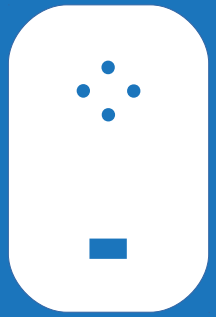
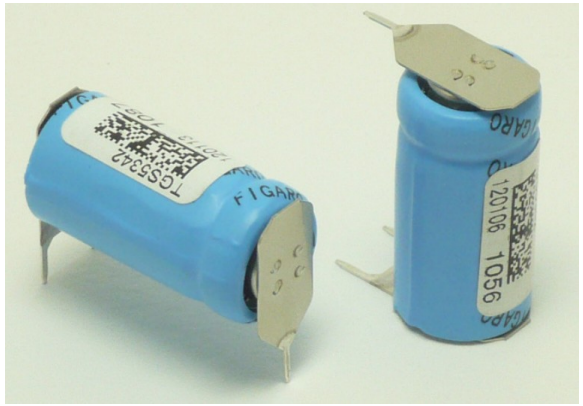
# Project Overview



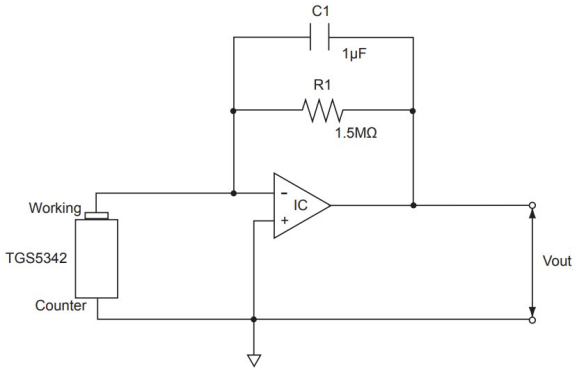
CO Detector

# Project Overview



TGS5342 Carbon Monoxide Sensor

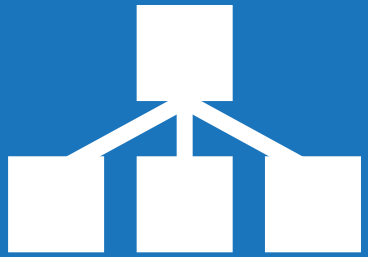
Carbon Monoxide Detector (Marine)




Reference Circuit

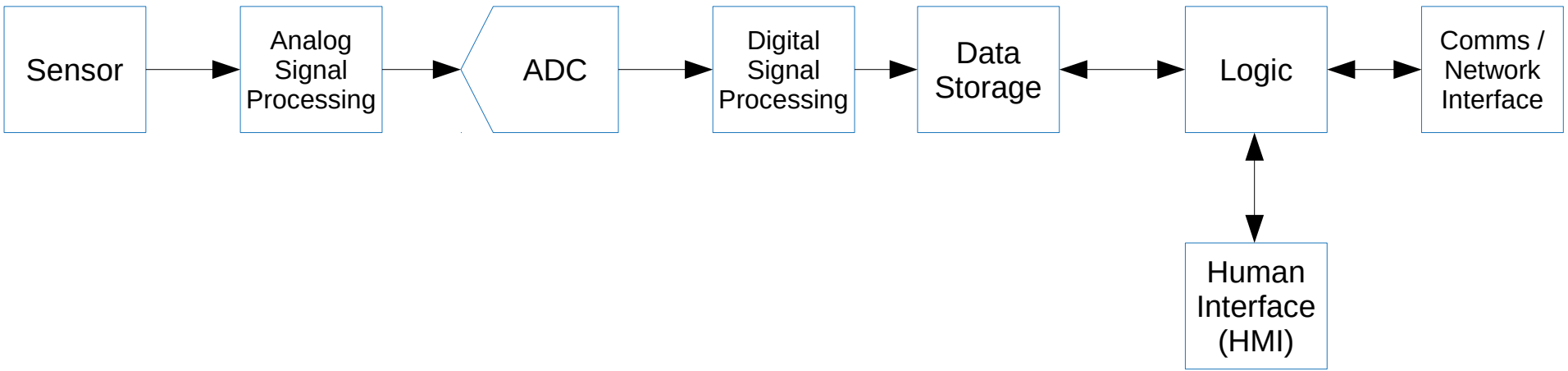
Safety Certifications

# System Diagram



# System Diagram

## Generic Data Acquisition System



# System Diagram

## CO Detector Black Box

**Alarm Horn**
Greatest of:
- 15dB above average
- 5dB above maximum
- 75dB

(NFPA 72)

**Air Intake**
30-69 ppm: 30 day alarm
70-149 ppm: 1-4 hour alarm
150-399 ppm: 10-50 min alarm
400+ ppm: < 4 min alarm

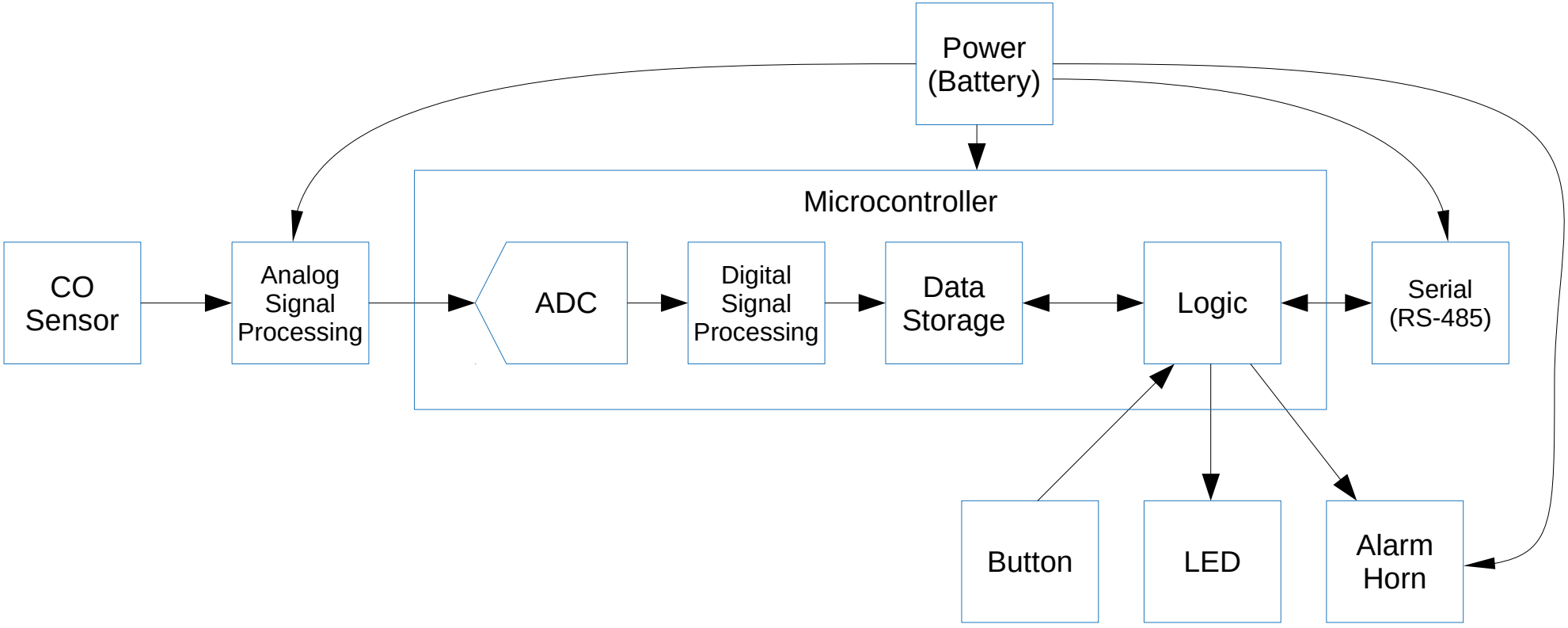
(UL)

