Electronics
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Research Interests:
Optical Properties of Semiconductors
Photonic Crystals – Dielectric and Metallic
Solid-state Quantum Information Processing

Who am I & how to find me?

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Course Outline

- **Circuit Analysis**
- **Diodes, BJT, FET and their Applications**
- **Op-Amps, Linear and Non-linear Circuits**
- **Digital Electronics : Gates, FlipFlops, Counters,..**

- **Introduction to Micro-Processor**
- **D/A and A/D converters**
- **Principles of Modern Instrumentation**
  - **SCA, MCA etc.**
- **Transducers : Pressure, Temperature, Light, Voltage**

Evaluation

- **Home Assignments**
- **Quizzes**
  - **Could be surprise – those who miss gets zero**
- **Mid-semester Exam**
- **Final Exam**

- **Any other suggestions?**
  - **Term paper, project,...**

Books to Follow

- Mainly,
- Electronic Principles by Malvino and Bates
- Digital Electronics by Leach and Malvino
- Electronic Devices and Circuits by Millman and Halkias
  - Some material from various websites is also used

Detailed Topics to be covered

Circuit Analysis

- Passive Components – R, C, L
- Circuits with R, C, L combinations
- Ohm's Law
- Kirchoff's Laws
- Joule's Law
- Superposition Theorem
- Thevenin's Theorem
- Norton's Theorem
- Millman's Theorem
- Reciprocity theorem
- Compensation Theorem
- Maximum Power Transfer Theorem
- Kennelly's Star-Delta Transformations

Diode

- Thermionic Diode
  - Space charge current, thermionic diode vs p-n junction diode
  - Thermionic emission current
- Semiconductor Diodes :
  - Bonds in solids
  - Metals, insulators and semiconductors
- Semiconductors :
  - Energy bands of semiconductors
  - e-h pairs and carrier densities
  - Conductivity
  - Carrier densities – intrinsic and doped semiconductors
  - Charge densities
  - Impurity
  - Fermi level -- intrinsic and doped semiconductors
  - Diffusion
  - Carrier lifetime
- Carrier transport : drift, mobility, and diffusion

- **Processes in Semiconductors:**
  - Excitation in direct and indirect semiconductors
  - Nonradiative processes
- **Carrier recombination and generation**
  - Simple recombination-generation model
  - Band-to-band, Trap-assisted and Surface recombination
- **Generation due to light**
- **Continuity equation**
- **The diffusion equation**
- **The drift-diffusion model**
- **Semiconductor thermodynamics**
  - Thermal equilibrium
  - Fermi energy and Quasi-Fermi energies
  - Energy loss in recombination processes
- **Diffusion current**
- **Tunneling**
- **Metal-Semiconductor contacts**

- **p-n Junctions**
  - Introduction
  - Structure and principle of operation as diode
- **Derivation for barrier width :**
  - solution to Poisson equation with full depletion approximation
  - Flatband diagram
  - Thermal equilibrium
  - The built-in potential at contact
  - Forward and reverse bias
- **p-n diode currents – Solving the Continuity equation for Forward and reverse saturation currents**
- **Capacitance**
  - Junction capacitance
  - Space charge capacitance
  - Diffusion or storage capacitance
- **Diode resistance**
- **p-n diode switching times**
- **Alloy Junction**

- **Reverse bias : Breakdown**
  - General breakdown characteristics
  - Avalanche breakdown
  - Zener breakdown
  - Derivations
  - Surface leakage current
- **Optoelectronic and all-optical devices**
- **Special Purpose Diodes :**
  - Varactor, Zener diode, Tunnel diode, Photodiodes, Schottky diode
- **LEDs :**
  - Introduction to Photoluminescence, Cathodoluminescence, Electroluminiscence
  - Complete analysis of LEDs including fabrication technology
  - p-i-n photodiodes
  - Introduction to Photonic crystals and All-optical Diode
- **Application of Diodes :**
  - Rectifiers, clippers, clampers, voltage multipliers, capacitor input filter, choke input filter, peak-to-peak detector, p-i-n structure for single quantum dot spectroscopy
- **Effect of temperature, doping density, confinement (quantum wells, quantum wires, and quantum dots) on band gap**

