

# **Electronics for IoT**

## **Analog Input/Output**

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# Analog Signals

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# Example: Phonograph

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<https://en.wikipedia.org/wiki/Phonograph>

# Noise

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Digital

Analog

# Error Sources

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# Thermodynamics

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**Brownian Motion**

**Thermal Noise**

# Dynamic Range

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# deciBel [dB]

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# dB versus Bits

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# Achievable DR

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Analog

Digital

# DR of “Real World” Signals

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# Analog – Digital Conversion

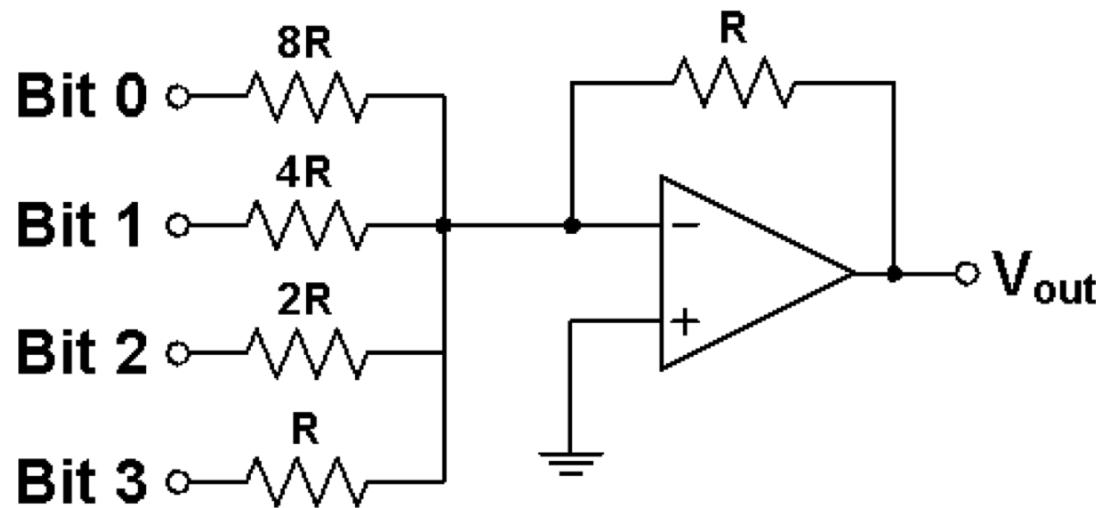
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# ESP32 Analog I/O

<i>GPIO</i>	<i>ALT</i>	<i>μPy</i>	
RESET		3.3V	
GND			
26	DAC2	A0	
25	DAC1	A1	
34	ADC6	A2	
39	ADC3	A3	
36	ADC0	A4	
4		A5	
5	SCK	A16	
18	MOSI	A17	
19	MISO	A18	
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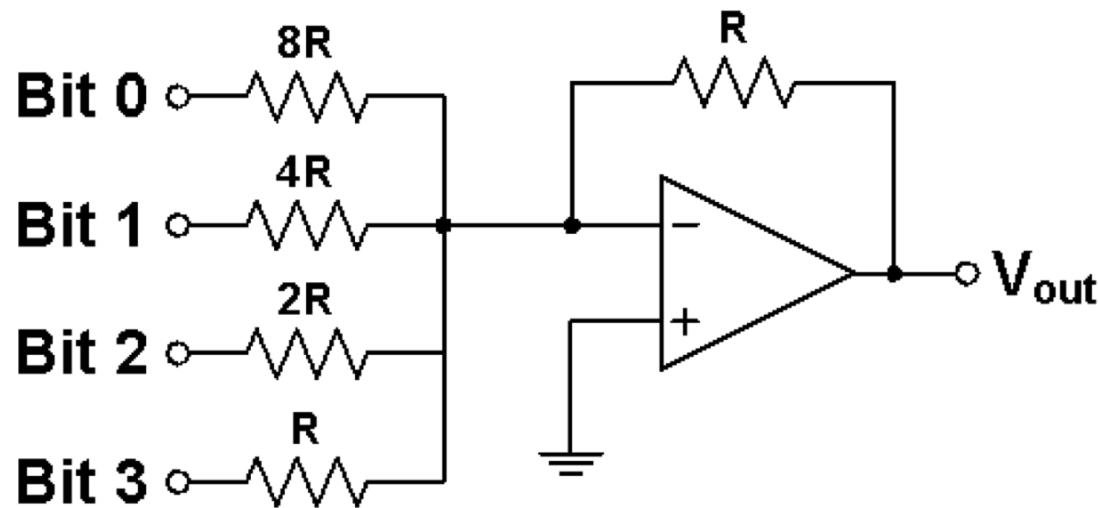
# Digital-to-Analog Converter