**LED**
Status & operation confirmation

**Button**
Silence & test

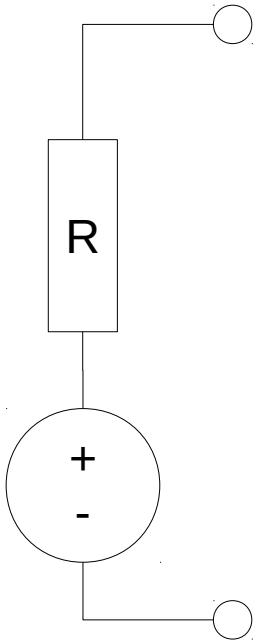
# System Diagram

## CO Detector System Diagram

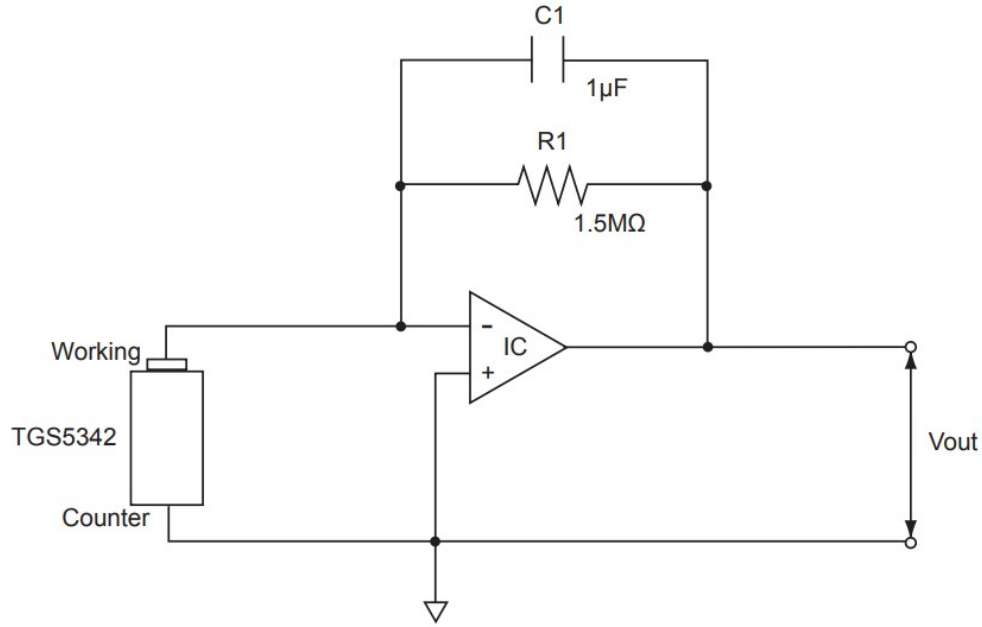


# Analog Signal Processing

# CO Sensor Circuit

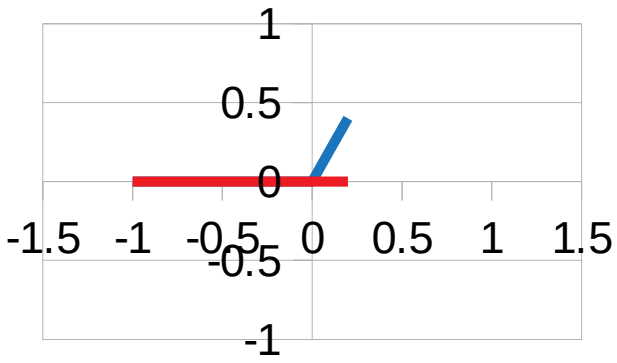



Sensor Equivalent Circuit



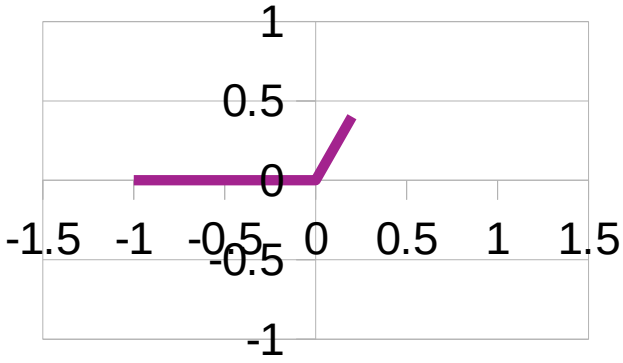

Simple Single-Ended Op-Amp Circuit

# Negative Feedback

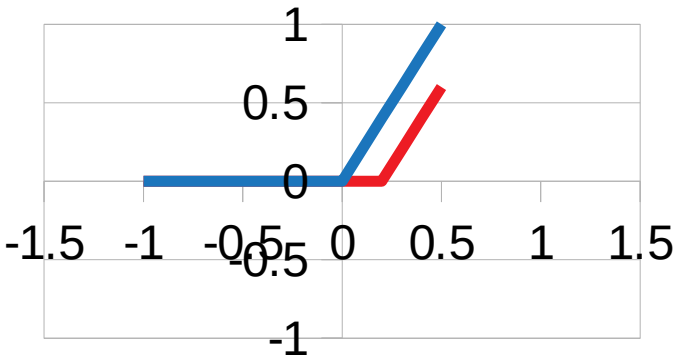


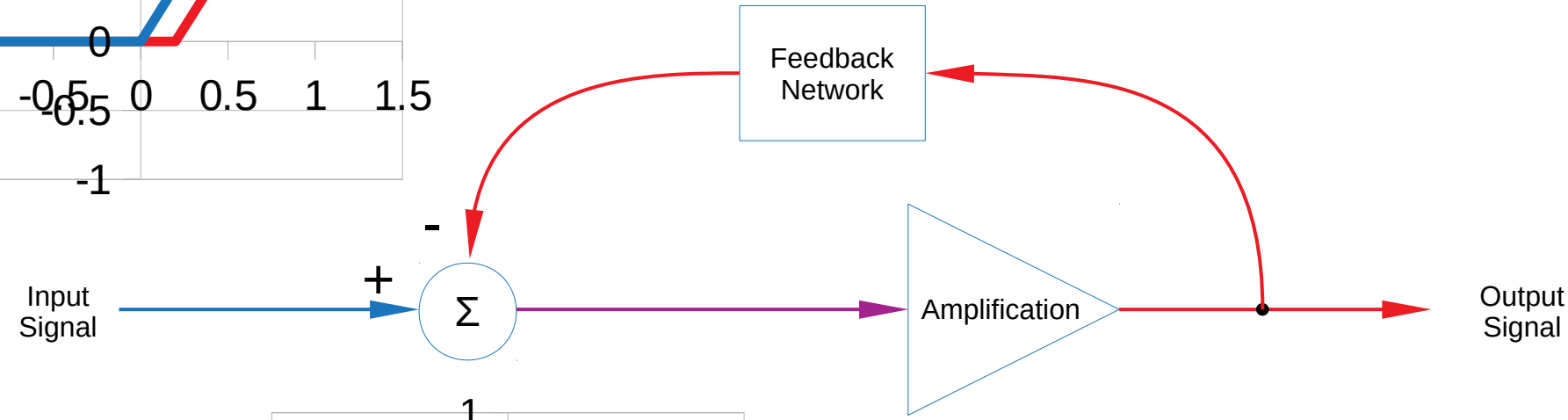


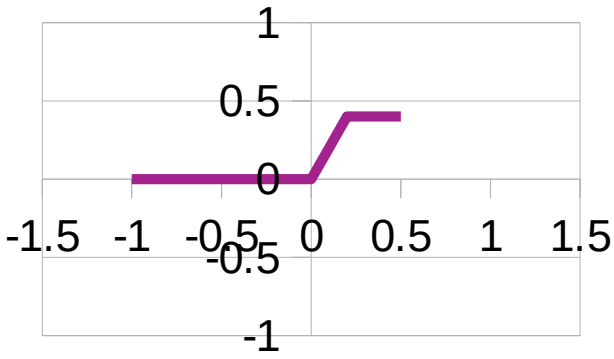




# Negative Feedback



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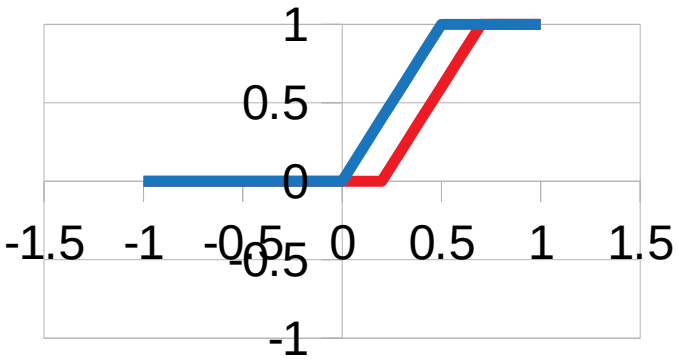


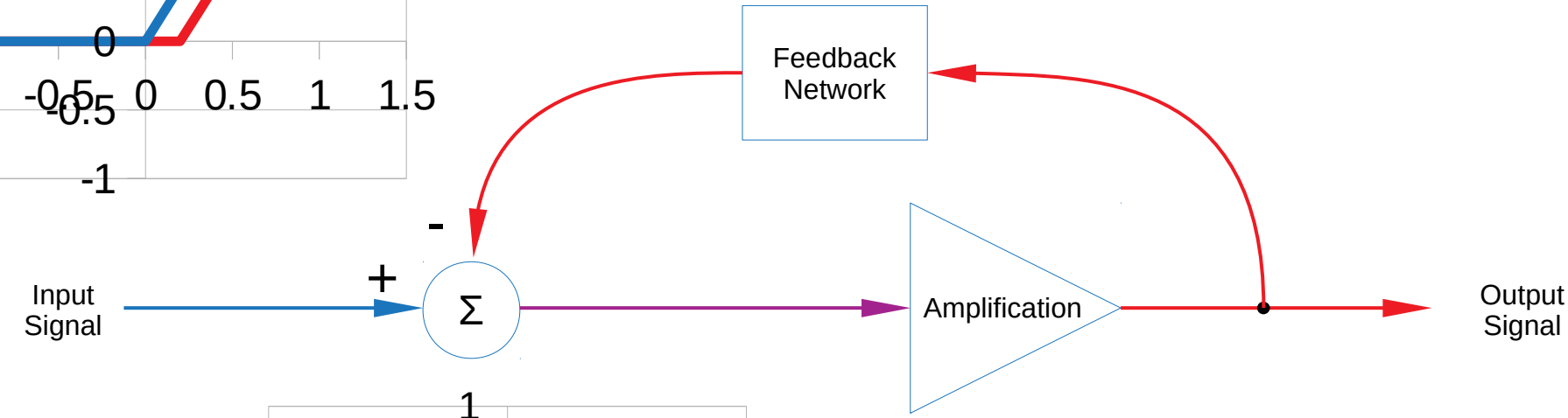


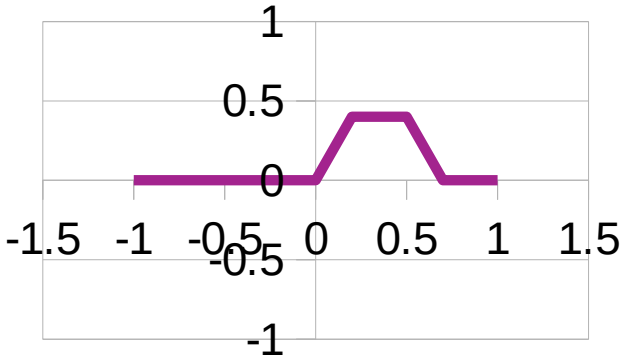

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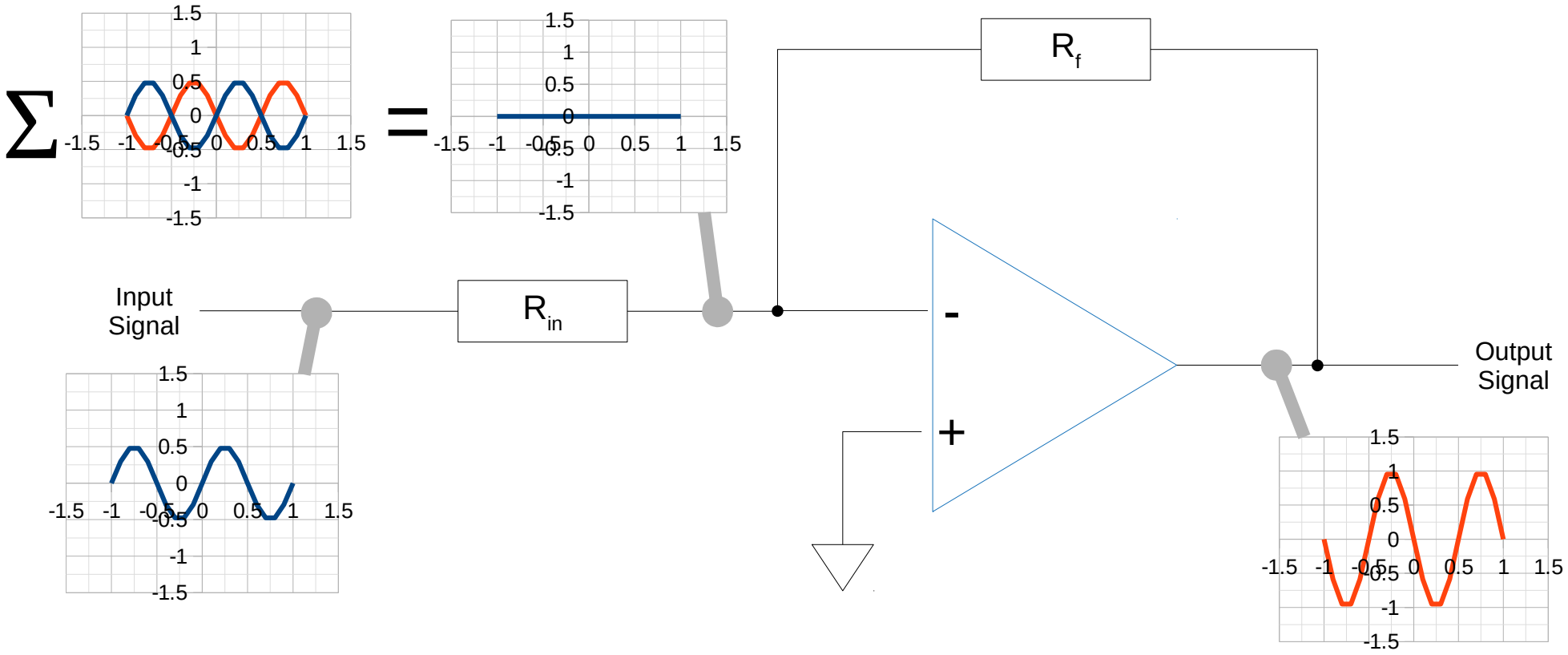

