Chapter 1. INTRODUCTION

The purpose of the first chapter is to introduce some fundamental concepts and terminology which will be used through the book. In particular, we shall learn about signals and about one of the most important signal-processing functions electronics circuits are designed to perform, namely, signal amplification. We shall then look at models for linear amplifier. These models will be employed in subsequent chapters in the design and analysis of actual amplifier circuits.

Whereas the amplifier is the basic element of analog circuits, the logic inverter plays this role in digital circuits. We shall therefore take a preliminary look at the digital inverters, its circuit function, and important characteristics.

In addition to motivating the study of electronics, this chapter serves as a bridge between the study of linear circuits and that of the subject of this book: the design and analysis of electronic circuits.

1.1. FUNDAMENTAL PARAMETERS

1.1.1. Voltage and current

a. Voltage

Originating from the point of view in physics, a voltage is defined as the difference between the potentials of two arbitrary points in electronics circuits:

$$U_{AB} = U_A - U_B \tag{1-1}$$

where U_A and U_B are the potentials of two points A and B in a circuit towards the ground. As another definition, a voltage is determined as the electrical "pressure" that causes free electrons to travel through an electrical circuit. It is also known as electromotive force (emf) and measured in ***volts*** (**V**). Usually, one location in the circuit is selected as the ground which has zero potential.

Kirchoff's voltage Law **(KVL)**

The KVL states that the voltages between the two end-points of parallel connected components are equal. From this fact, the sum of potential falls U_i on i^{-th} component in a loop of a circuit is equal to zero. That means:

$$\sum_i U_i = 0 \tag{1-2}$$

b. Current

A current is defined as the amount of electrical charge or the number of free electrons moving across a given point in an electrical circuit per unit of time and measured in ***amperes*** (**A**). If a circuit is broken at any point, the electric current will cease in the entire loop, and the full voltage produced by the battery will be manifested across the break, between the wire ends that used to be connected. When a voltage source is connected to a circuit, the voltage will cause a current through that circuit which is directed from a point with higher potential to the one with lower potential. That means the current is reversely directed to the direction of electron flow.

Kirchoff's current Law **(KCL)**

In one loop of a circuit, the amount of electrical charge at any point is the same as the amount of electrical charge at any other point. Therefore, the KCL states that an arithmetical sum oxaf the currents I_i coming into a node and out from that node are equal to zero.

$$\sum_i I_i = 0 \tag{1-3}$$

A circuit is directed from a point with a high potential to the one with lower potential in a circuit. That means it is reverse to the moving direction of the electrons.

1.1.2. Independent and dependent sources

a. Source

A source is an element or a device which can generate a voltage or a current. A source can be represented either as a voltage or current sources depending on its internal resistance.

b. Independent sources

1. ***Voltage source***:

An ideal source U_{source} has zero internal resistance R_{source}, so that change in load resistance R_{load} will not change in voltage supplies E_{source}. In general, a real source is defined as:

$$U_{source} = E_{supply} \cdot \frac{R_{load}}{R_{source} + R_{load}} \tag{1-4}$$

2. ***Current source***:

An ideal current source I_{source} has infinity internal resistance so that changes in load resistance will not change in current supplies. A real source:

$$I_{source} = I_{source} \cdot \frac{R_{source}}{R_{source} + R_{load}} \tag{1-5}$$

3. ***Relation between voltage and current sources***:

From equations 1-4 and 1-5 above, relation bitween can be acrived as:

$$I_{load} = \frac{E_{source}}{R_{source}} \tag{1-6}$$

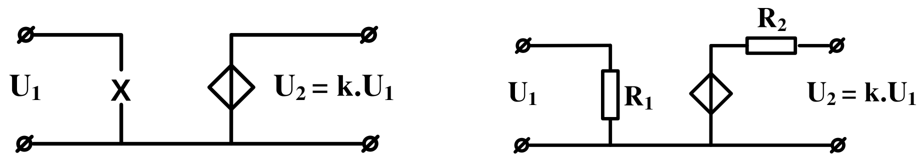
$$U_{load} = I_{source} \cdot R_{source} \tag{1-7}$$

c. Dependent sources

In real circuits, the dependent sources considered in Figure 1-4 play the role of amplifiers. From Figure 1-4 thee sources are represented as amplifier circuit models and we can observe that the input resistance R_1 of the given amplifiers can be determined by applying an input voltage and measuring the input current. The output resistance is found as the ratio of the open-circuit output voltage to the short-circuit output current. Alternatively, the output resistance can be found by eliminating the input signal source and applying a voltage signal to the output of the amplifier.

