and laser diodes.
- Detectors are typically built with photodiodes or phototransistors.
- The emitter and detector are positioned so that an object will block or reflect a beam when present. A basic optical sensor is shown below.

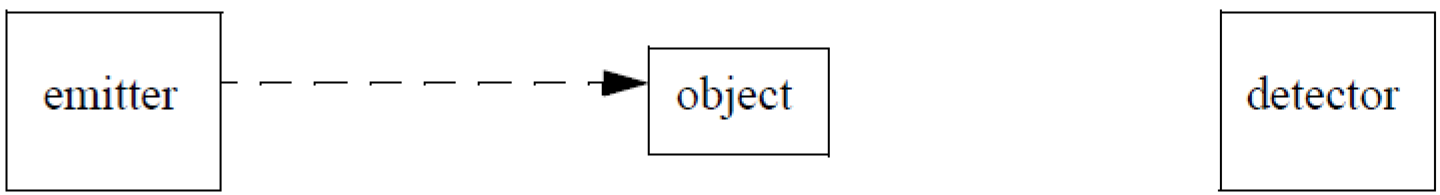

square wave
smaller signal
+V
+V
lens
lens
light
oscillator
amplifier
demodulator
detector and
switching circuits
LED
phototransistor





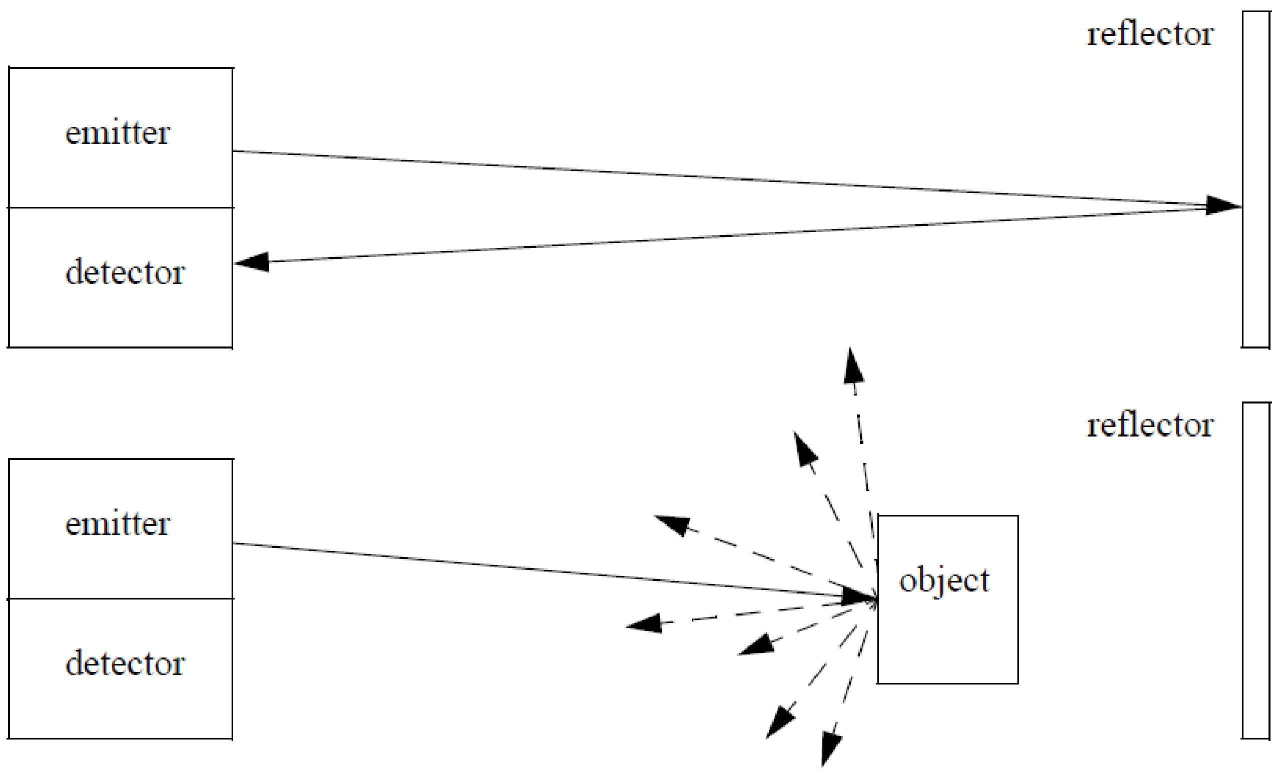
- The light beam is generated on the left, focused through a lens.
- At the detector side the beam is focused on the detector with a second lens.
- If the beam is broken the detector will indicate an object is present.
- The oscillating light wave is used so that the sensor can filter out normal light in the room.
- The light from the emitter is turned on and off at a set frequency.
- When the detector receives the light it checks to make sure that it is at the same frequency.
- If light is being received at the right frequency then the beam is not broken.

