March16 (Wed)

Topics: 1° PWM Architecture/Hardware Aspect — Waveforms, Timing Diagrams, SPRs

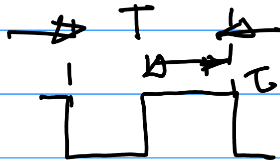
2° LSM303 Sensor I2C

Example: PWM Discussion.

f_{PWM}

Duty Cycle

One Period



Duty Cycle = τ / T ... (1).

Square Wave: D.C. = 50%.

Architectural Aspects:

2021F-105-#0-cpu-arm11-2018S-29-...

P1106

6410X_UM

32 PWM TIMER

This chapter describes the functions and usage of PV

C. Prescaler for f_{PWM} Config

8 bit

PP1107

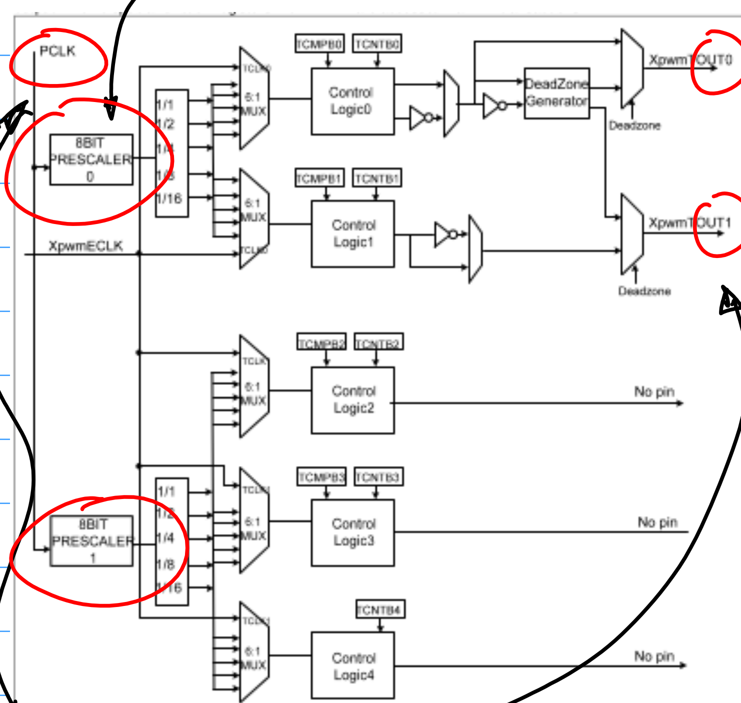


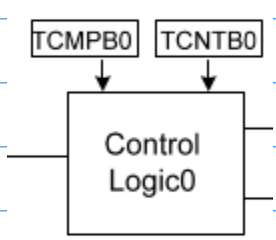
Figure 32-1. PWMTIMER Clock Tree Diagram

a. Input: PCLK peripheral clock.

1/2, 1/4, 1/8, ..., of the System Clock

b. Output (2 outputs)

d. Special Purpose Registers



CONF (Configuration Register)

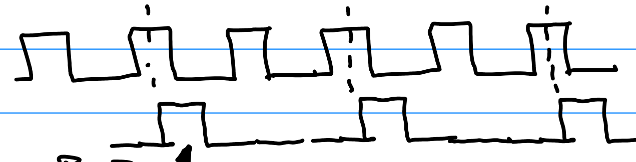
CNT (Control — "Count")

CMP (Comparision)

define f_{PWM} & Duty Cycle.

- 2022S-107e-pwm-waveform-v3-2018-3-4.jpg
- 2022S-107f-pwm-specialPurposeRegister-v3-2018-3-4.jpg
- 2022S-107g-pwm-calculation-v3-2018-3-4.pdf

Note: Background on Counters.



Count By 2

Expand this to A counter for Both integer Number & Fractional Number (in General) → f_{PWM} (for interger Only) then, use Another Counter to get Duty Cycle.

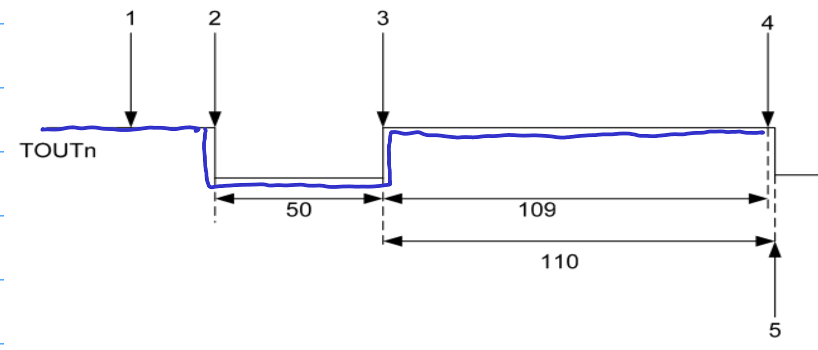
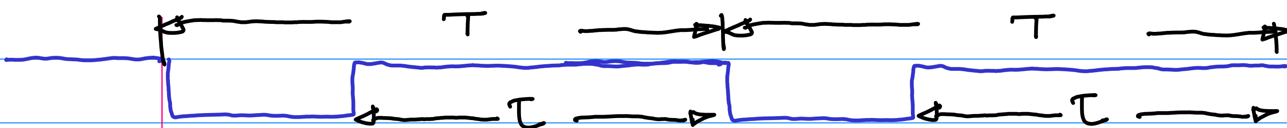


Figure 32-2. Simple Example of PWM Cycle Block Diagram



$T = 1/f_{PWM} \ldots (2)$, $f_{PWM} = \dfrac{PCLK}{(Prescaler+1)\,DIV} \ldots (3)$

Frequency = PCLK / ({prescaler value + 1}) / {divider value}

Suppose $PCLK = \frac{1}{4}(\text{System Clock}) = \frac{1}{4}(800 \times 10^6)$

$= 200 \times 10^6$

Defined By Special Purpose Register.

Design Guidelines for PWM:

① CNT (TCNTB0) Define f_{PWM}

Control Count, Timer, Buffer0 for PWM0

② CMP (TCMPB0) Defines Duty Cycle

Comparision

③ CONF Configuration Register. Defines f_{PWM}

Example: Suppose $PCLK = 500 \times 10^6$ (MHz), Suppose to Drive A Stepper Motor $f_{PWM} = 2\text{KHz} = 2 \times 10^3$

Find the Counts N for TCNTB0

$\dfrac{PCLK}{N} = f_{PWM} \ldots (4)$

$\frac{PCLK}{N} = f_{PWM}$, Substitute the design Requirements into it.

$$\frac{500\times10^6}{N} = 2\times10^3,$$

$$\therefore N = \frac{500\times10^6}{2\times10^3} = 250\times10^3$$

Verify if TCNTB0 Can hold up to that Number

PP1117

32.4 SPECIAL FUNCTION REGISTERS

32.4.1 REGISTER MAP

Register	Offset	R/W	Descrip
TCFG0	0x7F006000	R/W	Timer Configuration Registe two 8-bit Prescaler and Dea
TCFG1	0x7F006004	R/W	Timer Configuration Registe and DMA Mode Select Bit
TCON	0x7F006008	R/W	Timer Control Register
TCNTB0	0x7F00600C	R/W	Timer 0 Count Buffer Regis
TCMPB0	0x7F006010	R/W	Timer 0 Compare Buffer Re
TCNTO0	0x7F006014	R	Timer 0 Count Observation
TCNTB1	0x7F006018	R/W	Timer 1 Count Buffer Regis

2^{32}

32.4.1.4 TCNTB0 (Timer0 Counter Register)

Register	Offset	R/W	
TCNTB0	0x7F00600C	R/W	Timer 0 Count I

Conclusion: 5-Steps operation of PWM. Can be described as (1) Count By N with Eqn (4), PP3. And deposit N into TCNTB0; (2) Deposit Count M into TCMPB0, where $M = (D.C.) \times N$ ...(5)

(3) The Down Counting will decrement TCNTB0's count by 1 at a time, And a Comparison is made to TCMPB0, if matched, then trigger the Output to "1", Down Counting continues till the Count in TCNTB0 = 0 One period is reached. Then Repeat this process.

Feb.21. 21.

Example: Suppose CLK = 50 MHz. Design Implementation Technique to produce $f_{PWM} = 1000$ Hz, to Drive Stepper motor Controller, in addition, Duty Cycle is 30%.

Find: (1) $TCNTB_n = ?$; (2) Find TCMP

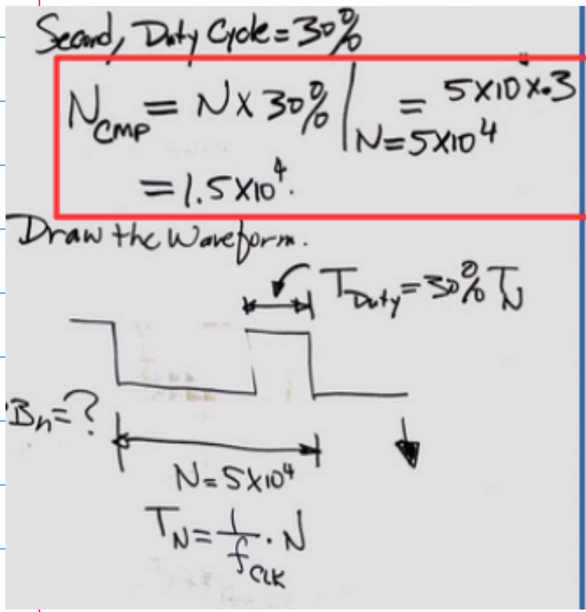
TCMPBn

Sol First, find the Counts N Based on the given condition.

$$\frac{50\times10^6}{N} = f_{PWM}, \quad \cdots (1) \qquad f_{PWM} = 1000$$

$$N = \frac{50\times10^6}{1\times10^3} = 5\times10^4 \to \text{Hex}$$

TCNTn



March21 (monday)

Midterm ON 23rd (Wed).

1 hr. Exam, + 15 min.

Review on Midterm.

3 Questions.

1. A question on Basic Concepts.

1. CPU Architecture
   32 Bit Architecture

a. Memory map. Banks,

b. GPP/IO Peripheral controller.

c. SPRs. Naming, functions.
   GPx CON, GPxDAT
   Tech. Spec ⇄ Binary Pattern

d. ARM11 Reference, Code
   User Space, Kernel Space

e. Target Platform, NAND,

Software Side. O.S. distribution.
Tool chain,
menu config.

f. SPRs in Driver Code.
GPIO user program.
fd = open(" path/Driver ");
ioctl( );
Kernel Space Program Sample
GPECON, etc → CPU Datasheet

g. GPIO Testing. I/P Testing
O/P Testing.

Ref:
2022S-101-notes-cmpe242-3-14.pdf

PP.9 CKT → Pin Selection
gpio79 (pin12)
gpio78 (pin40)

2.
Question(s) ON PID Controller Design.

Hardware / Software → Motor Drive GPP/PWM

Motor Drive Pin Connection Requirements
Sch., Connectivity Table.

"Demo" Live Execution of your program.

i. Board is Ready. Take a photo of your Board During the exam.

ii. Stepper motor/motor Drive And the Prototype Board work together, Take a photo, Screen Capture of program execution.

Motor Operation, micro steps, Angular Displacement.

Target Platform. Hardware Configuration to access device driver, such as GPIO, PWM or I2C.

3. Theoretical Aspects of the PID Controller Design.

a. PID Block Diagram.

P~, PI~, PD, ... etc.

D (erivative Controller) Short Future.

I (ntegration Controller) History

b. Computation. Forward Difference, Backward Difference, Central Difference. Kernels, Computation.

Integration Controller. History Back N Steps.

c. Sensor Interface Hardware I2C I/F.

LSM303 I2C Based Sensor.

