CMPE242
Spring2023
PART II

April 3rd (Monday)

Road map for the 2nd half of the Semester:

IIOT (Industrial IOT):

- ADC Data Validation → ① F.F.T. (Fast Fourier Transform)
- Analog Sensor interface Design.

② Power Spectrum Technique.

③ Hardware Architecture Aspects

Ion Selective Electrode Sensors { Many Applications in different Industry Sector.

Homework Extension Next Monday with Demo.

Project: Due the End of the Semester.

Implementation (1/3) 33% to { PID. I2C Sensor, PWM Motor Control { Pre-processing CKT. ADC

Research Part (1/3): ① P.P.T Presentation on State-of-the-Art Technology in the Embedded World.

② Report (GuideLine).

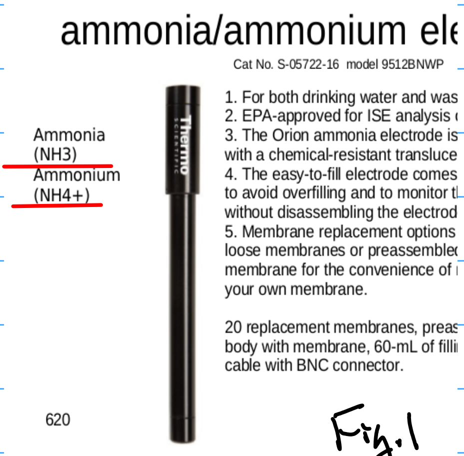
③ Proposal (One page, No more than), Submit to the CANVAS for Approval. — By Wednesday | Monday Next

(1/3) Demo & Presentation: By the end of the Semester.

Example: for Analog ISE Sensor interface Design.

Ref: →

2018S-20-NH3- 4Design2018-1-16.pdf



ammonia/ammonium ele

Cat No. S-05722-16 model 9512BNWP

Ammonia (NH3)

Ammonium (NH4+)

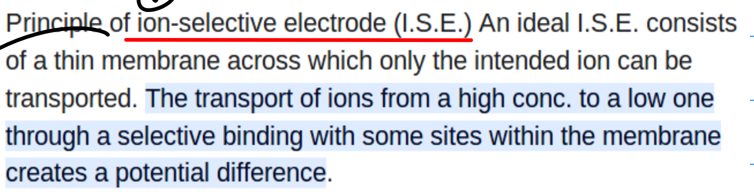
1. For both drinking water and was
2. EPA-approved for ISE analysis
3. The Orion ammonia electrode is with a chemical-resistant transluce
4. The easy-to-fill electrode comes to avoid overfilling and to monitor t without disassembling the electrod
5. Membrane replacement options loose membranes or preassemble membrane for the convenience of your own membrane.

20 replacement membranes, preas body with membrane, 60-mL of filli cable with BNC connector.

620

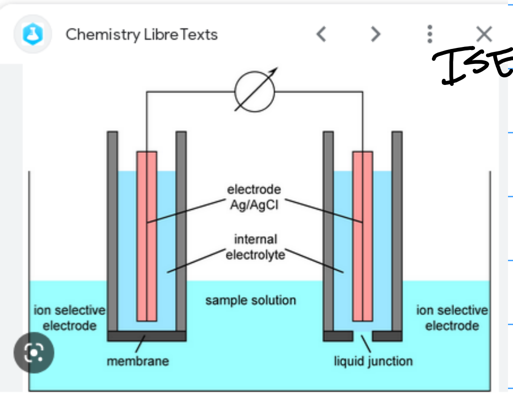
Fig.1

google Definition: ①



Principle of ion-selective electrode (I.S.E.) An ideal I.S.E. consists of a thin membrane across which only the intended ion can be transported. The transport of ions from a high conc. to a low one through a selective binding with some sites within the membrane creates a potential difference.

→ Example of A Battery



ISE Sensor

Fig.2

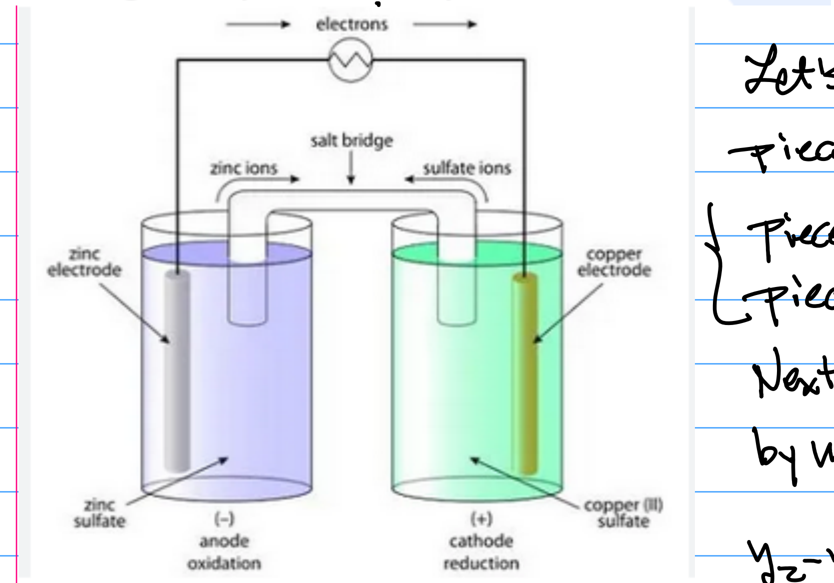


Fig. 3

Observation: Use Battery As An Example to Demonstrate Ion Selective Electrode Sensor. See NH3/NH4+ sensor in Fig. 1.

Characteristic

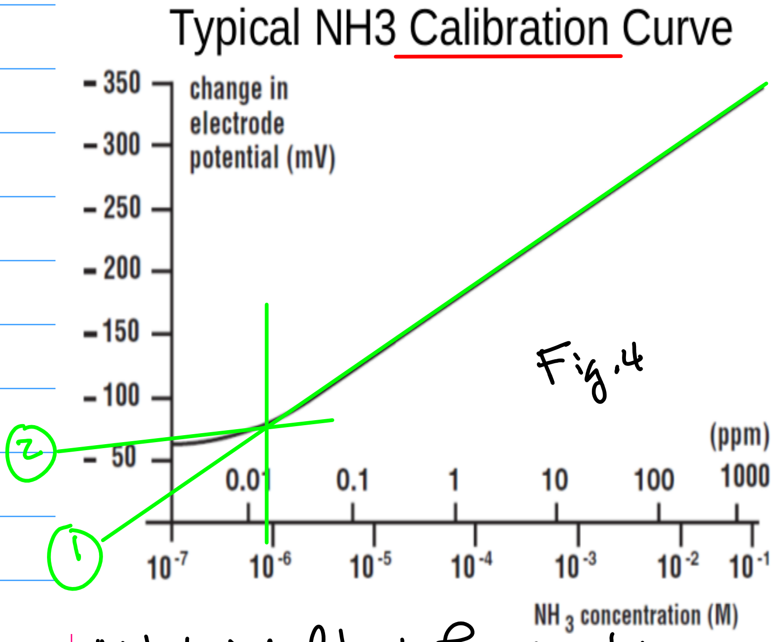


Fig. 4

Note 1. We like to have the Linear Characteristics from the Calibration Curve, Such as [1,10], [10,100], [100,1000], etc.

