Electronics for IoT

Analog Input/Output

Bernhard E. Boser
University of California, Berkeley
boser@eecs.berkeley.edu

Analog Signals

Example: Phonograph

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

Noise

Digital

Analog

Error Sources

Thermodynamics

Brownian Motion

Thermal Noise

Dynamic Range

deciBel [dB]

dB versus Bits

Achievable DR

Analog

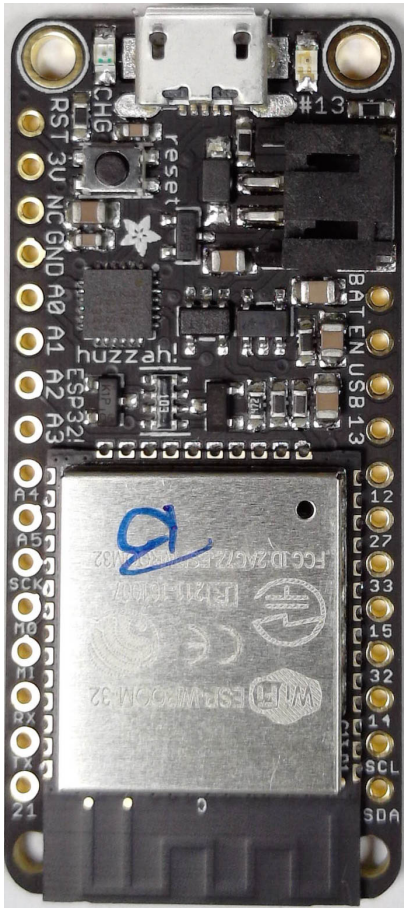
Digital

DR of “Real World” Signals

Analog – Digital Conversion

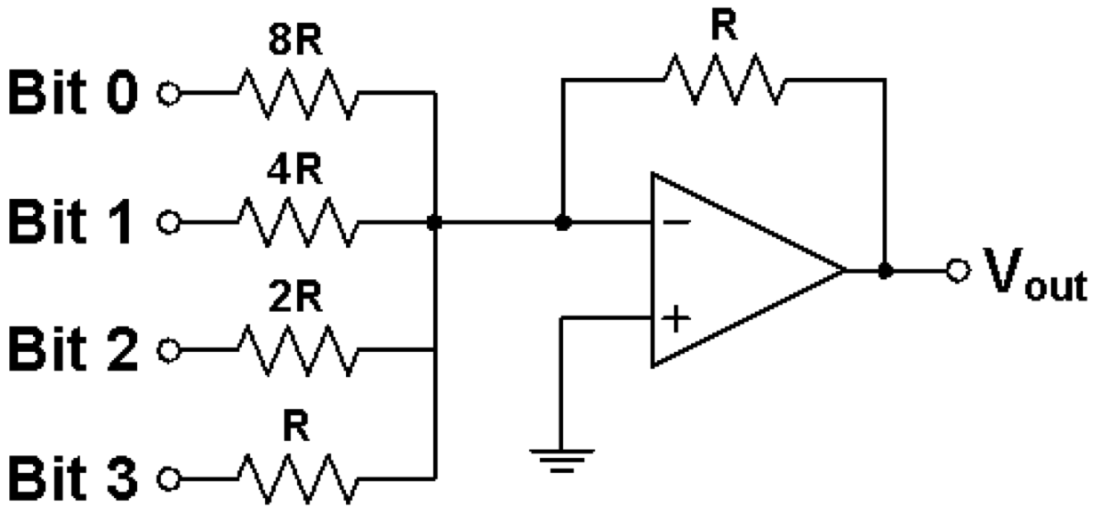
ESP32 Analog I/O

GPIO	ALT	µPy		
		RESET	1	
		3.3V	2	
			3	
		GND	4	
26	DAC2	A0	5	
25	DAC1	A1	6	
34	ADC6	A2	7	
39	ADC3	A3	8	
36	ADC0	A4	9	
4		A5	10	
5	SCK	A16	11	
18	MOSI	A17	12	
19	MISO	A18	13	
16		A19	14	
17		A20	15	
21		A21	16	

