HY-330

fall semester 2024

Introduction to telecommunication systems theory

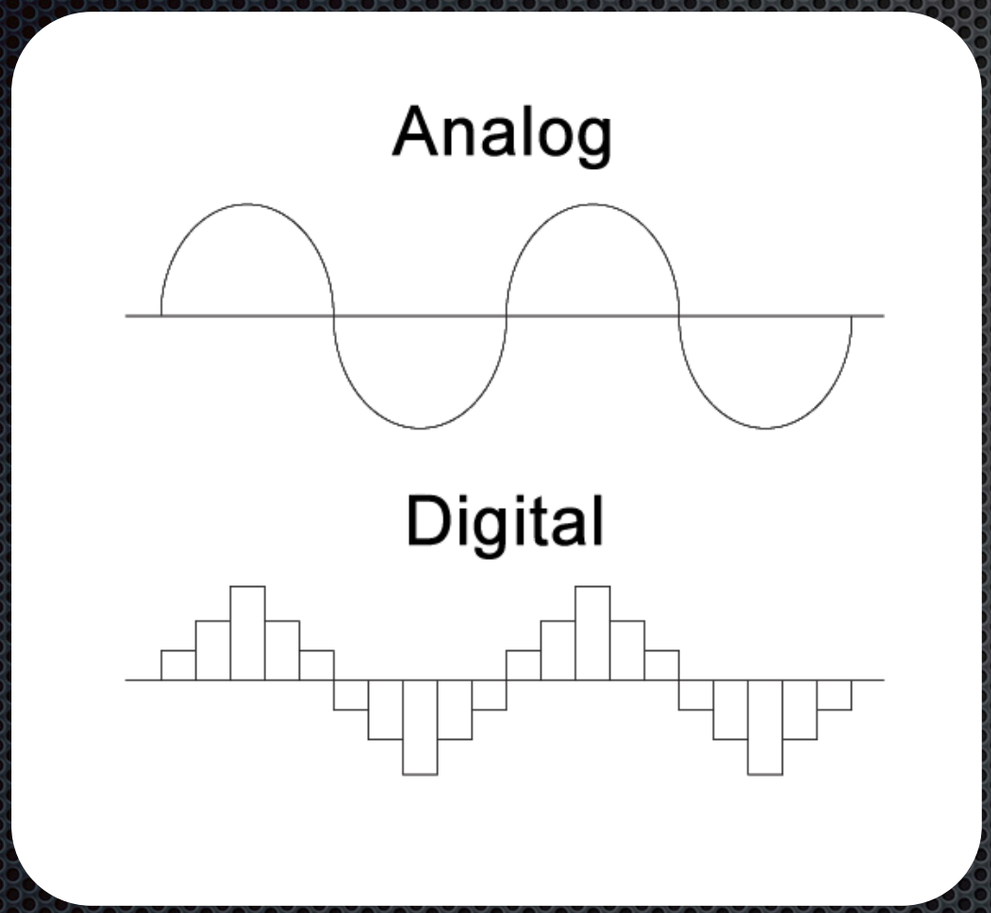
University of Crete
Computer Science Department

