

# ADC Characterization

Today's Topics:

1° Introduction to ADC. (CPU Datasheet)

2° Data Validation.

Reference: CPU ADC Chapter (392)  
for ARM11 or Equivalent

Table 1 ADC Characterization

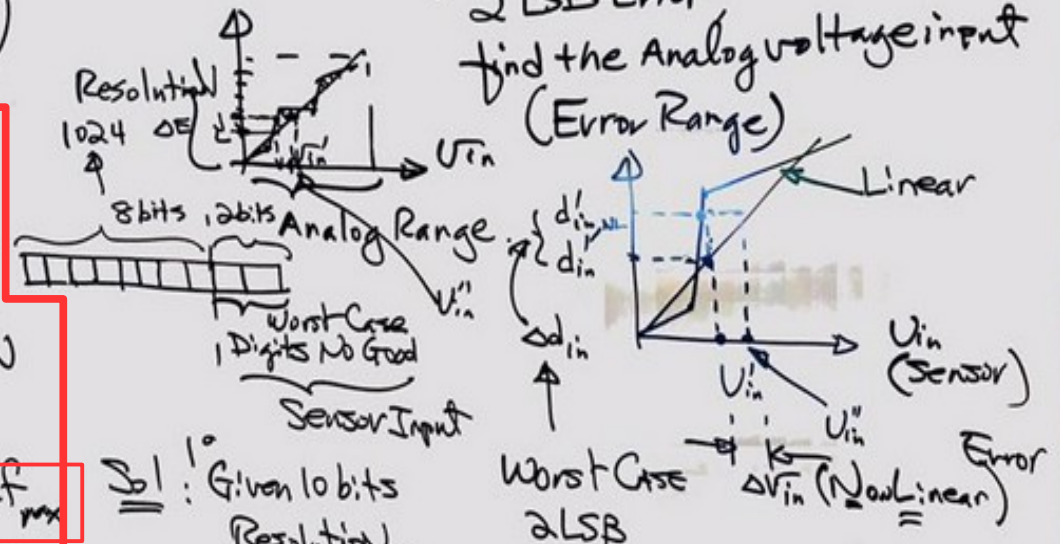
No	Description	Note
1° Resolution	10 bit (1024) 12 bit (4096)	Quantization Levels per given Resolution
2° Conversion Rate	1 MSPS	Conversion Time per Sample $f_{\text{Sampling}} \geq 2f_{\text{max}}$
3° Analog Input Range	[0, 3.3]	for Sensor I/F Design. OpAmp Preprocessing CKT.
4° Linearity (Non)	2LSB Difference	Calculation for Sensor Input

Note:

1° Conversion Time,  $T_{\text{conv}} = \frac{1}{f_{\text{Sampling}}} = 1 \times 10^{-6}$   
 $\mu\text{S} = 1 \times 10^{-6}$

2° Non-Linearity

Example: Given 2 LSB Error  
find the Analog voltage input (Error Range)



Sol: 1° Given 10 bits Resolution,

2° Analog Range 3.3V.

3° Therefore for LSB (1 bit):  $\frac{3.3V (\text{Full Range})}{1024 (\text{Full Resolution})} \approx 3.3 \times 10^{-3} \text{ VDC}$

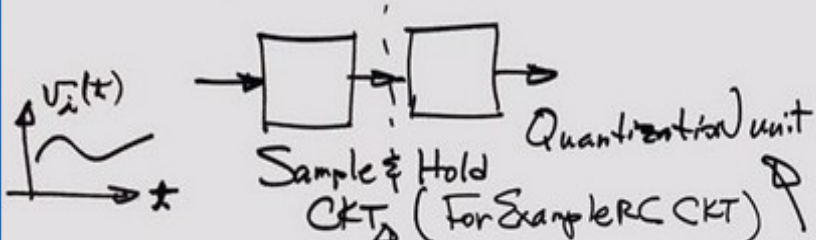
4° For Additional Bits:  $2^{10} (\text{LSB}) \rightarrow 1024$

Hence  $\frac{3.3V}{2^9} = 6.6 \times 10^{-3}$   
 $2^9 (\text{2 bits, LSB}) \rightarrow 512 \rightarrow \text{bit Error}$   
 1 Additional

# Introduction To DFT For Data Validation

April 16/2018 CMPE42 2/.

## ADC Hardware Aspects.



Quantization unit

Sample & Hold CKT (For Sample RC CKT)

Nyquist Theory

$f_{\text{Sampling}} \geq 2f_{\text{Max}}$

Signal itself

$\Delta t = \frac{1}{f_{\text{Sampling}}}$

$\tau = RC$

Define D.F.T.