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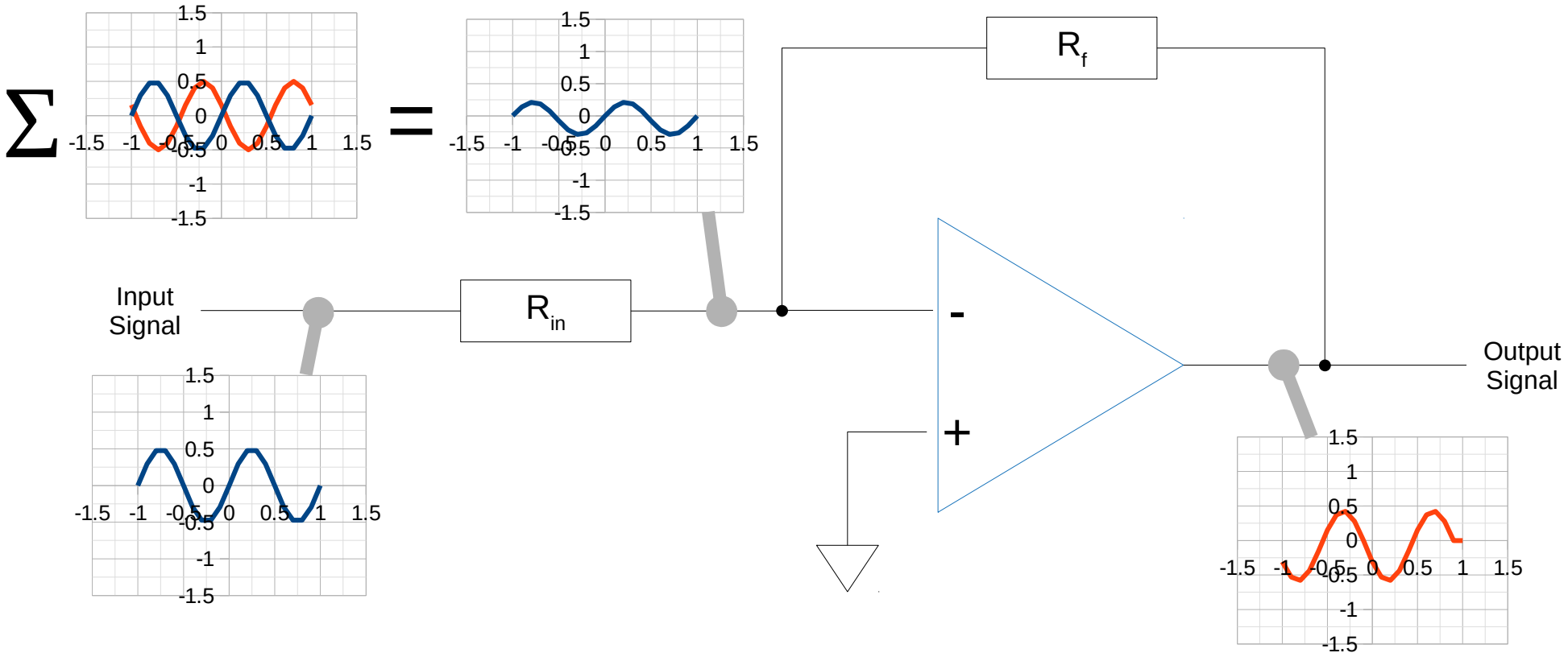
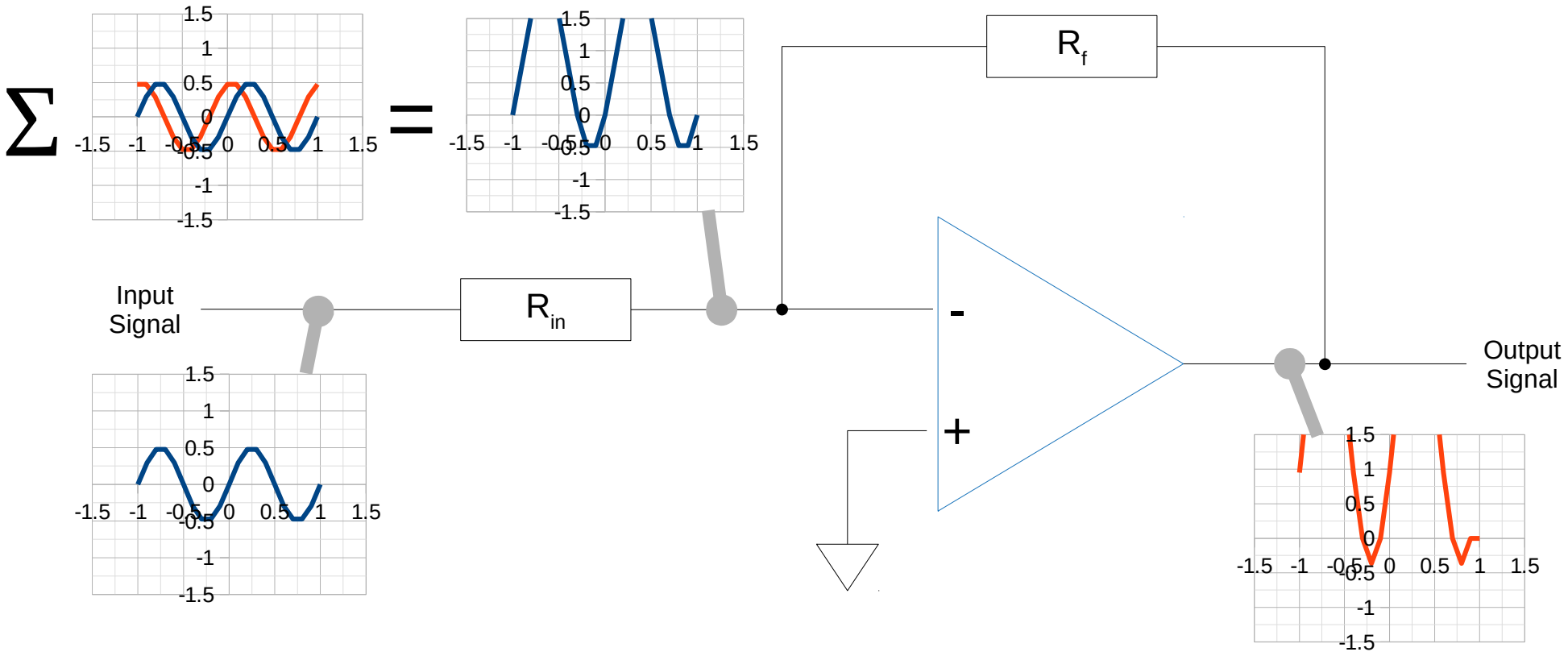
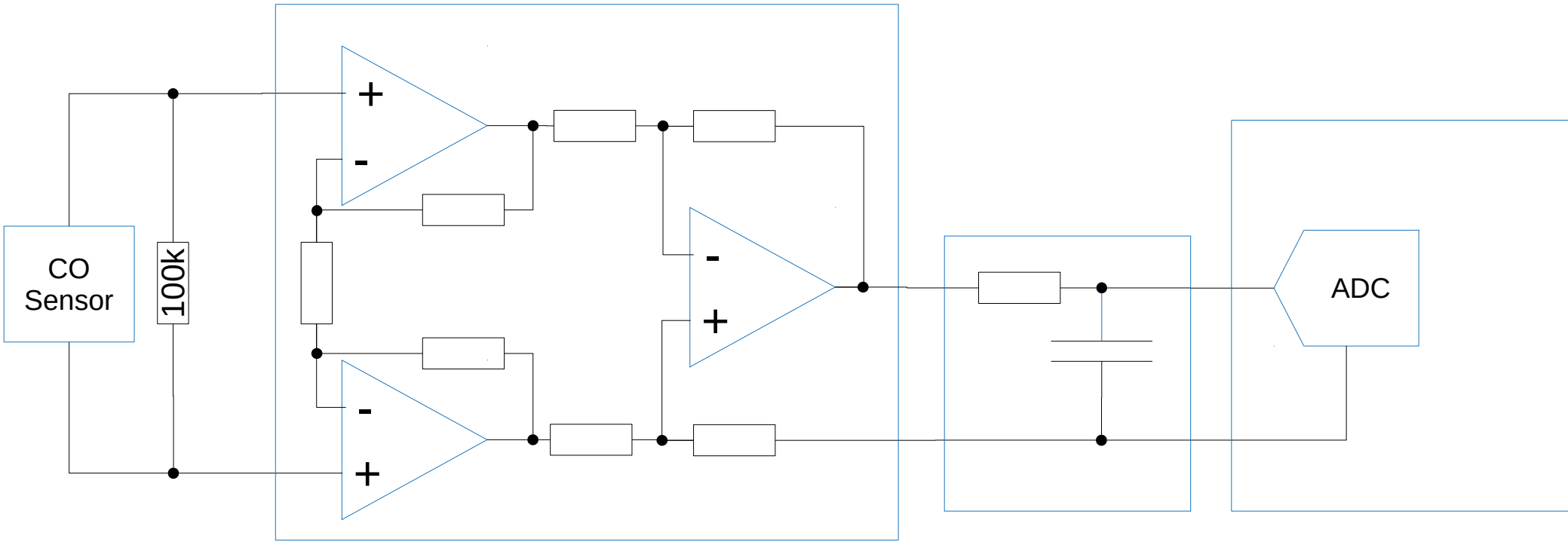


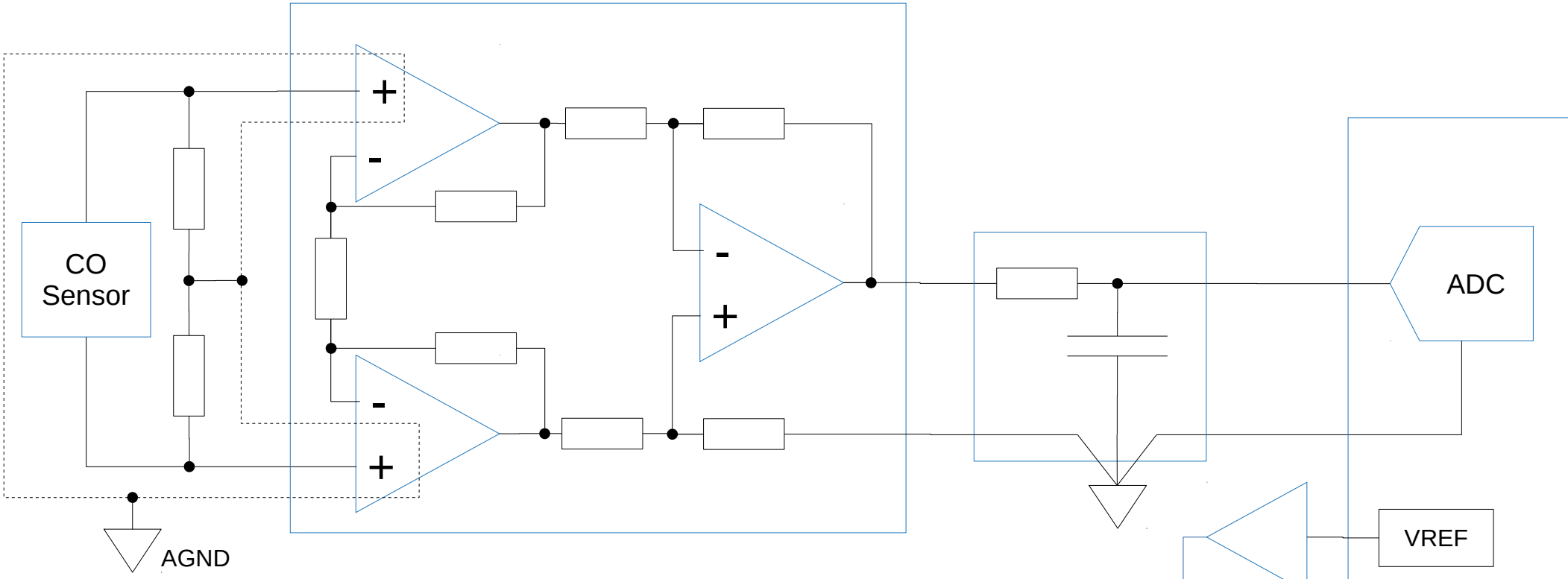
# Negative Feedback



# Signal Path Implementation



# Signal Path Implementation Improvements




Sensor Circuit
- **Guard Traces**
- **Bias Current Path**

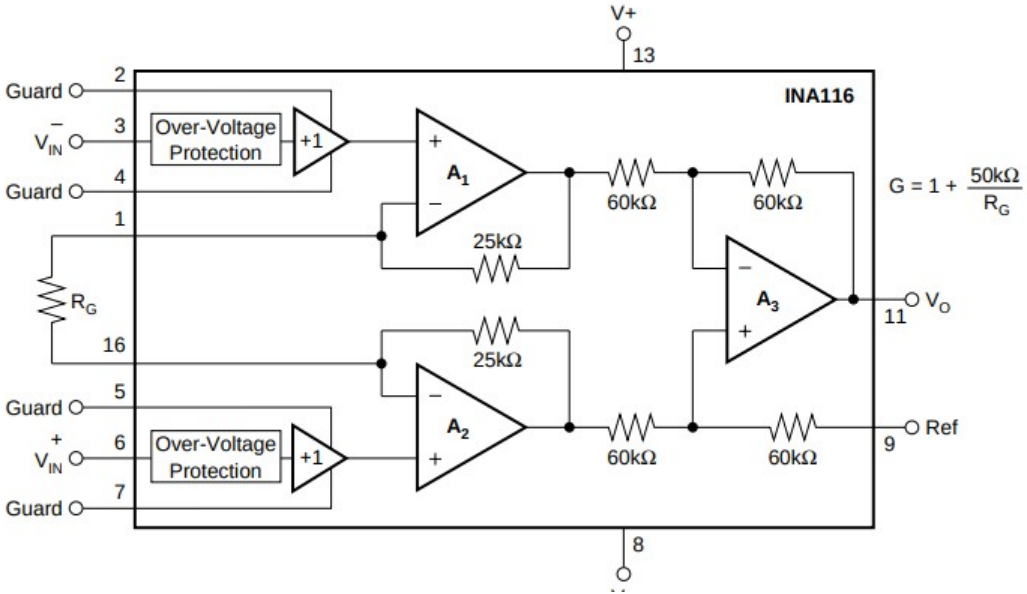
Instrumentation Amplifier

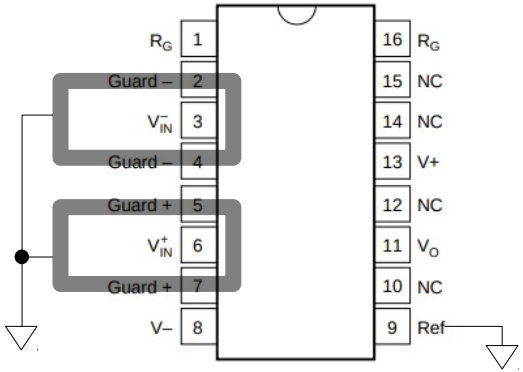
Anti-aliasing Filter
- **Corrected Values**

