Prof. Sumanta Hait

SACT,

Dept. Of Physics, Narajole Raj College

DSE4T (Experimental Technique) , Topic :- Transducer (part-II)

Introduction

Devices used to transform one kind of energy to another. When a transducer converts a measurable quantity (sound pressure level, optical intensity, magnetic field, etc) to an electrical voltage or an electrical current we call it a **sensor.** We will see a few examples of sensors shortly.

When the transducer converts an electrical signal into another form of energy, such as sound (which, incidentally, is a pressure **field**), light, mechanical movement, it is called an **actuator.** Actuators are important in instrumentation. They allow the use of feedback at the source of the measurement. However we will pay little attention to them in this course. The study of using actuators and feedback belongs to a course in Control theory.

A sensor can be considered in its bare form, or bundled with some electronics (amplifiers, decoders, filters, and even computers). We will use the word **instrument** to refer to a sensor together with some of its associated electronics. The distinction between a sensor and an instrument is extremely vague, as it is increasingly common to manufacture integrated sensors.

What follows is equally applicable to sensors and/or instruments. The discussion is also applicable to circuits, such as amplifiers, filters, mixers and receivers. Signal processing circuits are, in a sense, instruments. It is not very important that both input and output signals are, for example, voltages.

The linear model of a Sensor

There is a fair amount of jargon associated with sensors, used to describe the usefulness or quality of a piece of hardware. Sensor specification terms are often used in an erroneous or misleading way, especially in the advertising literature of equipment manufacturers; they tend to manipulate definitions in order to make their product appear better than it is. It is always a good idea to investigate the precise meaning of specifications, before accepting them. Below we attempt the definition of some important specifications from the engineering point of view.

The following discussion refers to an implicit linear model for the sensor. A sensor is assumed to be linear so that its response y to a stimulus x is idealised to have the form:

$$y\,(x) = Ax\,, \qquad 0 \leq x \leq x_{max}\,,\ A>0$$

Please note that we have defined the stimulus to be positive. This makes it easier to define quantities such as the threshold, and consequently makes it easier to understand that there may exist gaps in the response of an instrument.

Sensitivity

The constant A in (1.1) is called the **sensitivity** or the **transducer gain** or, simply, the **gain** of the sensor. To simplify the discussion we also take the gain to be positive.

The linear model satisfies the definition of linearity, as it should:

$$y\ (x+z) = A\ (x+z) = y\ (x) + y\ (z)$$

Please note that the response of a sensor defined this way exhibits no time dependence. Such an idealised sensor has no memory and its output instantly tracks the input. In the more general case we may know the steady state transfer function of the sensor. We can define the sensitivity as the derivative of the output with respect to the input:

$$s = \frac{\partial y}{\partial x}$$

This is a **partial** derivative. As we shall see below, the sensor will exhibit sensitivities to other ambient (e.g.temperature) or operating parameters (e.g. a supply voltage). It is essential to study the sensor with all other (usually unintended) stimuli held constant.

Sensitivity is, in a few words, the ratio of electrical output to signal input (input transducer), or physical output to electrical input (output transducer). e.g., a temperature sensor may be quoted as 50 μV/K. and a loudspeaker as 90dBspl/W. However, the term sensitivity may also be used in its usual electronic sense, i.e, the %change of some property of a device (e.g.gain) as a result of a % change in some parameter, (e.g. the ambient temperature). For clarity, we will refer to this as the **cross-sensitivity of x on y.** The sensitivity is also called the **Gain** of the sensor or instrument.

The term sensitivity is occasionally misused to refer to the *minimum detectable signal*, i.e.the sensor's ***detectivity*** or *threshold*, which incidentally, equals the noise floor of the sensor**.**

Threshold and detectivity

No sensor will respond to arbitrarily small signals. Signals in the range between zero and the sensor **threshold** min *x* will not cause the output of the sensor to change**.** The existence of a threshold is related to nonlinearity and noise. A stimulus which is too small for the output to exceed the noise floor is considered to be smaller than the threshold. Nonlinearity can play a role as well. Consider an enhancement mode MOSFET as a voltage sensor (MOSFETs are used as very high impedance voltage or charge probes in high end “active” oscilloscope probes). Clearly such an instrument cannot respond to voltages smaller than the MOSFET threshold voltage.

A sensor will also fail to respond to stimuli which are arbitrarily large. A sensor will necessarily have a **range** or a **full scale** max *x***.** The full range of a sensor can be limited by **compression** or by clipping. (Note that clipping is an extreme example of compression!) Since both compression and clipping are manifestations of **non-linearity** we conclude that all sensors are non-linear.