2022S-108b-AngularSensing-i2c-LSM303- final HL 2017-3-13.pdf

Example: An Application of LSM303

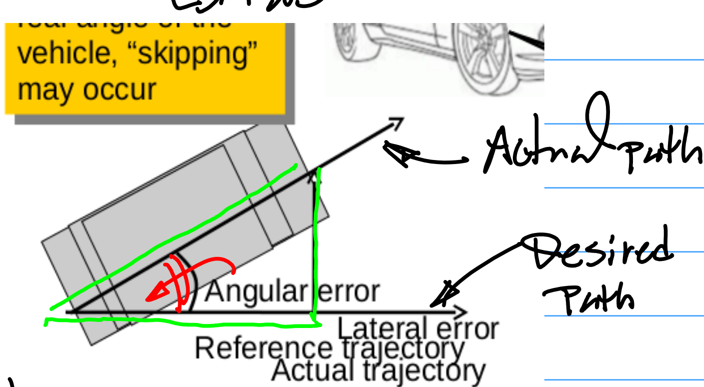


Fig 1.

α : from LSM303

$\vec{P_A}$: is measurable

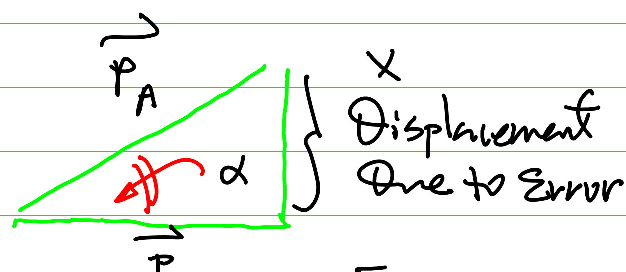


Fig. 1b

CmpE242 March 21, 22

Find $\|\vec{P_A}\|$ is defined by PWM Driven Stepper motor action.

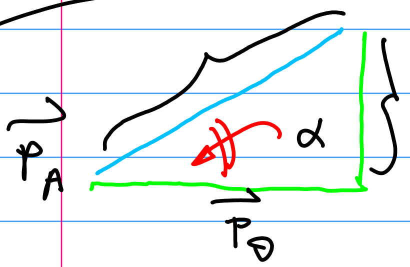
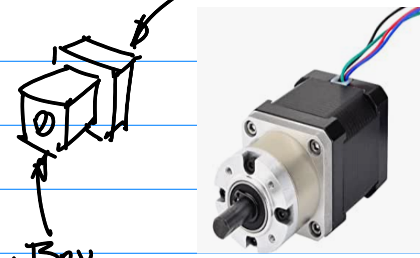


Fig. 2



b

Fig 3.

STEPPERONLINE Nema 17 Geared Stepper Motor Gear Ratio 5:1 3D Printer Extruder Motor DIY CNC Robotics

Visit the STEPPERONLINE Store

25 ratings

Amazon's Choice in 3D Printer Motors by STEPPERONLINE

$40.05

Reduction Ratio, R_R

For the purpose of increasing the Torque.

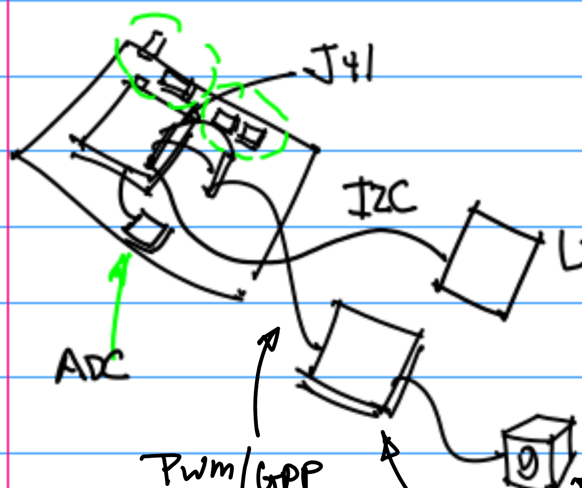


Fig. 2.

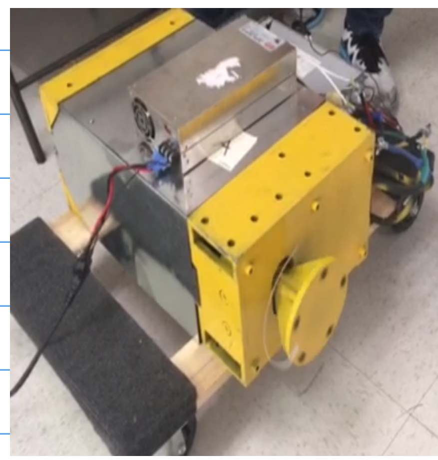
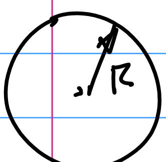


Fig. 4a, 4b With Reduction Ratio Gear Box.



the wheel of the Robot has the dimension R = 100mm

Now, Let's take a look at the hard ware of the motor Combo.

To find /Establish one-to-one mapping Between the actual path and PWM operation.

April 4 (monday)

Topics: 1° I2C Interface for LSM303 Sensor Integration.

Ref:

2022S-108b-AngularSensing-i2c-LSM303- final HL 2017-3-13.pdf

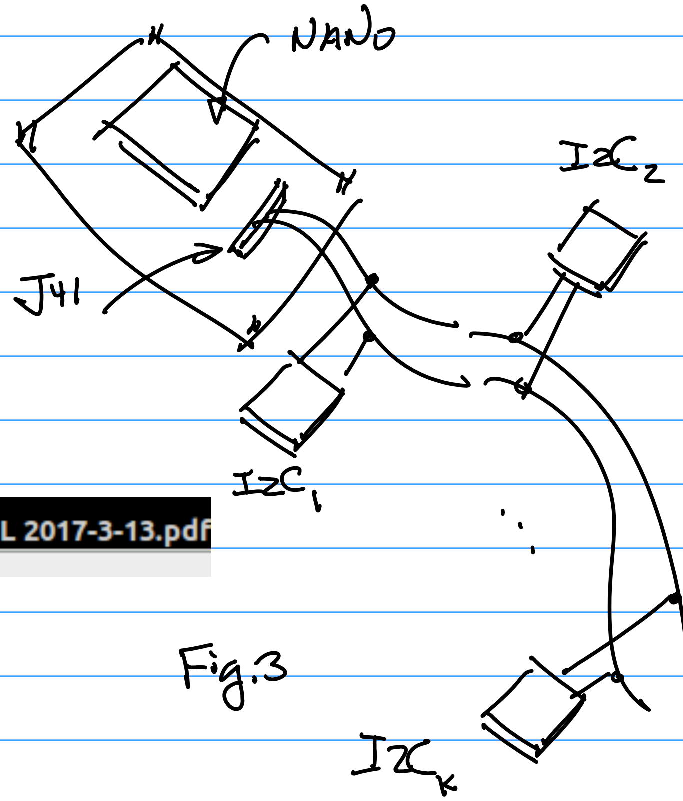


Fig.3

I2C Hardware Features
- Protocol Definition
- Coding Implementation

Hardware Features:

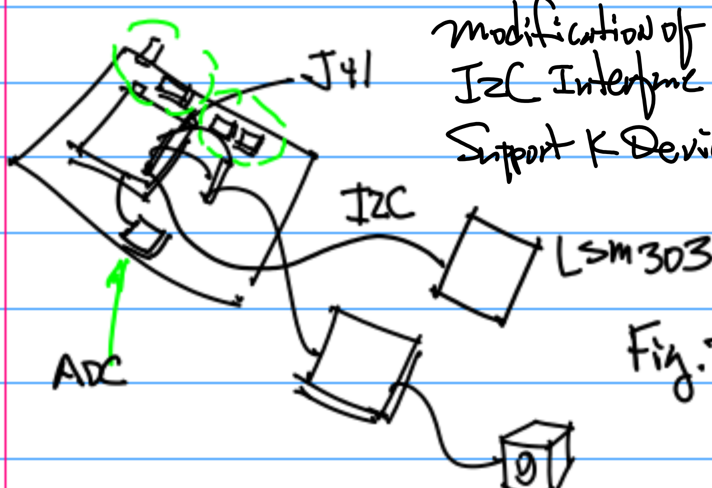
1. Pins
   - SDA: Bi-Directional Data Pin. (Signals in Both Direction)
   - SCK: Serial Clock.

   Speed: ~4 mbps, ≤ 10 mbps

2. I2C Bus

Sub Address: 7 bits, $2^7 = 128$ → K=128 Devices, But in Real Engineering Design, "FAN-IN", "FAN-OUT" (e.g. Adequate Electric Current) have to be taken into Consideration.

Bus Communication
- Master Device
- Slave Device(s)



Modification of I2C Interface to Support K Devices

Fig.2.

Ref:

2022S-108-LSM303DLHC.PDF

I2C Interface

(1) The transaction started through a START (ST) signal, defined as a high-to-low on the data line while the SCL line is held high.
(2) After ST, the next byte contains the slave address (the first 7 bit), bit 8 for if the master is receiving or transmitting data.
(3) When an address sent, each device compares the first seven bits after ST. If they match, the device is addressed.

Note: t_0 . t_1 t_2 t_3

Table 11. Transfer when master is writing one byte to slave, pp 20, datasheet

Master	ST	SAD + W		SUB		DATA		SP
Slave			SAK		SAK		SAK	

0X3D Table16

0x3D Table17

Fig4.

7 bits for the Address "Slave"

Directional Bit:

WRITE: 1
READ: 0.

Note: Space-Time Diagram.

→ Space

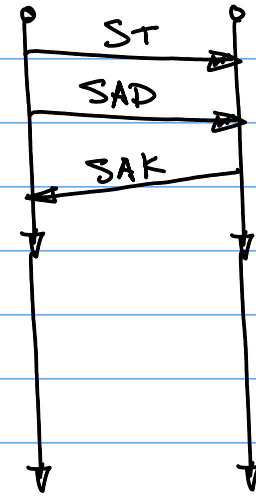
Spatial

Target (NAND) "Slave"

I2C Master LSM303

→ time

a. On SDA Line
b. from the master
c. 7 bits for SAD (Salve Addr)



Time

Fig.5

Note: 1° ST Start
2° SAD Slave Address
3° SAK Slave Ack.

And at t_3: SUB Sub-Slave-Addr. to Address the unit inside the Slave Device.

Question: SAD for LSM303

a. b. SAD[7:1]

Pp.20

Table 14. SAD+Read/Write patterns

Command	SAD[7:1]	R/W	SAD+R/W
Read	0011001	1	00110011 (33h)
Write	0011001	0	00110010 (32h)

0011001X

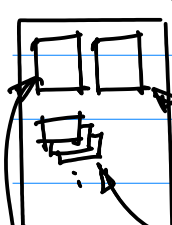
3 (1) 0011 Read: 3
(2) 0010 Write: 2

0X33 Read
0X32 Write

Note: Read Op is very often the 1st one from the master to get Manufacturer's ID & Device ID etc.

LSM303

Fig.6



"I2C Slave"

meg. Sensor

Special Purp. Registers

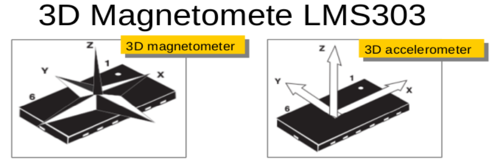
MCU: microprocessor

FSM: Finit State machine

SPRs: Config & Control, Data Sensing

Example: Find Sub-Addr.

3D Accelerometer and
3D Magnetomete LMS303



CmpE242 April 4, 22

Ref: Slide 7. a. Sub-Addr. for Magnetic Sensor

2. identify control register(s) for the right sensor block with the sub-address to set data rate
(1) CRA_REG_M register (0x00) to set data rate

Control/Config Register's Address: 0X00 "SUB"

For Magnetic Sensor.

Table 16. SAD

Command	SAD[6:0]	R/W	SAD+R/W
Read	0011110	1	00111101 (3Dh)
Write	0011110	0	00111100 (3Ch)

Table 17. Register address map (continued)

Name	Slave address	Type	Register address		Default
			Hex	Binary	
TIME_LATENCY_A	Table 14	rw	3C	011 1100	00000000
TIME_WINDOW_A	Table 14	rw	3D	011 1101	00000000
Reserved (do not modify)	Table 14		3E-3F	--	--
CRA_REG_M	Table 16	rw	00	00000000	0001000
CRB_REG_M	Table 16	rw	01	00000001	0010000
MR_REG_M	Table 16	rw	02	00000010	00000011
OUT_X_H_M	Table 16	r	03	00000011	output

Example: Tech Spec.
1° Read Angular Information / x-, y-, z-Acceleration
2° Sample Rate (of Read): 30Hz
Find 1° Special Purpose Register Responsible to perform Configuration.
2° Find Binary Pattern to initialize the SPR.