MCU

# Signal Path Implementation Improvements

- **Guarded Traces**




Example In-Amp with Guarded Inputs

Image: https://www.ti.com/lit/ds/sbos034/sbos034.pdf?ts=1588264952402

BURR-BROWN®

**INA116**

## Ultra Low Input Bias Current INSTRUMENTATION AMPLIFIER

### FEATURES

- LOW INPUT BIAS CURRENT: 3fA typ
- BUFFERED GUARD DRIVE PINS
- LOW OFFSET VOLTAGE: 2mV max
- HIGH COMMON-MODE REJECTION: 84dB (G = 10)
- LOW QUIESCENT CURRENT: 1mA
- INPUT OVER-VOLTAGE PROTECTION: ±40V

### DESCRIPTION

The INA116 is a complete monolithic FET-input instrumentation amplifier with extremely low input bias current. ***Difet***® inputs and special guarding techniques yield input bias currents of 3fA at 25°C, and only 25fA at 85°C. Its 3-op amp topology allows gains to be set from 1 to 1000 by connecting a single external resistor.

Guard pins adjacent to both input connections can be used to drive circuit board and input cable guards to

# Signal Path Implementation Improvements

- **Analog Ground Plane**

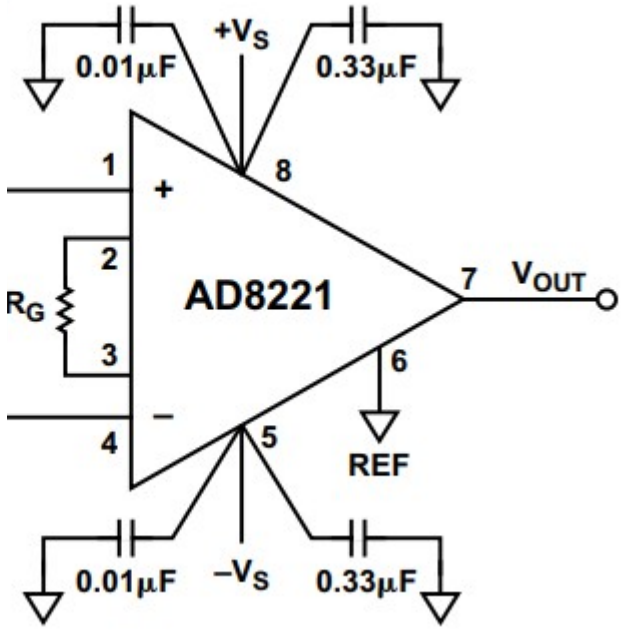
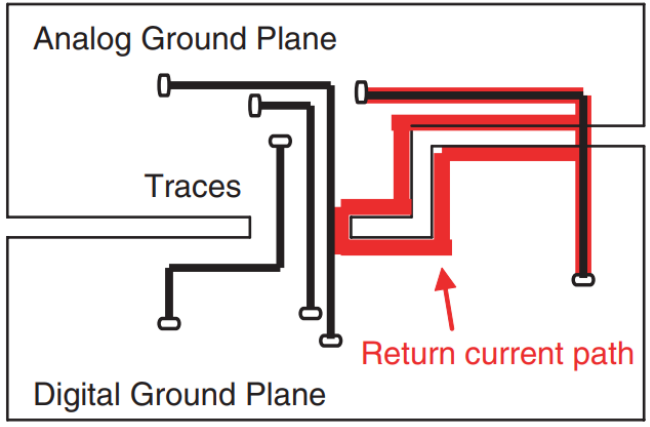



Image: https://www.analog.com/media/en/training-seminars/design-handbooks/designers-guide-instrument-amps-chI.pdf

Decoupling Caps with Complimentary Frequency Response



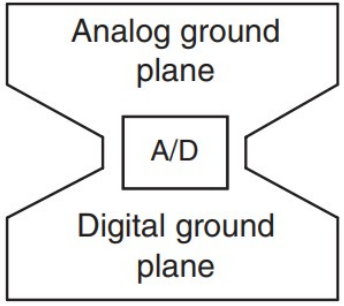
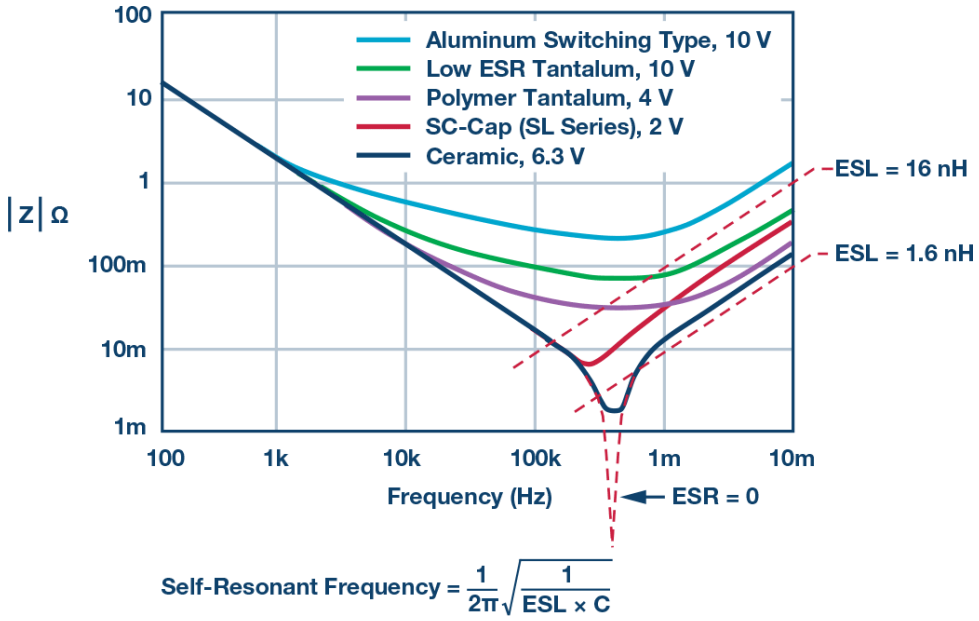
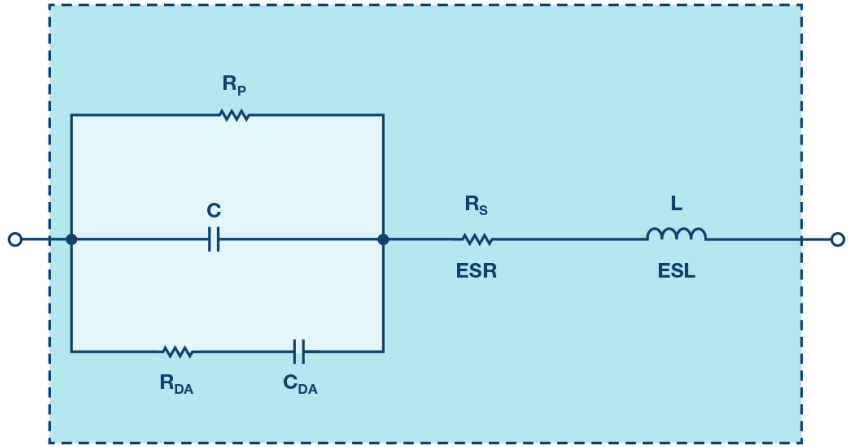




Image: https://www.teledyne-e2v.com/content/uploads/2014/09/Board-Layout.pdf

Isolation of Analog and Digital Ground Return Current

# Non-Ideal Capacitors



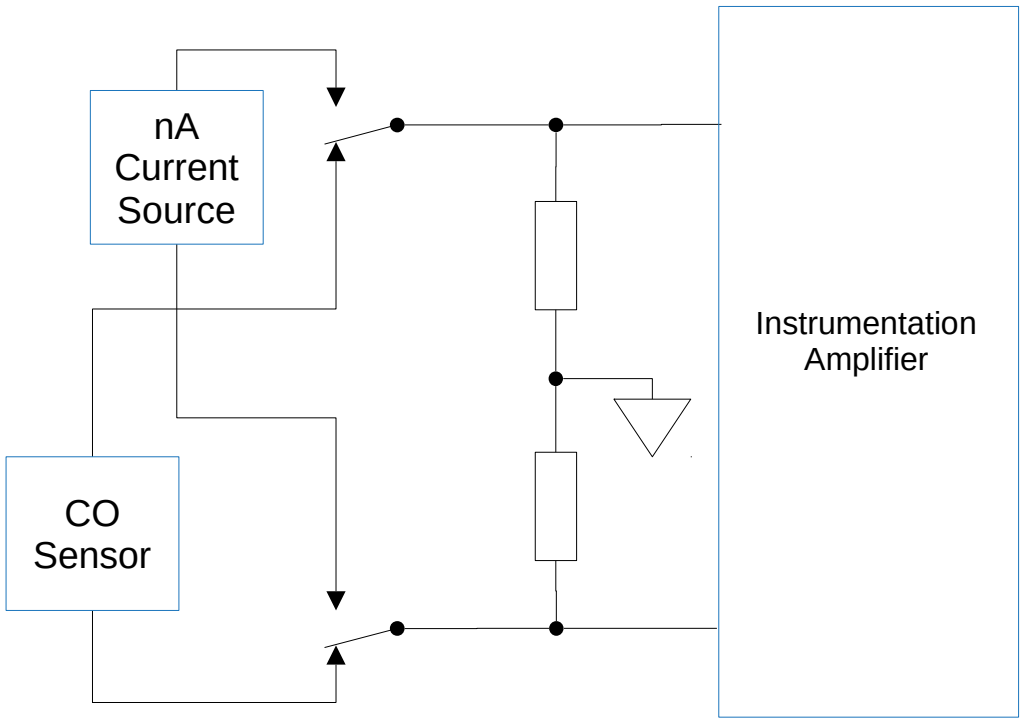

Images: https://www.analog.com/en/analog-dialogue/studentzone/studentzone-may-2017.html