Note 2: For the Non Linear Part, Let's Perform Linearization — By using Piece-wise Linear Lines.

{ Piece-wise Line 1.
Piece-wise Line 2.

Next Step is to formulate Each Line by using Linear Equation.

$$\frac{y_2-y_1}{x_2-x_1} = \frac{y-y_1}{x-x_1} \quad \ldots (1)$$

Solve for $y=bx+c$ (see the Previous Notes).

With Simplification By Removing Very Low Concentration Part, we have

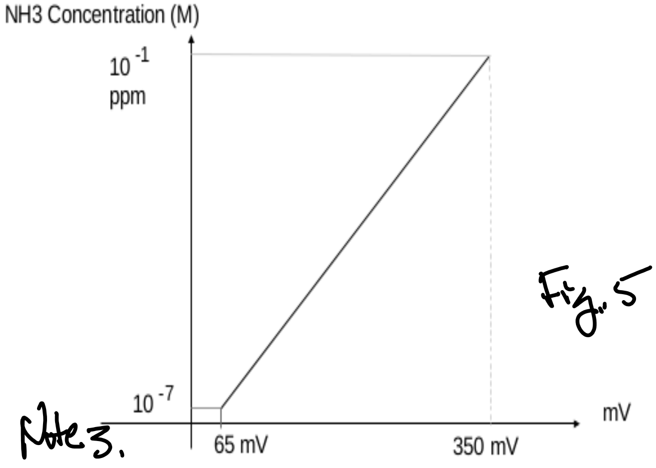


Fig. 5

Note 3. Then, Change the Cal-Curve to the Characteristic Curve e.g. Horizontal Axis is voltage for the Design of interface.

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Industrial Analog Sensor Interface Protocol:
1° Output has to be defined by Current. 2° The Range 4~20mA.

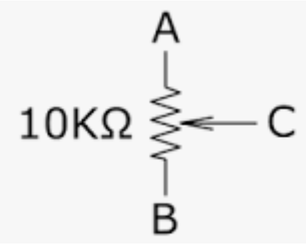
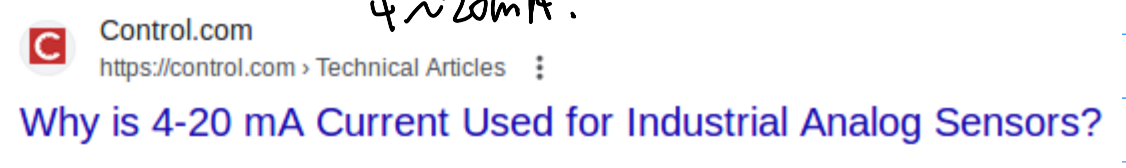


Fig.1



Control.com
https://control.com › Technical Articles

Why is 4-20 mA Current Used for Industrial Analog Sensors?

Note 4. Fit to the Dynamic Range of your target platform.
↓
External ADC Needed
CMOS Range ADC [0,3.3]
TTL " " [0,5.0]

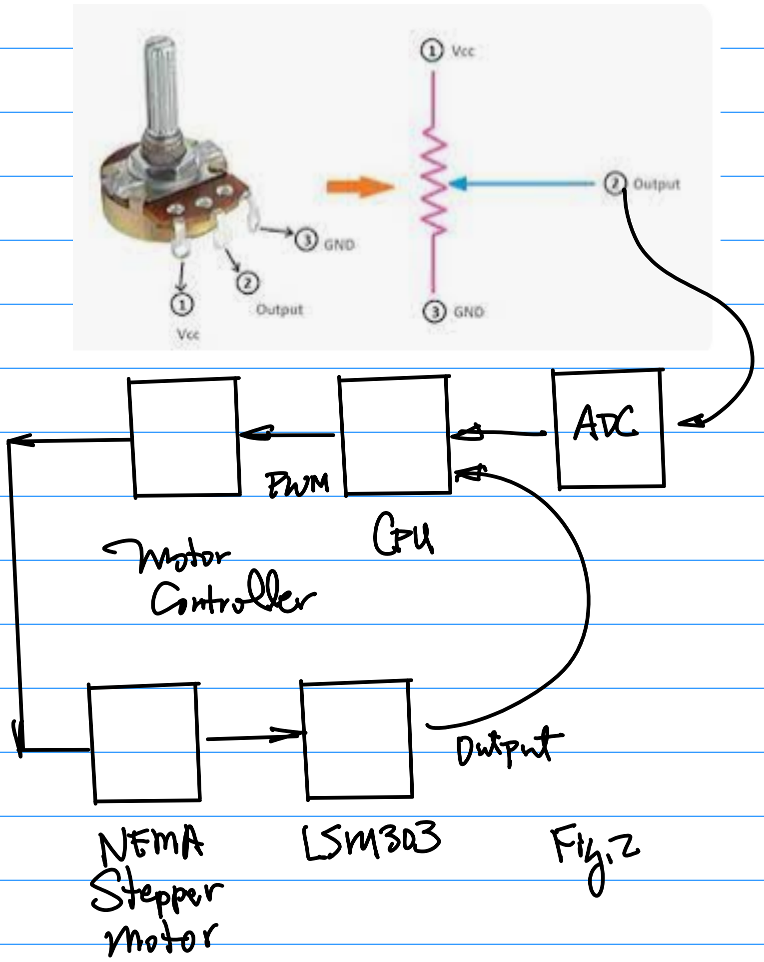


Fig.2

https://www.adafruit.com/product/1083

April 5th (Wed)

Note 1° New updated Due Date for the Motor Control, please use PWM from your target platform as the input to the motor controller.

2° ADC Unit for the project Selection Guide.
1° Interface protocol I2C; ~4 mbps
2° 0.5~2 MSPS (Million Samples per Second)
3° 10~12 bits per Sample.
Example: P.O.T.

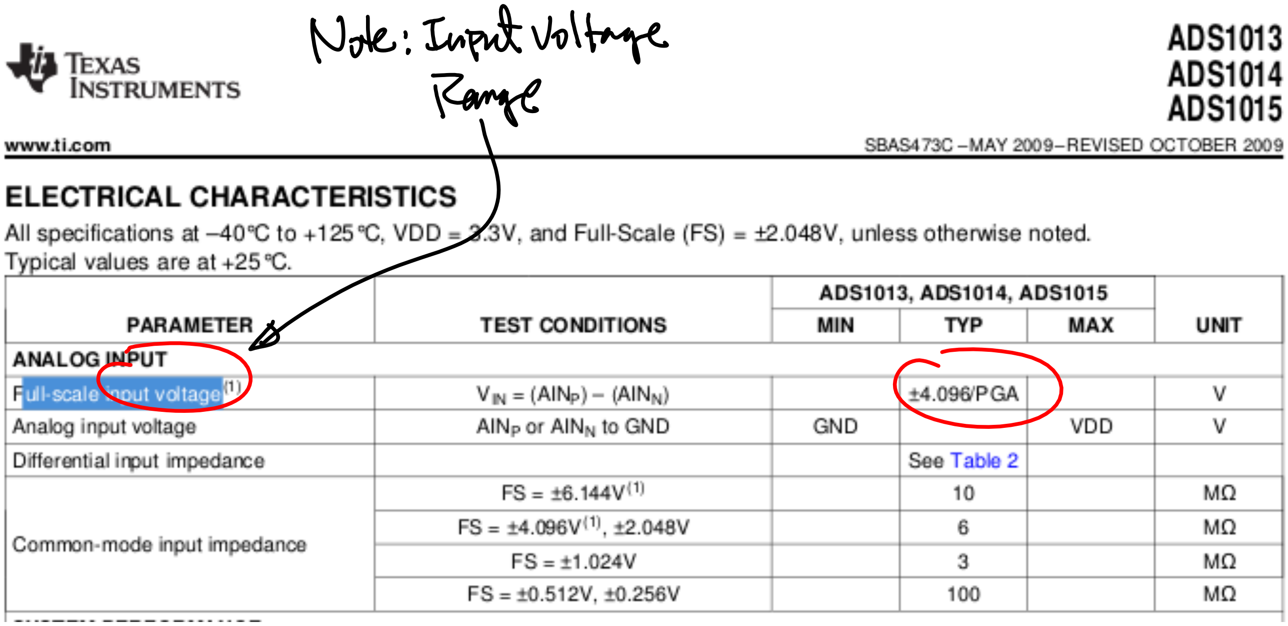
ADS1015 12-Bit ADC - 4 Channel with Programmable Gain Amplifier - STEMMA QT / Qwiic