The amplifier models considered above are unilateral. That is, signal flow is unidirectional, from input to output. Most real amplifiers show some reverse transmission, which is usually undesirable but must nonetheless be modeled.

1. ***Voltage source controlled by a voltage* (VV)**: Voltage amplifier

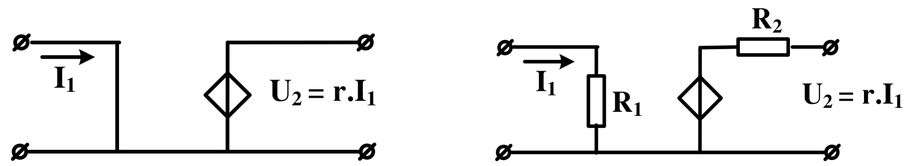


a. b.

Figure 1-1. ***Voltage source controlled by a voltage***

a. Ideal source; b. Real source

2. Voltage source controlled by a current (**VC**): Transresistance amplifier



a. b.

Figure 1-2. ***Voltage source controlled by a current***

a. Ideal source; b. Real source

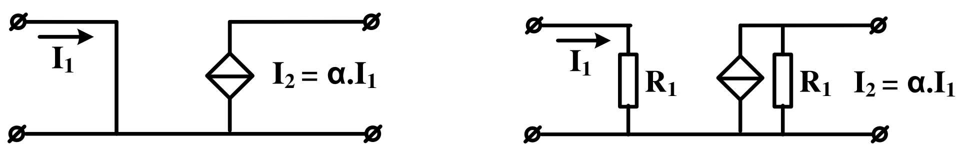
3. Current source controlled by voltage (**CV**): Transconductance amplifier

a. b.

Figure 1-3. ***Current source controlled by voltage***

a. Ideal source; b. Real source

4. Current source controlled by a current (**CC**): Current amplifier



a. b.

Figure 1-4. ***Current source controlled by a current***

a. Ideal source; b. Real source

1.1.3. Linear and non-linear elements

a. Resistor (R)

Special components called resistors are made for the express purpose of creating a precise quantity of resistance for insertion into a circuit. They are typically constructed of metal wire or carbon, and engineered to maintain a stable resistance value over a wide range of environmental conditions. Typically, the purpose of a resistor is not to produce usable heat, but simply to provide a precise quantity of electrical resistance, which is measured in Omh (Ω). In other word, the resistance is defined as the property of a resistor to oppose the flow of electrical current through itself. Regarding resistor R, voltage U and current I in a circuit, there are some useful relations as given below:

1. *Ohm's Law*:

$$U = I \cdot R \tag{1-8}$$

or

$$R = \frac{U}{I} \tag{1-9}$$

2. *Electric power:*

$$P = U \cdot I = I^2 \cdot R = \frac{U^2}{R} \tag{1-10}$$

3. *n resistors in parallel*:

Current flow in each resistor: $$I = \sum_{i=1}^{n} I_i \tag{1-11}$$

Voltage drop over each resistor: $$U_{R_1} = U_{R_2} = \cdots = U_{R_n} \tag{1-12}$$

Equivalent resistance: $$\frac{1}{R_{total}} = \sum_{i=1}^{n} \frac{1}{R_i} \tag{1-13}$$

4. *Current divider formula fo two resistors R_1 and R_2 in parallel*:

The current flow in each resistor:

$$I_1 = I \cdot \frac{R_2}{R_1 + R_2} \tag{1-14}$$

$$I_2 = I \cdot \frac{R_1}{R_1 + R_2} \tag{1-15}$$

5. n resistors in series:

Voltage between A and B end-points: $U_{AB} = \sum_{i=1}^{n} U_i$ (1-16)

Current flow in each resistor: $I_{R_1} = I_{R_2} = \cdots = I_{R_n}$ (1-17)

