THE ART AND SCIENCE OF PCB DESIGN

IAP 2025

Lecture 04 - TOPOLOGIES

Common electrical topologies (2/2)

@ MIT

Outline

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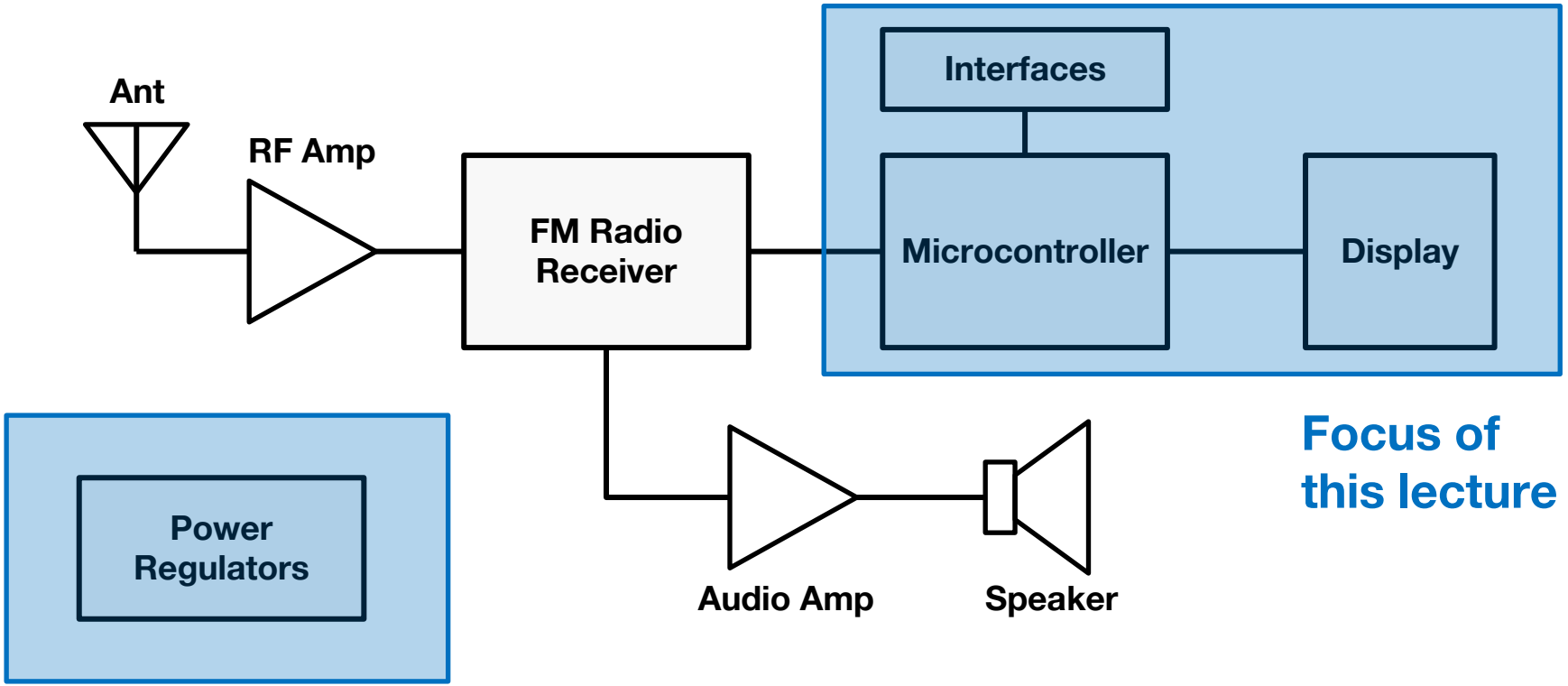
- Introduction
- LDO Regulators
- Buck and Boost Converters
- ESP Module
- Switches and Potentiometers
- Display and Shift Registers
- Summary

Introduction

Block Diagram



Low Dropout Regulators (LDOs)