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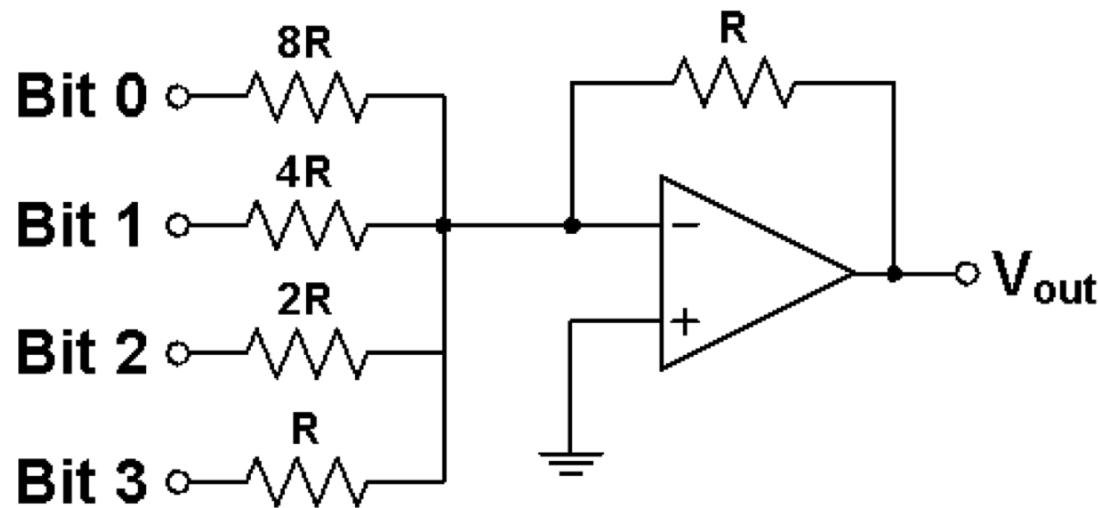
# Digital-to-Analog Converter

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# Digital-to-Analog Converter

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# Digital-to-Analog Converter (DAC)

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$$V_{\text{out}} = (\text{code}/255) * V_{\text{DD}}$$