Capacitor Frequency Response

Actual Capacitor Equivalent Circuit

# Signal Path Implementation Improvements

- **Self Test**

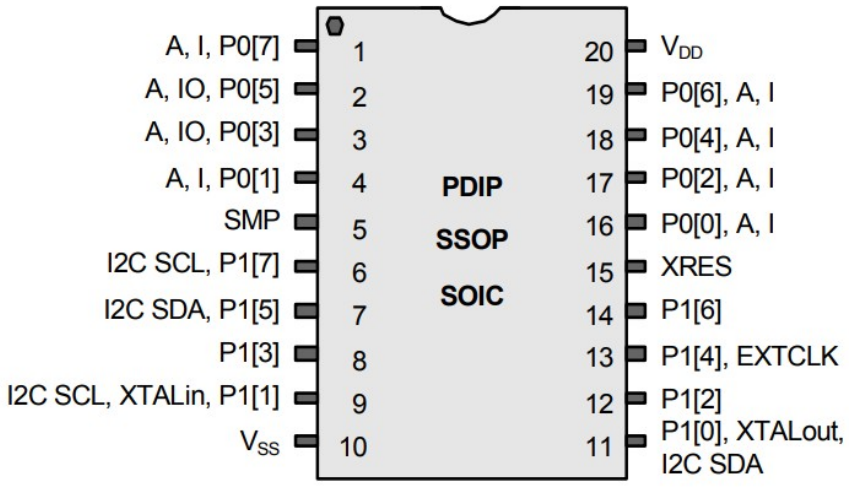



Sensor Circuit

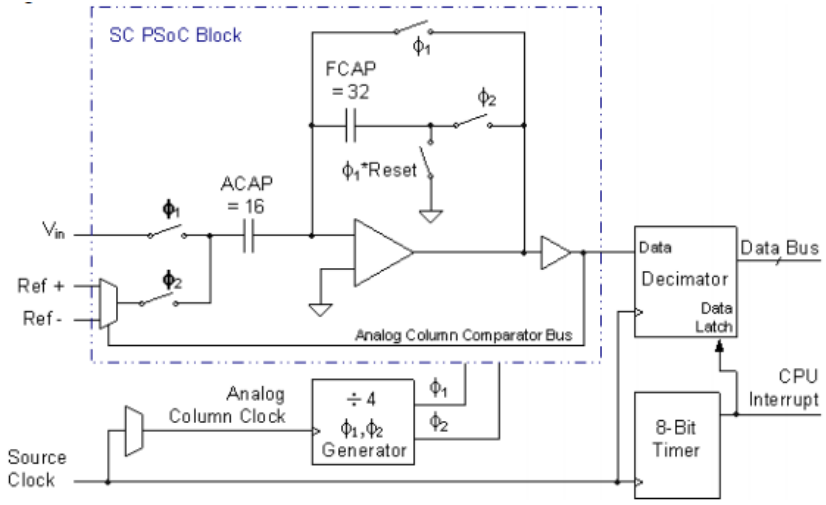
- **Mechanical relay enables connection to self-test current source.**

# ADC

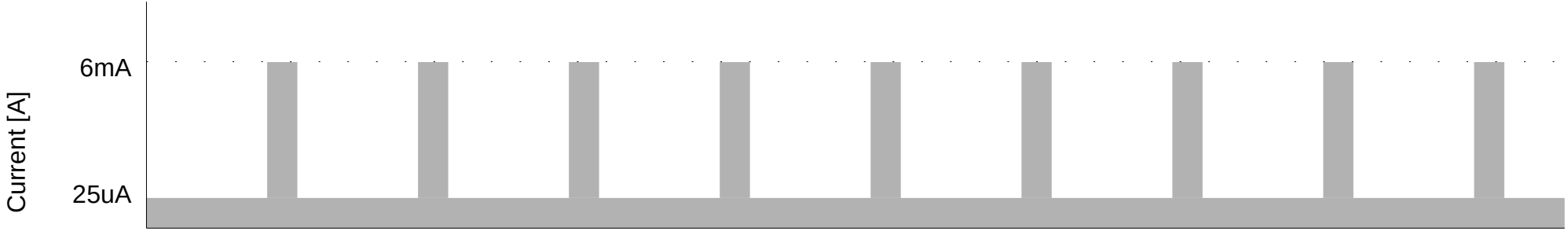
# Physical Restrictions




Cypress PSoC1 CY8C24223A



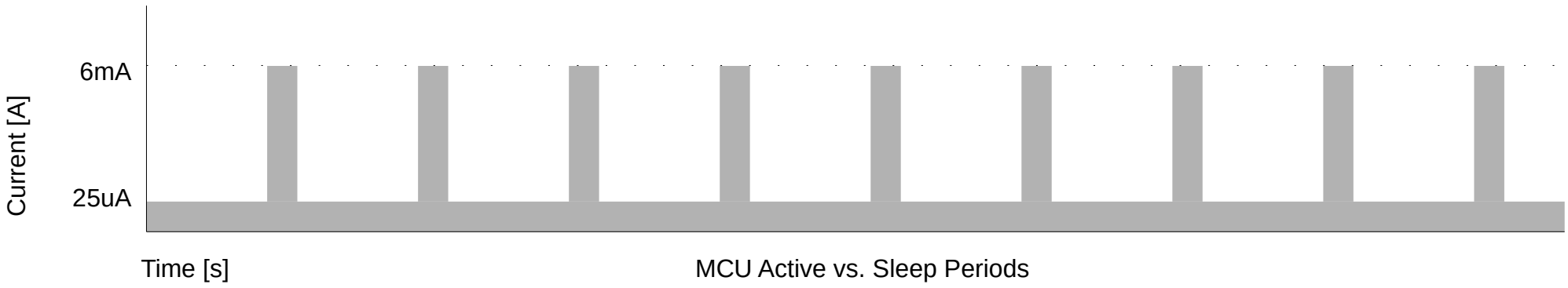

DELSIG8 8-Bit Delta Sigma ADC




MCU Active vs. Sleep Periods

# Physical Restriction: Power

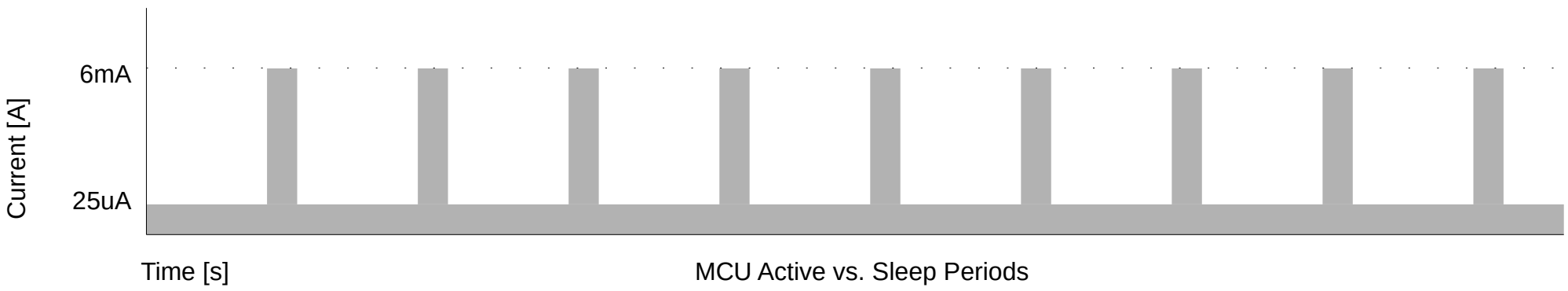
| Restriction | Value | Units |
|---|---|---|
| Energy capacity of two AA batteries | 7.8 | Wh |
| Energy capacity of two AA batteries (90% efficiency) | 7.0 | Wh |
| Current capacity at 3.3V | 2.1 | Ah |
| MCU current draw while active | 6.0 | mA |
| MCU current draw while in sleep | 25 | uA |
| Minimum interval between battery replacements | 1 | year |
| Max seconds with MCU active | 1.15E+06 | sec |
| Min seconds with MCU in sleep | 30.39E+06 | sec |
| Percent active | 3.6 | % |



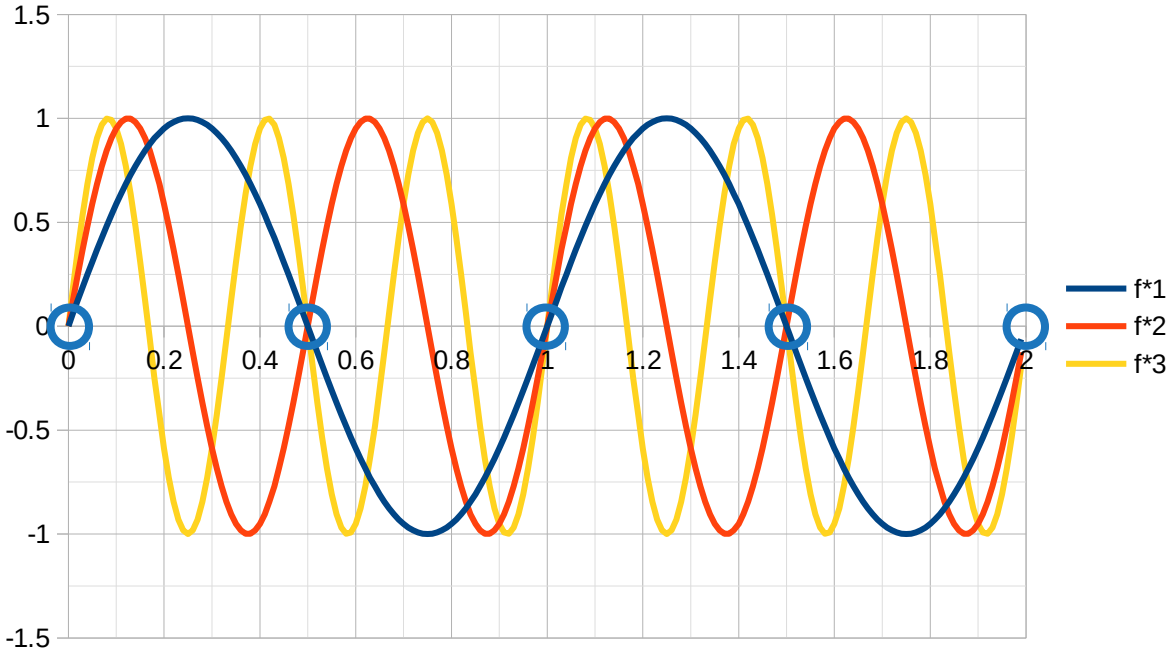

MCU Active vs. Sleep Periods

# Physical Restriction: Time

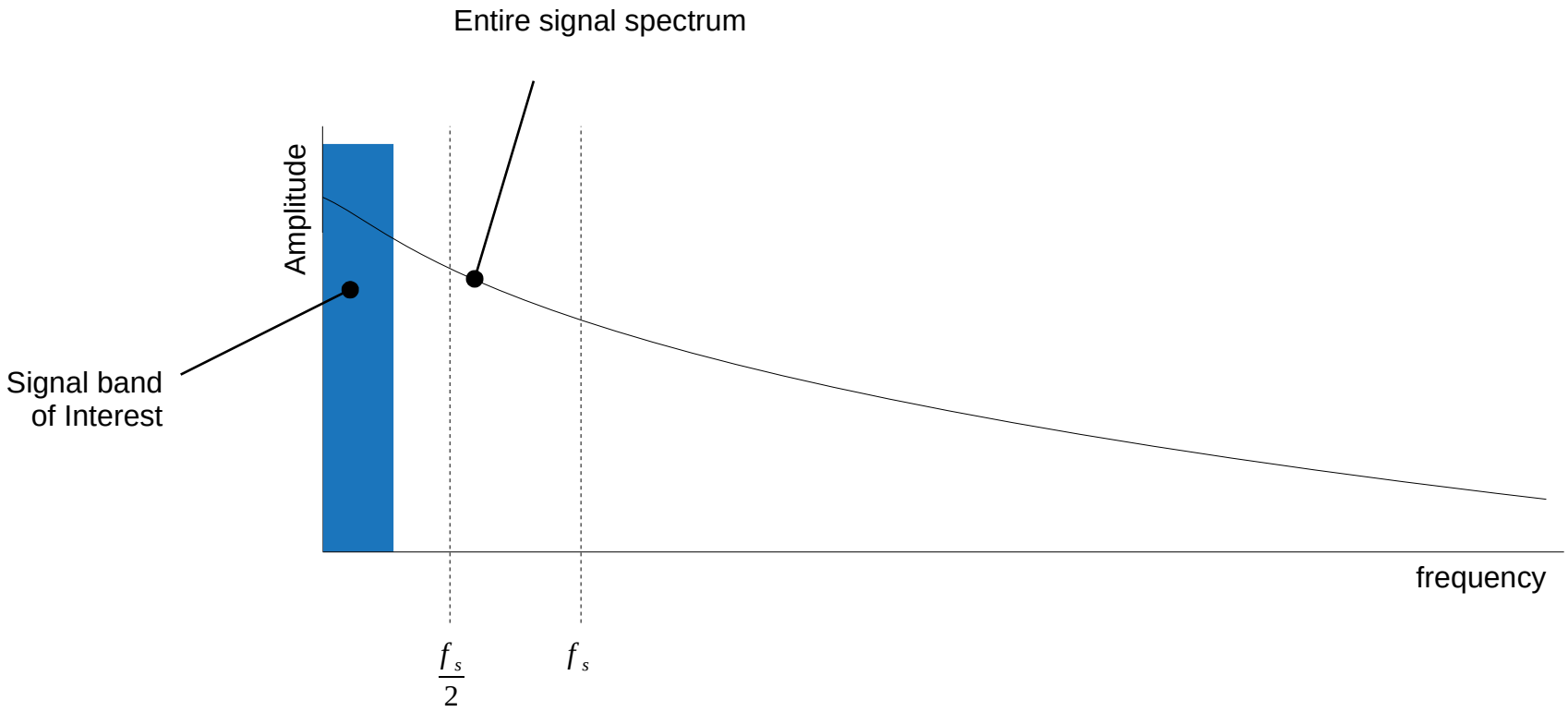
| Restriction | Value | Units |
|---|---|---|
| Minimum ADC sample conversion time | 31.25 | us |
| Minimum MCU wake + sample time (estimated) | 100 | us |
| Sleep time (from ratio) | 2.74 | ms |
| Minimum sample interval time (100us + 2.74ms) | 2.75 | ms |
| Maximum sample rate | 352 | Hz |