Power Regulation

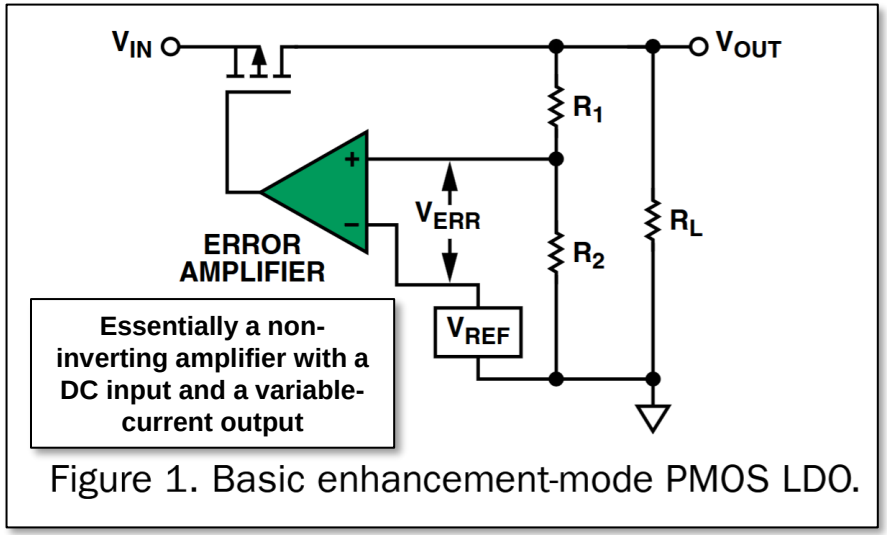


Figure 1. Basic enhancement-mode PMOS LDO.

LDOs are crucial for their low noise and simplicity

- **No switching occurs**
- **Small size (no large inductors required)**
- **Cheaper**

LDOs, however, cannot be used for all applications:

- **Cannot boost voltages**
- **Lossy (requires heatsinking)**
- **In order to bias output transistor, a dropout voltage is required (0.1 V to 2 V depending on topology)**

R_1 and R_2 form a voltage divider feedback network that amplifies V_{REF} to provide a variable voltage output

Typically, LDOs should be preferred for use in for low-noise and/or low current voltage step-down applications

Switching Converters

Schematics

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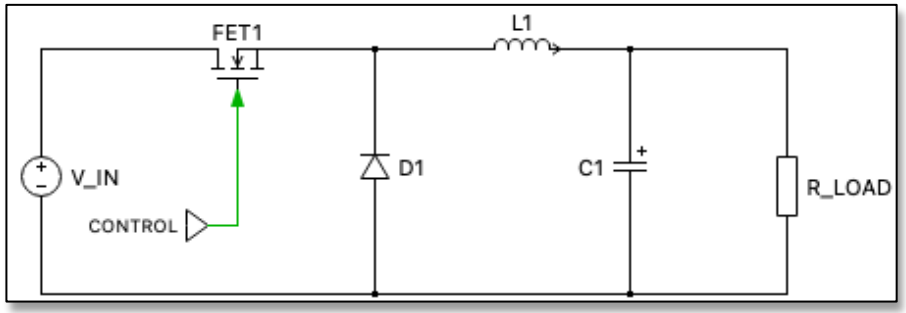
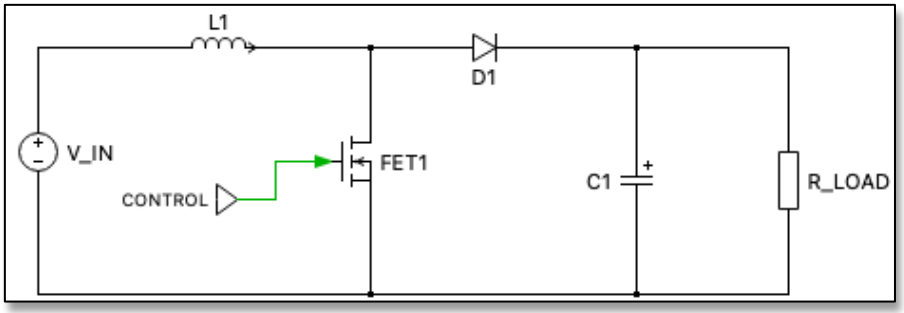
Buck Converter