- The frequency of oscillation is in the KHz range, and too fast to be noticed. A side effect of the frequency method is that the sensors can be used with lower power at longer distances.
- An emitter can be set up to point directly at a detector, this is known as opposed mode. When the beam is broken the part will be detected. This sensor needs two separate components, as shown.



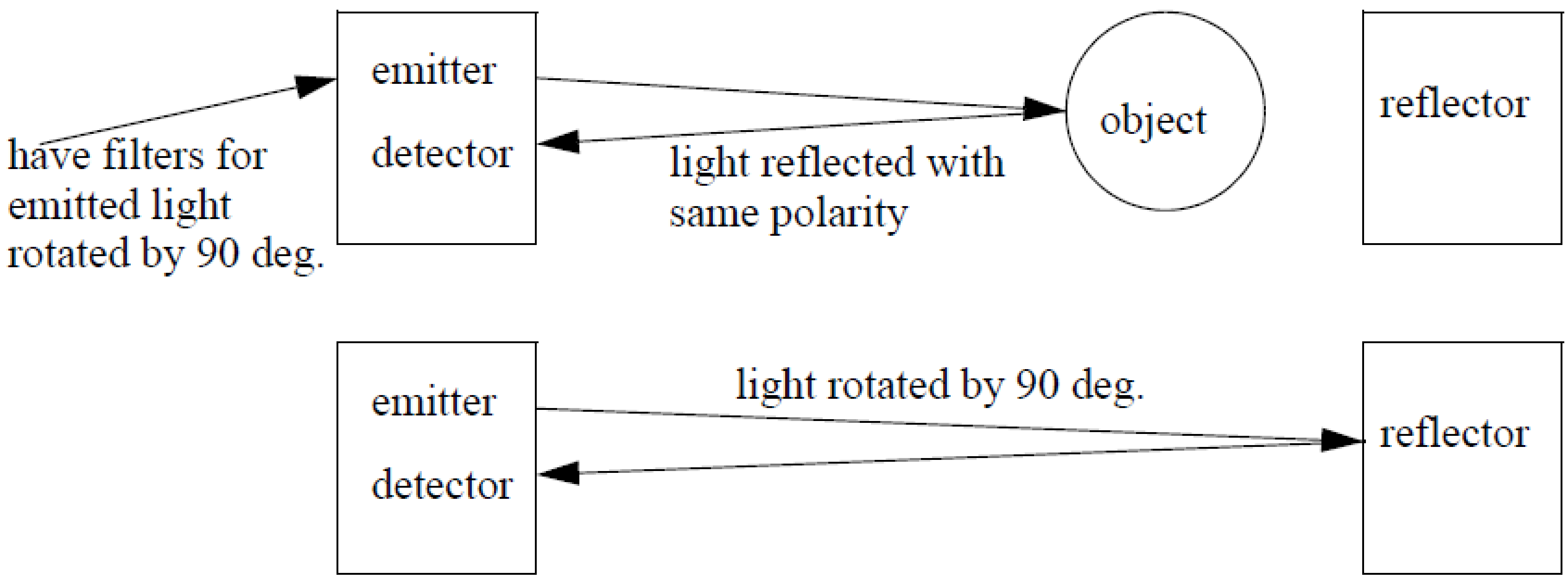
- This arrangement works well with opaque and reflective objects with the emitter and detector separated by distances of up to hundreds of feet.

