**Circuits Module**

**Basic Electrical Quantities and Relationships**

* **Voltage and Voltage Difference:** Understand the concept of voltage as the potential difference between two nodes in a circuit and its role in driving current.
* **Current:** Learn that current is the flow of electric charge through a circuit and how it is measured in amperes.
* **Resistance:** Know how resistance opposes current flow and is measured in ohms.
* **Calculation of Resistance of Materials:** Be able to calculate resistance using the expression
* **Ohm's Law:** Aapply V=IR to relate voltage, current, and resistance in a circuit.

**Circuit Components and Sources**

* **Open and Short Circuits:** Understand that an open circuit has an infinite resistance (no current flow), while a short circuit has nearly zero resistance (does not affect current flow or drop voltage).
* **Voltage and Current Sources:** Learn the behavior of ideal voltage sources (constant voltage) and current sources (constant current) in circuits.
* **Drawing Circuits:** Be able to represent circuits graphically, including sources, resistors, diodes, and transistors.

**Circuit Analysis Techniques**

* **Kirchhoff's Voltage Law (KVL):** Be able to write and solve equations for voltage loops in a circuit (sum of voltages around a loop equals zero).
* **Kirchhoff's Current Law (KCL):** Be able to write and solve equations for current at a node (sum of currents entering equals the sum of currents leaving).
* **Resistors in Series and Parallel:**
  + **Series:** Understand how total resistance is found
  + **Parallel:** Understand how total resistance is found
* **Voltage Dividers:** Understand how to calculate the output voltage across a resistor in a series configuration
* **Current Dividers:** Be able to calculate current through a branch in a parallel circuit

**Measurement Techniques**

* **Using a Voltmeter:** Learn to measure voltage across components without affecting the circuit significantly.
* **Using an Ammeter:** Understand how to measure current by placing the ammeter in series with the circuit.
* **Using an Ohmmeter:** Be able to measure resistance by disconnecting the component from the circuit and using the ohmmeter.

**Advanced Circuit Analysis**

* **Nodal Analysis:** Learn to write equations for circuits using KCL at each node and solve for unknown node voltages.
* **Voltage at Nodes and Current Through Resistors:** Be able to use nodal analysis and Ohm’s Law to determine these quantities.

**Special Concepts and Applications**

* **Fuses:** Understand the purpose of fuses as safety devices that break the circuit when current exceeds a threshold.
* **Resistive Touchscreens:** Learn how voltage at nodes is calculated in resistive touchscreens and how to determine current flow through resistors in these systems.

**Device Module**

* **Electronic materials - conductors, insulators, and semiconductors:** Understand the difference between conductors, insulators, and semiconductors in terms of their electron flow and how their band structures affect their electrical properties.
* **Charge carrier concentration of electronic materials:** Know how to define and calculate electron and hole concentrations in semiconductors and what factors affect their values.
* **p and n-type doping of silicon:** Understand how the addition of dopants introduces free electrons or holes, and how doping affects the electrical behavior of silicon.
* **Bandgap of materials:** Be able to explain the concept of a bandgap and how it determines whether a material behaves as a conductor, semiconductor, or insulator.
* **Diode:** Know the basic structure of a p-n junction diode, how it conducts current primarily in one direction, and its I-V characteristic curve.
* **Depletion layer:** Understand how the depletion region forms at a p-n junction and how it influences the diode’s conduction properties under various biases.
* **Forward and reverse biasing diodes:** Be able to describe how a diode behaves and conducts (or does not conduct) current when it is forward biased versus reverse biased.
* **Diode equation:** Know the diode current-voltage relationship and the factors influencing the diode’s forward current.
* **Metal-oxide-semiconductor field-effect transistor (MOSFET):** Understand the basic structure of a MOSFET and how the gate voltage controls the current between the source and drain.
* **p and n-type MOSFET:** Be aware of the difference in operation and doping for p-channel and n-channel MOSFETs, and how their thresholds differ.
* **Complementary Metal-Oxide-Semiconductor (CMOS) inverter:** Know how an inverter is constructed using a p-channel and an n-channel MOSFET and how it achieves logic inversion with low power consumption.
* **Linear and saturation mode operation of MOSFET:** Understand how a MOSFET transitions from linear (ohmic) region to saturation (active) region, and that equations for these regions will be provided if needed.
* **Direct vs indirect semiconductors:** Know the difference between direct and indirect bandgap semiconductors and how it affects their optical emission properties.
* **LEDs (Light Emitting Diodes) and Photodiodes (PDs):** Understand how LEDs convert electrical energy into light and how photodiodes convert incident light into electrical signals.
* **LED operation:** Know how biasing and material choice affect the color and efficiency of LED emission.
* **PD operation:** Be able to explain how photodiodes generate a current proportional to incident light intensity and how they are used in sensing applications.
* **LED drive circuit:** Understand the purpose of current-limiting resistors or constant-current drivers for powering LEDs and ensuring stable light output.