Step-Down Converter
output voltage = duty cycle × input voltage

Boost Converter



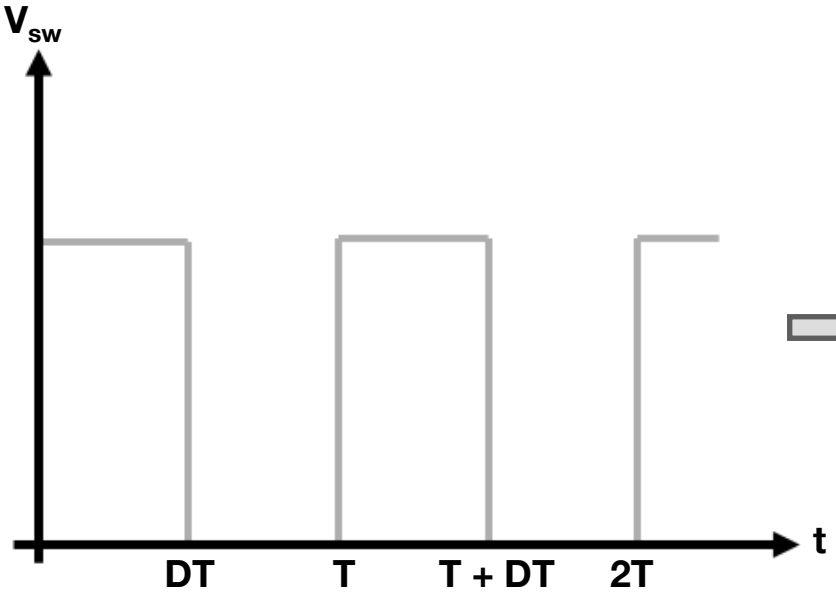
Step-Up Converter
output voltage = input voltage ÷ (1 – duty cycle)

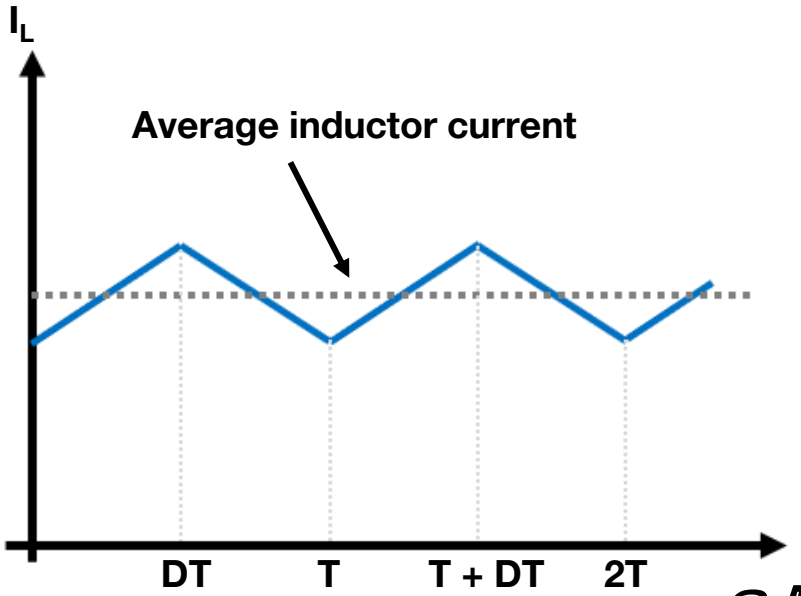
Switching Converters

Control

The FET of the converter is controlled via PWM, where the duty cycle determines the ratio between the input voltage and the output voltage

This causes the current across the inductor to ramp up and ramp down, which in conjunction with the capacitor, provides a voltage to the load





