

Wireless Embedded Systems

Department of Radio & Information Communications Engineering

CHUNGNAM NATIONAL UNIVERSITY

김병관

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Course Overview

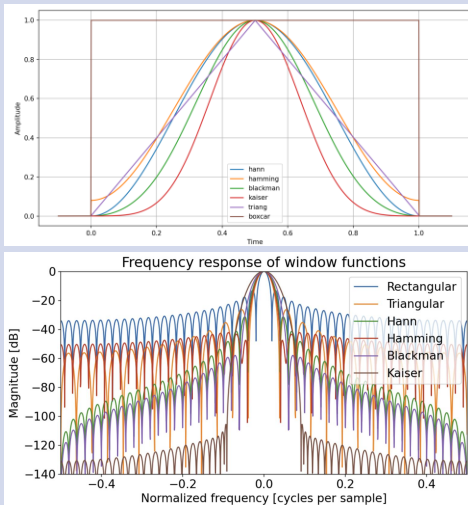
- Tentative Schedule

#	Topic	Lab/Assignment
1	Introduction	
2	Review: Python Basics, Signal & Systems	1. DFT vs FFT
3		
4		
5	Digital Signals and Sampling	2. Sampling & Windowing
6		
7	Analog & Digital Modulation	
8	Midterm Exam	
9	Software-Defined Radio	Env. Setup
10		
11	Wireless Communication Experiments (Spectrum Monitoring, Communication)	3. Time-Frequency Analysis
12		
13		
14		
15	Final Exam	

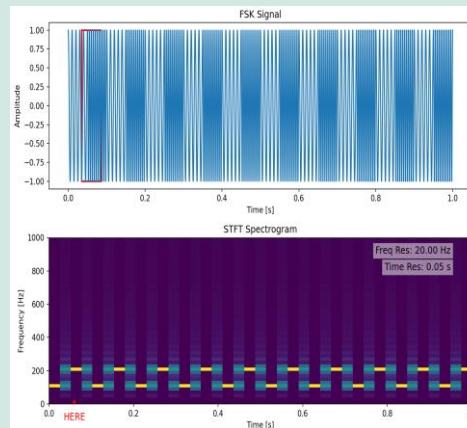
Digital Signals & Sampling

- Overview of this chapter

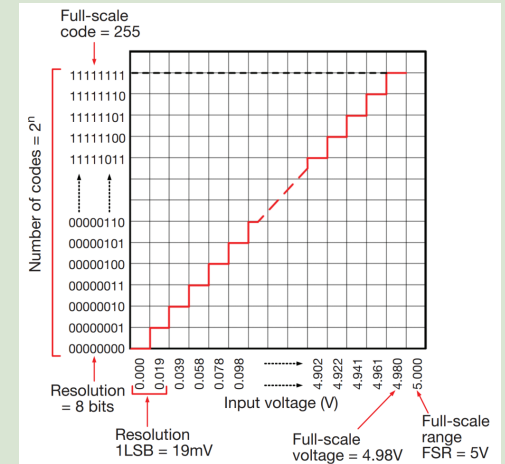
Sampling & Window Function



Time-Frequency Analysis



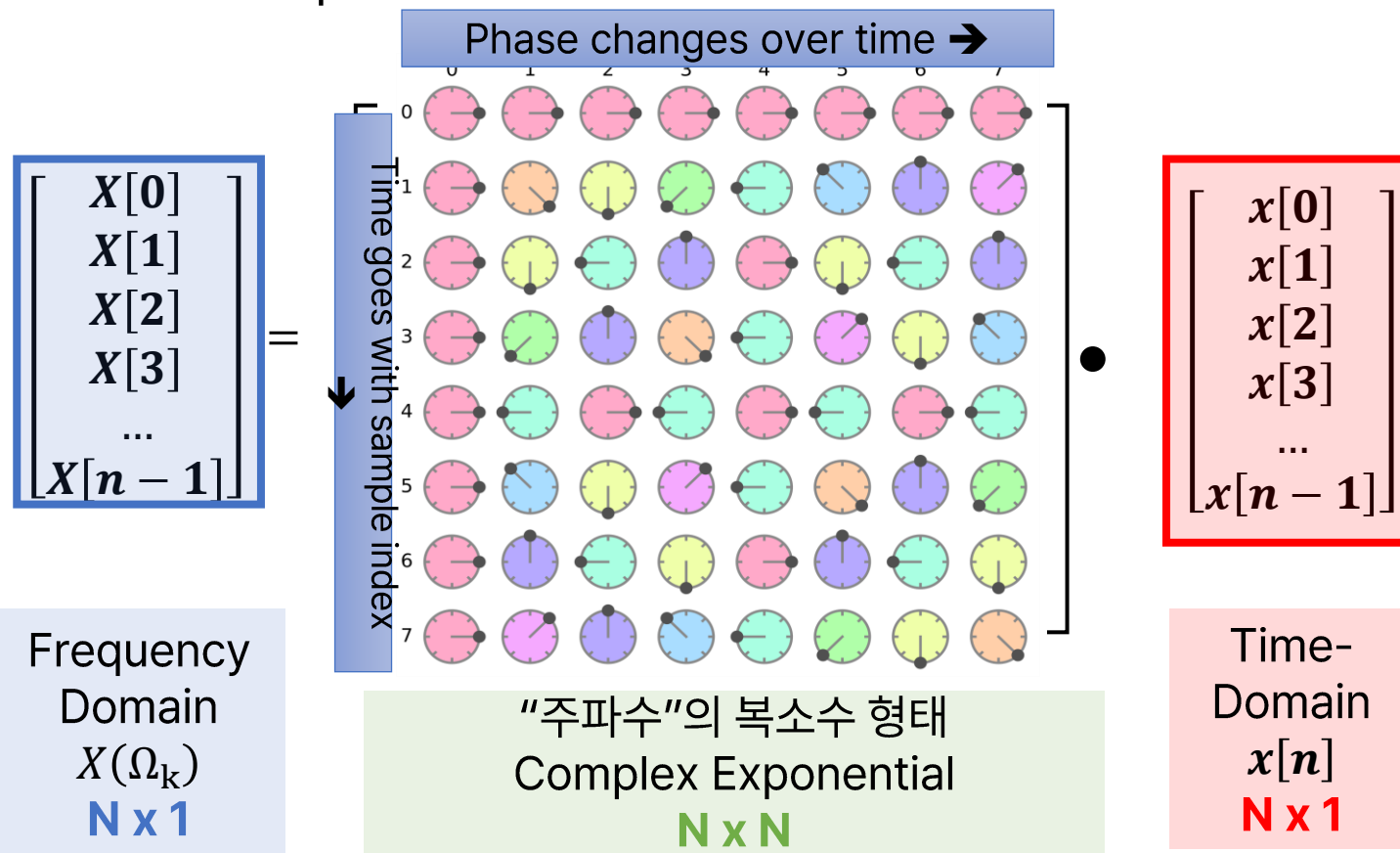
Analog-Digital Converter



Digital Signals & Sampling

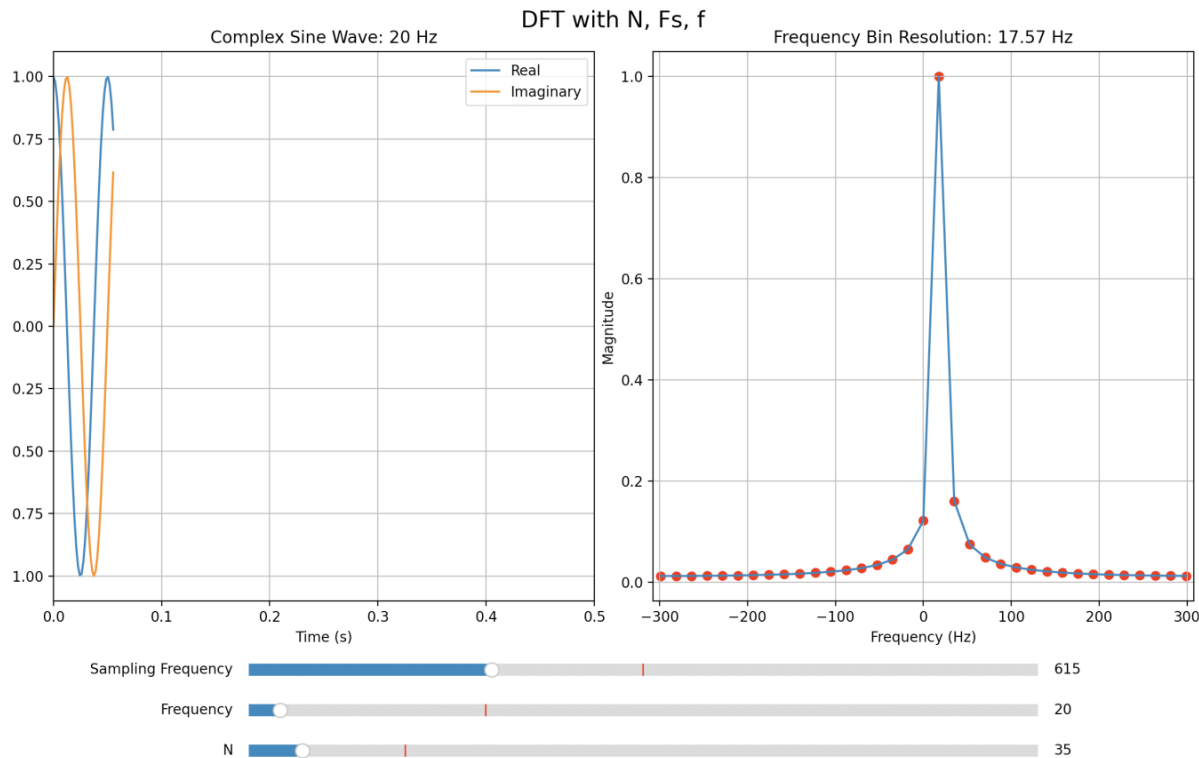
- Discrete Fourier Transform
 - A visual explanation

$$X(\Omega_k) = \sum_{n=0}^{N-1} x(n) e^{-j \frac{2\pi k}{N} n}$$



Digital Signals & Sampling

- The uncertainty of the time and frequency
 - For a fixed f_s , larger N will give small Δf (high freq. resolution)
 - For a fixed t , higher f_s will give higher f_{max}



Digital Signals & Sampling

무선임베디드시스템 (1217-3016)

중간고사

2023-10-30

1. (15pt) 아래 질문에 답하여라.

- A. (8pt) 10^3 Sample/s 의 샘플링 주파수를 가진 Analog-Digital Converter가 $5 \cdot 10^4$ 개의 샘플을 획득하는데 걸리는 시간은 몇초인가?