←      **8-Bit DAC**

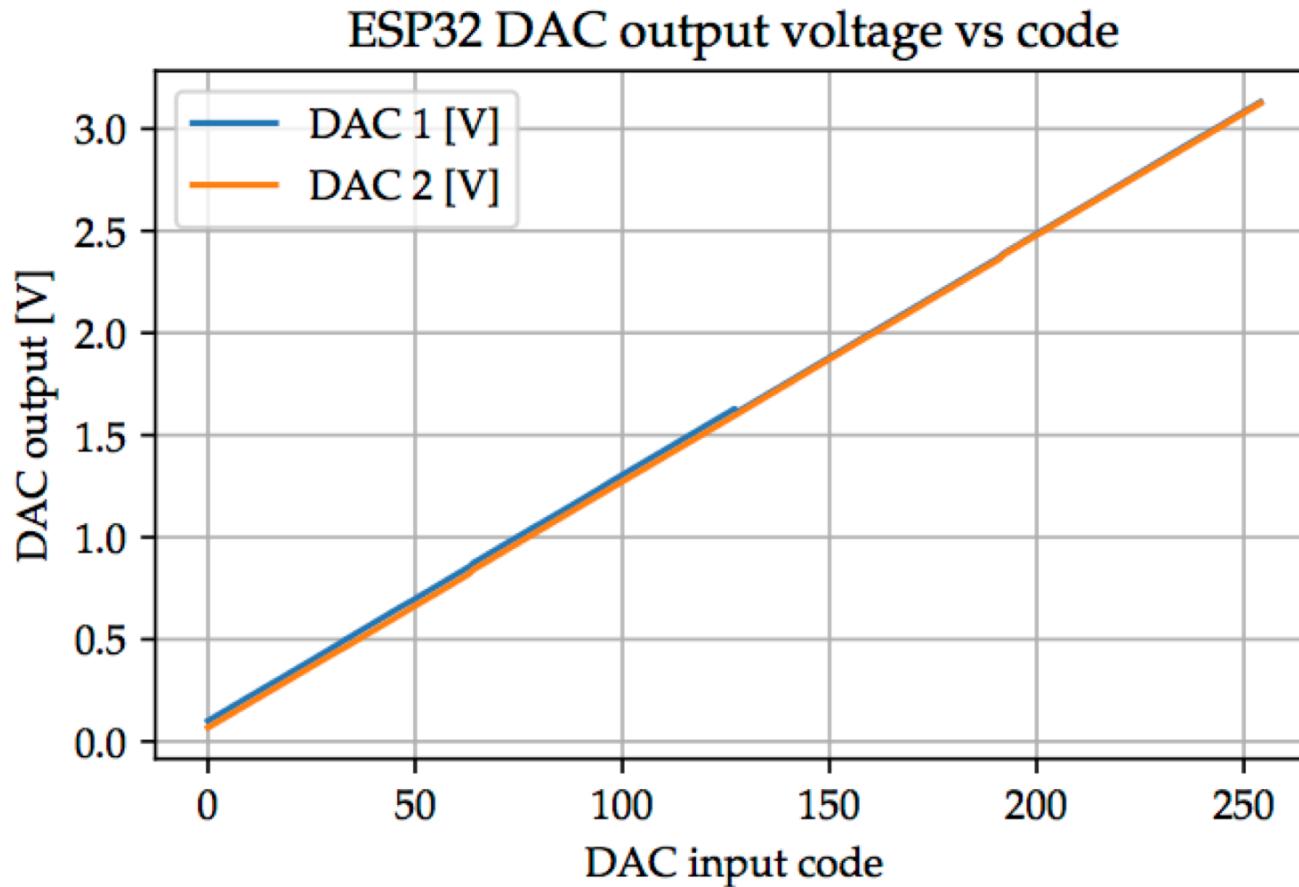
```
from board import DAC1
from machine import Pin, DAC