Equivalent resistance: $R_T = \sum_{i=1}^{n} R_i$ (1-18)

6. Voltage divider formula in case of two resistors in series:

$$U_1 = U_{AB} \cdot \frac{R_1}{R_1 + R_2} \tag{1-19}$$

$$U_2 = U_{AB} \cdot \frac{R_2}{R_1 + R_2} \tag{1-20}$$

b. Inductor (L)

A component having the property to oppose any change in current through itself, by storing and releasing energy in a magnetic field surrounding itself is called inductor and typically denoted by L. An inductor's ability to store energy as a function of current results in a tendency to try to maintain current at a constant level, and therefore it is called inductance and measured by Henry (H). When current through an inductor I_L is increased or decreased, the inductor "resists" the change by producing a voltage U_L between its leads in opposing polarity to the change. This relation can be expressed by the following equations:

Voltage drop over an inductor L: $U_L = L \cdot \frac{dI_L}{dt}$ (1-21)

$$I_C = \frac{1}{L} \int U_L dt \tag{1-22}$$

c. Capacitor (C)

A component having the property to oppose any change in voltage across its terminals, by storing and releasing energy in an internal electric field is called capacitor and typically denoted by C. A capacitor's ability to store energy as a function of voltage results in a tendency to try to maintain voltage at a constant level, and therefore it is called capacitance and measured in Farad (F). In other words, capacitors tend to resist changes in voltage drop. When voltage across a capacitor is increased or decreased, the capacitor "resists" the change by drawing current from or supplying current to the source of the voltage change, in opposition to the change. This relation can be expressed by the following equations:

$$I_C = C \cdot \frac{dU_C}{dt} \tag{1-23}$$

$$U_C = \frac{1}{C}\int I_C dt \tag{1-24}$$

1.2. INFORMATION AND SIGNALS

1.2.1. Definition

Signals contain information about a variety of things and activities in our physical world. To extract required information from a set of signals, the observer invariably needs to process the signals in some predetermined manner. This signal processing is usually performed by electronic systems. However the signal must be converted into an electric signal, that is, a voltage or current by using devices called transducers. The information is represented by a signal.

Signals may fall into two categories: analog and digital. An analog signal is continuous in time and analogous to the physical signal that it represents. The magnitude of an analog signal exhibits a continuous variation over its range of activity. Electronic circuits that process such signals are known as analog circuits.

A digital signal is an alternative form of signal representation as a sequence of numbers, each number representing the signal magnitude at an instant of time.

The conversion between the two categories of signals can be done by analog-to-digital converter (ADC) or digital-to- analog converter (DAC).

1.2.2. Signal presentation

From the discussion above, it should be apparent that a signal is the time-varying quantity that can be represented as a continuous signal as shown in Figure 1-5. In fact, the information content in the signal is represented by the changes in its magnitude as time in progresses. In general, such waveforms are difficult to be characterized mathematically. In other words, it is not easy to describe succinctly an arbitrary-looking waveform such as that in Figure 1-2. Of course, such a description is of great importance for the purpose of designing appropriate signal-processing circuits that perform desired functions on the given signal.

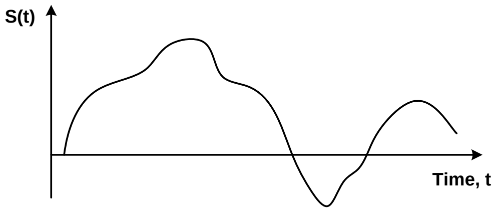


Figure 1-5. ***An example of a signal waveform***

Let's consider some special representations of signals that are frequently used in practice:

1. A sinusoidal signal is determined as:

$$s(t) = A_m \sin(\omega t + \varphi) \tag{1.25}$$

where A_m: The amplitude of the signal;

$\omega = \frac{2\pi}{T} = 2\pi f$: Angle frequency, where T and f are the period and frequency of the signal, respectively.

φ: Initial phase offset or displacement.