Zero offset

A real sensor will deviate from the idealised linear model. The smallest improvement we can make to the description of an assumed linear sensor is the addition of a constant **zero offset** as follows:

$$y\left(x\right) = b_0 + Ax$$

This is not a linear form, despite the fact that it is described by a first order polynomial. This is called an **affine** relation. The constant 0 *b* is called the **zero offset** of the sensor. The **zero offset** can be defined in two ways: The sensor reading when the input is zero, or the value of the stimulus required to make the output zero. The zero offset is simple to correct. By subtracting 0 *b* from y we recover a linear description of the sensor:

$$Y'(x) = y(x) - b_0 = Ax$$

Examples of sensors

Active sensors

These include:

Photovoltaic transducers: e.g,solar cells, portable exposure meters

Piezoelectric transducers generate electric polarisation, which is linearly related to the applied force (stress). Examples include gas igniters, microphones, older record player cartridges, stress/strain gauges. Piezoelectric crystals are used to measure small displacements and also as actuators to implement small (as small as 1 Angstrom!) displacements in scanning tunnelling microscopes (STM) and atomic force microscopes (AFM).

Thermoelectric transducers: A thermocouple junction is formed when two dissimilar metals are joined at one end. When the junction is heated, a small voltage appears between the two wires which is monotonically increasing with temperature (the Seebeck effect). By suitably biasing a thermocouple junction we can *cool* a specimen. (the Peltier effect).

Electromagnetic transducers: Lentz's law dictates that a changing magnetic flux through a loop conductor will induce a voltage across its terminals. Electromagnetic sensors include microphones, phonograph pick-ups, metal detectors, and dynamos. Actuators include earphones, loudspeakers and motors, both rotational and linear. Particularly fascinating are the linear motors and associated magnetic levitation. Linear motors were apparently invented by Charles Wheatstone at Kings College in the 1840s and the first working full scale model was developed by Eric Laithwaite at Imperial College in the 1940s. (please read in the web about linear motors, especially the high acceleration types).

Passive sensors

These include:

Variable resistance transducers: The change in resistance of an element can be readily measured. Various components exist whose resistance changes in response to some external parameter, including potentiometers, strain gauges, resistive temperature detectors (RTDs), thermistors, photoconductive devices, and of course, potentiometers. The resistance of most metals and semiconductors depends on magnetic field, but usually in a very minor way. A recent development is that some alloys exhibit Giant Magnetoresistance (GMR). GMR sensors are used in the read heads of many modern hard disk drives.

Other variable resistance devices include:

Photoconductors - photoconductive material drops its resistance when light is shone on it.

Strain gauges - A strain gauge is a piezoresistive element designed to change resistance when a force is applied. A strain gauge is essentially a thin metallic conductor. Stretching (tension) increases the length of the wire while reducing cross-sectional area, thus increasing resistance. Compression has the opposite effect. Strain gauges are generally classified as either bonded or unbonded. An unbonded gauge typically consists of a wire resistance element stretched between two supports. A bonded gauge consists of a thin pattern of conducting foil (e.g.copper-nickel alloy) intimately bonded to a backing material, which is in turn firmly affixed onto a solid object.

Resistive temperature detectors (RTDs) - RTDs are generally constructed from platinum and their resistance increases with increasing temperature (positive temperature coefficient, PTC). The resistance is usually modelled as a polynomial in temperature, and the fitting coefficients are supplied with the sensor

$$R = R_0 (1 + \alpha\ T + \alpha\ T^2 + \alpha\ T^3 + \ldots\ldots\ldots + \alpha\, T^n)$$

Thermistors (i.e.thermal resistors) are constructed from semiconductors or ceramics which exhibit a strong negative temperature coefficient (“tempco”) (NTC). The temperature characteristic is generally very non-linear. Physically, thermistors come in various shapes and sizes including beads, disks, wafers, rods etc. These are generally encapsulated in glass or resin. Since the conductivity of a piece of semiconductor varies exponentially with temperature.

A related class of passive sensors are a bit more fundamental, appearing

pn-junction diodes: The voltage across a biased pn-junction is given by

$$V_d = VT \ln (I_d / I_s + 1)$$

where VT is the thermal voltage kT/q. As long as the bias current greatly exceeds the reverse saturation current, which is typically a few A.