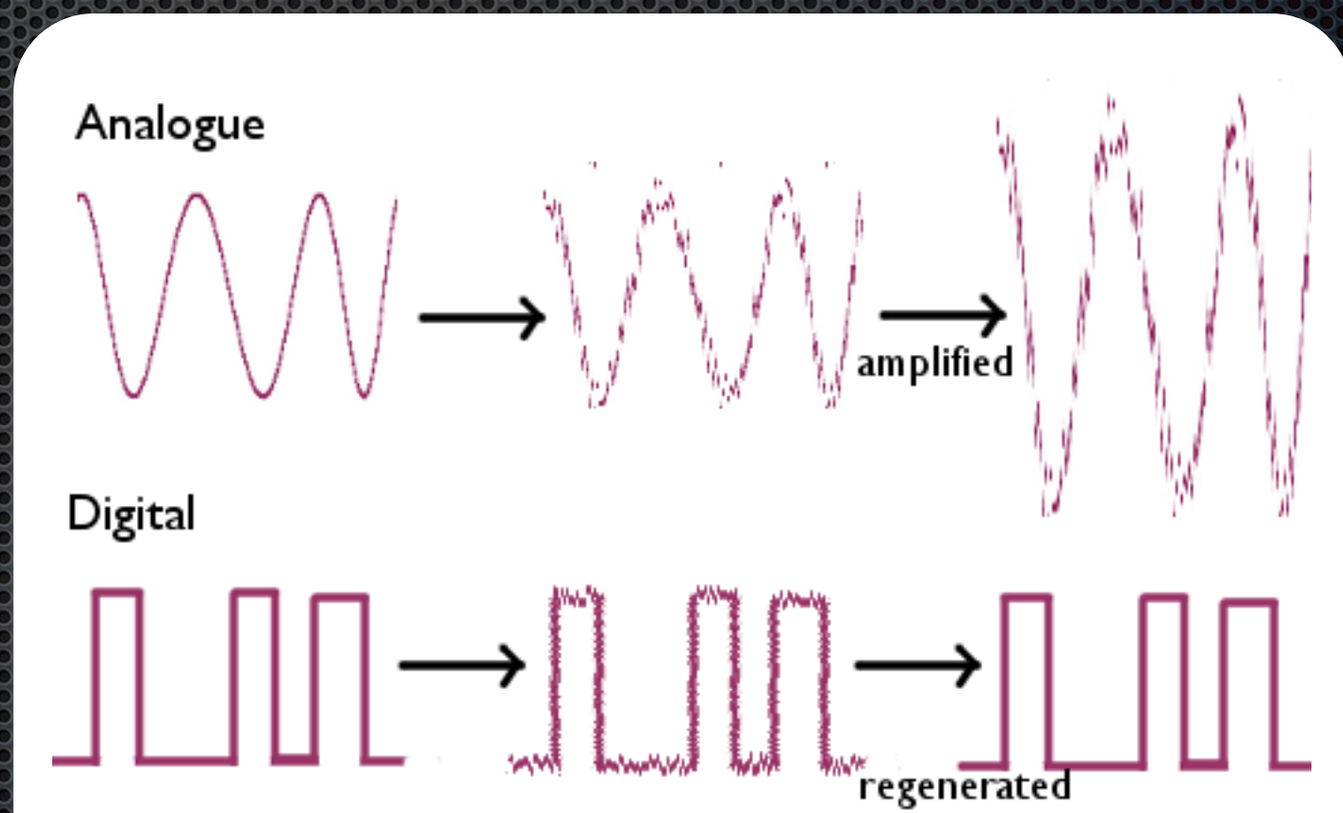
Stefanos Papadakis

Sampling & Quantization

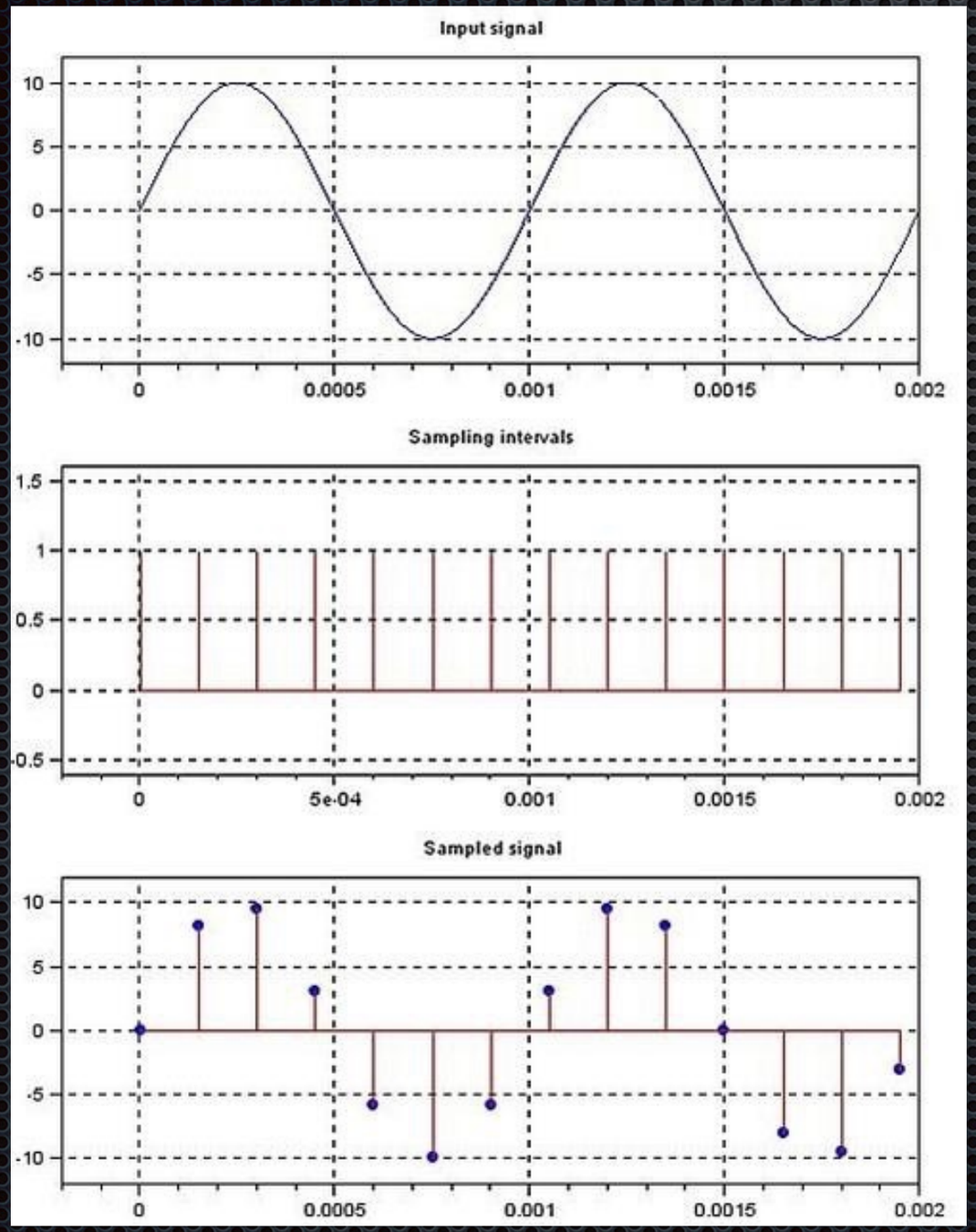
- Why?
- Analog domain - Digital domain
  - continuous-time vs. discrete-time signals
- Limits
- Aliasing…