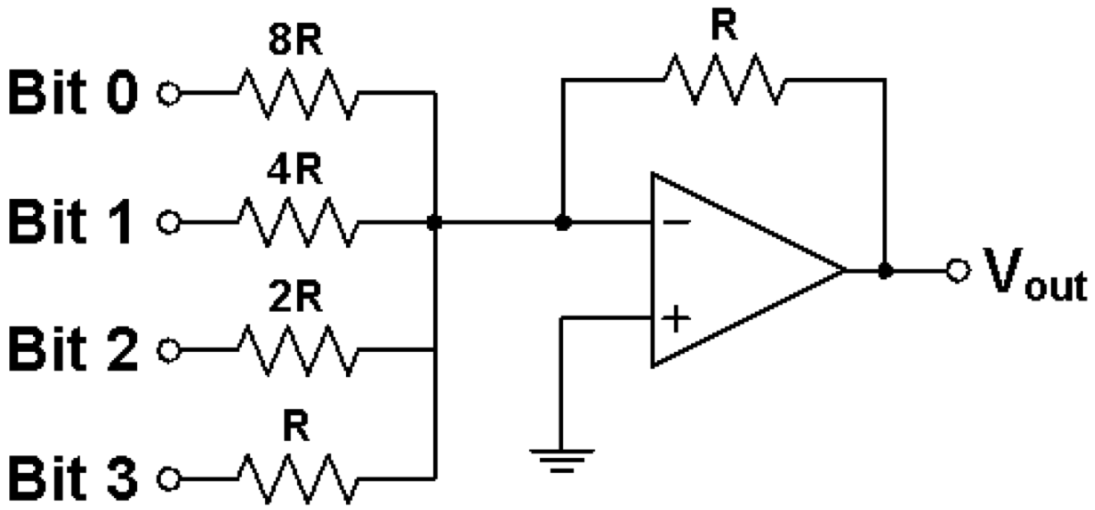


µPy	ALT	GPIO	
	VBAT		28
	EN 3.3V		27
	VUSB		26
A12	LED	13	25
A11	BOOT	12	24
A10		27	23
A9	ADC5	33	22
A8		15	21
A7	ADC4	32	20
A6		14	19
A15	SCL	22	18
A14	SDA	23	17

