EE 204 - Analog Circuits
Lecture 1

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1 Circuit Fundamentals

Circuits lie at the heart of Analog and Digital Systems. Everything that we are able to realise in electrical and electronics would not be possible without circuits.

Let's go over some formal definitions for circuits.

1.1 Definition of a Circuit

Definition 1.1

Logical arrangement of electrical components form a circuit. It must form a closed loop.

Alternate: A circuit is a path between two or more points along which an electrical current can be carried.

1.2 Types of Circuits

Circuits can be further classified into two types:

1. Discrete Circuit
   (a) A discrete circuit is an electronic circuit built out of discrete components, such as resistors, transistors, etc., instead of a single integrated circuit.
2. Integrated Circuit
   (a) An integrated circuit (IC), sometimes called a chip or microchip, is a semiconductor wafer on which thousands or millions of tiny resistors, capacitors, and transistors are fabricated.
   (b) An IC can function as an amplifier, oscillator, timer, counter, computer memory, or microprocessor. A particular IC is categorized as either linear (analog) or digital, depending on its intended application.

1.3 Electrical vs Electronic Circuits

- "Electrical circuit" comprises only PASSIVE components, such as resistors, capacitors and inductors.
  - Passive: No external energy/power source is required
- In "electronic circuit" at least one of the components is ACTIVE, or executes some transformation (magnification/reduction) of the current passing through
  - Active: External energy/power source is required

2 Circuit Elements

In order to construct a circuit, we need logical circuit elements. Some of them are:

1. Resistor ($E_g \approx 9$eV)(E_g is the Band Gap Energy. Depending on the Band Gap Energy, we can classify materials as conductors, insulators or semiconductors)
2. Capacitor
3. Inductance
4. Diode ($E_g \approx 1.1$eV)
5. Variable Resistor
6. RRAM (Resistive Random Access Memory)

Before going into the various circuit elements, let's understand the types of materials that are used.

2.1 Types of Materials

- Metals: Resistivity $\approx 10^{-6}\Omega$ cm
- Semiconductors: Resistivity $\approx 10^{-3}$ to $10^{9}\Omega$ cm
- Insulators: Resistivity $\approx 10^{2}2\Omega$ cm

2.2 Resistor

We can relate resistance as a property of the resistor using the material properties as follows:

$$R = \frac{\rho l}{A}$$

where,

- ρ is the resistivity of the material,
- l the length of the resistor,
- and A the area of cross-section.

But, how can we find the resistivity(ρ) from material properties.
The following relations help us achieve that (Proof has been omitted):
Conductivity,

$$\sigma = ne\mu$$

Resistivity,

$$\rho = \frac{1}{\sigma}$$

where,

- μ is the permeability,
- n is the electron density,
- and e is the electronic charge.

Resistors in Series

$$R = R_1 + R_2 + ...$$

Resistors in Parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + ...$$

In physical usage, Resistors are color coded whicb aids the calculation of the value of resistor (with a tolerance value).

Here, is the color coded chart which is very important in actual usage of resistors.

2.3 Capacitors

We can relate capacitance as a property of the capacitor using the material properties as follows:

$$C = \frac{\epsilon A}{d}$$

where,

- ϵ is permittivity,

Color	Signficant figures			Multiply	Tolerance (%)	Temp. Coeff. (ppm/K)	Fail Rate (%)
black	0	0	0	x 1		250 (U)	
brown	1	1	1	x 10	1 (F)	100 (S)	1
red	2	2	2	x 100	2 (G)	50 (R)	0.1
orange	3	3	3	x 1K		15 (P)	0.01
yellow	4	4	4	x 10K		25 (Q)	0.001
green	5	5	5	x 100K	0.5 (D)	20 (Z)	
blue	6	6	6	x 1M	0.25 (C)	10 (Z)	
violet	7	7	7	x 10M	0.1 (B)	5 (M)	
grey	8	8	8	x 100M	0.05 (A)	1(K)	
white	9	9	9	x 1G			
gold			3th digit only for 5 and 6 bands	x 0.1	5 (J)		
silver				x 0.01	10 (K)		
none					20 (M)		