Digital Signals & Sampling

무선임베디드시스템 (1217-3016)

중간고사

2023-10-30

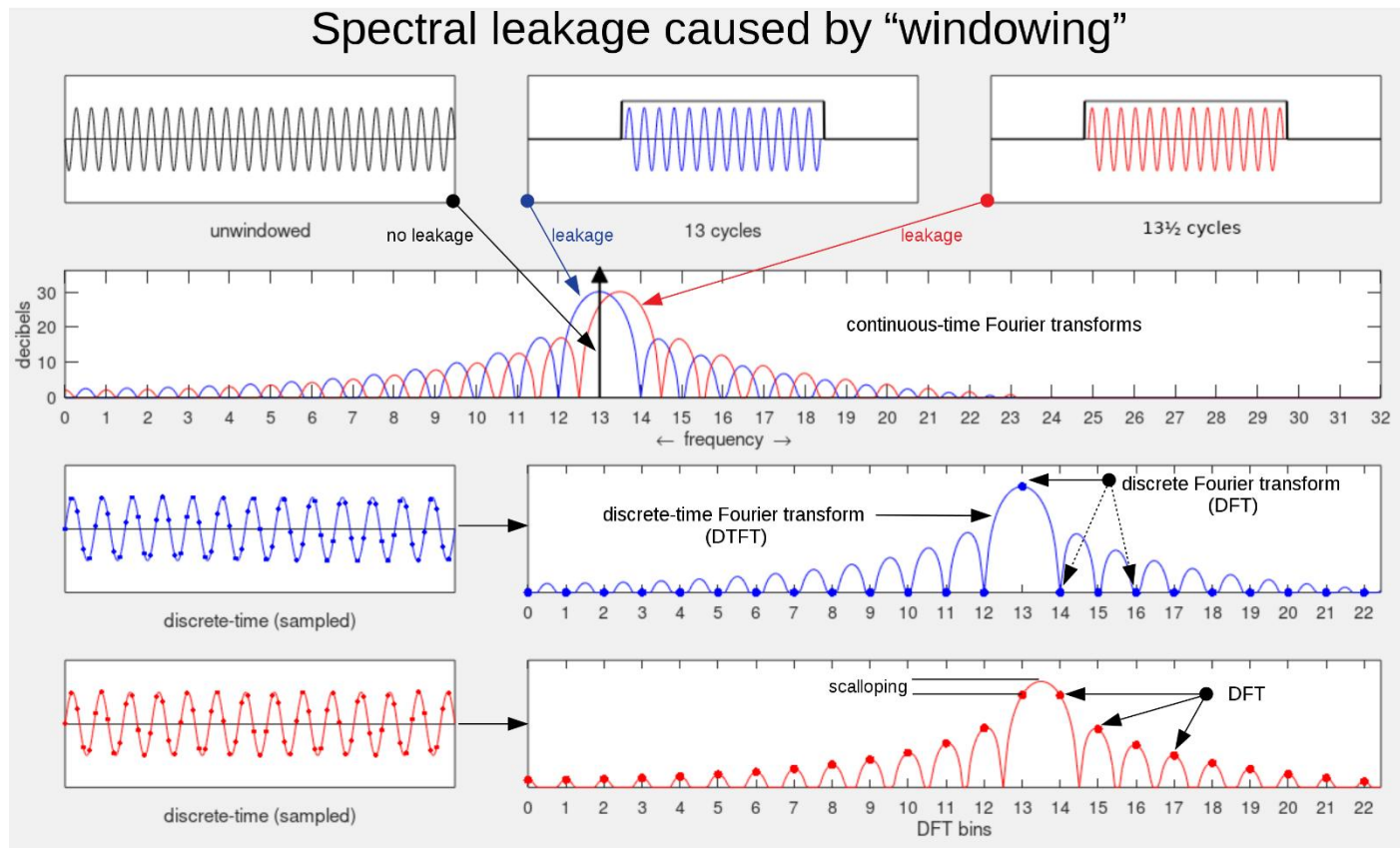
3. (15pt) 시간 영역 신호 x_n 가 이상적인 ADC에 의해 다음과 같이 획득되었다. 아래 DFT 수식을 참고하여, 주파수 영역 신호 $X_k[300]$, $X_k[700]$ 가 나타내는 주파수는 얼마인가?

- Sampling rate (F_s): 3000 Samples/s
- Number of Samples (N): 1000

$$\begin{aligned} X_k &= \sum_{n=0}^{N-1} x_n \cdot e^{-\frac{i2\pi}{N}kn} \\ &= \sum_{n=0}^{N-1} x_n \cdot \left[\cos\left(\frac{2\pi}{N}kn\right) - i \cdot \sin\left(\frac{2\pi}{N}kn\right) \right] \end{aligned}$$

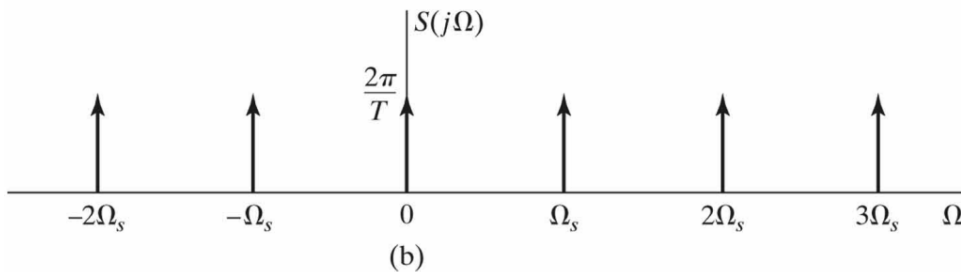
Digital Signals & Sampling

- The Sampling and Windowing
 - Sampling is a multiplication of two functions: **Impulse train & Window**

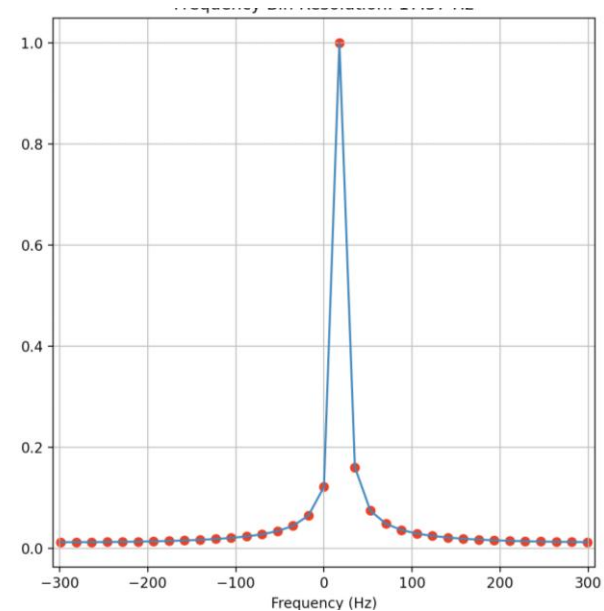


Digital Signals & Sampling

- The Sampling and Windowing
 - **Why** does the sampled signal not look like an impulse function?