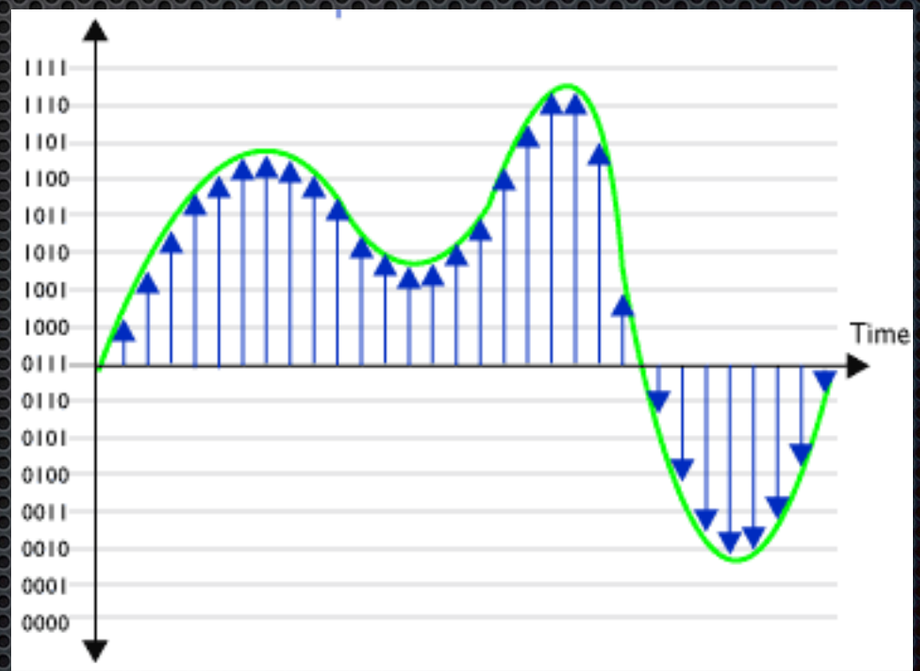
Analog == Perfect?



