



CIS009-2, MECHATRONICS SENSORS & SIGNAL CONDITIONING

David Goodwin

Department of Computer Science and Technology
University of Bedfordshire

29th November 2012



Outline

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

1 Sensors

Position sensor

Potentiometer

Linear variable differential
transformer

Proximity Sensors

Rotary Encoders

Temperature Sensors

Thermostat

Thermistors

Resistance Temperature
Detector

Thermocouple

Optical

LDR

Photodiode

Phototransistor



Mechatronics

David Goodwin

Sensors

3

- Position sensor
- Potentiometer
- LVDT
- Proximity Sensors
- Rotary Encoders
- Heat
- Thermostat
- Thermistors
- RTD
- Thermocouple
- Optical
- LDR
- Photodiode
- Phototransistor

SENSORS



Sensors

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

4

- Sensors are “Input” devices which convert one type of energy or quantity into an electrical analog signal.
- Detect Position, Temperature, Light, Pressure and Velocity.
- Some sensors called “Self-generating” sensors generate output voltages or currents relative to the quantity being measured, such as thermocouples and photo-voltaic solar cells and their output bandwidth equals that of the quantity being measured.
- Some sensors called “Modulating” sensors change their physical properties, such as inductance or resistance relative to the quantity being measured such as inductive sensors, LDR’s and potentiometers and need to be biased to provide an output voltage or current.
- Not all sensors produce a straight linear output and linearization circuitry may be required.



Signal Conditioning

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

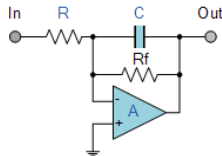
Photodiode

Phototransistor

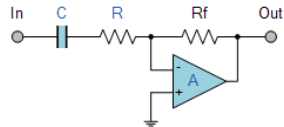
Department of
Computer Science and
Technology
University of
Bedfordshire

5

- Op-amps can be used to provide amplification of signals
- Very small analogue signal voltages produced by sensors (few milli-volts)
- Voltage gain up to 10,000 and a current gain up to 1,000,000 with the amplification of the signal being linear with the output signal being an exact reproduction of the input, just changed in amplitude.
- Generally some form of amplification, impedance matching, isolation between the input and output or filtering may be required before the signal can be used and this is conveniently performed by Operational Amplifiers.



Low Pass Active Filter



High Pass Active Filter

31



Position sensors

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

6

- A position sensor is any device that permits position measurement.
- It can either be an absolute position sensor or a relative one (displacement sensor).
- Position sensors can be linear, angular, or multi-axis.



Potentiometer

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

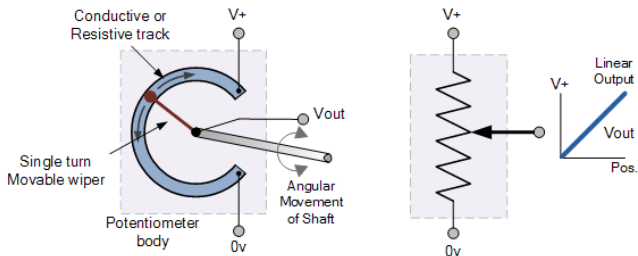
Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

7

- inexpensive and easy to use position sensor.
- either angular (rotational) or linear (slider type) in its movement
- resistance value between the wiper/slider and the two end connections changes giving an electrical signal output
- resistance is proportional to position.
- can be used as position feedback devices in order to create “closed loop” control, such as in a servomechanism.



31



Potentiometer

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

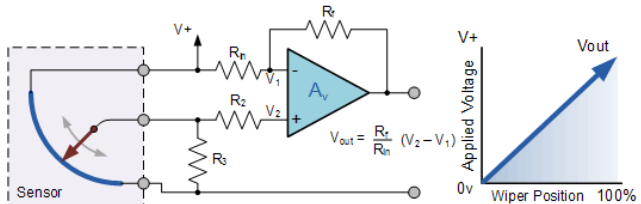
Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

8

- DC reference voltage is applied across the two outer fixed connections. The output voltage signal is taken from the wiper terminal of the sliding contact as shown below.
- configuration below produces a potential divider type circuit.
 - apply a 10v across the resistive element of the potentiometer the maximum output voltage 10 volts, with the minimum of 0 volts.
 - Then the potentiometer wiper will vary the output signal from 0 to 10 volts, with 5 volts indicating that the wiper or slider is at its half-way or centre position.