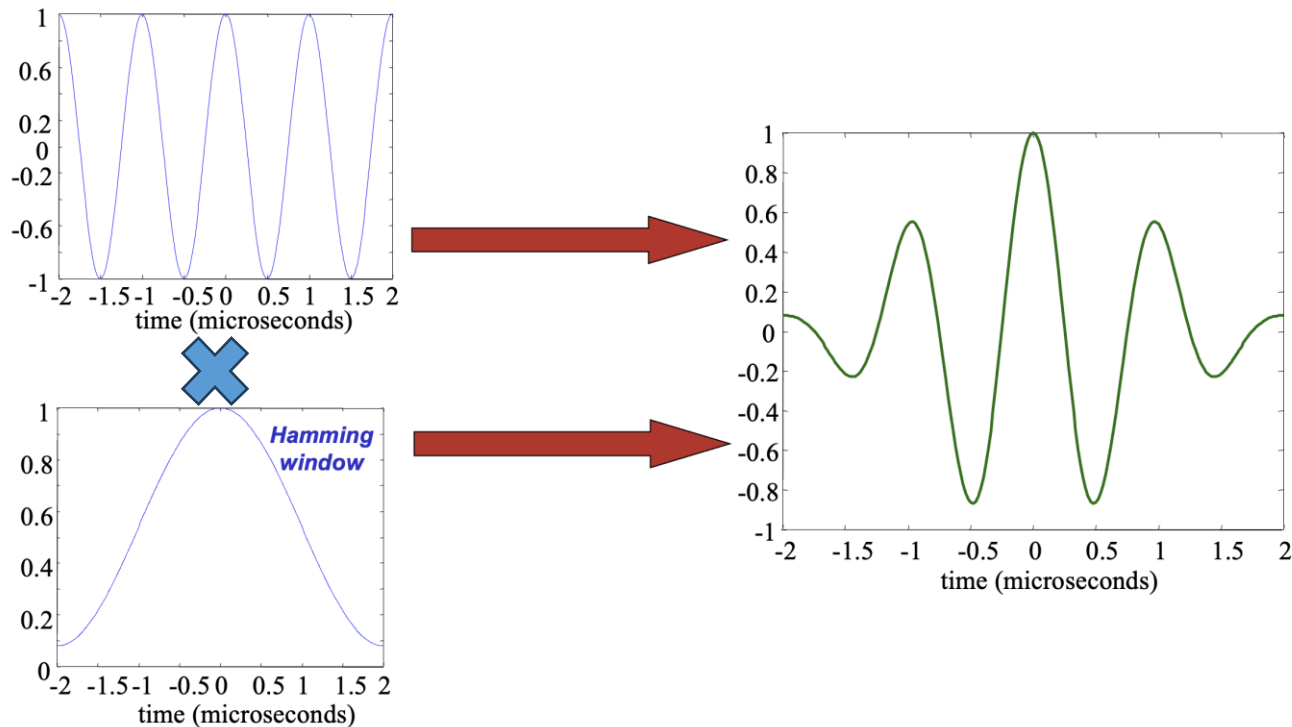
In a textbook



Our screen

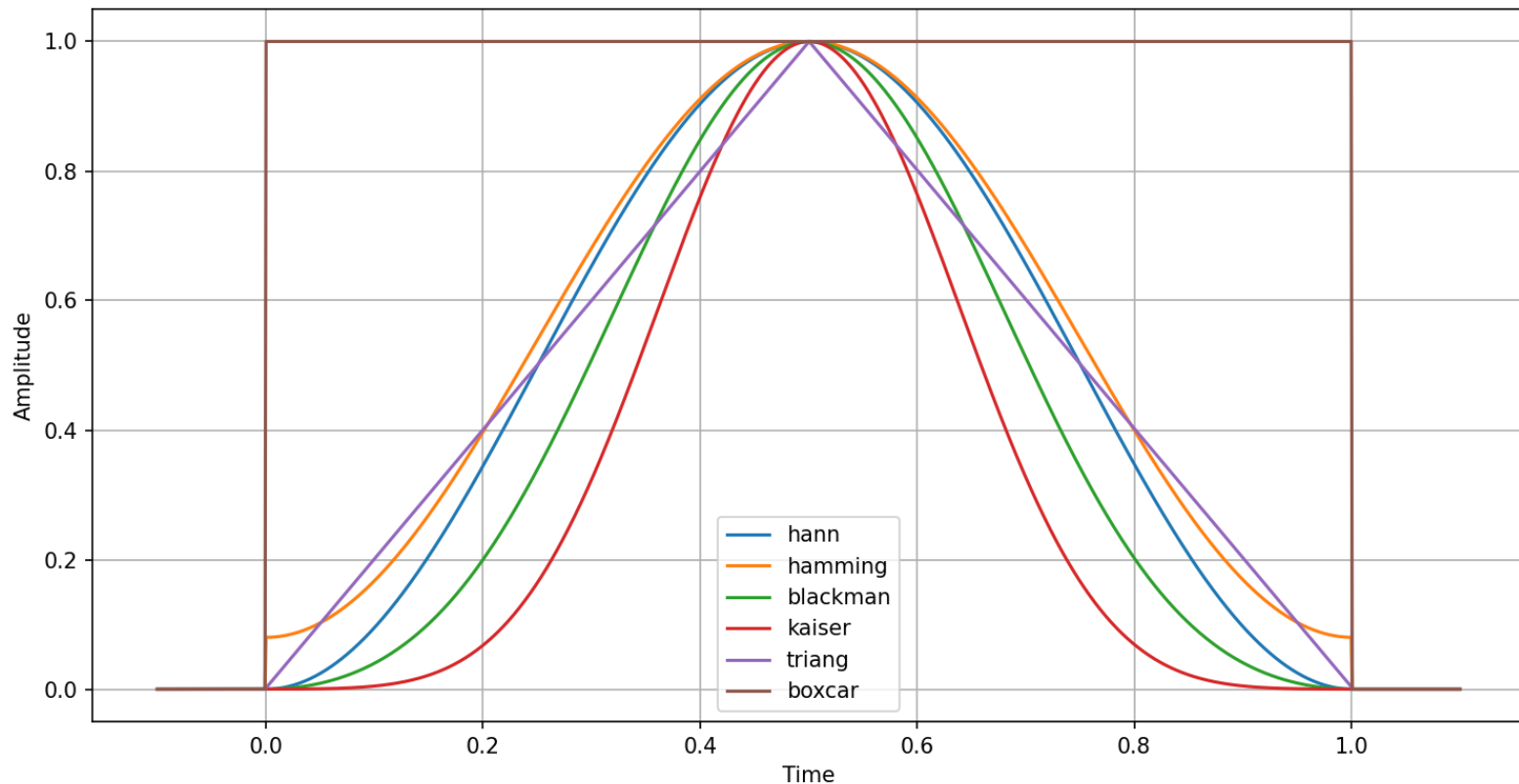
Digital Signals & Sampling

- The Sampling and Windowing
 - The spectral leakage cannot be avoided.
 - Multiply with window function (apodization)



Digital Signals & Sampling

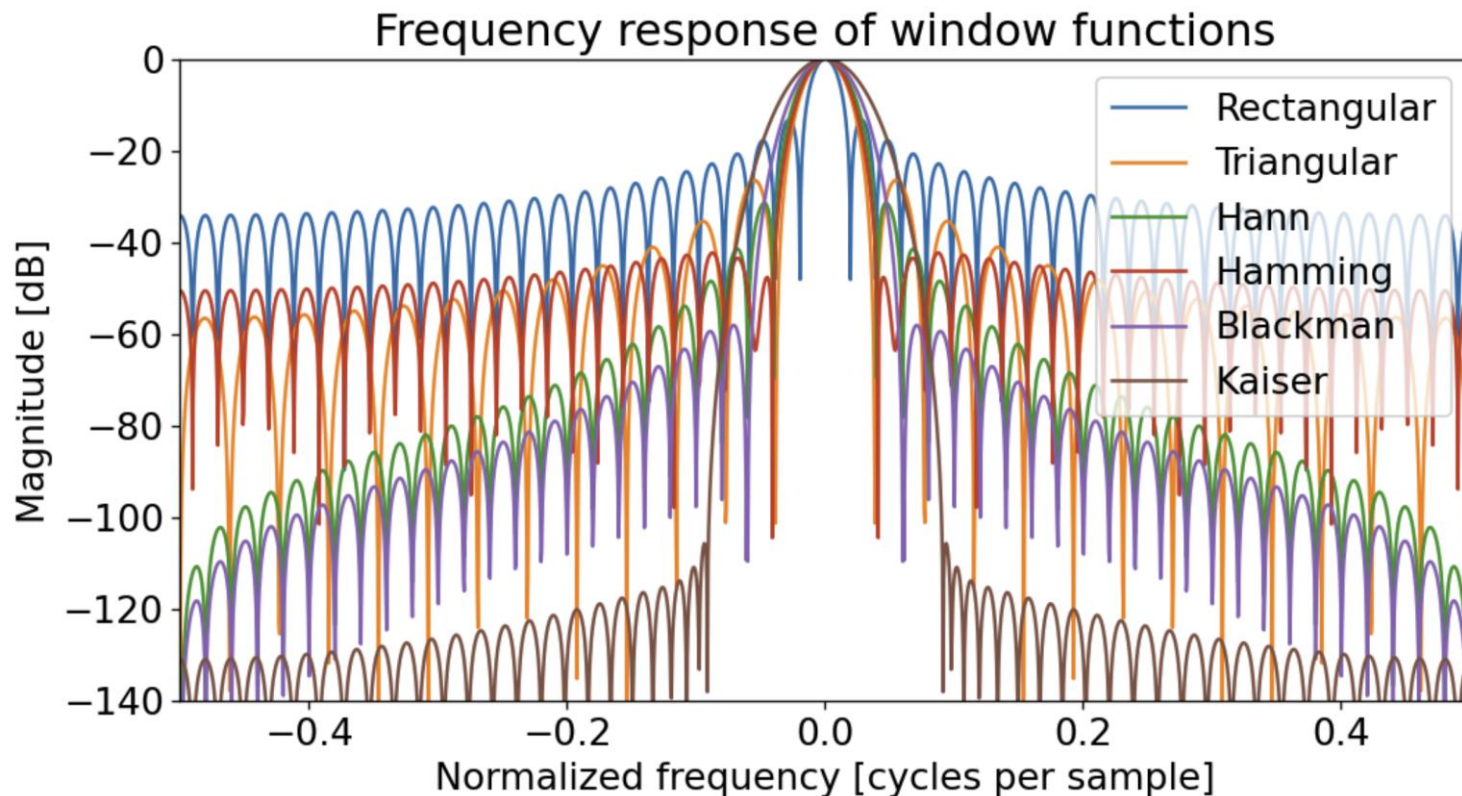
- The Sampling and Windowing
 - Window functions in time domain



Digital Signals & Sampling

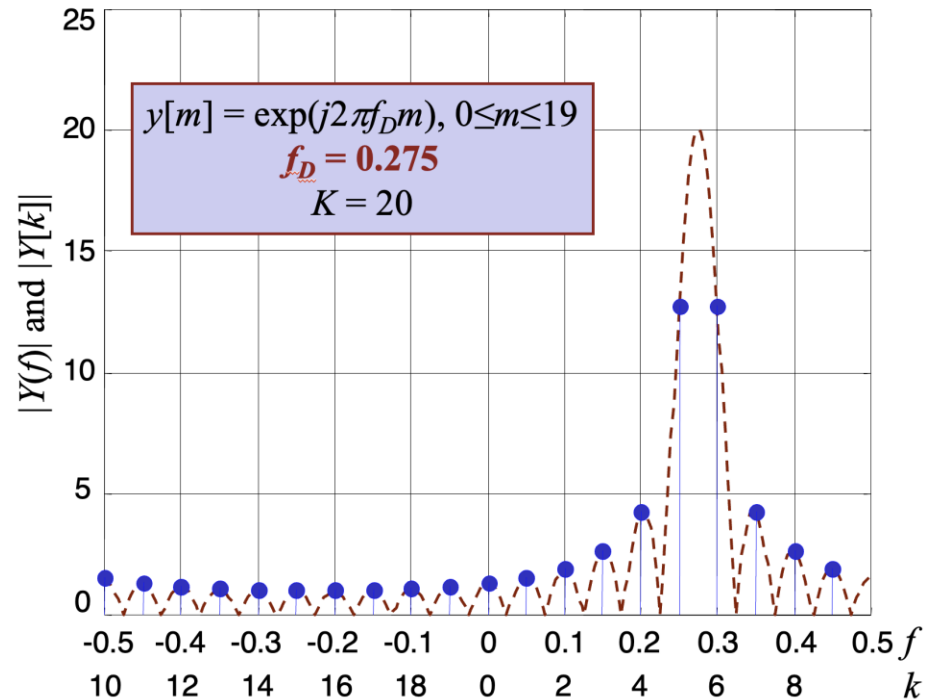
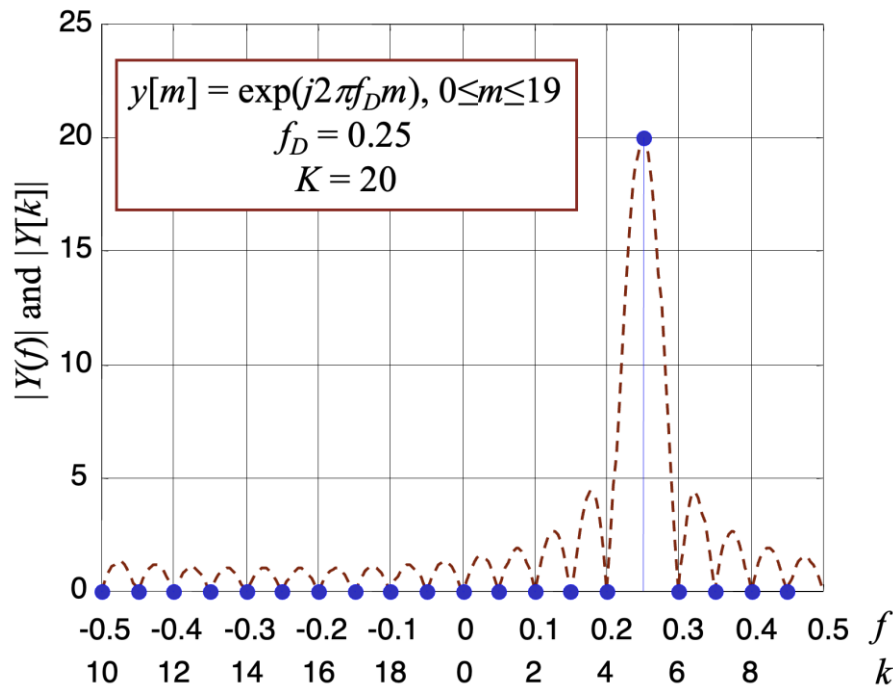
- The Sampling and Windowing

- The trade-offs of window function (Mainlobe width vs. sidelobe)
- Small signal cannot be discovered due to high sidelobes.