- Having the emitter and detector separate increases maintenance problems, and alignment is required.
- A preferred solution is to house the emitter and detector in one unit. But, this requires that light be reflected back as shown below.
- These sensors are well suited to larger objects up to a few feet away.

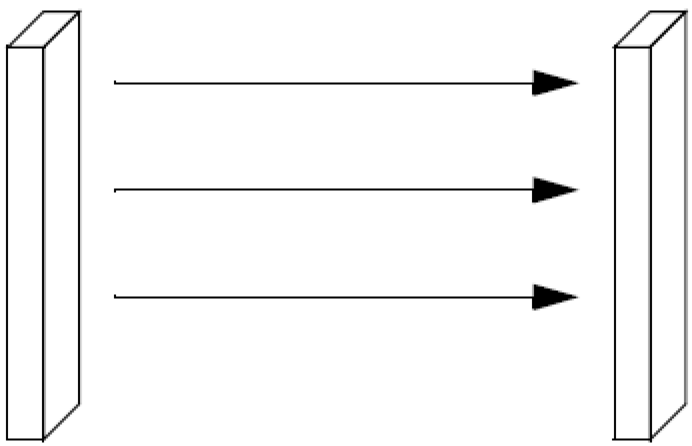


- The emitter sends out a beam of light. If the light is returned from the reflector most of the light beam is returned to the detector.
- When an object interrupts the beam between the emitter and the reflector the beam is no longer reflected back to the detector, and the sensor becomes active.
- A potential problem with this sensor is that reflective objects could return a good beam. This problem is overcome by polarizing the light at the emitter (with a filter), and then using a polarized filter at the detector. The reflector uses small cubic reflectors and when the light is reflected the polarity is rotated by 90 degrees. If the light is reflected off the object the light will not be rotated by 90 degrees.

The polarizing filters on the emitter and detector are rotated by 90 degrees, as shown below.