dac1 = DAC(Pin(DAC1))

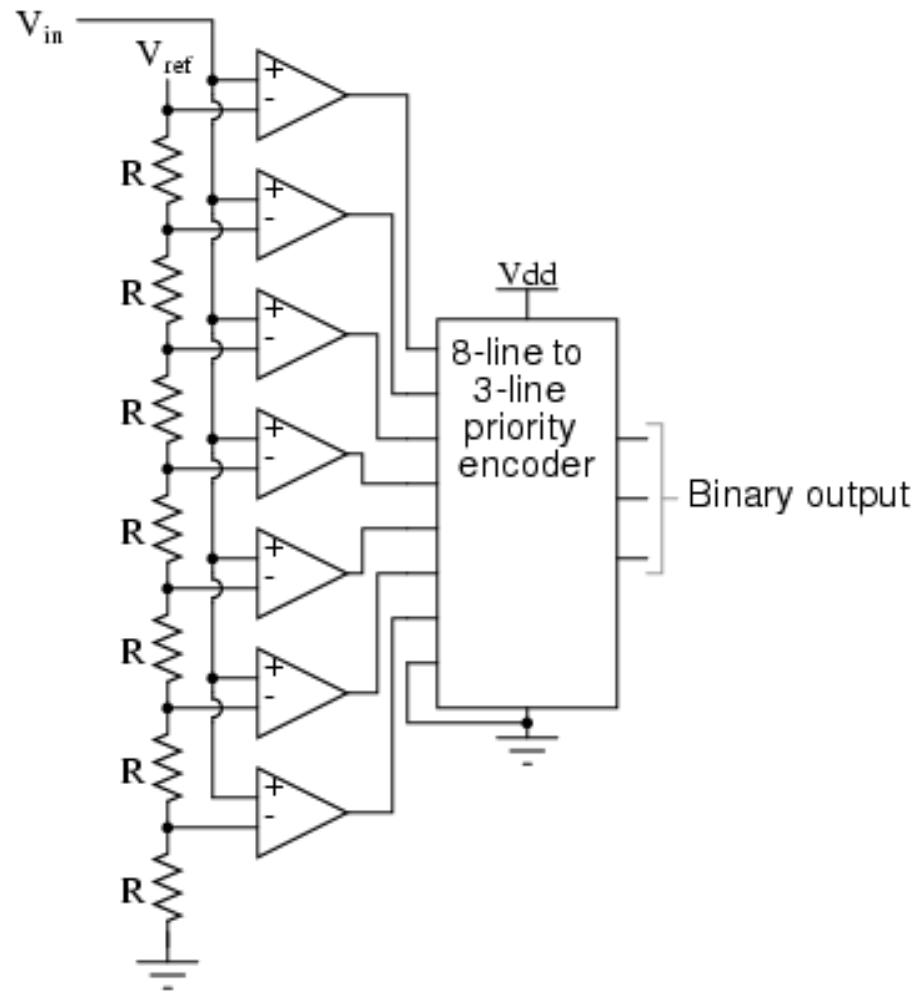
code = 100
# perform conversion
dac1.write(code)
```