April 7, Wed

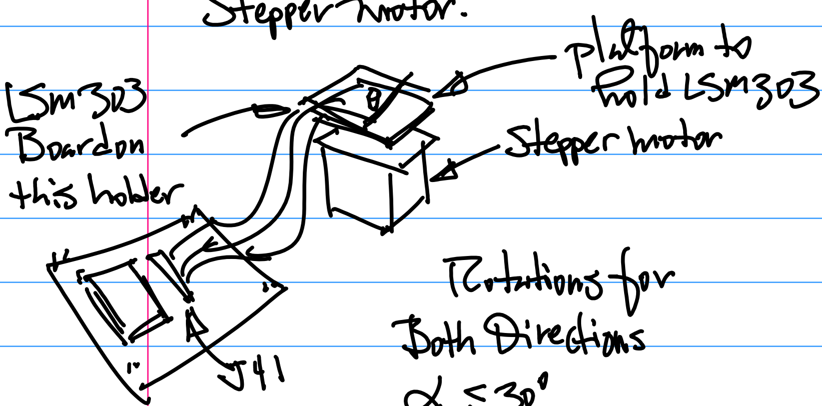
Topics: 1° LSM303 Interface Design.
Project Due April 18 before Class.

CMPE242 April 7, 22

Project Requirements:

1. Written Requirements + Rubrics Are to Be posted onLine, on CANVAS.

2. Integrate LSM303 Sensor to Stepper motor.



Rotations for Both Directions $\alpha \le 30^\circ$

3. to Run Stepper motor program to Actuate motor Rotation, then Read LSM303 Data to find for each Actual the displacement Value.

4. Test 3 Configuration of the motor, e.g.
   a. Full Step. 1.8 Degree Angle per step.
   b. Half Step. 0.9 Degree
   c. 1/4 Step. 0.45 Degree

5. Form A table to List the Data Read from LSM303

PWM pulses	LSM303 Input

Note: Try to Run multiple pulses of the PWM, for Example, 5~10 pulses. when collecting Data

6. Create Readme file, one page to Describe your implementation.
   a. Schematics
   b. Screen Capture of your code execution
   c. Generate 10 Sec.~15 Sec. Video Clips to Show the working system.
   d. 2 photos. { One for the entire System. (Laptop, Target Platform, Stepper Motor, Sensor)
   One for the Sensor (LSM303) Interface Design }

7. Includes All your Source code for testing/verification.

8. Put all of the Above into A Zip file, Submit the file to CANVAS

Note: please Bring your Implementation Board to the Class for Demo. Next Monday.

Example: Process/Steps to Interface to LSM303.

Step 1. Addr. of the Sensor. See Table 16 For mag. Sensor.

Note: Table 17, Special Purpose Registers { For Config/Control
For Data

CMPE242 April 7, 22 11

7.2 Magnetic field sensing register

7.2.1 CRA_REG_M (00h)

8 bit Register

a.

			0	0	0	0	0

Table 73

CRA_REG[7:5]

Table 73. CRA_REG register

GN2	GN1	GN0	0[1]	0[1]	0[1]	0[1]	0[1]

1. This bit must be set to '0' for correct working of the device.

b. For Mag. Sensor

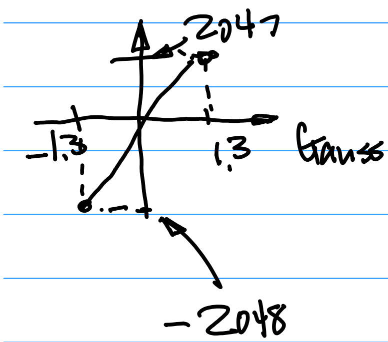
Smaller Range / more Sensitive

c. Out Range

Table 75. Gain setting

GN2	GN1	GN0	Sensor input field range [Gauss]	Gain X, Y, and Z [LSB/Gauss]	Gain Z [LSB/Gauss]	Output range
0	0	1	±1.3	1100	980	0xF800–0x07FF (-2048–2047)
0	1	0	±1.9	855	760	
0	1	1	±2.5	670	600	
1	0	0	±4.0	450	400	
1	0	1	±4.7	400	355	
1	1	0	±5.6	330	295	
1	1	1	±8.1	230	205	

$2^{11} = 1024 \times 2$
$= 2048$



Larger Range / Less Sensitive

GN2=0, GN1=0, GNØ=1

Note: Start with either default setting of the Gain, or set the gain to GN2 GN1 GN0 = 100

Then, Control Register for Operation mode Selection

Only 2 Bits

4. identify the control register responsible for mode of operation, from datasheet, pp 37, table 76, 78 MR_REG_M (02h) ← Sub-Addr. for this Register

0[1]	0[1]	0[1]	0[1]	0[1]	0[1]	MD1	MD0

Use Continuous mode

MD1	MD0	Mode
0	0	Continuous-conversion mode
0	1	Single-conversion mode

To Config/Access to Special Purpose Register(s), follow this "Write" Pattern:

SPR's Address: 0x01 for GAIN Setting, CRB_REG_M
0x02 for mode MR_REG_M,

Binary Pattern

For Reading After the Configuration, we will need find SADHR (Sub Addr. for Read), Example is given in PPT, from Datasheet, Table 15, PP:20.

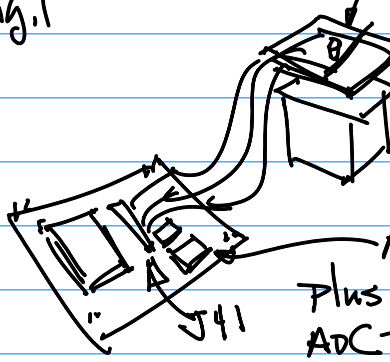
Coding Implementation: C/C++ Option
Python Option.

This Capability is to be implemented in this Class as a ~~project~~ Part of the

April 11 (monday). ADC

Analog To Digital Conversion.
Industrial IOT Application
Analog Sensor Interface

Fig. 1



LSM303 Board on this holder

ADC Unit plus ADC Testing Circuit

J41

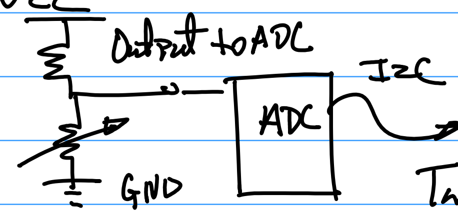
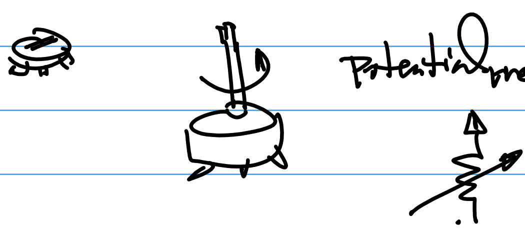


Fig. 2.

Example: Background of Analog to Digital Conversion.

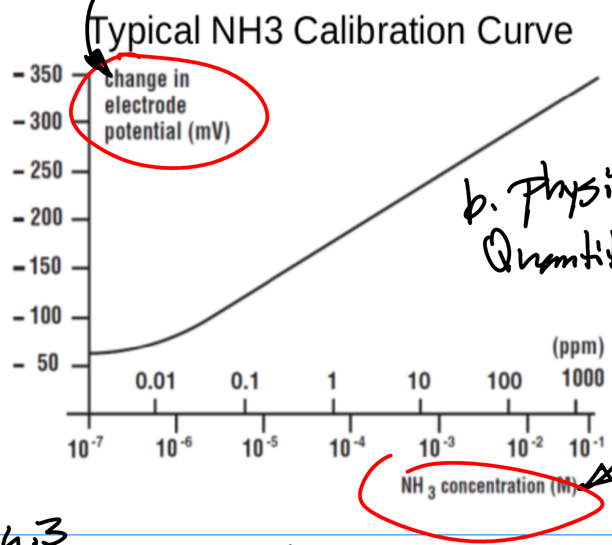
Sensor (Analog) Input,
Analog Current



Potentiometer

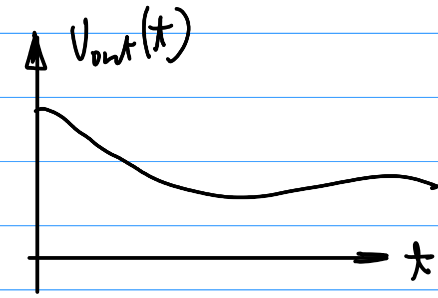
2018S-20-NH3- 4Design2018-1-16.pdf

Note: a. Analog Change Output



b. Physical Quantity

Fig.3



1° Sampling ADC.

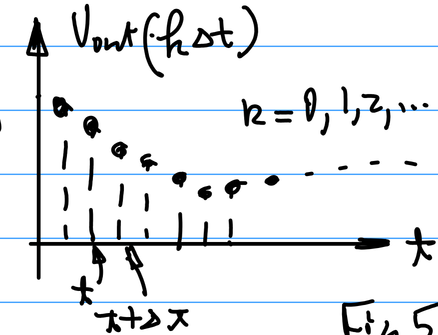
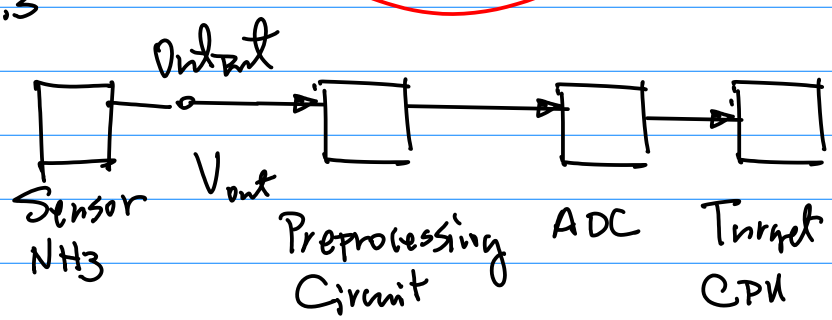
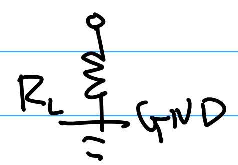


Fig.5



2° Quantization



Conversion: Current i to Voltage v.

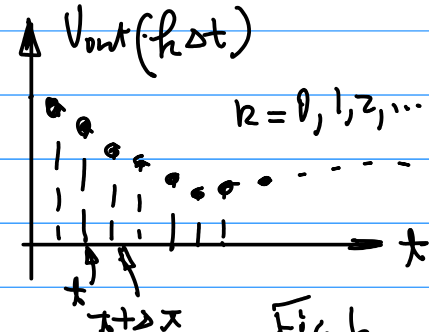
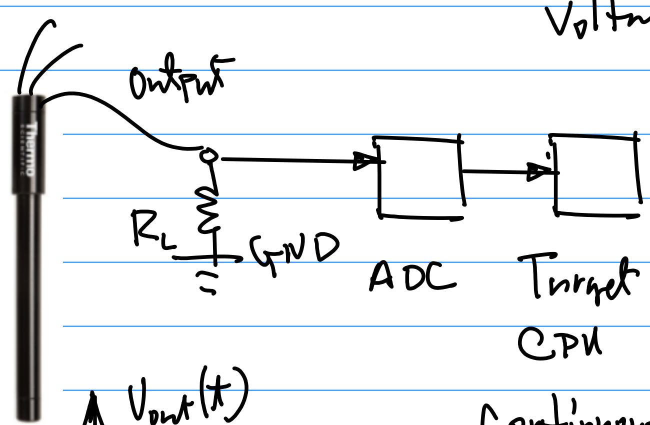


Fig.6

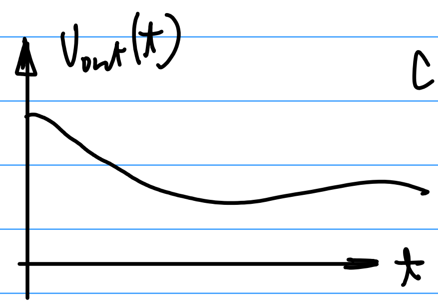


Note: the magnitude after the quantization becomes one of 2^x Possible Levels.

