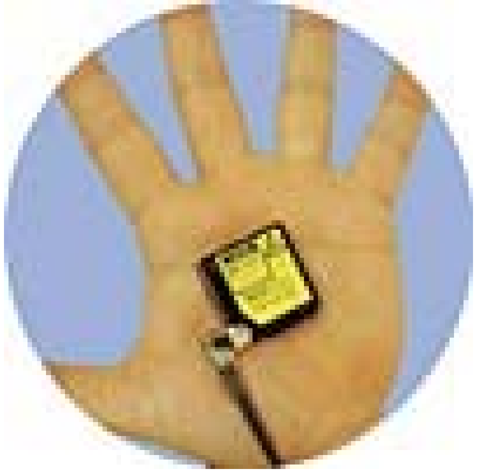
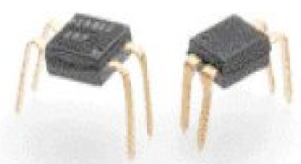




SENSORS




Introduction to Sensors and Transducers

- **Definitions of Sensor and Transducer**
- The word 'sensor' is derived from entire meaning 'to perceive' and 'transducer' is from transducer meaning 'to lead across'. A dictionary definition of 'sensor' is `a device that detects a change in a physical stimulus and turns it into a signal which can be measured or recorded; a corresponding definition of 'transducer' is 'a device that transfers power from one system to another in the same or in the different form'. A sensible distinction is to use 'sensor' for the sensing element itself and 'transducer' for the sensing element plus any associated circuitry. All transducers would thus contain a sensor and most (though not all) sensors would also be transducers.

Figure 1 The sensing process

Sensor Classification

- **Sensor classification schemes range from very simple to the complex. One good way to look at a sensor is to consider all of its properties, such as stimulus, specifications, physical phenomenon, conversion mechanism, material and application field.**

- **For machine tools, sensor's conversion phenomena are mainly physical phenomena such as thermoelectric, photoelectric, photomagnetic, electromagnetic, magnetoelectric, thermoelastic, thermomagnetic, thermooptic, photoelastic, and so on**

Table 1: Stimulus

Stimulus	
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave velocity
Electric	Charge, Current, Potential, Voltage, Electric field (amplitude, phase, polarization & spectrum), Conductivity, and Permitivity
Magnetic	Magnetic field (amplitude, phase, polarization, spectrum), Magnetic flux, Permeability
Optical	Wave (amplitude, phase, polarization, spectrum), Wave velocity, Refractive index, Emissivity, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific heat, Thermal conductivity
Mechanical	Position (linear, angular), Acceleration, Force, Stress, Pressure, Strain, Mass, Density, Moment, Torque, Shape, Roughness, Orientation, Stiffness, Compliance, Crystallinity, Structural

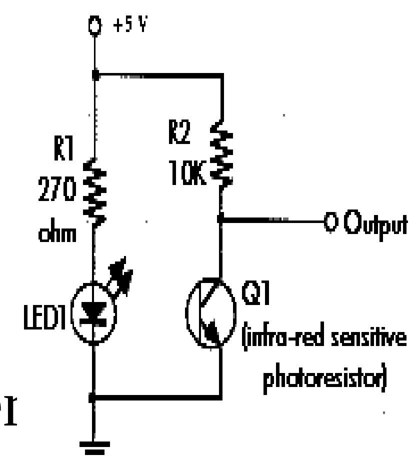
Sensor Selection

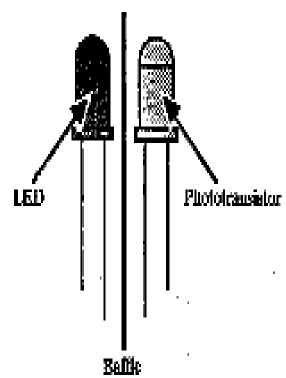
- Any sensor is based on a simple concept that physical property of a sensor must be altered by an external stimulus to cause that property either to produce an electric signal or to modulate (to modify) an external electric signal. Quite often, the same stimulus may be measured by using quite different physical phenomena, and subsequently, by different sensors. Selection criteria depend on many factors, such as availability, cost, power consumption, environmental conditions, etc. The best choice can be done only after all variables are considered

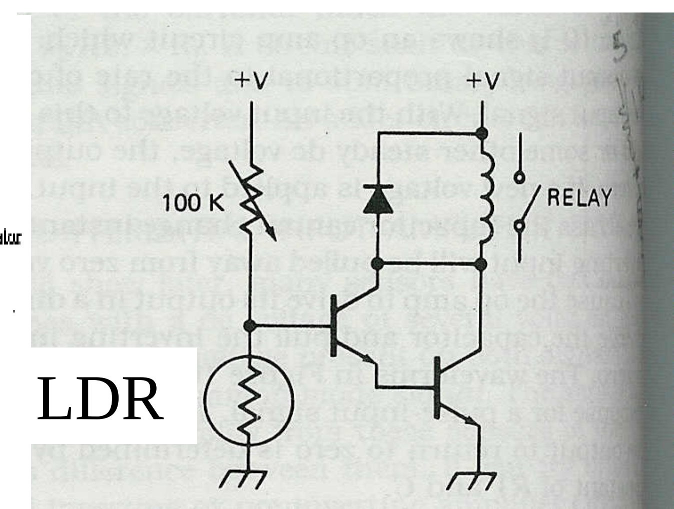
Visible Light Sensors

- Light dependent resistor like CL905. Light falls on Cd Sulfide or Cd Selenide thru glass window. Resistance depends on amt of light. Resistance varies from 15 M ohm to 15 K ohm when in bright light.
- Response time more, not stable with temp but inexpensive, durable & sensitive. Used when measurement of amount of light is not reqd to be precise, say for turning on street lights.
- As it gets dark, resistance of the photo resistor goes up, this increases the voltage at the base of the transistor until, it turns on. This turns on the transistor driving the rely, which in turn switches on the lamp

Optical Transceiver



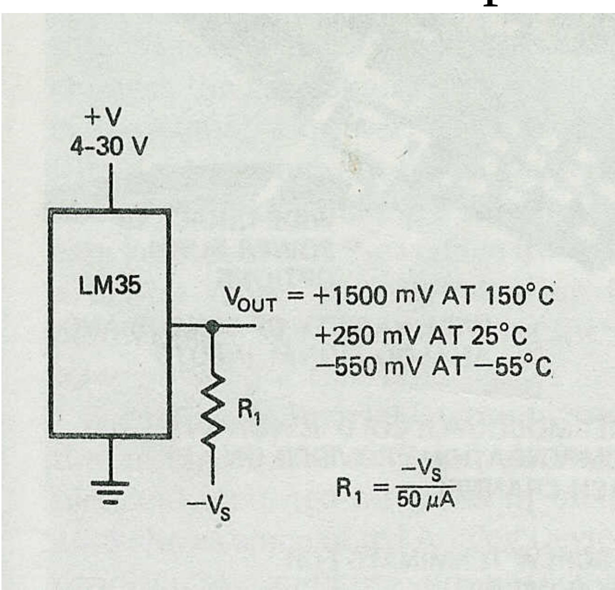




LDR

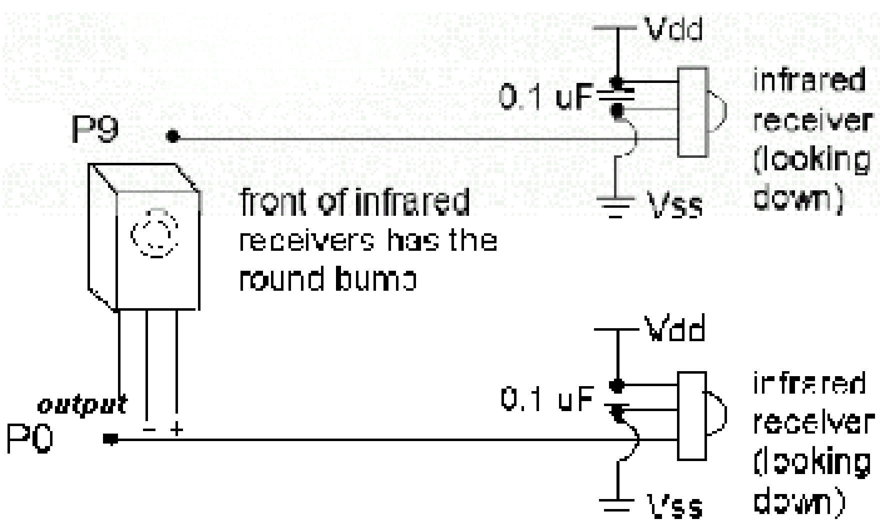
Temp Sensors

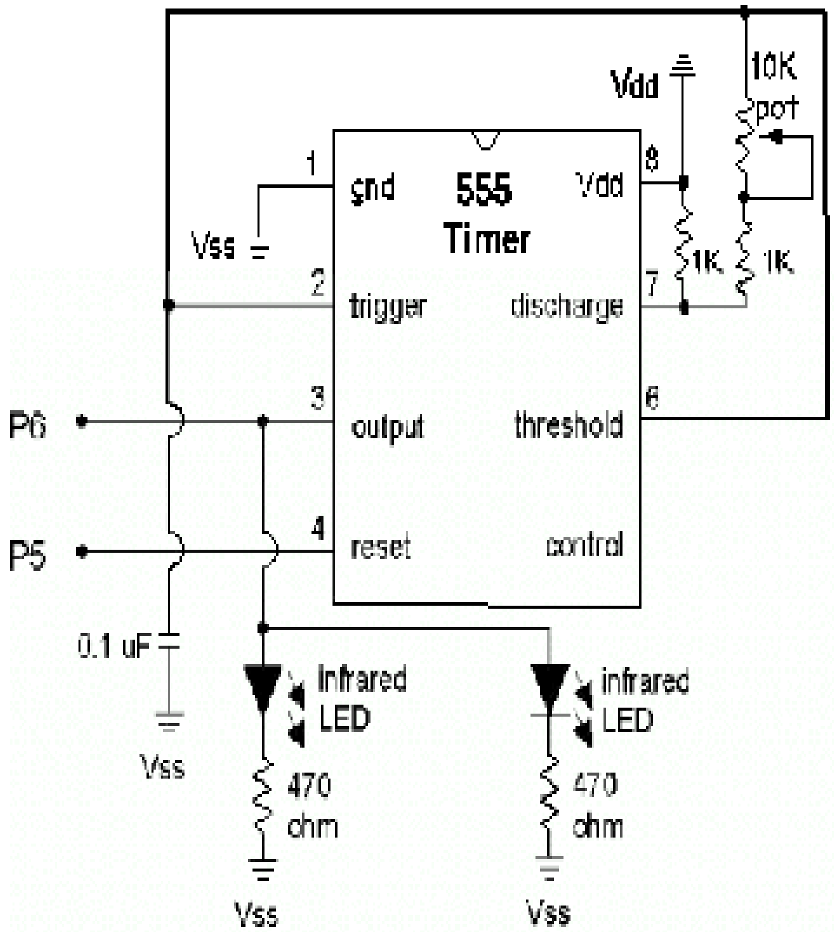
- Semiconductor sensors which are inexpensive for temp range of –55 to 100^0C.Thermocouples used for very high & very low temp.Two main types- temp sensitive current source or temp sensitive voltage source.AD 590 is a temp sensitive current source which produces a current of 1micro amp/Kelvin
- LM 35 is a temp sensitive voltage source. Voltage o/p increases by 10mV for each degree Celsius. By connecting the the o/p to a –ve ref voltage, sensor will give a meaningful o/p for a temp rg of –55 to +155 Celsius. The o/p is adjusted to zero volts at 0 C.



