Special-Purpose Diodes and 7805 Voltage Regulator

Topics Covered from Module 1: *Photodiode, LED, Photocoupler. 78XX Series and 7805 Fixed IC Voltage Regulator*

Light Definition and Units

Light has a dual nature. According to this, light behaves like a particle (called a photon), which explains how light travels in straight lines. Also, light behaves like a wave, which explains how light bends (or diffracts) around an object.

As per quantum theory, light is in the form of photons and each photon delivers a packet of energy to the surface on which it falls.

$$W = hf \text{ joules}$$

where $h =$ Planck's constant (6.624×10^{-34} Js)

$f =$ frequency of light waves in Hz

Light also behaves as a travelling wave. The frequency of light is inversely proportional to its wavelength.

$$f = v/\lambda$$

where $v =$ velocity of light (3×10^8 m/s)

$\lambda =$ wavelength in metres

Units of wavelength are angstrom (Å) or micrometer (μm)

$1\text{Å} = 10^{-10}\text{m}$, $1\mu\text{m} = 10^{-6}\text{m}$

Intensity of light is measured in units of luminous flux incident on unit area. Units of luminous flux are *lumens (lm)* where

$$1\ lm = 1.496 \times 10^{-10}\ \text{W}$$

Practical unit of intensity of light is lm/ft^2 called *foot-candle (fc)*

$$1\ fc = 1.609 \times 10^{-9}\ \text{W/m}^2$$

Photodiode

A photodiode is a semiconductor device that converts light into electric current. It is also called photo-detector, photo-sensor or light detector.

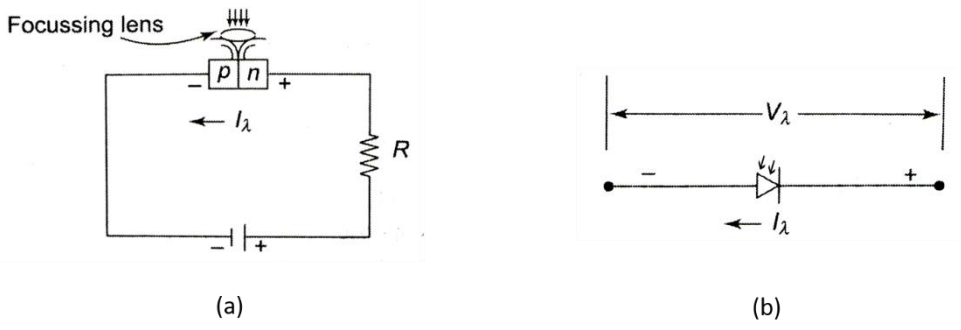

Fig. 1 (a) Photodiode in reverse bias (b) Symbol of photodiode

It is a pn junction operated in reverse bias region as shown in Fig. 1. The photodiode has a small transparent window that allows light to strike the pn junction.

The reverse saturation current (I_λ) flows limited by the availability of thermally generated minority carriers. When the PN junction is exposed to light, the reverse current increases with the light intensity. When there is no incident light I_λ is almost negligible and is called the *dark current*. As light is made to impinge on the junction, the light photons impart energy to the valence electrons causing more electron-hole pairs to be released. As a result, the concentration of minority charge carriers increases, thus increasing I_λ.

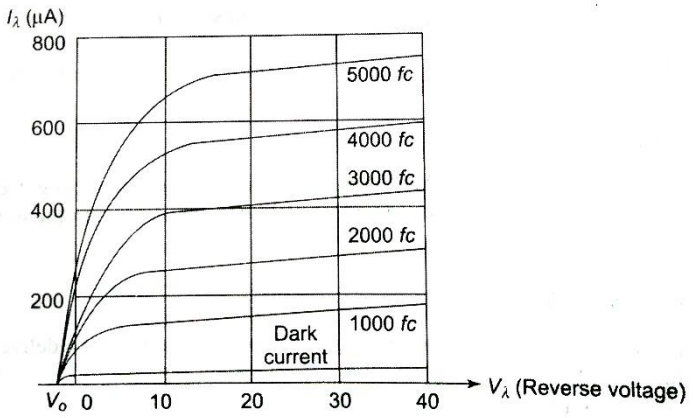

Fig. 2 VI characteristics of photodiode

Fig. 2 shows the VI characteristics of a photodiode for various light intensity (fc). The dark current corresponds to the current when there is no light impingement. It is the same as reverse saturation current ($I_\lambda = I_S$). From the characteristics, it is found that at a certain V_λ, I_λ increases almost linearly with fc.

