INDUSTRIAL PROCESS MEASUREMENT – Signal Processing Systems.

The aim of this unit is to introduce the learner to principles and techniques related to the operation and application of a range of Signal Processing Systems.

STANDARD SIGNALS

So far then, we have considered the measurement of just 7 process variables, and we have looked at many different ways to do this. Rather flippantly we have said that 'a device' uses a particular technology to measure a process variable, and then produce a standard output signal. But now we are going to look at what that flippancy means.

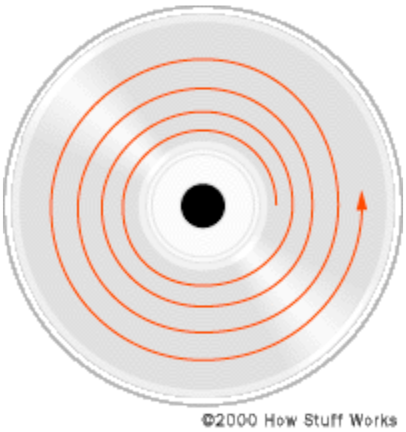
We need to consider, what we mean, when we use the term 'signal'. The name *'signal'* refers to the information which is given out by a measurement system/ transmitting device and may be in many different forms.

The number and variety of commercially available instruments is truly extensive and this exhaustive list continues to grow as technology continually changes. As a consequence throughout industry, the field of instrumentation has, over the years, adopted a number of standardised instrument signals, for reasons of economy, practicability and most important, flexibility.

In a number of cases the size of the outputs of measuring devices is extremely small, such as millivolts. So In order to get signals into a usable standard form, the raw measured signal may need to be processed, conditioned and manipulated, in such a way, so that the standard signal may be derived.

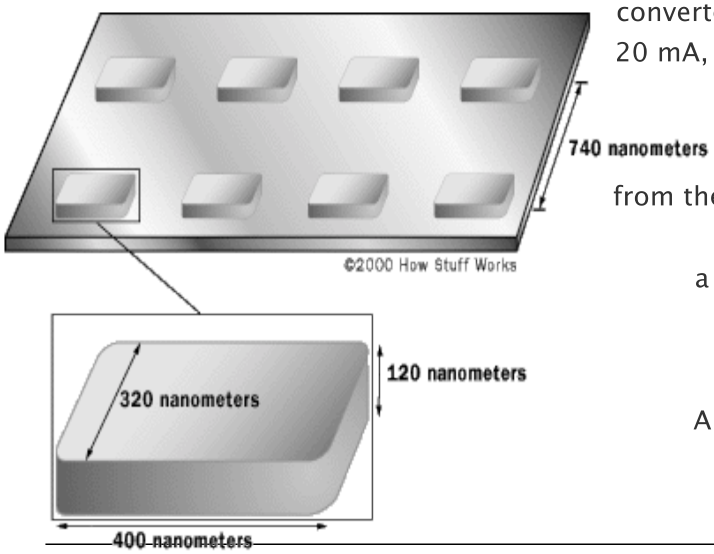
The next time you sit and watch a movie, or listen to your favourite music cd, ask yourself, how does it work? If we consider how a dvd or cd system works, then we can gain a good insight into how a process measurement system works, but importantly consider the signal processing that is taking place. Remember, this is not about cd/dvd players, more importantly, its how those same principles relate to process measurement systems.

In the example below, we see a cd/ dvd disc, the disc is loaded with information. A laser is then used to read the information from the disc, the laser is the transducer of the system, and eventually this information appears as an audio track blasting through a set of speakers or headphones, or even a movie. But what do we know about the information source, Well, each cd/dvd disc is one big spiral of microscopic data. (just like our process variable). Likewise, on the process recorder, is a stream of data, but this data is a continuous stream taken from a process measuring instrument.



