Electro-optical and Radio Acoustic Transducers

Chapter 4

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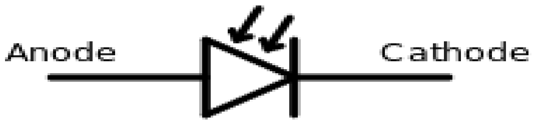
ELECTRO-OPTICAL AND RADIO ACOUSTIC TRANSDUCERS

PHOTODIODE:

A photodiode is a semiconductor device that converts light into current. The current is generated when photons are absorbed in the photodiode. A small amount of current is also produced when no light is present. Photodiodes may contain optical filters, built-in lenses, and may have large or small surface areas. Photodiodes usually have a slower response time as its surface area increases. The common, traditional solar cell used to generate electric solar power is a large area photodiode.

Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fiber connection to allow light to reach the sensitive part of the device. Many diodes designed for use specifically as a photodiode use a PIN junction rather than a p-n junction, to increase the speed of response. A photodiode is designed to operate in reverse bias.[1]

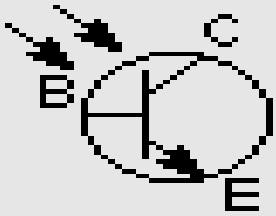


Principle of operation

A photodiode is a p-n junction or PIN structure. When a photon of sufficient energy strikes the diode, it creates an electron, hole pair. This mechanism is also known as the inner photoelectric effect. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in electric field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced. The total current through the photodiode is the sum of the dark current (current that is generated in the absence of light) and the photocurrent, so the dark current must be minimized to maximize the sensitivity of the device.[2]

PHOTO TRANSISTOR:

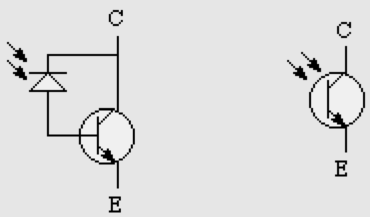
Phototransistors:



Like diodes, all transistors are light-sensitive. Phototransistors are designed specifically to take advantage of this fact. The most-common variant is an NPN bipolar transistor with an exposed base region. Here, light striking the base replaces what would ordinarily be voltage applied to the base -- so, a phototransistor amplifies variations in the light striking it. Note that phototransistors may or may not have a base lead (if they do, the base lead allows you to bias the phototransistor's light response.

For phototransistor selection and comparison information, see the phototransistor section of the BEAM Reference Library's BEAM Pieces collection.

Note that photodiodes also can provide a similar function, although with much lower gain (i.e., photodiodes allow much less current to flow than do phototransistors). You can use this diagram to help you see the difference (both circuits are equivalent):



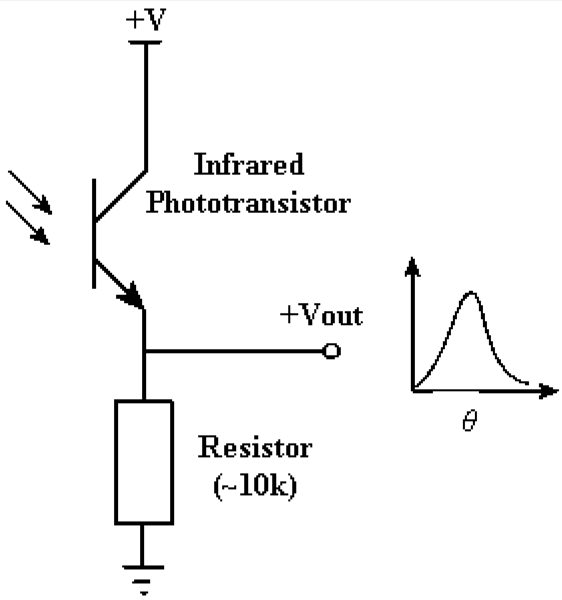


PHOTO VOLTAIC CELL:

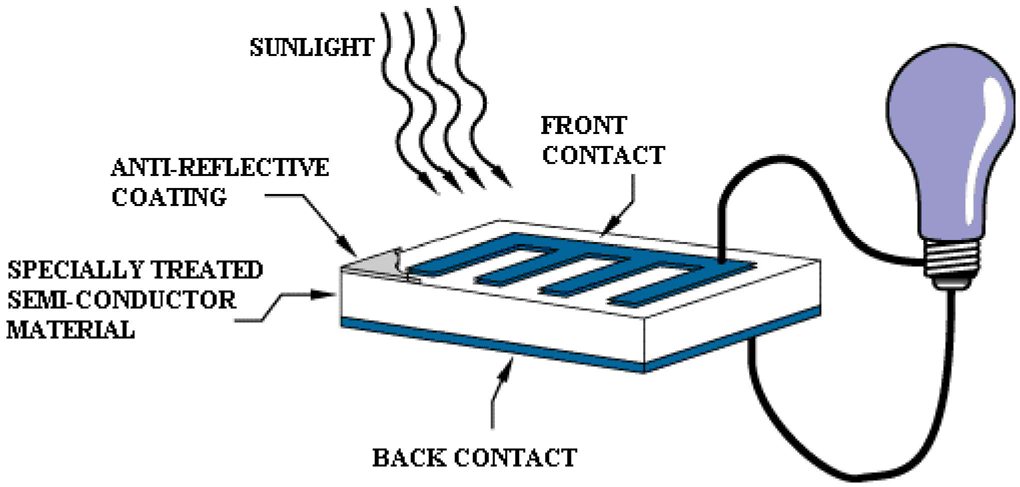
Photovoltaic Cells: Converting Photons to Electrons

The solar cells that you see on calculators and satellites are also called photovoltaic (PV) cells, which as the name implies (photo meaning "light" and voltaic meaning "electricity"), convert sunlight directly into electricity. A module is a group of cells connected electrically and packaged into a frame (more commonly known as a solar panel), which can then be grouped into larger solar arrays, like the one operating at Nell is Air Force Base in Nevada.