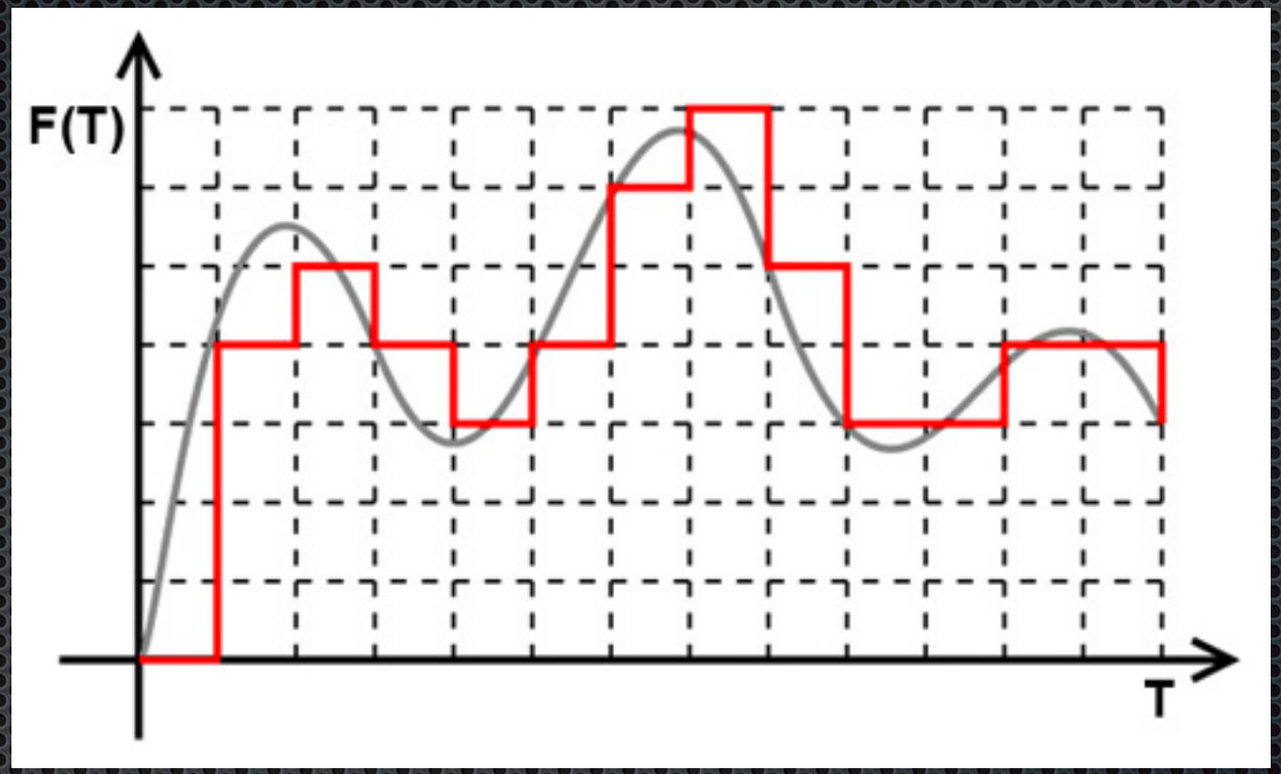


Sampling

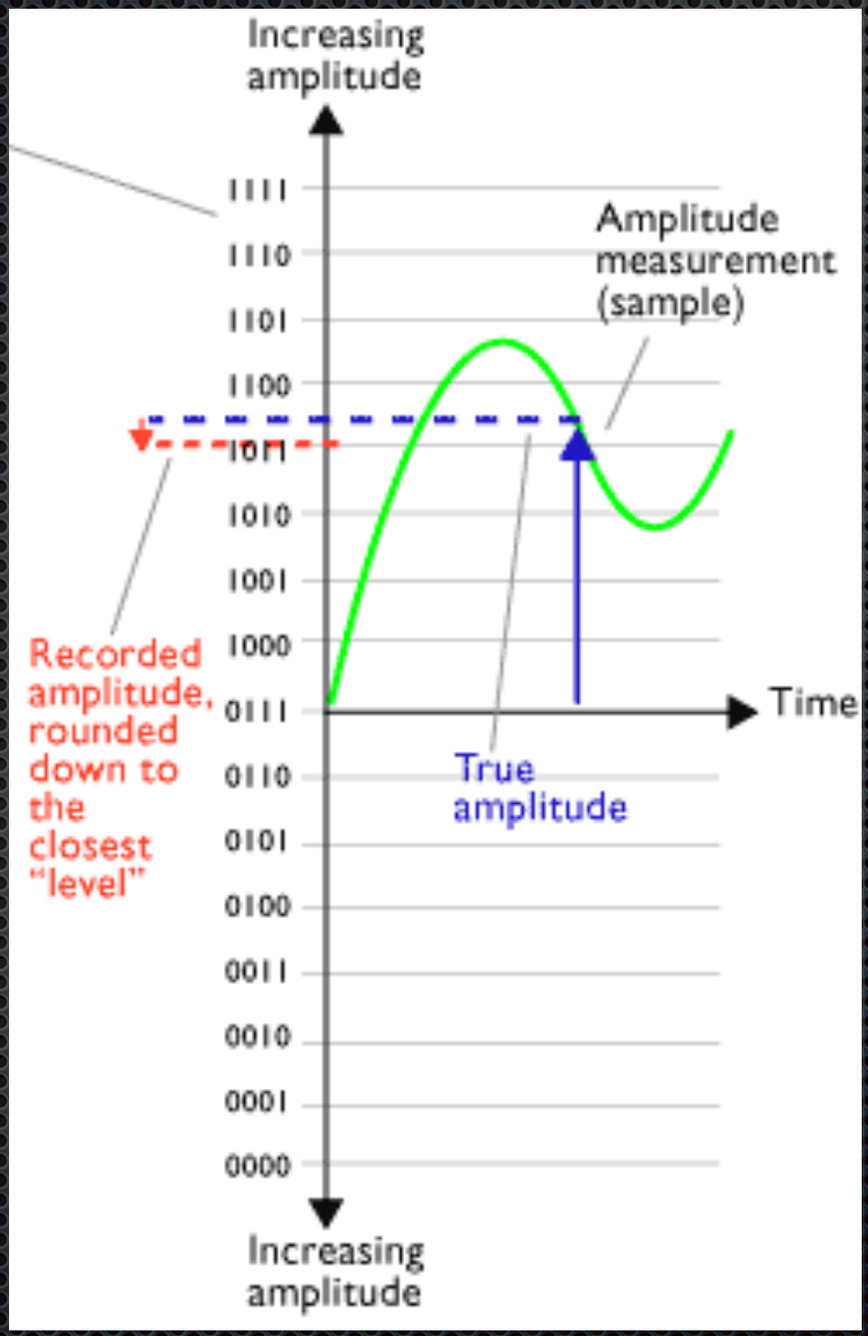

Input signal
10
5
0
-5
-10
0
0.0005
0.001
0.0015
0.002
Sampling intervals
1.5
1
0.5
0
-0.5
0
5e-04
0.001
0.0015
0.002
Sampled signal
10
5
0
-5
-10
0
0.0005
0.001
0.0015
0.002


1111
1110
1101
1100
1011
1010
1001
1000
0111
0110
0101
0100
0011
0010
0001
0000
Time