BJT

- **Ideal Transistor :**
  - No recombination losses, small diode, no recombination current in depletion layer
- **Bias modes of Transistors :**
  - Detailed analysis of forward active mode, reverse active mode, saturation mode and cut-off mode
- **Ebers-Moll Model**
- **Non-Ideal effects :**
  - base-width modulation, Early effect, change in ideality factor of Collector current, Punch Through effects
  - Current due to recombination in depletion layers
  - High injection effects
  - base spreading resistance
  - temperature dependence and
  - breakdown mechanisms in BJT
- **Load line and Q-point**
- **BJT Technology – history and fabrication technology of BJT, Si IC, Resistor-transistor Logic (RTL)**

FET

- JFET, D-MOSFET, E-MOSFET
  - Drain Curves, Transconductance curves
- Biasing in different regions
- Applications to amplifiers, switches and other applications of each of the different FETS

Digital Electronics

- *Digital Principles and Applications* by Leach and Malvino

Introduction

- **Newton's laws, Maxwell's Equations….**
- **Electronics – involves design and analysis of electronic circuits**
  - **Based on 2 Kirchoff's laws and Ohm's law**
  - **These 3 laws give Network theorems like Thevenin, Norton, Superposition, Y-Delta transform,…..**
  - **what is circuit analysis?**

In the beginning….

- **Voltage (Volts, v): Work done to move a unit of positive charge between 2 points, from a more negative point (lower potential) to a more positive point (higher potential)**
  - **Equivalently, it is amount of energy released when a unit charge moves from higher potential to lower potential**
  - **Voltage is also known as potential difference or electromotive force (emf)**
  - **A joule of work is needed to move a coulomb of charge through a potential difference of 1 volt**

Current

- **Current (Ampere, i) : Rate of flow of electric charge past a point.**
  - **Current of 1 amp => flow of 1 coulomb of charge per second**
  - **Conventional current in a circuit flows from a more positive point to a more negative point (Note : electron flow is in opposite direction)**

Power

- **Power (Watts,P) : Work per unit time is, *v.i* (work/charge x charge/time).**
  - ***v* in volts, *i* in amps, gives Power in Watts**
  - **1 Watt = 1Joule/sec**
  - **Power goes into heat (usually), mechanical energy (motors), radiated energy (lamps, transmitters), or stored energy (batteries, capacitors)**

Voltage and Current Sources

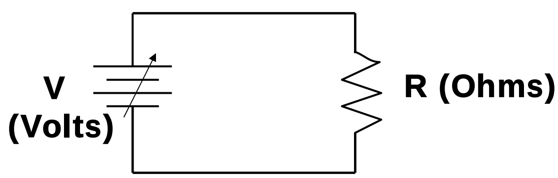
- Voltage Source : A perfect one can maintain a fixed voltage drop across its terminals, regardless of load resistance.
- Current Source : It can maintain constant current through the external circuit, regardless of load resistance or applied voltage.

Heart of Electronics

- I vs V characteristics :
  - To design and develop gadgets with useful I-V characteristics
  - Eg., Resistors, capacitors, diodes, transistors,..

A simple Circuit

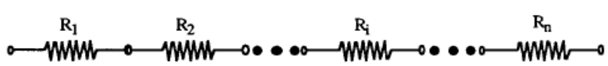
- **Resistor : Current is proportional to Voltage -- Ohm's law : v=i R or R= v/i**



Imagine what a simple circuit like this can do? What could be happening here?

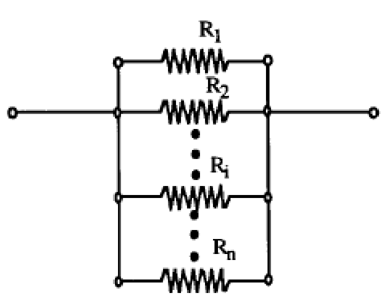
Resistors in Series and Parallel

- **Resistances in Series :**



$R = \Sigma R_i$

- **Resistances in Parallel :**



$$\frac{1}{R} = \sum_{i=1}^{n} \frac{1}{R_i}$$

Colour Code for Resistors

Color	First Band	Second Band	Third Band	Fourth Band Tolerance, %
Black	0	0	1	
Brown	1	1	10	
Red	2	2	100	
Orange	3	3	1,000	
Yellow	4	4	10,000	
Green	5	5	100,000	
Blue	6	6	1,000,000	
Violet	7	7	10,000,000	
Gray	8	8	100,000,000	
White	9	9	1,000,000,000	
Gold			0.1	5%
Silver			0.01	10%
No band				20%