Digital Signals & Sampling

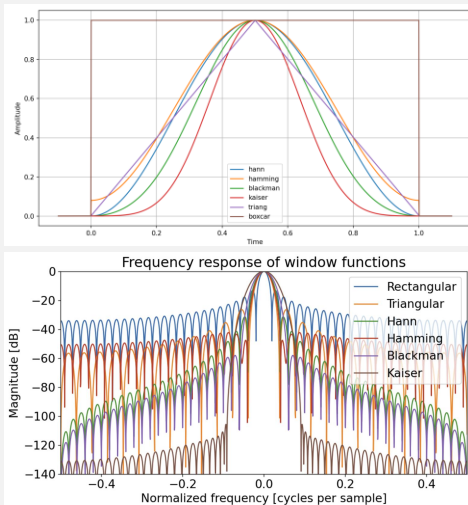
- The windowing and spectral leakage
 - Understanding the straddling loss
 - DFT : "Sampled version of DTFT"



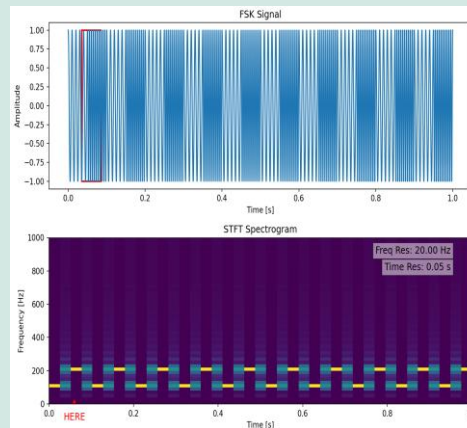
Digital Signals & Sampling

- Overview of this chapter

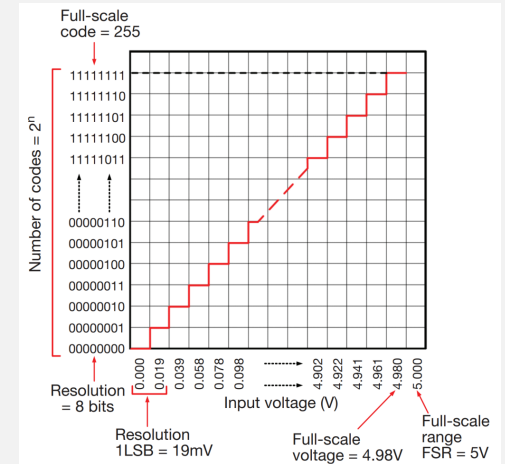
Sampling & Window Function



Time-Frequency Analysis

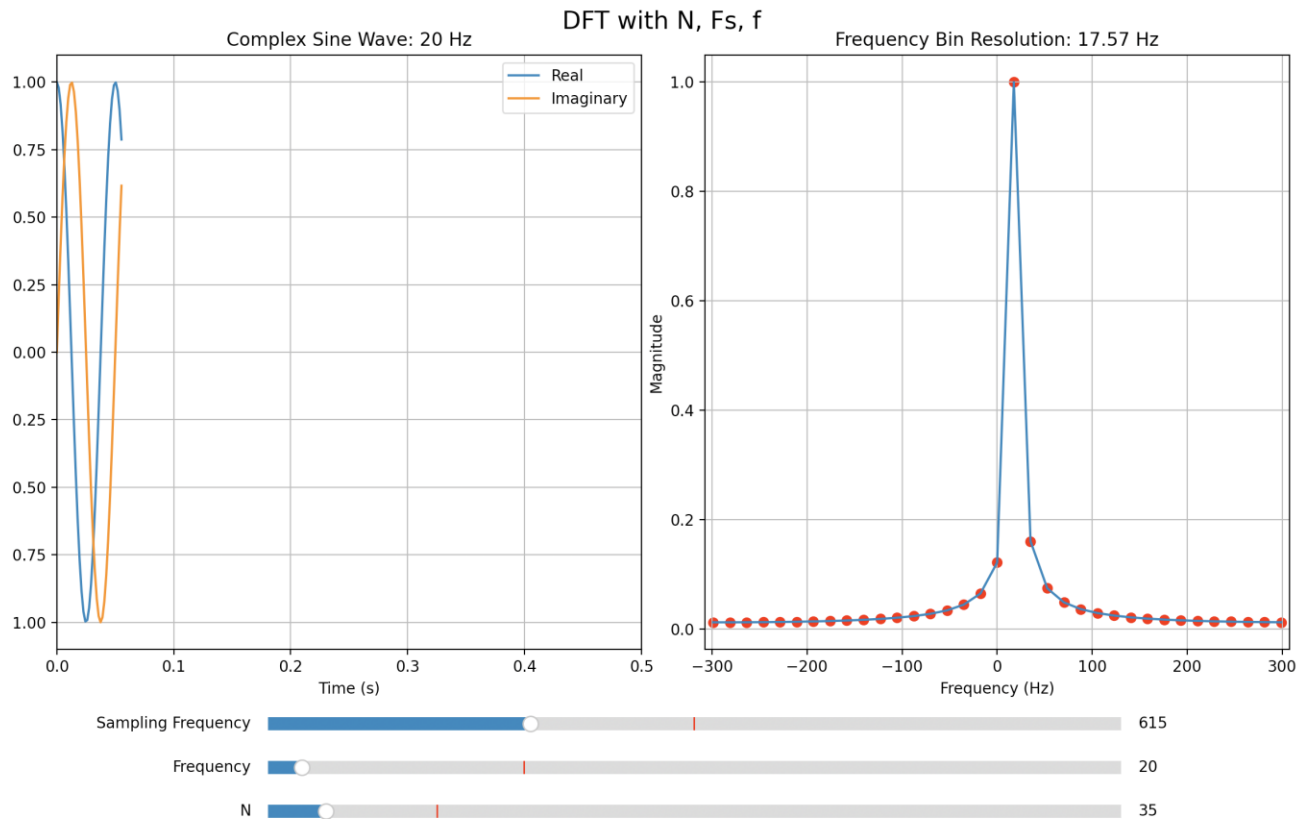


Analog-Digital Converter



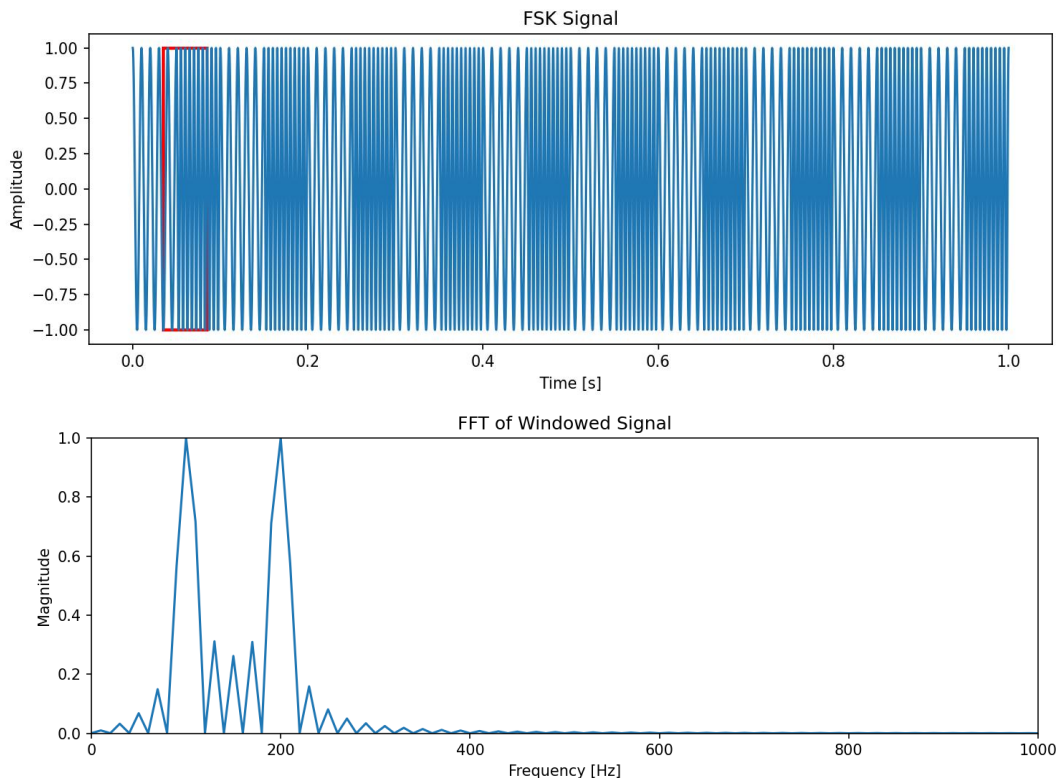
Digital Signals & Sampling

- The continuous, unchanged signal
 - We can observe the signal for a long time.



