Pearson BTEC Higher Nationals in Electrical and Electronic Engineering (QCF)

Unit 22: Electronic Devices and Circuits

Unit Workbook

Learning Outcome 4:

Testing Procedures

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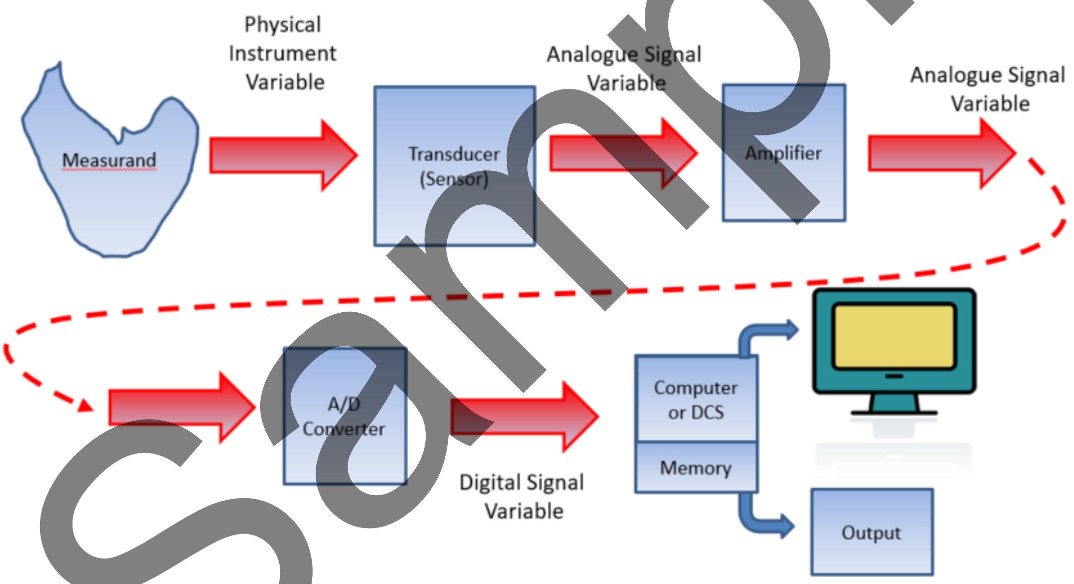
1.1 Measurement Systems and Terms

1.1.1 Measurement Systems

Measurement systems inevitably collect some form of information from the real world and increasingly the information collected will be processed and stored in a computer. We will deal with the process of making the information compatible with computers later, but it is sufficient to say at this point that most real-world events and their measurements are in an analog form. That is, the measurements can take a wide and continuous range of values. The physical quantity of interest could be temperature, pressure, velocity, position or any other aspect of the system under consideration. In order that the measurement of interest can be processed by our measuring system, these physical quantities need to be converted to some form that can be recognised by the measuring system. These will usually be electrical quantities such as voltage, current, or impedance and the device which undertakes this conversion is a transducer. The analog voltage or current is then converted into a digital signal which can be interpreted and processed by a Digital Control System (DCS) or computer system. Thus, the general arrangement of a measuring system is as shown below.



1.1.2 Transducers

Most data acquisition signals can be described as analog, digital, or pulse. While analog signals typically vary smoothly and continuously over time, digital signals are present at discrete points in time. In most control applications, analog signals range continuously over a specified current or voltage range, such as 4-20 mA dc or 0 to 5 V dc. While digital signals are essentially on or off, analog signals represent continuously variable entities such as temperatures, pressures, or flow rates. Because computer-based controllers and systems understand only discrete on/off information, conversion of analog signals to digital representations is necessary.

Transduction is the process of changing energy from one form into another. Hence, a transducer is a device that converts physical energy into an electrical voltage or current signal for transmission. There are many different forms of analog electrical transducers. Common transducers include load cells for measuring strain via resistance, and thermocouples and resistance temperature detectors (RTDs) for measuring temperature via voltage and resistance measurement, respectively. Transmission channels are many and varied and we will discuss these later in this workbook.

The operation of a transducer can be described by the following simple equation:

$$Output\ Quantity = H * Input\ Quantity$$

Where H is the transfer function.