Photovoltaic cells are made of special materials called semiconductors such as silicon, which is currently used most commonly. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely.

PV cells also all have one or more electric field that acts to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off for external use, say, to power a calculator. This current, together with the cell's voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce.

That's the basic process, but there's really much more to it. On the next page, let's take a deeper look into one example of a PV cell: the single-crystal silicon cell.



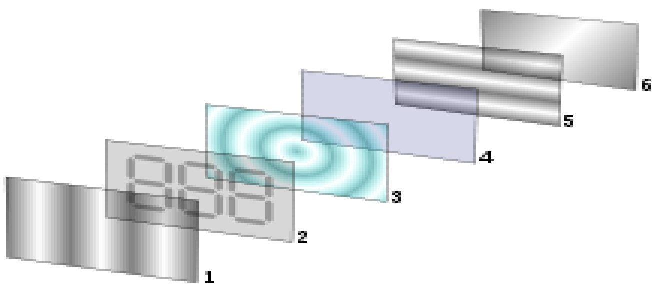
LCD:

liquid-crystal display (LCD) is a flat panel display, electronic visual display, or video display that uses the light modulating properties of liquid crystals. Liquid crystals do not emit light directly.

LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images which can be displayed or hidden, such as preset words, digits, and 7-segment displays as in a digital clock. They use the same basic technology, except that arbitrary images are made up of a large number of small pixels, while other displays have larger elements.

LCDs are used in a wide range of applications including computer monitors, televisions, instrument panels, aircraft cockpit displays, and signage. They are common in consumer devices such as video players, gaming devices, clocks, watches, calculators, and telephones, and have replaced cathode ray tube (CRT) displays in most applications. They are available in a wider range of screen sizes than CRT and plasma displays, and since they do not use phosphors, they do not suffer image burn-in. LCDs are, however, susceptible to image persistence.

The LCD screen is more energy efficient and can be disposed of more safely than a CRT. Its low electrical power consumption enables it to be used in battery-powered electronic equipment. It is an electronically modulated optical device made up of any number of segments filled with liquid crystals and arrayed in front of a light source (backlight) or reflector to produce images in color or monochrome. Liquid crystals were first discovered in 1888.[2] By 2008, annual sales of televisions with LCD screens exceeded sales of CRT units worldwide, and the CRT became obsolete for most purposes.



Reflective twisted nematic liquid crystal display.

1. Polarizing filter film with a vertical axis to polarize light as it enters.
2. Glass substrate with ITO electrodes. The shapes of these electrodes will determine the shapes that will appear when the LCD is turned ON. Vertical ridges etched on the surface are smooth.
3. Twisted nematic liquid crystal.

4. Glass substrate with common electrode film (ITO) with horizontal ridges to line up with the horizontal filter.
5. Polarizing filter film with a horizontal axis to block/pass light.
6. Reflective surface to send light back to viewer. (In a backlit LCD, this layer is replaced with a light source.)

LED

light-emitting diode (LED) is a two-lead semiconductor light source that resembles a basic pn-junction diode, except that an LED also emits light. When an LED's anode lead has a voltage that is more positive than its cathode lead by at least the LED's forward voltage drop, current flows. Electrons are able to recombine with holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

An LED is often small in area (less than 1 mm^2), and integrated optical components may be used to shape its radiation pattern.

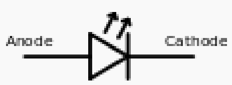
Appearing as practical electronic components in 1962, the earliest LEDs emitted low-intensity infrared light. Infrared LEDs are still frequently used as transmitting elements in remote-control circuits, such as those in remote controls for a wide variety of consumer electronics. The first visible-light LEDs were also of low intensity, and limited to red. Modern LEDs are available across the visible, ultraviolet, and infrared wavelengths, with very high brightness.

Early LEDs were often used as indicator lamps for electronic devices, replacing small incandescent bulbs. They were soon packaged into numeric readouts in the form of seven-segment displays, and were commonly seen in digital clocks.

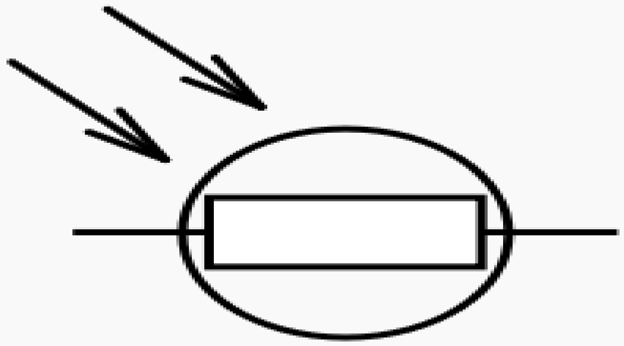
Recent developments in LEDs permit them to be used in environmental and task lighting. LEDs have many advantages over incandescent light sources including lower energy consumption, longer lifetime, improved physical robustness, smaller size, and faster switching. Light-emitting diodes are now used in applications as diverse as aviation lighting, automotive headlamps, advertising, general lighting, traffic signals, and camera flashes. However, LEDs powerful enough for room lighting are still relatively expensive, and require more precise current and heat management than compact fluorescent lamp sources of comparable output.

LEDs have allowed new text, video displays, and sensors to be developed, while their high switching rates are also useful in advanced communications technology.

Electronic symbol



Photoresistor(LDR):



symbol for a photoresistor

A photoresistor or light-dependent resistor (LDR) or photocell is a light-controlled variable resistor. The resistance of a photoresistor decreases with increasing incident light intensity; in other words, it exhibits photoconductivity. A photoresistor can be applied in light-sensitive detector circuits, and light- and dark-activated switching circuits.