Switching Converters

Buck Converter Operation

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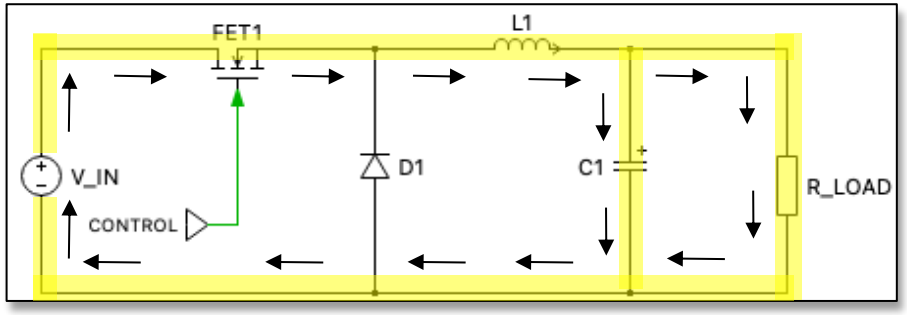
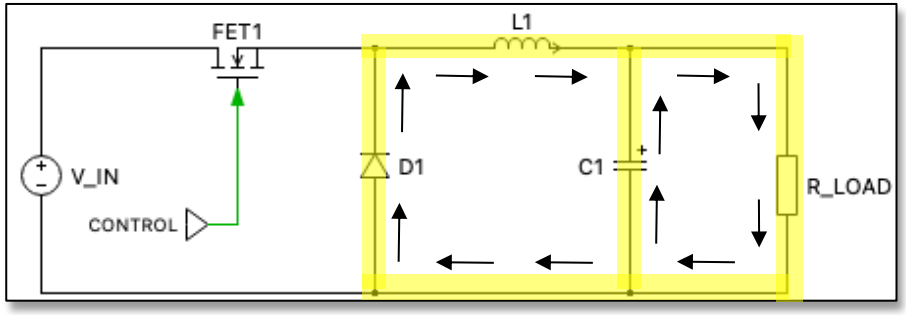
MODE 1: Switch On



When the switch is turned on, positive voltage is forced across the inductor, causing the current to increase. This inductor current flows through the capacitor and the load.

MODE 2: Switch Off



When the switch is turned off, the inductor current decreases, forcing a negative voltage across the inductor and turning on the diode. The capacitor discharges into the load as well.

In a buck converter, the load current is the average inductor current.

Switching Converters

Boost Converter Operation

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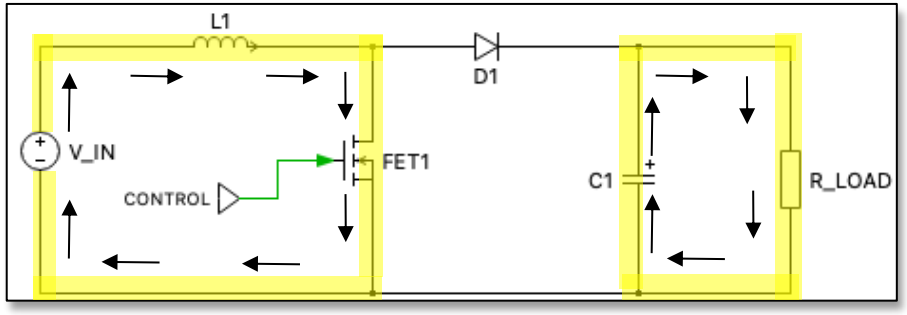
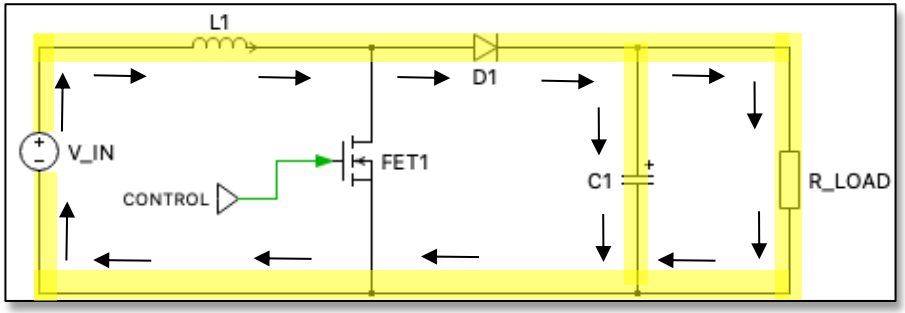
MODE 1: Switch On



When the switch is turned on, positive voltage is forced across the inductor, causing the current to increase. The capacitor supplies current to the load in isolation.

MODE 2: Switch Off



When the switch is turned off, the inductor current decreases, forcing a negative voltage drop across the inductor. This causes the capacitor voltage, and in turn the load voltage, to increase beyond the input voltage.

In a boost converter, the load current is the average diode current.