(10 bits ADC, $2^{10} = 1024$ Levels,

12 bit ADC, $2^{10} \cdot 2^2 = 4096$ Levels)

Fig4.



Continuous from the Analog Sensor.

Performance of ADC:

CMPE242 April 11, Monday. 22

1. Sampling Rate:
(Common) 500KSPS
(Samples per Second)

Sampling Theorem (Nyquest ~)

$$f_{Sampling} \geq 2 f_{max} \quad \cdots (1)$$

The Sampling Speed has to be greater than or equal to Twice of the maximum Speed of a given Signal.

2. Measurement of ADC. No. of Quantization Level. 10 bits ($2^{10} = 1024$), 8 bits ($2^8 = 256$)
12 bits ($2^{12} = 4096$).

3. Linear Characteristic.

ADC Output (10 bits)

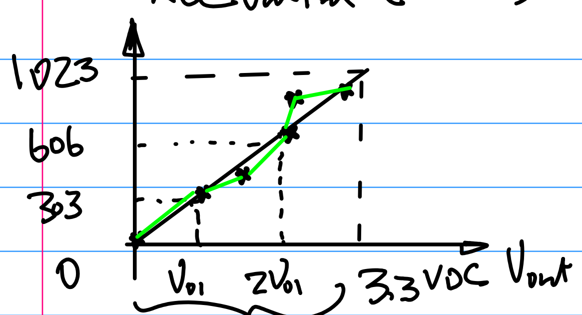


Fig.7

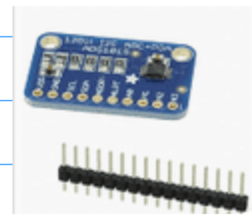
Fig.7 ADC Input Range
(Dynamic ~)

$$\frac{\Delta Output}{\Delta V_{out}} = k \text{ (Slop of the Line in Fig.7)}.$$

We have to measure "Linearity" of a given ADC.

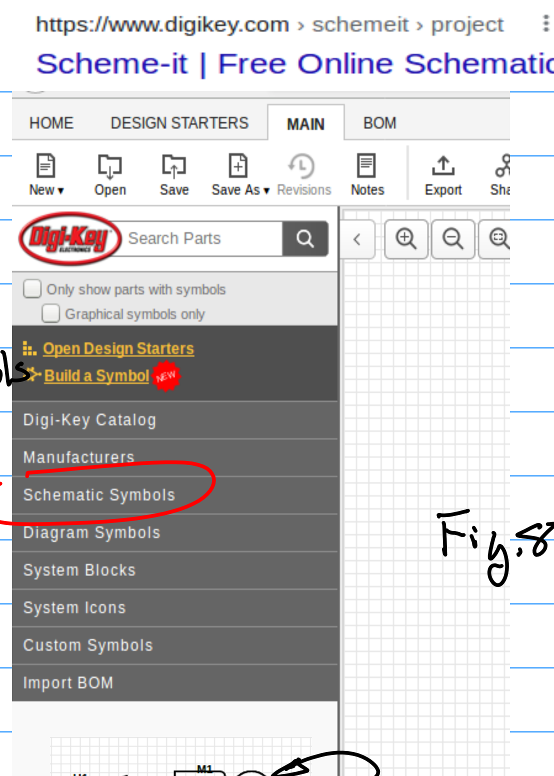
Homework (After the project of LSM303)
Formal Due Date to Be Announced in the next lecture.

1° Identify & Purchase Your ADC module.



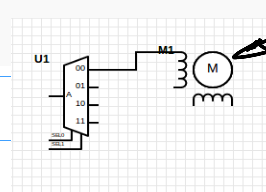
ADC with I2C Interface, ADS1115.

2° Generate Schematics.



Start with Symbols

Fig.8



Example here with a stepper motor

3. Use your Built Circuit Below, to collect 10 pairs of Data points.

$(V_{o1}, D_1), (V_{o2}, D_2), \ldots (V_{o10}, D_{10}),$

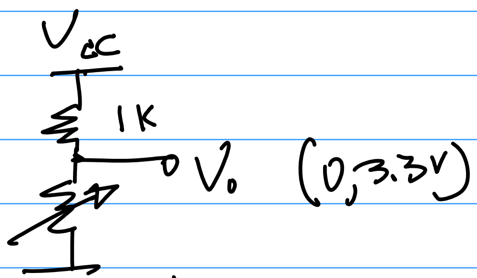


Fig. 9 (~~4.7 KΩ~~ Potential meter 470 KΩ

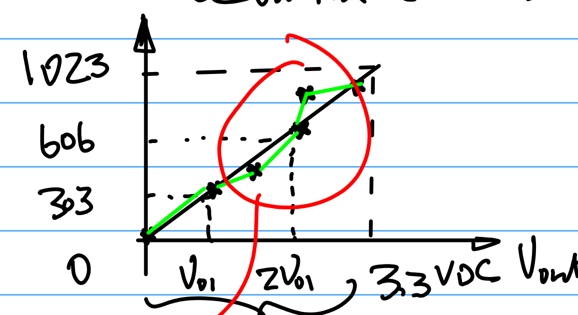
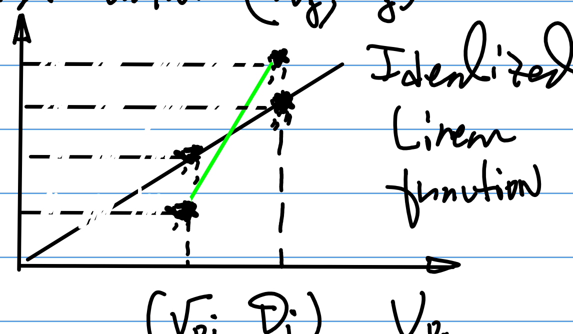


Fig. 11 ADC Input Range (Dynamic ~)

4. In order to do 3, you will have to have Python or C/C++ interface to your ADC.

5. plot your data, as in the Fig. here



Actual measurement

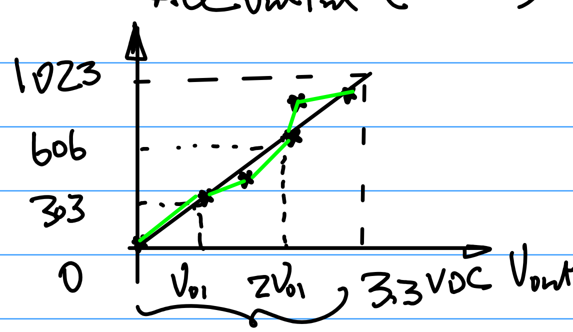


Fig. 10 ADC Input Range (Dynamic ~)

Develop A Correction function to correct Non-Linear Behavior By Developing A function.

6. Correction of Non-Linear Behavior

April 13.

Topics: 1° ADC Linear Compensation

Example: To Correct/Compensate the NonLinear Deviation (Green Line) to make it as Linear function (Black Line).

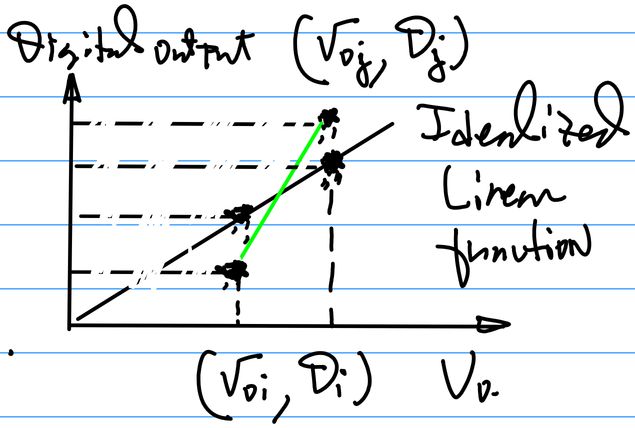


Fig 1.

Define $g(x,y)$ as the "green" Line.

$f(x,y)$ as the desired Linear Characteristic Line

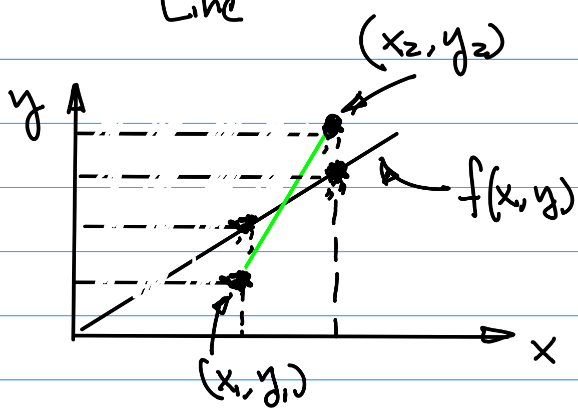


Fig 1-b

Objective: To Develop Post Processing Technique to Correct/Compensate the green Line (Actual Data).

Step 1. Desired Linear Characteristic Line.

Take A target form with An ADC

ADC has: 10 bits ADC

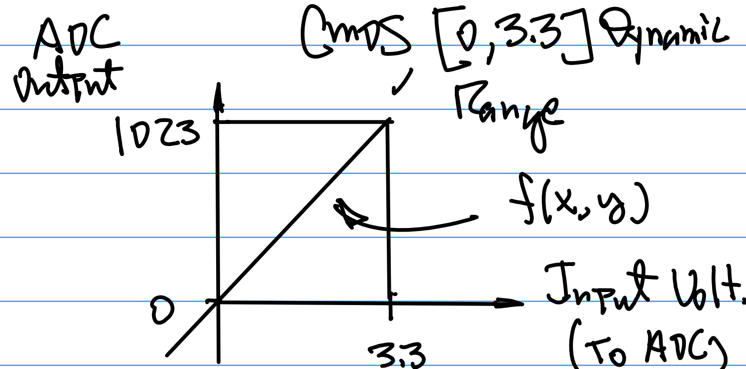


Fig. 2

$10 \text{ bits} = 2^{10} \text{ bits} \Rightarrow 1024 \text{ Levels}$

Since $y = ax + b$ ... (1)

where $b = 0$ B/C the Line passes the origin.

a is a slop.

$$a = \frac{\Delta y}{\Delta x} \quad \Bigg| \quad \begin{aligned} \Delta y &= 1024 \\ \Delta x &= 3.3 \end{aligned}$$

$$= 1024/3.3 = 310.3$$

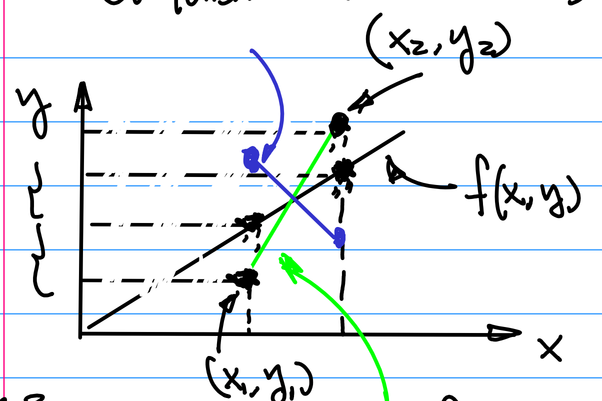
Step 2.

$$g(x,y) + h_{Comp}(x,y) = f(x,y) \quad \ldots (2)$$

we have

$$h_{Comp}(x,y) = f(x,y) - g(x,y) \quad \ldots (2\text{-}b)$$

Compensation function $h(x,y)$



Could be 3 (with Ref. to pp.19. Features)

Actual function $g(x,y)$

Step3. $g(x,y)$ from the Actual Data, we have from the Calibration Process.

From Fig.1-b.

