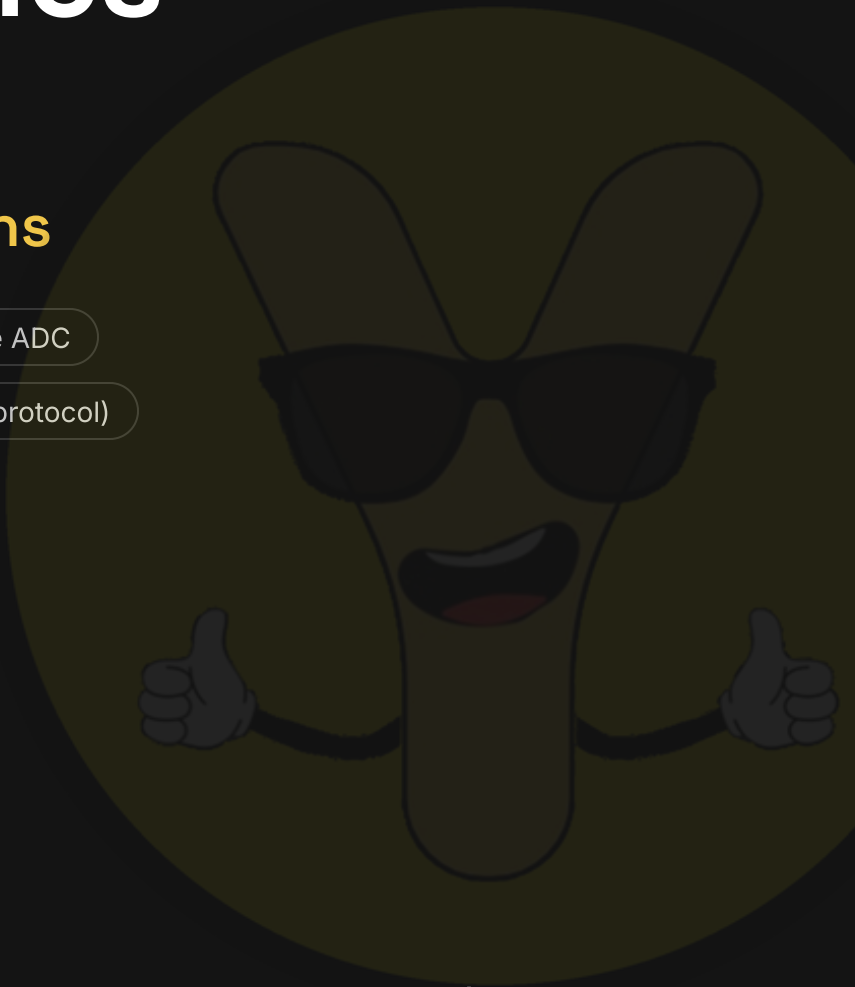
AKTU · 1ST YEAR · AEC101A / AEC201A

Fundamentals of Electronics Engineering

Unit 5 — Electronic Systems and Emerging Applications

- Microcontroller overview: what is a microcontroller, GPIO pins
- ADC: ADC types - digital ramp type & flash type ADC
- PWM (concept only, not programming)
- communication interfaces: UART, SPI, I2C (what they do, not detailed protocol)
- sensors and signal chain: sensor → conditioning (op-amp) → ADC → microcontroller
- wireless communication basics: Bluetooth, Wi-Fi, Zigbee (concept)



DECODED BY

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Founder, Ycotes · Gold Medalist in Artificial Intelligence, IIT Madras · taught 10,000+ students

Unit 5 Introduction

ELECTRONIC SYSTEMS

An integrated arrangement of hardware, microcontrollers, sensors, and power management circuits designed to execute specific tasks.

- Combines analog front ends with digital processing.
- Crucial for modern smart devices and automation.
- Covers embedded control, communication, and power systems.

Microcontroller Overview

MICROCONTROLLER (MCU)

A compact integrated circuit designed to govern a specific operation in an embedded system, containing a processor, memory, and input/output peripherals.

- Integrates CPU, RAM, Flash memory, and I/O on a single chip.
- Optimized for control applications rather than heavy computation.
- Operates autonomously with minimal external components.

GPIO Pins

General Purpose Input/Output pins are the fundamental interface between the microcontroller and the external physical world.

- Digital Input
  - Reads binary states like HIGH (5V/3.3V) or LOW (0V).
  - Used for push buttons, switches, and digital sensors.
- Digital Output
  - Drives external loads by sourcing or sinking current.
  - Used to turn on LEDs, buzzers, and relays.
- Configurability
  - Pins can be configured via software registers as input or output.
  - Often multiplexed with internal peripherals like ADC or UART.