ESP32 Module

The Brains of Our Circuit

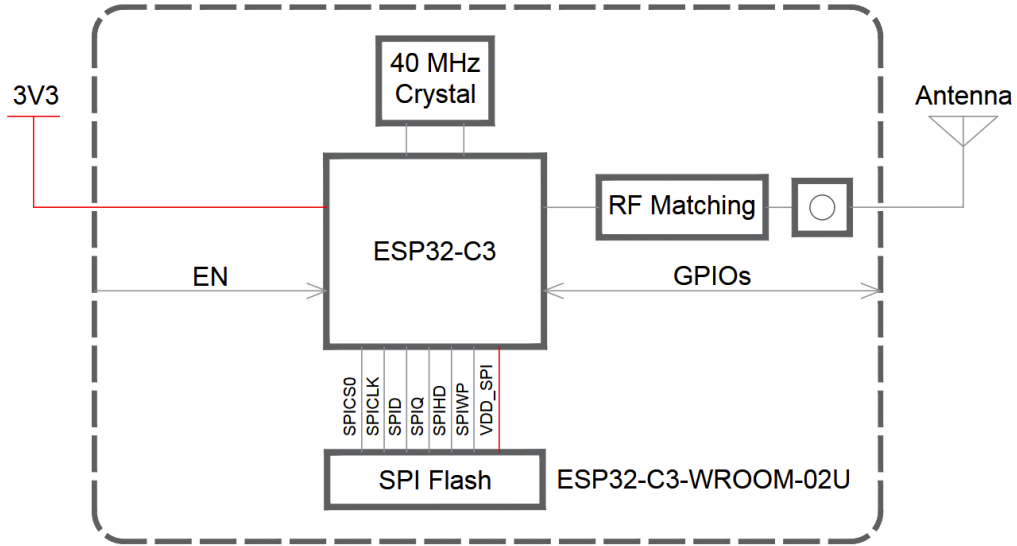


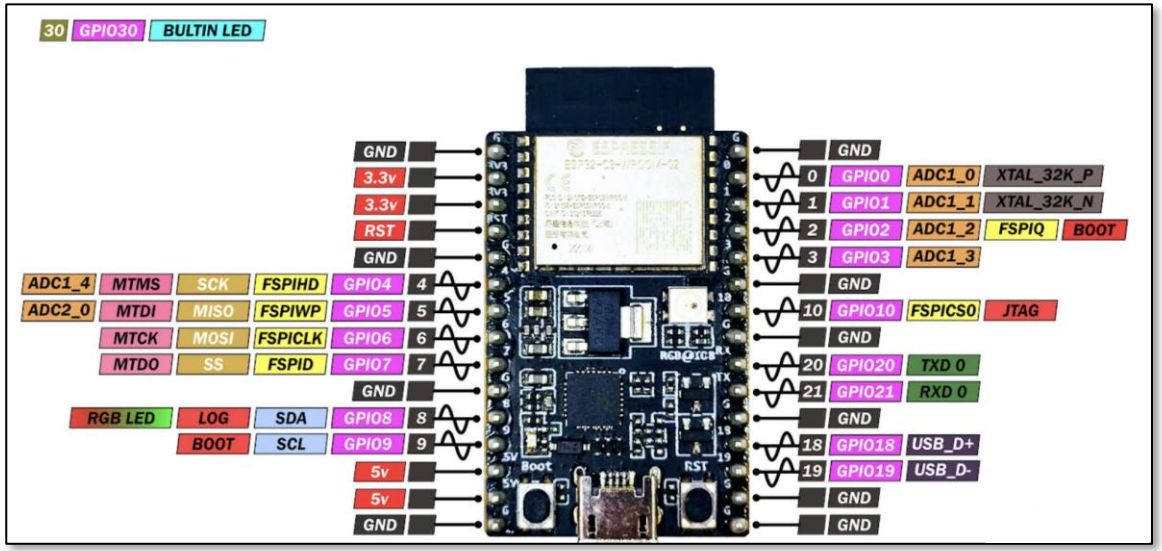
Figure 2: ESP32-C3-WROOM-02U Block Diagram

The ESP32-C3-WROOM-02U module conveniently houses the peripheral circuits needed the support the ESP32-C3 microcontroller, such as:

- **Crystal oscillator – required to set the clock frequency and timing of the microprocessor**
- **SPI flash – to provide extra off-microcontroller storage for collected data or programs**
- **GPIO fanouts – makes routing to the GPIO pins much easier**
- **RF matching – for the WiFi/Bluetooth functionality**
- **Metal housing – for environmental and EMI shielding**

ESP32 Module

Functionality



32 pins, several with multiple potential functions including:

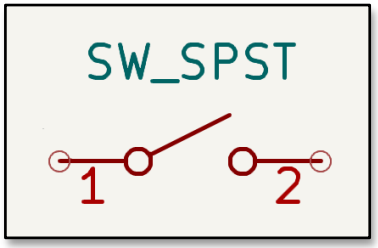
- **Power (3.3V and 5V power rails)**
- **GPIO**
- **USB data lines**
- **SPI functionality**
- **UART functionality**
- **I2C and I2S functionality**
- **ADC channels**
- **LED PWM Control**

Switches

Types of Switches

SPST
Single-Pole, Single-Throw

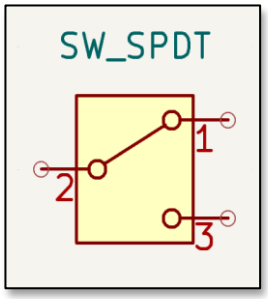
...aka one input, one output



Schematic Symbol

SPDT
Single-Pole, Double-Throw

...aka one input, two outputs



Schematic Symbol

Potentiometers

Variable Resistors

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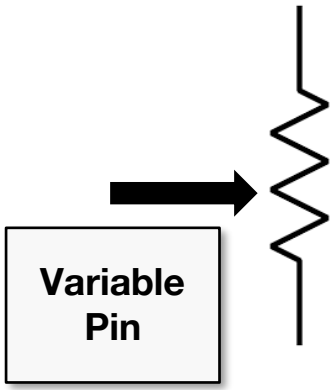
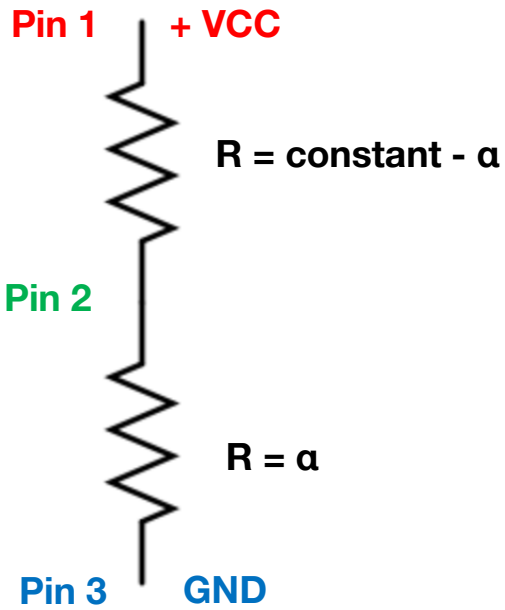
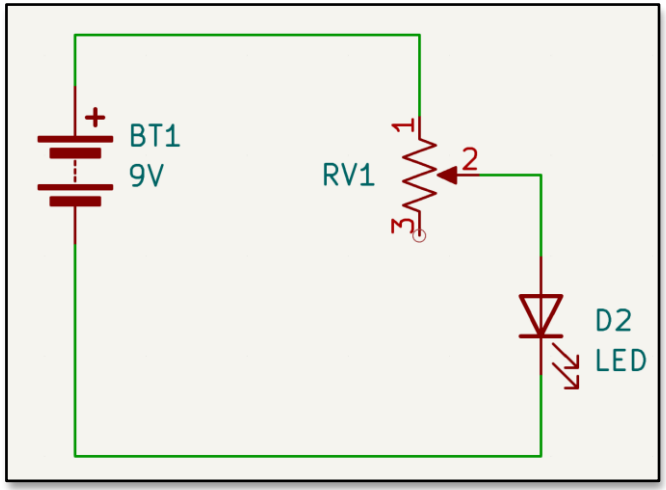
Symbol



Pinout



Example Circuit



Adjustable-brightness LED!