Product ID: 1083

$9.95

Fig.3

Note: Input Voltage Range



TEXAS INSTRUMENTS

ADS1013
ADS1014
ADS1015

www.ti.com

SBAS473C –MAY 2009–REVISED OCTOBER 2009

ELECTRICAL CHARACTERISTICS

All specifications at –40°C to +125°C, VDD = 3.3V, and Full-Scale (FS) = ±2.048V, unless otherwise noted. Typical values are at +25°C.

PARAMETER	TEST CONDITIONS	ADS1013, ADS1014, ADS1015			UNIT
		MIN	TYP	MAX	
ANALOG INPUT					
Full-scale input voltage[1]	$V_{IN} = (AIN_P) - (AIN_N)$		±4.096/PGA		V
Analog input voltage	AIN_P or AIN_N to GND	GND		VDD	V
Differential input impedance			See Table 2		
Common-mode input impedance	FS = ±6.144V[1]		10		MΩ
	FS = ±4.096V[1], ±2.048V		6		MΩ
	FS = ±1.024V		3		MΩ
	FS = ±0.512V, ±0.256V		100		MΩ

Example: Design Objective.

1° Selection of An ADC.

Construct the Characteristic Curve of the ADC

V_{max}=3.3V for CMOS

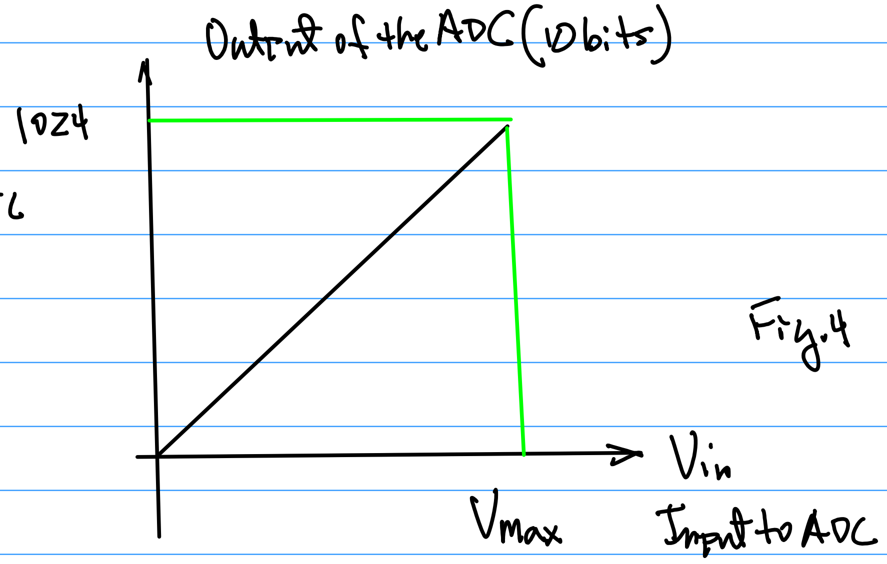


Fig.4

2° Design Objective: To Design A pre-process unit to make the Analog Sensor Output match to the ADC input dynamic Range.

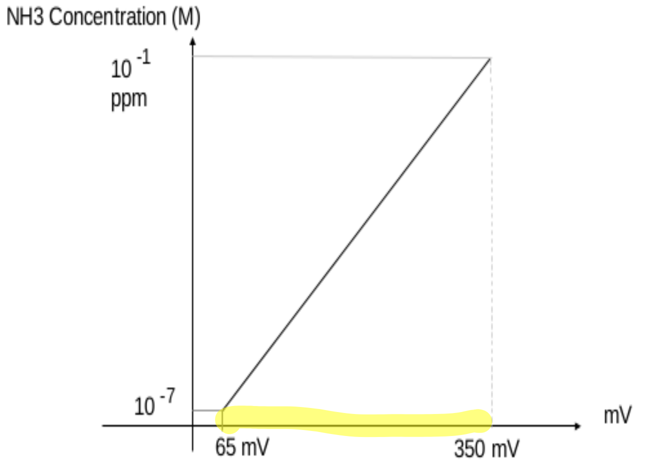
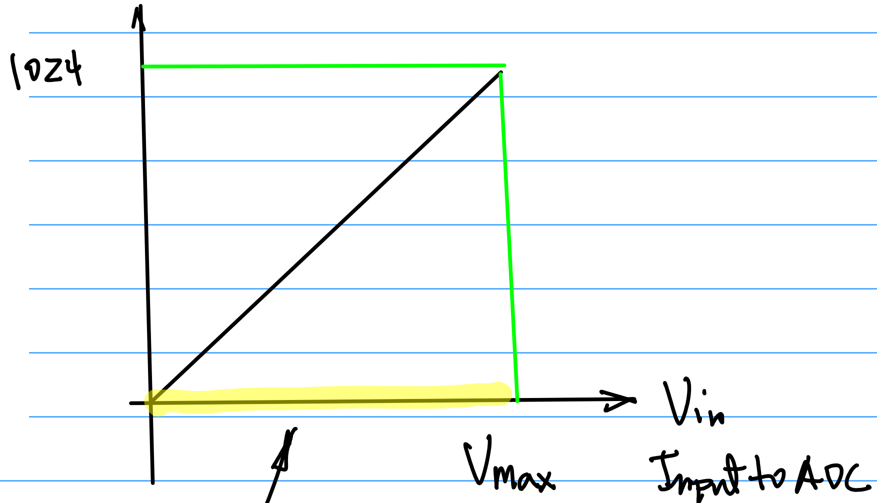


Fig.5



Step1. 65mV → 0

350mV → Vmax

In general,

$V_{s,min} \rightarrow V_{ADC,min}$ ...(1)

$V_{s,max} \rightarrow V_{ADC,max}$ ...(2)

April 10 (Mon).

Example: Continuation of the Preprocessing Design.

Note1. Check 1015 ADC Dynamic Range for the Input. [0, 3.3V]. Verification is Needed

Theoretical Analysis:

Step1. Provide "offset" to shift → The Sensor dynamic Range, Subtraction Can be utilized for this purpose. e.g.