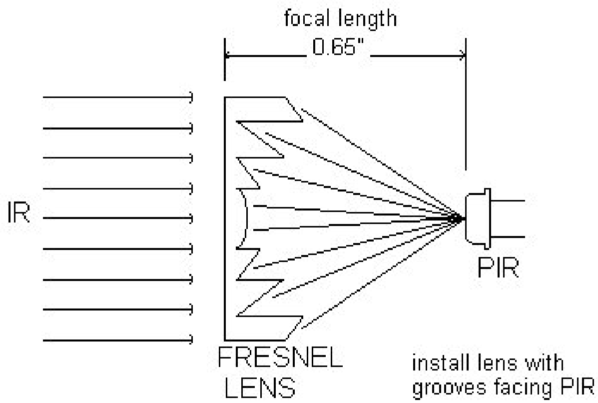
IR Sensing

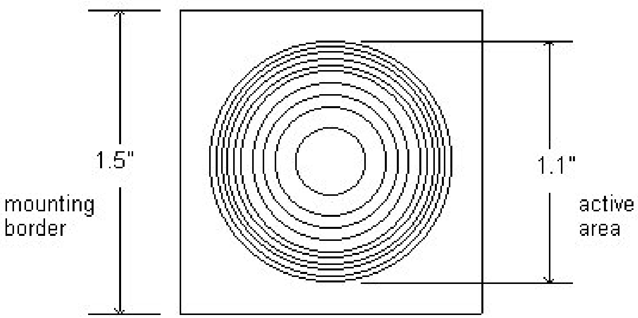
- Reflection sensor
- Interruption sensor
- Thermal sensors for furnace control





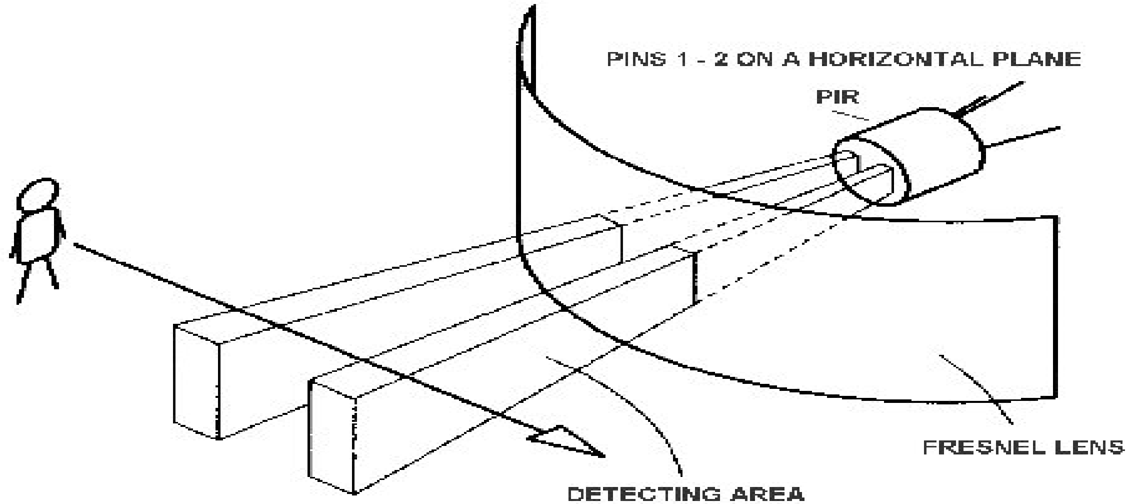
IR Motion detectors

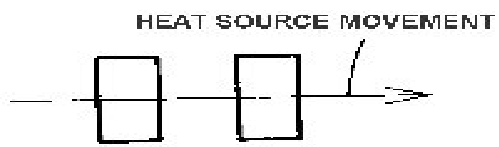


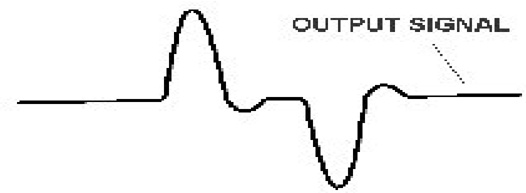


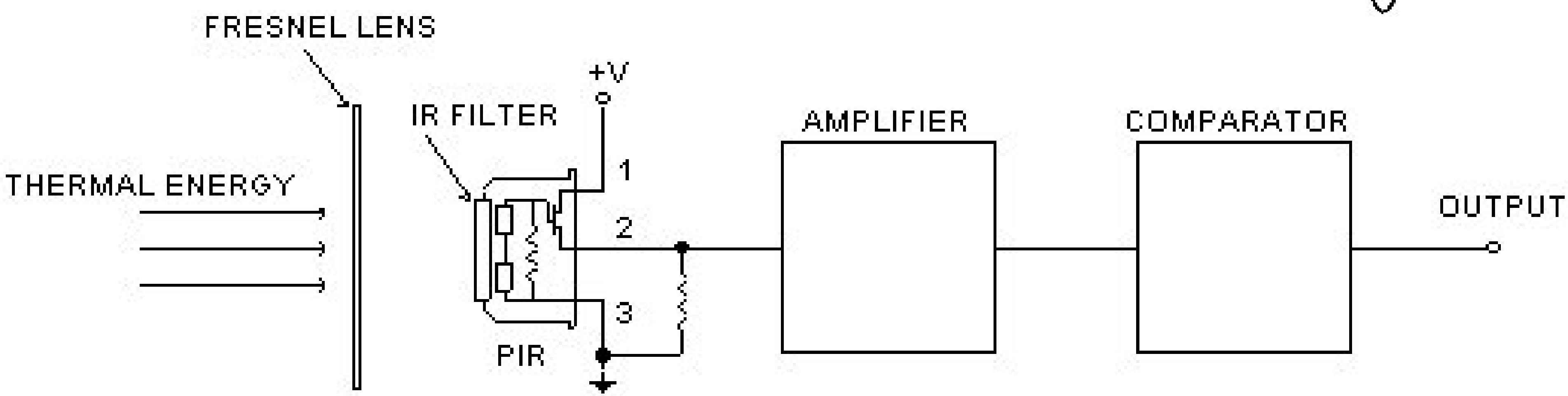
0.015" thickness

Optimum transmittance in the 8 to 14 um region









- The pyroelectric sensor is made of a crystalline material that generates a surface electric charge when exposed to heat in the form of infrared radiation. When the amount of radiation striking the crystal changes, the amount of charge also changes and can then be measured with a sensitive FET device built into the sensor. The sensor elements are sensitive to radiation over a wide range so a filter window is added to the TO5 package to limit incomong radiation to the 8 to 14mm range which is most sensitive to human body radiation