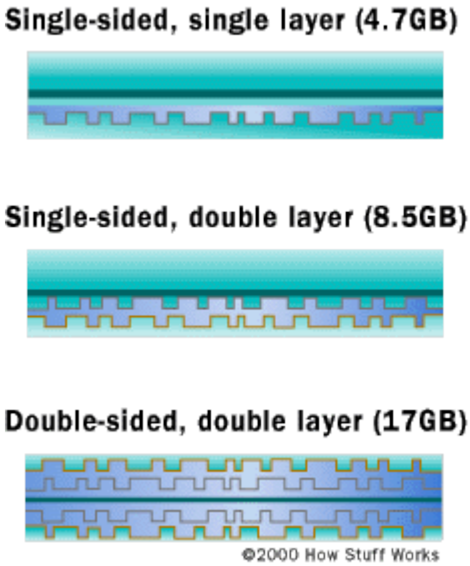
If we look at the next diagram we can see how incredibly small that data system is.

In exactly the same way, the measurements taken from process measuring systems, are converted into small, low level signals such as 4-20 mA, or 0.2 – 1bar.



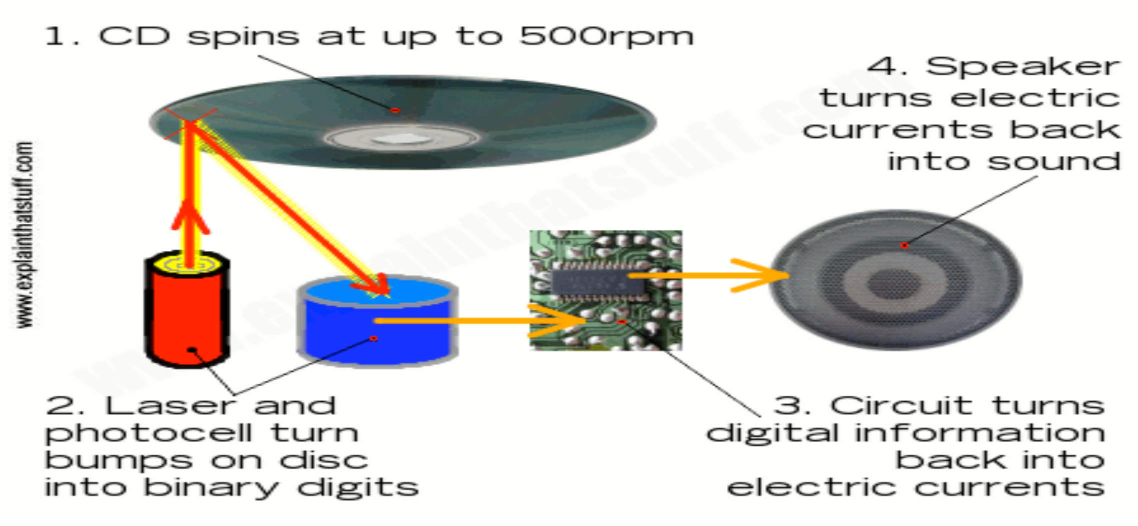
Just 740 nanometers separate one track from the next, and the elongated bumps that make up the track are just 320 nanometers wide, a minimum of 400 nanometers long and 120 nanometers high.

A nanometer is a mere 1 billionth of a meter.



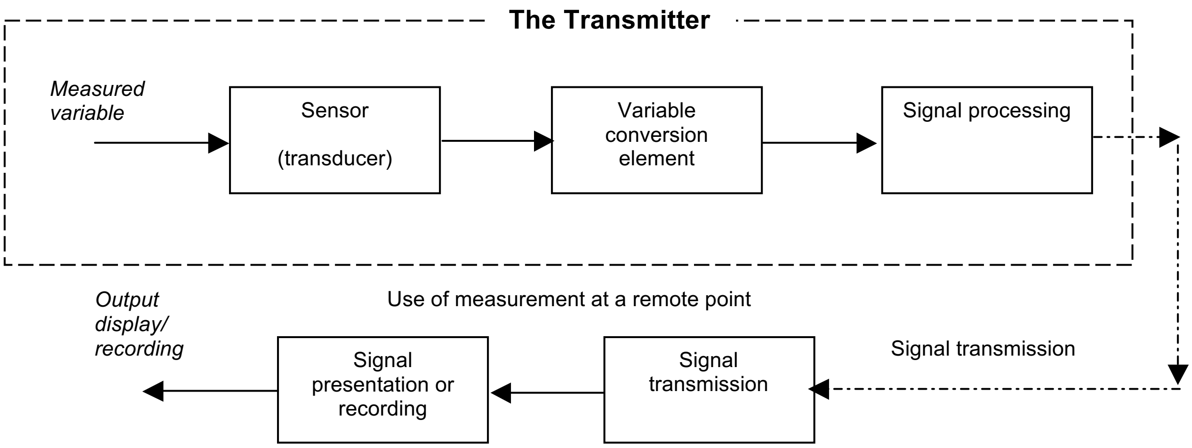
If we could lift the data track off a single layer of a DVD, and stretch it out into a straight line, it would be almost 7.5 miles long! That means that a double-sided, double-layer DVD would have 30 miles of data! In a process system, data is continuous, it is produced 24hrs a day, 365 days a year.