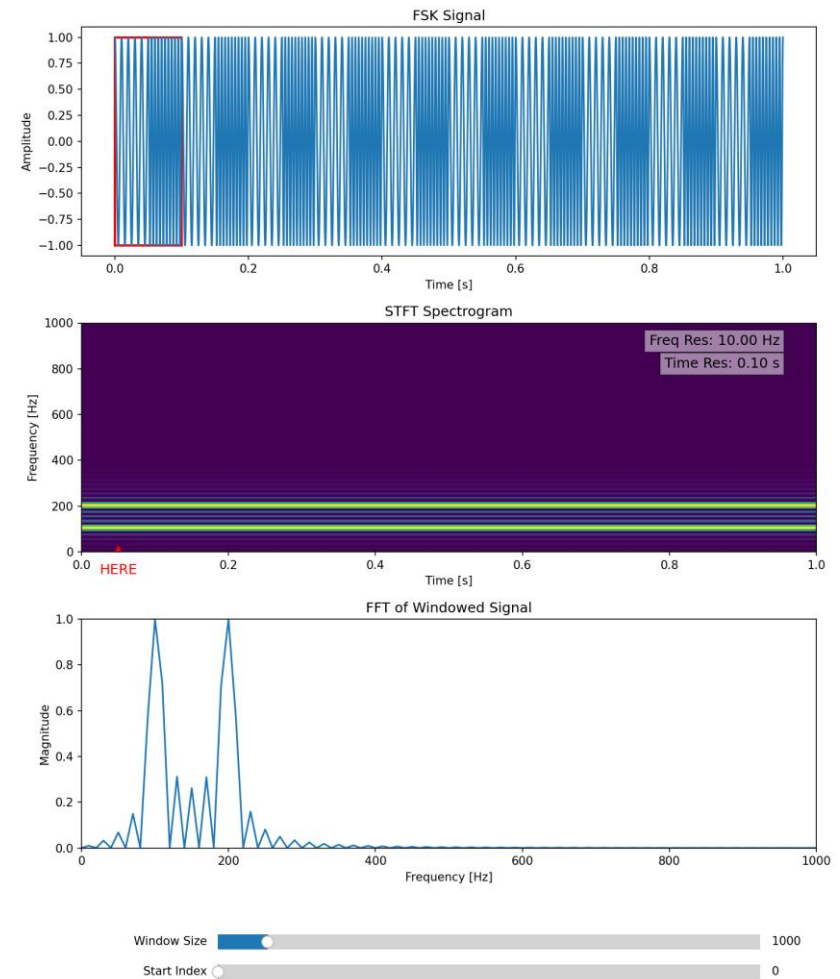
Digital Signals & Sampling

- Time-Frequency Analysis
 - Time-varying Signals
 - Example) Frequency-Shift Keying Signal



Digital Signals & Sampling

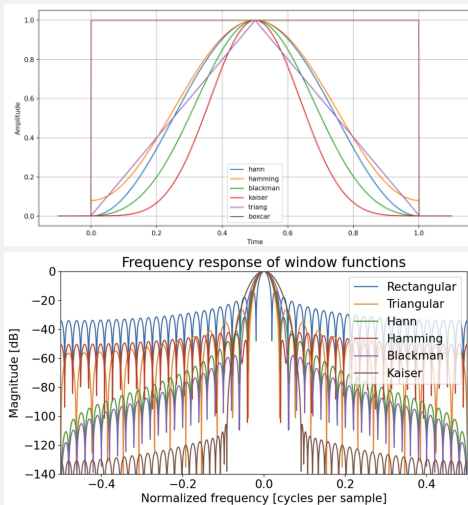
- Time-Frequency Analysis
 - Time-domain Signal
 - Short-Time Fourier Transform
 - Fast Fourier Transform
- See the Demo



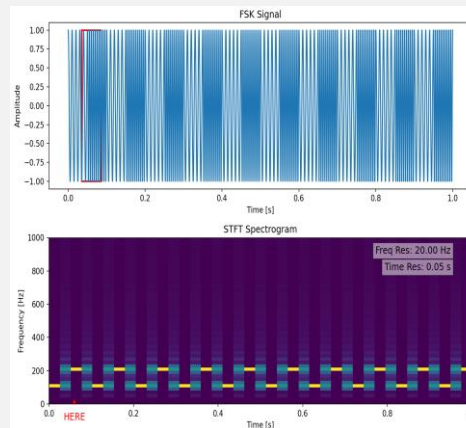
Digital Signals & Sampling

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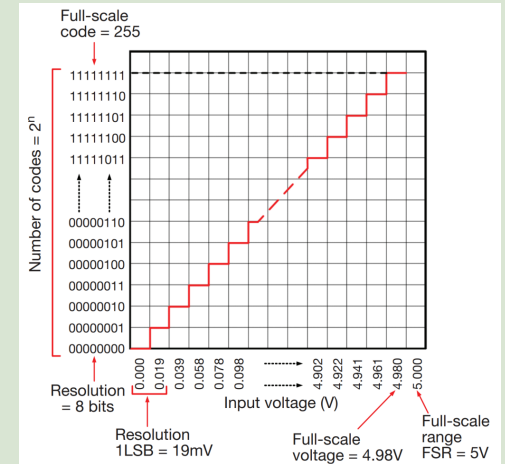
Sampling & Window Function



Time-Frequency Analysis

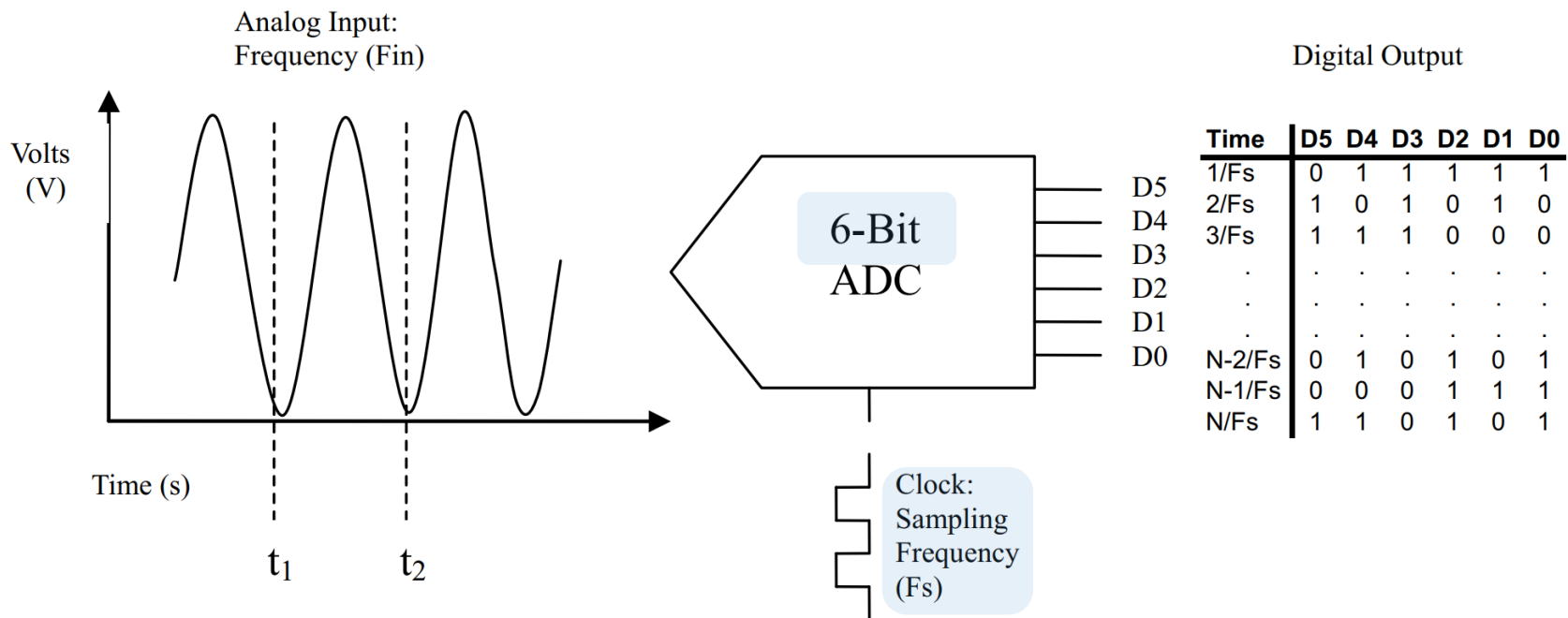


Analog-Digital Converter



Digital Signals & Sampling

- Sampling of a Continuous Signal
 - Analog-Digital Converter



<https://www.ti.com/lit/an/slaa510/slaa510.pdf>

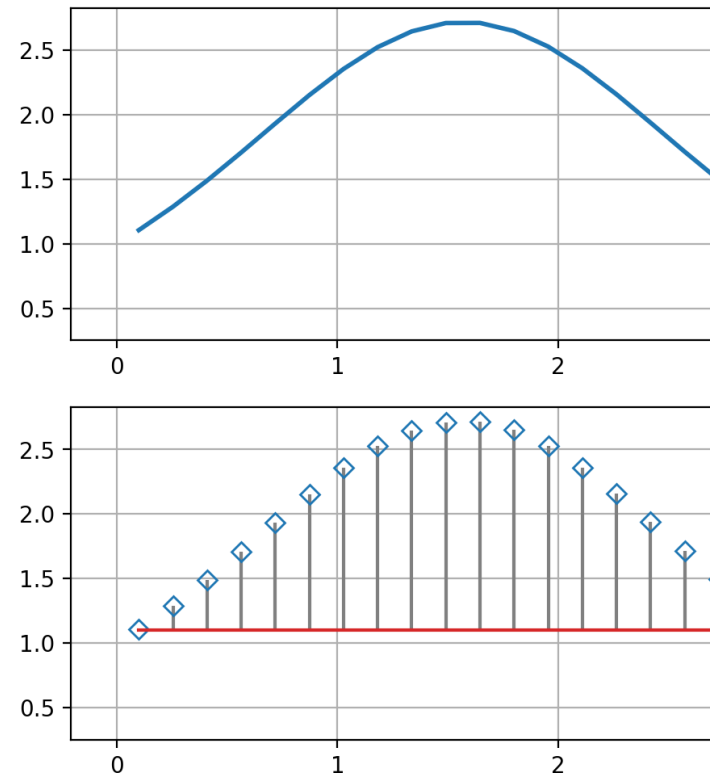
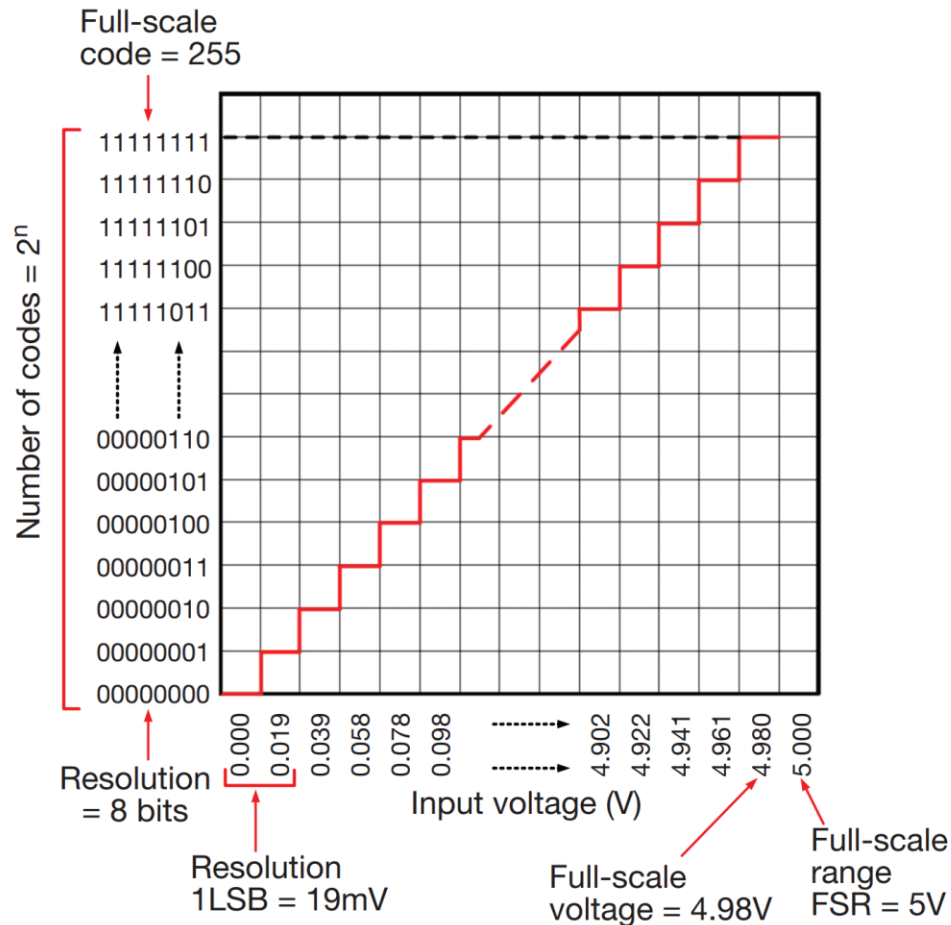
Digital Signals & Sampling