Proximity switches and security sensors

- The Inductive proximity sensor

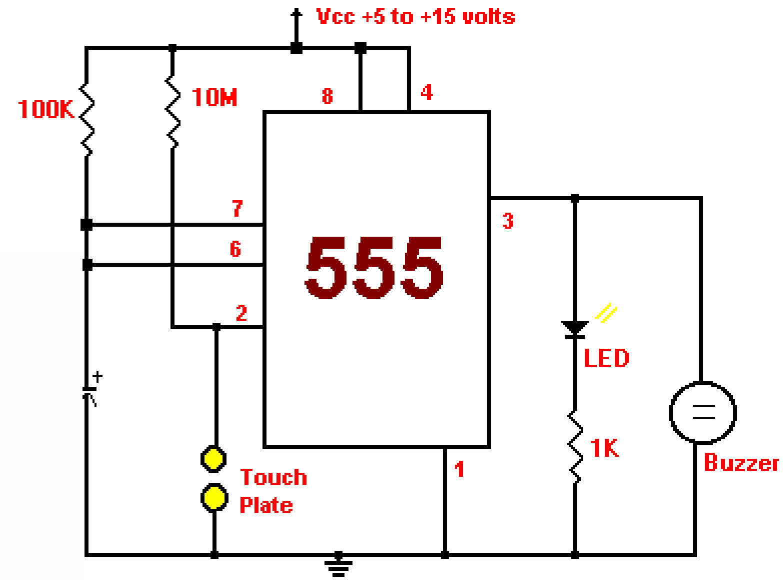
- Photoelectric proximity Switches

- LDR type proximity switch

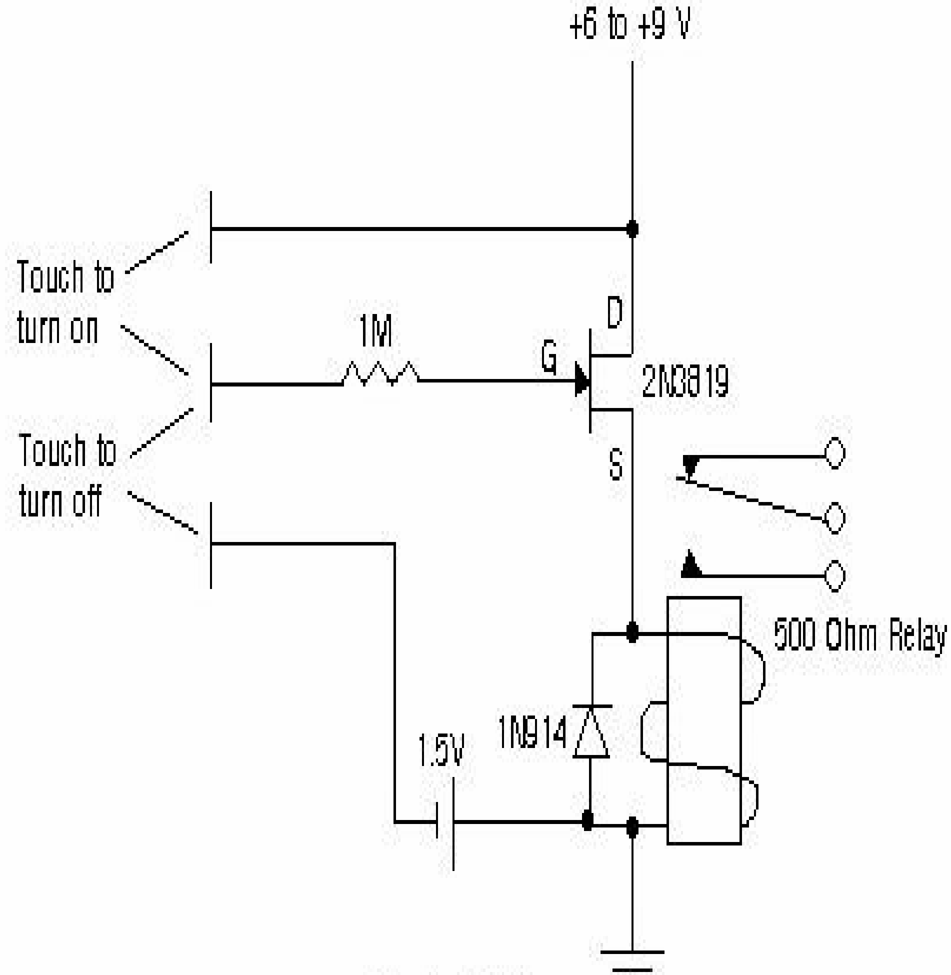
- Capacitive proximity switches

- Magnetic contact for security systems (door switch)
- Magnetic float switch (in stainless steel and plastic)
- Brake-interlock system for aircraft refueller

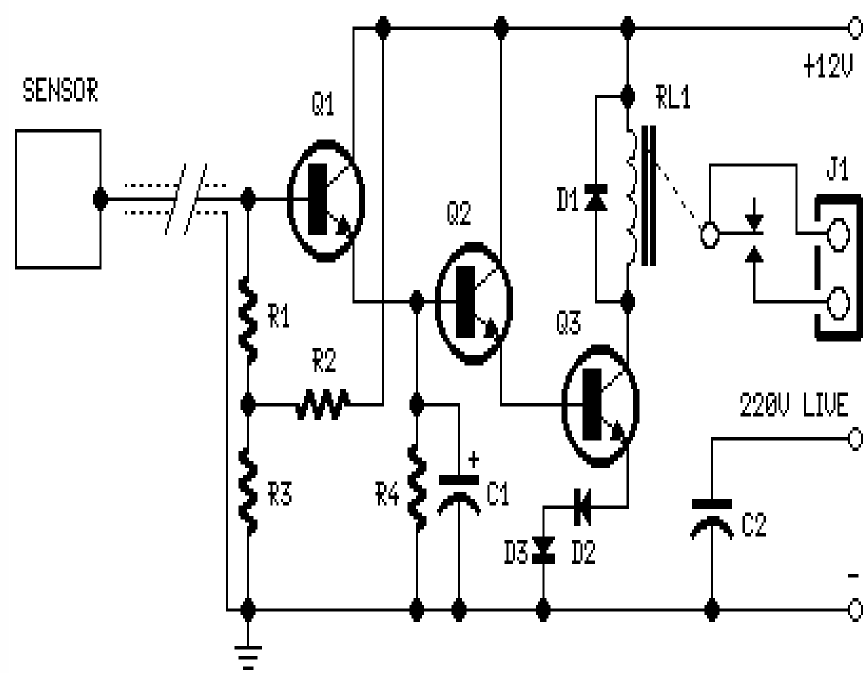
- <u>Touch sensing</u>



Touch Switch

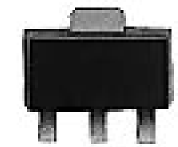


Touch Switch



Hall Effect Sensors

- Brushless DC motors
- Digital current sensor
- Anti-skid braking sensor
- Piston detection in hydraulic cylinder
- • Valve position sensing
- • Cam, lever, shaft position sensing
- • Tachometer, counter pickup
- • Push-button sensor
- • Disk speed, tape rotation, flow rate se
- • Speed sensing - rate, under, over spee
- • Remote reading sensor
- • Magnetic card reader



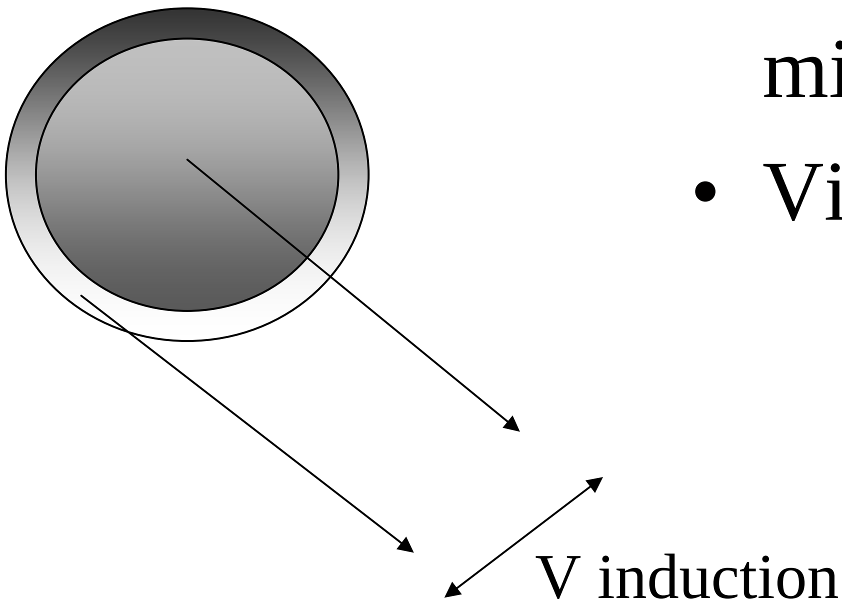
Load Cell

- Load cells work like calibrated springs.
  A force is applied and there is a flexion: there is a Wheatstone bridge with strain gauges that measure this mechanical flexion thence giving a proportional electrical signal.

Load/Force Sensors

- Detect and measure a relative change in force or applied load
- Detect and measure the rate of change in force
- Identify force thresholds and trigger appropriate action
- Detect contact and/or touch

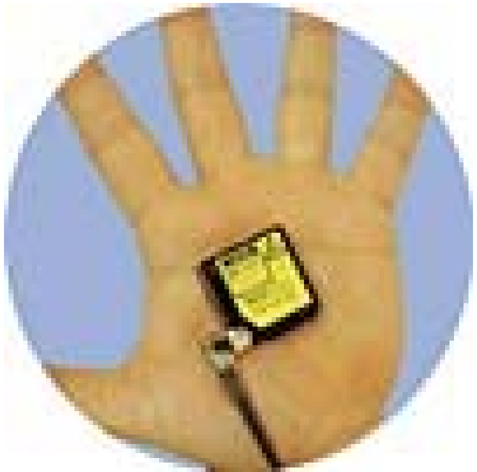
Piezo Transducers



- Electret microphones
- Vibration sensors

Analog Distance Sensors

- Sensors capable of measuring distance and displacement by providing a distance-proportional analog output



Displacement sensing

- These sensors have built in electronics, which allows the unit to be set up for any displacement range within its total measurement range. So for example, a 100mm version can be programmed with a 4-20mA output, which correlates exactly with any range required to be measured - say from 20mm to 80mm

Applications

- Absolute distance measurement
- Thickness calculation
- Slope and deformation control
- Linear distance measurement
- Position control
- Profile logging
- Centering control
- Diameter/eccentricity measurement.

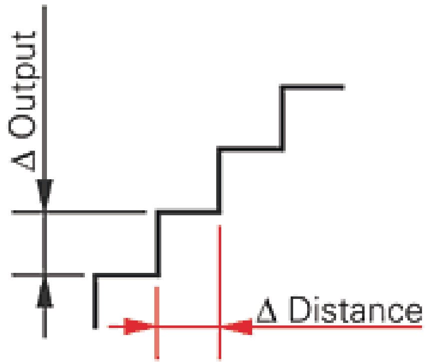


Figure 2. Resolution corresponds to the smallest possible change in distance that causes a detectable change in the output signal.

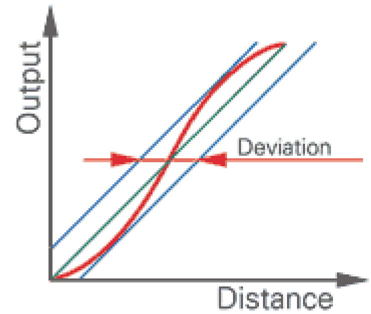


Figure 4. Linearity is the deviation from a proportional linear function or a straight line, given as a percentage of the upper limit of the measuring range (full scale).

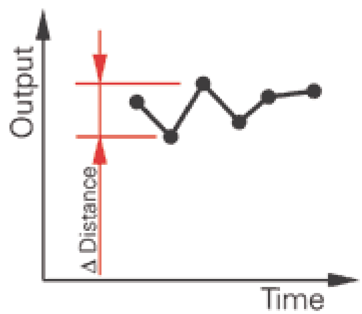


Figure 3. Repeat accuracy is the difference between measured values in successive measurements within a period of 8 hours at an ambient temperature of 23ºC ±5ºC.