So, dealing with information so small, how is it that such a tiny piece of information becomes that movie or music tracked we have just watched or listened to.



We can see in the previous diagram, that the measured microscopic digital data goes through a signal processing system, to make it ready to be presented to next piece of equipment, the whole of this system we call 'the dvd/ cd player'. The complete system comprises of multiple elements that detect the process, process what is measured, and then have the information in a form that can be utilised. The information in its transition stages are what we refer to as signals.

So far we have looked at the measurement of a range of process variables, and if we consider the initial diagram (as seen below), it is the sensing element or 'transducer' which actually comes into contact with the process medium (data source), and produces an output which then needs to be processed to produce an output capable of being utilised by other control system devices.



The whole of this we quite often group together and refer to as 'the transmitter'.

So, a transmitter is a device which measures a process condition, using a transducer, this inturn, produces an output that requires some modification, before being converted into one of the usable output types. These can be analog or digital.

Because the signal is not always in a perfect state, it may require some conditioning to make it fit for purpose.

SIGNAL CONDITIONERS.

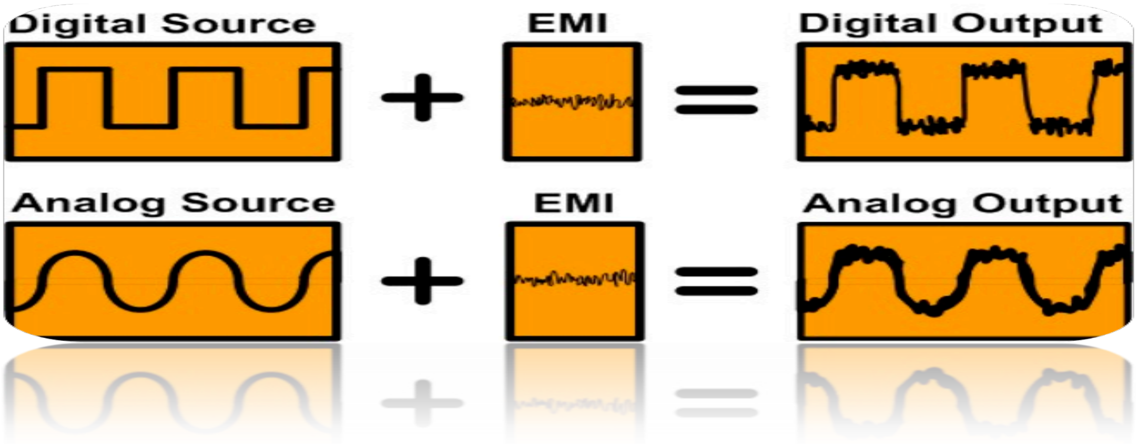
The idea of signal conditioning is to improve the quality of the produced signal, or to condition in to make it suitable for use in the control system.

The functions applied to condition a signal depend on the signal type. Typical examples of signal conditioners include amplification of the signal by operational-amplifiers and differential amplifiers, attenuation, linearisation, and filtering. These techniques are normally applied to make correction in the raw signal, before it is further utilised. However in some cases these principles may be re-applied to ensure a quality output signal.

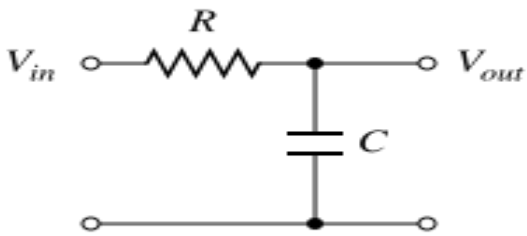
Attenuation is the reduction in amplitude and intensity of a signal. Signals may be attenuated exponentially by transmission through a medium, in which case attenuation is usually reported in dB with respect to distance traveled through the medium. Attenuation can also be understood to be the opposite of amplification.