- Analog-to-Digital Converter

Item	Description
Resolution (n)	The number of bits used to quantize
Number of codes (2^n)	The number of output code combinations
Full-scale Range Input (FSR)	Sets the converter input range and LSB voltage
Least significant bit ($LSB = FSR / 2^n$)	The voltage step size
Full-scale input voltage $(2^n - 1) \cdot LSB$	Maximum input voltage of ADC
Full-scale output code ($2^n - 1$)	Largest code that can be read
Transfer Function	Relationship between input(V) and output code

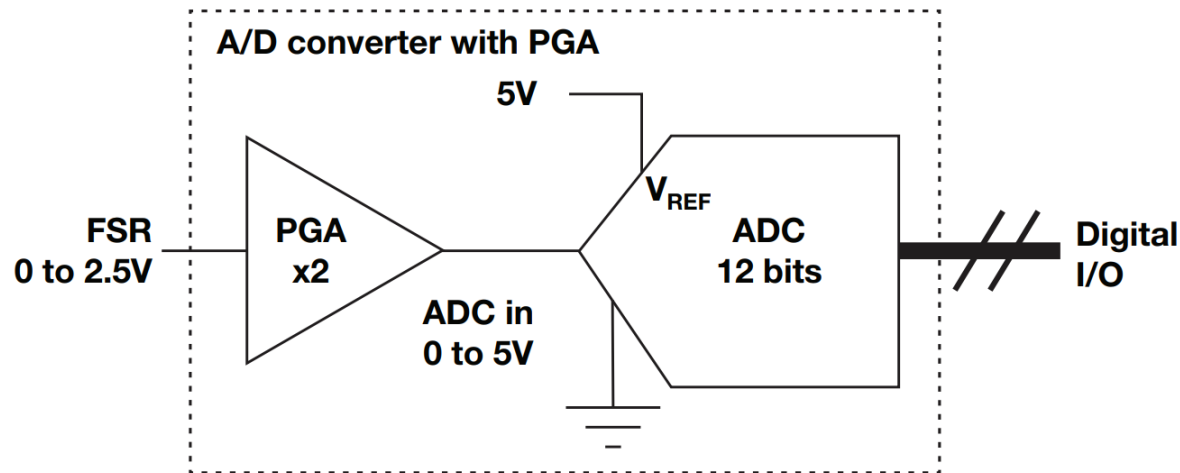
Digital Signals & Sampling

- Transfer Function of ADC



Digital Signals & Sampling

- An Example



$$\text{FSR} = \frac{V_{\text{REF}}}{\text{PGA}} = \frac{5\text{V}}{2} = 2.5\text{V}$$

$$1\text{LSB} = \frac{\text{FSR}}{2^n} = \frac{2.5\text{V}}{2^{12}} = 610.35\mu\text{V}$$

Where

FSR = full-scale range

PGA = PGA gain

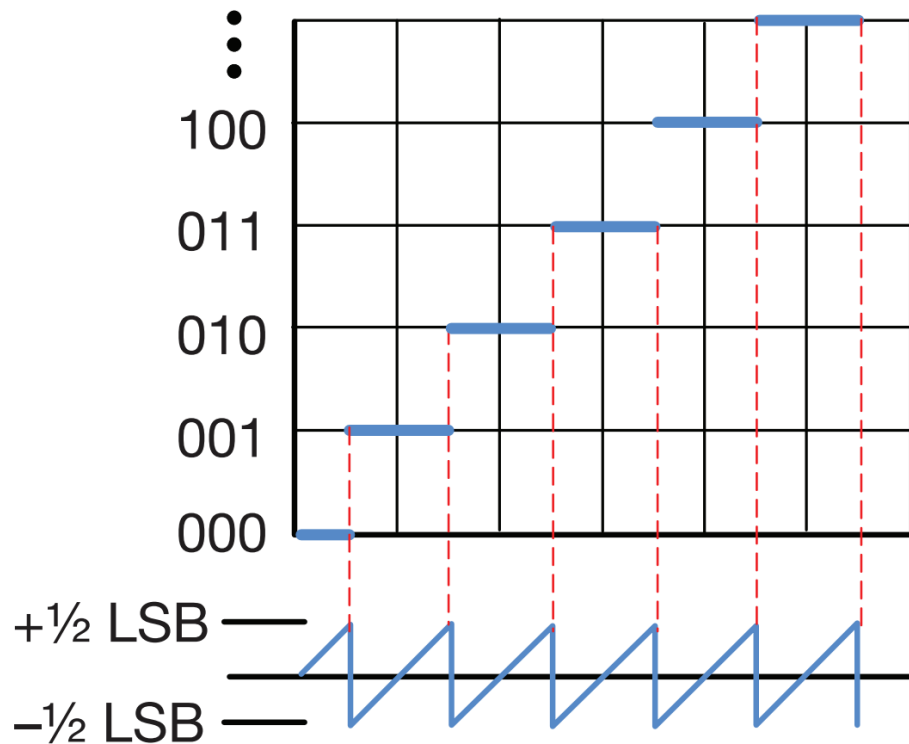
1LSB = one least significant bit or resolution of the data converter

n = resolution number of bits

V_{REF} = reference voltage

Digital Signals & Sampling

- Error & Noise in ADC Systems
 - **Quantization** Error = $1/2$ LSB
 - RMS of Quantization Error = $1\text{LSB} / \sqrt{12}$



Digital Signals & Sampling

- Error & Noise in ADC Systems
 - SNR Derivation from ADC Systems

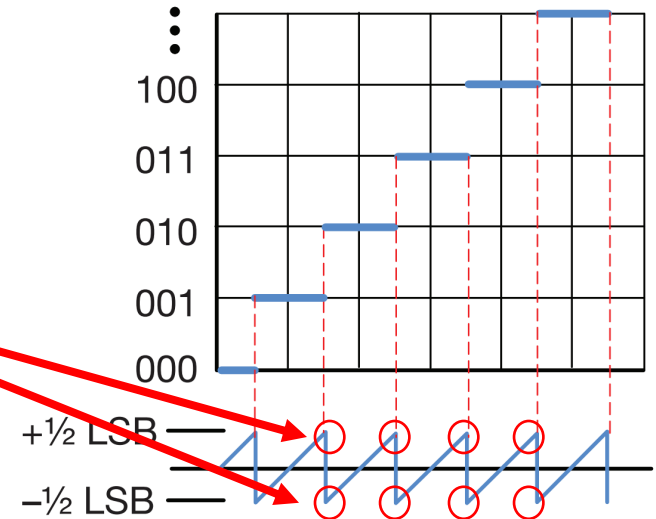
$$\text{MaxRMSSignal} = \frac{\text{FSR} / 2}{\sqrt{2}} = \frac{1 \text{ LSB} \times 2^{N-1}}{\sqrt{2}}$$

$$\text{RMSNoise} = \frac{1 \text{ LSB}}{\sqrt{12}} \text{ from quantization only}$$

$$\text{SNR} = \frac{\text{MaxRMSSignal}}{\text{RMSNoise}} = \frac{1 \text{ LSB} \times 2^{N-1} / \sqrt{2}}{1 \text{ LSB} / \sqrt{12}} = 2^{N-1} \sqrt{6}$$

$$\text{SNR(dB)} = 20 \log(\text{SNR}) = [20 \log(2)]N + 20 \log\left(\frac{\sqrt{6}}{2}\right)$$

$$\text{SNR(dB)} \approx 6.02N + 1.76$$



Digital Signals & Sampling

- Error & Noise in ADC Systems
 - $\text{SNR} = 6.02N + 1.76 \text{ (dB)}$

Example

What is the SNR for an 8-bit ADC converter with 5V reference, assuming only quantization noise?