ADC Overview

ANALOG-TO-DIGITAL CONVERTER

An electronic circuit that converts continuous analog signals (voltage/current) into discrete digital numbers for microcontroller processing.

- Quantizes continuous time and continuous amplitude signals.
- Key parameters include resolution (bits) and conversion speed.
- Formula for resolution: $V_{\text{resolution}} = \frac{V_{\text{ref}}}{2^n - 1}$

Digital Ramp Type ADC

A counter-based analog-to-digital converter that uses a digital-to-analog converter and a comparator.

- Working: A binary counter starts at zero and increments with each clock pulse.
- DAC converts the counter output to an analog staircase voltage.
- A comparator continuously checks if the staircase voltage exceeds the input analog voltage.
- When the DAC voltage exceeds the input, the counter stops and its value is the digital output.
- Advantage: Simple circuit architecture.
- Disadvantage: Slow conversion speed, especially for high-resolution outputs.

Flash Type ADC

FLASH ADC

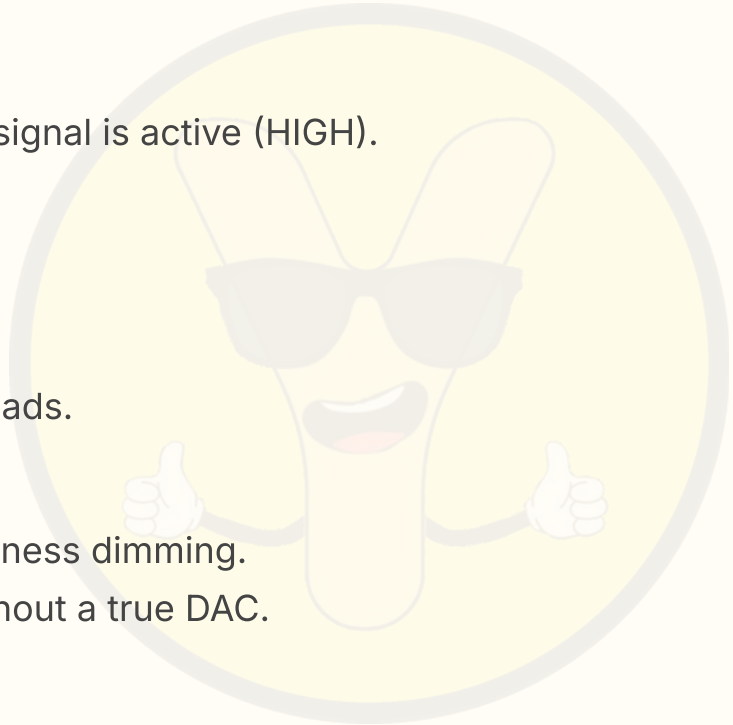
A direct-conversion ADC that uses a large bank of comparators operating in parallel to compare the input voltage against reference voltage dividers.

- Working: Voltage divider sets reference thresholds for every comparator simultaneously.
- All comparators evaluate the input voltage in a single clock cycle.
- Encoder logic translates comparator outputs into standard binary format.
- Advantage: Extremely high conversion speed (nanoseconds).
- Disadvantage: High hardware complexity and high power consumption for higher bit resolutions.

Pulse Width Modulation (PWM)

A technique for getting analog results with digital means by varying the width of digital pulses.