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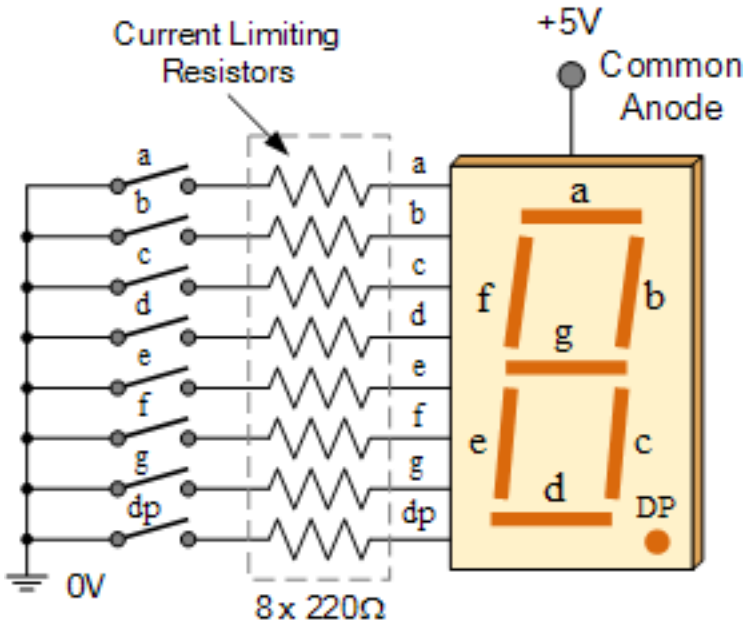
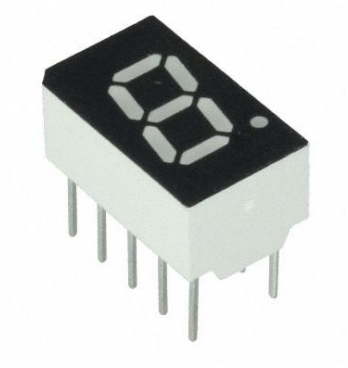
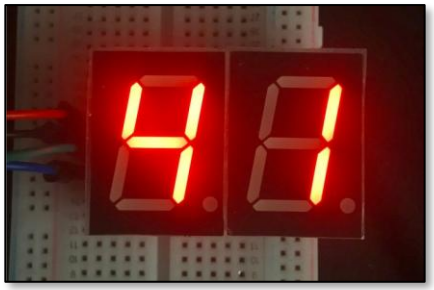
Display

7-Segment Display







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7-Segment displays are commonly used for displaying numbers (and some letters).

- **Consists of 7 individually addressable LEDs**

If we decide to use four 7-segment displays for our FM radio to display tuned frequency (e.g., 101.5), that requires digital control of 4 x 7 = 28 pins!

But our ESP32 microcontroller only has 13 general-purpose input/output (GPIO) pins…
How do we control of the LEDs?