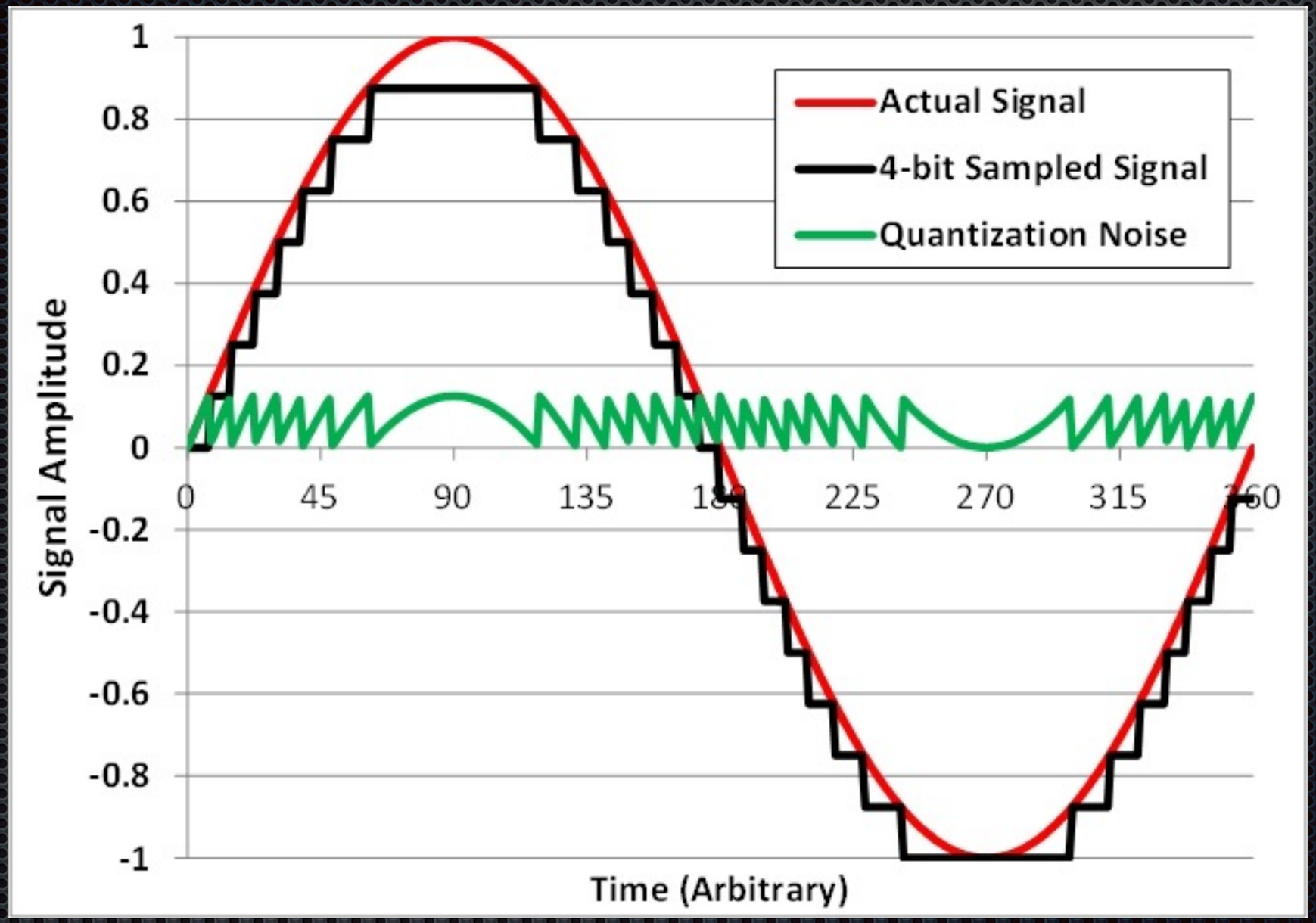
Quantization



Quantization Error



Quantization Noise

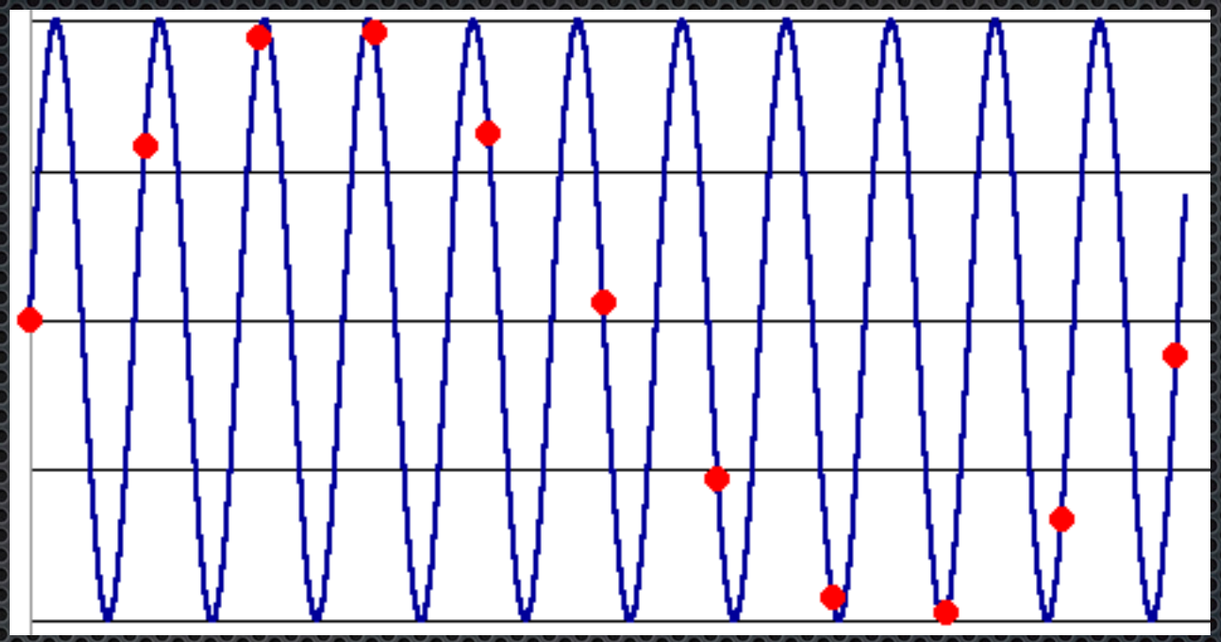


$$SQNR = 20\log_{10}(2^Q) \approx 6.02 \cdot Q\, dB$$