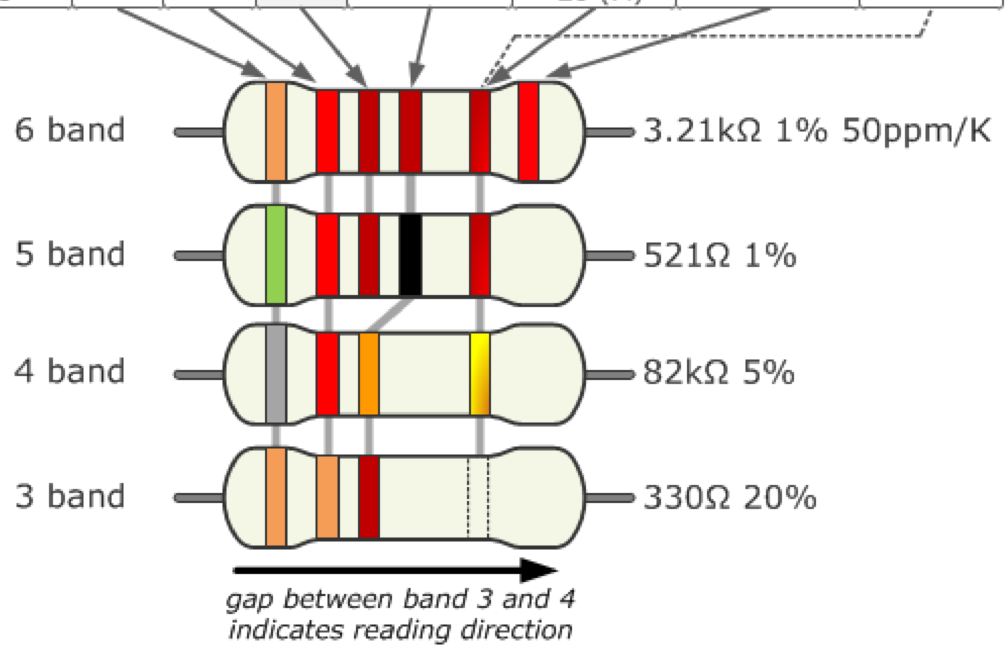

Figure 1: Resistor Color Codes

- A is the area of the plate,
- and d is the separation between the plates

Capacitors in Series

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$$

Capacitors in Parallel

$$C = C_1 + C_2 + \ldots$$

3 Kirchhoff's Laws

3.1 Kirchhoff's Current Law (KCL)

For any network of wires, algebraic sum of current meeting in any branch point is zero

3.2 Kirchhoff's Voltage Law (KVL)

The algebraic sum of the e.m.f in any close circuit or loop at the network is equal to the algebraic sum of the product of the resistance of each line of that circuit or loop and the current flowing through them, provided that for each line ohm's law is obeyed. (In general, for voltage drop across any circuit element)

4 Combination of Circuit Elements

4.1 LR Circuits

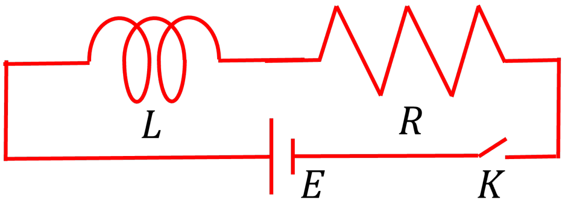

Figure 2: LR Circuit

4.1.1 Growth of Current

$i = i_0(1 - e^{-\frac{RT}{L}})$ is the equation for the current growth that is obtained by using KVL

4.1.2 Decay of Current

$i = i_0 e^{-\frac{RT}{L}}$ is the equation for the current decay by solving KVL

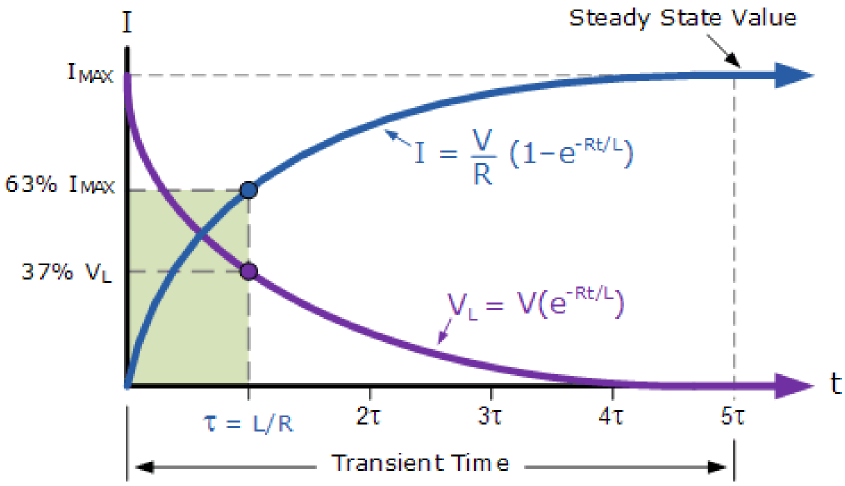

Figure 3: Growth and Decay for LR Circuit

4.2 RC Circuits

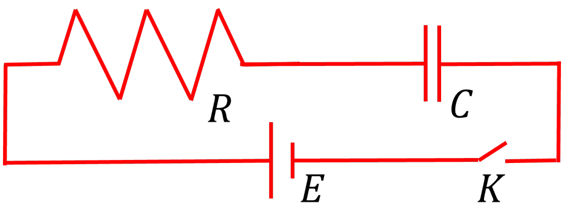

Figure 4: RC Circuit

4.2.1 Growth of Current

$q = q_0(1 - e^{-\frac{t}{RC}})$ represents current growth for the RC Circuit.
Also, $i = \frac{dq}{dt}$

4.2.2 Decay of Current

$q = q_0 e^{-\frac{t}{RC}}$ represents current decay for the RC circuit.