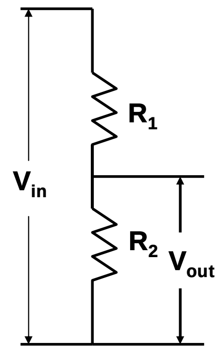
Kirchoff's Laws

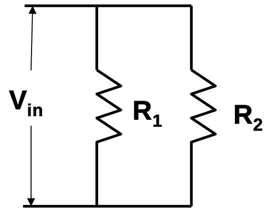
- **Kirchoff's Voltage Law : The sum of voltage drops around any loop in any circuit is zero : Conservation of Energy**
  - **Things placed in parallel have same voltage drop across them**
- **Kirchoff's Current Law :The sum of currents flowing into each node of a circuit is equal to the sum of currents flowing out of that node : Conservation of charge**
  - **For a series circuit, the current is same everywhere**

Resistor combination

$$I = \frac{V_{in}}{R_1 + R_2}$$

$$V_{out} = IR_2 = \frac{R_2}{R_1 + R_2} V_{in}$$





What does this circuit do?

Use of Kirchoff's Laws

- **Solved examples**

Thumb Rules in Using Ohm's Law

For series circuits:

	R_1	R_2	R_3	Total	
E	→	→	→	Add	Volts
I	→	→	→	Equal	Amps
R	→	→	→	Add	Ohms
P	→	→	→	Add	Watts

$$E_{total} = E_1 + E_2 + E_3$$

$$I_{total} = I_1 = I_2 = I_3$$

$$R_{total} = R_1 + R_2 + R_3$$

$$P_{total} = P_1 + P_2 + P_3$$

For parallel circuits:

	R_1	R_2	R_3	Total	
E	→	→	→	Equal	Volts
I	→	→	→	Add	Amps
R	→	→	→	Diminish	Ohms
P	→	→	→	Add	Watts

$$E_{total} = E_1 = E_2 = E_3$$

$$I_{total} = I_1 + I_2 + I_3$$

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

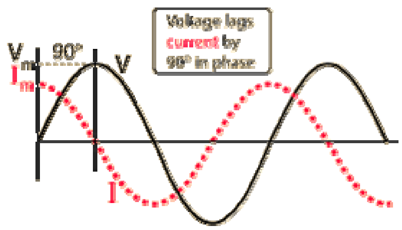
$$P_{total} = P_1 + P_2 + P_3$$

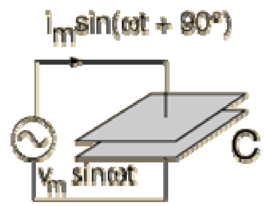
Capacitor

- **Electronic component that stores energy in the form of electrostatic field.**
  - **Two conducting plates separated by an insulating material**
- **C = Q / V (Charge / Voltage)**
- **Capacitors in series :** $$\frac{1}{C} = \sum_{i=1}^{n} \frac{1}{C_i}$$
- **Capacitors in parallel :** $$C = \sum_{i=1}^{n} C_i$$
- **Applications : Filters, block dc, pass ac, bypass, shift phase, isolate, store energy, suppress noise,...**

Capacitor-AC Response

- Charging of capacitor : $Q = CV(1-e^{-t/RC})$, $\tau = RC$





$$I = \frac{I_m}{\sqrt{2}}, V = \frac{V_m}{\sqrt{2}}$$

- Impedance (Z) : Due to phase difference between resistive and capacitor and inductor components
- Capacitive Reactance: $X_C = \frac{1}{\omega C}$

Inductor

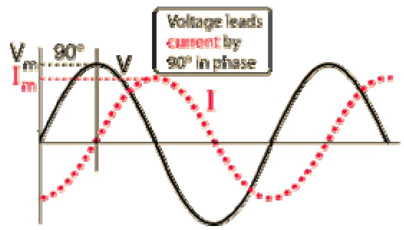
- An electronic component that stores energy in the form of magnetic field.
  - Wire loop or coil

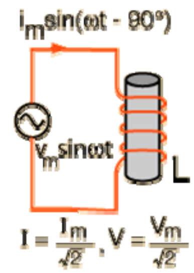
- Inductors in series : $L = \sum_{i=1}^{n} L_i$
- Inductors in parallel : $\frac{1}{L} = \sum_{i=1}^{n} \frac{1}{L_i}$

- Applications : tuners, filters, transformers, ...