A photoresistor is made of a high resistance semiconductor. In the dark, a photoresistor can have a resistance as high as a few megaohms (MΩ), while in the light, a photoresistor can have a resistance as low as a few hundred ohms. If incident light on a photoresistor exceeds a certain frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electrons (and their hole partners) conduct electricity, thereby lowering resistance. The resistance range and sensitivity of a photoresistor can substantially differ among dissimilar devices. Moreover, unique photoresistors may react substantially differently to photons within certain wavelength bands.

A photoelectric device can be either intrinsic or extrinsic. An intrinsic semiconductor has its own charge carriers and is not an efficient semiconductor, for example, silicon. In intrinsic devices the only available electrons are in the valence band, and hence the photon must have enough energy to excite the electron across the entire bandgap. Extrinsic devices have impurities, also called dopants, added whose ground state energy is closer to the conduction band; since the electrons do not have as far to jump, lower energy photons (that is, longer wavelengths and lower frequencies) are sufficient to trigger the device. If a sample of silicon has some of its atoms replaced by phosphorus atoms (impurities), there will be extra electrons available for conduction.

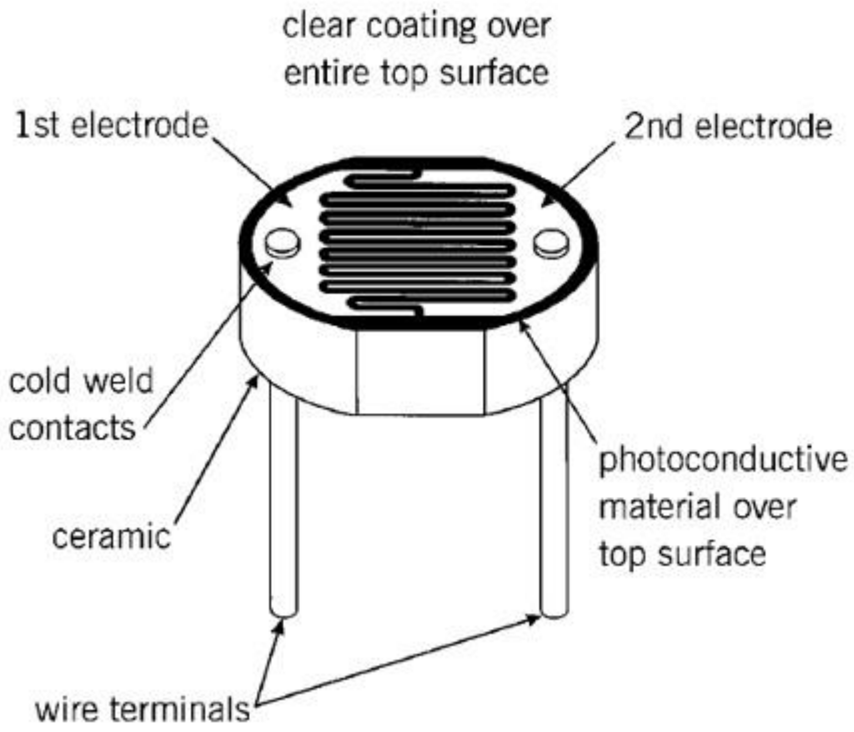


Figure 3
Typical Construction of a Plastic Coated Photocell

IR EMITTER:

An infrared emitter, or IR emitter, is a source of light energy in the infrared spectrum. It is a light emitting diode (LED) that is used in order to transmit infrared signals from a remote control. In general, the more they are in quantity and the better the emitters are, the stronger and wider the resulting signal is. A remote with strong emitters can often be used without directly pointing at the desired device. Infrared emitters are also partly responsible for limits on the range of frequencies that can be controlled. An IR emitter generates infrared light that transmits information and commands from one device to another. Typically one device receives the signal then passes the infrared (IR) signal through the emitter to another device.

Types of Infrared Emitters

There are several different kinds of infrared emitters. At Future Electronics we stock many of the most common types categorized by wavelength, angle of half intensity, intensity, forward voltage, packaging type and forward (drive) current. The parametric filters on our website can help refine your search results depending on the required specifications.

The most common sizes for wavelength are 875 nm, 880 nm, 890 nm, 940 nm and 950 nm. We also carry infrared emitters with wavelength up to 940 m. Forward voltage can range from 800 mV to 5 kV, with the most common sizes being 1.2 V, 1.5 V and 1.7 V.

PHOTO EMMISIVE CELL:

Operating principles

Phototubes operate according to the photoelectric effect: Incoming photons strike a photocathode, generating electrons, which are attracted to an anode. Thus current flow is dependent on the frequency and intensity of incoming photons. Unlike photomultiplier tubes, no amplification takes place, so the current that flows through the device is typically of the order of a few microamperes.[1]

The light wavelength range over which the device is sensitive depends on the material used for the photoemissive cathode. A caesium-antimony cathode gives a device that is very sensitive in the violet to ultra-violet region with sensitivity falling off to blindness to red light. Caesium on oxidised silver gives a cathode that is most sensitive to infra-red to red light, falling off towards blue, where the sensitivity is low but not zero.[2]

Vacuum devices have a near constant anode current for a given level of illumination relative to anode voltage. Gas filled devices are more sensitive but the frequency response to modulated illumination falls off at lower frequencies compared to the vacuum devices. The frequency response of vacuum devices is generally limited by the transit time of the electrons from cathode to anode.

A category of photoelectric tubes in which light falling on a sensitized cathode causes current to flow to an anode. The current may be enhanced at the expense of linearity by using a gas-filled envelope and operating above the ionization potential of the gas. Photomultiplier tubes are photoemissive.

The photo emissive cell consists of a glass envelope with a vacuum inside.

The envelope also contains a light sensitive cathode and an anode.

When light strikes the cathode negative electrons are emitted and are attracted by the positive anode.

The value of this current is proportional to the intensity of light falling on the cathode.

The PEC can be used as part of a potential divider circuit.