Answer

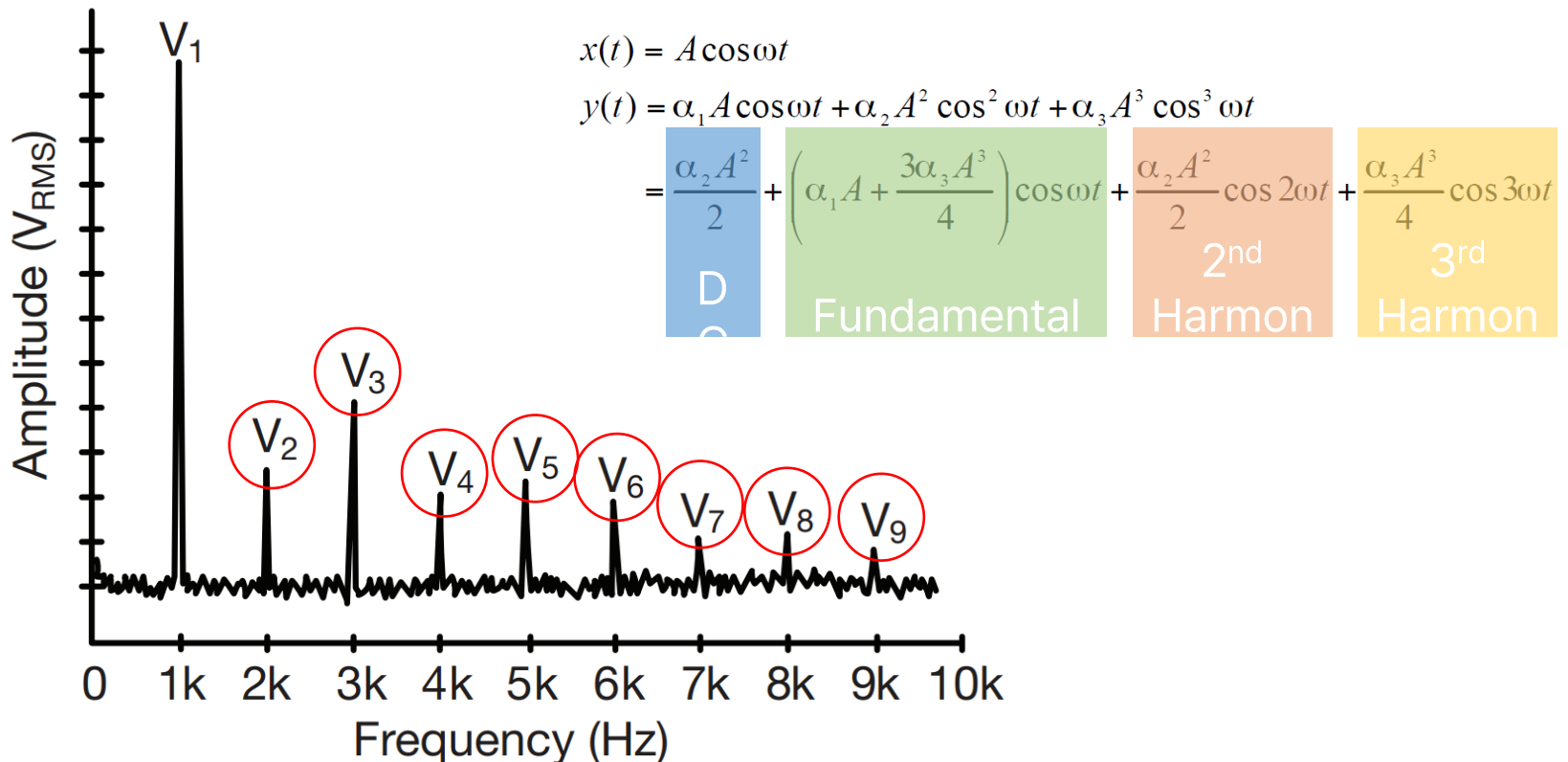
$$\text{SNR} = 2^{N-1}\sqrt{6} = 2^{8-1}\sqrt{6} = 314$$

$$\text{SNR(dB)} = 20\log(314) = 49.9 \text{ dB}$$

$$\text{SNR(dB)} = 6.02(8) + 1.76 = 49.9 \text{ dB}$$

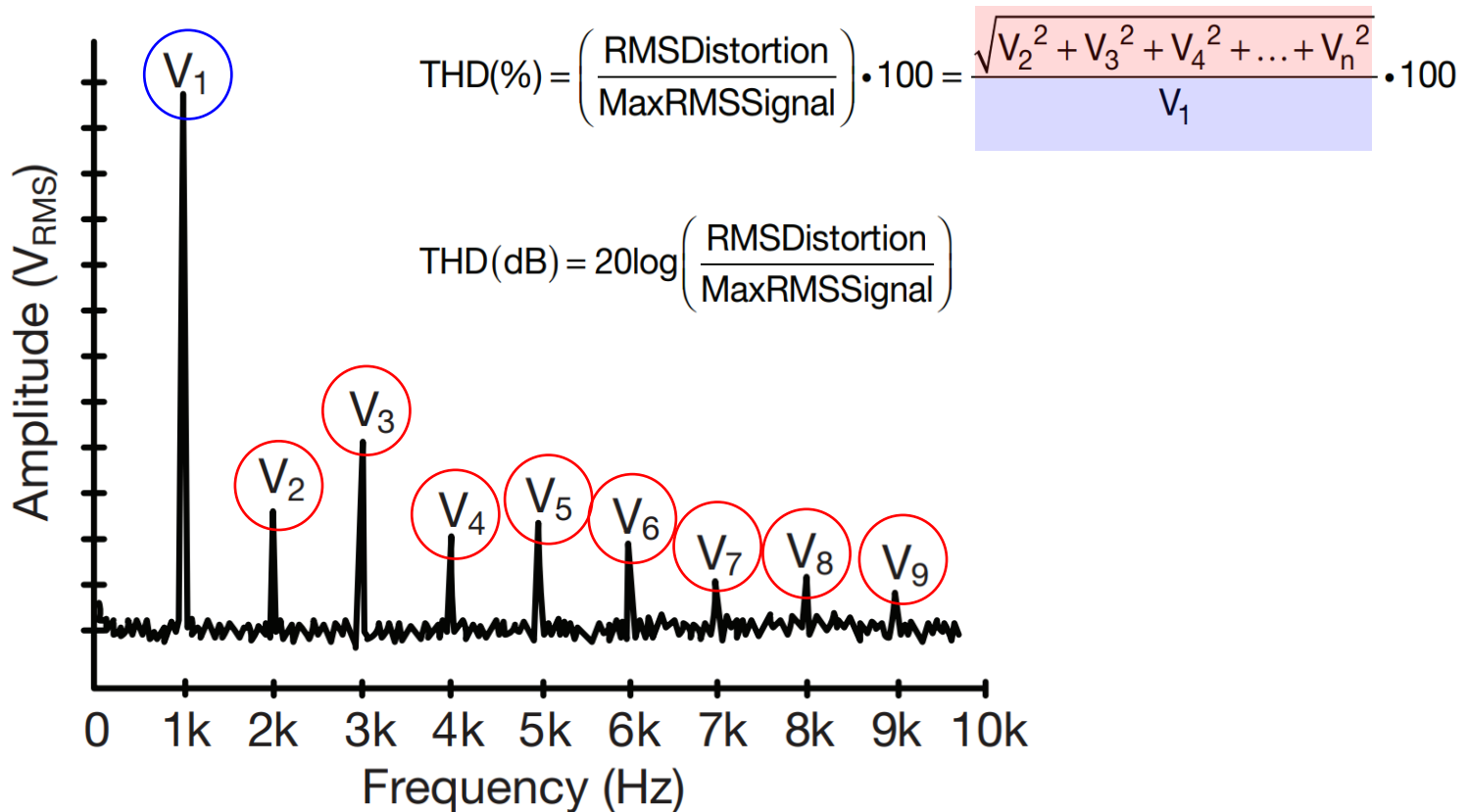
Digital Signals & Sampling

- Performance Metrics of ADC Systems
 - Total Harmonic Distortion
 - Harmonics from any **non-linear characteristic** of ADC



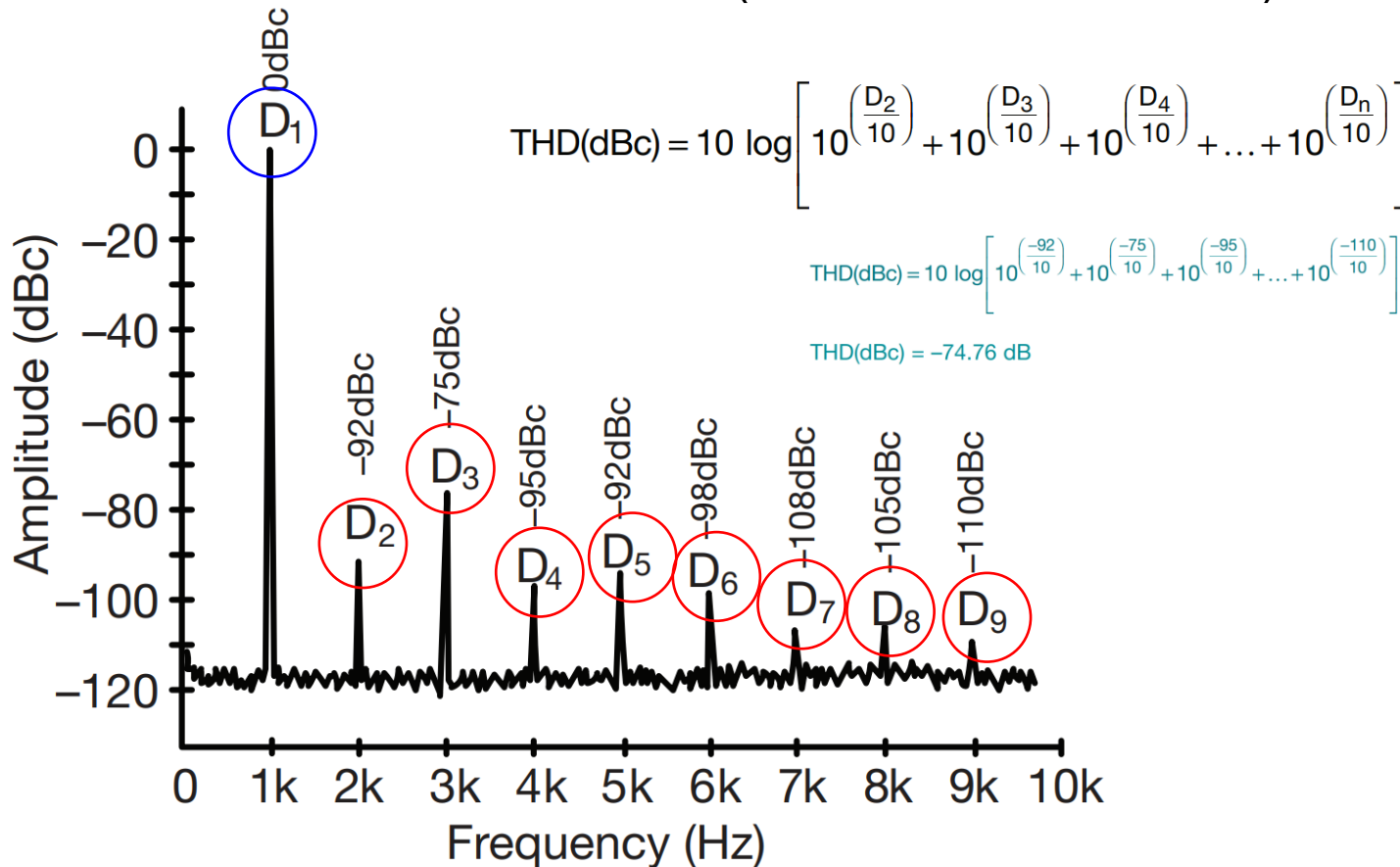
Digital Signals & Sampling

- Performance Metrics of ADC Systems
 - Total Harmonic Distortion



Digital Signals & Sampling

- Performance Metrics of ADC Systems
 - Total Harmonic Distortion (dBc : reference is carrier)