2. Continuous voltage and current signals in sinusoidal waveform:

$$u(t) = U_m \sin(\omega_0 t + \varphi_u) \tag{1.26}$$

$$i(t) = I_m \sin(\omega_0 t + \varphi_i) \tag{1.27}$$

3. Imaginary presentation of voltage and current signals:

$$u(t) = U_m e^{j(\omega_0 t + \varphi_u)} \tag{1.28}$$

$$i(t) = I_m e^{j(\omega_0 t + \varphi_i)} \tag{1.29}$$

4. Relation between voltage and current signals in a circuit can be written in a vector form that is derived from Ohm Law:

$$u_R(t) = R \cdot i(t) \tag{1.30}$$

$$\text{or } \overrightarrow{U_R} = R \cdot \overrightarrow{I_R} \tag{1.31}$$

$$u_L(t) = L \cdot \frac{di_L(t)}{dt} \tag{1.32}$$

$$\text{or } \quad \overrightarrow{U_L} = L \cdot \frac{d\overrightarrow{I_L}}{dt} = L \cdot I_m \cdot e^{j(\omega_0 t + \varphi_i)} \cdot \omega_0 j \tag{1.33}$$

Thus:

$$\overrightarrow{U_L} = j\omega_0 L \cdot \overrightarrow{I_L} \tag{1.34}$$

$$u_C(t) = \frac{1}{C}\int i_C(t)dt \tag{1.35}$$

$$\text{or } \overrightarrow{U_C} = \frac{1}{C} \cdot \int \overrightarrow{I_C} dt = \frac{1}{j\omega_0 C} \cdot \overrightarrow{I_C} \tag{1.36}$$

Thus:

$$\overrightarrow{U_C} = \frac{1}{j\omega_0 C} \cdot \overrightarrow{I_C} \tag{1.37}$$

5. General Om's Law:

$$\vec{U} = Z \cdot \vec{I} \tag{1.38}$$

where

$$Z = \begin{cases} R \\ j\omega L \\ \dfrac{1}{j\omega C} \\ j\omega M \end{cases}$$

or

$$\vec{I} = Y \cdot \vec{U} \tag{1.39}$$

Here Z and Y stand for the impedance and susceptance, respectively.

6. Binary representation of impedance and susceptance:

$$Z = R + jX \tag{1.40}$$

Therefore: $Z_R = R$ (1.41)

$$Z_L = jX_L \text{, where } X_L = \omega L \quad (1.42)$$

$$Z_C = jX_C \text{, where } X_C = -\frac{1}{\omega C} \quad (1.43)$$

Analogically: $Y = G + jB$ (1-44)

$$Y_R = \frac{1}{R} \quad (1\text{-}45)$$

$$Y_L = jB_L \text{, where } B_L = -\frac{1}{\omega L} \quad (1\text{-}46)$$

$$Y_C = jB_C \text{, where } B_C = \omega C \quad (1\text{-}47)$$

7. Presentation in imaginary exponential form:

$$Z = |Z| \cdot e^{j\varphi_Z} \quad (1\text{-}48)$$

where $|Z|$ represents the module and φ_Z the phase angle.

$$|Z| = \sqrt{R^2 + X^2} \quad (1\text{-}49)$$

$$\varphi_Z = \arctan\left(\frac{X}{R}\right) \quad (1\text{-}50)$$

8. Om's Law represented in imaginary exponential form:

$$Z = \frac{\vec{U}}{\vec{I}} = \frac{E_m e^{j(\omega t + \varphi_e)}}{I_m e^{j(\omega t + \varphi_i)}} = |Z| e^{j\varphi_Z} \quad (1\text{-}51)$$

where $|Z| = \frac{E_m}{I_m}$ and $\varphi_Z = \varphi_e - \varphi_i$

$$Y = \frac{\vec{I}}{\vec{U}} = \frac{I_m e^{j(\omega t + \varphi_i)}}{E_m e^{j(\omega t + \varphi_e)}} = |Y| e^{j\varphi_Y} \quad (1\text{-}52)$$

where $|Y| = \frac{I_m}{E_m}$ and $\varphi_Y = \varphi_i - \varphi_e$

1.2.3. Properties of signal

A length of a signal is defined as the existing time of the signal. The signal length typically means the busy period of a circuit or an electronic system. If the signal $s(t)$ appears at t_0 and its length is τ, then its average value, denoted as $s_a(t)$ is represented as:

$$s_a(t) = \frac{1}{\tau}\int_{t_0}^{t_0+\tau} s(t)dt \tag{1-53}$$

where τ is the length of the signal appearing at t_0

Energy $E_s(t)$ of a signal is determined by:

$$E_s(t) = \int_{t_0}^{t_0+\tau} s^2(t)dt = \int_{-\infty}^{+\infty} s^2(t)dt \tag{1-54}$$