31



Linear variable differential transformer

LVDT

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

9

31

- One type of positional sensor that does not suffer from mechanical wear problems is the “Linear Variable Differential Transformer”.
- an inductive type position sensor which works on the same principle as the AC transformer that is used to measure movement.
- It is a very accurate device for measuring linear displacement and whose output is proportional to the position of its moveable core.
- consists of three coils wound on a hollow tube former, one forming the primary coil and the other two coils forming identical secondaries connected electrically together in series but 180° out of phase either side of the primary coil.
- A moveable soft iron ferromagnetic core is connected to the object being measured
- A small AC reference voltage is applied to the primary winding which induces an EMF signal into the two adjacent secondary windings.



Linear variable differential transformer LVDT

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

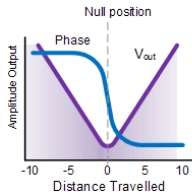
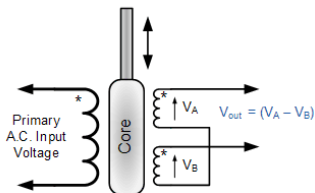
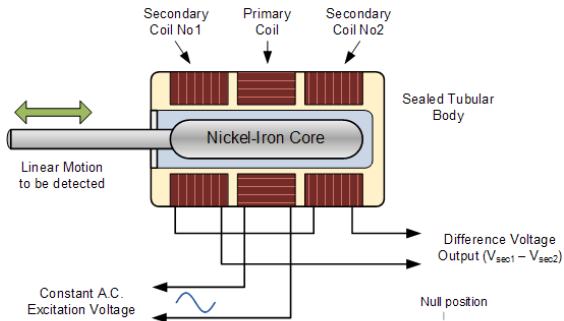
LDR

Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

10



31



Linear variable differential transformer

LVDT

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

11

- in the centre of the tube and the windings the two induced emf's in the secondary windings cancel each other out so the resultant output voltage is zero.
- As the core is displaced slightly to one side the induced voltage in one of the secondaries will become greater than the other and an output will be produced.
- The polarity of the output signal depends upon the direction and displacement of the moving core.
- The result is a differential voltage output which varies linearly with the core's position.
- typical application as a pressure transducer.
- Advantages of the LVDT
 - linearity; that is its voltage output to displacement is excellent; very good accuracy; good resolution; high sensitivity as well as frictionless operation. They are also sealed for use in hostile environments.

31



Proximity sensors

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

12

- A proximity sensor is a sensor able to detect the presence of nearby objects without any physical contact.
- Often emits an electromagnetic field or a beam of electromagnetic radiation, and looks for changes in the field or return signal.
- Different proximity sensor targets demand different sensors. For example,
 - capacitive photoelectric sensor might be suitable for a plastic target
 - inductive proximity sensor always requires a metal target.
- A proximity sensor adjusted to a very short range is often used as a touch switch.

31



Proximity Sensors

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

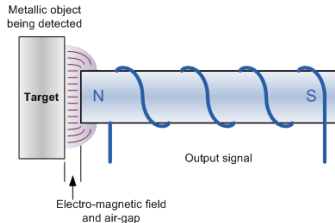
Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

13

- Proximity sensors do not actually measure displacement or angular rotation they are mainly used to detect the presence of an object within a close proximity.
- Non-contact devices that use a magnetic field for detection.
- A coil is wound around an iron core within an electromagnetic field to form an inductive loop.
- When a ferromagnetic material is placed within the “eddy current field” generated around the inductive sensor the inductance of the coil changes significantly.



31



Proximity Sensors

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

14

- Ideal for use in dirty or wet environments.
- The range of proximity sensors is very small, typically 0.1mm to 12mm.
- One main disadvantage of these types of sensors is that they are “Omni-directional” (can sense a metallic object either above, below or to the side of it).
- Do not detect non-metallic objects
 - Although Capacitive Proximity Sensors (suitable for non-metallic target) and Ultrasonic Proximity Sensors (uses sound) are available.