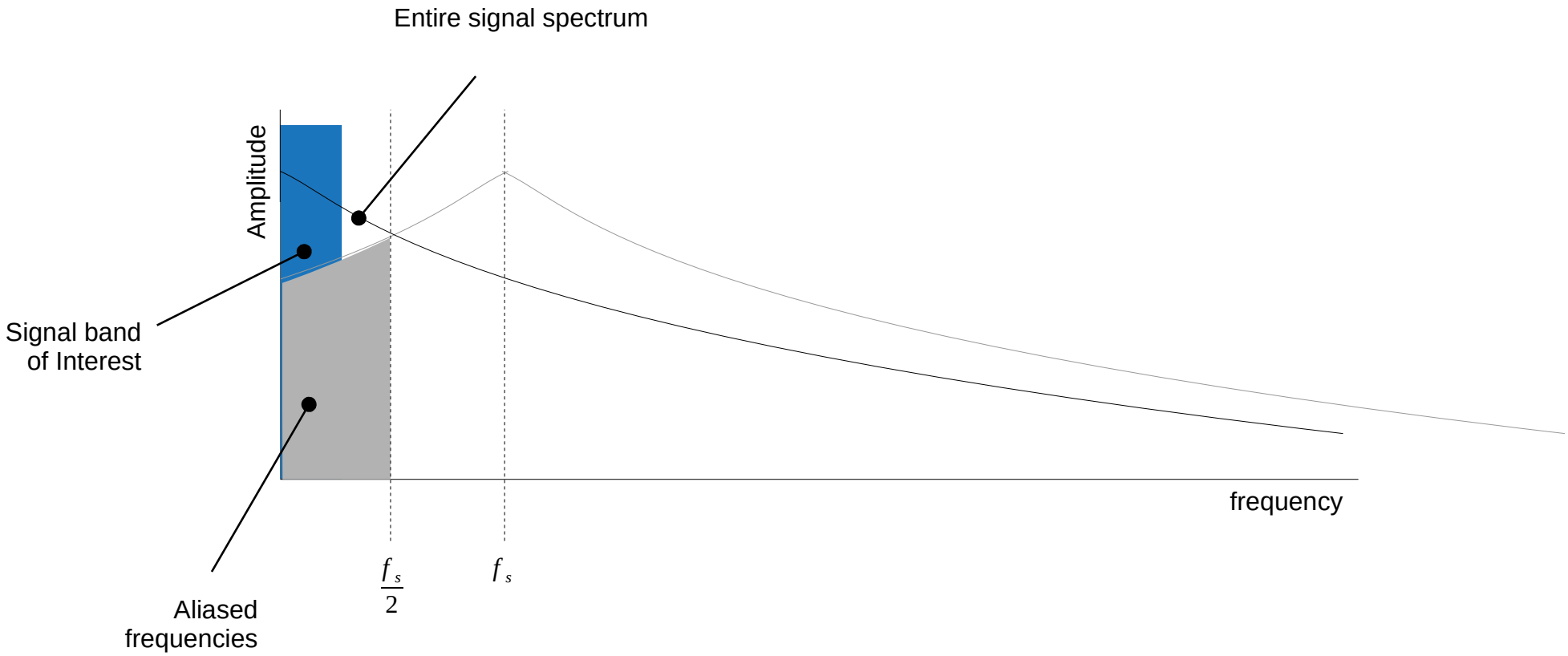
# Sampling Rate & Nyquist-Shannon Theorem



# Frequency Aliasing



# Frequency Aliasing



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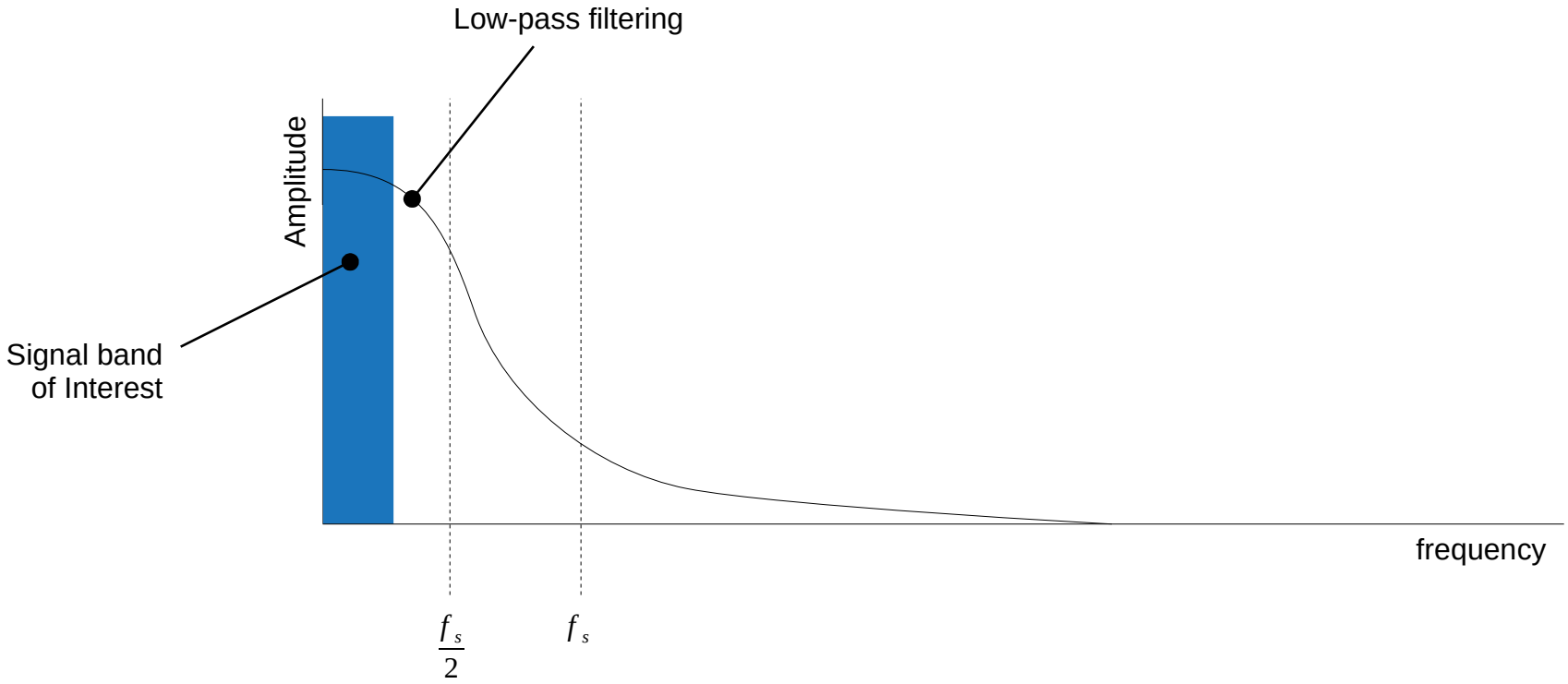
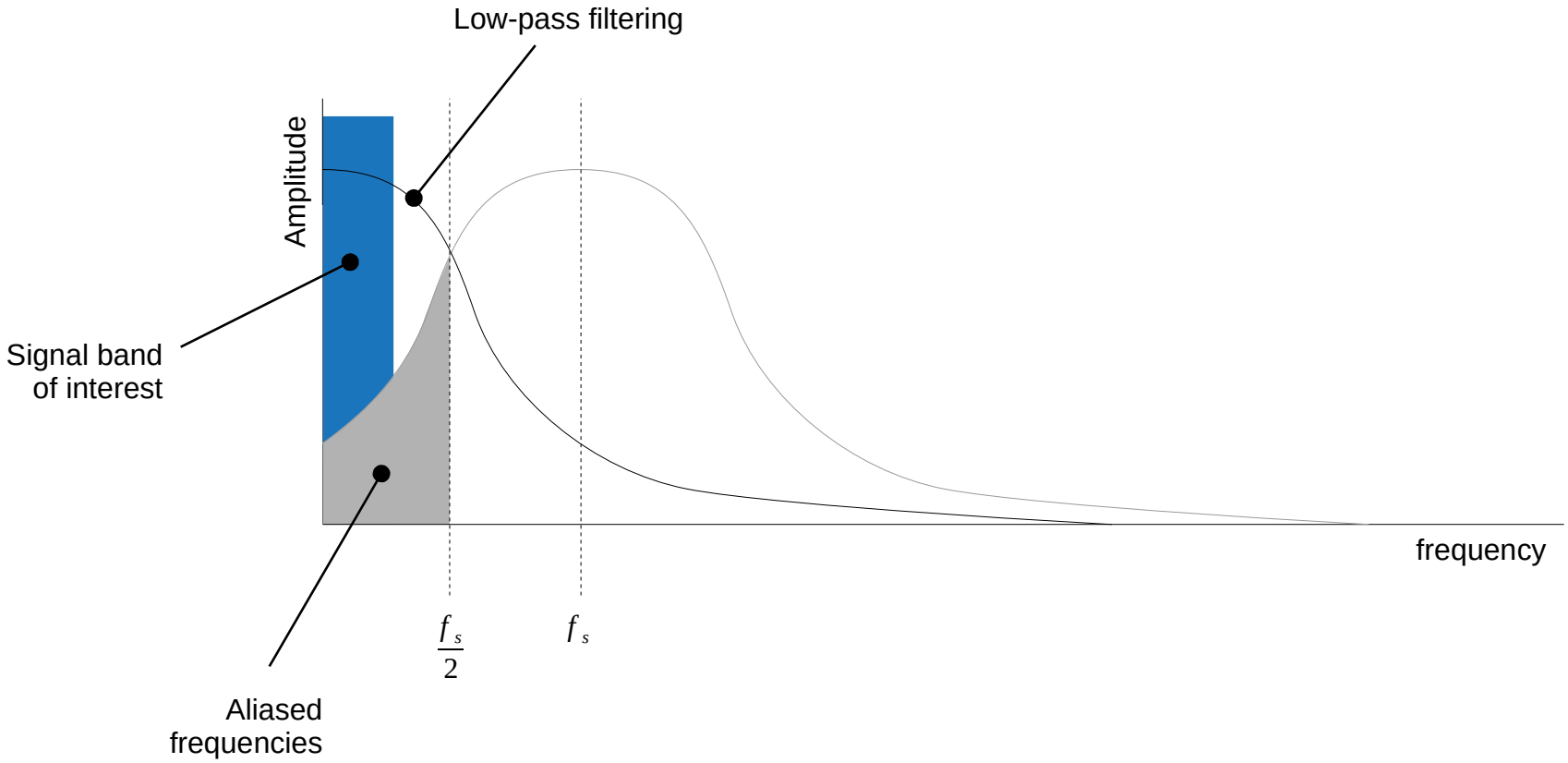
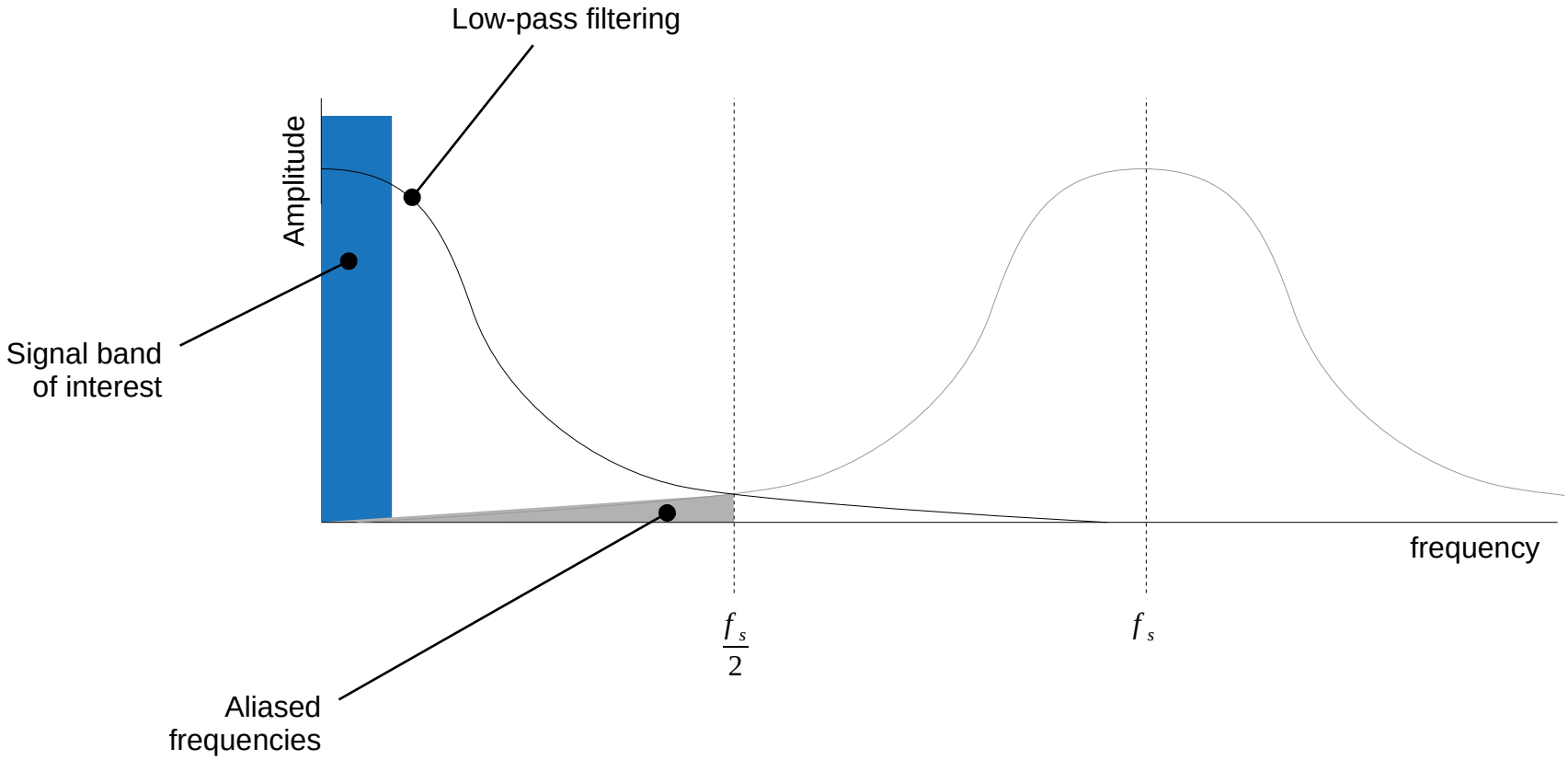