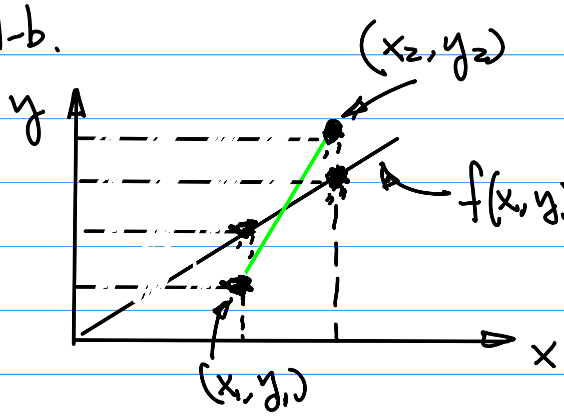


Fig.1-b

$$\underbrace{\frac{x-x_2}{y-y_2} = \frac{x_1-x_2}{y_1-y_2}} = \frac{x_2-x_1}{y_2-y_1} \quad \ldots (3)$$

$$y = ax + b.$$

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

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

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

$$\frac{y_1-y_2}{x_1-x_2}x - \frac{y_1-y_2}{x_1-x_2}x_2 + y_2 = y$$

$$y = \underbrace{\frac{y_1-y_2}{x_1-x_2}}_{b} x \underbrace{- \frac{y_1-y_2}{x_1-x_2}x_2 + y_2}_{c}$$

Hence

$$y = bx + c \quad \ldots (4)$$

where

$$b = \frac{y_2-y_1}{x_2-x_1} \quad \ldots (4\text{-}b)$$

$$c = -\frac{y_2-y_1}{x_2-x_1}x_2 + y_2 \quad \ldots (4\text{-}c)$$

From Step2, Eqn (2-b), find the Compensation.

$$h(x,y) = f(x,y) - g(x,y)$$

where $f(x,y)$: $y = ax$

$$f(x,y) = y - ax \quad \ldots (5)$$

$$g(x,y): \; y = \cancel{a}^{\,b'} x + \cancel{b}^{\,c'}$$

$$g(x,y) = y - (a'x + b') \quad \ldots (6)$$

Therefore

CmpE242 April 13, Wed, 22 18

$$h(x,y) = y - ax - [y - (\cancel{a'}^{\,b'} x + \cancel{b'}^{\,c'})]$$

$$= -ax + \cancel{a'}^{\,b'} x + \cancel{b'}^{\,c'}$$

$$= (\cancel{a'}_{\,b'} - a)x + \cancel{b'}\,c'$$

$$= (b' - a)x + c' \quad \ldots (7)$$

Hardware, Architectural Aspects of ADC

2021F-105-#0-cpu-arm11-2018S-29...

github, in 244 folder

6410X_UM

pp 1209

39 ADC & TOUCH SCRE

This chapter describes the functions and usage of ADC & Touch

for 10 bits for 12 bits

Note: a. 10/12 bit ADC. [0, 1023], or [0, 4095]

b. CMOS, Dynamic Range [0, 3.3V]

c. 8 ADCs

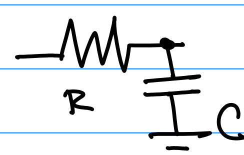
39.1 OVERVIEW

The 10-bit/12-bit CMOS ADC (Analog to Digital Converter) is a recycling type device with 8-channel analog inputs. It converts the analog input signal into 10-bit/12-bit binary digital codes at a maximum conversion rate of 1MSPS with 5MHz A/D converter clock. A/D converter operates with on-chip sample-and-hold function. The power down mode is supported.

Touch Screen Interface can control input pads (XP, XM, YP, and YM) to obtain X/Y-position on the external touch screen device. Touch Screen Interface contains three main blocks; these are touch screen pads control logic, ADC interface logic and interrupt generation logic.

d. $f_{Sampling,max} = 1 \times 10^6$ Hz, $f_{ADC} = 5 \times 10^6$ Hz

e. Sample-And-Hold



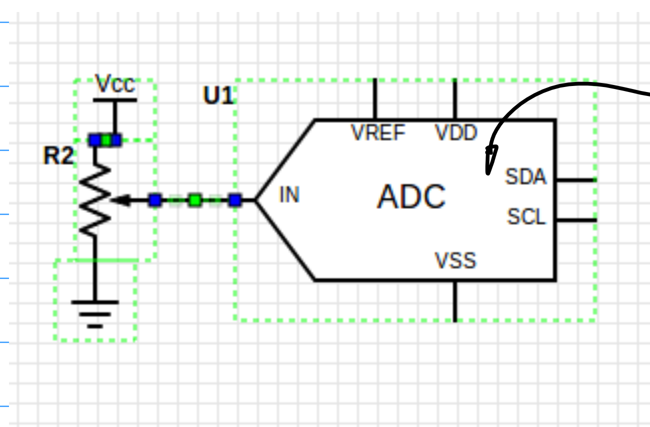
Inside ADC

Schematic Symbols

- Amplifiers
- Circuit Protection
- Clock Management
- Connectors
- **Converters**
  - Analog to Digital

15

- Resolution: 10-bit/12-bit
- Differential Nonlinearity: ± 2.0 LSB
- Integral Nonlinearity: ± 4.0 LSB
- Maximum Conversion Rate: 1MSPS
- Low Power Consumption
- Power Supply Voltage: 3.3V
- Analog Input Range: 0 ~ 3.3V
- On-chip sample-and-hold function
- Normal Conversion Mode
- Separate X/Y position conversion Mode
- Auto(Sequential) X/Y Position Conversion Mode
- Waiting for Interrupt Mode
- STOP mode wakeup source



Suppose for 10 bits ADC Configuration

$b_9 b_8 \cdots b_1 b_0$

- Resolution: 10-bit/12-bit
- Differential Nonlinearity: ± 2.0 LSB
- Integral Nonlinearity: ± 4.0 LSB
- Maximum Conversion Rate: 1MSPS
- Low Power Consumption
- Power Supply Voltage: 3.3V
- Analog Input Range: 0 ~ 3.3V
- On-chip sample-and-hold function
- Normal Conversion Mode
- Separate X/Y position conversion Mode
- Auto(Sequential) X/Y Position Conversion Mode
- Waiting for Interrupt Mode
- STOP mode wakeup source

$6 \begin{cases} +3 \ (=11) \\ -3 \end{cases}$

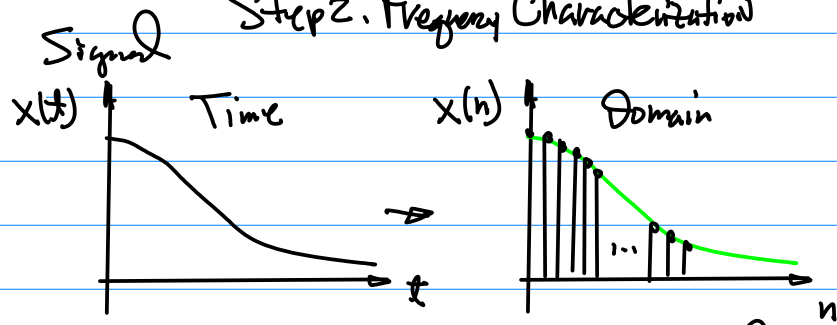
max error Due to Non-Linear Behavior.

"Sampling"

Nyquest Theorem

$$f_{Sampling} \geq 2 f_{max} \quad \ldots (8)$$

Step 2. Frequency Characterization



Continuous Signal From a Sensor.

Discrete Signal (After ADC)

April 18 (Monday).

Topics: 1° Data Validation.

Background:

Sampling Theorem (Nyquest Theorem)

$$f_{Sampling} \geq 2 f_{max} \quad \ldots (1)$$

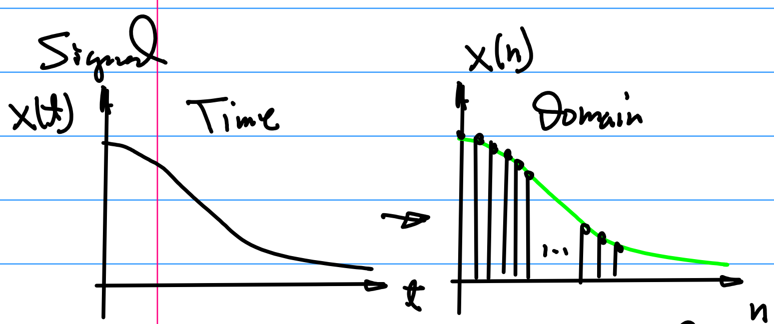
Sampling Freq. (ADC)

Signal Freq.

Freq. Domain Fourier Transform

Discrete Fourier Transform

$$X(f) \triangleq \int_{-\infty}^{+\infty} x(t) e^{-j2\pi f t} dt \quad \ldots (2)$$



Continuous Signal From a Sensor.

Discrete Signal (After ADC)

Fig.1

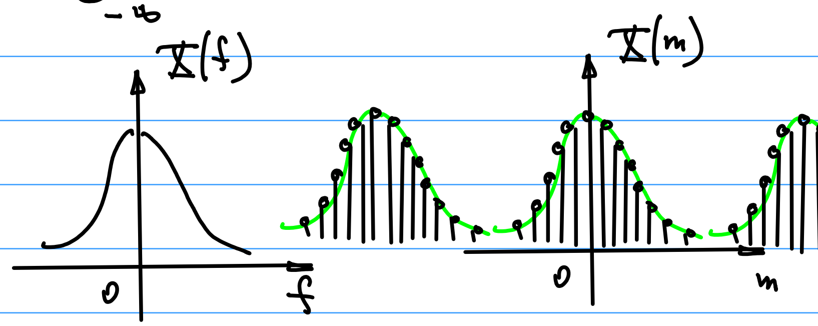
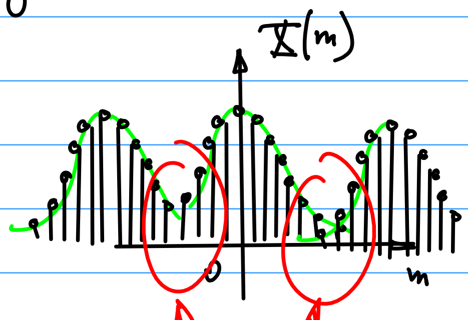


Fig.2

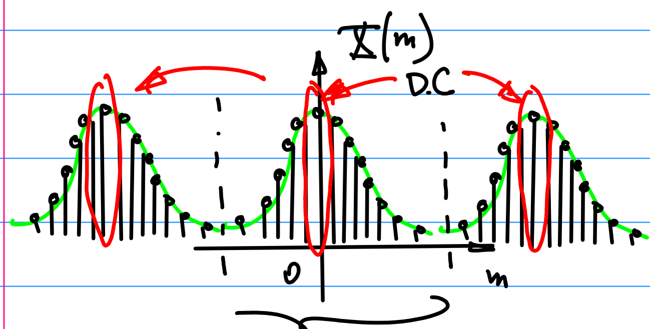
Note: Discrete Signal's Fourier Transform is defined as D.F.T (Discrete Fourier Transform) it repeats itself (Periodic Function). And it could have "Alising" (Distortion).

Fig.3.



"Alising" Distortion

Fig.4. Analyzing the Distortion. Analyze Sampling Rate



One Period of the Signal $x(n)$ (After ADC/Digitization)

1° $x(n) = x(n+kN)$, $k = 0, 1, 2, \dots$ ...(3)

Time Index

Total Number of Points of One Period.

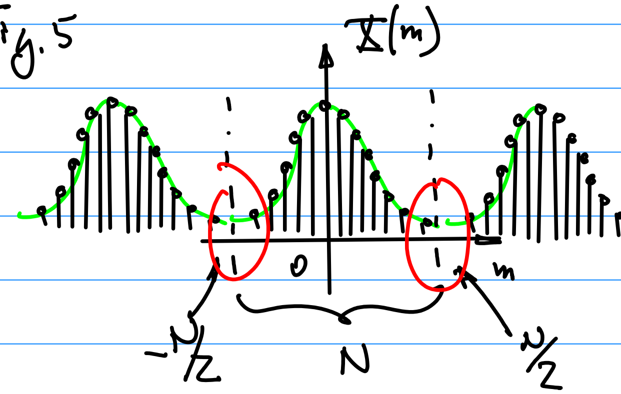
2° DC Component

$X(m)$: Discrete Fourier Transform.