Digital Signals & Sampling

- Performance Metrics of ADC Systems
 - Signal-to-Noise and Distortion (SINAD)
 - **Effective** Number of Bits (ENOB) – Consider distortion vs. Designed

$$\text{SINAD(dB)} = 20 \log \left(\frac{\text{MaxRMSSignal}}{\sqrt{\text{RMSNoise}^2 + \text{RMSDistortion}^2}} \right)$$

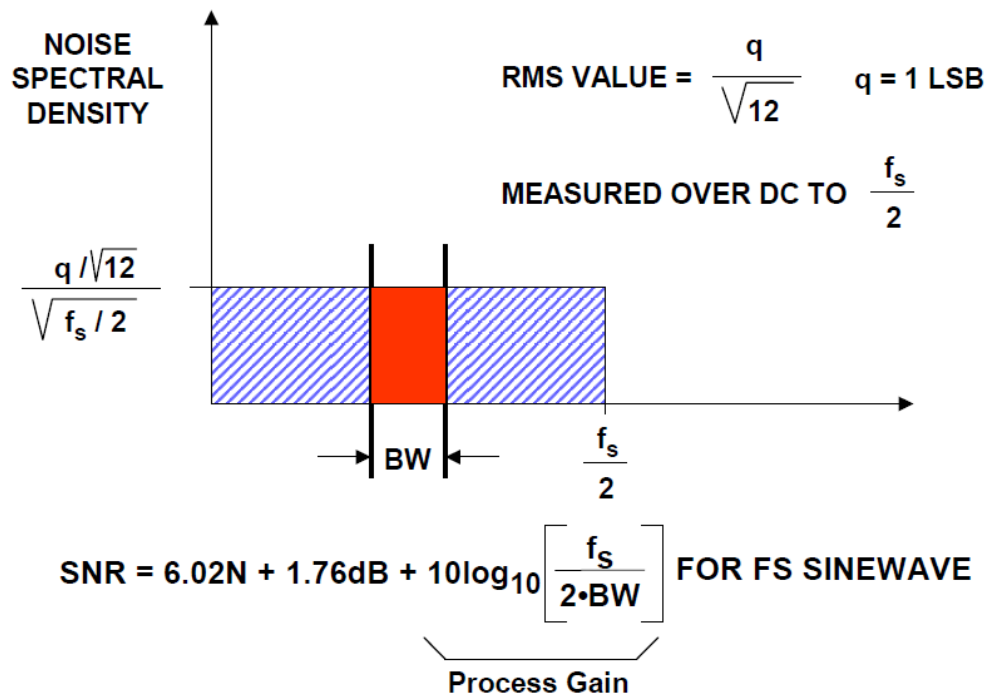
$$\text{SINAD(dB)} = -20 \log \left(\sqrt{10^{\left(\frac{-\text{SNR(dB)}}{10} \right)} + 10^{\left(\frac{\text{THD(dB)}}{10} \right)}} \right)$$

$$\text{ENOB} = \frac{\text{SINAD(dB)} - 1.76\text{dB}}{6.02}$$

Digital Signals & Sampling

• Noise and Sampling

- White Noise power will be uniformly distributed in freq domain.
- Noise power is determined by ADC.
- If our frequency of interest is wider, then..



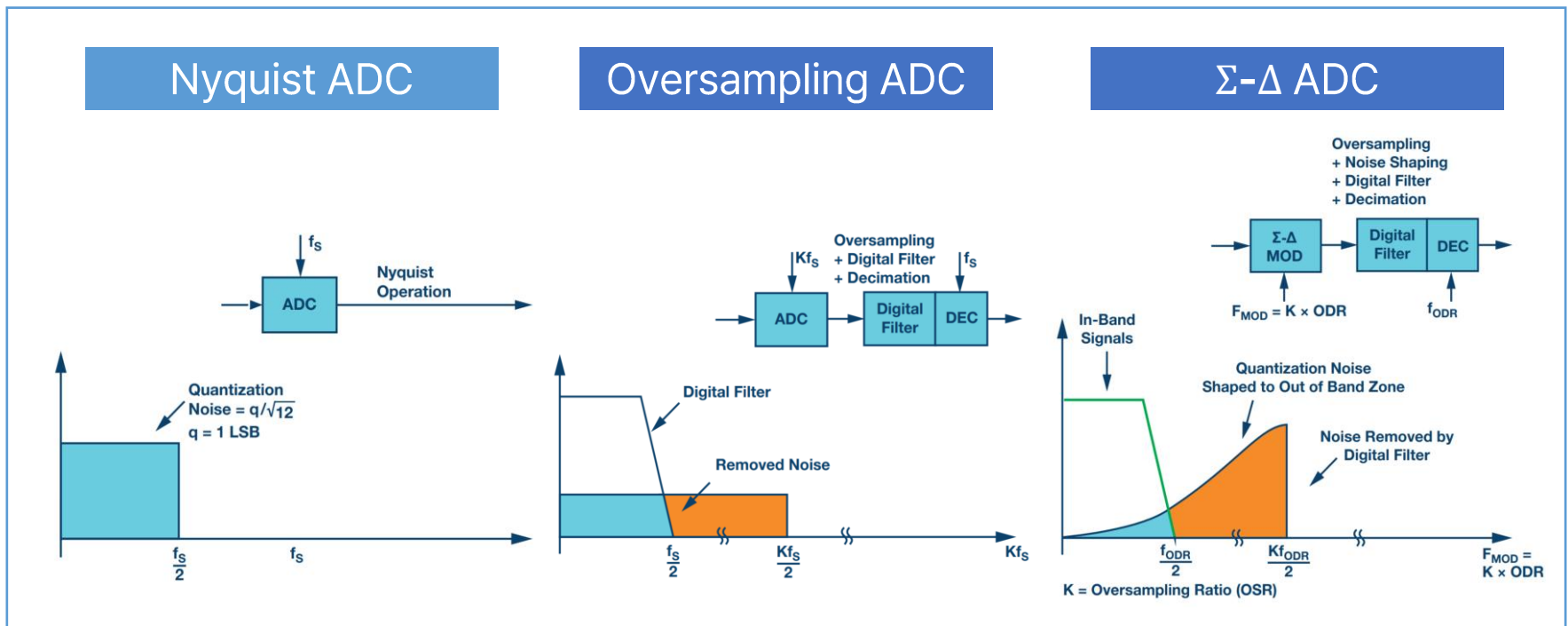
Example

- ADC: 65Msps
- $F_{in} = 12.5\text{MHz BW}$

$$\begin{aligned} \text{Process Gain} &= 10 \log_{10} \frac{f_s}{2 \cdot BW} \\ &= 10 \log_{10} \frac{65 \times 10^6}{2 \times 30 \times 10^3} = 30.3 \text{ dB} \end{aligned}$$

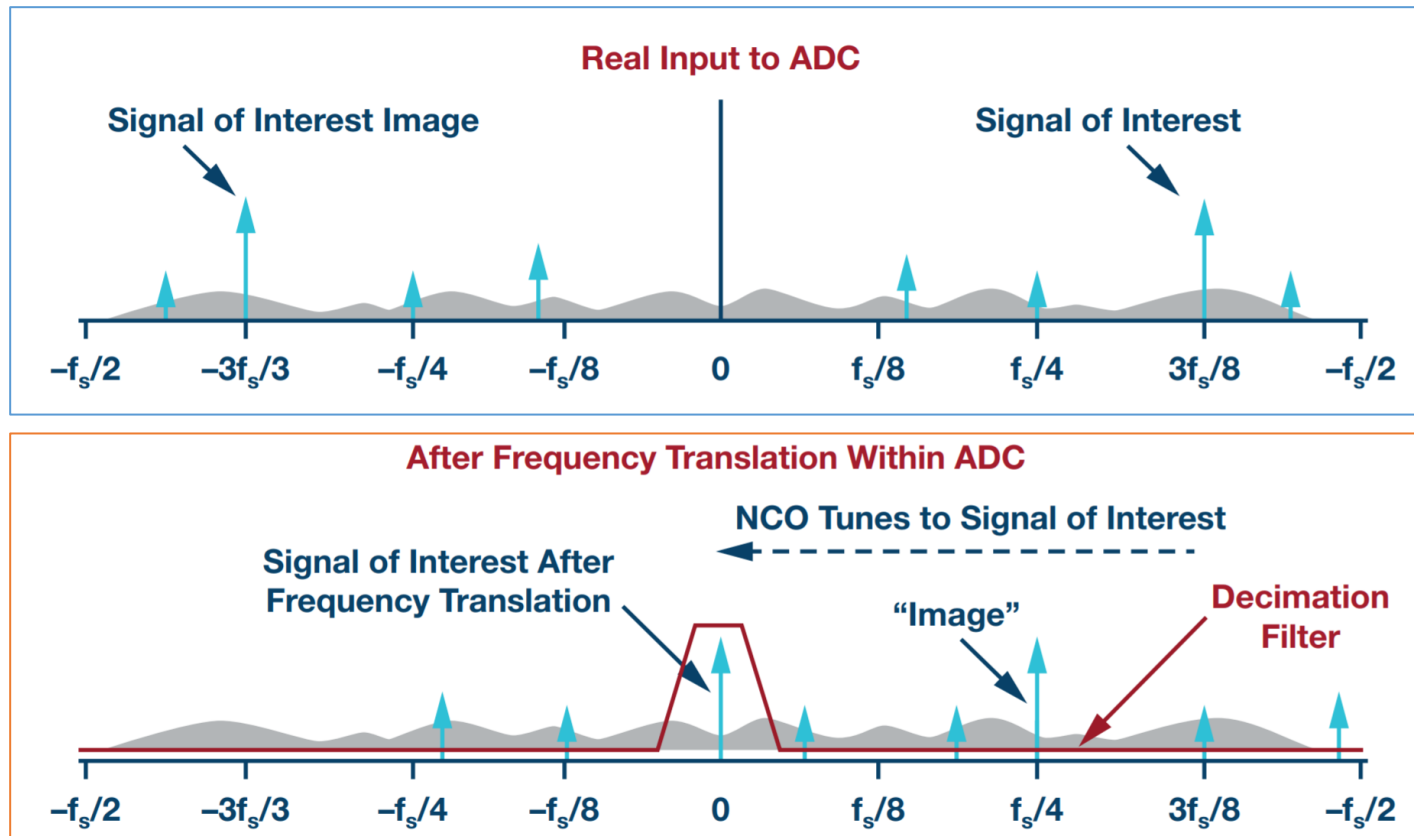
Digital Signals & Sampling

- Sigma-Delta ADC
 - Shapes the noise spectrum for selected band.



Digital Signals & Sampling

- Preview: Digital Down Converting



Thank you

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