# Frequency Aliasing

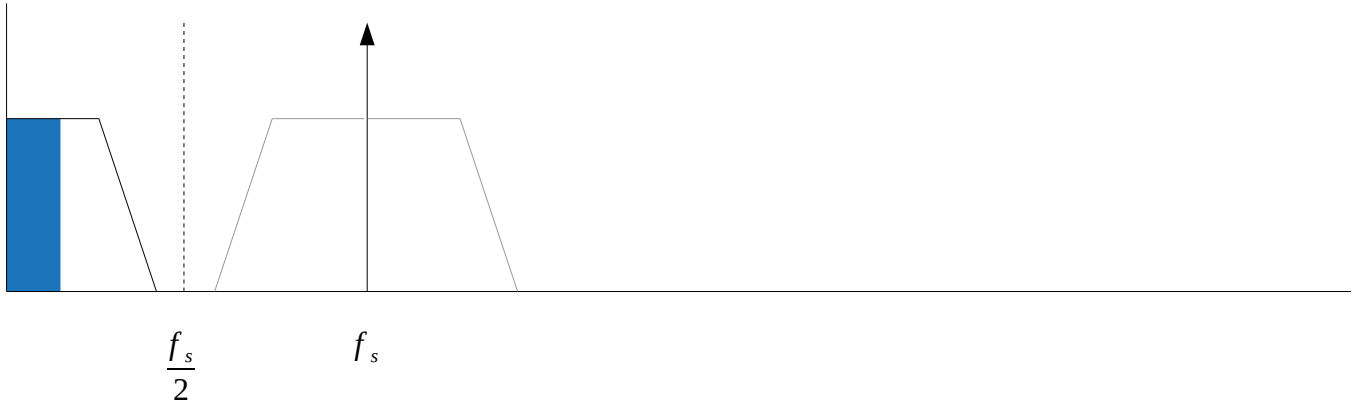


# Frequency Aliasing



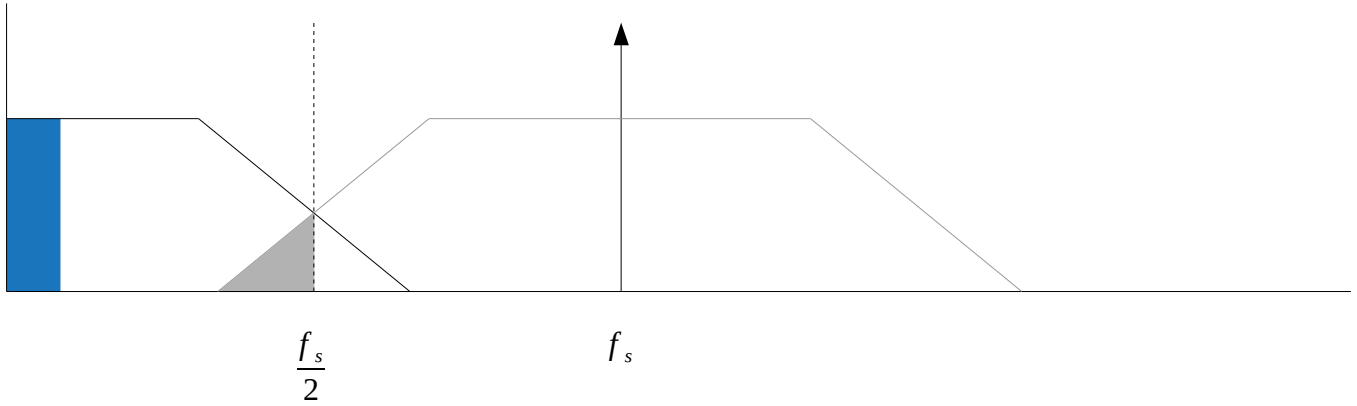
# Anti-Aliasing Option 1: Precision Analog

High-order analog “anti-aliasing” filter before ADC

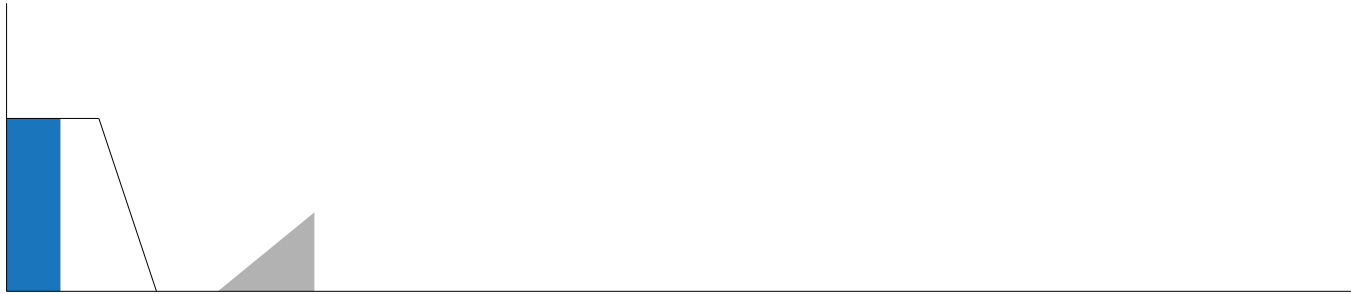


# Anti-Aliasing Option 2: Oversampling

Low-order analog “anti-aliasing” filter before ADC




High-order digital filter after ADC



# Signal Band of Interest

Decay time-constant for stable sensor reading:

τ ≈ 10 seconds
f ≈ 0.1 Hz

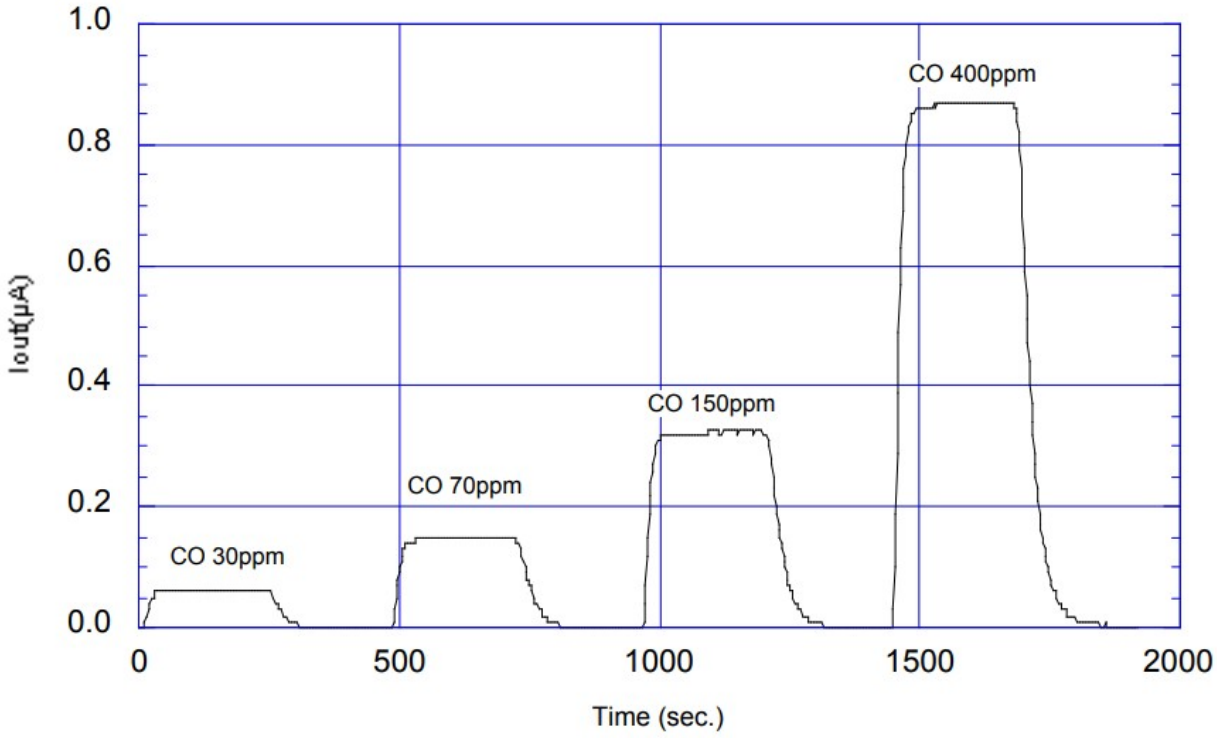
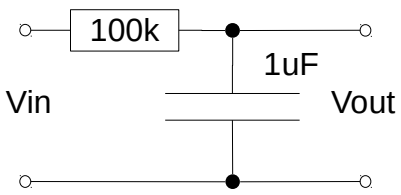