For the purposes of this course, all transducers convert physical quantities into electrical ones; in other words, they convert one form of energy into another. Given that the transducer is at the front end of measurement operations, its properties and performance are critical to the performance of the measurement system as a whole. Some of these properties are as follows;

- Response; or more accurately, the **Dynamic Response** of a measuring instrument is the change in the output y caused by a change in the input x, where x and y are functions of time t.
- Impulse Response; the **Impulse Response**, of a dynamic system is its output when presented with a brief input signal, called an impulse.
- Frequency Response; **Frequency Response** is the quantitative measure of the output spectrum of a system or device in **response** to a stimulus, and is used to characterize the dynamics of the system. It is a measure of magnitude and phase of the output as a function of **frequency**, in comparison to the input.
- Resolution; **Resolution** is the smallest unit of measurement that can be indicated by the measuring system.
- Sensitivity; **Sensitivity** is a measure of the efficiency of the conversion process. It is the smallest amount of **difference** in quantity that will change an instrument's reading. A measuring tape for example will have a **resolution**, but not **sensitivity**.
- Transfer Function; Transfer Function is the ratio of the output quantity to the input quantity of a system
- Stability; Stability is a measure of how the accuracy and precision of the measurement system perform over time. In other words, it is a measure of how much the output drifts in the face of a constant input. Stability will determine the required interval between calibration of the measurement system.
- Noise; There are many sources of noise in electronic systems, but all electronic systems are subject to it and exhibit random fluctuations of output for no discernible input.
- Signal to Noise Ratio (SNR); Signal to Noise Ratio is simply the ratio between the wanted signal and the unwanted background noise. Obviously, it is desirable that the SNR is as high as possible.
- Dynamic Range; **Dynamic range** is a term used to describe the ratio between the smallest and largest signals that can be measured by a **system**. The **dynamic range** of a data acquisition **system** is defined as the ratio between the minimum and maximum amplitudes that a data acquisition **system** can capture.
- Linearity; Linearity describes how accurate measurements are across the complete expected range of the measurements. It answers the question about how accurate the system is across the dynamic range of the system.

Some examples of TYPES of transducers are as follows;

- Temperature Sensors.

These have electrical parameters that vary with temperature, following well-characterised transfer functions. This should be no surprise since nearly all electronic components have properties that vary with temperature. Many of these components could potentially be used as temperature transducers if their transfer functions were well behaved and insensitive to other variables. Examples include; Thermocouples, Thermistors, Resistance Temperature Detectors, and Monolithic Temperature Transducers.

- Optical Sensors

Optical sensors are used for detecting light intensity. Typically, they respond only to particular wavelengths or spectral bands. Examples include; Vacuum Tube Photo Sensors, Photoconductive Cells, Photovoltaic (Solar) Cells, Semiconductor Light Sensors, and Thermoelectric Optical Sensors.

- Force and Pressure Transducers

A Wide range of sensors are used for measuring force and pressure. Most pressure transducers rely on the movement of a diaphragm mounted across a pressure differential and the transducer measures minute movements in the diaphragm. Capacitive and inductive pressure sensors operate in a similar way to capacitive and inductive displacement sensors, which are described later. Examples include; Strain Gauges, and Piezoelectric Transducers.

- Magnetic Field Sensors

These group of transducers measure either varying or fixed magnetic fields.

- Ionising Radiation Sensors

Ionizing radiation can be particle produced by radioactive decay, such as alpha or beta rays, or high-energy electromagnetic radiation, such as gamma rays or X rays. In many of these detectors, a radiation particle or photon collides with an active surface material which as a result produces charged particles which are measured as an electric current. Examples include Geiger Counters, Semiconductor Radiation Detectors, and Scintillation Counters.

- Position Displacement Sensors

A wide variety of transducers are used to measure mechanical displacement or position of an object. Some require physical connection to the object, others do not. Examples include; Potentiometers, Capacitive and Inductive Sensors, Linear Voltage Differential Transformers (LVDT), Optical Encoders, and Ultrasonic Range Finders.

- Humidity Sensors

Relative humidity is the moisture content of the air which can cause pressure variations in the air or can cause variation in the electrical properties of materials. Examples include; Resistive Hygrometer Sensors and Capacitive Hygrometer Sensors.

- Fluid Flow Sensors

Many Industrial processes involve fluids and so there is a need to measure and control their flow. A wide range of transducers and techniques are commonly used to measure fluid flow rates. Examples include; Head meters, Rotational Flowmeters, and Ultrasonic Flowmeters.

- Fibre Optic Sensors

These are a new class of sensor which tend to be immune from Electro-Magnetic Interference (EMI) and measure amplitude, phase or polarization of light. The transducer is constructed so that one or more of these parameters varies with the physical quantity of interest.