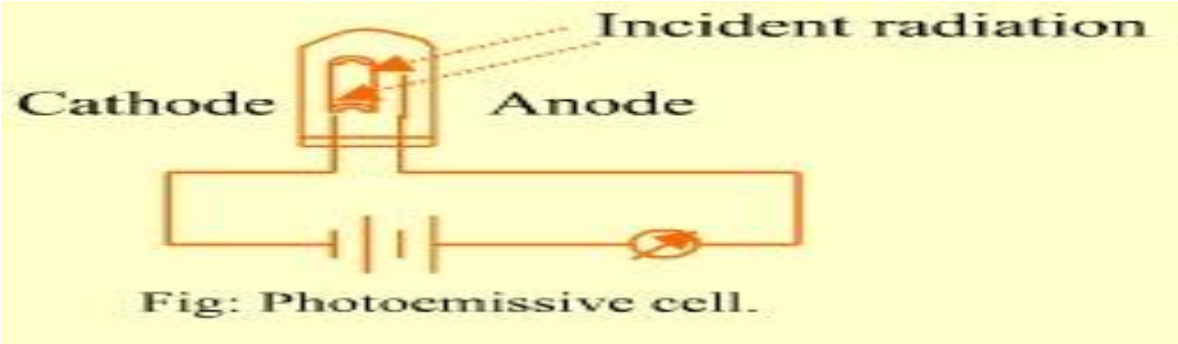


Fig: Photoemissive cell.

LASER:

A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The term "laser" originated as an acronym for "light amplification by stimulated emission of radiation".[1][2] Lasers differ from other sources of light because they emit light coherently. Spatial coherence allows a laser to be focused to a tight spot, enabling applications like laser cutting and lithography. Spatial coherence also allows a laser beam to stay narrow over long distances (collimation), enabling applications such as laser pointers. Lasers can also have high temporal coherence which allows them to have a very narrow spectrum, i.e., they only emit a single color of light. Temporal coherence can be used to produce pulses of light—as short as a fem to second.

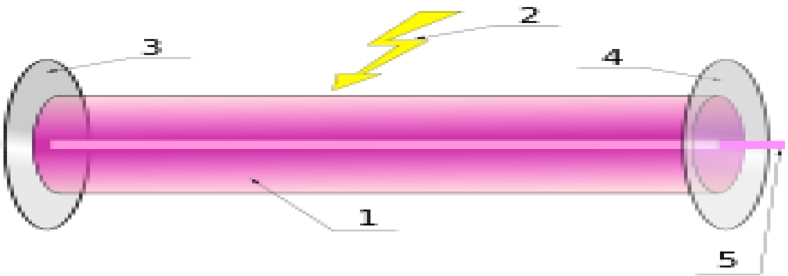
Lasers have many important applications. They are used in common consumer devices such as Optical disk drives, laser printers, and barcode scanners. They are used in medicine for laser surgery and various skin treatments, and in industry for cutting and welding materials. They are used in military and law enforcement devices for marking targets and measuring range and speed. Laser lighting displays use laser light as an entertainment medium. Lasers also have many important applications in scientific research.

Fundamentals

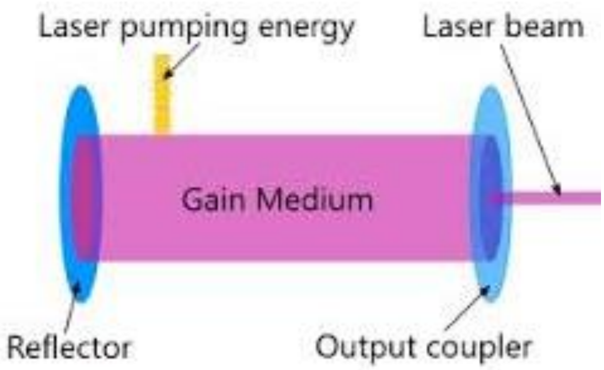
Lasers are distinguished from other light sources by their coherence. Spatial coherence is typically expressed through the output being a narrow beam which is diffraction-limited, often a so-called "pencil beam." Laser beams can be focused to very tiny spots, achieving a very high irradiance, or they can be launched into beams of very low divergence in order to concentrate their power at a large distance.

Temporal (or longitudinal) coherence implies a polarized wave at a single frequency whose phase is correlated over a relatively large distance (the coherence length) along the beam.[3] A beam produced by a thermal or other incoherent light source has an instantaneous amplitude and phase which vary randomly with respect to time and position, and thus a very short coherence length.

Most so-called "single wavelength" lasers actually produce radiation in several *modes* having slightly different frequencies (wavelengths), often not in a single polarization. And although temporal coherence implies monochromaticity, there are even lasers that emit a broad spectrum of light, or emit different wavelengths of light simultaneously. There are some lasers which are not single spatial mode and consequently their light beams diverge more than required by the diffraction limit. However all such devices are classified as "lasers" based on their method of producing that light: stimulated emission. Lasers are employed in applications where light of the required spatial or temporal coherence could not be produced using simpler technologies.