Analog Sensor Output  $x(t)$

$x(t)$  (Vol/Current)

$x(n)$

$\Delta t = \frac{1}{f_{\text{Sampling}}}$

$f_{\text{Sampling}} = \frac{1}{\Delta t}$

$X(n) \leftrightarrow X(m)$  D.F.T. Fourier Transform.

Frequency Index:  $0, 1, 2, \dots, N-1$

$m=0$ . D.C.

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

$X(\frac{N}{2}-1)$  highest Freq. Component

$N$ : Total of Pts per period

$X(m) = X(m + k \cdot N)$   $k=1, 2, \dots$

$N$  pts: ONE period.

Signal

Basis function

Compare to Taylor Expansion.

$f(x) = f(x_0) + \frac{f'(x_0)}{1!}(x-x_0) + \frac{f''(x_0)}{2!}(x-x_0)^2 + \dots$

$f(x) = c + a(x-x_0)$

$y = ax + b$

\* Let's Consider Data Validation.  
(To verify if  $f_{\text{Sampling}} \geq 2f_{\text{Max}}$ )

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



# DFT Power Spectrum

April 18, 18. 7+L CMPE242 Embedded Hardware

Today's Topics:

1° Device Driver/CPU Datasheet.

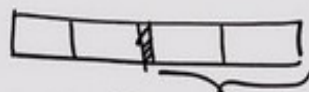
Special Purpose Register →

\* Define/Select clock Rate f<sub>Sampling</sub>

2° Data Validation (D.F.T.)

CPU Datasheet 39.62 Example: User App. Program.

```
f_d = open("/dev/adc", 0);
read(f_d, buffer, sizeof buff);
```



1° ADCCON[13:6] Prescaler Range.

Formula for f<sub>Sampling</sub> is to be verified. HL

2° ADCCON[5:5] 3° Map Device Drivers.

Consider D.F.T.

$$X(m) = X(m + KN)$$

Power Spectrum.

$$P(m) = \text{Sqrt} \left( \text{Re}^2[X(m)] + \text{Im}^2[X(m)] \right) \dots (3)$$

$$\approx \text{Re}^2[X(m)] + \text{Im}^2[X(m)]$$

$$P(m) = P(m + K \cdot N)$$

Example

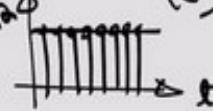
$$\begin{aligned} \therefore &= \text{Re}^2(X(m + KN)) + \text{Im}^2(X(m + KN)) \\ &= \text{Re}^2(X(m)) + \text{Im}^2(X(m)) \end{aligned}$$

Distribution of the Energy v.s. freq. Index.



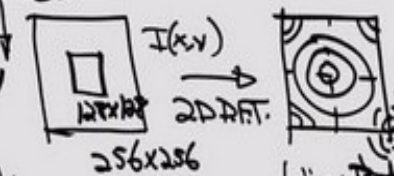
"m=0 Low Pass" type DC Comp.

$$P(m) |_{m=0}$$



(3) Periodic Function

(4)  $m = \frac{N}{2} - 1$  Highest Freq. Index



(5)  $P(\frac{N}{2} - 1)$  highest freq. Comp.

(6) Verification:  $\sum_{m \in \Omega} P(m) \leq \text{Threshold}_{15\%} \dots (4)$

Total  $\sum_{m=0}^{N-1} P(m)$

# DFT Power Spectrum Calculation

Example:

$\{x(n) | n=0, 1, 2, \dots, N-1\}$

A.V. Oppenheim  
"Digital Signal Processing"

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

$$= \frac{1}{N} \left[ x(0) e^{j2\pi \frac{m \cdot 0}{N}} + x(1) e^{-j2\pi \frac{m \cdot 1}{N}} + \dots + x(N-1) e^{-j2\pi \frac{m(N-1)}{N}} \right]$$

$n(\text{Time})$

$X(p)$

$X(0)$   
 $X(1)$   
 $\vdots$   
 $X(N-1)$

$N \times 1$

$\dots$

$x(0)$   
 $x(1)$   
 $\vdots$   
 $x(N-1)$

$N \times 1$

$\dots(4)$

$e^{-j2\pi \frac{p \cdot q}{N}}$

where  $p$  for freq. index,  $q$  for time index

From Matrix Form,

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

$$= \frac{1}{N} \left( x(0) e^{-j2\pi \frac{m \cdot 0}{N}} + x(1) e^{-j2\pi \frac{m \cdot 1}{N}} + \dots + x(N-1) e^{-j2\pi \frac{m(N-1)}{N}} \right)$$