Filtering

Signal filtering consists of processing the signal to remove unwanted bands of frequencies within it, often referred to as interference or noise. These can be removed at the low, high or middle of the frequency range. This interference may come from difference sources, such a Static, Electromagnetism, Transformers, Power lines, Radio wave interference, or even Poor connectivity. In analog systems, this noise is read as part of the signal, whereas in digital systems, it will always see a 0 or a 1.

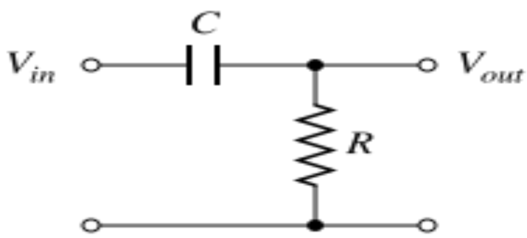


A **low-pass filter** is a filter that passes low-frequency signals but attenuates (reduces the amplitude of) signals with frequencies higher than the cutoff frequency. The actual amount of attenuation for each frequency varies from filter to filter. It is sometimes called a **high-cut filter**, or **treble cut filter** when used in audio applications.



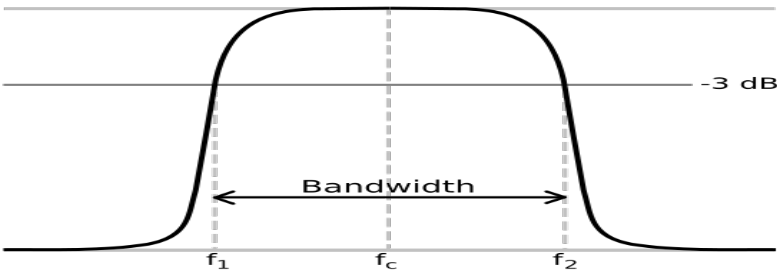
Simple Low Pass filter circuit

A **high-pass filter** is a filter that passes high frequencies well, but attenuates (reduces the amplitude of) frequencies lower than the cutoff frequency. The actual amount of attenuation for each frequency varies from filter to filter. It is sometimes called a **low-cut filter**; the terms **bass-cut filter** or **rumble filter** are also used in audio applications. A high-pass filter is the opposite of a low-pass filter, and a band-pass filter is a combination of a high-pass and a low-pass.



Simple high pass filter circuit

A **band-pass filter** is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range, as shown by the frequency diagram below.

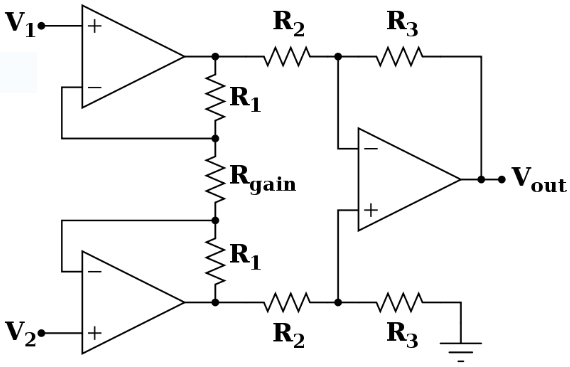


The bandwidth of the filter is simply the difference between the upper and lower cutoff frequencies.

Signal Amplifiers

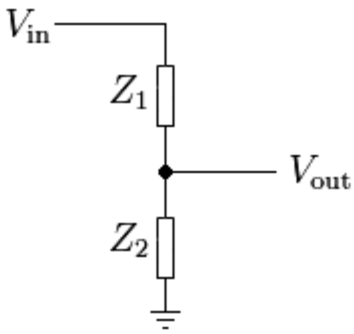
Some signals are produced at such a low level, that they require amplification before they can be used effectively. Non better than that produced by a hi-fi system, where a amplifier is employed to increase the volume so the signal can be heard when driven through a set of speakers. In instrument system, the pressure behind the nozzle of a pneumatic transmitter is small, hence the need for a Relay which acts as a signal booster. Likewise in Rosemount transmitters, the transducer uses capacitance, this has to be converted electronically before being boosted to a 4 - 20mA signal.