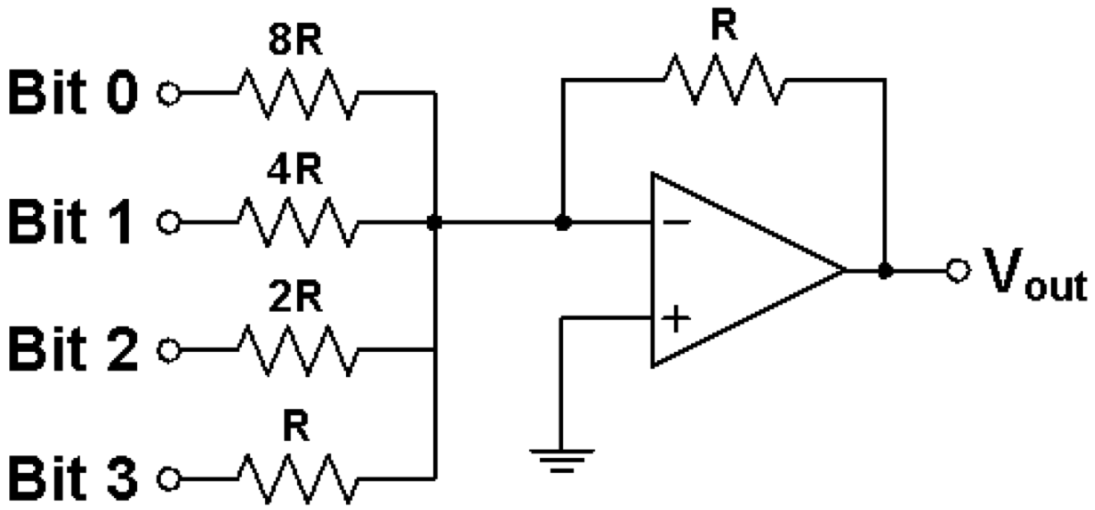
Digital-to-Analog Converter



Digital-to-Analog Converter



Digital-to-Analog Converter

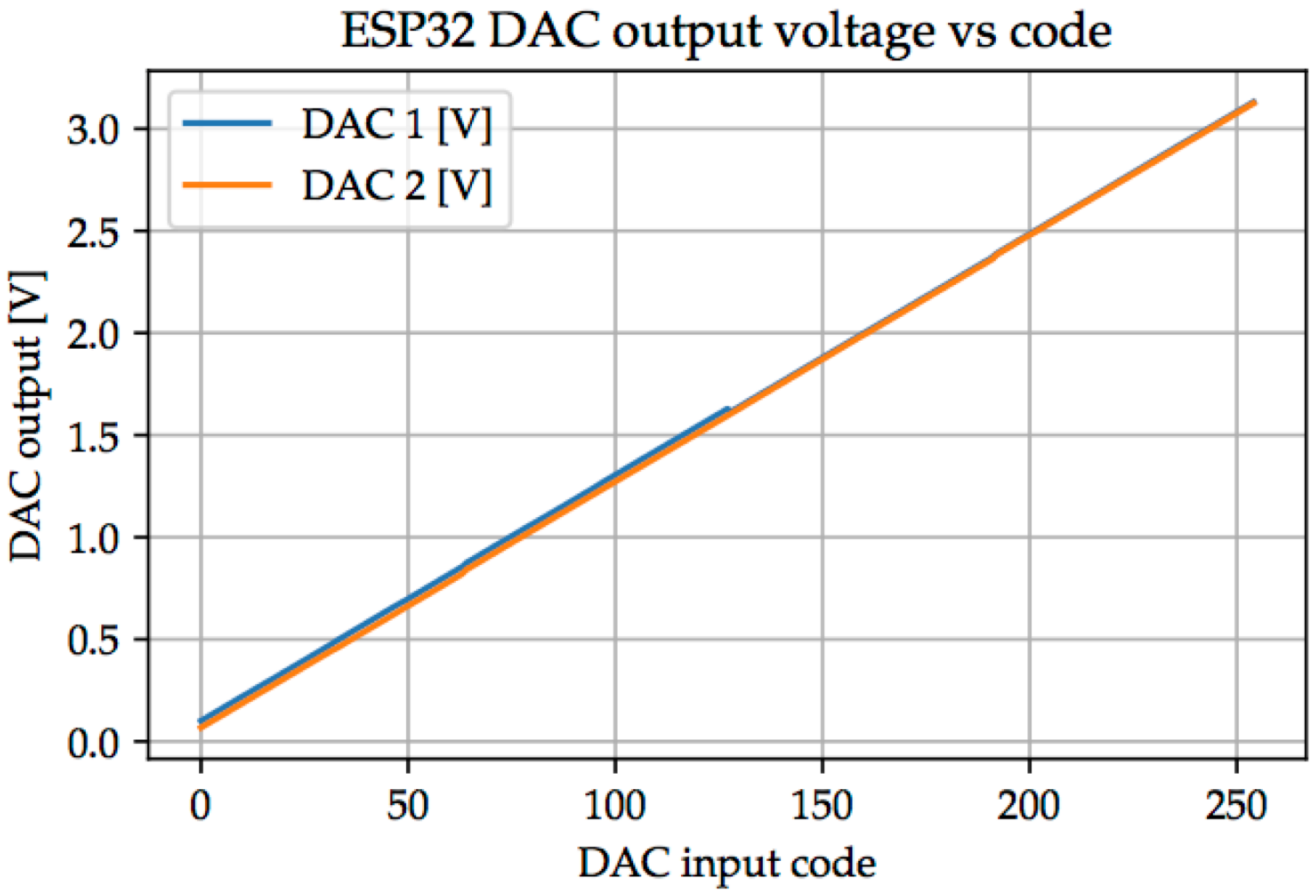


Digital-to-Analog Converter (DAC)