Inductor – AC Response

Inductor Current build-up : $I = (V/R)(1-e^{-t/(L/R)})$, $\tau = L/R$



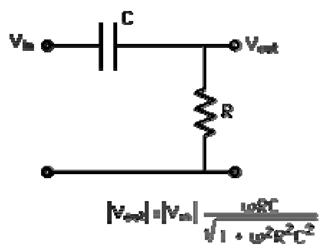


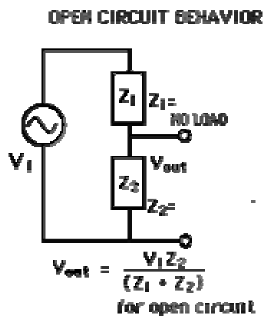
- **Inductive Reactance:** $X_L = \omega L$

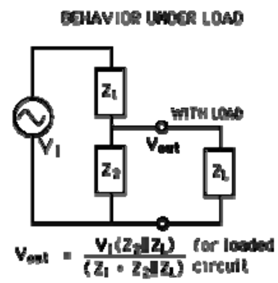
Combination of R,C,L

RC – High Pass Filter Circuit

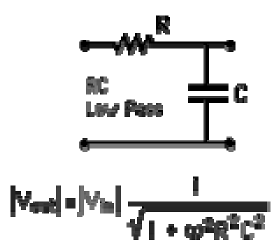
- **Capacitive reactance decreases with frequency**
  - **Passes high frequency components**

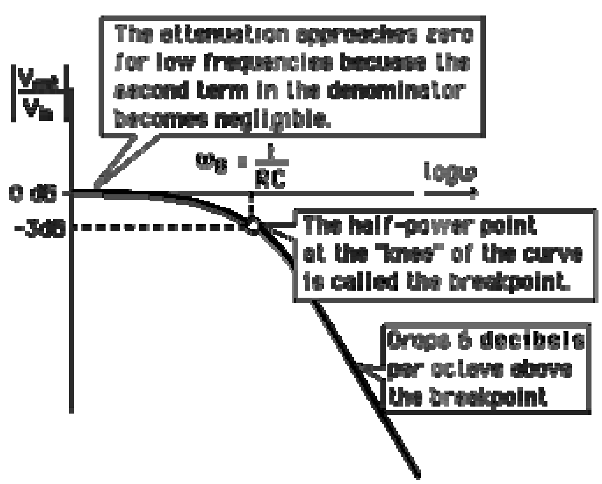






RC – Low Pass Filter Circuit

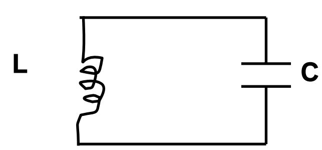




LR Circuit

- **Check what happens**

LC Circuit



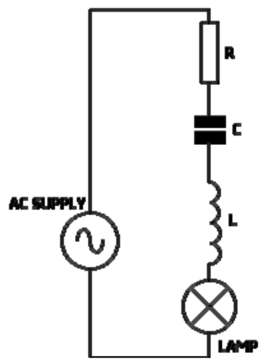
$$X_L = \omega L \qquad X_C = \frac{1}{\omega C}$$

At Resonant Frequency (ω_r), $X_L = X_C$ $\quad \omega_r = \frac{1}{\sqrt{LC}}$

For $\omega < \omega_r$, $X_L < X_C$ -- Circuit is Capacitive
For $\omega > \omega_r$, $X_L > X_C$ -- Circuit is Inductive

In Series : X_C leads by 90° while X_L lags by 90°
--At ω_r they cancel each other and current is maximum
-- Series resonant ckt provides voltage magnification
In Parallel: $X_L = X_C \Rightarrow$ branch currents equal and opposite
--Current in main line is minimum
-- Parallel resonant ckt provides current magnification

LCR Circuit



$$\frac{V_{ac}}{I_{ac}} = Z \text{ ohms}$$

$$Z = \sqrt{(X_c - X_L)^2 + R^2} \text{ ohms}$$