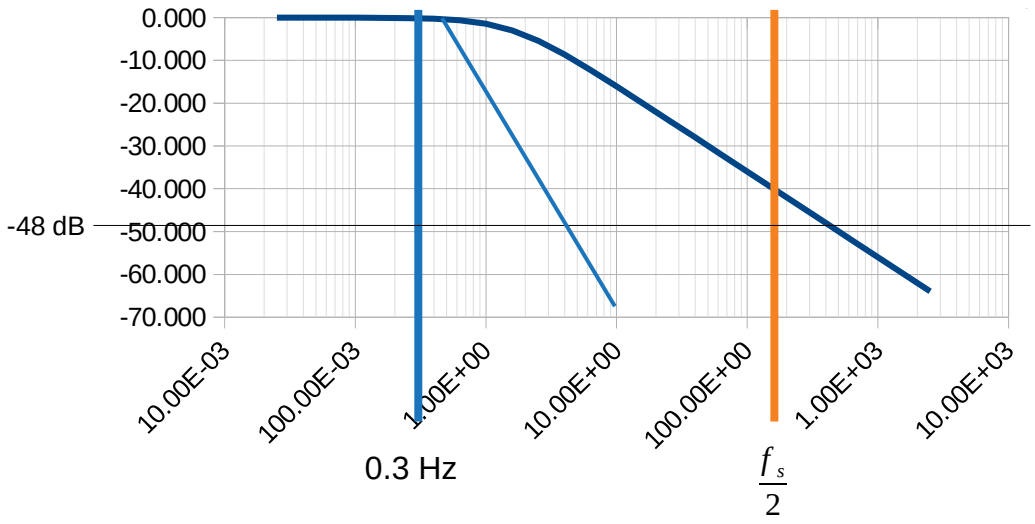

Image: https://www.figaro.co.jp/en/product/docs/tgs5141-p00_technical%20infomation%28en%29_rev05.pdf

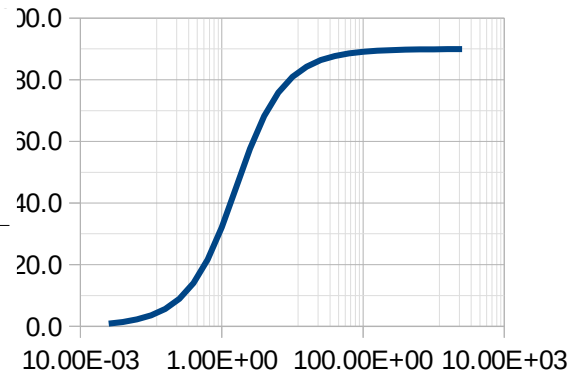
Sensor Curves from Datasheet

# Physical Restriction: Resolution

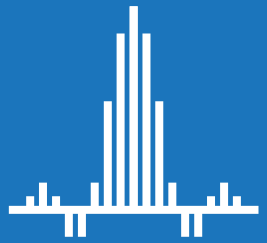
| Restriction | Value | Units |
|---|---|---|
| ADC bit resolution | 8 | bit |
| Band of interest | 0.3 | Hz |
| Maximum sample frequency | 352 | Hz |
| Percent size of least significant bit (1 / 2^8) | 0.39 | % |
| Amplitude of least significant bit | -48 | dB |



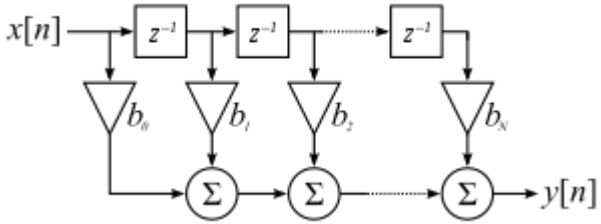
# Digital Signal Processing

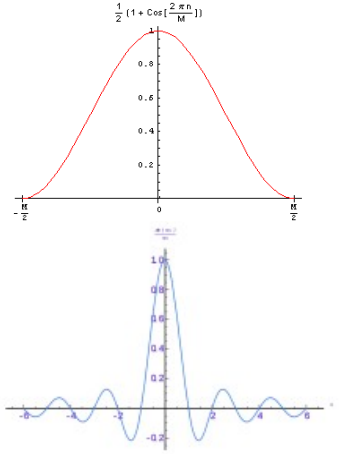


# FIR vs. IIR Filters

Finite Impulse Response (FIR)

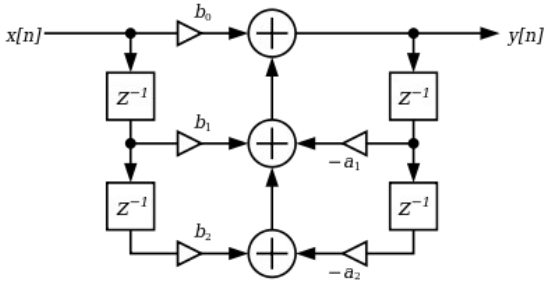
- Function of input only: unconditionally stable.
- High-order FIR filters require large number of taps.
- Introduces larger phase delay than IIR filter.

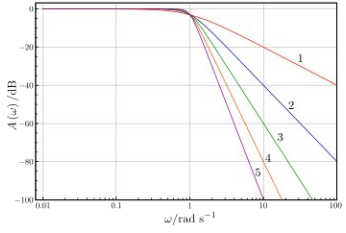


Infinite Impulse Response (IIR)

- Function of both input and output; can be unstable.
- High-order FIR filter requires low number of taps.



# FIR Filter

$$y[n]=\frac{1}{4}x[n]+\frac{1}{4}x[n-1]+\frac{1}{4}x[n-2]+\frac{1}{4}x[n-3]$$

Moving Average Filter

- Simplest FIR filter.
- Flat time-domain response.

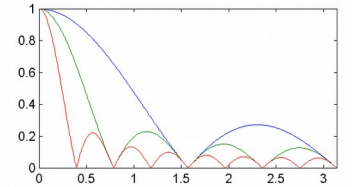
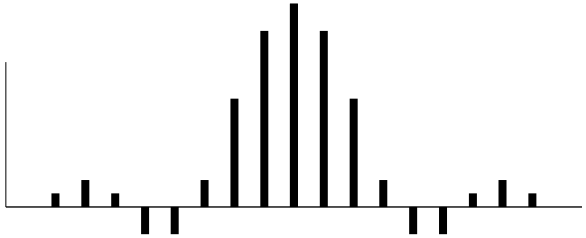



Image:https://ptolemy.berkeley.edu/eecs20/week12/freqResponseRA.html

Windowed Sinc Filter

- Coefficients of a sinc function scaled by a window function.



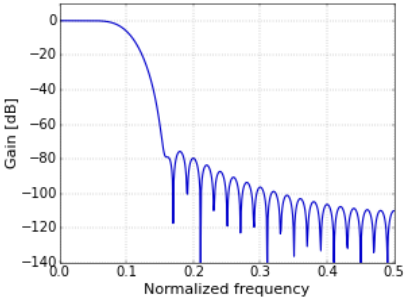
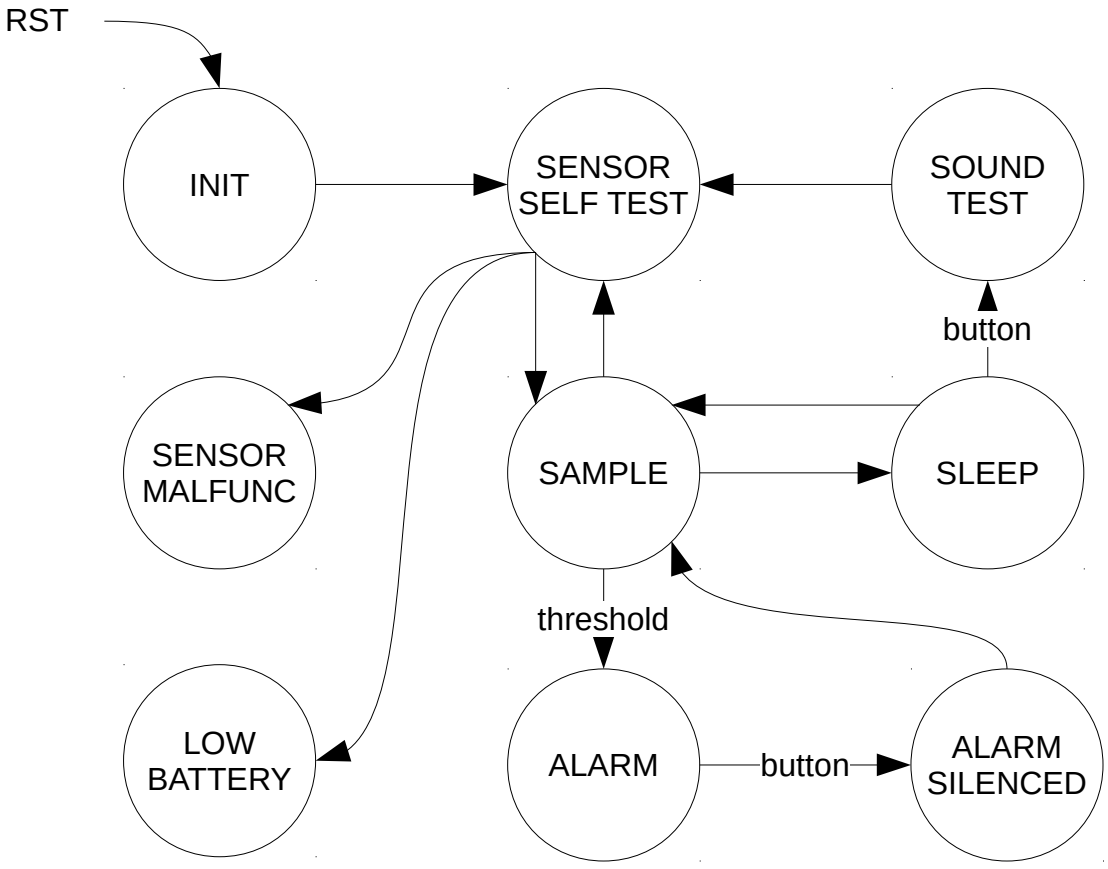



Image: https://tomroelandts.com/articles/how-to-create-a-simple-low-pass-filter

# Logic Implementation

# Logic Implementation

## CO Detector Algorithm



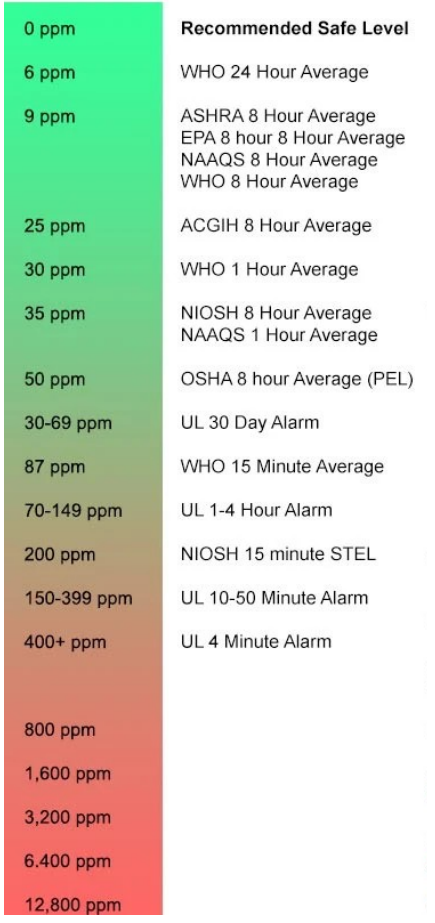
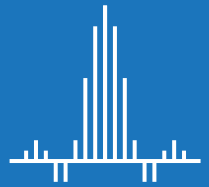




Image: https://gaslab.com/blogs/articles/carbon-monoxide-levels-chart








# Review & Questions