An **instrumentation amplifier** is a type of differential amplifier that has been specifically designed to have characteristics suitable for use in measurement and test equipment. These characteristics include low drift, low noise, and very high input impedances. They are used where great accuracy and stability of the circuit both short- and long-term are required.



Voltage Divider

A **voltage divider** (also known as a **potential divider**) is a simple linear circuit that produces an output voltage (V_{out}) that is a fraction of its input voltage (V_{in}). A simple example of a voltage divider consists of two resistors in series or a potentiometer. It is commonly used to create a reference voltage.



A voltage divider referenced to ground is created by connecting two impedances in series, as shown in the diagram above. The input voltage is applied across the series impedances Z_1 and Z_2 and the output is the voltage across Z_2.

Z_1 and Z_2 may be composed of any combination of elements such as resistors, inductors and capacitors.

Applying Ohm's Law, the relationship between the input voltage, V_{in}, and the output voltage, V_{out}, can be found:

$$V_{\mathrm{out}} = \frac{Z_2}{Z_1 + Z_2} \cdot V_{\mathrm{in}}$$

The transfer function (also known as the divider's **voltage ratio**) of this circuit is simply:

$$H = \frac{V_{out}}{V_{in}} = \frac{Z_2}{Z_1 + Z_2}$$

Now that the signal has been conditioned, it is likely to be in one of the follow common signal types:

		Pneumatic Transmitter			Electronic Transmitter	
% Level	0%	3 psi	20KPa	0.2Bar	4 mA	1V
	25%	6 psi	40KPa	0.4Bar	8 mA	2V
	50%	9 psi	60KPa	0.6Bar	12 mA	3V
	75%	12 psi	80KPa	0.8Bar	16 mA	4V
	100%	15 psi	100KPa	1.0 Bar	20 mA	5V

In common applications, the transmitter conditions the measured value (e.g. level, flow, pressure, temperature etc.) into a safe and representative output signal, often at a much lower value, or even much higher value, to that which is being measured. Signals in this format are now ready to be used by the control system.

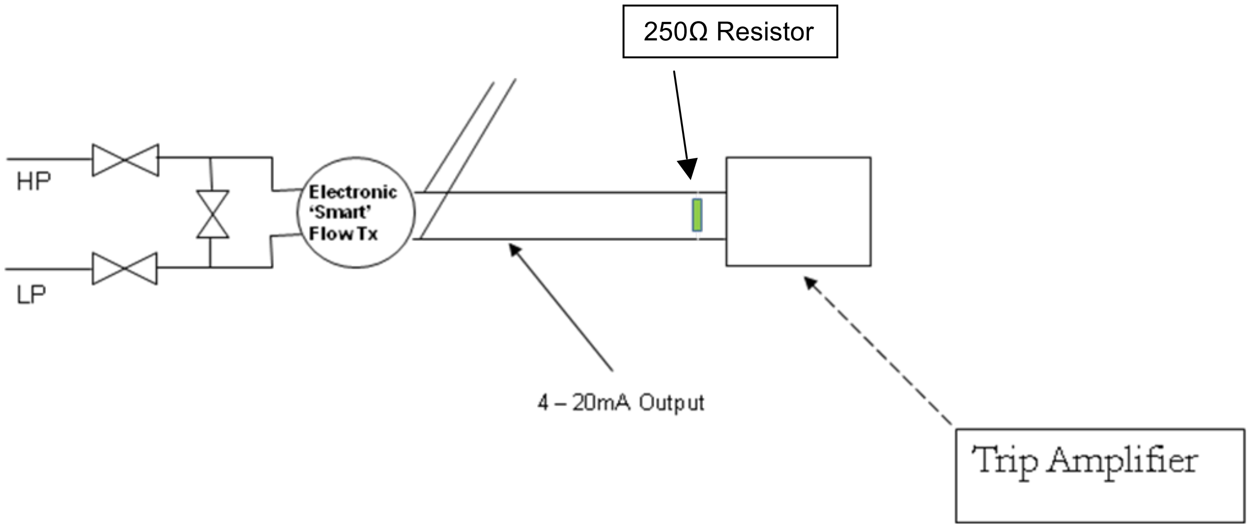
SIGNAL CONVERTERS

This pneumatic or electronic output signal will usually require transmission to a suitable receiving device, usually some distance away. It is not always safe or practical to have control or monitoring systems right next to the process they are connected with. For these reasons, signals may need to be processed to meet specific requirements.