Rotary Encoders

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

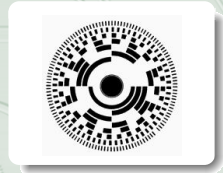
LDR

Photodiode

Phototransistor

15

- Rotary Encoders resemble potentiometers mentioned earlier but are non-contact optical devices used for converting the angular position of a rotating shaft into an analogue or digital data code.
- Light source is passed through a rotating high-resolution encoded disk that contains the required code patterns.
- Photo detectors scan the disk as it rotates and information in a stream of binary output pulses is fed to counters or controllers which determine the actual angular position of the shaft.





Rotary Encoders

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

16

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

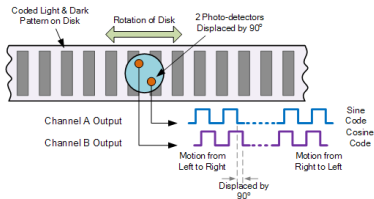
Photodiode

Phototransistor

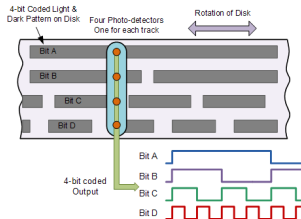
Department of
Computer Science and
Technology
University of
Bedfordshire

31

Simple Incremental Encoder



Absolute Position Encoder





Temperature Sensors

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

17

- Temperature sensors vary from simple ON/OFF thermostatic devices to highly sensitive semiconductor types that can control complex process control plants.
- Moving molecules/atoms produces heat (kinetic energy) and the greater the movement, the more heat that is generated.
- Temperature sensors consist of two basic physical types:

Contact Temperature Sensors Required to be in physical contact with the object being sensed and use conduction to monitor changes in temperature. They can be used to detect solids, liquids or gases over a wide range of temperatures.

Non-contact Temperature Sensors Use convection and radiation to monitor changes in temperature. They can be used to detect liquids and gases that emit radiant energy as heat rises and cold settles to the bottom in convection currents or detect the radiant energy being transmitted from an object in the form of infra-red radiation (the sun).

31



Thermostat

Bi-metallic strip

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

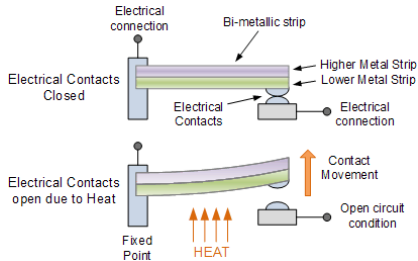
Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

18

- The Thermostat is a contact type electro-mechanical temperature sensor or switch,
- consists of two different metals such as nickel, copper, tungsten or aluminium etc, that are bonded together to form a Bi-metallic strip.
- The different linear expansion rates of the two dissimilar metals produces a mechanical bending movement when the strip is subjected to heat.



31



Thermistors

Thermally sensitive resistor

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

19

- The Thermistor is a *thermally sensitive resistor*, a resistor which changes its resistance with changes in temperature.
- Thermistors are generally made from ceramic type semiconductor materials such as oxides of nickel, manganese or cobalt coated in glass which makes them easily damaged.
- Their main advantage over snap-action types is their speed of response to any changes in temperature, accuracy and repeatability.
- Most types of thermistor's resistance value goes **DOWN** with an increase in the temperature.
- Thermistors are rated by their resistive value at room temperature (usually at 25°C), their time constant (the time to react to the temperature change) and their power rating with respect to the current flowing through them.
- For sensing purposes resistances in the kilo-ohms are generally used.

31



Thermistors

Thermally sensitive resistor

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

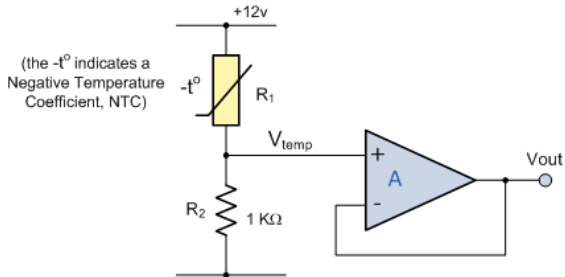
Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

- Thermistors are passive resistive devices which means we need to pass a current through it to produce a measurable voltage output. Then thermistors are generally connected in series with a suitable biasing resistor to form a potential divider network and the choice of resistor gives a voltage output at some pre-determined temperature point or value.