$V_{sen} - V_{offset}$ ... (1)

which will Lead to the Result Below.

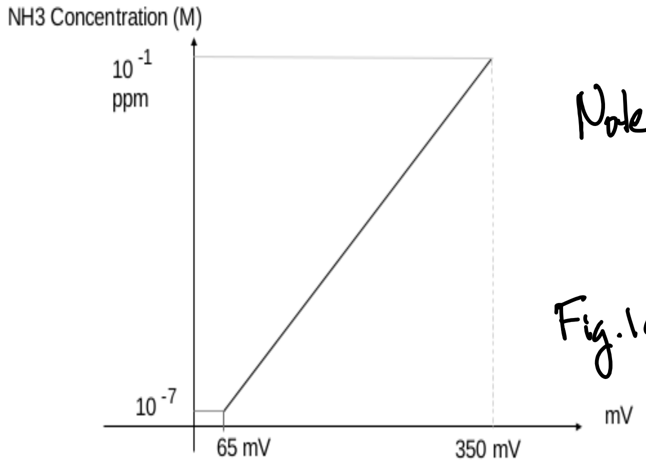


Fig.1a

Note1. For more generalized Case, Let
$V_{min} = 65mV$, $V_{max} = 350mV$.
So, the offset = $-V_{min}$.
then, the Upper Bound after offset is
$V_{max} - V_{min}$

↓ Subtraction/offset

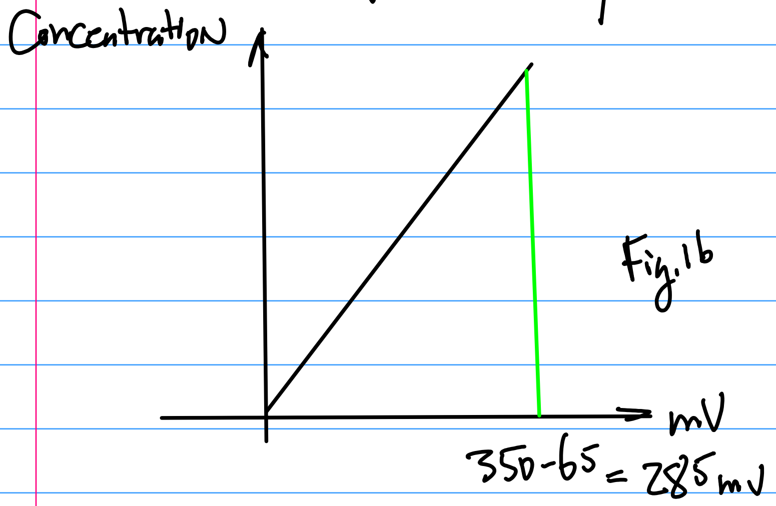


Fig.1b

Step2. To magnify the Sensor Output Range to Match the entire Dynamic Range of the ADC.

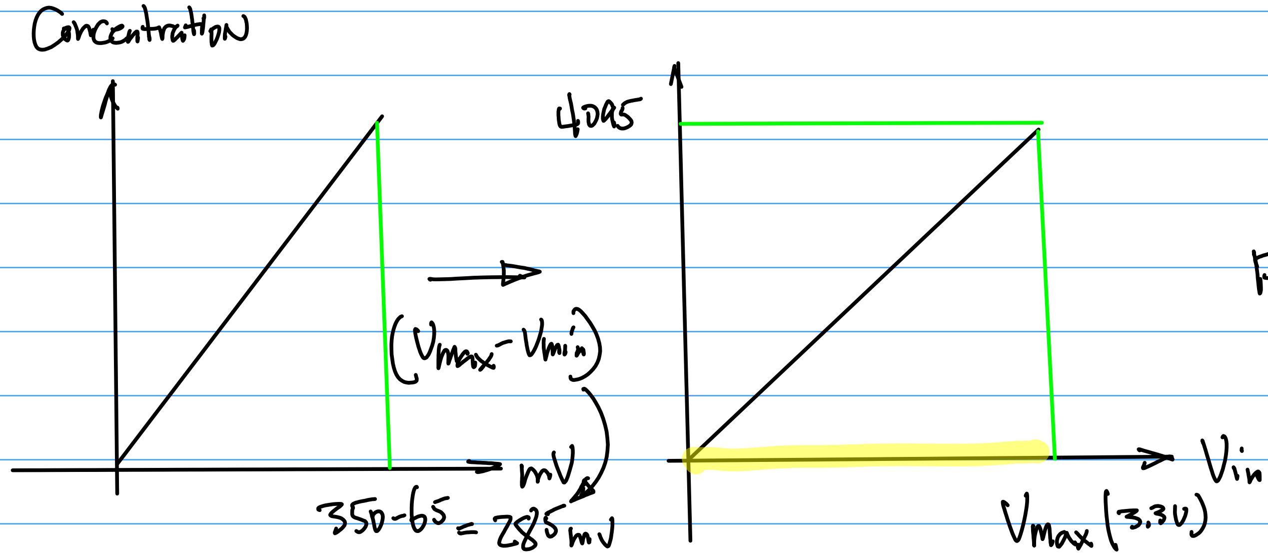


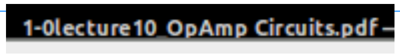
Fig.2

Find the Gain for the Magnification

$$A = \frac{V_{\text{Output Range}}}{V_{\text{Input Range}}} = \frac{3.3}{285\times10^{-3}} \cong 11.58$$

where 3.3VDC is from 1015 ADC
for Example.

Example: Hardware Design for the Pre-processing.
Ref.

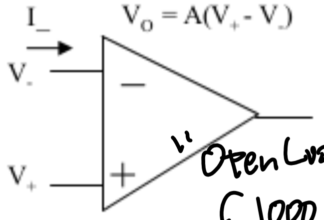

1-0lecture10_OpAmp Circuits.pdf –

Note1: Using OpAmp for Pre-processing
Not for the Buffering.

OpAmp Device As a Buffering Stage

Both Analog and Digital Circuit

Note2: Background



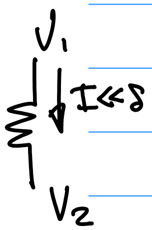
"Open Loop"

(1) To protect the previous stage's output signal, which is the input to the next stage, while sampling/connecting the signal to its next stage logic circuit. (2) Unit gain non-inverting OpAmp configuration is an excellent choice.

1000 or Bigger

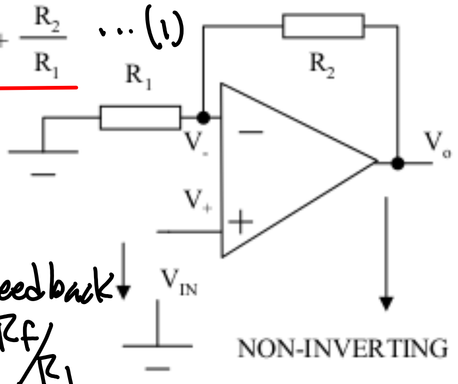
1×10^{-9} A or Smaller

Ideal OpAmp Properties: (1) very large gain, A>>M; (2) draws very little current, $I_- \sim 0$, e.g., very high impedance; (3) $V_O = A(V_+ - V_-)$ is finite range, which leads to $V_+ = V_-$.



for Example
100MΩ or
higher.

$$\frac{V_O}{V_{IN}} = 1 + \frac{R_2}{R_1} \quad \ldots(1)$$



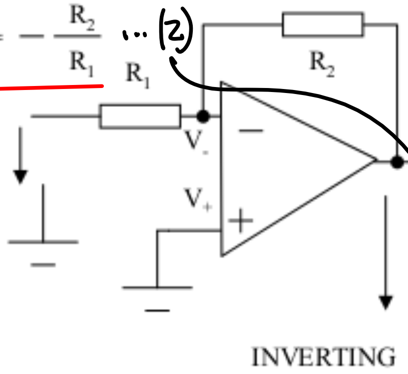
R₂ for feedback

So $A = 1 + R_f/R_1$

Harry Li, PH.D. SJSU

Fig.3

$$\frac{V_O}{V_{IN}} = -\frac{R_2}{R_1} \quad \ldots(2)$$



$$A = -\frac{R_f}{R_1}$$

Now, Consider the design Implementation for 2-Step Process.