For  $m=0$

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

$m=1$

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

$\vdots$

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

$$e^{-j2\pi \frac{p \cdot q}{N}} \text{ where } p \text{ for freq. index, } q \text{ for time index}$$

$\dots(5)$

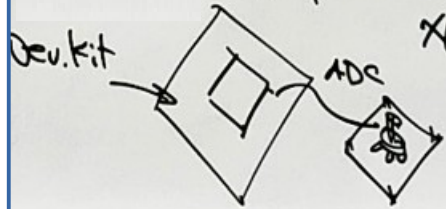
Euler Formula,

$$e^{-j2\pi \frac{p \cdot q}{N}} = \cos 2\pi \frac{p \cdot q}{N} - j \sin 2\pi \frac{p \cdot q}{N} \quad (5^*)$$



# Power Spectrum Example

Example: Given from my ADC:  $\{x(n) | n=0,1,2,\dots,N-1\}$   
 $x(0)=2, x(1)=3, x(2)=4, x(3)=4$   
 $N=4$ .



1st Step

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -j & -1 & j \\ 1 & -1 & 1 & -1 \\ 1 & j & -j & -j \end{bmatrix}_{4 \times 4}$$

for  $m=1, n=1$ , hence from (5)

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

$N=4$

$$= \cos \frac{\pi}{2} - j \sin \frac{\pi}{2} = 0 - j = -j$$

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

$$= \cos \pi - j \sin \pi = -1 - j0 = -1$$

for  $m=1, n=3$ ,  $e^{-j2\pi \frac{1 \cdot 3}{4}} = e^{-j\frac{3\pi}{2}} =$   
 $= \cos \frac{3\pi}{2} - j \sin \frac{3\pi}{2} = 0 - j(-1) = j$

For  $m=2, n=2$ ,  $e^{-j2\pi \frac{2 \cdot 2}{4}} = e^{-j2\pi} = \cos 2\pi - j \sin 2\pi = 1 - j0 = 1$   
 For  $m=2, n=3$ ,  $e^{-j2\pi \frac{2 \cdot 3}{4}} = e^{-j3\pi} = \cos 3\pi - j \sin 3\pi = -1$   
 For  $m=3, n=3$ ,  $e^{-j2\pi \frac{3 \cdot 3}{4}} = e^{-j\frac{9\pi}{2}} = e^{-j(\frac{8\pi}{2} + \frac{\pi}{2})}$   
 $= e^{-j\frac{8\pi}{2}} \cdot e^{-j\frac{\pi}{2}} = 1 \cdot e^{-j\frac{\pi}{2}} = \cos \frac{\pi}{2} - j \sin \frac{\pi}{2} = -j$

2nd Step

$$\begin{bmatrix} x(0) \\ x(1) \\ x(2) \\ x(3) \end{bmatrix}_{4 \times 1} = \frac{1}{4} \mathbf{E}_{4 \times 4} \begin{bmatrix} 2 \\ 3 \\ 4 \\ 4 \end{bmatrix}$$

$$P(m)_{m=\frac{N}{2}-1} = P(1)$$

'Bigger'

$$f_{\text{sampling}} \geq 2f_{\text{max}}$$

Hence;

$$x(0) = \frac{1}{4}(1 \cdot 2 + 1 \cdot 3 + 1 \cdot 4 + 1 \cdot 4) = \frac{1}{4} \cdot 13 = 13/4$$

$$x(1) = \frac{1}{4}(1 \cdot 2 + (-j) \cdot 3 + (-1) \cdot 4 + j \cdot 4) = \frac{1}{4}(2 + j)$$

$$x(2) = \frac{1}{4}(1 \cdot 2 + (-1) \cdot 3 + 1 \cdot 4 + (-1) \cdot 4) = \frac{1}{4}(-1)$$

$$x(3) = \frac{1}{4}(1 \cdot 2 + j \cdot 3 - 1 \cdot 4 - j \cdot 4) = \frac{1}{4}(-2 - j)$$

$$P(m)_{m=0} = P^2[x(m)] + I_m^2[x(m)] = P^2[x(0)] + I_m^2[x(0)] = \left(\frac{13}{4}\right)^2 + 0 = \left(\frac{13}{4}\right)^2$$

$$P(1) = \left(-\frac{2}{4}\right)^2 + \left(\frac{1}{4}\right)^2; P(2) = \left(-\frac{1}{4}\right)^2 + 0 = \left(\frac{1}{4}\right)^2; P(3) = \left(-\frac{2}{4}\right)^2 + \left(-\frac{1}{4}\right)^2$$

Reference: A.V. Oppenheim, Digital Signal Processing