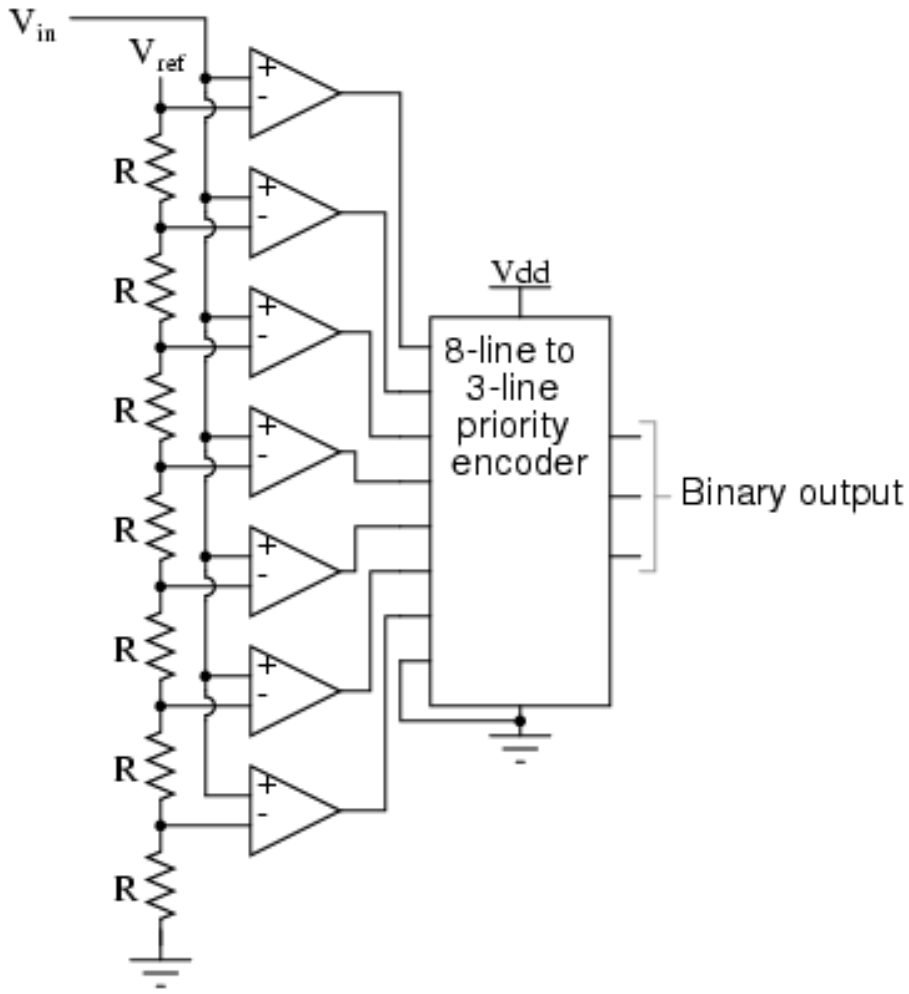
$V_{out} = (code/255) * V_{DD}$ ⟵ **8-Bit DAC**

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

dac1 = DAC(Pin(DAC1))

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

DAC Output

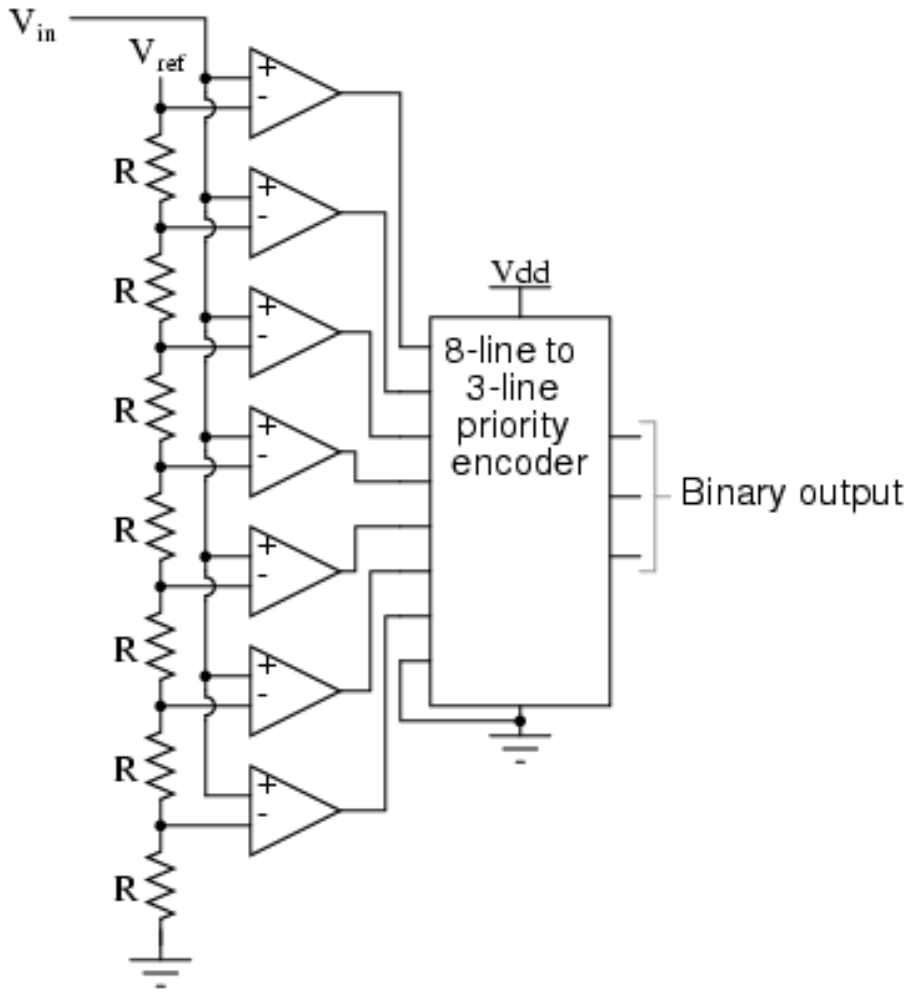

ESP32 DAC output voltage vs code
DAC 1 [V]
DAC 2 [V]
DAC output [V]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
DAC input code