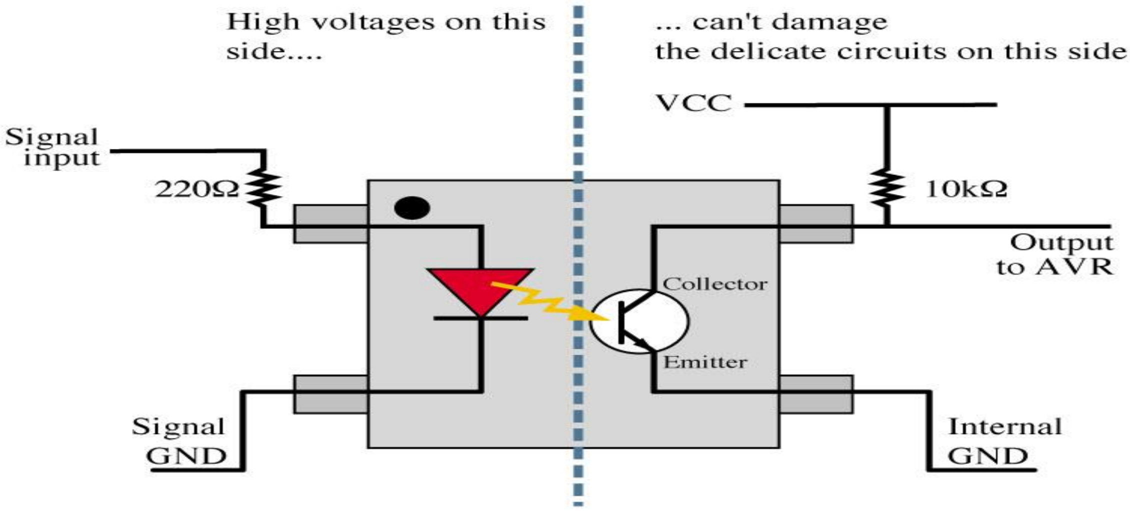
Components of a typical laser:
1. Gain medium
2. Laser pumping energy
3. High reflector
4. Output coupler
5. Laser beam



OPTOCOUPLER:

In electronics, an opto-isolator, also called an optocoupler, photocoupler, or optical isolator, is a component that transfers electrical signals between two isolated circuits by using light.[1] Opto-isolators prevent high voltages from affecting the system receiving the signal.[2]Commercially available opto-isolators withstand input-to-output voltages up to 10 kV[3] and voltage transients with speeds up to 10 kV/μs.[4]

A common type of opto-isolator consists of an LED and a phototransistor in the same opaque package. Other types of source-sensor combinations include LED-photodiode, LED-LASCR, and lamp-photoresistor pairs. Usually opto-isolators transfer digital (on-off) signals, but some techniques allow them to be used with analog signals.



Operation

An opto-isolator contains a source (emitter) of light, almost always a near infrared light-emitting diode (LED), that converts electrical input signal into light, a closed optical channel (also called dielectrical channel, and a photosensor, which detects incoming light and either generates electric energy directly, or modulates electric current flowing from an external power supply. opto-isolator can transfer the light signal not transfer the electrical signal . The sensor can be a photoresistor, a photodiode, a phototransistor, a silicon-controlled rectifier (SCR) or a triac. Because LEDs can sense light in addition to emitting it, construction of symmetrical, bidirectional opto-isolators is possible. An optocoupledsolid state relay contains a photodiode opto-isolator which drives a power switch, usually a complementary pair of MOSFETs. A slotted optical switch contains a source of light and a sensor, but its optical channel is open, allowing modulation of light by external objects obstructing the path of light or reflecting light into the sensor.

Digital Encoder

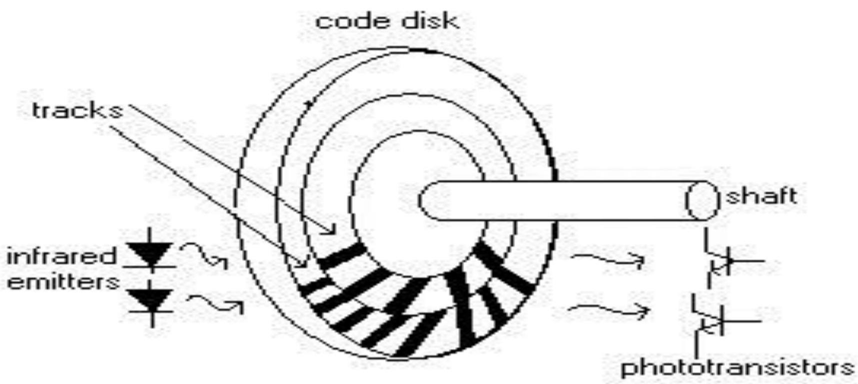


Fig 1. A rotary optical encoder

Digital Encoder is a Digital Device opposite of the Digital Decoder . A simple encoder circuit can receive a single active input out of 2^n input lines generate a binary code on *n*parallel output lines.

For example a single bit 4 to 2 encoder takes in 4 bits and outputs 2 bits. The illustrated gate level example implements the simple encoder defined by the truth table, but it MUST be understood that for all the non-explicitly defined input combinations (i.e. inputs containing 0, 2, 3, or 4 bits) the outputs are treated as don't cares. Thus this implementation is useless as a priority encoder and only useful as a simple encoder if some previous circuit guarantees that there is one and only one bit high in the input or if it is understood that non-single-active-inputs will produce garbage encodings.

OR

A digital optical encoder is a device that converts motion into a sequence of digital pulses. By counting a single bit or by decoding a set of bits, the pulses can be converted to relative or absolute position measurements. Encoders have both linear and rotary configurations, but the most common type is rotary. Rotary encoders are manufactured in two basic forms: the absolute encoder where a unique digital word corresponds to each rotational position of the shaft, and the incremental encoder, which produces digital pulses as the shaft rotates, allowing measurement of relative position of shaft. Most rotary encoders are composed of a glass or plastic code disk with a photographically deposited radial pattern organized in tracks. As radial lines in each track interrupt the beam between a photoemitter-detector pair, digital pulses are produced.

Absolute Encoder

The optical disk of the absolute encoder is designed to produce a digital word that distinguishes N distinct positions of the shaft. For example, if there are 8 tracks, the encoder is capable of producing 256 distinct positions or an angular resolution of 1.406 (360/256) degrees. The most common types of numerical encoding used in the absolute encoder are gray and binary codes. To illustrate the action of an absolute encoder, the gray code and natural binary code disk track patterns for a simple 4-track (4-bit) encoder are illustrated in Fig 2 and 3. The linear patterns and associated timing diagrams are what the photodetectors sense as the code disk circular tracks rotate with the shaft. The output bit codes for both coding schemes are listed in Table 1.