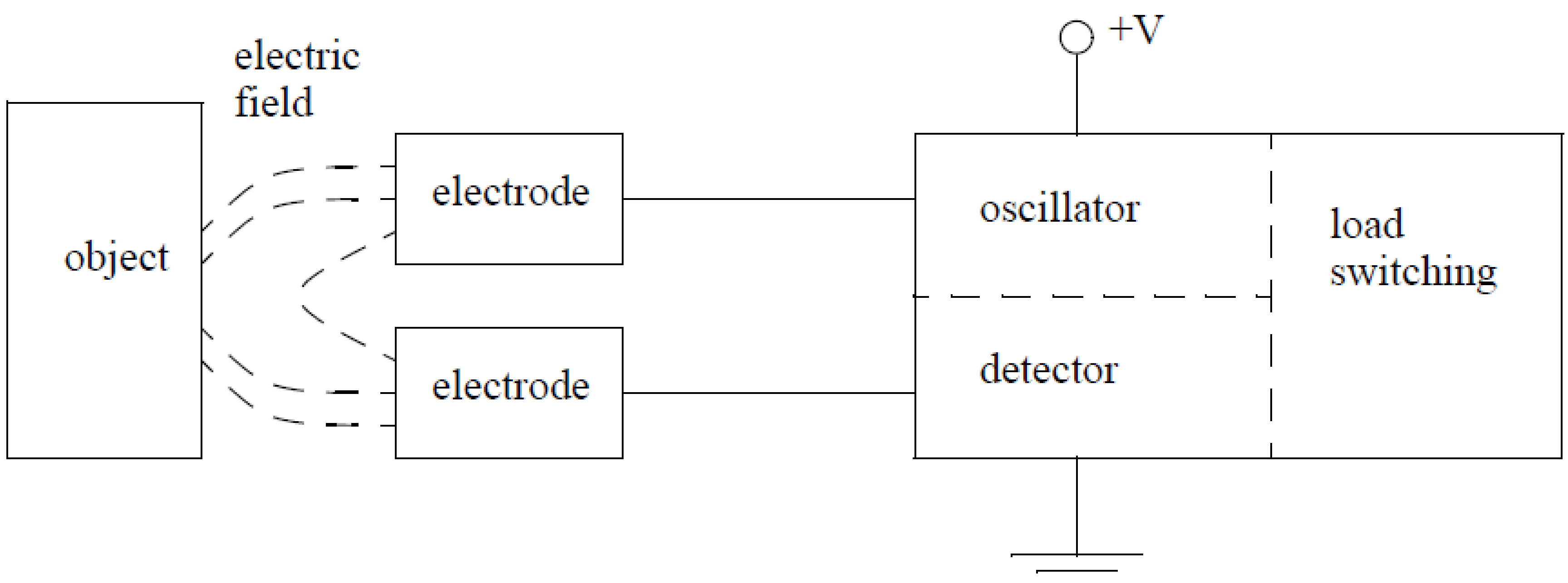


- Light curtains are an array of beams, set up as shown below.
- If any of the beams are broken it indicates that somebody has entered a work cell and the machine needs to be shut down.
- This is an inexpensive replacement for some mechanical cages and barriers.



Capacitive sensors

- An illustration of a capacitive sensor is shown below.
- An oscillating field is used to determine the capacitance of the plates.
- When this changes beyond a selected sensitivity the sensor output is activated.



Capacitive Sensors

- Capacitive sensors are able to detect most materials at distances up to a few centimeters.
- Basic relationship for capacitance.

$$C = \frac{\varepsilon A}{d}$$

where,

C = capacitance (Farads)

ε = dielectric constant

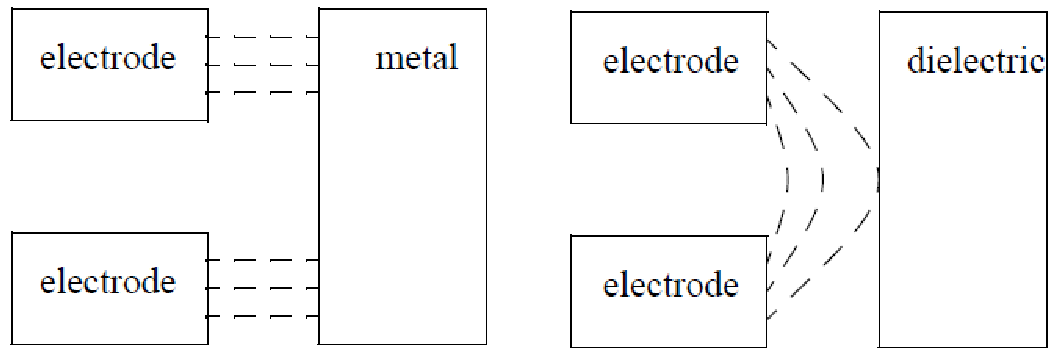
A = area of plates

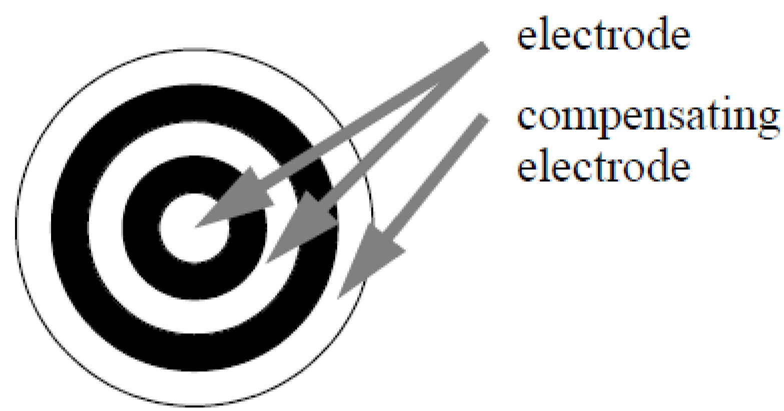
d = distance between plates (electrodes)