20



31



Thermistors

Thermally sensitive resistor

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

21

- Thermistors are non-linear devices and their standard resistance values at room temperature is different between different thermistors.
- have an exponential change with temperature which can be used to calculate its resistance for any given temperature point.
- However, when used with a series resistor such as in a voltage divider network or Whetstone Bridge type arrangement, the current obtained in response to a voltage applied to the divider/bridge network is linear with temperature.
- Then, the output voltage across the resistor becomes linear with temperature.



Electrical resistance temperature sensor

RTD

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

22

- The Resistance Temperature Detector (RTD) is a precision temperature sensors made from high-purity conducting metals such as platinum, copper or nickel wound into a coil and whose electrical resistance changes as a function of temperature, similar to that of the thermistor.
- Unlike the thermistor their output is extremely linear producing very accurate measurements of temperature.
- However, they have poor sensitivity, that is a change in temperature only produces a very small output change for example, 1Ω per 1°C .
- Like the thermistor, RTD's are passive resistive devices and by passing a constant current through the temperature sensor it is possible to obtain an output voltage that increases linearly with temperature.
- The RTD is usually connected into a Whetstone Bridge network which has additional connecting wires for lead-compensation and/or connection to a constant current source to avoid errors from self heat of the resistive wires.

31



Thermocouple

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

23

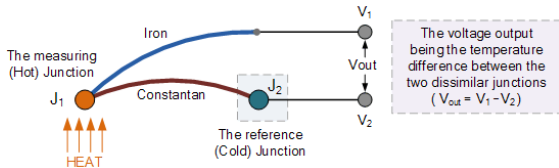
Optical

LDR

Photodiode

Phototransistor

- Thermocouples have the widest temperature range of all temperature sensors, from below $-200\text{ }^{\circ}\text{C}$ to over $2000\text{ }^{\circ}\text{C}$.
- Thermocouples are thermoelectric sensors that consists of two junctions of dissimilar metals, such as copper and constantan that are welded or crimped together.
- One junction is kept at a constant temperature called the reference (Cold) junction, while the other the measuring (Hot) junction.
- When the two junctions are at different temperatures, a voltage is developed across the junction which is used to measure the temperature sensor as shown below.





Thermocouple

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

24

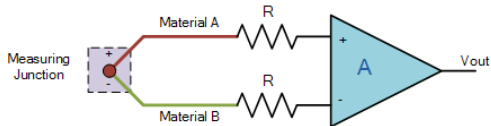
Optical

LDR

Photodiode

Phototransistor

- When fused together the junction of the two dissimilar metals produces a “thermo-electric” effect which gives a constant potential difference of a few millivolts (mV) between them (Seebeck effect).
- If both the junctions are at the same temperature the potential difference across the two junctions is zero.
- When the junctions are connected within a circuit and are both at different temperatures a voltage output will be detected relative to the difference in temperature between the two junctions.





Light Sensors

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

Photodiode

Phototransistor

25

- Light Sensors generate an output signal indicating the intensity of light by measuring the radiant energy that exists in a very narrow range of frequencies (light).
- The light sensor is a passive devices that convert “light energy” into an electrical signal output.

Photo-conductive Cells Vary their electrical resistance when subjected to light. Photoconductivity results from light hitting a semiconductor material which controls the current flow through it. More light increases the current for a given applied voltage.

Photo-junction Devices Mainly true semiconductor devices such as the photodiode or phototransistor which use light to control the flow of electrons and holes across their PN-junction. Photojunction devices are specifically designed for detector application and light penetration with their spectral response tuned to the wavelength of incident light.



Light Dependent Resistor

LDR

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

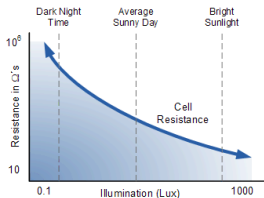
LDR

Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

- Light Dependent Resistor (LDR) is made from exposed semiconductor material that changes resistance from several thousand Ohms in the dark to only a few hundred Ohms when light falls upon it.
- Photoresistive cells have a long response time requiring many seconds to respond to a change in the light intensity.