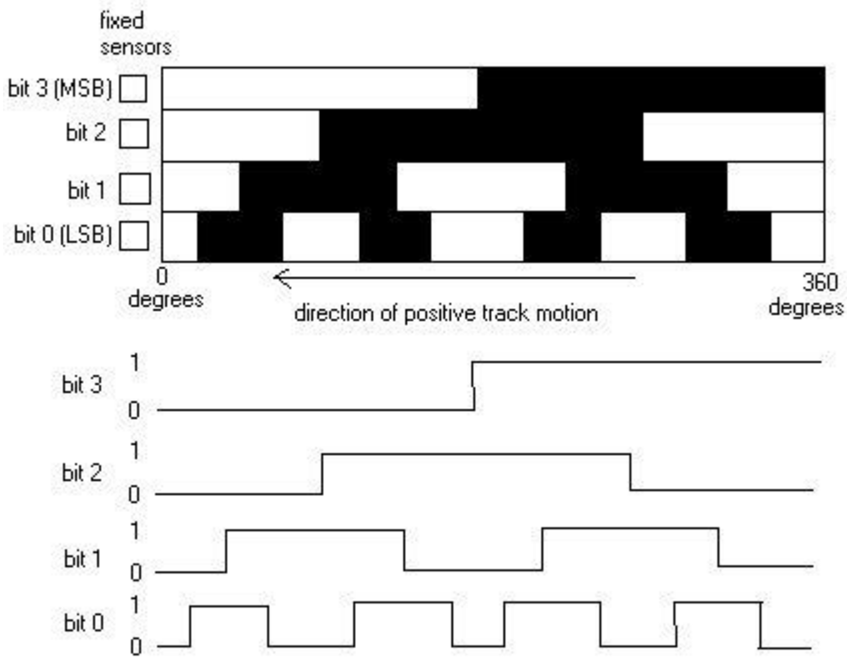


Fig 2. 4-Bit gray code absolute encoder disk track patterns

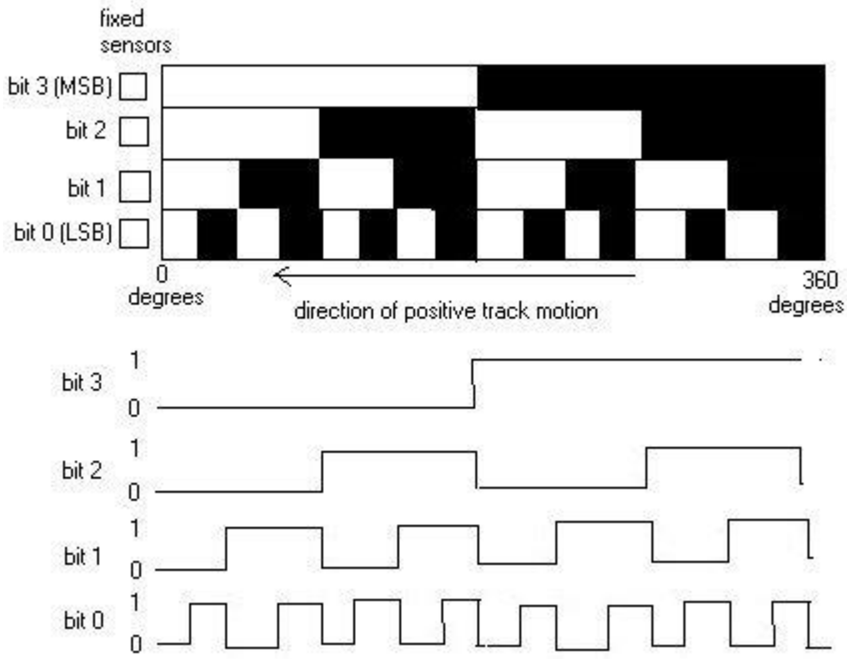


Fig 3 4-Bit binary code absolute encoder disk track patterns

Incremental encoder

The incremental encoder, sometimes called a relative encoder, is simpler in design than the absolute encoder. It consists of two tracks and two sensors whose outputs are called channels A and B

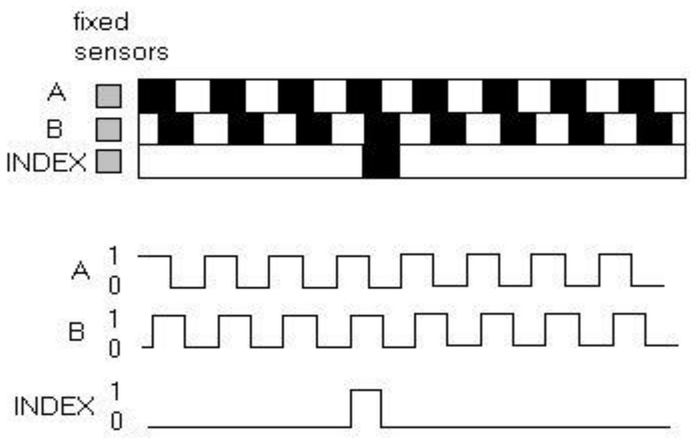


Fig 5. Incremental encoder disk track patterns

. As the shaft rotates, pulse trains occur on these channels at a frequency proportional to the shaft speed, and the phase relationship between the signals yields the direction of rotation. The code disk pattern and output signals A and B are illustrated in Figure 5. By counting the number of pulses and knowing the resolution of the disk, the angular motion can be measured. The A and B channels are used to determine the direction of rotation by assessing which channels "leads" the other. The signals from the two channels are a 1/4 cycle out of phase with each other and are known as quadrature signals. Often a third output channel, called INDEX, yields one pulse per revolution, which is useful in counting full revolutions. It is also useful as a reference to define a home base or zero position.

Figure 5 illustrates two separate tracks for the A and B channels, but a more common configuration uses a single track with the A and B sensors offset a 1/4 cycle on the track to yield the same signal pattern. A single-track code disk is simpler and cheaper to manufacture.