- If the sensor the area of the plates and distance between them is fixed.
- The dielectric constant of the space around them will vary as different materials are brought near the sensor.

- For this sensor the proximity of any material near the electrodes will increase the capacitance.
- This will vary the magnitude of the oscillating signal and the detector will decide when this is great enough to determine proximity.
- These sensors work well for insulators (such as plastics) that tend to have high dielectric coefficients, thus increasing the capacitance.
- They also work well for metals because the conductive materials in the target appear as larger electrodes, thus increasing the capacitance as shown below. In total the capacitance changes are normally in the order of pF.

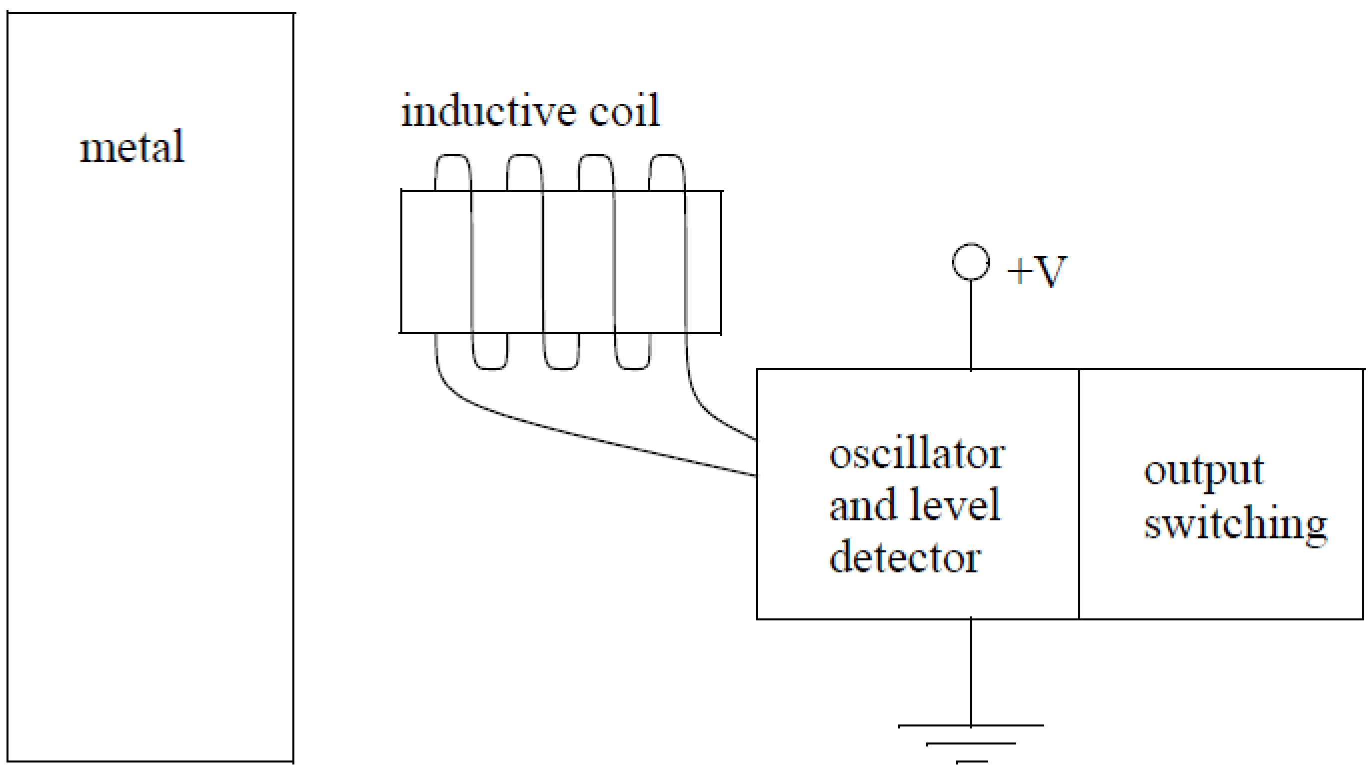
- The sensors are normally made with rings (not plates) in the configuration shown below.
- In the figure the two inner metal rings are the capacitor electrodes, but a third outer ring is added to compensate for variations.
- Without the compensator ring the sensor would be very sensitive to dirt, oil and other contaminants that might stick to the sensor.