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

3° Period

Fig.5



$X(m) = X(m+kN)$ ... (4)

You can take Any N points (Consecutive Points)

$\underbrace{\text{Highest Frequency index}}_{m}$

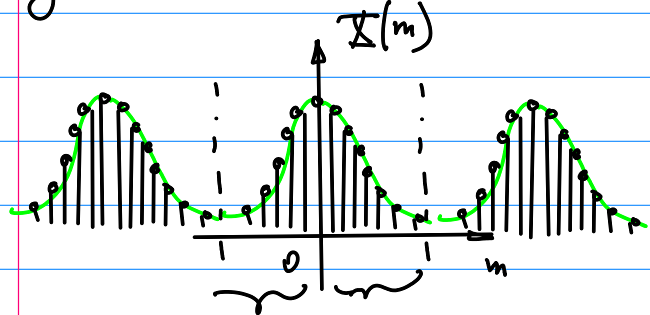
$N = 2^x$ ... (5) — Even Number

Condition for Computed D.F.T, e.g. FFT (Fast Fourier Transform)

a. One Component (D.C) at $m=0$, $N-1$ Components Left.

b. $N-1$ has to be distributed

Fig.6

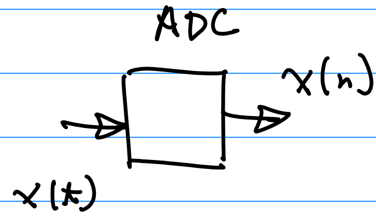


highest Freq. index $m = \frac{N}{2}-1$

↓

Highest Frequency of A given Signal.

$$f_{Sampling} \geq 2 f_{max}$$



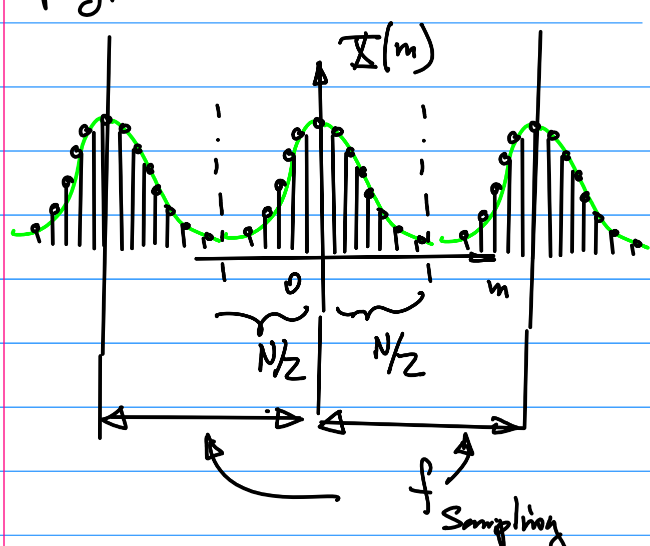
Take $x(n)$ (ADC output) Perform Discrete Fourier Transform.

$$X(m) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)\, e^{-j 2\pi \frac{mn}{N}} \quad \cdots (6)$$

Ref 1D DFT v2.pdf

C. One Period N for $X(m)$ D.F.T. is apart from the other period by $f_{Sampling}$

Fig.7



Define Discrete Fourier Transform

$$\begin{bmatrix} X(0) \\ X(1) \\ \vdots \\ X(N-1) \end{bmatrix} = \frac{1}{N} \begin{bmatrix} W_N^0 & W_N^0 & W_N^0 & \cdots & W_N^0 \\ W_N^0 & W_N^1 & W_N^2 & \cdots & W_N^{N-1} \\ W_N^0 & W_N^2 & W_N^4 & \cdots & W_N^{2(N-1)} \\ \vdots & & & & \\ W_N^0 & W_N^{N-1} & W_N^{2(N-1)} & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix} \begin{bmatrix} x(0) \\ x(1) \\ \vdots \\ x(N-1) \end{bmatrix} \quad \cdots (7)$$

Note: 1° Left hand Side

$$\underbrace{X(0), X(1), \ldots, X(N-1)}_{N \text{ Points}}$$

D.C. $X(0)$.

The Highest Freq Component $X(\frac{N}{2}-1)$, The Highest Freq. Index $m = \frac{N}{2}-1$

2° $W_N^{mn} = e^{-j2\pi \frac{mn}{N}}$

ADC Architecture, ARM-11

Ref:

hualili / **CMPE244**

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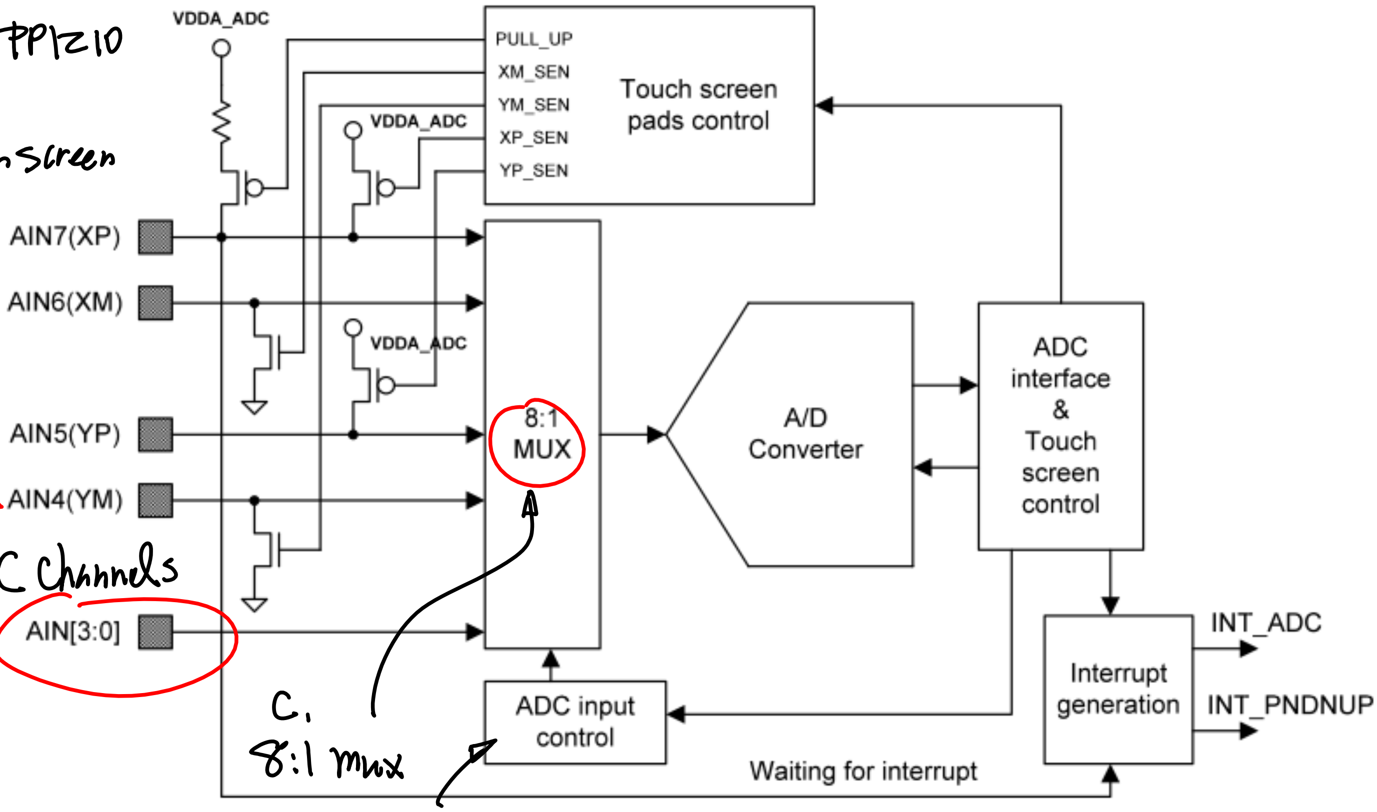
PP1210

b. Touchscreen

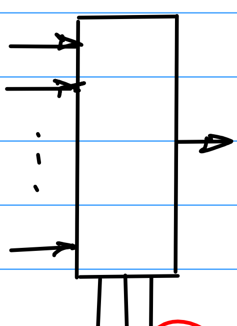


a. ADC Channels

c. 8:1 mux

d. ADC Input (mux) control

$2^3 = 8$, 3 bits mux



ADC[3]

$X_2 X_1 X_0$

April 20, Wed.

Topics: 1° Continue on D.F.T. for Data Validation.

Example:

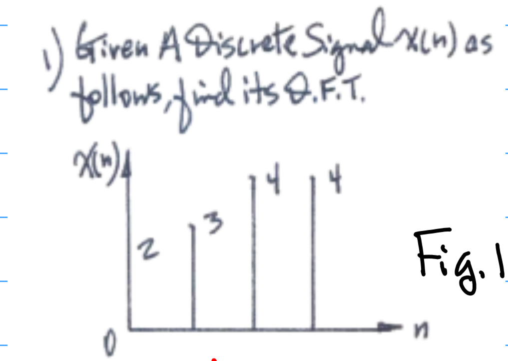
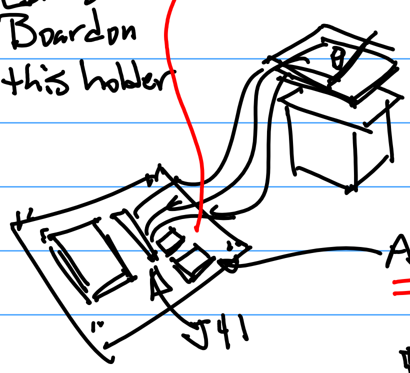


Fig. 1-a

Given Data from ADC: $x(0), x(1), x(2), x(3)$

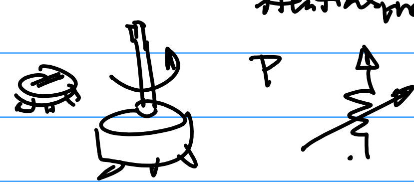
$N=4,\ 2^x = N$

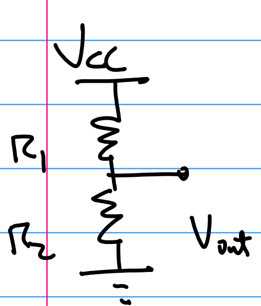
LSM303 Board on this holder



ADC Unit

Potentiometer





$$V_{out} = \frac{R_2}{R_1+R_2} V_{cc}$$

Note: if $N=2^x$, then FFT Program Can be directly Applied without Pading Extra 0's to make it Satisfy 2^x Requirements.

To validate this ADC Data.

From Eqn (6)

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

We Can derive Eqn (7)

$$\begin{array}{c} m \\ \downarrow \end{array} \begin{bmatrix} X(0) \\ X(1) \\ X(2) \\ X(3) \end{bmatrix} = \begin{bmatrix} & & \\ & \cdots & \\ & & \end{bmatrix}_{4\times4} \begin{bmatrix} x(0) \\ x(1) \\ x(2) \\ x(3) \end{bmatrix}$$

a. D.F.T

b. $N\times N$

c. From ADC

N: No. of pts per one period

d. $e^{-j2\pi\frac{m\cdot n}{N}}$

Fig 1-b

$m=p,\ n=q$ @ (p,q)

e. Euler Formula

$$e^{-j\alpha} = \cos\alpha - j\sin\alpha \quad \cdots (1)$$

From D.F.T.