**Biosensor System Module**

* **Sensor definition and operation:** Know what a sensor is, what it measures, and how it converts physical quantities into measurable electrical signals.
* **Temperature sensors:** Understand how common temperature sensors (like thermistors or RTDs) change their electrical properties with temperature.
* **Voltage divider circuit for sensors:** Be able to set up and analyze a voltage divider and understand how it can convert a sensor’s resistance change into a measurable voltage.
* **Wheatstone bridge circuit for sensors:** Know how a Wheatstone bridge is used to precisely measure small changes in resistance, often in strain gauges and similar sensors.
* **Sensitivity:** Understand the definition of sensitivity for a sensor and how to determine how much output change corresponds to a given input change.
* **Differential measurements for sensors:** Be aware of why measuring differences between two signals improves accuracy and reduces noise.
* **Op-amp (Operational Amplifier):** Know the purpose of op-amps and their ideal characteristics, and how they are used to amplify and process sensor signals.
* **Inverting and non-inverting op-amp schematic and circuit derivation:** Be able to draw the basic schematics for inverting and non-inverting amplifiers, and derive the relationships between input and output voltages.
* **PD read circuit:** Understand how to use an op-amp or other front-end circuitry to convert a photodiode’s current output into a readable voltage signal.
* **Sensor systems and use of analog front ends:** Know how analog front-end circuits condition the sensor signal (amplify, filter, offset) before it’s digitized or used for further processing.
* **Pulse oximeter, transmission and reflection mode oximeters:** Understand how pulse oximeters measure oxygen saturation using LEDs and PDs in either transmission or reflection mode.
* **Beer-Lambert’s law:** Be able to state and use Beer-Lambert’s law to relate the intensity of transmitted light to the concentration of an absorbing substance.
* **Calculation of oxygenation from the ratio of the ratios of the optical signals:** Know the principle behind measuring oxygen saturation by comparing red and infrared light absorption ratios.
* **Fourier transform and why it's needed:** Understand the importance of the Fourier transform in analyzing signals in the frequency domain, filtering, and extracting useful information.
* **Filters (low, high, band, and notch):** Be able to define low-pass, high-pass, band-pass, and notch filters and understand their effects on signal frequency components.

**Linear Algebra**

* **Vectors:** Know how to represent vectors, perform vector addition, and understand the geometric meaning of vectors.
* **Matrices:** Be able to write, interpret, and manipulate matrices in various dimensions and contexts.
* **Vector addition:** Understand how to add two or more vectors and what that represents geometrically.
* **Vector/matrix multiplication:** Know how to multiply vectors by matrices and how this operation transforms one vector into another.
* **Dot products:** Understand the dot product operation and its interpretation in terms of projection and angle between vectors.
* **Matrix transpose:** Know how to transpose a matrix and understand why and when this operation is used.
* **Matrix determinant:** Be able to calculate the determinant of a matrix and understand what the determinant represents in terms of matrix invertibility.
* **Matrix inverse:** Know how to find the inverse of a matrix (when it exists) and how the inverse is used to solve systems of linear equations.
* **Eigenvalues, eigenvectors:** Understand how to find eigenvalues and eigenvectors and why they are important for analyzing linear transformations and systems.
* **Linear regression:** Be aware of how linear algebra can be used to fit a line (or more complex linear model) to data, and the meaning of the least-squares solution.

**Neural Networks**

* **Fundamental Unit of a Neural Network:** Understand the mathematical definition of neurons.
* **Activation Functions:** Be familiar with Sigmoids, ReLUs
* **Layered Architecture:** Know the structure of input, hidden, and output layers
* **Feedforward Operation:** Understand how inputs propagate through layers to generate outputs.
* **Training Neural Networks:** Be able to explain supervised learning a
* **Perceptrons:** Understand the perceptron model
* **Logical Operations:** Know how perceptrons can implement logical functions like AND, OR, and NAND.
* **Deep Neural Networks (DNNs):** Understand why depth (number of layers) enables the network to learn abstract representations.
* **Hidden Layers and Pattern Detection:** Learn how hidden layers detect features and patterns in data and pass these abstractions to subsequent layers.
* **Cost Functions:** Know the quadratic cost function (mean squared error) and how it measures the difference between predicted and actual outputs.
* **Learning Rate:** Know the role of the learning rate (γ) in determining step size during optimization.

**Noise Module**

* **Noise Definition:** Understand noise as any unwanted signal interfering with the desired signal. Recognize its various effects on electronic systems. Know the mathematical expressions for calculating each type of noise and the frequency spectrum of the noise.
* **Thermal Noise (Johnson-Nyquist):** Know that thermal noise arises from random charge carrier motion in resistive materials and is proportional to temperature and resistance.
* **Shot Noise:** Understand that shot noise is due to the discrete nature of charge carriers and is independent of temperature. It increases with current and follows a Poisson distribution.
* **Flicker Noise (1/f Noise):** Learn that flicker noise dominates at low frequencies and arises from material imperfections. Its power spectral density decreases as frequency increases.

**Communications**

**Properties of Light**

* **Wavelength:** Learn how the wavelength represents the spatial periodicity of light.
* **Refractive Index:** Understand the refractive index and how it relates to speed of light in the medium
* **Snell’s Law:** Use Snell’s law to calculate the relationship between the angles of incidence and refraction at an interface.
* **Polarization:**
  + **Definition:** Learn that polarization refers to the oscillation plane of the electric field in light.
  + **s-Polarization:** Electric field oscillates perpendicular to the interface.
  + **p-Polarization:** Electric field oscillates parallel to the interface.

**Waveguides and Optical Fibers**

* **Waveguides:** Understand that light confined in a waveguide undergoes total internal reflection, enabling it to propagate over long distances.
* **Optical Fibers:** Know that optical fibers function as waveguides and are crucial for modern high-speed data transmission.