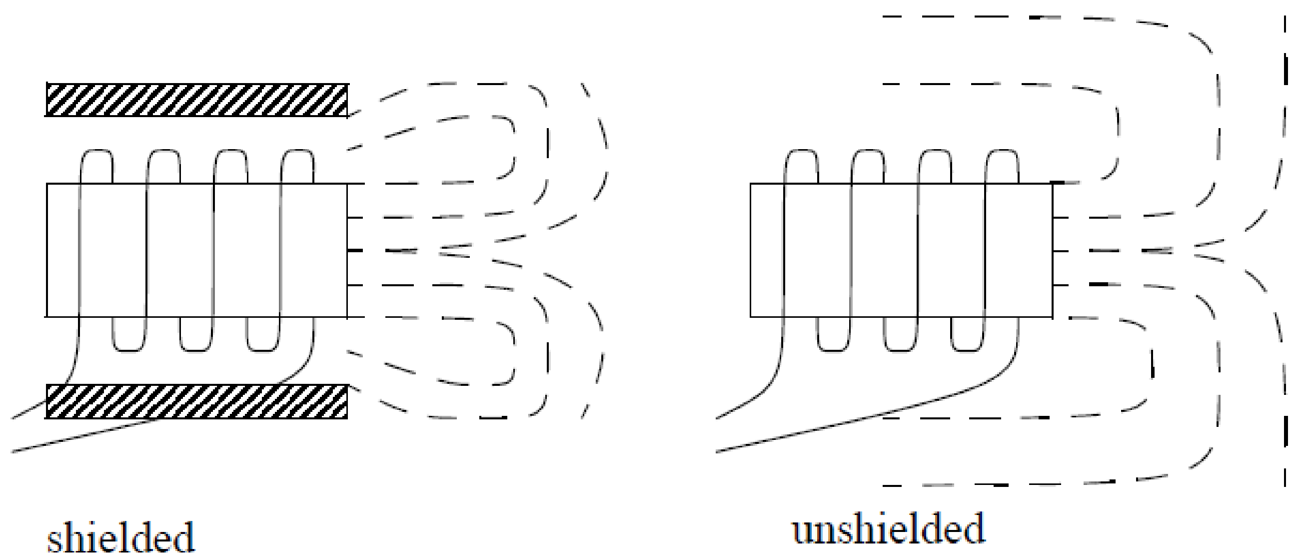
Inductive Sensors

- Inductive sensors use currents induced by magnetic fields to detect nearby metal objects.
- The inductive sensor uses a coil (an inductor) to generate a high frequency magnetic field as shown below.



- If there is a metal object near the changing magnetic field, current will flow in the object.
- This resulting current flow sets up a new magnetic field that opposes the original magnetic field.
- The net effect is that it changes the inductance of the coil in the inductive sensor.
- By measuring the inductance the sensor can determine when a metal have been brought nearby.
- These sensors will detect any metals, when detecting multiple types of metal multiple sensors are often used.