- Micro-Electro-Mechanical Systems (MEMS)

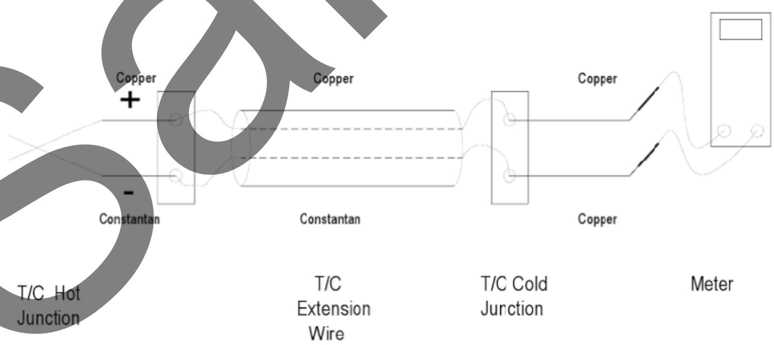
These are small electromechanical devices made using semiconductor integrated circuits.

- Smart Sensors

Smart Sensors cover a wide variety of devices which could range from a traditional transducer that simply contains its own signal conditioning circuitry to a device that can calibrate itself, acquire data, analyse it, and transmit the results over a network to a remote computer. An emerging class of smart sensors is defined by the family of IEEE 1451 standards, which are designed to simplify the task of establishing communications between transducers and networks.

1.1.3 Thermocouples

Thermocouples convert a temperature into a small DC voltage or current. They consist of two dissimilar metal wires in contact with two or more junctions. The output voltage varies linearly and proportionately with the temperature difference between the junctions.



Thermocouple Schematic

The chief advantages of thermocouples are their linearity, their ruggedness, and their ability to operate over a very large temperature range. Including temperatures of over $1000^{o}C$.

The chief disadvantages include low output voltage (especially at low temperatures), low sensitivity (typically being only 5mV for a $100^{o}C$ temperature change), susceptibility to noise (externally induced and caused internally by wire imperfections and impurities), and the need for a reference junction (at a known temperature) for calibration.

When several thermocouples, made of the same materials, are combined in series, they are called a thermopile. The output voltage of a thermopile consists of the sum of all the individual thermocouple outputs, resulting in increased sensitivity but all the reference junctions need to be kept at the same temperature.

1.1.4 Thermocouples; Principle of Operation

A thermocouple is formed by the junction of two dissimilar metals. This junction creates an open-circuit thermoelectric voltage and is called the Seebeck effect. The **Seebeck effect** is the conversion of heat directly into electricity at the junction of different types of metal. It is named after the German physicist Thomas Johann Seebeck, who in 1821 discovered that a compass needle would be deflected by a closed loop formed by two different metals joined in two places, with a temperature difference between the joints. This was because the electron energy levels in each metal shifted differently and a potential difference between the junctions created an electrical current and therefore a magnetic field around the wires. Seebeck did not recognize there was an electric current involved, and so he called the phenomenon "thermomagnetic effect." Danish physicist Hans Christian Ørsted rectified the oversight and coined the term "thermoelectricity".

Various types of thermocouples exist and some are listed below. A thermocouple's output voltage increases almost linearly with the temperature difference over a range of temperatures.

Type	Elements +/-	Seebeck coefficient (μV/°C)	Range (°C)	Range (mV)
E	Chromel/constantan	58.70 at 0°C	-270 to 1,000	-9.835 to 76.358
J	Iron/constantan	50.37 at 0°C	-210 to 1,200	-8.096 to 69.536
K	Chromel/alumel	39.48 at 0°C	-270 to 1,372	-8.096 to 69.536
R	Pt (10%) – Rh/Pt	10.19 at 600°C	-50 to 1,768	-0.236 to 18.698
T	Copper/constantan	38.74 at 0°C	-270 to 400	-6.258 to 20.869
S	Pt (13%) – Rh/Pt	11.35 at 600°C	-50 to 1,768	-0.226 to 21.108

1.1.5 Signal Characteristics

One of the common aspects of all measurement systems is that they are required to transmit signals (information) from one place to another, from one instrument to another. The way that this is achieved rests very much on the type of signal (information) that is required to be conveyed. Here we will consider some of the many signal (information) types that measurement systems may have to contend with and some of the features of those signal (information) types.

Generally, signals (information) at the measurement side of the measurement system are analog signals and can be characterised as being either Direct Current (Non-Alternating) Signals or Alternating Current (Alternating Signals), the latter being further characterised as Low and High Frequency.