Applications of photodiodes

- Optical communication system
- Automotive devices
- Solar cell panels
- Consumer electronics devices like smoke detectors, compact disc players, televisions and remote controls
- Medical applications like instruments to analyse samples, detectors for *computed tomography* and blood gas monitors

Light-Emitting Diode (LED)

An LED is a pn junction diode that emits light when forward biased. Fig. 3 shows the symbol of an LED.

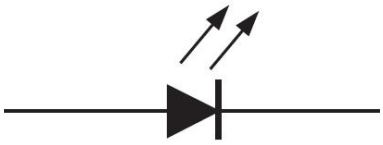

Fig. 3 Symbol of an LED

When the device is forward biased, electrons cross the PN junction from the n-type material and recombine with holes in the p-type material. These free electrons are in the conduction band and at a higher energy than the holes in the valence band. The difference in energy between the electrons and the holes corresponds to the energy of visible light. When recombination takes place, the recombining electrons release energy in the form of photons.

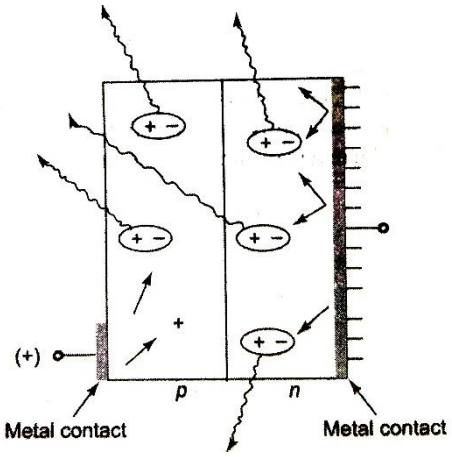

Fig. 4 Light emission in PN junction

In silicon diodes, most of this energy is given off as heat but in materials like Gallium Arsenide (GaAs) or Gallium Phosphide (GaP), photons are generated to create a visible light. The emitted light tends to be monochromatic (one colour) that depends on the band gap (and other factors).

A large exposed surface area on one layer of the semiconductor material permits the photons to be emitted as visible light. This process of light emission in pn junction is called *electroluminescence*.

Various impurities are added during the doping process to establish the wavelength of the emitted light. The wavelength determines the colour of visible light. LEDs emit red, green, orange, blue and yellow lights.

Intensity of light increases linearly with forward current. The voltage levels of LEDs are 1.7 V to 3.3 V.

Advantages of LEDs

- Lower energy consumption
- Longer lifetime
- Improved physical robustness
- Smaller size
- Faster switching

Applications of LEDs

- Display applications like 7-segment displays
- Display boards
- General lighting

- LED TVs
- Automotive headlamps
- Advertising
- Traffic signals
- Camera flashes
- Medical devices

Photocoupler

A photocoupler is a component that transfers electrical signals between two isolated circuits by using light. It is also called opto-isolator, optocoupler or optical isolator.

A photocoupler is a package of an LED and photodiode where circuits are electrically isolated as shown in Fig. 5. The LED acts as a source of light and the photodiode behaves as a sensor.