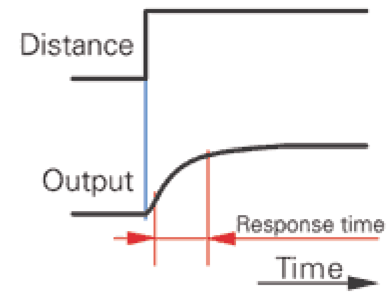
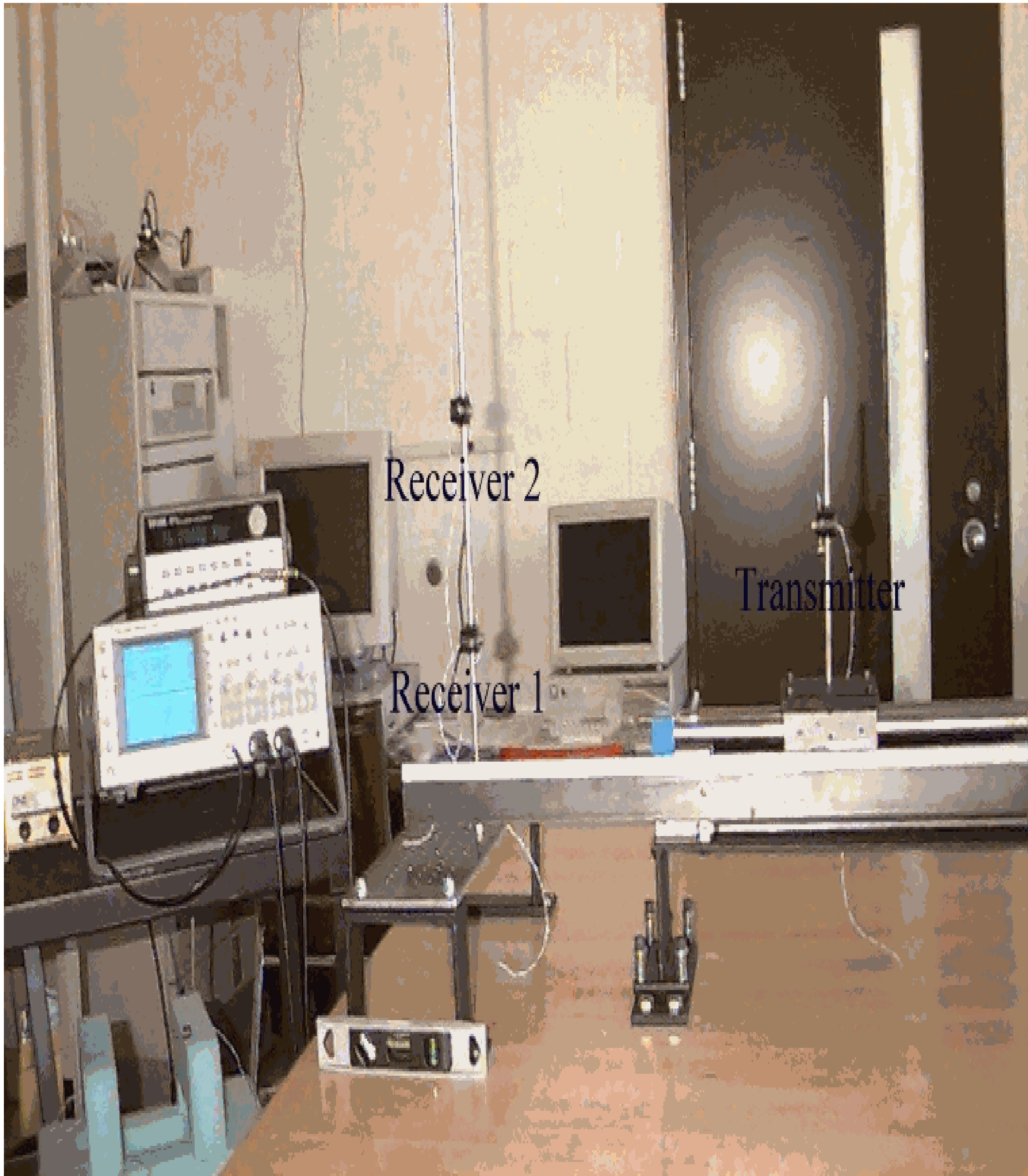


Figure 5. Reaction time is the time required by the sensor’s signal output to rise from 10% to 90% of the maximum signal level. For sensors with digital signal processing, it is the time required for calculation of a stable measured value.

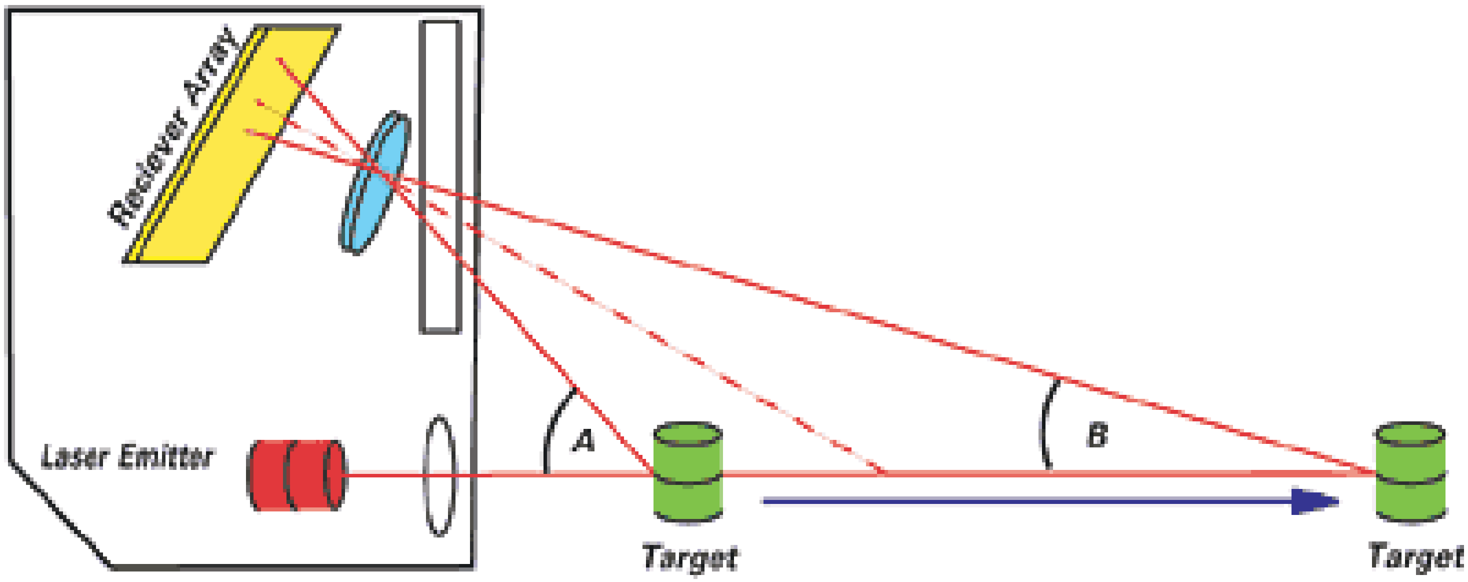
Ultrasonic transducers

Sensors offer distance measurement via ultrasonic transmission. Based on the speed of sound through air, ultrasonic sensors measure distance by calculating the time required for the sound to return to the sensor, and offer resolutions up to >0.3 mm.



Laser-based triangulation displacement sensors

- project a collimated beam that reflects off the target and passes through a lens that focuses the reflected beam onto a receiving element. These sensors are the standard for industrial machinery applications.

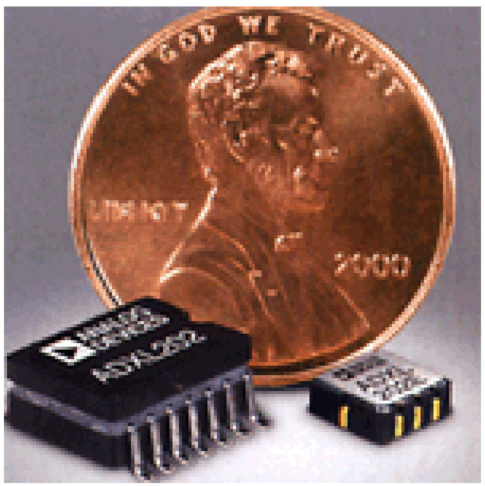


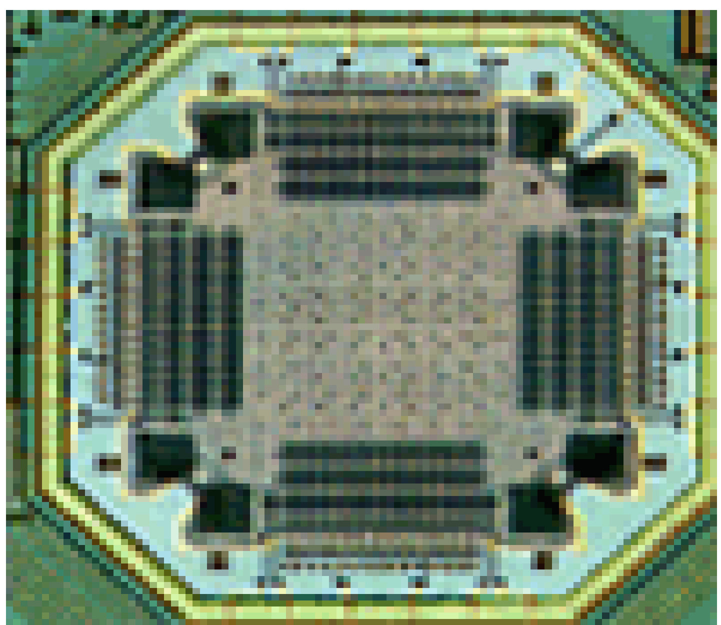
Optical Encoders

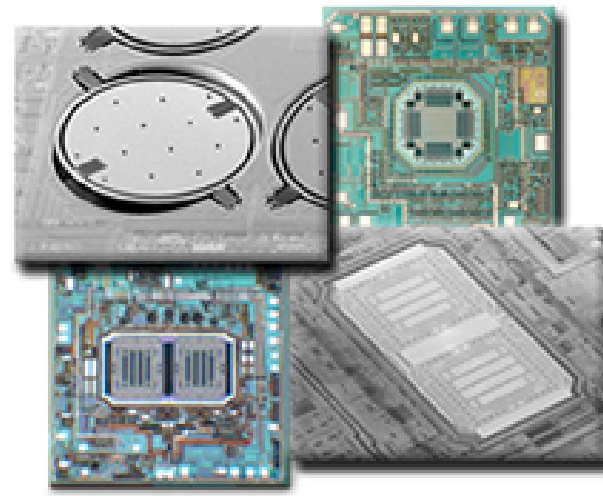
- Provide a digital output in the form of a square wave pulse
- Both shaft type and hollow shaft type
- Resolution better than 0.01deg available