The reverse saturation current I_s exhibits a strong positive temperature coefficient, and the net effect is that V_d decreases with increasing temperature (typically $-2mV/K$, K is the degree Kelvin), making it difficult to use this measurement for precise temperature observation. If, however, the same diode voltage drop is measured at two different currents,

This allows a truly linear measurement of absolute temperature. Alternatively, the two current values may be applied to two identical diodes held at the same temperature, and the voltage difference can be directly measured.

Extending sensor usefulness

(1)Calibration

No instrument is intrinsically perfect. **C*alibration techniques*** are used to extend the usefulness of an instrument, correcting for offsets, nonlinearity, hysteresis and other undesired characteristics of an instrument. To calibrate an instrument one needs to measure known quantities, and then devise an ***Error Model,*** i.e. a set of equations that allow the instrument raw reading to be corrected. Error models often involve lookup tables and interpolation, i.e. they are applicable for measurements between the minimum and maximum values of the **Calibration Standards** used. Some calibration scheme is always present in commercial instruments, although it often consists of adjusting a few trimmer potentiometers in the associated electronics. Calibration becomes essential, mathematically complicated and rather tricky to perform at high frequency and/or high precision measurements.

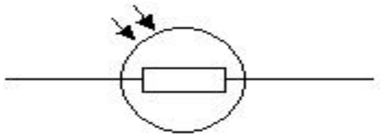
Calibration is related to fitting and interpolation, discussed later in the course. We will discuss
calibration issues as we discuss specific measurement techniques.

(2)Bridge Measurements

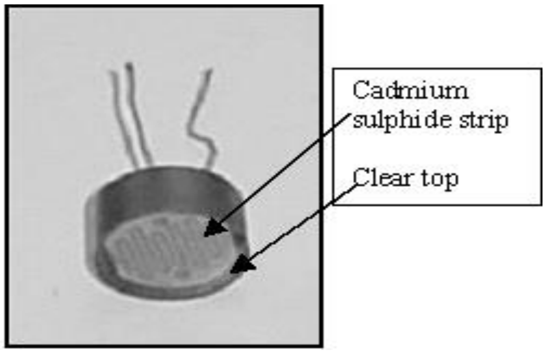
The sensitivity of a sensor can be increased by incorporating it in a bridge arrangement. Impedance varying sensors are often arranged in DC or AC Wheatstone bridges. In some types of measurement (e.g.in strain measurements) it is possible to perform a differential measurement comparing the outputs of 2 sensors subjected to opposite stimuli (for example, tensile and compression).

Light Dependent Resistors

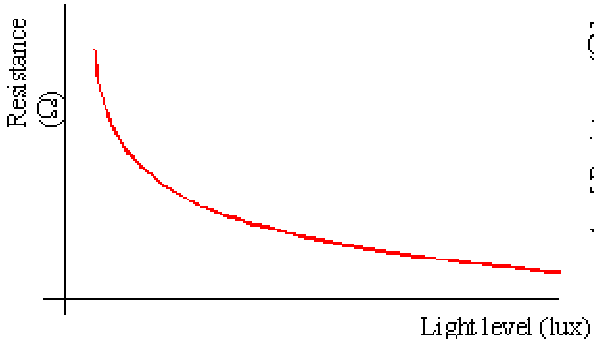
The **light dependent resistor** consists of a length of material (cadmium sulphide) whose resistance changes according to the light level. Therefore the brighter the light, the lower the resistance.

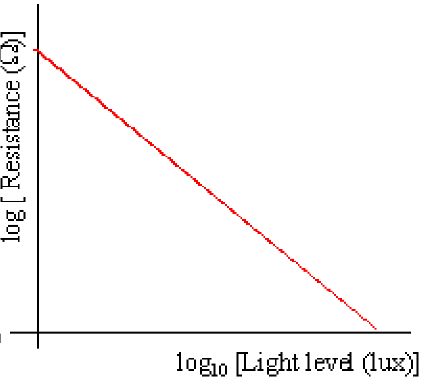


Symbol for LDR



We can show the way the resistance varies with light level as a graph:





LDRs are used for:

Smoke detection
Automatic lighting
Counting
Alarm systems.