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

$$= \frac{1}{N}\sum_{n=0}^{N-1} x(n)\left(\cos 2\pi\frac{mn}{N} - j\sin 2\pi\frac{mn}{N}\right)$$

f. m, n Index on matrix $E_{N\times N}$

From d, e, Let's Build E matrix

$$\begin{bmatrix} 1 & - & - & - \\ 1 & & & \\ 1 & & & \\ & & & \end{bmatrix}$$

(0,0) First Row, m=0
First Col. n=0

$$e^{-j2\pi\frac{mn}{N}}\Big|_{\substack{m=0\\n=0}} = e^{0} = 1$$

For m=0, n=1

$$e^{-j2\pi\frac{m\cdot n}{N}} = e^{0} = 1,$$

$$\begin{bmatrix} 1 & 1 & & \\ & & & \\ & & & \\ & & & \end{bmatrix}$$

For the rest of the elements on this row, $e^{-j2\pi\frac{mn}{N}}\Big|_{m=0} = 1.$

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ & & & \\ & & & \\ & & & \end{bmatrix}$$

For m=1, n=0, $e^{-j2\pi\frac{mn}{N}} = e^{0} = 1$

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & & & \\ & & & \\ & & & \end{bmatrix}$$

For m=1, n=1, $e^{-j2\pi\frac{m\cdot n}{N}}$

$$= e^{-j2\pi\frac{1\cdot 1}{4}} = e^{-j\pi/2}$$

$$= \cos\pi/2 - j\sin\pi/2 = 0 - j = -j$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & & \\ & & & \\ & & & \end{bmatrix}$$

For m=1, n=2, $e^{-j2\pi\frac{2\cdot 1}{4}} = e^{-j\pi}$

$$= \cos\pi - j\sin\pi = -1$$

For m=1, n=3, $e^{-j2\pi\frac{1\cdot 3}{4}} = e^{-j3\pi/2}$

$$= \cos 3\pi/2 - j\sin 3\pi/2 = j$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ & & & \\ & & & \end{bmatrix}$$

Please Complete the rest of the Calculation!

Note 1.

(0,1)

(1,0)

$$\begin{bmatrix} X(0) \\ X(1) \\ X(2) \\ X(3) \end{bmatrix} = \frac{1}{4}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -1 & -j \end{bmatrix}\begin{bmatrix} 2 \\ 3 \\ 4 \\ 4 \end{bmatrix}$$

Since

$$e^{-j2\pi\frac{m\cdot n}{N}} = e^{-j2\pi\frac{n\cdot m}{N}} \quad \cdots (2)$$

So, $E_{N\times N}$ matrix is Symmetric.

Note 2:

$\mathbb{X}(0) = \frac{1}{N}$(First Row x First Col)

$= \frac{1}{N}(x(0)+x(1)+\cdots+x(N-1))$

is the DC Component!

Note 3: Highest Frequency Component

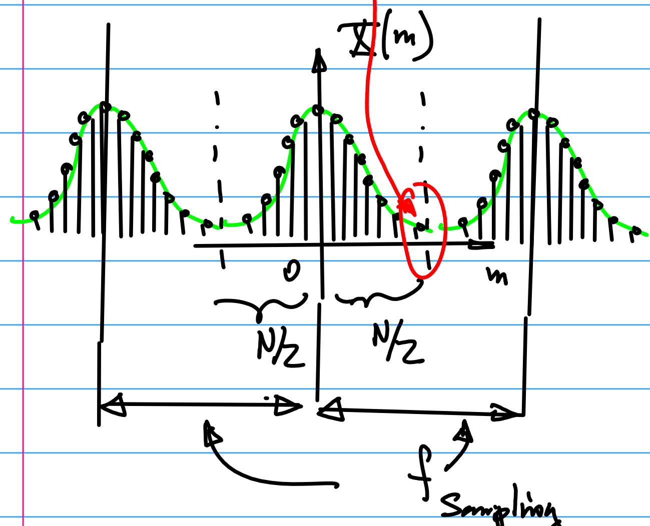
N: Total Number of Elements in One Period;

if $N=2^x$ if using Computer Based F.F.T.

then $\frac{N}{2}-1$ highest Frequency Index

Therefore, the Highest Freq. Comp.

$\mathbb{X}(\frac{N}{2}-1)$



April 25 (Monday), 22

Example: Analyze the Result

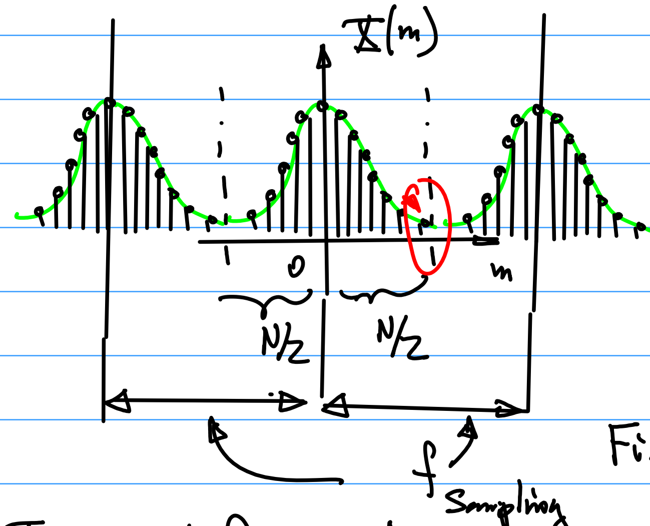
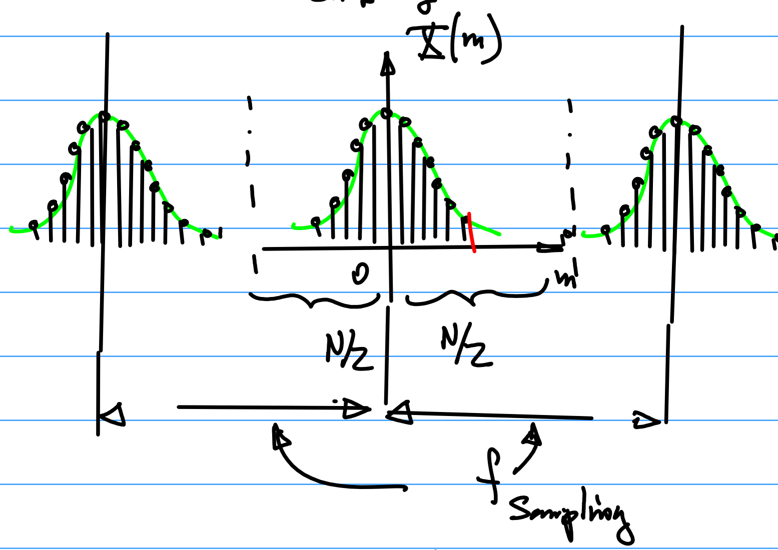


Fig 1.

Increased $f_{sampling}$



Observation: To validate data, check the highest frequency component, and its neighbouring components to make sure they are zero all smaller enough. If they are, then the data is valid. Otherwise not valid. (Need to Increase Sampling Frequency).

CmpE242 April 25, Monday, 22

Ref: for D.F.T. Calculation

1D DFT v2.pdf

$$\mathbb{X}(0) = \frac{1}{4}(2+3+4+4) = 3.25$$
$$\mathbb{X}(1) = \frac{1}{4}(2-3j-4+4j) = \frac{1}{4}(-2+j)$$
$$\mathbb{X}(2) = \frac{1}{4}(2-3+4-4) = \frac{1}{4}(-1)$$
$$\mathbb{X}(3) = \frac{1}{4}(2+3j-4-4j) = \frac{1}{4}(-2-j)$$

a. fft : Fast Fourier Transform

```
/*****************************************************************************
 * This Program is for CMPE class use, see Harry Li's lecture notes*
 *  details
 * Reference: Digital Signal Processing, by A.V. Oppenhaim;            *
 * fft.c for calculting 4 points input, but you can easily expand      *
 * this to 2^x inputs;                                                  *
 * : x0.1;         Checked: April 2021 on version Sept. 09;             *
 *                 Last checked: April 20, 2022                         *
 * Note: cross compiled for arm-linux-gcc, be sure to modify make      *
 * file to link math lib when compiling, by adding -lm                  *
 * This code then was tested on ARM11 board.                            *
 * $gcc thisCode.c -o main -lm                                          *
 *****************************************************************************/
```

b. $N = 2^x$

c. Compilation & Linking

Power Spectrum Definition

$$P(m) = \sqrt{Re^2[\mathbb{X}(m)] + Im^2[\mathbb{X}(m)]} \quad \cdots (1)$$

Note: Buffer size = 1024

```
struct Complex
{       double a;          //Real Part
        double b;          //Imaginary Part
}       X[1024], U, W, T, Tmp;
```

where

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

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

Note: To preserve the Original FORTRAN code.

```
float arr[5] = {0.0, 2.0, 3.0, 4.0, 4.0};
int i;
```

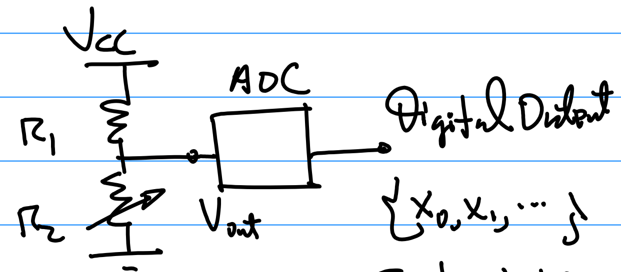
This element is not processed by F.F.T.

(Not Computed)

from the Above Calculation,

$$P(0) = \sqrt{3.25^2 + 0^2} = 3.25$$
$$P(1) = \frac{1}{4}\sqrt{(-2)^2 + 1^2} = \frac{1}{4}\sqrt{5}$$
$$P(2) = \frac{1}{4}\sqrt{(-1)^2 + 0^2} = \frac{1}{4}$$
$$P(3) = \frac{1}{4}\sqrt{(-2)^2 + (-1)^2} = \frac{1}{4}\sqrt{5}$$

$$P\left(\frac{N}{2}\right) = \frac{1}{4} \neq 0$$, Alising, Distortion!



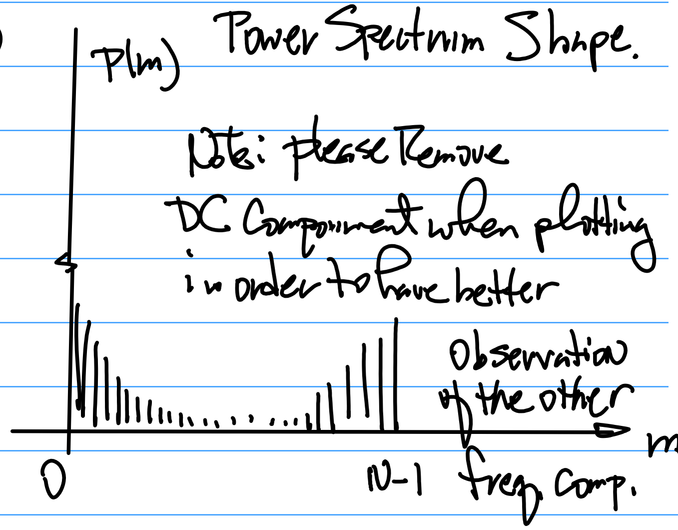
To Be feeded to the FFT program.

Homework on ADC with Data Validation

2022S-109a-powerSpectrum-fft.c

Homework Due A week from Today. May 2nd.

1. Implement ADC with I2C Interface.
2. Take 512 or 1024 points of some arbitrary data sequence, note if from your ADC output, then it is better. Then, feed the data into FFT Program, to Compute
   (a) D.F.T.
   (b) Power Spectrum.
3. Plot the power Spectrum Result using Spreadsheet.
   (a) Title of the plot.
   Power Spectrum of my ADC
   April 20, 22
   Name (First, Last)
   SID. Total Number of Point.
   1024 pts.
   (b) Power Spectrum Shape.



Note: please Remove DC Component when plotting in order to have better Observation of the other freq. Comp.

4. Submission.
   (a.) C Code;
   (b.) Screen Capture of the execution
   (c) plot of the power Spectrum.
   (d.) Conclusion of Data Validation

Note: Last Date of Class with Research Presentation, Upto 5 slides. 5~7 min. 1~2 min. Q&A. Total 10 min. Presentation.

Analog Sensor Interface Design. (w.r.t ADC I/F)

Example:

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

2018S-21-Ammonia 05722-16.pdf

Ion Selective Electrode Sensor I/F

Step1. Analyze the Characteristic Curve of the Sensor

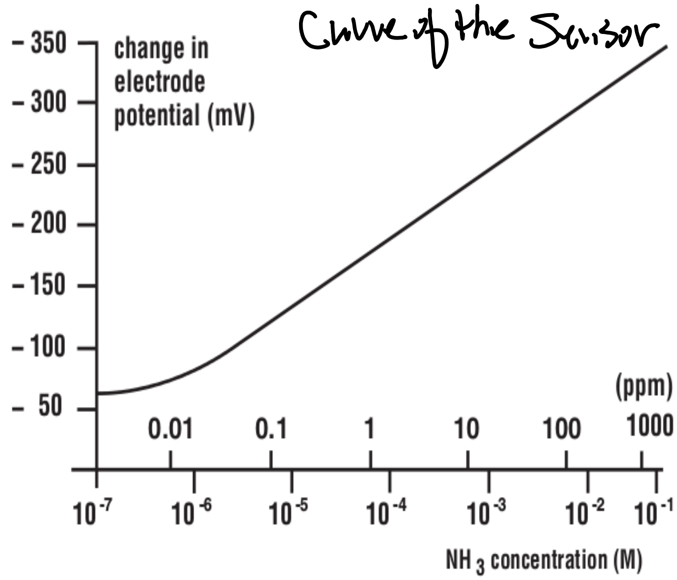


Fig. 1.