MEMS Sensors

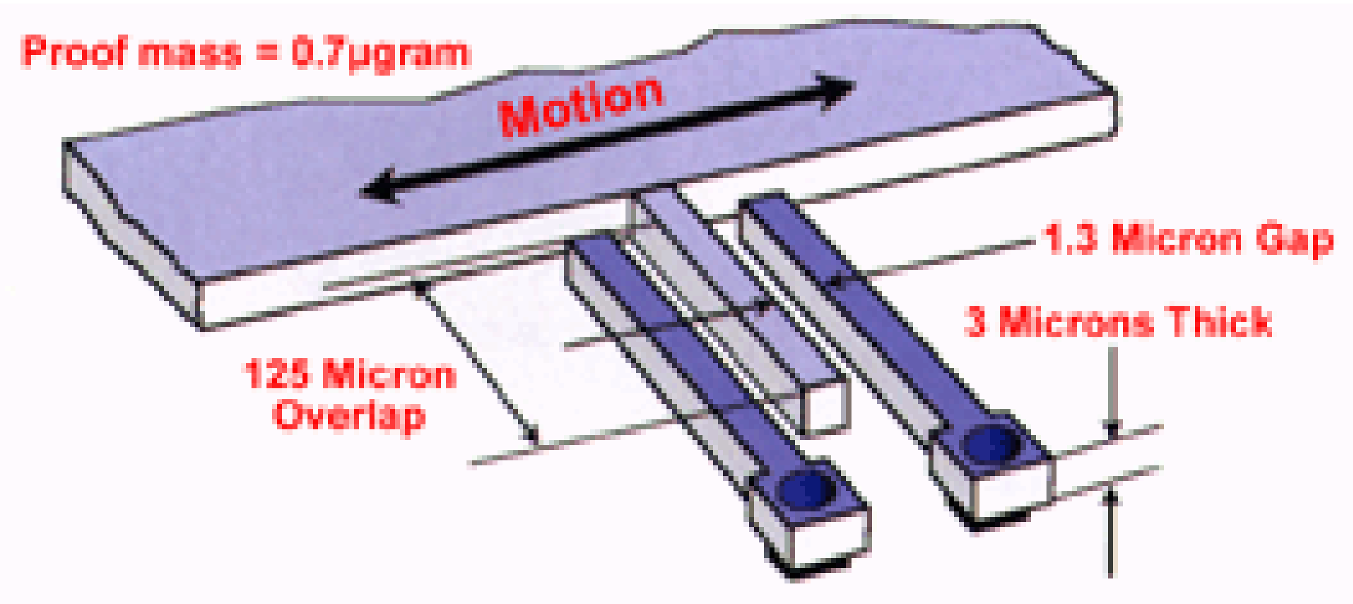
- **MEMS (Micro Electro-Mechanical Systems) Technology**



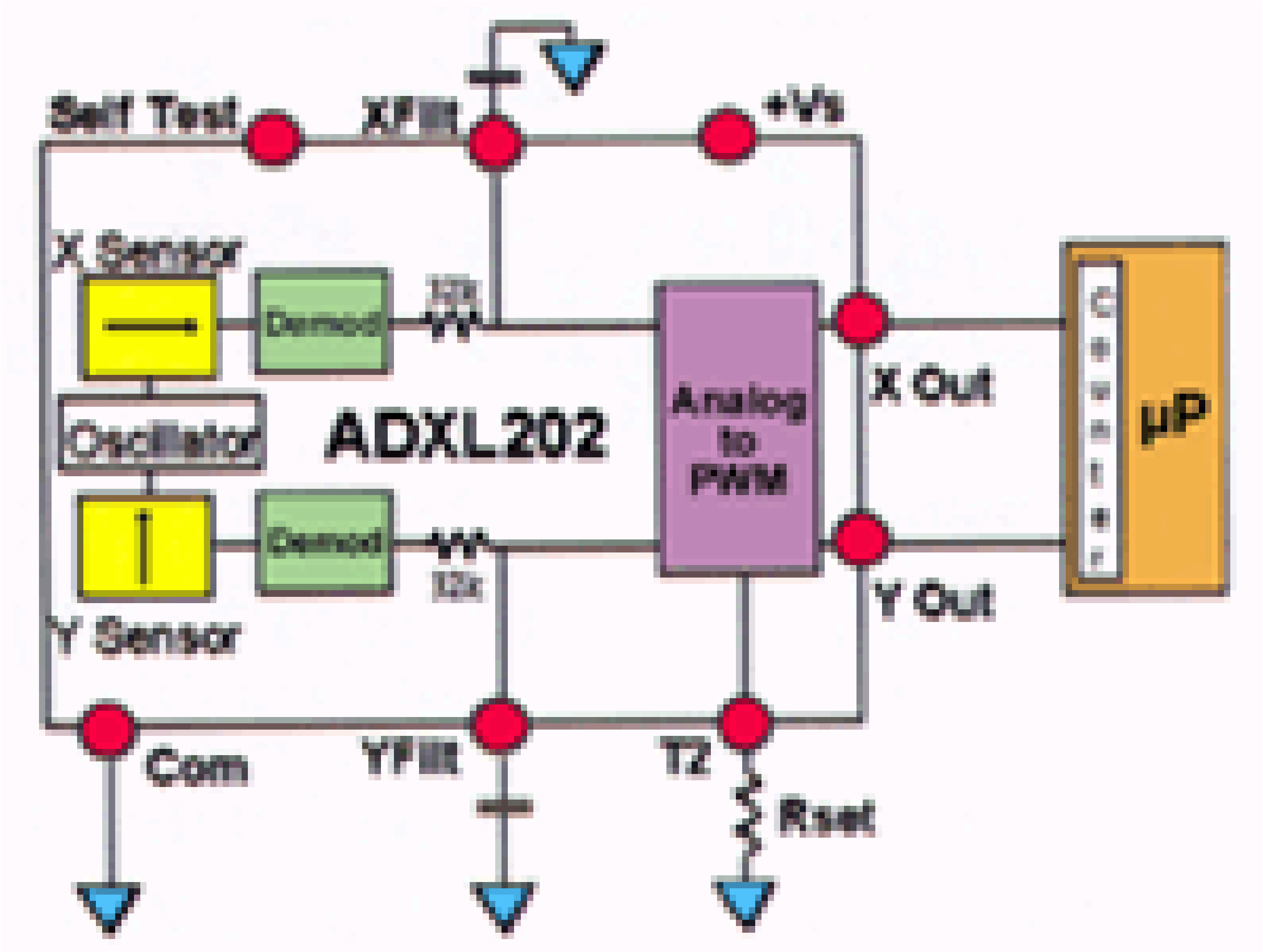




- Polysilicon springs suspend the MEMS structure above the substrate such that the body of the sensor (also known as the proof mass) can move in the X and Y axes. Acceleration causes deflection of the proof mass from its centre position. Around the four sides of the square proof mass are 32 sets of radial fingers. These fingers are positioned between plates that are fixed to the substrate. Each finger and pair of fixed plates make up a differential capacitor, and the deflection of the proof mass is determined by measuring the differential capacitance. This sensing method has the ability of sensing both dynamic acceleration (i.e. shock or vibration) and static acceleration (i.e. inclination or gravity).



MEMS Sensor



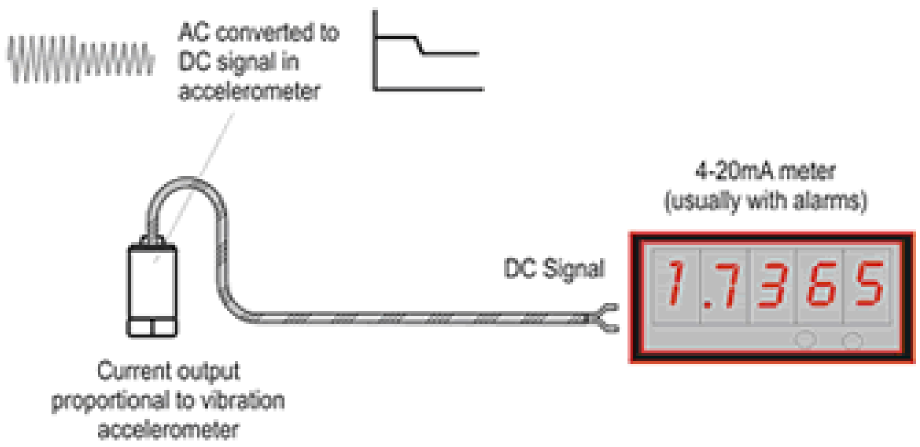
Self Test
XFilt
+Vs
X Sensor
Demod
ADXL202
Analog to PWM
X Out
µP
Oscillator
Demod
Y Sensor
Y Out
Com
YFilt
T2
Rset

Applications

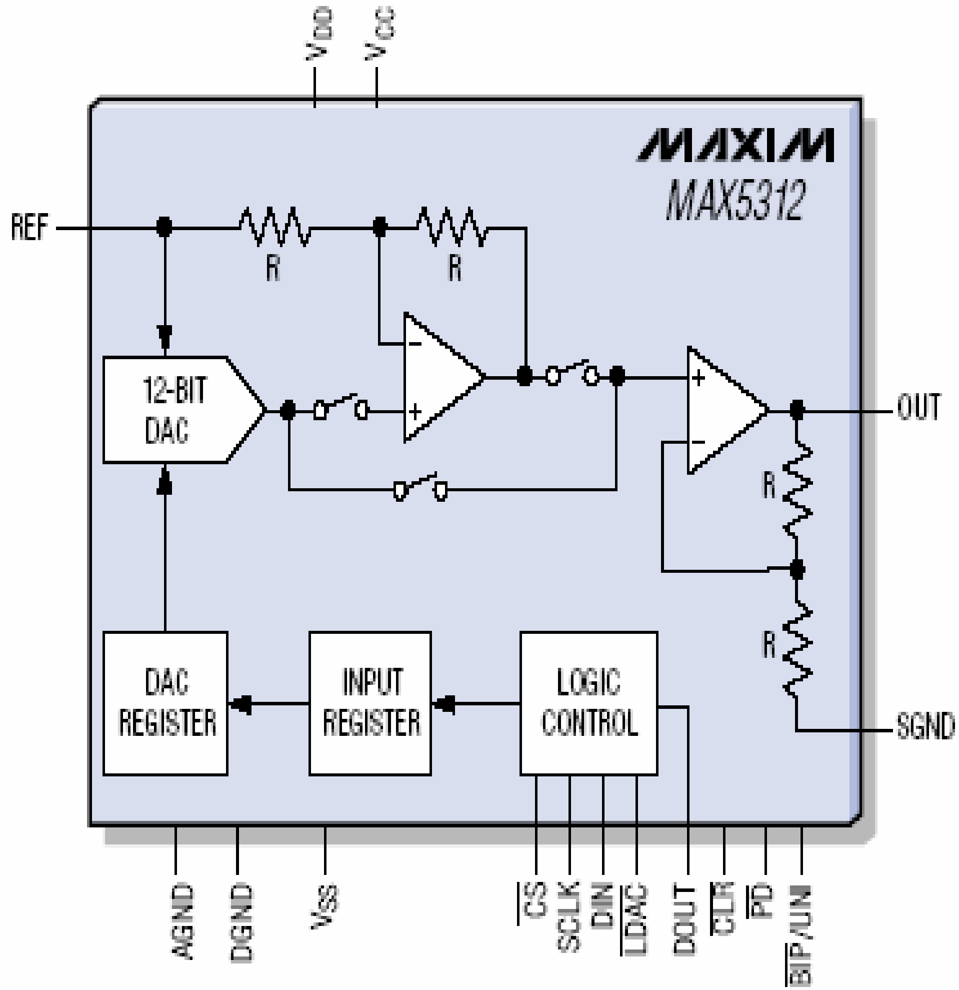
- VR Devices
- Vehicles, ships, aircraft
- Digital Compass