Tools { Non-Inverting∼ | Inverting∼
{ Linear System: Super-Impose One Signal (offset) on to the other Signal (Input).

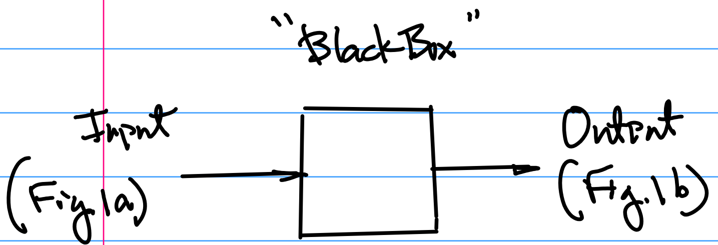
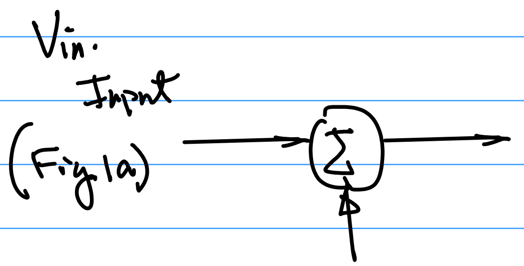


Fig. 4.

Linear System. "Super-Impose Signal for offset"



$V_{in}' = V_{in} + V_{ref}$

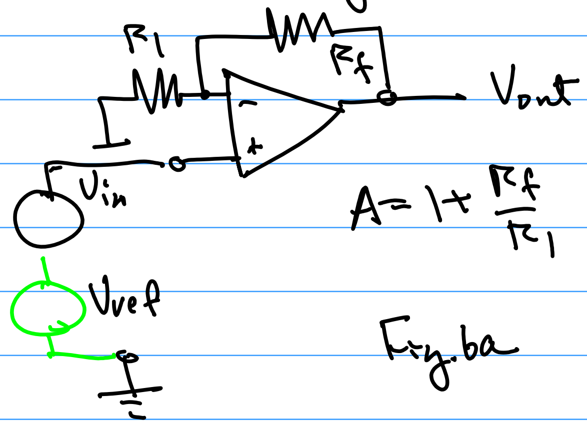
$V_{ref} = -V_{min}$

$(= -65\,mV.)$

Fig. 5

In the Circuit Design. Just Connect 2 inputs together.

For Non-Inverting



$A = 1 + \frac{R_f}{R_1}$

Fig. 6a

For Inverting.

$A = -R_f/R_1$

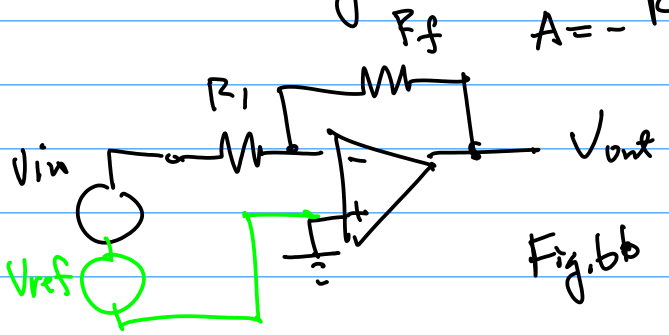


Fig. 6b

Note: Selection of Non-∼ v.s. Inverting Configuration Depends on your design Need. This Design is an illustration of Super Imposing an "offset", e.g. Vref.

Now, to Magnify the Signal to match ADC's Dynamic Range. Choose Non-Inverting Configuration (see Fig. 2)

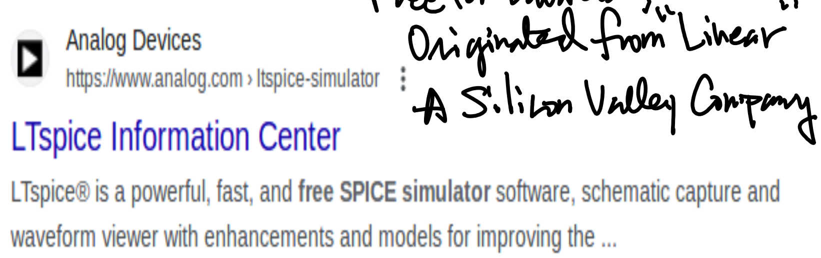
Hence

$$A = 1 + \frac{R_f}{R_1} = 11.58$$

Choose $R_1 = 1\,k\Omega$ 10.58 kΩ

solve for $R_f \cong$ ~~77~~ kΩ ?

please verify it ?



Analog Devices

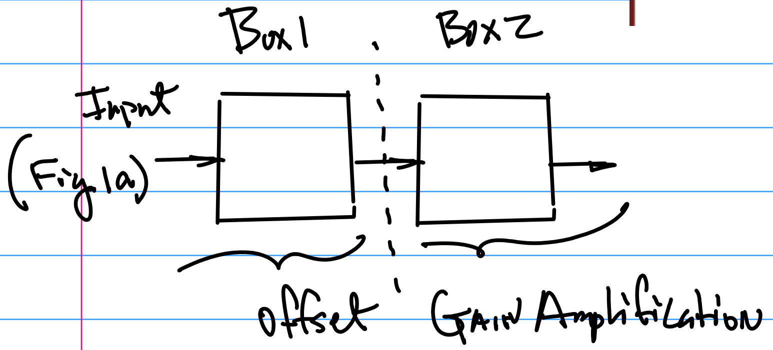
https://www.analog.com › ltspice-simulator

LTspice Information Center

LTspice® is a powerful, fast, and **free SPICE simulator** software, schematic capture and waveform viewer with enhancements and models for improving the ...

Free for Download, Originated from "Linear" A Silicon Valley Company.

Stage1 Stage2



EasyEDA

https://easyeda.com

EasyEDA - Online PCB design & circuit simulator

EasyEDA is a **free** and easy to use circuit design, **circuit simulator** and in your web browser.

Requirements: To Be Able to Run SPICE Simulator.

April 12 (Wed).

Note 1. The Last Project Preparation.

(Requires the Semester End Presentation).

Note 2. Implementation of ADC Unit.

P.O.T. 47K or 470K or Similar.

↓

ADC → Target → PWM → Controller

↑ ↓

LSM303 ← Motor ←

Note 3. ADC Data Validation

FFT. Power Spectrum.

Note 4. Road Map.