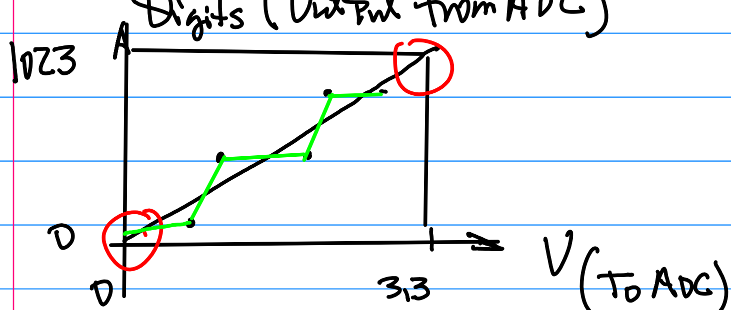
CMPE242 April 27, Wed.

April 27. (Wed)

Note: Final Exam. May 24th. (Tue)
12:15-2:30pm.

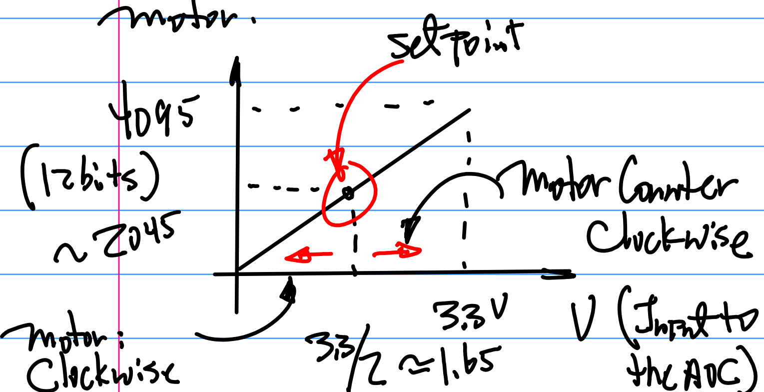
1. In Person final
2. Please Bring Your Prototype Board to the final Exam to Be used for Some Design Question.

Last project on CANVAS.
Due May 16th. (Monday)

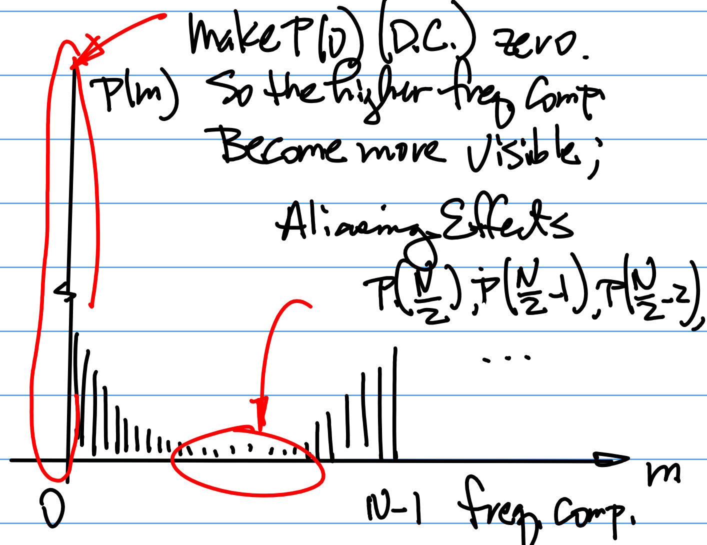


Analyze your data from the plot, identify 2 Consecutive Points that deviated most from the idealized line.

For ADC Control Stepper motor.



Data Validation, plot Power Spectrum of 1024 point



Individually, $P(\frac{N}{2}-i) \ll \varepsilon$
for $i = 1, 2, \cdots, K$

Collectively,

$$P(\tfrac{N}{2}) + P(\tfrac{N}{2}-1) + P(\tfrac{N}{2}-2) + \cdots + P(\tfrac{N}{2}-K)$$

$$= \underbrace{\sum_{i=1}^{K} P(\tfrac{N}{2}-i)}_{\text{less than 20\% of the total Energy.}} \ll \varepsilon'$$

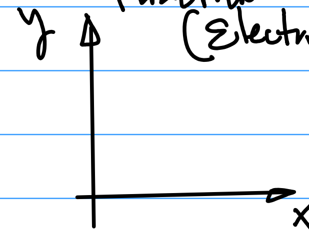
Consider Analog Sensor I/F Design.
ISE (Ion Selective Electrode)

General Approach:

Step 1. Characteristic Curve
a. Physical Quantity v.s. Electric Charge
Independent v.s. function.

excessive Lines if Possible.

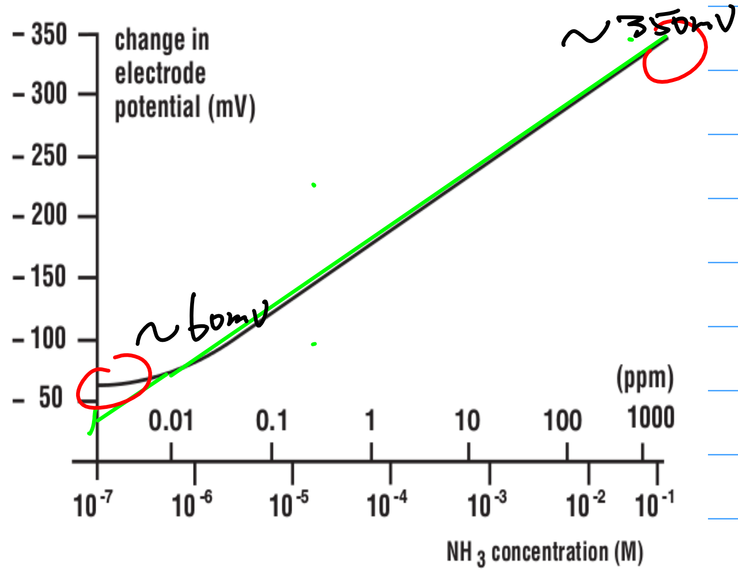
Function (Electric Charge)

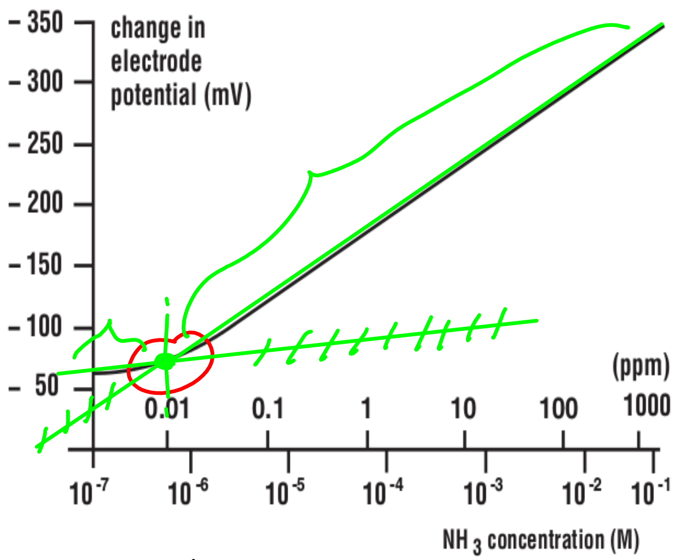


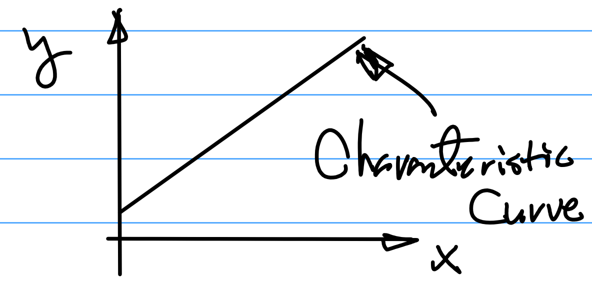
(Independent Variable) physical Quantity

b. Inspect the Curve, Produce Linearized Characteristic Curve As An Estimate.

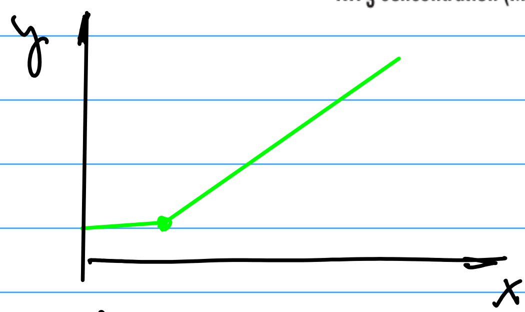
Use multiple straight lines to Approximate the Curve







Step3. Map the Characteristic Curve (y) to the Entire Dynamic Range of the ADC.



Step2. Analysis Design Spec, Simplify By Removal of

May 2nd Monday.

1. Final Exam in-person.
2. Last Homework, Presentation
   a. upto 5 slides;
   b. State-of-the-Art Technology Review
   c. Reference Sources

Topics: 1° Characteristic Curve
2° Preprocessing Technique.

Example: Design GuideLines.

1. Datasheet — Characteristic Curve.
2. Linearization / Approximation to Simplify Non-Linear Characteristic.
3. Map the Linear characteristic Curve to the Dynamic Range of your ADC

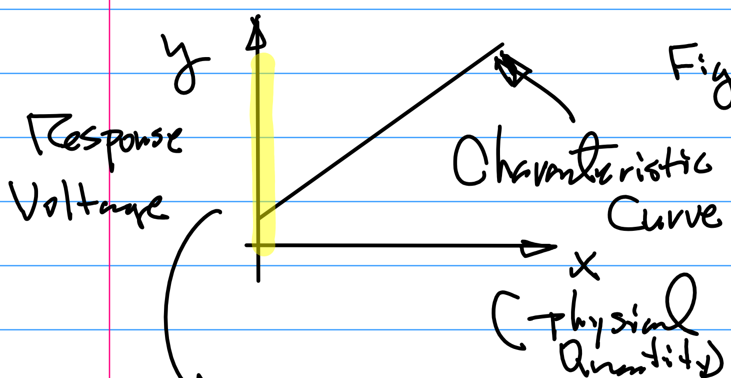


Fig 1a

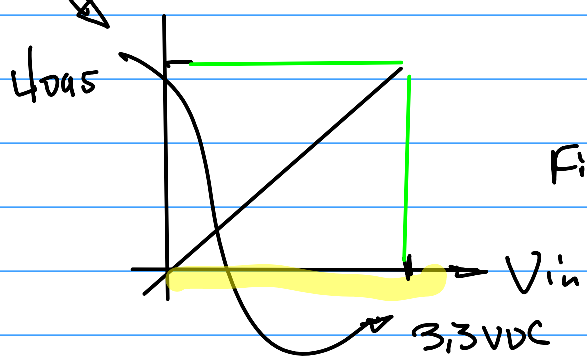


Fig 1b

Step 4. Design Preprocessing Circuit to Provide A Gain to Match the full Dynamic Range.

Example: From (1) the Linearized Characteristic Curve, (2) Dynamic Range of the Chosen ADC, find/Design A Gain to Realize full Dynamic Range Utilization of the ADC.

Sol.

From the Sensor Response we have

$\Delta V_{SEN} = 350 - 60 \ (mV)$

$\Delta ADC = 3.3 - 0 = 3300 \ (mV)$

$\therefore A = \frac{3300}{290} = 11.379$

Note: 60mV is offset, and it can be moved to zero with reference voltage.