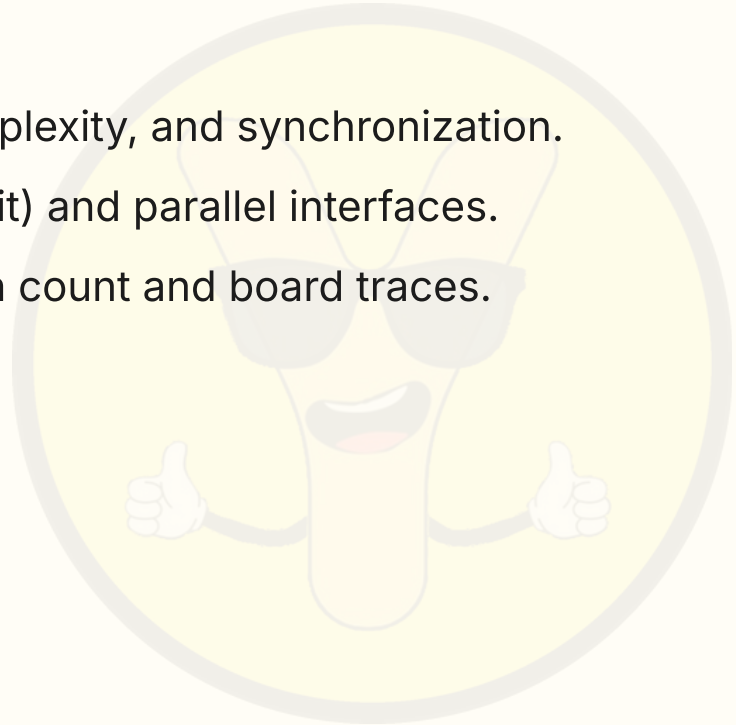
- Duty Cycle
  - Percentage of one period in which the signal is active (HIGH).
  - Formula: $D = \frac{T_{\text{on}}}{T_{\text{on}} + T_{\text{off}}} \times 100\%$.
- Average Voltage
  - Calculated as $V_{\text{avg}} = D \times V_{\text{max}}$.
  - Controls effective power delivered to loads.
- Applications
  - DC motor speed control and LED brightness dimming.
  - Generates pseudo-analog voltages without a true DAC.



Communication Interfaces Overview

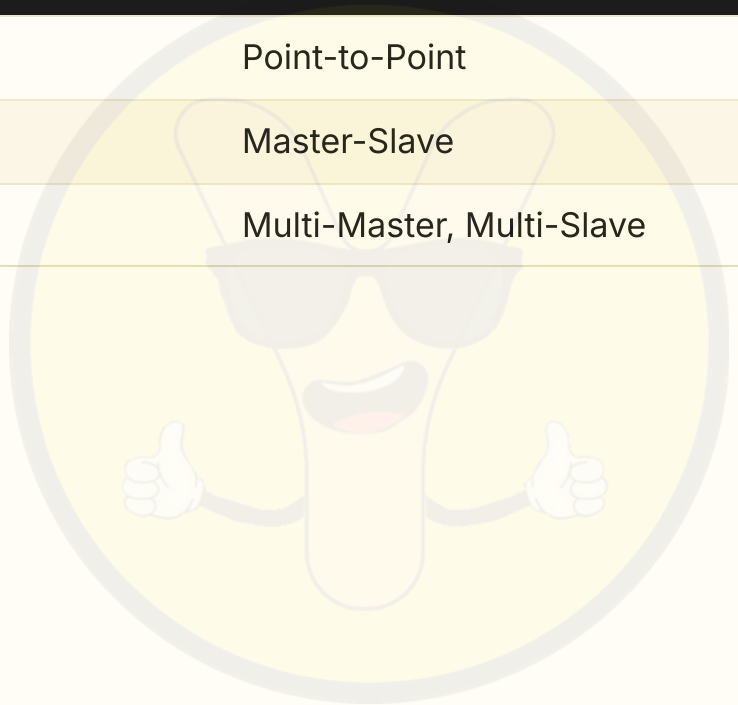
Microcontrollers use standardized protocols to exchange data with external chips and sensors over short or long distances.

- Protocols define speed, wiring complexity, and synchronization.
- Broadly divided into serial (bit-by-bit) and parallel interfaces.
- Serial communication minimizes pin count and board traces.



Comparison of Serial Protocols

Protocol	Wires Needed	Master/Slave	Speed / Range
UART	2 (TX, RX)	Point-to-Point	Medium / Meters
SPI	4 (MOSI, MISO, SCLK, SS)	Master-Slave	Very High / Board level
I2C	2 (SDA, SCL)	Multi-Master, Multi-Slave	High / Board level



Sensor Signal Chain



Standard signal conditioning and acquisition pipeline in embedded electronic systems.

Sensors and Signal Chain Details

The journey of a physical parameter from measurement to digital computation.

- Sensor
  - Converts physical quantities (temperature, pressure) into electrical signals.
- Signal Conditioning
  - Uses operational amplifiers for amplification, filtering, and level shifting.
  - Ensures sensor output matches ADC input range.
- ADC
  - Converts conditioned analog voltage into discrete digital values.
- Microcontroller
  - Processes digital data for control decisions, logging, or transmission.

Wireless Communication Basics

Enables untethered data exchange between electronic devices using radio frequency waves.