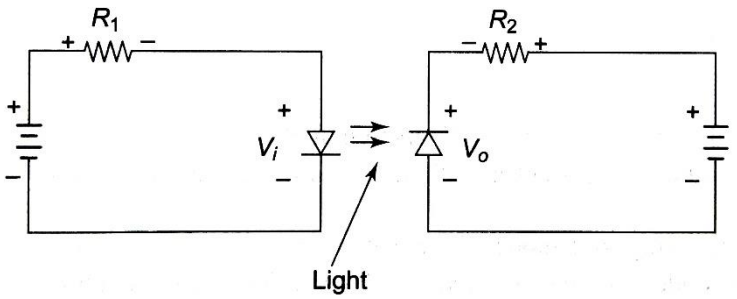

Fig. 5 Photocoupler

The LED is forward biased and the photodiode is reverse biased. The output is available across R_2.

Advantage of Photocouplers

The advantage of photocoupler is the electrical isolation between two circuits. It prevents high voltages affecting the system receiving the signal.

Applications of Photocouplers

Photocouplers are used to couple circuits whose voltage levels may differ by several thousand volts. They can be used in:

- Microprocessor input/output switching
- DC and AC power control
- Signal isolation and power supply regulation

78XX Series Voltage Regulator

The 78XX series is typical of the three-terminal voltage regulators (XX = 05, 06, 10, 12, 15, 18 or 24). 7805 produces an output voltage of +5V, 7806 produces +6V, and so on, up to 7824, which produces +24V.

Fig. 6 shows the functional block diagram of three-terminal IC regulator. A built-in reference voltage V_{ref} drives the non-inverting input of an amplifier. A voltage divider consisting of R'_1 and R'_2 samples the output voltage and returns a feedback voltage to the inverting input of a high-gain amplifier.

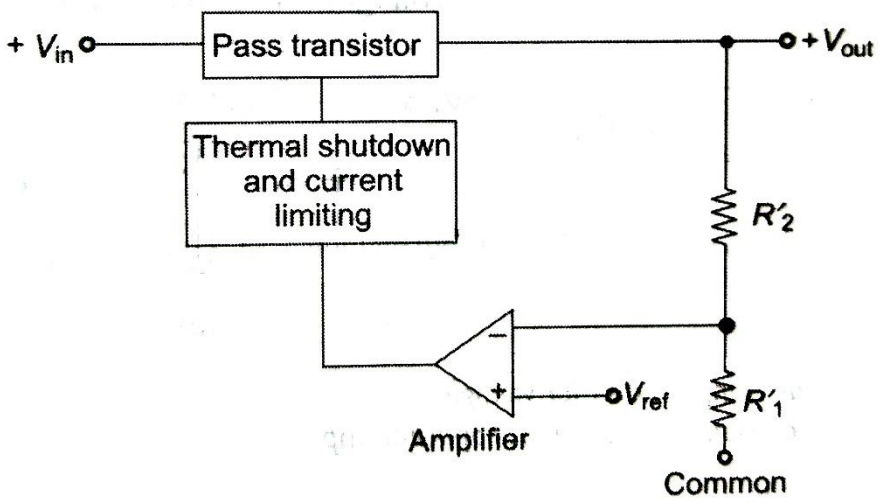

Fig. 6 Functional block diagram of three-terminal IC regulator

The output voltage is given by

$$V_{out} = \frac{R'_1 + R'_2}{R'_1} V_{ref}$$

The reference voltage is equivalent to Zener voltage. The resistors R'_1 and R'_2 are inside the IC itself and are factory trimmed to get different output voltages. The tolerance of the output voltage is ± 4 percent.

The LM78XX includes a pass transistor that can handle 1 A of load current. The thermal shutdown and current limiting unit makes sure that the chip will shut itself off when the internal temperature becomes too high, around 175°C. This is a precaution against excessive power dissipation and this makes the devices in 78XX series almost indestructible.

7805 Fixed IC Voltage Regulator

The LM7805 has an output voltage of +5V and a maximum load current of 1A (LM stands for Linear Monolithic).

