EE 204 - Analog Circuits
Lecture 4

Harsh S Roniyar

August 18, 2023

Contents

1 Using LEDs

Electroluminescence as a phenomenon was discovered in 1907 by the English experimenter H. J. Round of Marconi Labs, using a crystal of silicon carbide and a cat's-whisker detector. Russian inventor Oleg Losev reported the creation of the first LED in 1927.

A light-emitting diode (LED) is a semiconductor device that emits light when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons. The color of the light (corresponding to the energy of the photons) is determined by the energy required for electrons to cross the band gap of the semiconductor White light can be obtained by using multiple semiconductors or a layer of light-emitting phosphor on the semiconductor device.

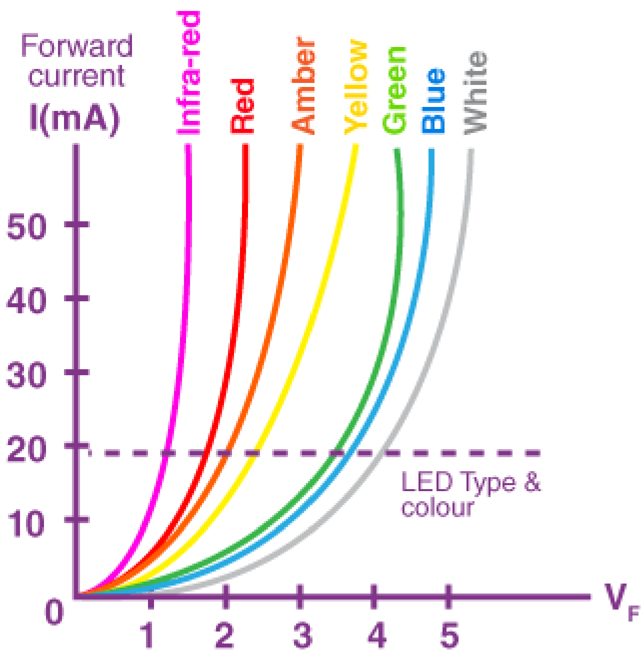

Figure 1: V-I Characteristics of LEDs

Just like standard diodes, in forward bias the value of current through the device begins to rise drastically after a given voltage. Due to this, if you were to directly apply a voltage significantly greater than the LED's drop-off voltage (say 15V for a $\sim$ 2V LED), the high current will destroy the diode.

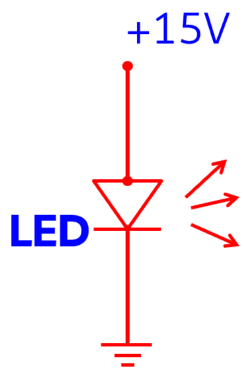

Figure 2: Bare LED

To fulfill this objective, we employ a resistor, strategically positioned in a series configuration alongside the LED. The rationale behind this arrangement lies in the necessity to regulate the flow of current and manage the distribution of voltage within the circuit.

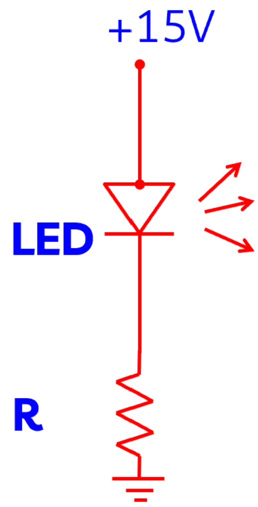

Figure 3: LED with a Resistor in Series

In this context, the voltage drop across both the resistor and the LED is pivotal. Their individual voltage drops collectively accumulate, resulting in a sum that aligns with the overall voltage (referred to as V) supplied to the circuit. This sequential arrangement capitalizes on the inherent characteristics of the resistor and the LED to control the overall electrical behavior of the circuit.

$$\mathrm{V} = \mathrm{V_R} + \mathrm{V_{LED}}$$

Critical to the success of this arrangement is the selection of an appropriate resistor. The resistor's value must be meticulously determined so as to ensure that the LED operates under optimal conditions. This entails calculating the desired current that should traverse the LED based on its specified rating. By adhering to this principle, the chosen resistor facilitates the establishment of a current flow that aligns precisely with the LED's recommended operational level.

$$\mathrm{I_{rated}} = \frac{\mathrm{V_R}}{\mathrm{R}} = \frac{\mathrm{V} - \mathrm{V_{LED}}}{\mathrm{R}}$$
$$\Rightarrow \mathrm{R} = \frac{\mathrm{V} - \mathrm{V_{LED}}}{\mathrm{I_{rated}}}$$

2 Using Transistors as a Switch

Transistors are commonly used as switches in electronic circuits, and they can be effectively utilized to control an LED circuit. Transistors come in various types, but for simplicity, I'll focus on the NPN bipolar junction transistor (BJT) configuration, which is frequently used in switching applications.

In this scenario, we'll use a transistor to switch an LED on and off. The transistor acts as a gatekeeper, allowing or blocking the flow of current through the LED. To achieve this, we'll need to select appropriate resistors to ensure proper current control and prevent damage to the LED.

2.1 Analysis of LED On-Off Circuit

LED OFF State :

- The control signal source is initially low (0V).
- Because there's no voltage applied to the base (B) of the NPN transistor, no current flows through R1 or the base-emitter junction of the transistor.
- As a result, the transistor remains in its cutoff state. No current flows from the collector (C) to the emitter (E).
- Since there's no current through R2, the LED remains off.