IIOT (Analog Sensors. 4~20mA)

↓

Preprocessing

↓

OpAmp. (On-Line Simulation Tool)

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Spring 2023

Example:

ISE
① Analog Sensor


ammonia/ammoı

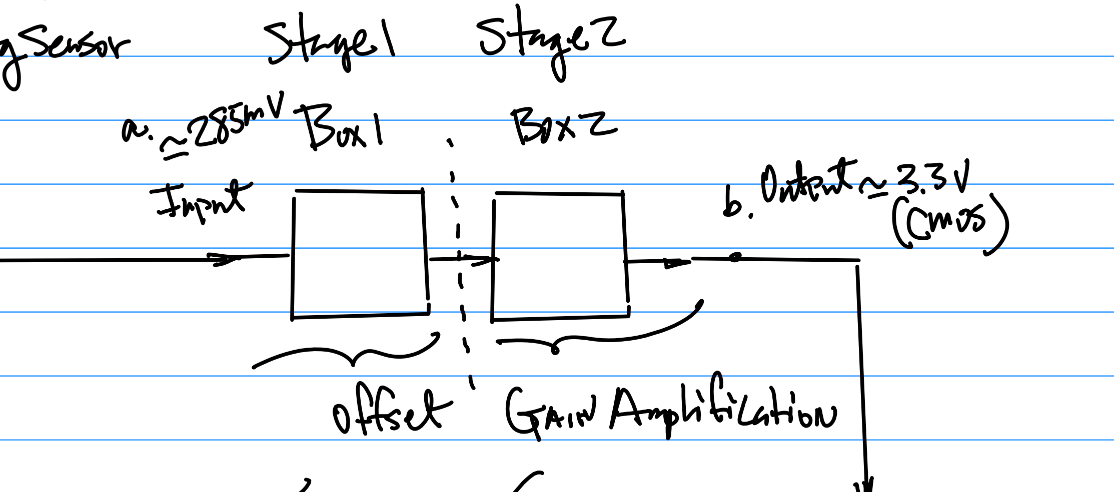
Cat No. S-05722-1

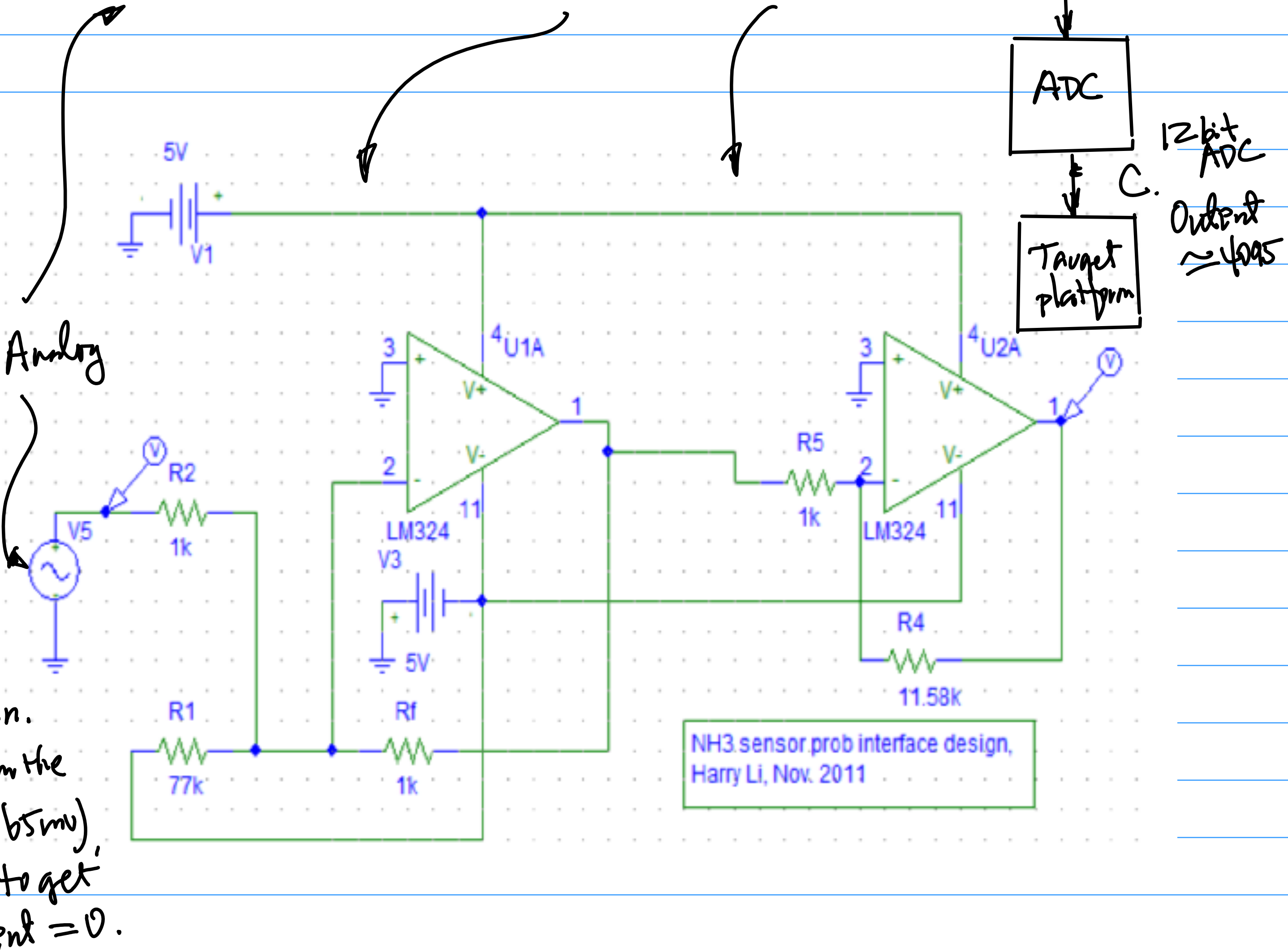
Ammonia
(NH3)
Ammonium
(NH4+)

1. For both drinl
2. EPA-approve
3. The Orion an
with a chemical-
4. The easy-to-f
to avoid overfilli
without disasser
5. Membrane re
loose membran
membrane for tl
your own memb

20 replacement
body with memb
cable with BNC

620





Note: 1° Analog
Sensor—
Signal
Source
sine
wave
Signal

2° for min.
Input from the
Sensor. (~65mV),
we want to get
ADC Output = 0.