Light Dependent Resistor

LDR

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

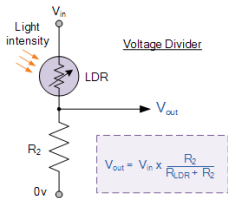
Optical

LDR

Photodiode

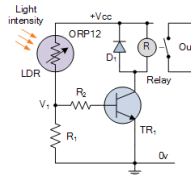
Phototransistor

27



- Connecting a light dependant resistor in series with a standard resistor like this across a single DC supply voltage has one major advantage, a different voltage will appear at their junction for different levels of light.
- The amount of voltage drop across series resistor, R_2 is determined by the resistive value of the light dependant resistor.

- No light present, resistance of LDR is very high, zero base bias is applied to the transistor TR1 and the relay is “OFF”.
- Light level increases, resistance of LDR decreases, causing the base bias voltage at V1 to rise.
- At some point determined by the potential divider network, the base bias voltage is high enough to turn the transistor TR1 “ON” and activate the relay.



31



Light Dependent Resistor

Light Level Sensing Circuit

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

LDR

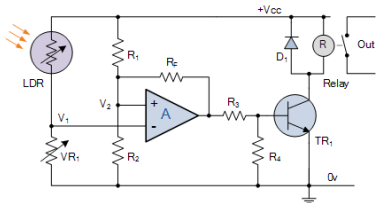
Photodiode

Phototransistor

Department of
Computer Science and
Technology
University of
Bedfordshire

- The operational amplifier is configured as a Differential Amplifier.
- As with the previous circuit the output from the operational amplifier is used to control a relay.
- When the light level sensed by the LDR falls below a reference the output from the op-amp changes state activating the relay and switching the connected load.
- The hysteresis of the two switching points is set by the feedback resistor R_f can be chosen to give any suitable voltage gain of the amplifier.

28



31



Photodiode

Photo-diode Amplifier Circuit

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

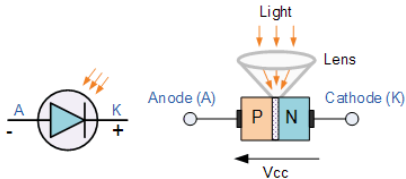
LDR

Photodiode

Phototransistor

- Photodiode light sensor is similar to that of a conventional PN-junction diode except that the diodes outer casing is either transparent or has a clear lens to focus the light onto the PN junction for increased sensitivity.
- When light falls upon the junction more hole/electron pairs are formed and the leakage current increases. This leakage current increases as the illumination of the junction increases.

29



31



Photodiode

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

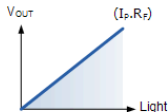
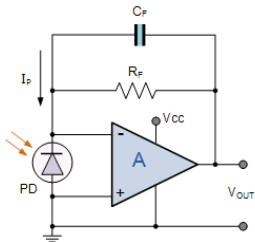
Optical

LDR

Photodiode

Phototransistor

- Photo-current-to-voltage convertor circuit using an operational amplifier as the amplifying device.
- The output voltage (V_{out}) is given as $V_{out} = I_p \times R_f$ and which is proportional to the light intensity characteristics of the photodiode.
- This “zero-bias” op-amp configuration gives a high impedance loading to the photodiode resulting in less influence by dark current and a wider linear range of the photocurrent relative to the radiant light intensity.



30

31



Phototransistor

Mechatronics

David Goodwin

Sensors

Position sensor

Potentiometer

LVDT

Proximity Sensors

Rotary Encoders

Heat

Thermostat

Thermistors

RTD

Thermocouple

Optical

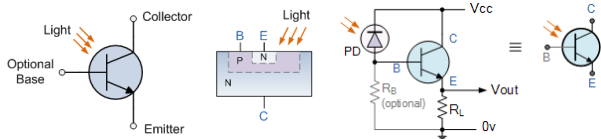
LDR

Photodiode

Phototransistor

- An alternative photo-junction device to the photodiode is the Phototransistor which is basically a photodiode with amplification.
- In the NPN transistor the collector is biased positively with respect to the emitter so that the base/collector junction is reverse biased.
- When light falls on the base more electron/hole pairs are formed in this region and the current produced by this action is amplified by the transistor.
- The overall sensitivity is a function of collector current and can be controlled by connecting a resistance between the base and the emitter.

31



31