# DAC Output

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# Analog-to-Digital Converter (ADC)

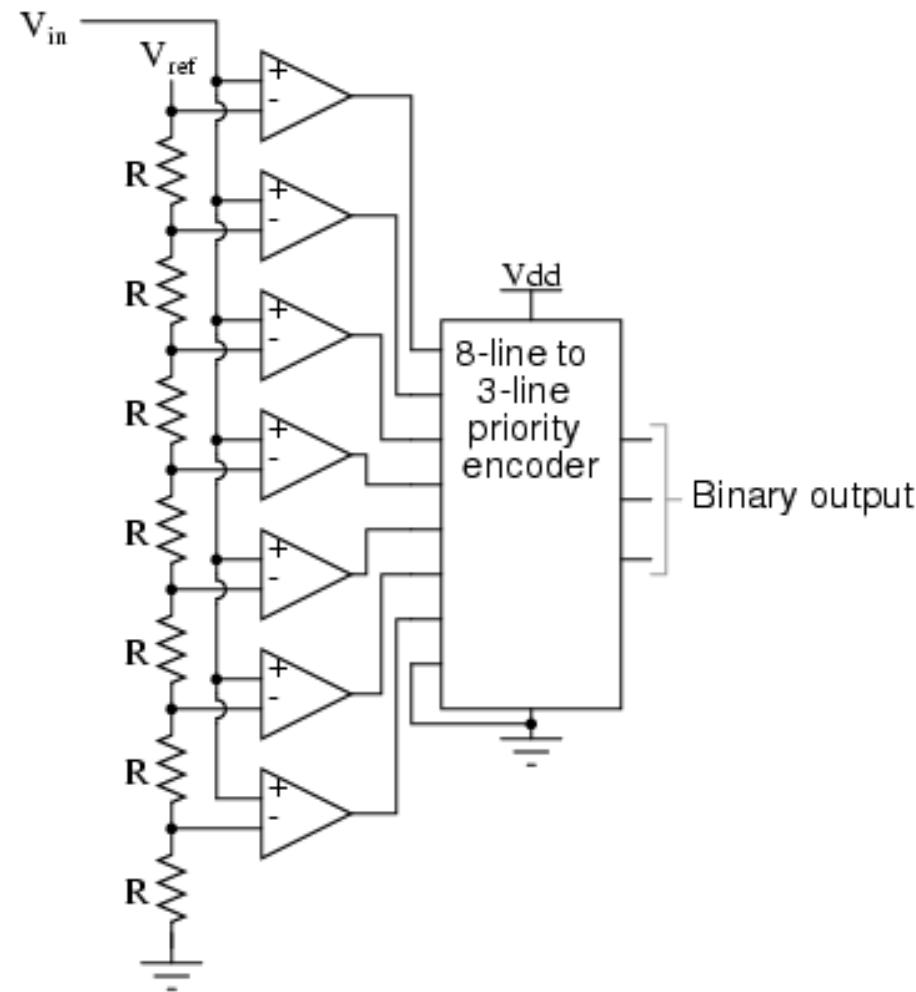


# Voltage Comparator

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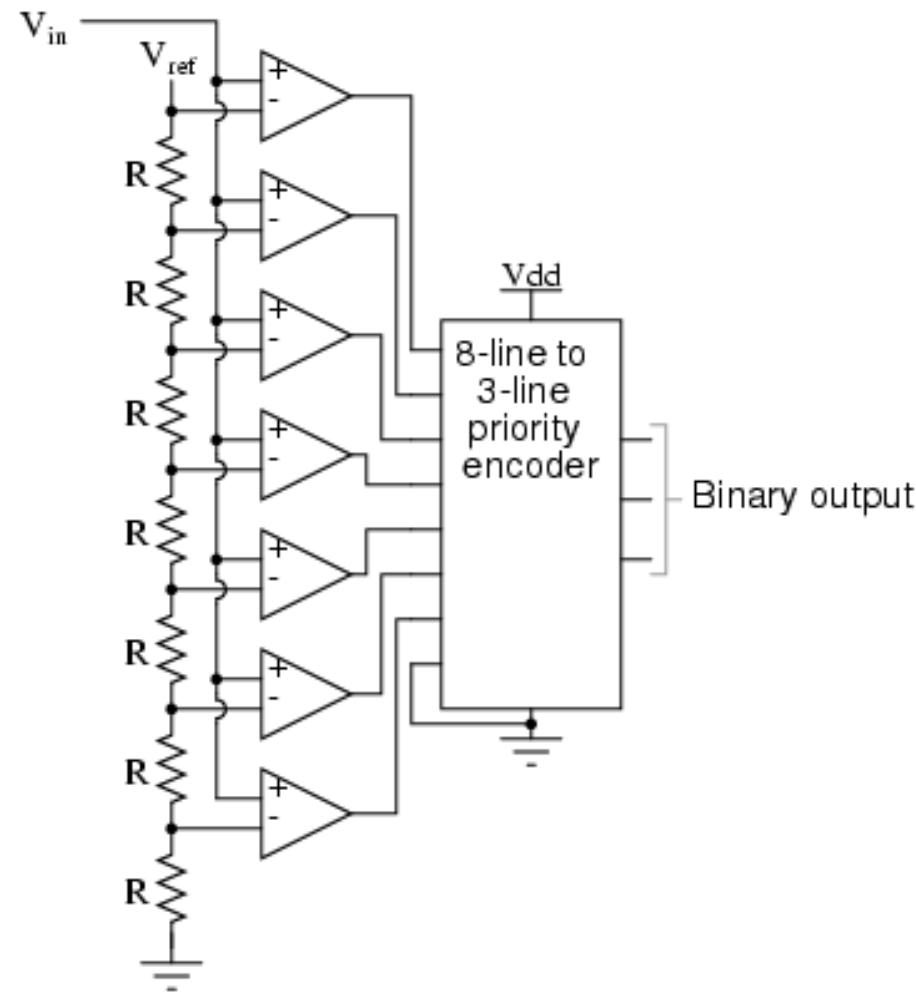
# Analog-to-Digital Conversion

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# Analog-to-Digital Conversion

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# ADC Circuits

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# ESP32 ADC

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# Analog-to-Digital Converter (ADC)

## 12-Bit ADC

The ADC output code for input  $V_{in}$  equals

$$\text{code} = 4095 * (V_{in}/V_{ref})$$

The `atten(arg)` function sets the reference  $V_{ref}$ .  
approximate values of  $V_{ref}$  are:

arg	$V_{ref}$
ADC.ATTN_0DB	1.1 V
ADC.ATTN_2_5DB	1.3 V
ADC.ATTN_6DB	1.8 V
ADC.ATTN_11DB	3.2 V

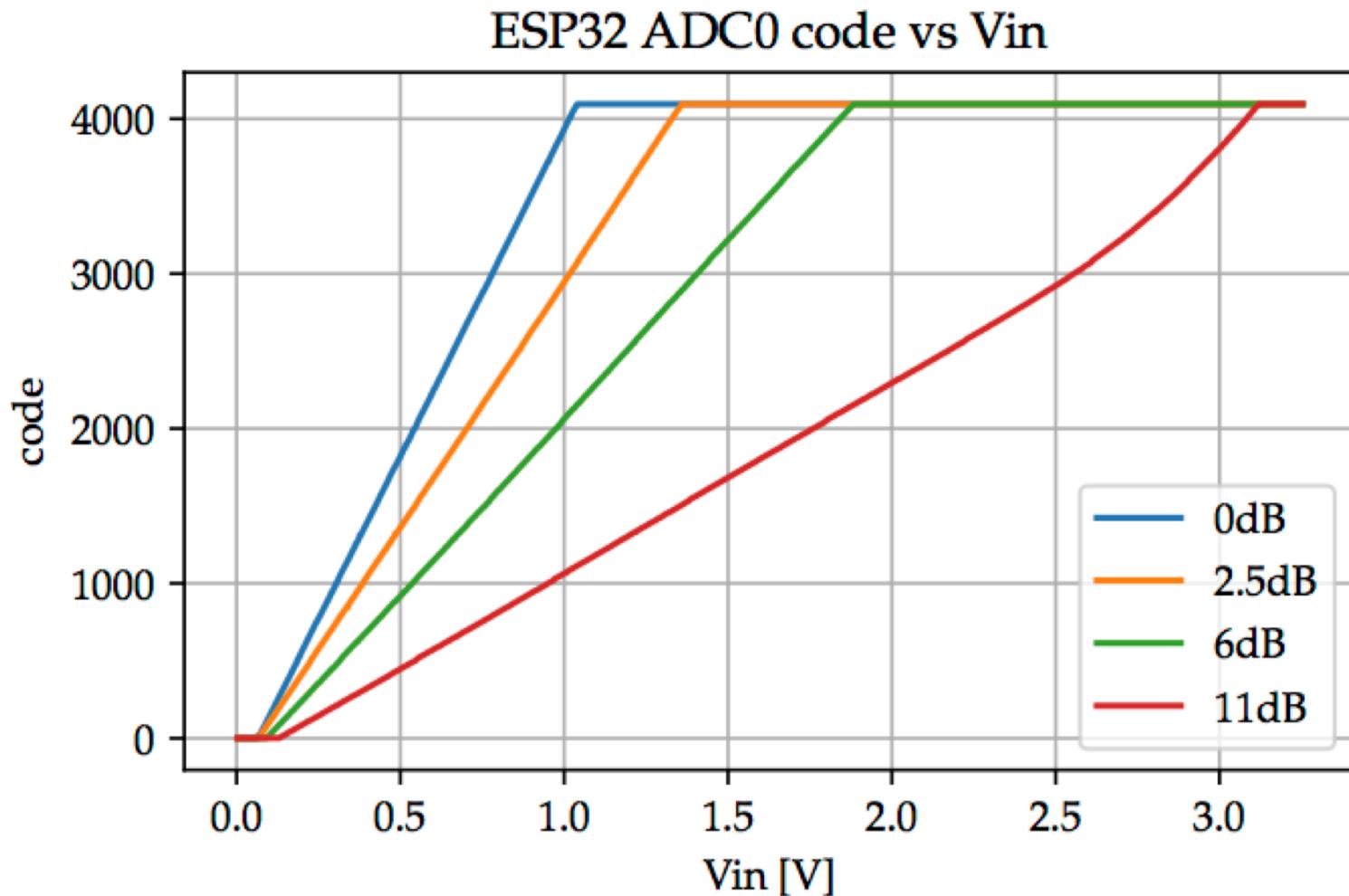
```
from board import ADC0
from machine import Pin, ADC

adc0 = ADC(Pin(ADC0))

# set full-scale range
adc0.atten(ADC.ATTN_0DB)

# perform conversion
code = adc0.read()
```