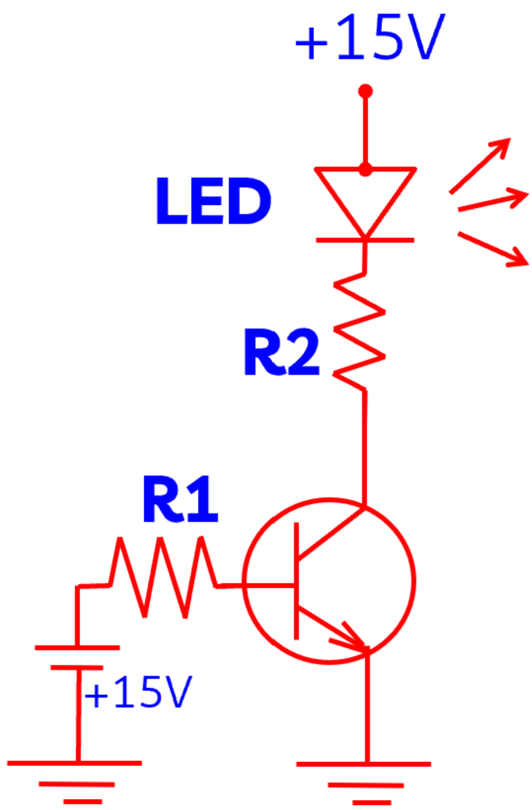

Figure 4: Transistor LED On-Off Circuit

LED ON State :

- The control signal source is set to a high voltage, which results in a positive voltage at the base (B) of the NPN transistor.
- A small current begins to flow through R1 and into the base-emitter junction of the transistor.
- This base current activates the transistor's amplifying action. The transistor enters its active mode.
- As the transistor amplifies the base current, a larger current flows from the collector (C) to the emitter (E).
- This collector current also passes through R2 and the LED.
- The LED lights up because of the current passing through it.
- As long as the control signal remains high and sufficient base current is supplied, the transistor remains in its active mode.
- The LED continues to be lit because the current flowing through R2 is regulated and controlled by the transistor's amplification.

Importance of Current-limiting Resistors :

- **R1 (Base Resistor) :** R1 is crucial for limiting the base current that flows into the transistor. It prevents excessive current from damaging the transistor and controls the transistor's on-off transition. Too much base current can lead to a saturated state, and too little can result in cutoff.
- **R2 (LED Resistor) :** R2 limits the current flowing through the LED. LEDs have a specific forward voltage drop and current rating. Without R2, the LED might draw excessive current and burn out. R2 ensures that the LED operates within its safe parameters.

By controlling the voltage applied to the transistor's Base terminal, you can effectively switch the LED on and off. When the Base voltage is high enough to forward-bias the Base-Emitter junction, the transistor turns on, allowing current to flow from Collector to Emitter, thus lighting up the LED.

In summary, the careful choice of R1 and R2 is essential for maintaining proper functionality and protection within the NPN transistor switch circuit. By understanding the characteristics of the components and their roles, engineers can design reliable circuits that control LEDs effectively while safeguarding the components from potential damage due to over-current or incorrect voltage levels.

2.2 Introduction to Bias Compensation Circuits

Now, after learning the basic transistor switching circuits, we can modify our circuits for better control and advantages.

Some of the (bias compensation) circuits which we would analyse in the upcoming lectures are :

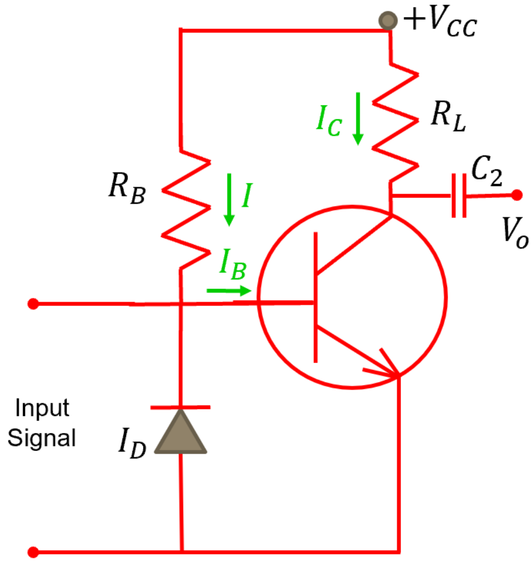

Figure 5: Bias Compensation with Diode

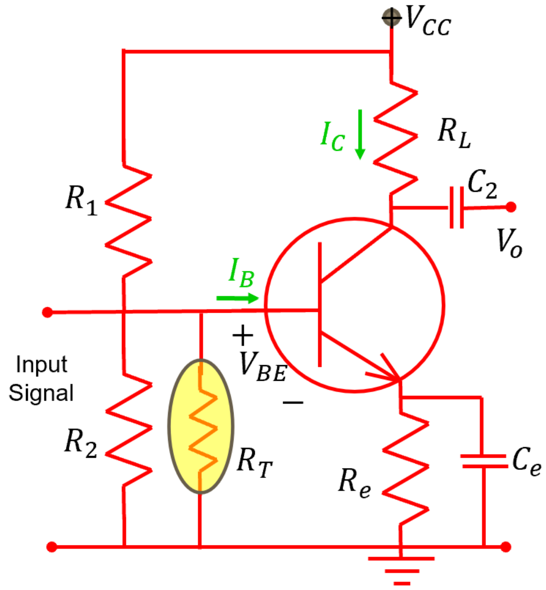

Figure 6: Bias Compensation using a Thermistor