- Current to Pressure (I / P or E / P) **4 - 20 mA to 3 - 15 psi or 0.2 - 1.0 Bar**
- Voltage to pressure **D.C.volts or Mv to 3 - 15 psi or 0.2 - 1.0 Bar**
- Pressure to Current (P / I) **3 - 15 psi or 0.2 - 1.0 Bar to 4 - 20 Ma**
- Resistance to Pressure or Current **Resistance to 3 - 15 psi or 0.2 - 1.0 Bar**
- Mv to current **Mv to 4 - 20 mA**
- Analogue to Digital **4 - 20 mA to 800 - 4000 counts**
- Digital to Analog **800 - 4000 counts to 4 - 20 mA**

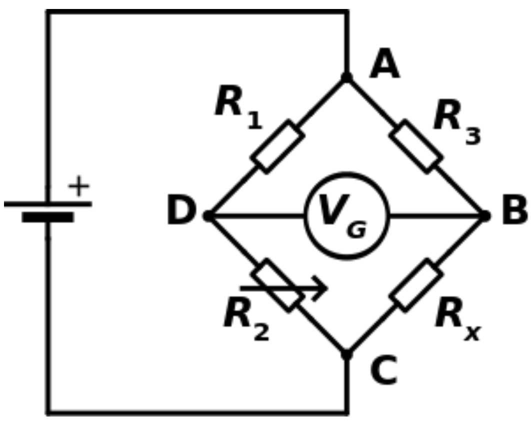
Outputs from measurement sensors that take the form of voltage signals can be measured, however in many cases the sensor output does not take the form of an electrical voltage or current. In some cases these may be resistance, capacitance, inductance, phase or frequency. In some cases, outputs may be in a complete non-voltage format. This section deals with methods of how signals may be converted. In some cases the signal converter may be as simple as a few basic components on a circuit board, as in the previous example of the Potential Divider, or may be as complex as a Pressure to Current converter.

In the diagram below, the signal of 4-20mA is fed across a 250Ω resistor, this drops the signal to 1 – 5v, based on a 24v power supply. Therefore the resistor is acting as a simple but effective signal convertor.



The **Wheatstone bridge** is used to convert resistance to voltage, by measuring an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component.

In the circuit, R_x is the unknown resistance to be measured; R_1, R_2 and R_3 are resistors of known resistance and the resistance of R_2 is adjustable. If the ratio of the two resistances in the known leg (R_2 / R_1) is equal to the ratio of the two in the unknown leg (R_x / R_3), then the voltage between the two midpoints (**B** and **D**) will be zero and no current will flow through the meter V_g. R_2 is varied until this condition is reached. The current direction indicates whether R_2 is too high or too low.



If R_1, R_2 and R_3 are known to high precision, then R_x

can be measured to high precision. Very small changes in R_x disrupt the balance and are readily detected.

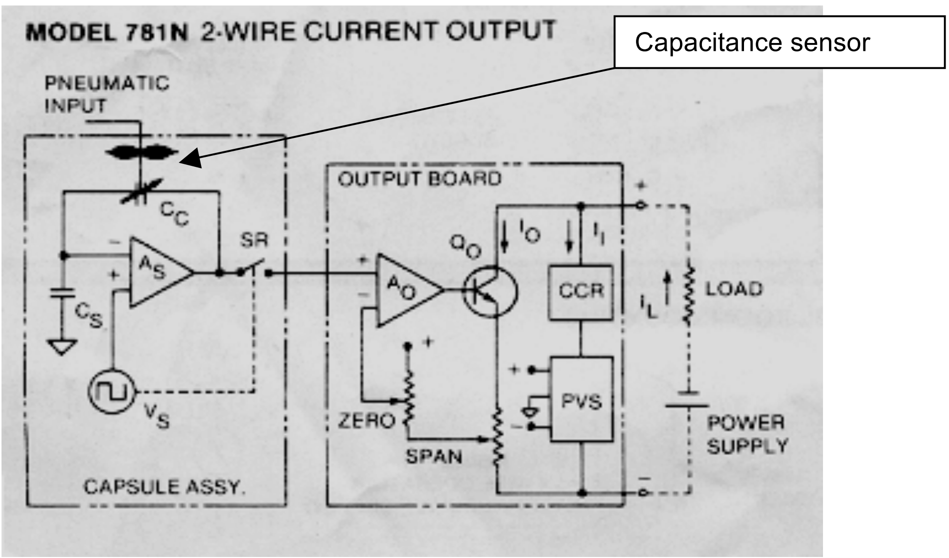
At the point of balance, the ratio of R_2 / R_1 = R_x / R_3