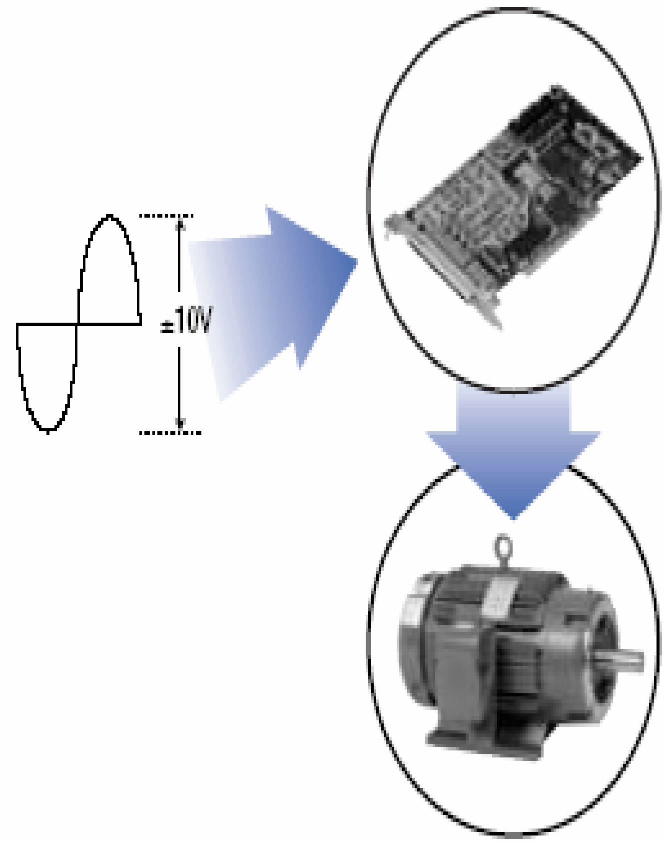
Accelerometers

- Accelerometers are a very common way to measure vibration. However, acceleration vibration data is most useful for high frequencies while velocity data is suited to lower frequencies and in particular vibration found in most rotating machinery. Velocity vibration data is also a much better indicator of machinery health as it changes with a linear relationship to machine health.



D/A Converter

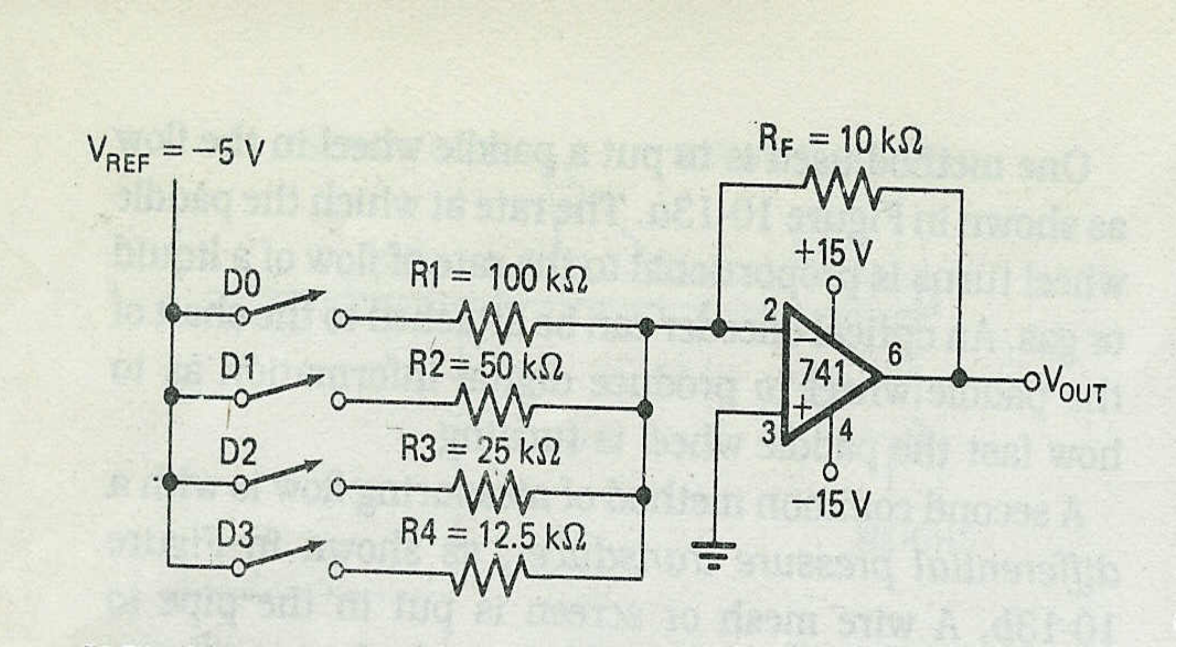




D/A converter

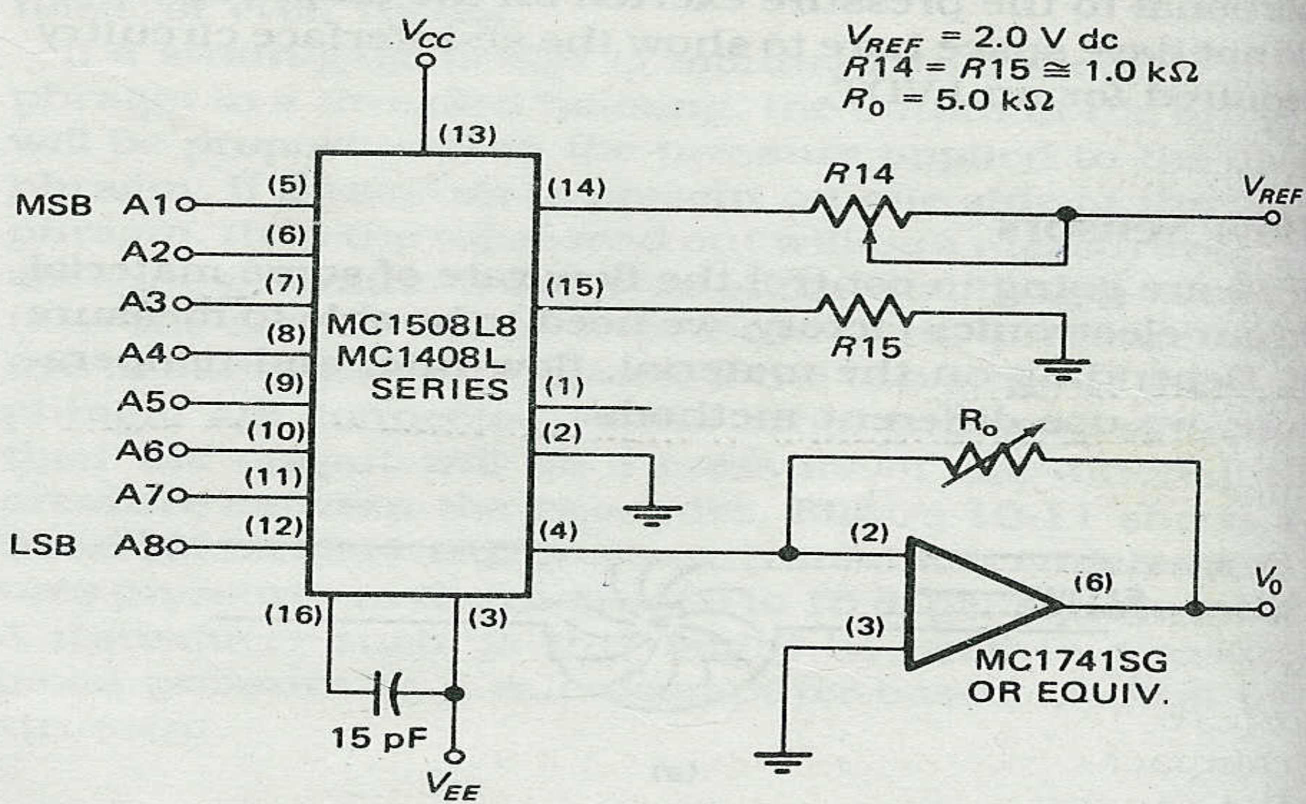
- If a converter has n I/p, it has (2)^n possible o/p levels. A DAC with 8 binary I/p has 256 o/p levels & has a RESOLUTION of 1 part in 256 or .39%.
- If the full scale analog voltage is 1V, smallest unit or LSB is equivalent to 1/(2^n).
- MSB represents half of full scale value .
- The max o/p voltage of a DAC has a value one LSB less than the named value.
- <u>Settling Time</u>. When binary word applied to the I/p of DAC is changed, the o/p may overshoot the correct value before settling down to correct value. The time o/p takes to reach within + LSB of final value is Settling Time.