Analog-to-Digital Converter (ADC)

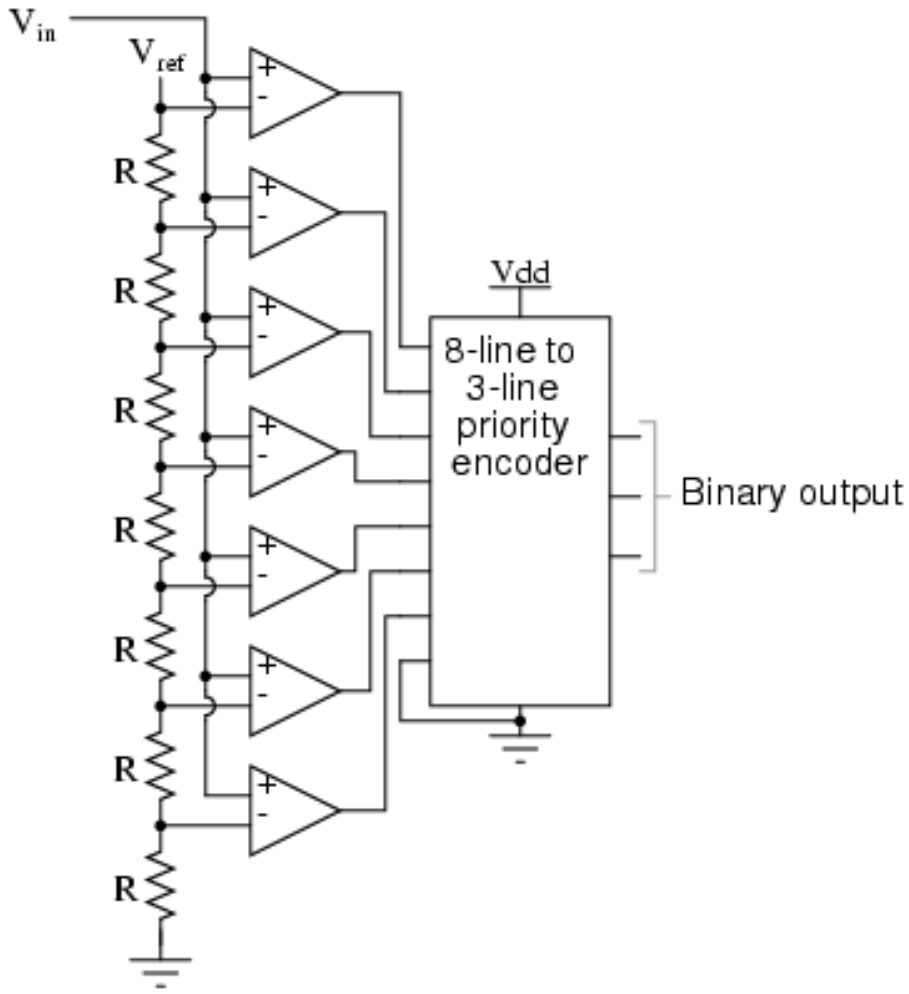


Voltage Comparator

Analog-to-Digital Conversion



Analog-to-Digital Conversion



ADC Circuits

ESP32 ADC

Analog-to-Digital Converter (ADC)