# ADC Characteristic

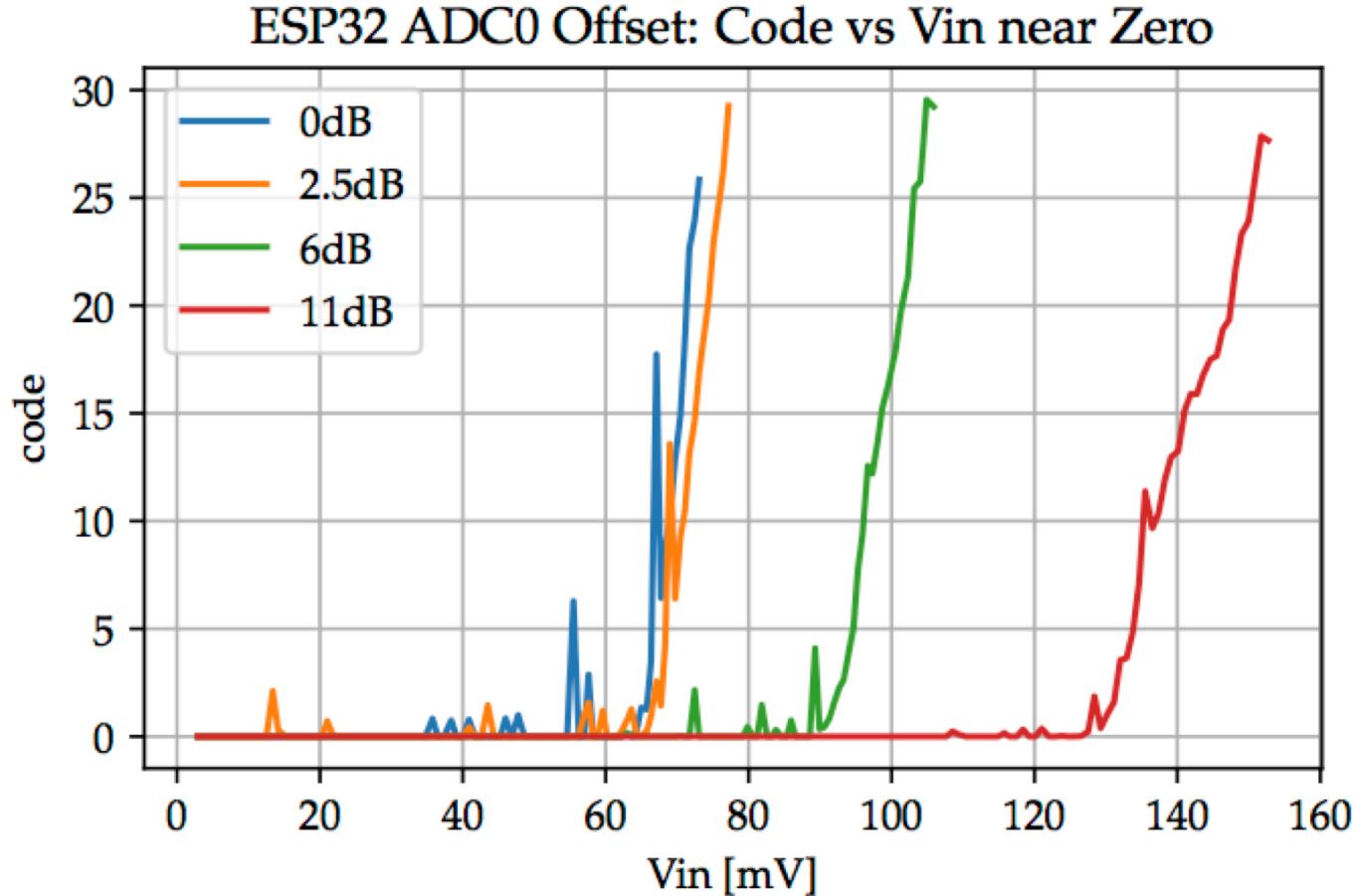


# ADC Errors

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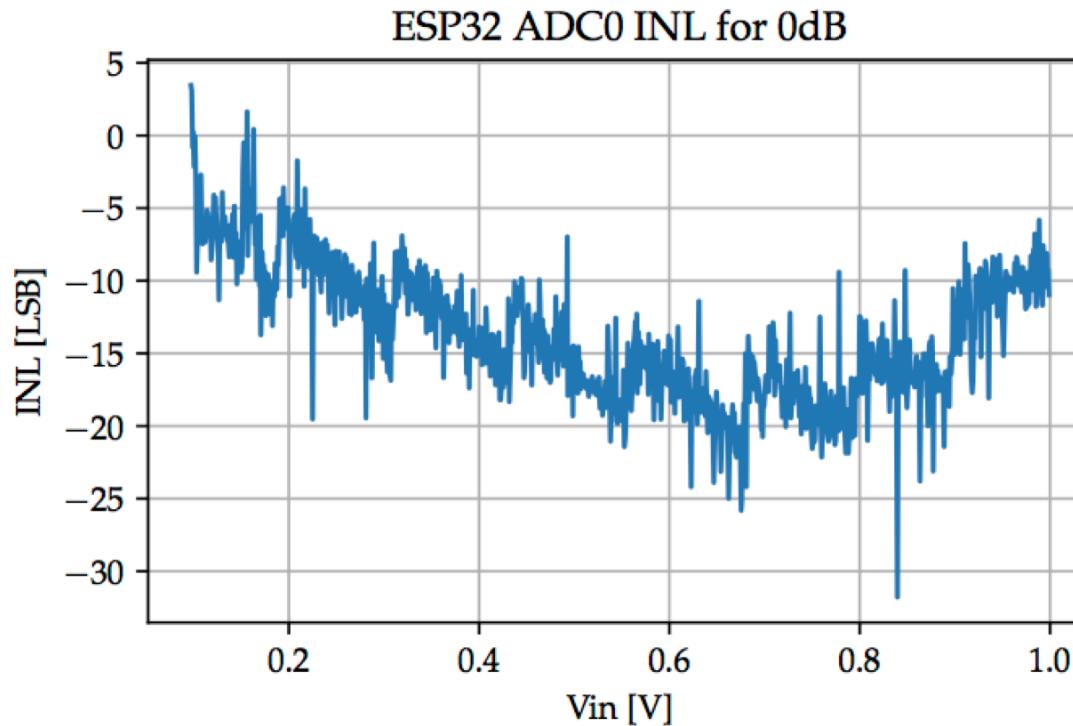
- Offset
- (Non) linearity
- (Non) monotonicity
- Noise
- Conversion speed
- ...