for max Input from the Sensor,
we want to get Output : (3.3VDC) 4095
ADC

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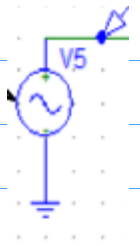
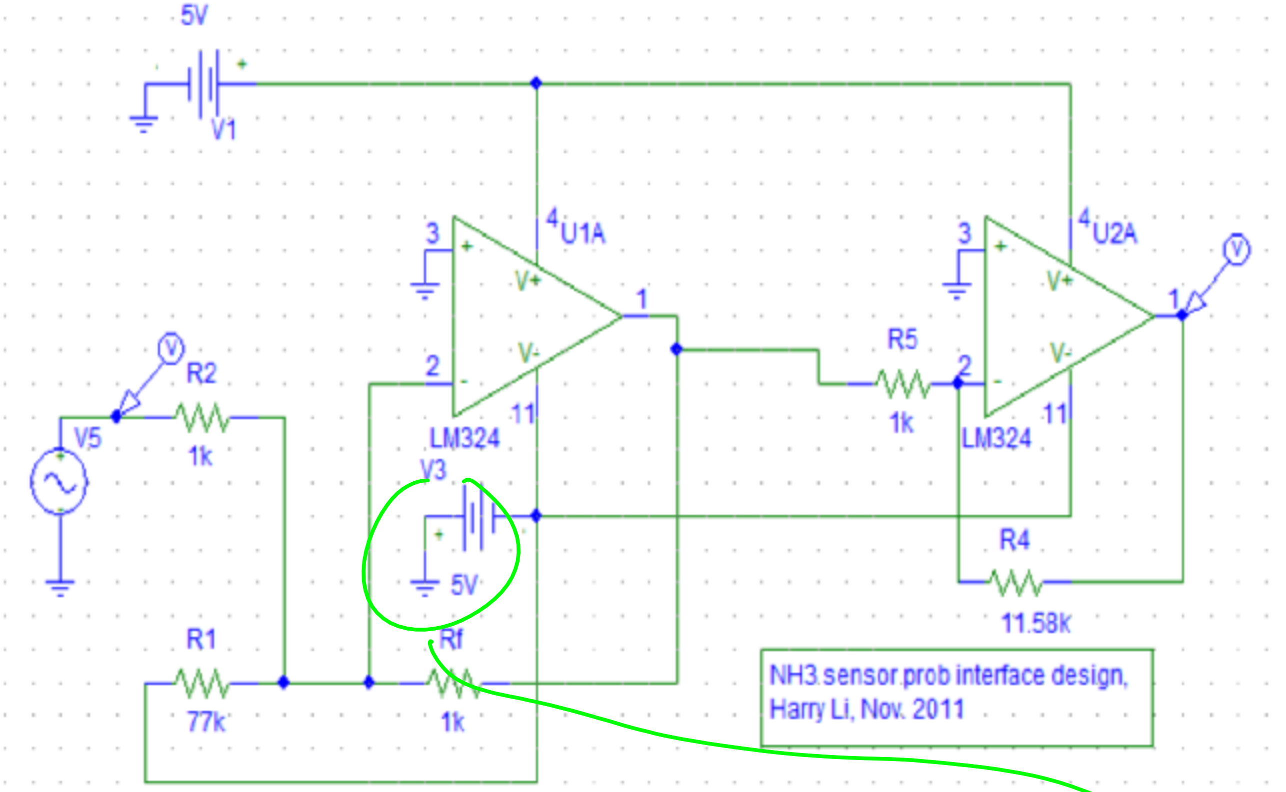
Note: 3. Simulation of the Sensor Output as the input to the pre-processing Circuit.





NH3 sensor prob interface design, Harry Li, Nov. 2011

April 17 (Monday).

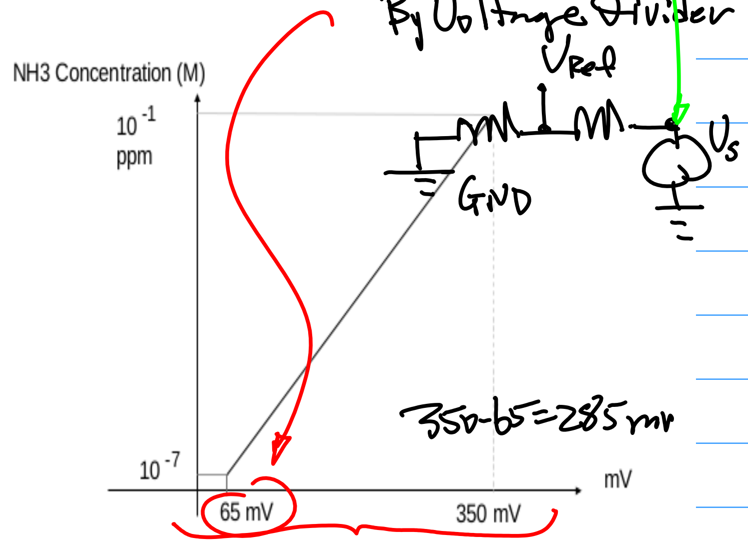
1° Project (Integration of Homework + ADC). Due May 7 (Sunday) plus Research Paper / Presentation.

2° Bonus Points (5%) for BLDC motor Control; 3-phase (u, v, w) motor Control.

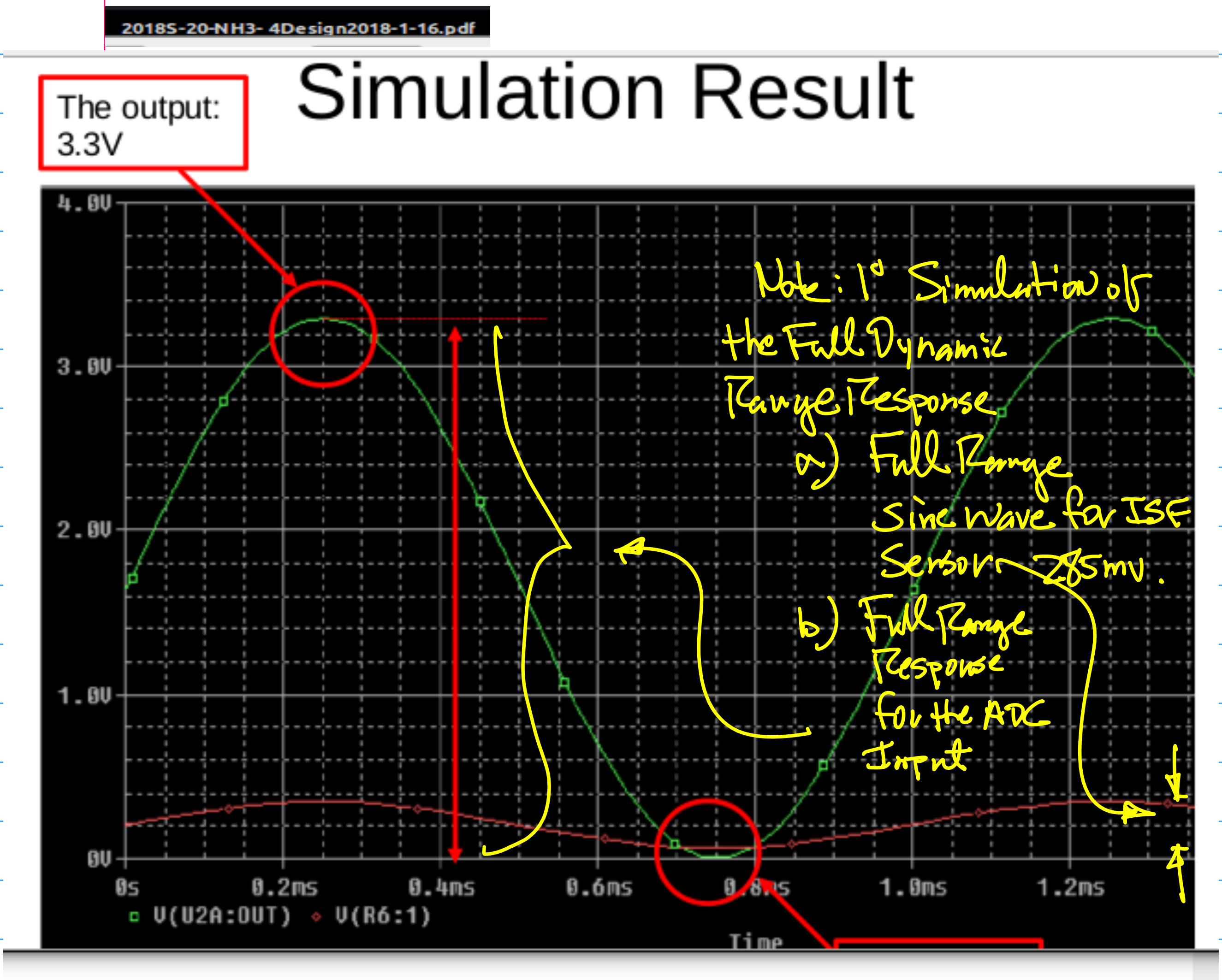
3° SPICE Simulation for

Pre-processing Circuit Simulation.