Therefore, $$R_x = (R_2/R_1) \cdot R_3$$

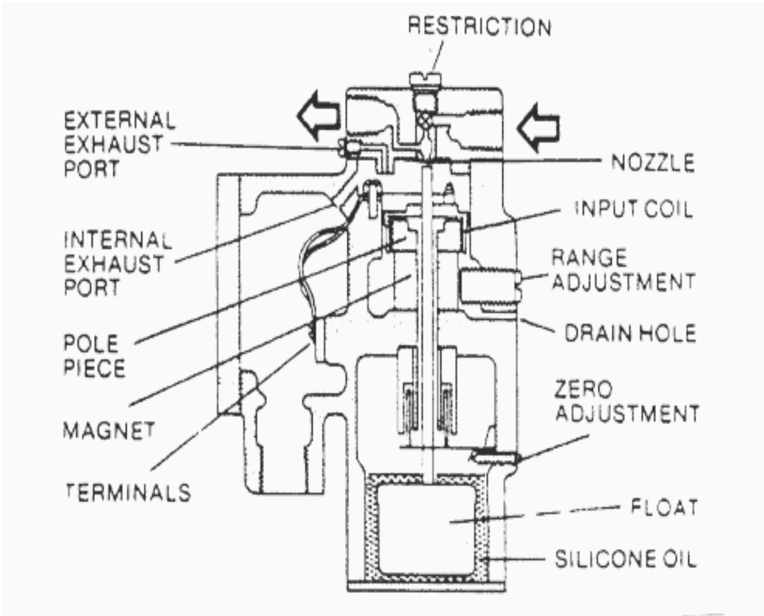
Alternatively, if R_1, R_2, and R_3 are known, but R_2 is not adjustable, the voltage or current flow through the meter can be used to calculate the value of R_x, This setup is frequently used in strain gauge and Resistance Temperature Detector measurements, where resistance is converted into voltage.

In the **Pressure to Current converter**, pressure is applied to the capacitance capsule between 20-100KPa, as the distance between the capacitance measurement plates is decreased the capacitance is also changed, this information is sent to a P.C.B where using signal amplifiers, it is converted into a 4 to 20mA output.

When looking at the circuit board, the a board appears in two parts, one looks at the handling the raw signal, and conditions it accordingly, and the second converts the signal into a usable output



In the **Current to Pressure converter,** the input coil and float are attached to a common centre shaft, which is free to move vertically, with the float being submersed in oil to absorb any shock/ vibration and to make the float appear weightless. A permanent magnet surrounds the input coil, and when the 4 - 20mA input signal is increased the 2 magnetic fields react causes the free coil to move nearer the nozzle. A 20psi supply is fed to the nozzle and the further away the float shaft is from the nozzle the more air is allowed to escape, equally when the shaft gets nearer the nozzle with increased pressure, the gap reduces thus restricting the air exit and thus causing the output pressure to increase proportionally, so that 4mA = 3psi, and 20mA = 15psi.



The **Analog-to-Digital converter** (abbreviated **ADC**, **A/D** or **A to D**) is an electronic integrated circuit, which converts continuous signals to discrete digital numbers. The reverse operation is performed by a digital-to-analog converter (**DAC**).

