Simulation-Driven Electronics Design

The easy way to design your own electronics projects

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Dedicated to

My Father's inspiration: My Grandmother

Smt. Janaki Kasi Iyer

&

My Family

— Dr. Poornima Mahesh

My Father

My Wife

&

My Brother

— Dr. Rajiv Iyer

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Thanks to everyone who has directly or indirectly contributed to the creation of this book. We are honored to be the authors of this work and hope it will serve as a valuable resource for years.

Happy reading!

Preface

This book intends to provide knowledge about simulating electronic devices through popular tools. Simulation is an essential step while designing electronics-based projects since it saves the end user a lot of time and money to experiment with hardware on a trial-and-error basis.

This book provides readers with complete laboratory knowledge of tinkering with electronic components, understanding how they operate, and the skills necessary to design and build their functional devices. It also improves the performance parameters like accuracy, precision, resolution, etc. This book intends to use some of the popularly available simulation tools and use it to build projects. Although this book will talk about building electronic projects, it is intended to be a ready reference for beginners and experts alike. The book will introduce some basic electronic concepts and working of commonly used electronic components, which will act as a guide for the beginner and a refresher for the expert user. A further intent of the book is to keep mathematical equations and derivations to a minimum so as to focus on the actual building of projects and analysis of the performance parameters of the projects.

Chapter 1: Introduction to the World of Electronics—1—Passive Elements- will give an introduction to passive electronic components, including basic working principles, symbols, and design considerations. Various passive elements, such as resistors, inductors, and capacitors, are discussed in detail.

Chapter 2: Introduction to the World of Electronics—2—Active Elements- discusses active elements and their working. It discusses various factors, which include the choice of a particular component, the parameters to make that decision, etc. Diode, LED, transistor, and MOSFET are discussed in detail. It also includes sensors to be used in different projects. Digital and logic circuits are also included in this chapter.

Chapter 3: Basic Arduino Projects Using Tinkercad- starts with the online tool Tinkercad. It gives step-by-step ideas to create various projects on that tool. The reader learns to work with Arduino and builds basic projects using LEDs and resistors.

Chapter 4: Sensor-based Arduino Projects- introduces readers to various sensors available in Tinkercad, and they learn to integrate these sensors with Arduino to build projects. In this chapter, they will learn to use LED, Ultrasonic sensors, PIR sensors, gas sensors, alarms, etc. They will also learn block coding using Tinkercad.

Chapter 5: Getting Started with WEBENCH Tool by TI- explains the importance of power supply in any electronic project, introduction to various power supplies, DC, AC, and dual power supply. It introduces a powerful simulation tool – TI Webench, which is used to design a power supply of desired specifications.

Chapter 6: Power Supply Design with TI WEBENCH- discusses basic power supply design required for ICs with 5V and 3.3V, voltage regulators, and SMPS. It explains designing power supply using TI Webench and analyzing various electronic parameters to generate bills of materials for the actual designing of the project.

Chapter 7: TI Filter Designer- starts with various types of filters in electronic circuits. It further explains the importance of filter design in any electronic project. This chapter introduces readers to the TI Filter design tool.

Chapter 8: Filter Design- discusses designing various filters like the Chebyshev filter and Butterworth filter using the TI Filter design tool. Projects using the tool are demonstrated using various case studies.

Chapter 9: TI Analog Devices Simulation and Basic Circuits- discusses operational amplifier, use of diode as a voltage-controlled switch, and a buffer circuit. It also explains the instrumentation amplifier in detail.

Chapter 10: Analog Device Simulation and Applications- discusses the simulation of analog circuits and its analysis such as DC and AC transient and noise analysis.

Chapter 11: PCB Designing TI Tool- emphasizes the importance of printed circuit boards (PCB) in every project. It demonstrates the use of the TI Tool for PCB designing.

Chapter 12: PCB Thermal Calculation- explains thermal calculations for various cases. It helps in estimating the junction temperature of components based on the copper spreading area on the PCB.

Code Bundle and Coloured Images

Please follow the link to download the
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The code bundle for the book is also hosted on GitHub at **https://github.com/bpbpublications/Simulation-Driven-Electronics-Design**. In case there's an update to the code, it will be updated on the existing GitHub repository.