12-Bit ADC

The ADC output code for input V_{in} equals

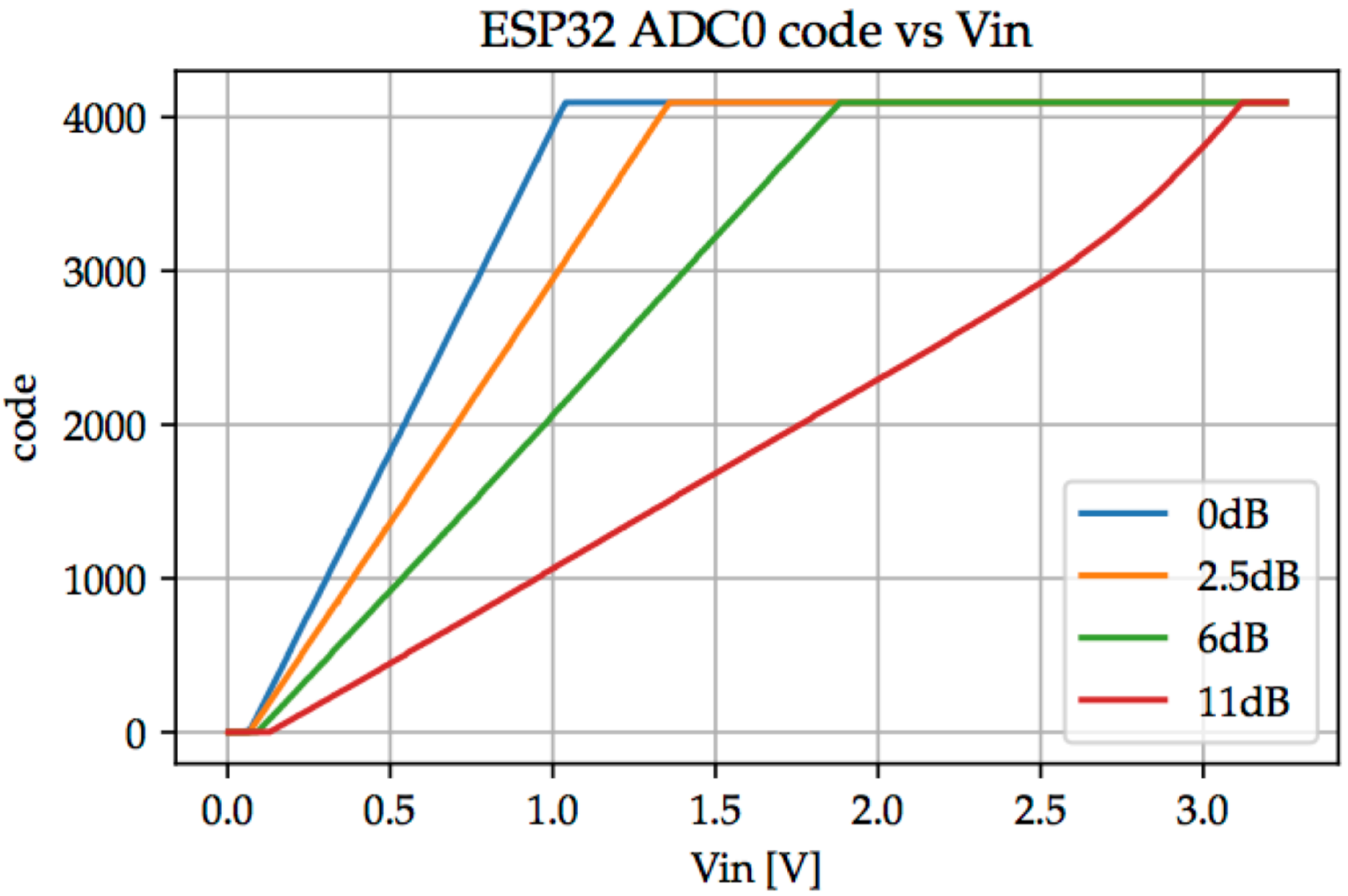
$$code = 4095 * (V_{in}/V_{ref})$$

The `attn(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()
```

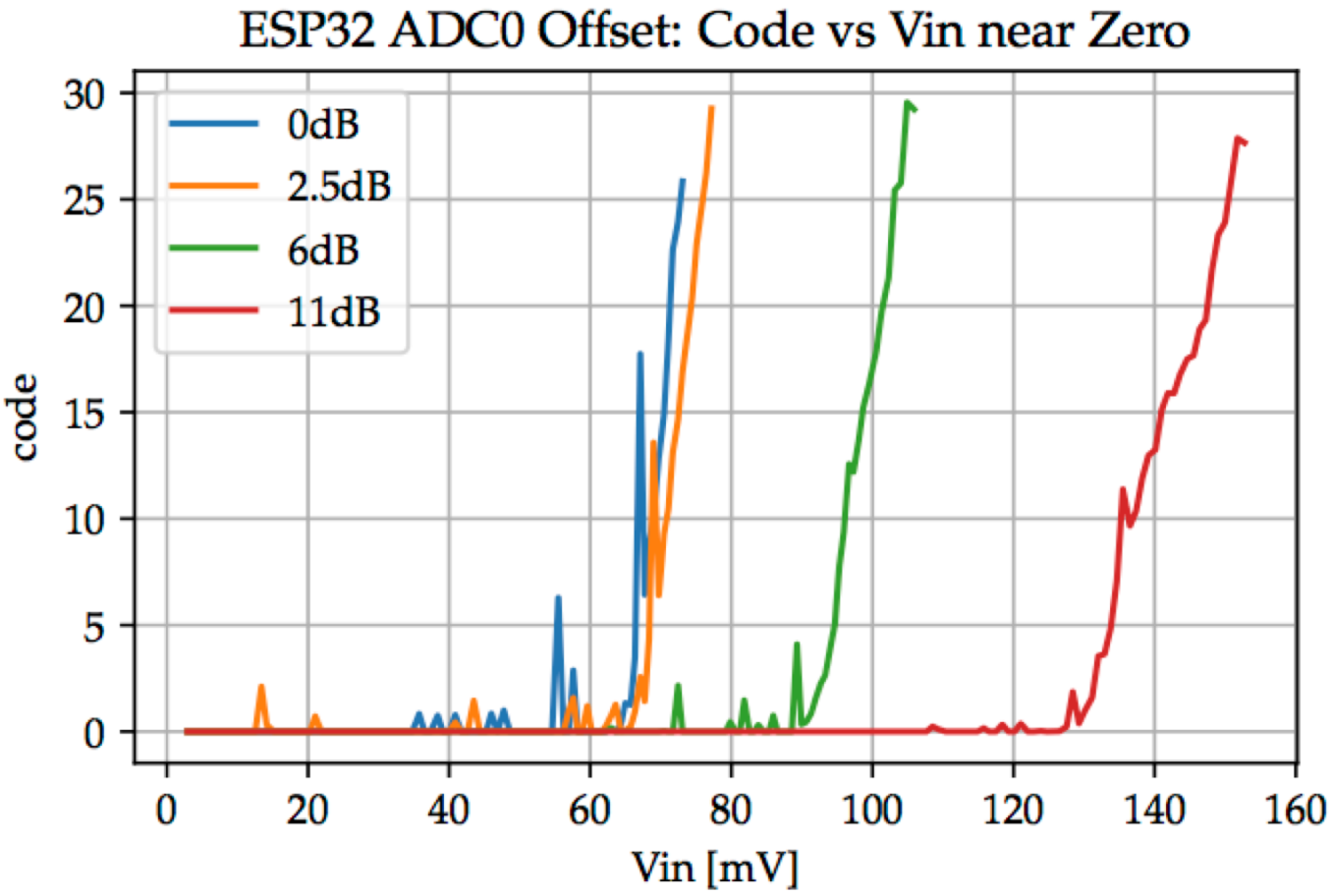
ADC Characteristic