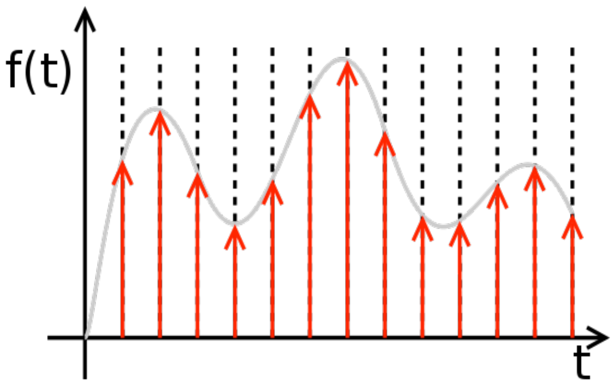
The analog signal is continuous in time and it is necessary to convert this to a flow of digital values. It is therefore required to define the rate at which new digital values are sampled from the analog signal. The rate of new values is called the *sampling rate* or *sampling frequency* of the converter.

Typically, an ADC is an electronic device that converts an input analog voltage (or current) to a digital number.

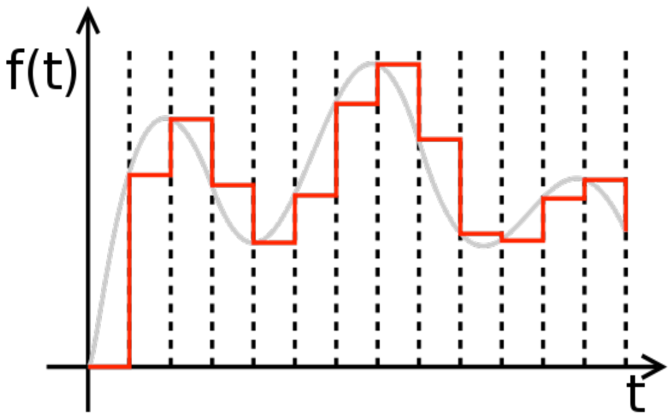
The **digital-to-analog converter** (**DAC** or **D-to-A**) is a device for converting a digital (usually binary) code to an analog signal (current, voltage or electric charge).

The DAC fundamentally converts finite-precision numbers (usually fixed-point binary numbers) into a physical quantity, usually an electrical voltage. Normally the output voltage is a linear function of the input number. Usually these numbers are updated at uniform samplin intervals and can be thought of as numbers obtained from a sampling process.

In the first of the diagrams, we see how a an analog signal can be sampled to produce a digital points



In the second diagram, we see how the digitised signal would look. The more times or more frequently we sample the analog signal, the closer we get to the original. In practical the analog signal is sampled hundreds if not 1000's of time per second.



Typical applications for signal converters

- Solving current loop loading problems
- Converting voltage signals to current, current signals to voltage or converting resistance type signals to current or voltage.
- Scaling of process variables
- Interfacing field sensors, transducers and transmitters with indicators, PLCs, and other process control instrumentation.
- Boosting signals to drive long signal lines
- Signal level changing

a) Current / Pressure (I or E / P):

Commonly used to convert standard 4 – 20 mA output signals from electronic controllers to 3 – 15 psi or 0.2 – 1.0 bar equivalents for operating pneumatic valve positioners. On the latest generation of electro-pneumatic valve positioners, signal conversion takes place in the positioner itself. On rare occasions, I / P's may also be used to convert an electronic signal into pneumatic for transmission through a hazardous area.

b) Pressure / Current (P / I):

Typically used on older plants where field instrumentation is pneumatic whilst panel room instrumentation has been up-graded to electronic or D.C.S. In this instance, racks of P / I transducers are normally housed in inter-posing cabinets which are normally located in an auxiliary room.

c) Volts or Mv to Pressure or Current:

Most commonly used in temperature measurement applications, converting the mV's generated by thermocouples to panel instrumentation. Resistance to pressure (or current) transducers perform a similar duty, converting resistance readings from RTD's to eqivalent current or pressure signals.

Disadvantages of Using Signal Conditioners/ converters

- Additional transducers in a loop can introduce additional errors.
- Errors may become cumulative – i.e. if we had even a relatively small zero or range error on the transmitter and a similar error on the transducer, this may result in a significant error at the receiver end).
- Accuracy and reliability of any instrument loop is therefore dependant upon all items of equipment being correctly calibrated.