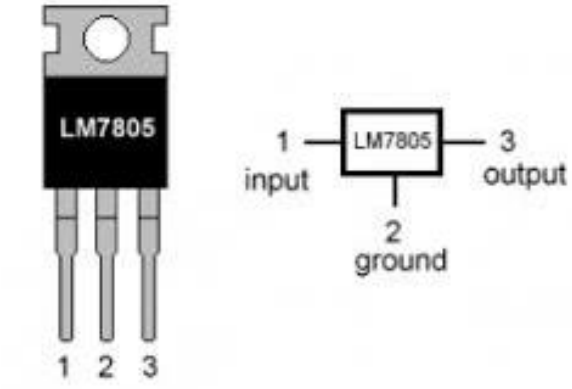

Fig. 7 Terminals of LM7805

The typical load regulation is 10 mV for a load current between 5 mA and 1.5 A. The typical line regulation is 3 mV for an input voltage between of 7 to 25 V. Ripple rejection ratio is 80 dB, which means it will reduce input ripple by a factor of 10000. The output resistance is approximately 0.01Ω.

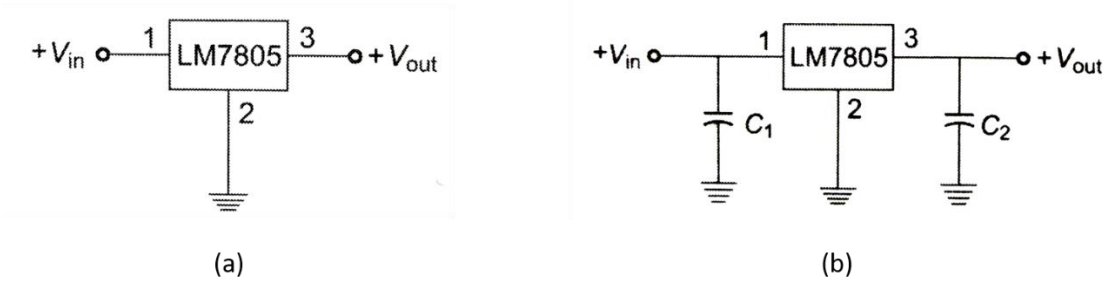

Fig. 8 (a) Using a 7805 for voltage regulation (b) Using bypass capacitors with 7805

Fig. 8 shows how 7805 is used for voltage regulation. Bypass capacitor C_1 is used to prevent the oscillations in the input. Bypass capacitor C_2 is used to improve the transient response. The typical values of the bypass capacitors are from 0.1 to 1μF. The datasheet of 78XX series suggests 0.22μF for the input capacitor and 0.1μF for the output capacitor.

The 78XX series regulators have a drop-out voltage of 2 to 3V. This means that the input voltage must be at least 2 to 3 V greater than the output voltage. Otherwise, the chip stops regulating. Also, there is a maximum input voltage because of excessive power dissipation.

Questions

1. Write a note on photodiode and mention its applications.
2. Explain the working of photodiode. ***(Jan '20 – 5M, Jul '19 – 5M)***
3. Write a short note on photodiode. ***(MQP '18 – 3M)***
4. Explain VI characteristics of photodiode and its operation. ***(Jan '19 – 4M)***
5. Explain photodiode and LED in brief. ***(Sep '20 – 6M)***
6. Explain the principle of operation of a light-emitting diode (LED) and mention its applications.
7. Write a short note on light-emitting diode. ***(MQP '18 – 4M)***
8. Write a short note on photocoupler. ***(MQP '18 – 4M)***
9. Explain the operation of 7805 fixed IC voltage regulator. ***(Sep '20 – 6M, MQP '18 – 6M)***
10. Explain the functional block diagram of 78XX series voltage regulator. ***(Jul '19 – 6M)***
11. Explain the features of LM7805 fixed regulator. ***(MQP '18 – 6M)***

References

1. D.P. Kothari, I. J. Nagrath, ***"Basic Electronics"***, McGraw Hill Education (India) Private Limited, Second Edition, 2014.
2. Thomas L. Floyd, ***"Electronic Devices"***, Pearson Education, Ninth Edition, 2012.