The quadrature signals A and B can be decoded to yield the direction of rotation as hown in Figure 6. Decoding transitions of A and B by using sequential logic circuits in different ways can provide three different resolutions of the output pulses: 1X, 2X, 4X. 1X resolution only provides a single pulse for each cycle in one of the signals A or B, 4X resolution provides a pulse at every edge transition in the two signals A and B providing four times the 1X resolution. The direction of rotation(clockwise or counter-clockwise) is determined by the level of one signal during an edge transition of the second signal. For example, in the 1X mode, A= $\downarrow$ with B =1 implies a clockwise pulse, and B= $\downarrow$ with A=1 implies a counter-clockwise pulse. If we only had a single output channel A or B, it would be impossible to determine the direction of rotation. Furthermore, shaft jitter around an edge transition in the single signal woudl result in erroneous pulses..

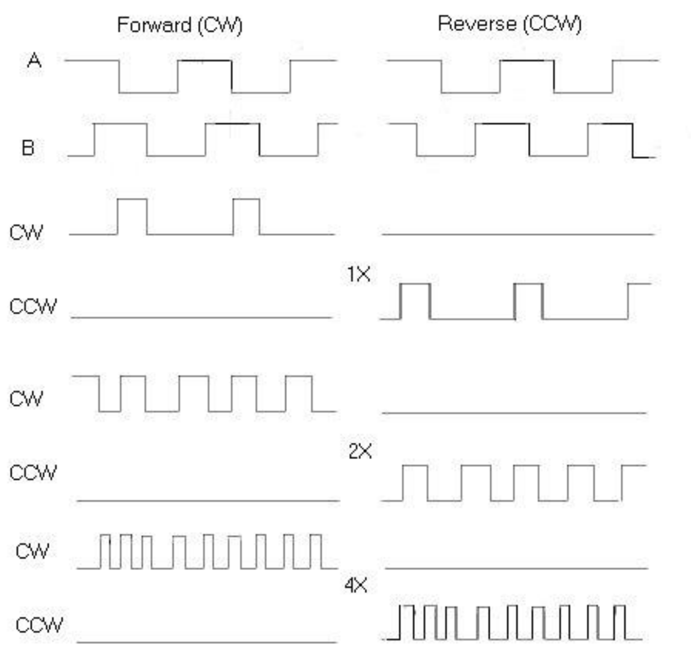


Fig 6. Quadrature direction sensing and resolution enhancement. (CW = clockwise, CCW= counter-clockwise)

RADIO ACOUSTIC TRANSDUCERS:

A radio acoustic sounding system (RASS) is a system for measuring the atmospheric lapse rate using backscattering of radio waves from an acoustic wave front to measure the speed of sound at various heights above the ground. This is possible because the compression and rarefaction of air by an acoustic wave changes the dielectric properties, producing partial reflection of the transmitted radar signal From the speed of sound, the temperature of the air in the planetary boundary layer can be computed. The maximum altitude range of RASS systems is typically 750 meters, although observations have been reported up to 1.2 km in moist air.

Principle

The principle of operation is as follows:

Bragg scattering occurs when acoustic energy (i.e., sound) is transmitted into the vertical beam of a radar such that the wavelength of the acoustic signal matches the half-wavelength of the radar. As the frequency of the acoustic signal is varied, strongly enhanced scattering of the radar signal occurs when the Bragg match takes place.

When this occurs, the Doppler shift of the radar signal produced by the Bragg scattering can be determined, as well as the atmospheric vertical velocity. Thus, the speed of sound as a function of altitude can be measured, from which virtual temperature (TV) profiles can be calculated with appropriate corrections for vertical air motion. The virtual temperature of an air parcel is the temperature that dry air would have if its pressure and density were equal to those of a sample of moist air. As a rule of thumb, an atmospheric vertical velocity of 1 m/s can alter a TV observation by 1.6°C.

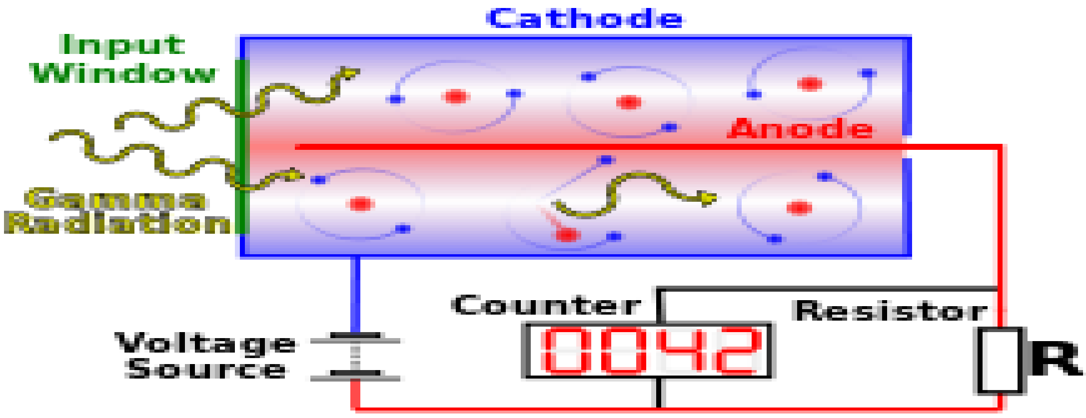
GEIGER MULLER COUNTER:

The Geiger–Müller counter, also called a Geiger counter, is an instrument used for measuring ionizing radiation.

It detects radiation such as alpha particles, beta particles and gamma rays using the ionization produced in a Geiger–Müller tube, which gives its name to the instrument. In wide and prominent use as a hand-held radiation survey instrument, it is perhaps one of the world's best-known radiation instruments.