Shift Registers

Digital Control

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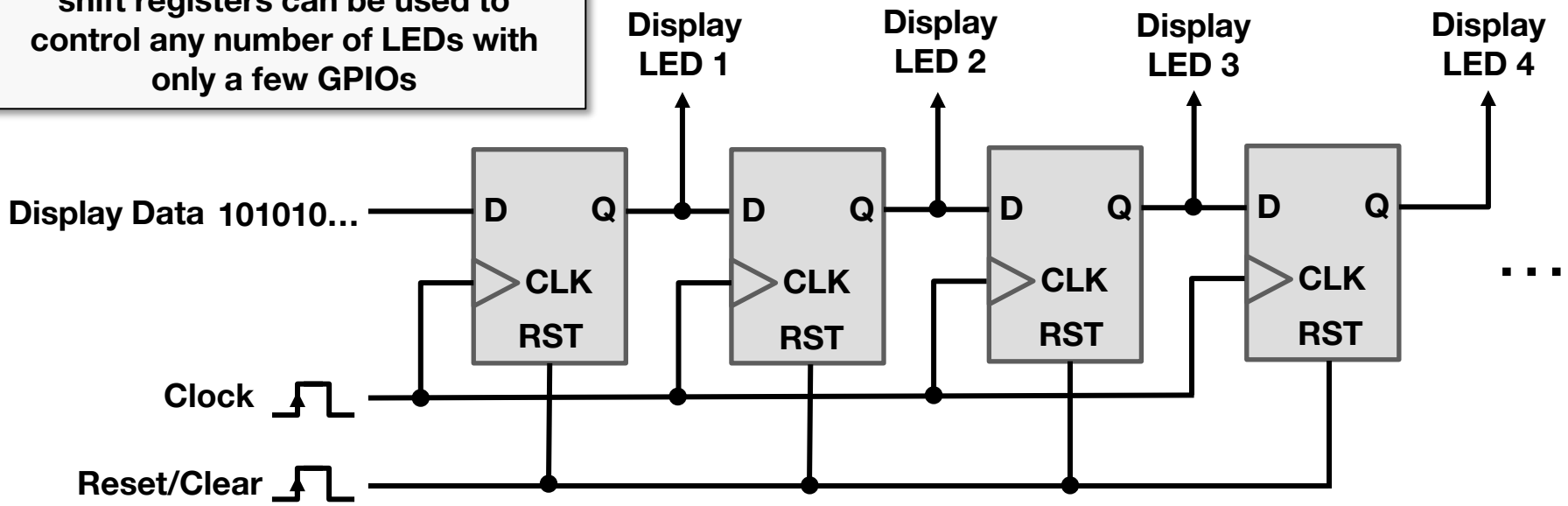
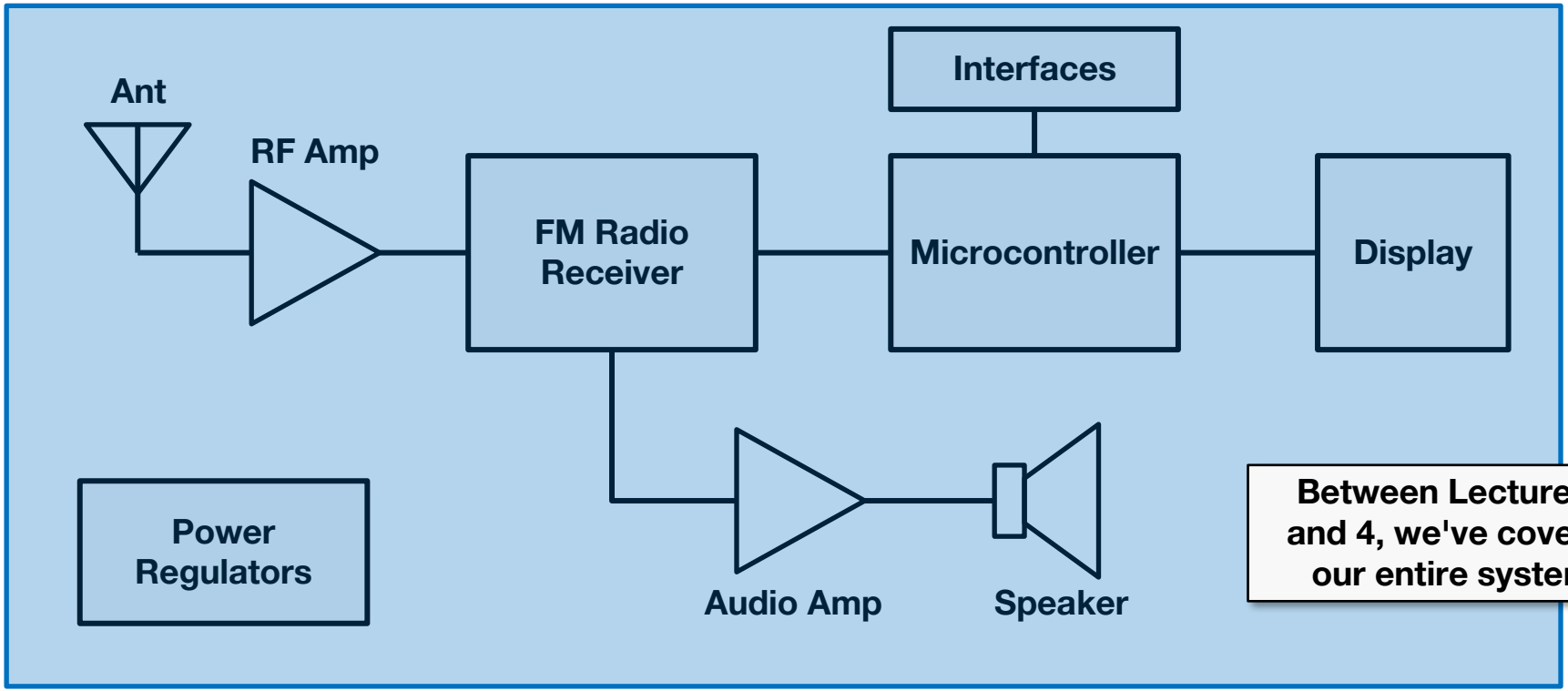
A chain of Serial-In, Parallel-Out shift registers can be used to control any number of LEDs with only a few GPIOs



Good solution for increasing number of digital outputs, given outputs that do not change often

Summary

Block Diagram, Revisited



Questions?