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Chapter 1

Introduction to the World of Electronics—1—Passive Elements

Introduction

The field of electronics has seen tremendous growth in recent years and has found numerous applications in the industry. Electronics play a very important role in quality control and automation. Electronics may have many challenges, but one can overcome them by simplifying the learning process.

Structure

In this chapter, we will discuss the following:

- Passive elements
- Types of passive elements
- Resistors
- Types of resistors
- Resistor color code
- Various combinations of resistors

- Capacitors
- Types of capacitors
- Inductors
- Types of inductors

Objectives

The aim of this chapter is to provide a fundamental concept about passive elements used widely in industry to make the readers ready for the subsequent chapters. The reader will be able to calculate resistance and capacitance values by looking into their color band. They will be able to understand various types of resistors, capacitors, and inductors.

Passive elements

Circuit elements can be classified into active and passive elements. Passive elements use power or energy in a circuit. They do not require any external source to operate. The word “passive” indicates that the passive element does not provide any gain or amplification. The energy in the passive element is stored in the form of voltage or current. Examples of passive elements are resistors, capacitors, inductor, transformer, thermistor, and so on.

Resistors

The resistor is an element that offers opposition to the flow of electricity through it. The property of opposing the current is called as **resistance**. Metals and acids offer very less resistance, and hence, are good conductors of electricity. It is due to the fact that they have a large number of free or loosely attached electrons in their atoms. Mica, rubber, dry wood, and so on act as bad conductors of electricity, and hence, offer very high resistance to the flow of current. The resistor is characterized by its resistance, tolerance, power handling capacity, maximum operating temperature, temperature coefficient, voltage rating, and so on. However, the most important terms being key: resistance value, tolerance, and power rating of the resistor. **Tolerance** is the allowed variation of resistance from its normal value and is expressed in percentage (%).

The unit of resistance is Ohm (Ω). A conductor is said to have a resistance of one Ohm (1 Ω) if it permits one ampere (1 A) current to flow through it when one volt (1 V) is applied across its terminals.

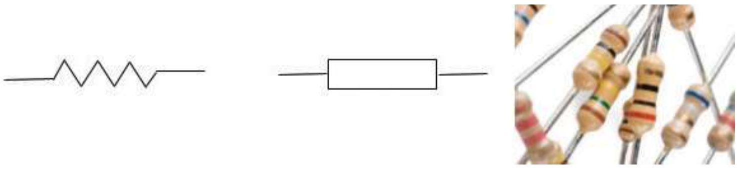


Figure 1.1: *Symbol of resistor*

Law of resistance

The resistance R depends on the following factors:

- **Length (ℓ):** Resistance is directly proportional to the length of the conductor.
- **Area of cross-section (a)**: Resistance is inversely proportional to the area of the cross-section of the conductor wire.
- Resistance also depends on the **material used**.
- Resistance depends on the **temperature of the conductor** (can be neglected if constant temperature is assumed).

Hence, $R \propto \ell$ *and* $R \propto a$

that is $R \propto \ell / a$

or $R = \rho \ell / a$ (1.1)

Where ℓ is the length, *a* is the area of the cross-section of the conductor, and ϱ is the resistivity of the material used.

From equation (1.1), we have the following:

$$\rho = R\, a / \ell \qquad \textbf{(1.2)}$$

SI unit of resistivity ϱ = R (Ω) a (meter^2) / ℓ (meter)

= Ohm–meter (Ω-m)

Conductance (G) and conductivity (σ)

The reciprocal of resistance is called **conductance.** From equation (1.1), we have the following:

$$R = \rho \ell / a$$

$$\text{Conductance } G = 1/R$$

$$\text{Hence} \quad G = (1/\rho)\, a / \ell$$

$$G = \sigma a / \ell \qquad (1.3)$$

Where σ is called as conductivity, and its unit is Siemens/meter (S/m). The unit of conductance is mho or Siemens (S).