Average power $\overline{s(t)}$ of a signal in its existing time is determined as:

$$\overline{s(t)} = \frac{1}{\tau}\int_{t_0}^{t_0+\tau} s^2(t)dt = \frac{E_s}{\tau} \tag{1-55}$$

Effective value $s_{eff}(t)$ is defined as:

$$\overline{s(t)} = \sqrt{\frac{1}{\tau}\int_{t_0}^{t_0+\tau} s^2(t)dt} = \sqrt{\frac{E_s}{\tau}} \tag{1-56}$$

A dynamic range of a signal is evaluated as the ratio between the maximum and minimum of the instantaneous power of the signal and usually measured in dB. Commonly this parameter characterizes the effect of the signal on an electronic system in its existing time:

$$D(dB) = 10\log\frac{\max\{s^2(t)\}}{\min\{s^2(t)\}} = 20\lg\frac{\max s(t)}{\min s(t)} \tag{1-57}$$

A signal can be expressed in terms of even and odd components, that is:

$$s_{even}(t) = s_{even}(-t) = \frac{1}{2}[s(t) + s(-t)] \tag{1-58}$$

$$s_{odd}(t) = s_{odd}(-t) = \frac{1}{2}[s(t) - s(-t)] \tag{1-59}$$

$$s_{even} + s_{odd} = s(t) \tag{1-60}$$

$$\overline{s_{even}} = s(t) \tag{1-61}$$

$$\overline{s_{odd}} = 0 \tag{1-62}$$

A signal can also be decomposed in an alternate current (AC) and discrete current (DC) components so that:

$$S(t) = S_{ac}(t) + S_{dc}(t) \tag{1-63}$$

From equation 1-53, an AC signal has an average value in time $S_{ac\_a} = 0$ and a DC signal has a constant value in time $S_{dc} = const$.

1.3. EXAMPLES

➢ Example 1-1

Calculate the amount of current (I), given values of voltage (E) and resistance (R) for the circuit in Figure 1-6a.

Solution

$$I = \frac{E}{R} = \frac{12V}{3\Omega} = 4A$$

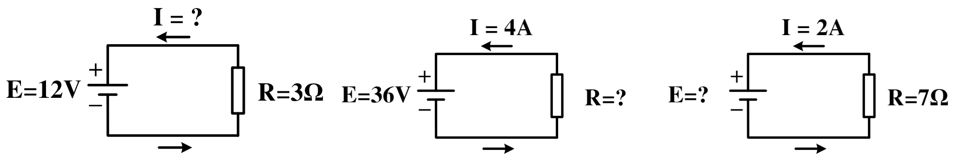


Figure 1-6. ***DA Circuit***

➢ Example 1-2

Calculate the amount of resistance (R), given values of voltage (E) and resistance (I) for the circuit in Figure 1-6b.

Solution

$$R = \frac{E}{I} = \frac{36V}{4A} = 9\Omega$$

➢ Example 1-3

Calculate the amount of resistance (R), given values of voltage (E) and resistance (I) for the circuit in Figure 1-6c.

Solution

$$E = IR = 2A \cdot 7\Omega = 14V$$

➢ Example 1-4

A serial circuit is given in Figure 1-7. Determine the voltage drop over each resistor.

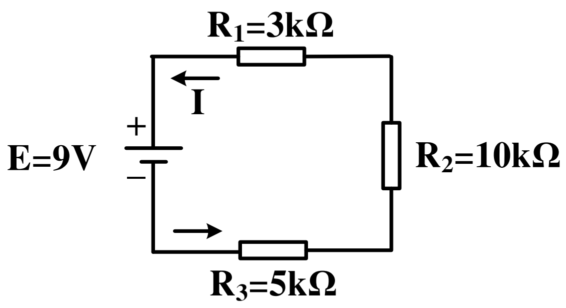


Figure 1-7. ***A serial circuit***

Solution

$$R_{equ} = R_1 + R_2 + R_3 = 3k\Omega + 10k\Omega + 5k\Omega = 18k\Omega$$

$$I = \frac{E}{R_{equ}} = \frac{9V}{18k\Omega} = 500\mu A$$

Then the voltage drop over each resistor is determined as follows:

$$U_{R_1} = IR_1 = 500\mu A \cdot 3k\Omega = 1.5V$$

$$U_{R_2} = IR_2 = 500\mu A \cdot 10k\Omega = 5V$$

$$U_{R_3} = IR_3 = 500\mu A \cdot 5k\Omega = 2.5V$$

➢ Example 1-5

A parallel circuit is given in Figure 1-8. Determine the current flowing across each resistor.

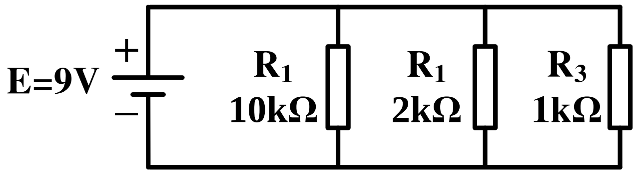


Figure 1-8. ***A parallel serial circuit***

Solution

$$I_{R_1} = \frac{E}{R_1} = \frac{9V}{10k\Omega} = 0.9mA$$

$$I_{R_2} = \frac{E}{R_2} = \frac{9V}{2k\Omega} = 4.5mA$$

$$I_{R_3} = \frac{E}{R_3} = \frac{9V}{1k\Omega} = 9mA$$

Total current in the circuit is given as:

$$I = I_{R_1} + I_{R_2} + I_{R_3} = 0.9mA + 4.5mA + 9mA = 14.4mA$$

Total resistance in the circuit is determined as:

$$R_{equ} = \frac{E}{I} = \frac{9V}{14.4mA} = 625\Omega$$

Actually, the equivalent resistance can be obtained from equation:

$$\frac{1}{R_{equ}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Substituting the values of R_1, R_2 and R_3 in to the above equation, the same value of R_{equ} is obtained.

1.4. HOMEWORK

- **Homework 1-1**

Given a circuit in Figure 1-9. Calculate the equivalent resistance and total current of the circuit. Determine the current flowing in each branch and the voltage drop over each resistor in the circuit.

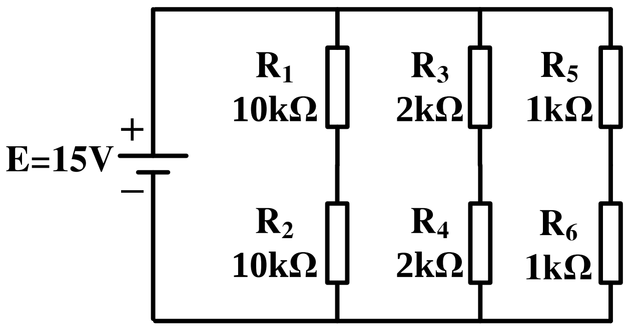


Figure 1-9. ***A circuit for homework 1-1***

➢ Homework 1-2

Given a circuit in Figure 1-10. Calculate the equivalent resistance and total current of the circuit. Determine the current flowing in each branch and the voltage drop over each resistor in the circuit. In addition, evaluate the equivalent resistance for each loop and the corresponding voltage drops.

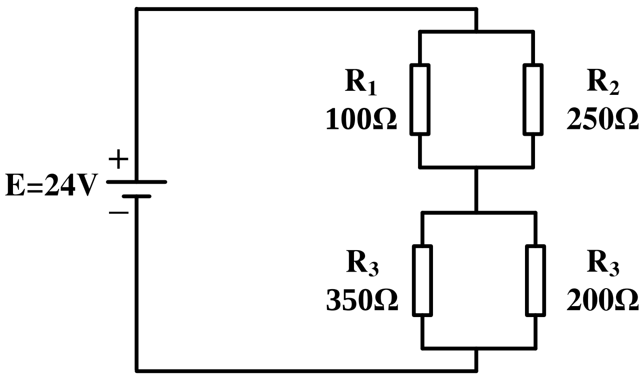


Figure 1-10. ***A circuit for homework 1-2***