Example: Continuation. Provide "offset" By Voltage Divider



350-65=285 mV



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Simulation Result

The output: 3.3V

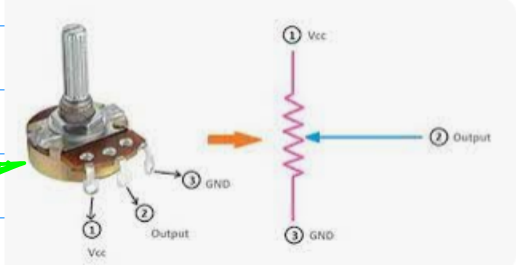
Note: 1° Simulation of the Full Dynamic Range Response
a) Full Range Sine Wave for ISF Sensor ~ 285mV.
b) Full Range Response for the ADC Input

ADC Data Validation

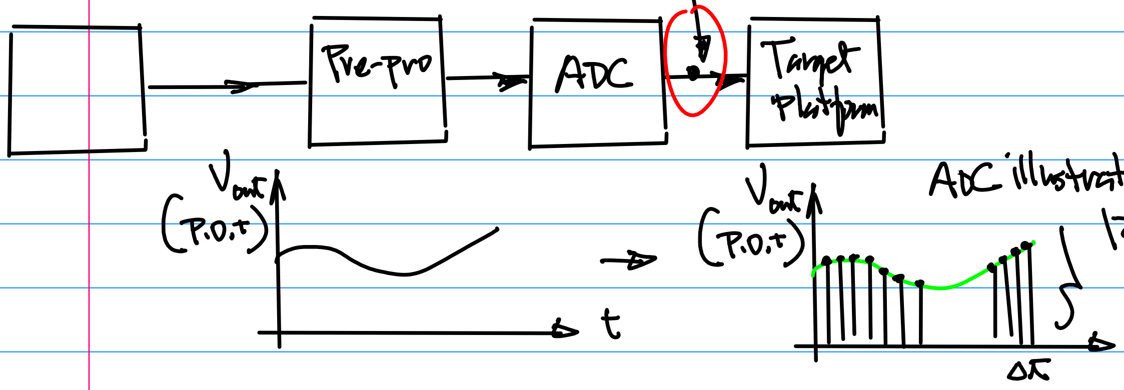
Tool: Fourier Spectrum Analysis.

Data Validation

P.O.T. Human Operator



See PP.48 For Details.



ADC Output

ADC illustration → $\{x(n) \mid n=0,1,2,\ldots\}$

12bit ADC.

[0,4095]

Background/Formulation.

To Validate $\{x(n)\}$, or $\{x(n) | n=0,1,2,\dots,\}$

$x(n)$.

D.F.T (Discrete Fourier Transform) is defined as follows.

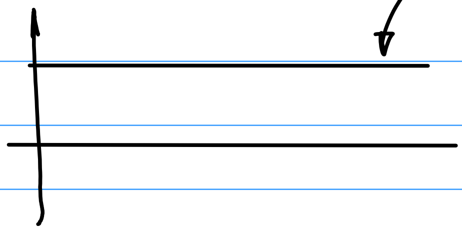
Time Index

$$X(m)=\frac{1}{N}\sum_{n=0}^{N-1}x(n)e^{-j2\pi\frac{mn}{N}} \quad \cdots (1)$$

Physical meaning: $X(m)$, Discrete Fourier Transform.

m: Frequency Index

m=0, D.C. index; $X(0)$ D.C. Component.



m=1, $X(1)$ Fundamental Frequency Component.

N: One Period. Total No. of Points Per a period. Such as N=1024, 2048, 4096, etc.

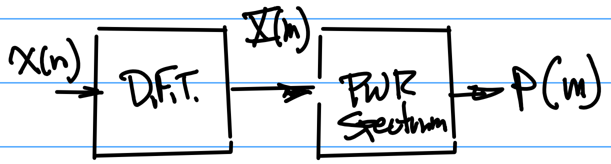
$N=2^x$ for FFT Only. (Fast Fourier Transform)

$$e^{-j2\pi\frac{mn}{N}} = \cos 2\pi\frac{mn}{N} - j\sin 2\pi\frac{mn}{N} \quad \cdots (2)$$

Euler Formula

$$e^{j\phi} = \cos\phi + j\sin\phi \quad \cdots (3)$$

Power Spectrum of $X(m)$.



Let's Define the Power Spectrum as:

$$P(m) = \sqrt{Re^2[X(m)] + Im^2[X(m)]} \quad \cdots (4)$$

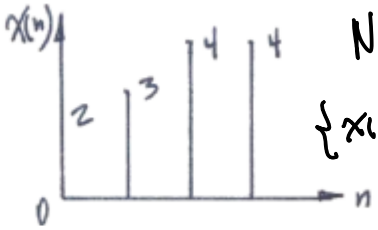
Where

$$Re[X(m)] = Re\left[\frac{1}{N}\sum_{n=0}^{N-1}x(n)e^{-j2\pi\frac{mn}{N}}\right]$$

$$Im[X(m)] = Im\left[\frac{1}{N}\sum_{n=0}^{N-1}x(n)e^{-j2\pi\frac{mn}{N}}\right]$$

Example:

Ref: github



N=4

$\{x(n)\}$

CMPE242-Embedded-Systems- / 2018S-26-1D-DFTv2.pdf

$x(0)=2$, $x(1)=3$, $x(2)=4$, $x(3)=4$.

Find $X(m)$ D.F.T.

$$X(m)=\frac{1}{4}\sum_{n=0}^{3}x(n)e^{j2\pi\frac{mn}{4}} \quad \cdots (5)$$

Next. From Eqn(5)

For m=0,

$$X(0) = \frac{1}{4}\sum_{n=0}^{3} x(n) e^{-j2\pi\frac{0n}{N}} = \frac{1}{4}\sum_{n=0}^{3} x(n)$$

$$= \frac{1}{4}\left(x(0)+x(1)+x(2)+x(3)\right)$$

$$\cdots(6a)$$

For m=1

$$X(1) = \frac{1}{4}\sum_{n=0}^{3} x(n) e^{-j2\pi\cdot\frac{1\cdot n}{4}}$$

$$= \frac{1}{4}\left(X(0)\cdot 1 + x(1)e^{-j2\pi\frac{1}{4}} + \right.$$

$$\left. x(2)e^{-j2\pi\frac{2}{4}} + x(3)e^{-j2\pi\frac{3}{4}}\right)$$