Types of resistors

The resistors are broadly classified as follows:

- Fixed resistors
- Variable resistors

Fixed resistors

A resistor whose value does not change or whose value is fixed is called a fixed resistor. Fixed resistors are further classified as follows:

- Wire-wound resistors
- Carbon composition resistors
- Metal film resistors and
- Carbon film resistors

Wire-wound resistors

Wire-wound resistors are made by winding resistance wire, such as Nichrome, Tungsten, or Manganin. It has an insulating core or rod (made of porcelain, Bakelite, or ceramic clay material) around which the wire is wound. To protect the resistor from moisture and breakage, it is coated with an insulated material. These resistors are very stable and reliable; however, they have large sizes and are costly.

Their typical range is from 0.1 Ω to 22 MΩ with a tolerance of 5%.

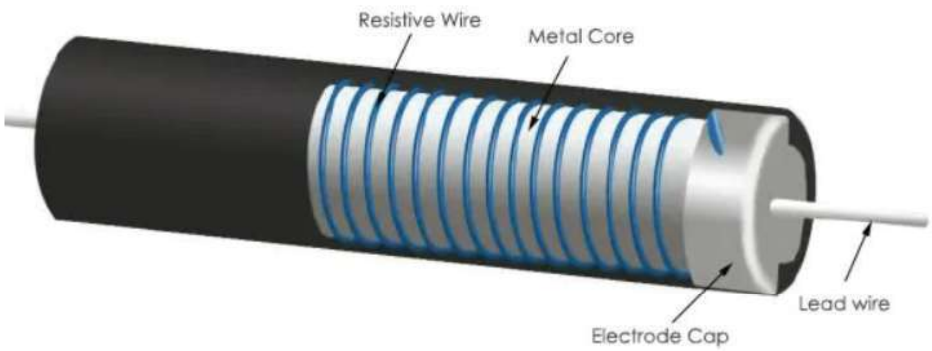


Figure 1.2: *Wire-wound resistor*

Carbon composition resistors

In order to obtain the desired value of resistance, carbon powder, and insulating binders are mixed. The actual value of resistance depends on the ratio of insulation material. To provide insulation and mechanical strength, a carbon rod having a length of 5 mm is covered with an insulating material. For easy connectivity in the circuit, two conductor wires are provided on both ends. Carbon composition resistors have the advantages of small size, low cost, and ruggedness. They are available from 1 Ω to 10 MΩ.

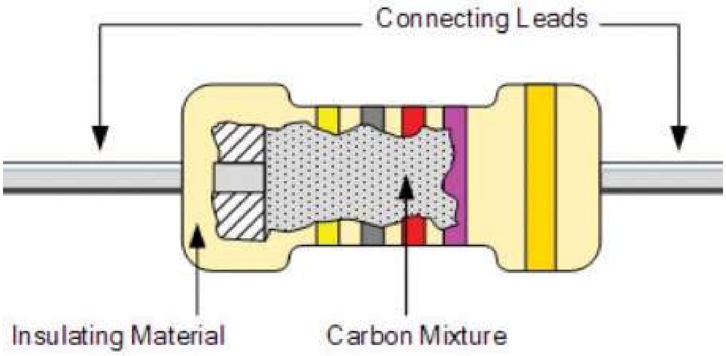


Figure 1.3: *Carbon compound resistor*

Metal film resistors

Metal film resistors are most widely used for their accuracy and consistency. It can be either a thin film or a thick film resistor. It is made of depositing metal oxide film on the surface of a ceramic core. They are available from 1 Ω to 10 MΩ. Metal film resistors have low-temperature coefficients. They are considered to be precision resistors due to their high stability. Please refer to the following figure:

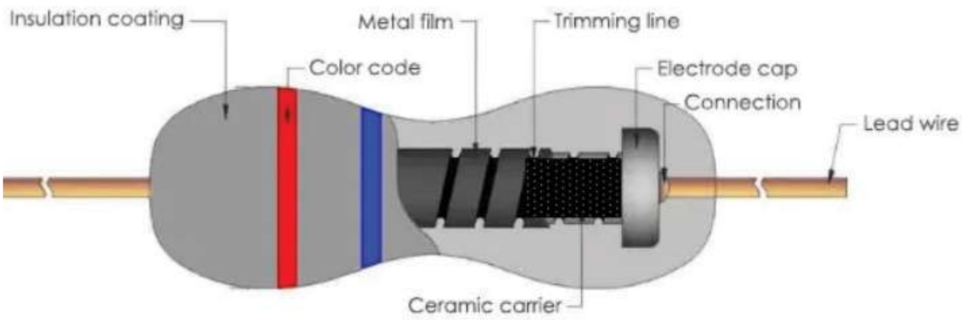


Figure 1.4: *Metal film resistor*

Carbon film resistors

In this type of resistor, a high-grade ceramic core or rod is used. A thin resistive carbon film is deposited on the core or rod. These resistors provide high stability for temperature and humidity; however, they are costly and fragile. Carbon film resistors are available from 10 Ω to 10 MΩ. Carbon film resistors have low tolerance than carbon composition resistors. Therefore, to achieve the desired value of resistance, the thickness of a carbon layer is trimmed, or carbon metal is cut along its length in a helical manner using the laser. Please refer to the following figure:

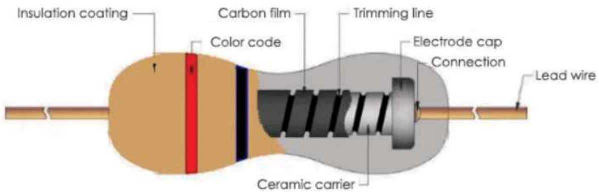


Figure 1.5: *Carbon film resistor*

Variable resistors

To adjust the value of current or voltage in an electronic circuit, variable resistors are used. As its name suggests, its resistance value is not fixed and can be varied depending on our requirements. Variable resistors are classified as wire-wound and carbon composition resistors. Rheostats and potentiometers are examples of variable resistors.

Rheostat

Rheostat is used to control and adjust the amount of current flowing in an electrical circuit. Rheostat does it by changing the resistance on the circuit without interrupting the supply of power. It allows the user to change the resistance value manually when required. Rheostat is used in high-power applications. It has a movable contact that can be slide through the iron rod to change the value of the resistance. Please refer to the following figure:

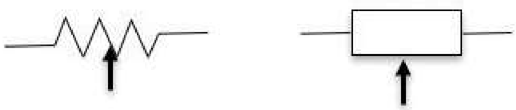
(a) ***(b)***

Figure 1.6: *(a) Rheostat and (b) symbol*

Potentiometer

Potentiometer is a three-terminal variable resistor and is used in volume control, brightness, and contrast control in radio or TV receivers. It can have a coil as a basic resistive element wound over a circular Bakelite or ceramic core. It has a rotating shaft that moves the contact point from one end of the core to the other end. The potentiometer can be linear or logarithmic. In a linear potentiometer, the resistance varies linearly, and in a logarithmic potentiometer, it changes exponentially. Potentiometers are available in the range of 470 Ω, 1 kΩ, 2.2 kΩ, 4.7 kΩ, 10 kΩ, 22 kΩ, 47 kΩ, and 100 kΩ.

(a)



(b)

Figure 1.7: *(a) Potentiometer and (b) symbol*

Resistance color code

Resistors are marked with color bands (or color codes), as shown in *Figure 1.8*. In order to calculate the value of the resistance, we begin with the band closest to the end of the component. The space between tolerance and multiplier is slightly larger than the space between digits and the multiplier. Please refer to the following figure:

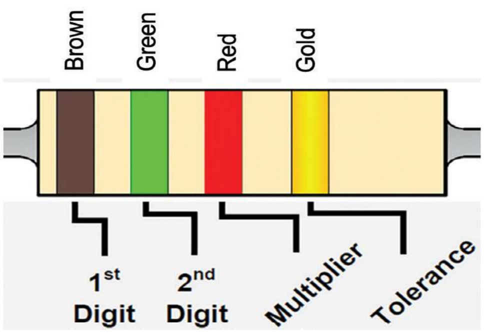


Figure 1.8: *Resistance color code*

The value for each color band is shown in *Table 1.1*:

Color	Digit	Tolerance
Black	0	
Brown	1	1%
Red	2	2%
Orange	3	NA
Yellow	4	NA
Green	5	0.5%
Blue	6	0.25%
Violet	7	0.1%
Grey	8	0.05%
White	9	NA
Gold	na	5%
Silver	na	10%
No Band	na	20%

Table 1.1: *Reference table*

Let us understand how to calculate the value of resistance by using the resistance color code. One resistor is shown in *Figure 1.9*:

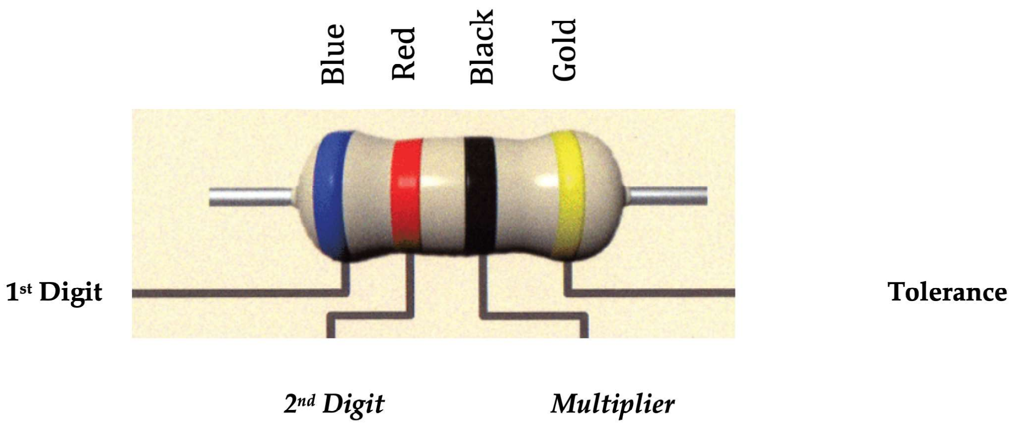


Figure 1.9: *Sample resistor*

As shown in *Figure 1.9*:

- 1st band is Blue, which makes the first digit 6.
- 2nd band is Red, and hence, 2nd digit is 2.

- 3^{rd} band is Black, and hence, the multiplier is $10^0 = 1$
- 4^{th} band is Golden, which signifies ±5% tolerance.

The final value of the resistor is $62 \times 10^0 = 62 \times 1 = 62\ \Omega$, ±5% Tolerance.

Various combinations of resistors

In circuits, resistors are generally used in combination. Several resistors can be either connected in *series* or *parallel (or shunt)*. It is important to understand the manner in which resistors are connected and to calculate the total resistance of the circuit.

Resistors in series connection

When two or more resistors are connected end-to-end, as shown in *Figure 1.10*, they are said to be connected in series. The total (or equivalent) resistance is equal to the sum of all individual resistances. It is important to note that the current through the series circuit is the same, while the voltage drop across each resistor will be different and depends on the resistance value and the current flowing. Please refer to the following figure:

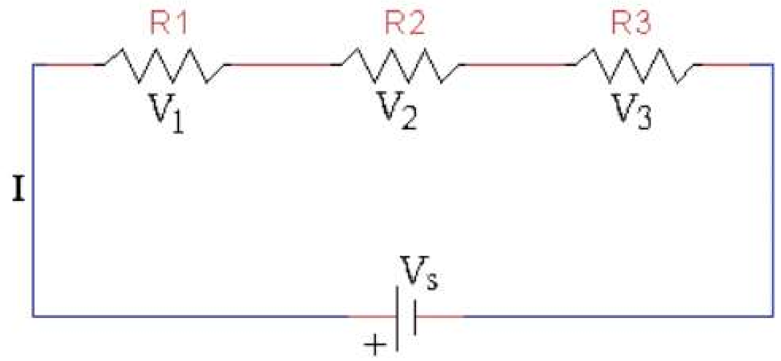


***Figure 1.10**:* *Series resistors*

The total or equivalent resistance can be written as follows:

$$\mathbf{R = R_1 + R_2 + R_3}$$

Resistors in shunt or parallel connection

When two or more resistors are so connected that both ends are joined together, resistors are said to be in **parallel**. The reciprocal of the total or equivalent resistance is the sum of the reciprocals of all individual resistances. Please note that in this case, the voltage across parallel terminals (or resistances) remains the same while the current gets divided among branches. The total current is the sum of all individual branch currents. It is important to remember that the equivalent resistance is less than the least among the resistors.