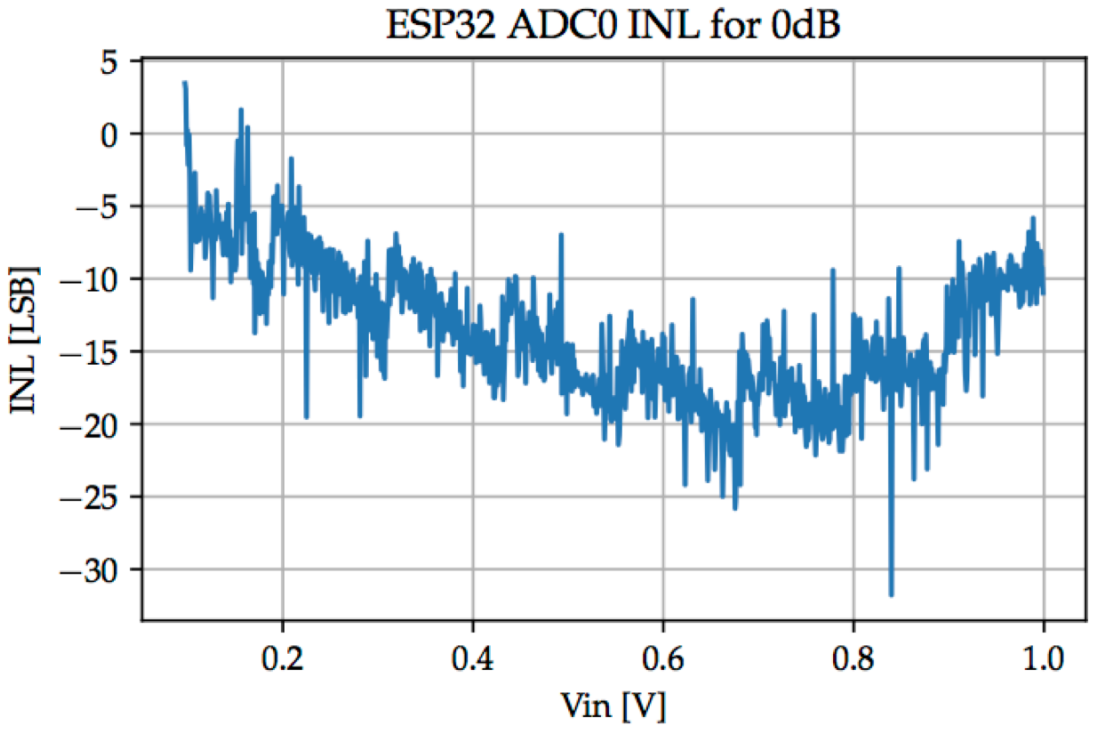
ADC Errors

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

ESP32 ADC Offset



ESP ADC Linearity / Monotonicity



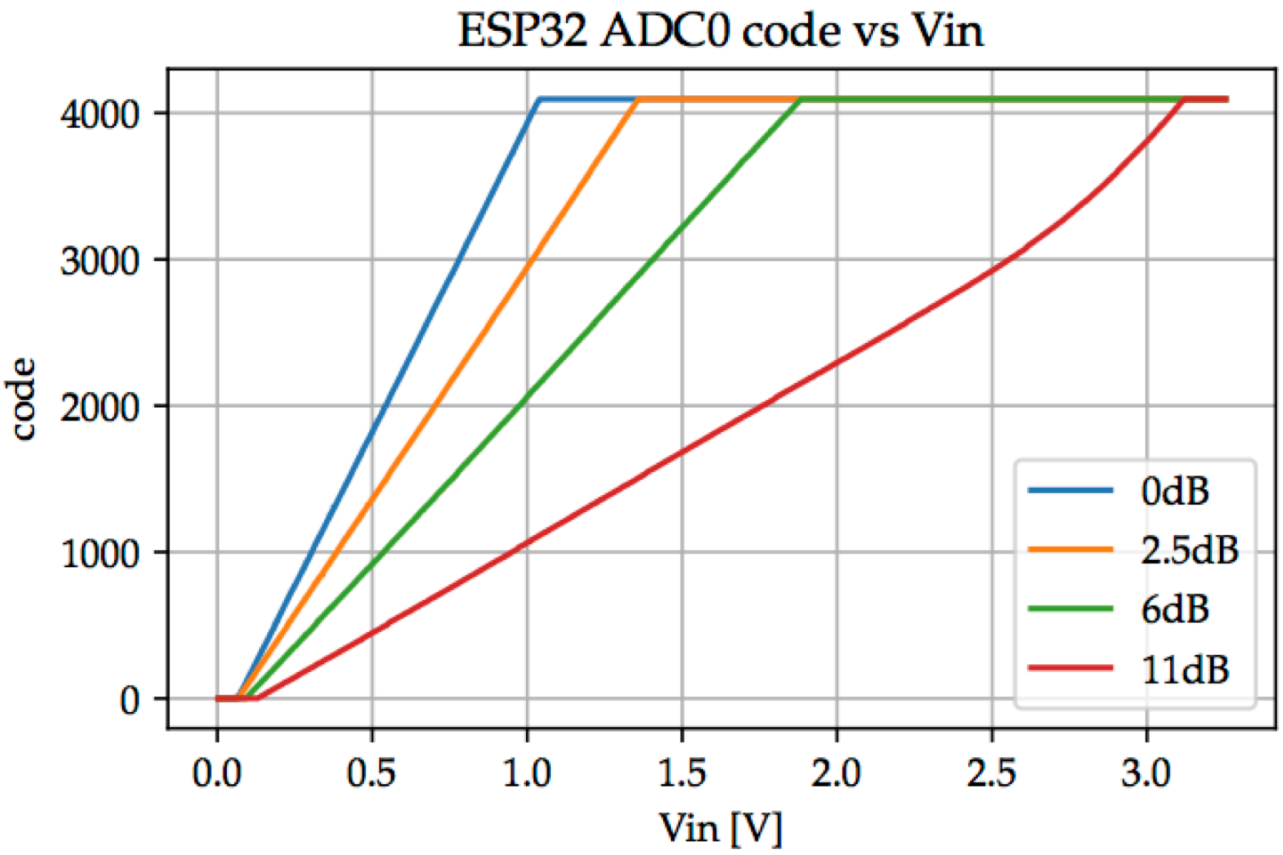
- 30 LSB nonlinearity → ~ 5 Bits!
  - Linearity good to only 7 Bits
- Big “jumps” indicate non-monotonic

ADC Application: Joystick

Joystick Circuit Diagram

Joystick Output Voltages vs Angle

Reading Joystick with ADC



Adjust Full-Scale and Correct ADC Offset

Joystick Readout Circuit

Summary

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