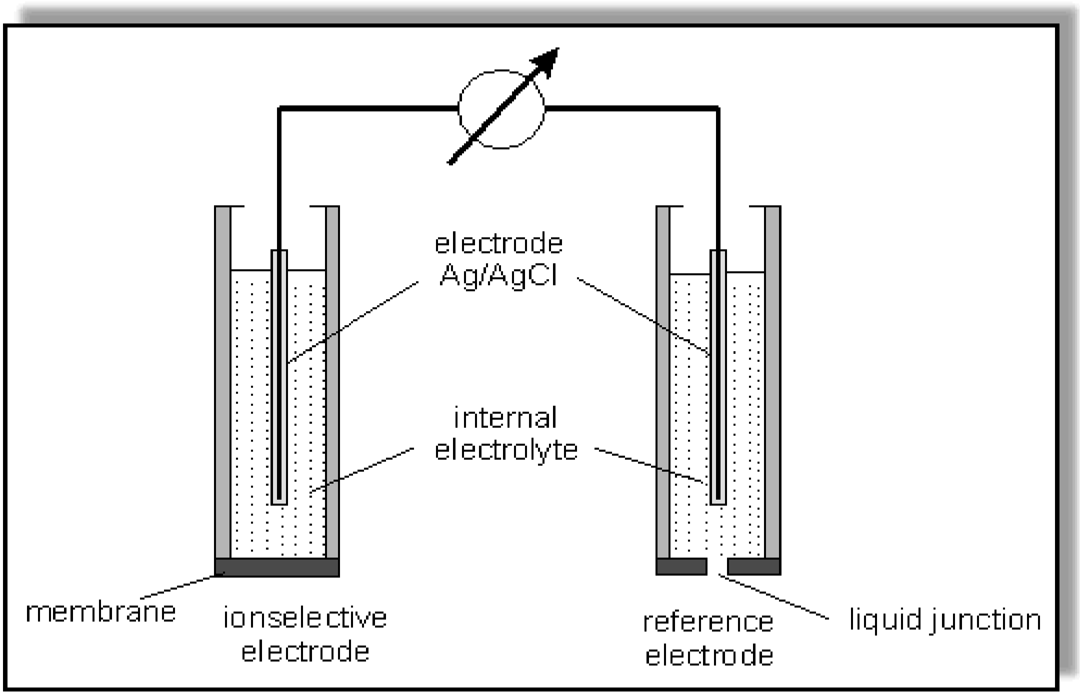
The original detection principle was discovered in 1908, but it was not until the development of the Geiger-Müller tube in 1928 that the Geiger-Müller counter became a popular instrument for use in such as radiation dosimetry, radiological protection, experimental physics and the nuclear industry. This was mainly due to its robust sensing element and relatively low cost, however there are limitations in measuring high radiation rates and in measuring the energy of incident radiation.

Operating principle:



The Geiger counter consists of two main elements; the Geiger-Müller tube which detects the radiation, and the processing and display electronics. The Geiger-Müller tube is filled with an inert gas such as helium, neon, or argon at low pressure, which briefly conducts electrical charge when a particle or photon of incident radiation makes the gas conductive by ionization. The ionization current is greatly amplified within the tube by the Townsend avalanche effect to produce an easily measured detection pulse. This makes the G-M counter relatively cheap to manufacture, as the subsequent electronic processing is greatly simplified.

ION SELECTIVE ELECTRODE:



An ion-selective electrode (ISE), also known as a specific ion electrode (SIE), is a transducer (or sensor) that converts the activity of a specific ion dissolved in a solution into an electrical potential, which can be measured by a voltmeter or pH meter. The voltage is theoretically dependent on the logarithm of the ionic activity, according to the Nernst equation. The sensing part of the electrode is usually made as an ion-specific membrane, along with a reference electrode. Ion-selective electrodes are used in biochemical and biophysical research, where measurements of ionic concentration in an aqueous solution are required, usually on a real time basis.

Construction

These electrodes are prepared from glass capillary tubing approximately 2 millimeters in diameter, a large batch at a time. Polyvinyl chloride is dissolved in a solvent and plasticizers (typically phthalates) added, in the standard fashion used when making something out of vinyl. In order to provide the ionic specificity, a specific ion channel or carrier is added to the solution; this allows the ion to pass through the vinyl, which prevents the passage of other ions and water.

One end of a piece of capillary tubing about an inch or two long is dipped into this solution and removed to let the vinyl solidify into a plug at that end of the tube. Using a syringe and needle, the tube is filled with salt solution from the other end, and may be stored in a bath of the salt solution for an indeterminate period. For convenience in use, the open end of the tubing is fitted through a tight o-ring into a somewhat larger diameter tubing containing the same salt solution, with a silver or platinum electrode wire inserted. New electrode tips can thus be changed very quickly by simply removing the older electrode and replacing it with a new one.

Types of ion-selective membrane

There are four main types of ion-selective membrane used in ion-selective electrodes (ISEs): glass, solid state, liquid based, and compound electrode.

Glass membranes

Glass membranes are made from an ion-exchange type of glass (silicate or chalcogenide). This type of ISE has good selectivity, but only for several single-charged cations; mainly H^+, Na^+, and Ag^+. Chalcogenide glass also has selectivity for double-charged metal ions, such as Pb^{2+}, and Cd^{2+}. The glass membrane has excellent chemical durability and can work in very aggressive media. A very common example of this type of electrode is the pH glass electrode.

Crystalline membranes

Crystalline membranes are made from mono- or polycrystallites of a single substance. They have good selectivity, because only ions which can introduce themselves into thecrystal structure can interfere with the electrode response. Selectivity of crystalline membranes can be for both cat-Ion and anion of the membrane-forming substance. An example is the fluoride selective electrode based on LaF_3 crystals.

Ion-exchange resin membranes

Ion-exchange resins are based on special organic polymer membranes which contain a specific ion-exchange substance (resin). This is the most widespread type of ion-specific electrode. Usage of specific resins allows preparation of selective electrodes for tens of different ions, both single-atom or multi-atom. They are also the most widespread electrodes with anionic selectivity. However, such electrodes have low chemical and physical durability as well as "survival time". An example is the potassium selective electrode, based on valinomycin as an ion-exchange agent.

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