# ESP32 ADC Offset



# ESP ADC Linearity / Monotonicity

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- 30 LSB nonlinearity  $\rightarrow \sim 5$  Bits!
  - Linearity good to only 7 Bits
- Big “jumps” indicate non-monotonic

# ADC Application: Joystick

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# Joystick Circuit Diagram

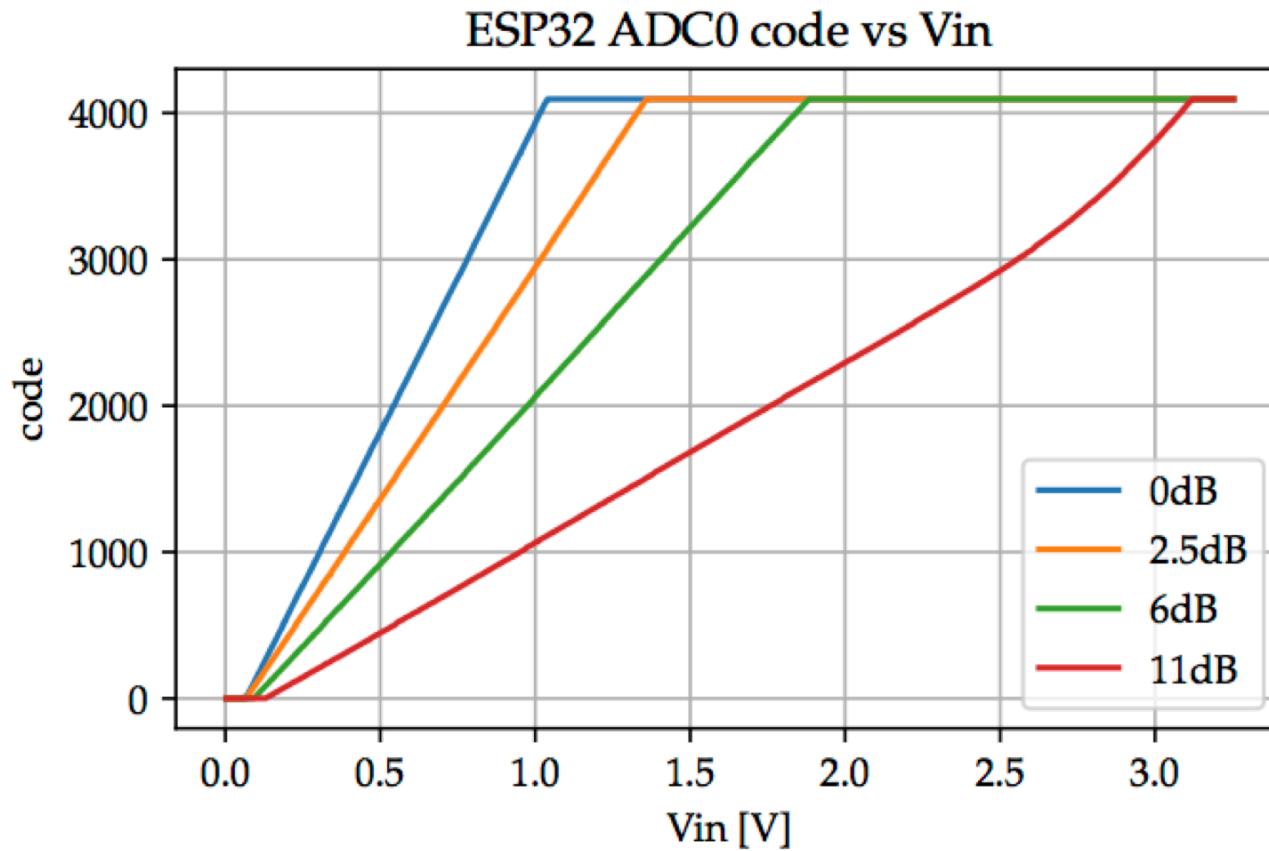
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# Joystick Output Voltages vs Angle

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# Reading Joystick with ADC

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# Adjust Full-Scale and Correct ADC Offset

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# Joystick Readout Circuit

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# Summary

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- Analog versus Digital
  - Dynamic range versus bits
  - Maximum achievable dynamic range
    - Analog
    - Digital
- Conversion: ADC & DAC
- Converter specifications
  - # of Bits
  - Offset
  - Linearity
  - ...