Op amp as D/A



- An op amp cct functioning as an adder can function as a simple DAC.
- I/p resistors are selected in binary weighted proportions; each double the value of the previous resistor.
- Binary word applied to I/P produces a proportional O/P voltage.
- If switch D0 is closed it produces a current of .05mA & thus a voltage of 0.5 V. D0 & D1 if closed produce an O/P of 1.5 V.
- Switch D3 is the MSB

MC 1408 D/A with Current to Voltage converter



Theoretical V_0

$$V_0 = \frac{V_{REF}}{R14}(R_0)\left\{\frac{A1}{2} + \frac{A2}{4} + \frac{A3}{8} + \frac{A4}{16} + \frac{A5}{32} + \frac{A6}{64} + \frac{A7}{128} + \frac{A8}{256}\right\}$$

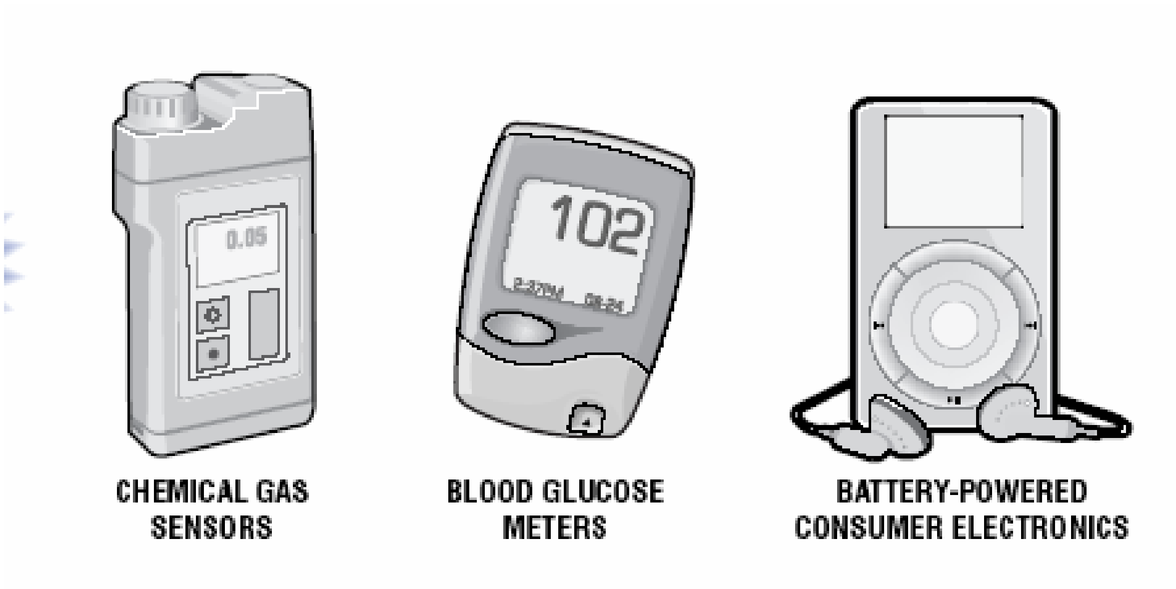
ADJUST V_{REF}, $R14$ OR R_0 SO THAT V_0 WITH ALL DIGITAL INPUTS AT HIGH LEVEL IS EQUAL TO 9.961 V

$$V_0 = \frac{2\ V}{1\ k\Omega}(5\ k\Omega)\left\{\frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \frac{1}{32} + \frac{1}{64} + \frac{1}{128} + \frac{1}{256}\right\}$$

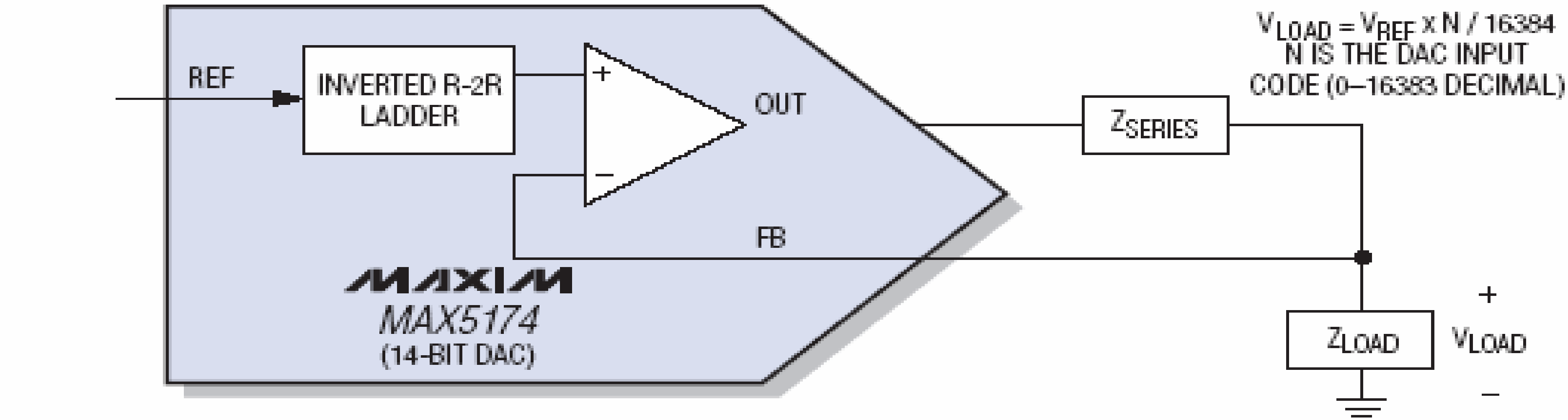
$$= 10\ V\left\{\frac{255}{256}\right\} = 9.961\ V$$

Applications

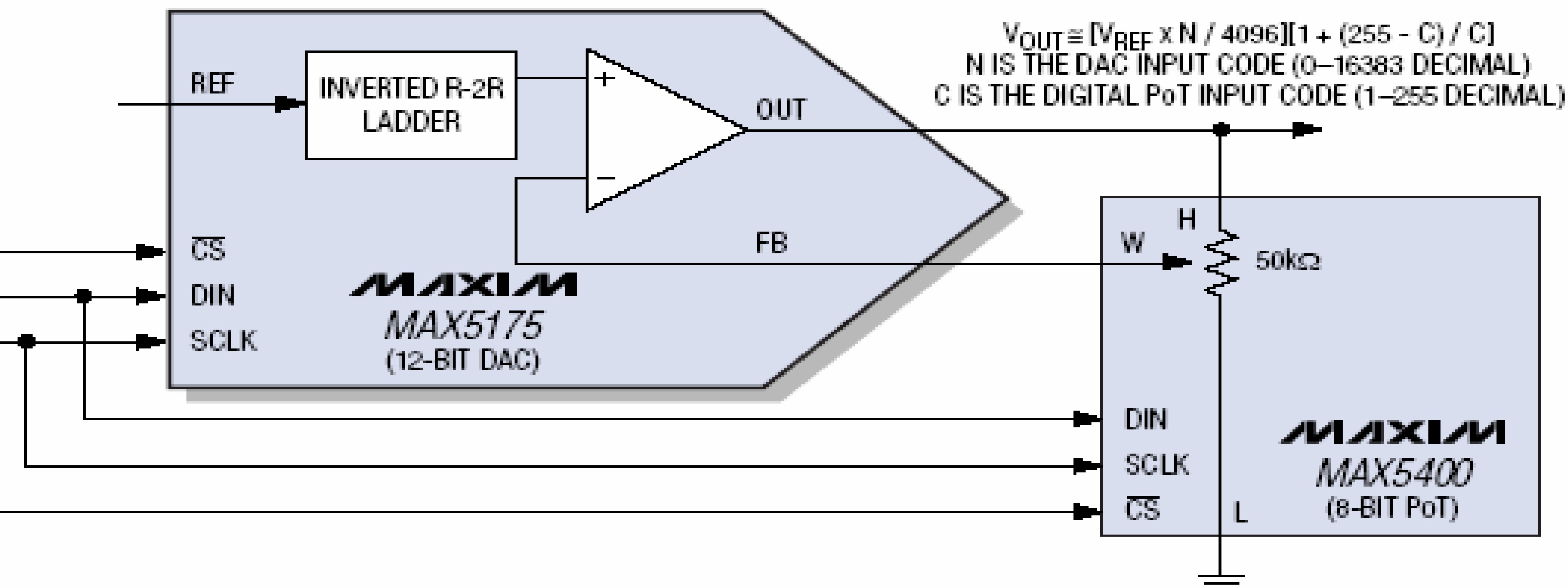
- CD audio player
- To produce desired o/p under s/w cont.
- Speech synthesizer IC's- convert data for words into audio sig.
- Interfacing with MPU.
- I/P of D/A connected to o/p port to produce any desired voltage under pgm control.



KELVIN SENSING MAINTAINS DESIRED VOLTAGE AT LOAD



DIGITAL POTENTIOMETER PROGRAMS DAC OUTPUT GAIN



D/A Terms

- **Differential Nonlinearity:** Ideally, any two adjacent digital codes correspond to output analog voltages that are exactly one LSB apart. Differential non-linearity is a measure of the worst case deviation from the ideal 1 LSB step. For example,
- a DAC with a 1.5 LSB output change for a 1 LSB digital code change exhibits 1⁄2 LSB differential non-linearity. Differential non-linearity may be expressed in fractional bits or as a percentage of full scale. A differential non-linearity greater than 1 LSB will lead to a non-monotonic transfer function in a DAC.
- **Gain Error (Full Scale Error):** The difference between the output voltage (or current) with full scale input code and the ideal voltage (or current) that should exist with a full scale input code.

- **Gain Temperature Coefficient (Full Scale Temperature Coefficient):** Change in gain error divided by change in temperature. Usually expressed in parts per million per degree Celsius (ppm/°C).
- **Integral Nonlinearity (Linearity Error)**: Worst case deviation from the line between the endpoints (zero and full scale). Can be expressed as a percentage of full scale or in fraction of an LSB.
- **LSB (Lease-Significant Bit)**: In a binary coded system this is the bit that carries the smallest value or weight. Its value is the full scale voltage (or current) divided by 2n, where n is the resolution of the converter.
- **Monotonicity**: A monotonic function has a slope whose sign does not change. A monotonic DAC has an output that changes in the same direction (or remains constant) for each increase in the input code. the converse is true for decreasing codes.

- **MSB (Most Significant Bit)**: In a binary coded system this is the bit that has the largest value or weight. Its value is one half of full scale.
- **Multiplying DAC**: In a sense, every DAC is a multiplying DAC since the output voltage (or current) is equal to the reference voltage times a constant determined by the digital input
- code divided by 2n (n is the number of bits of resolution). In a two quadrant multiplying DAC the reference voltage or the digital input code can change the output voltage polarity. If both the reference voltage and the digital code change the output voltage polarity, four quadrant multiplication exists.
- **Offset Error (Zero Error)**: The output voltage that exists when the input digital code is set to give an ideal output of zero volts. All the digital codes in the transfer curve are offset by the same value. Offset error is usually expressed in LSBs.