- Bluetooth
  - Short-range WPAN operating at 2.4 GHz.
  - Designed for cable replacement and audio/data streaming (low power variants).
- Wi-Fi
  - High-speed WLAN based on IEEE 802.11 standards.
  - Provides direct internet connectivity and high bandwidth over medium ranges.
- Zigbee
  - Low-power, low-data-rate mesh network standard (IEEE 802.15.4).
  - Ideal for home automation and industrial sensor networks.

Power Management: LDO Regulator

LOW DROPOUT (LDO) LINEAR REGULATOR

A DC linear voltage regulator that can regulate the output voltage even when the supply voltage is very close to the output voltage.

- Provides a stable, low-noise DC voltage from a higher DC input.
- Simple circuit topology with low external component count.
- Low efficiency when input-output voltage difference is large due to power dissipation as heat: $P = (V_{\text{in}} - V_{\text{out}}) \times I_{\text{load}}$.

Power Management: DC-DC Converter

SWITCHING DC-DC CONVERTER

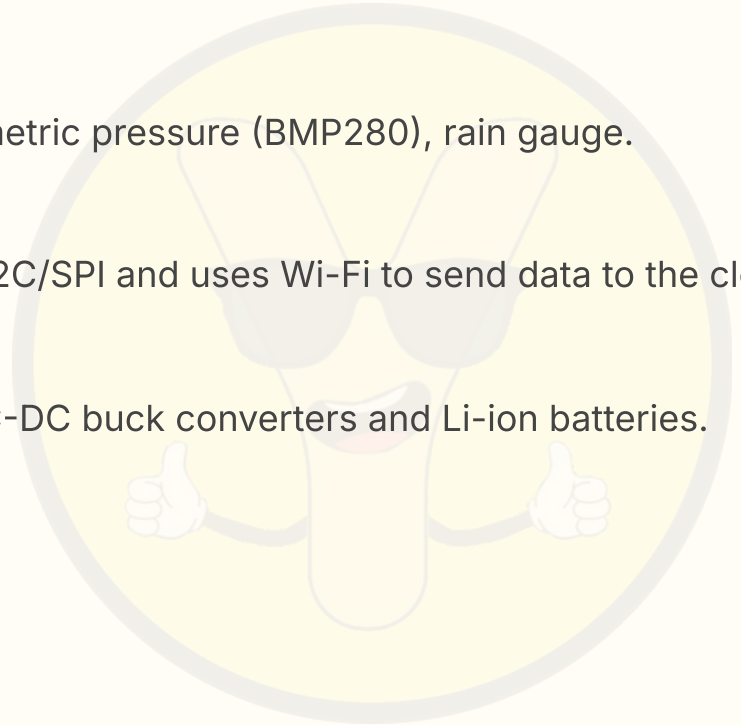
An electronic circuit that converts a DC source from one voltage level to another using high-frequency switching elements (transistors and inductors).

- Includes Buck (step-down), Boost (step-up), and Buck-Boost topologies.
- Achieves high energy efficiency (often > 85-90%) compared to LDOs.
- Generates switching noise and requires magnetic components (inductors/transformers).

Application: IoT Weather Station

An automated system for monitoring and uploading environmental meteorological parameters.

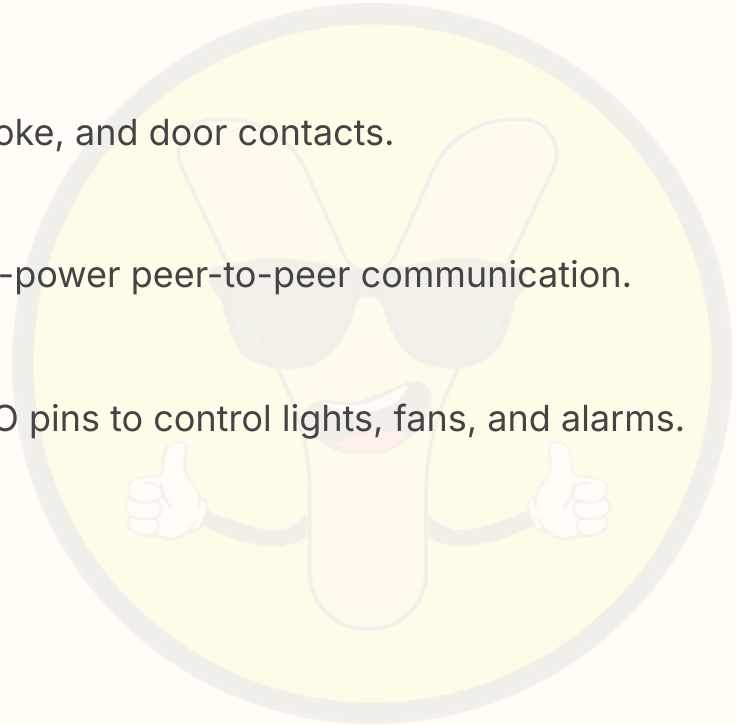
- Sensors
  - Temperature, humidity (DHT22), barometric pressure (BMP280), rain gauge.
- Processing & Comms
  - Microcontroller reads sensor data via I2C/SPI and uses Wi-Fi to send data to the cloud.
- Power
  - Powered by solar panels backed by DC-DC buck converters and Li-ion batteries.