Resistive components can get hot when excessive current is flowing through them, and this can impair their function, or damage them. This can be prevented by connecting a current limiting resistor in series, as shown in the picture below

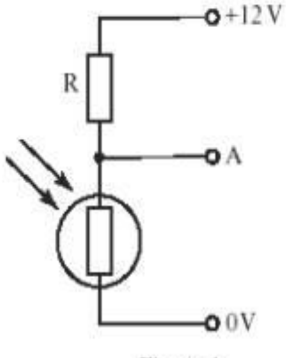


Figure 1

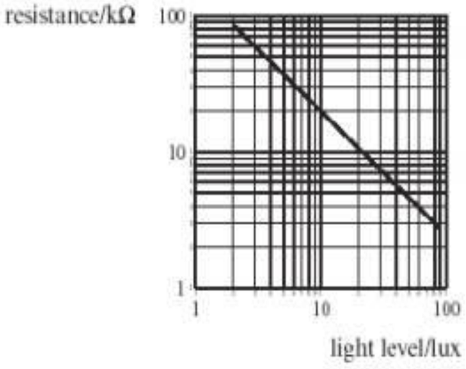
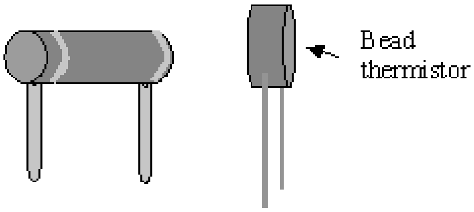
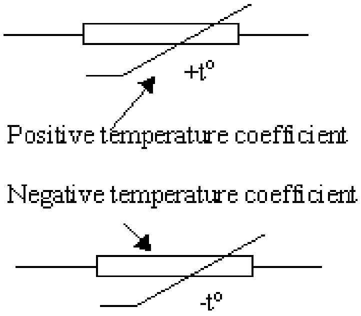


Figure 2

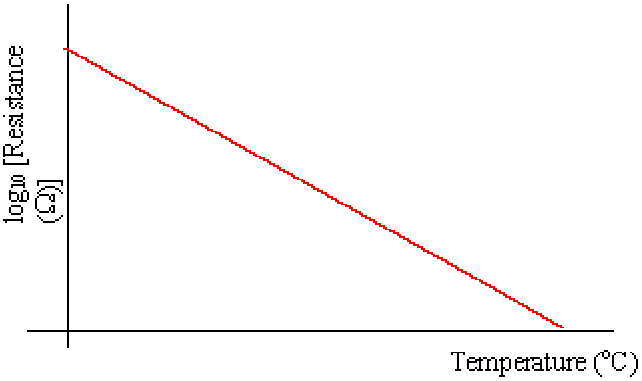
Thermistors

The most common type of **thermistor** that we use has a resistance that falls as the temperature rises. It is referred to as a negative temperature coefficient device. A positive temperature coefficient device has a resistance that increases with temperature.





The graph of resistance against temperature is like this.



The resistance on this graph is on a logarithmic scale, as there is a large range of values.

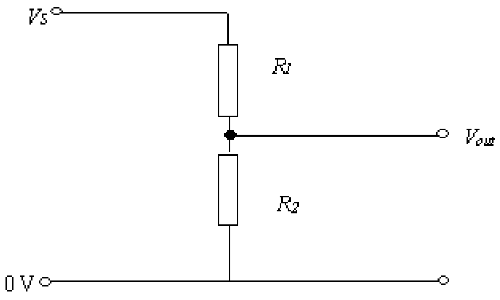
The LDR is most commonly used in a potential divider circuit.

Potential Divider

Although it is simple, the potential divider is a very useful circuit. In its simplest form it is two resistors in series with an input voltage Vs across the ends.

An output voltage Vout is obtained from a junction between the two resistors.

The potential divider circuit looks like this:



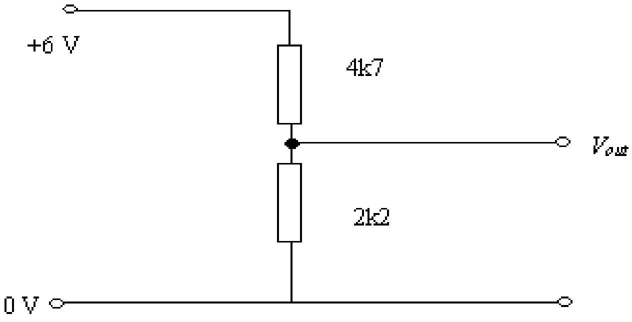
You need to learn this equation. It is very useful.

Learn this:

$$Vout = \frac{R_2}{R_1 + R_2} \times Vs$$

If you can't remember it, treat the circuit as a simple series circuit.

This result can be thought of as the output voltage being the same fraction of the input voltage as R2 is the fraction of the total resistance. Look at this circuit for the next example:



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