- **Power supply Rejection (Power Supply Sensitivity)**: The sensitivity of a converter to changes in the dc power supply voltages.
- **Resolution**: the smallest analog increment corresponding to a 1 LSB converter code change. For converters, resolution is normally expressed in bits, where the number of analog levels is equal to 2n.
- **Settling Time**: The time from a change in input code until a DAC's output signal remains within ±1⁄2 LSB (or some other specified tolerance) of the final value

ADC

- Produces a digital o/p which represents the magnitude of some analog voltage or current.
- Resolution of ADC is the No of bits in the o/p.
- Conversion time of a ADC is time taken to produce a valid binary code

Types

- **Successive Approximation Converter**----- A successive approximation converter provides a fast conversion of a momentary value of the input signal. It works by first comparing the input with a voltage which is half the input range. If the input is over this level it compares it with three-quarters of the range, and so on.

  Twelve such steps gives 12-bit resolution .
- **Dual Slope Integrating Converter** ------ This converter reduces noise but is slower than the

  successive approximation type

- **Charge Balancing Converter ----**The input signal again charges a capacitor for a fixed time, but in this converter the capacitor is simultaneously discharged in units of charge packets: if the capacitor is charged to more than the packet size it will release a packet, if not a packet cannot be released. This creates a pulse train. The input voltage is determined by counting the pulses coming out of the capacitor. Noise is reduced by integrating the input signal over the capacitor charging time
- **Flash Converter -------**A flash converter is the fastest type of converter we use. Like the successive approximation converter it works by comparing the input signal to a reference voltage, but a flash converter has as many comparators as there are steps in the comparison. An 8-bit converter, therefore, has 2 to the power 8, or 256, comparators

- **Sigma-Delta Converter------**This converter digitises the signal with very low resolution (1-bit) and a very high sampling rate (MHz). By oversampling, and using digital filters, the resolution can be increased to as many as 20 or more bits. Sigma-delta converters are especially useful for high resolution conversion of low-frequency signals as well as low-distortion conversion of signals containing audio frequencies. They have good linearity and high accuracy

Specifications of Analogue-to-Digital Converters

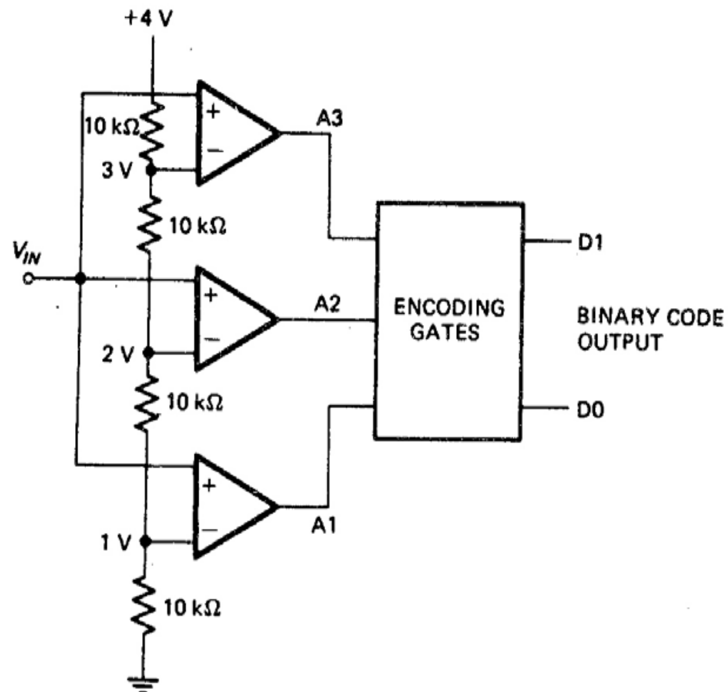
- **Resolution** ------The resolution of the A-D converter is the number of steps the input range is divided into. The resolution is usually expressed as bits (n) and the number of steps is 2 to the power n. A converter with 12-bit resolution, for instance, divides the range into 2 12, or 4096, steps. In this case a 0-10 V range will be resolved to 0.25 mV, and a 0-100 mV range will be resolved to 0.0025 mV. Although the resolution will be increased when the input range is narrowed, there is no point in trying to resolve signals below the noise level of the system: all you will get is unstable readings.

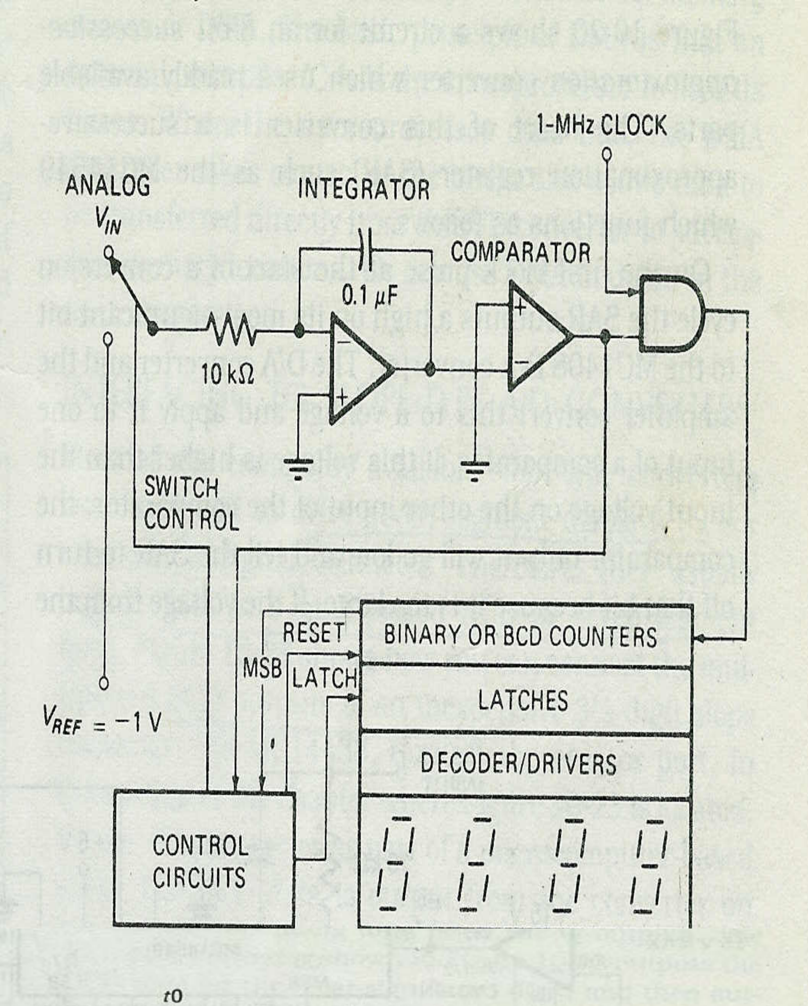
- **Linearity-----**Ideally an A-D converter with n-bit resolution will convert the input range into (2 to the power n)-1 equal steps (4095 steps in the case of a 12-bit converter). In practice the steps are not exactly equal, which leads to non-linearity in a plot of A-D output against input voltage
- **Sample and Hold Acquisition Time ----**A sample and hold circuit freezes the analogue input voltage at the moment the sample is required. This voltage is held constant whilst the A-D converter digitises it. The acquisition time is the time between releasing the hold state and the output of the sample circuit settling to the new input voltage value. Sample and hold circuits are not used with integrating converters

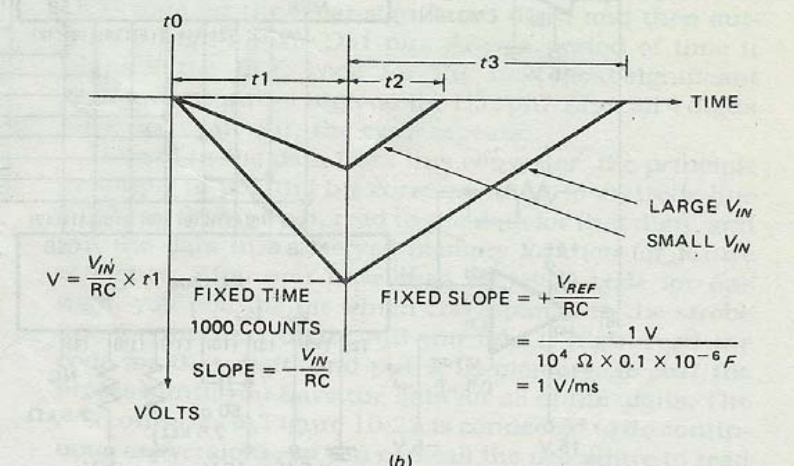
- **Throughput-----**The throughput is the maximum rate at which the A-D converter can output data values. In general it will be the inverse of the (conversion time + the acquisition time) of the A-D converter. Thus a converter that takes 10 microseconds to acquire and convert will be able to generate about 100 000 samples per second. Throughput can be increased by using a pipelined A-D converter, so a second conversion can start while the first is still in progress. Throughput may be slowed down, however, by other factors which prevent data transfer at the full rate
- **Integration Time-----**An integrating A-D converter measures the input voltage by allowing it to charge a capacitor for a defined period. The integration averages the input signal over the integration time, which if chosen appropriately will average over a complete mains cycle thereby helping to reduce mains frequency interference. The throughput of an integrating converter is not the inverse of the integration time, as throughput also depends on the maximum discharge time

- **Re-Calibration** ------Some A-D converters are able to re-calibrate themselves periodically by measuring a reference voltage, and compensating for offset and gain drifts. This is useful for long term monitoring since drifts do not accumulate. If the re-calibrations are set too far apart there may appear to be small discontinuities in the recorded data as the re-calibrations occur. (If you have a reading other than zero for a zero condition, then you have an offset error: every reading will be inaccurate by this amount. When the A-D converter is preceded by signal conditioning circuits offset errors need not normally be considered. Drift occurs because components in the amplifier change over time and with temperature. Drift is usually only significant for people tring to measure low-level signals - a few millivolts - over long periods of time or in difficult environmental conditions.)

Parallel Comparator ADC







Dual Slope ADC

- Give a large No of bits of resolution at low cost & used a s heart of digital voltmeter.
- To start the cont cct resets the counters & connects the I/p of integrator to I/p of ref voltage to be converted. If I/p voltage is +ve, o/p of integrator will be ramp -ve.
- As soon as o/p of integrator goes few micro volts below grnd, comparator o/p will go high enabling the AND gate allowing 1 Mhz clk into counter chain.
- After some fixed No of counts the cont cct switches the I/p of integrator to a –ve ref voltage & resets counters to zero.

- With a –ve I/p voltage the integrator o/p will be ramp +ve. When the integrator o/p crosses zero volts, comparator o/p will drop low & shut off clk sig to counters.
- No of counts reqd for integrator o/p to get back to zero is directly prop to I/p voltage.