Application: Smart Home Sensor Node

Distributed nodes inside a building providing automation and security.

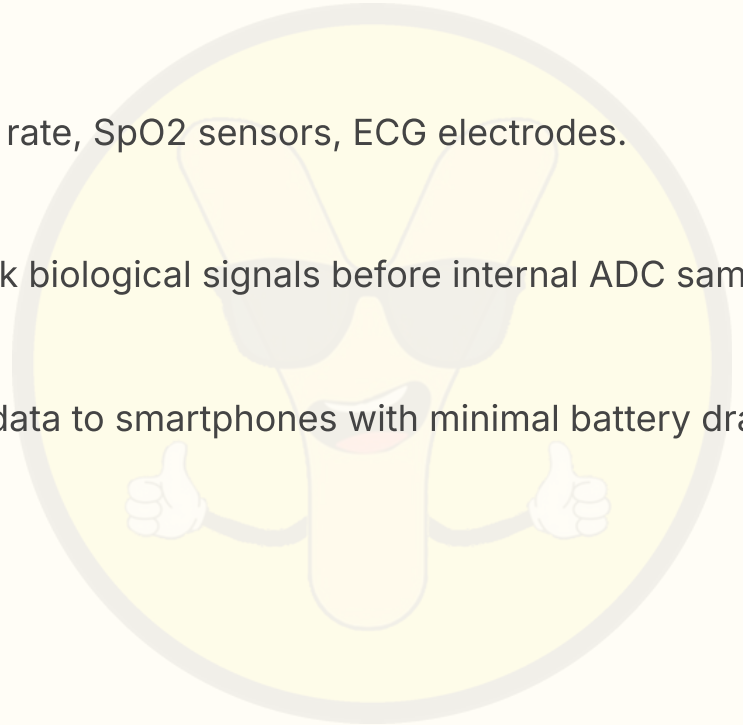
- Functionality
  - Monitors occupancy, ambient light, smoke, and door contacts.
- Networking
  - Uses Zigbee or Bluetooth Mesh for low-power peer-to-peer communication.
- Actuation
  - Microcontroller triggers relays and GPIO pins to control lights, fans, and alarms.



Application: Wearable Health Device

Compact medical electronics worn on the body for continuous health parameter tracking.

- Sensors
  - Photoplethysmography (PPG) for heart rate, SpO2 sensors, ECG electrodes.
- Signal Chain
  - High-precision op-amps condition weak biological signals before internal ADC sampling.
- Connectivity
  - Bluetooth Low Energy (BLE) transmits data to smartphones with minimal battery drain.



Application: EV Battery Management System (BMS)

Critical electronic safety and monitoring system for electric vehicle battery packs.

- Cell Monitoring
  - Measures individual cell voltages and temperatures using isolated SPI communication.
- State Estimation
  - Microcontroller calculates State of Charge (SoC) and State of Health (SoH).
- Protection
  - Controls power switch disconnects during over-voltage, under-voltage, or thermal runaway.

Exam Corner

- **Q1** Explain the architecture and working of a Digital Ramp type ADC with a neat block diagram.
- **Q2** Compare Flash type ADC and Digital Ramp type ADC in terms of speed, complexity, and resolution.
- **Q3** What are GPIO pins? Explain their configuration modes in microcontrollers.
- **Q4** Explain the concept of PWM and derive the formula for average voltage output.
- **Q5** Compare UART, SPI, and I2C communication protocols based on lines, speed, and master-slave configuration.
- **Q6** Describe the complete sensor signal chain from physical measurement to microcontroller input.
- **Q7** Explain the difference between an LDO regulator and a switching DC-DC converter.
- **Q8** Discuss the electronic system architecture of an Electric Vehicle Battery Management System (BMS).

Unit 5 done. You are exam-ready.

Revise the Exam corner once more, then open Unit 1 on theycotes.com. Every AKTU subject, unit by unit, free. Notes by Chirag Jain, Ycotes.