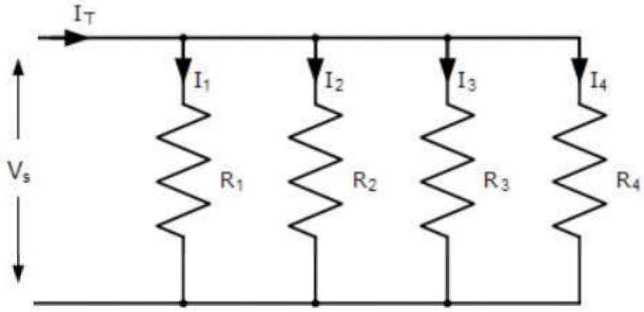


Figure 1.11: *Parallel resistors*

The total or equivalent resistance can be written as follows:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

Capacitors

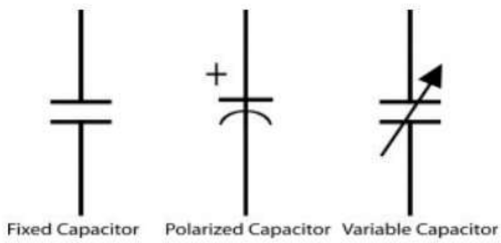


Figure 1.12: *Capacitor symbols*

The capacitor is another passive element used extensively. The symbol of the capacitor is shown in *Figure 1.12*. A capacitor consists of two conducting plates separated by an insulating material called a dielectric. Capacitors are used to store the charges, which can be released as desired. The conducting plates can be rectangular, circular, or cylindrical in shape. If a battery is connected across a capacitor, it starts charging exponentially, and when the battery is removed, it discharges (provided that the circuit is complete). One significant property of a capacitor is that it offers a very high impedance to dc and, hence, is said to block dc, whereas it offers a very low impedance to ac and, hence, allows ac to pass through it. Due to this property, it finds a variety of applications such as coupling, filtering dc, tuning, signal generation, and so on.

A parallel plate capacitor is shown in *Figure 1.13*:

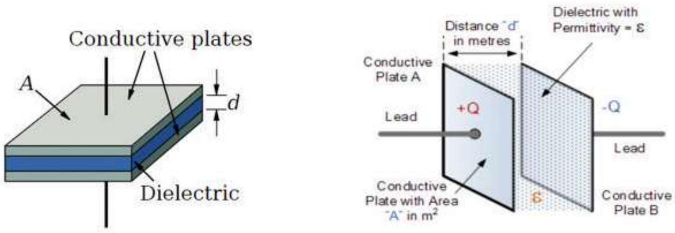


***Figure 1.13**: Parallel plate capacitor*

The value of the capacitance is given by the following:

$$C = \frac{\in A}{d} \quad \textbf{Farads}$$

Where C is the capacitance in farads (F), ∈ is the permittivity of the dielectric, d is the distance between the plates, and A is the area of the plates.

The relationship between current and voltage across a capacitor is given by the following:

$$I = C\frac{dV}{dt}$$

The reactance offered by a capacitor to ac signal is given by the following:

$$X_C = \frac{1}{2\pi fC}$$

Few important specifications

- **Working voltage:** The working voltage of a capacitor is the maximum voltage at which it can operate without failure.
- **Tolerance:** It is the allowed deviation (±) from the nominal value and is expressed in percentage (%).
- **Effective series resistance (ESR):** ESR acts like series resistance with the capacitor. Low ESR is desirable, which signifies low power dissipation. With the thickness remaining the same, ESR decreases when the plate area increases.
- **Insulation resistance:** Insulation resistance of the dielectric to dc voltage.
- **Temperature coefficient:** It is defined as the change in capacitance per degree change in temperature. It is expressed in ppm/°C.