- The sensors can detect objects a few centimeters away from the end. The direction to the object can be arbitrary as shown below.
- The magnetic field of the unshielded sensor covers a larger volume around the head of the coil.
- By adding a shield (a metal jacket around the sides of the coil) the magnetic field becomes smaller, but also more directed.
- Shields will improve sensors directivity and accuracy.



Ultrasonic

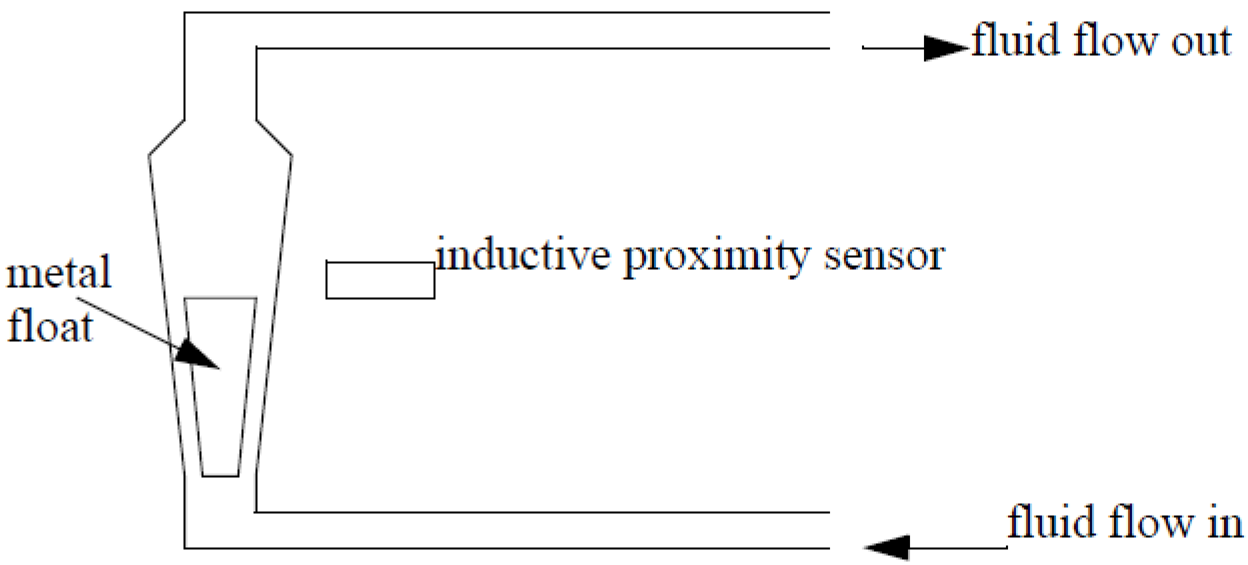
- An ultrasonic sensor emits a sound above the normal hearing threshold of 16KHz.
- The time that is required for the sound to travel to the target and reflect back is proportional to the distance to the target. The two common types of sensors are:
- **electrostatic** - uses capacitive effects. It has longer ranges and wider bandwidth, but is more sensitive to humidity.
- **piezoelectric** - based on charge displacement during strain in crystal lattices. These are rugged and inexpensive.
- These sensors can be very effective for applications such as fluid levels in tanks and crude distance measurement.

Hall Effect

- Hall effect switches are basically transistors that can be switched by magnetic fields.
- Their applications are very similar to reed switches, but because they are solid state they tend to be more rugged and resist vibration.
- Automated machines often use these to do initial calibration and detect end stops.

Fluid Flow

- A more complex sensors can be built out of simpler sensors.
- The example below shows a metal float in a tapered channel.
- As the fluid flow rate increases the pressure forces the float upwards.



- The tapered shape of the float ensures an equilibrium position proportional to flow rate.
- An inductive proximity sensor can be positioned so that it will detect when the float has reached a certain height, and the system has reached a given flow rate.