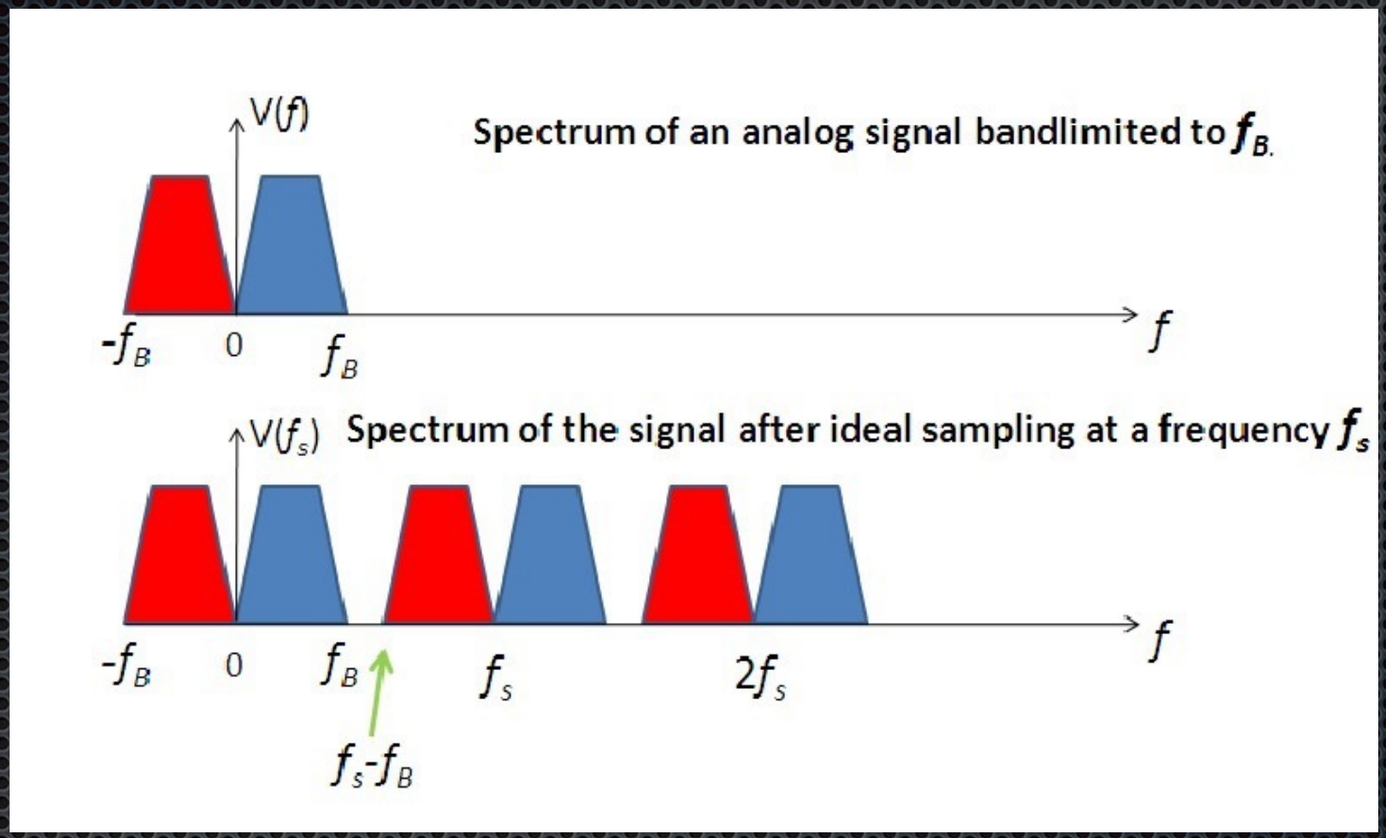
Nyquist rate

- Bandlimited signal of Bandwidth: B
- Sampling rate (uniform): f_s
- Nyquist Rate $f_s > 2B$
- Nyquist Bandwidth $B < f_s/2$

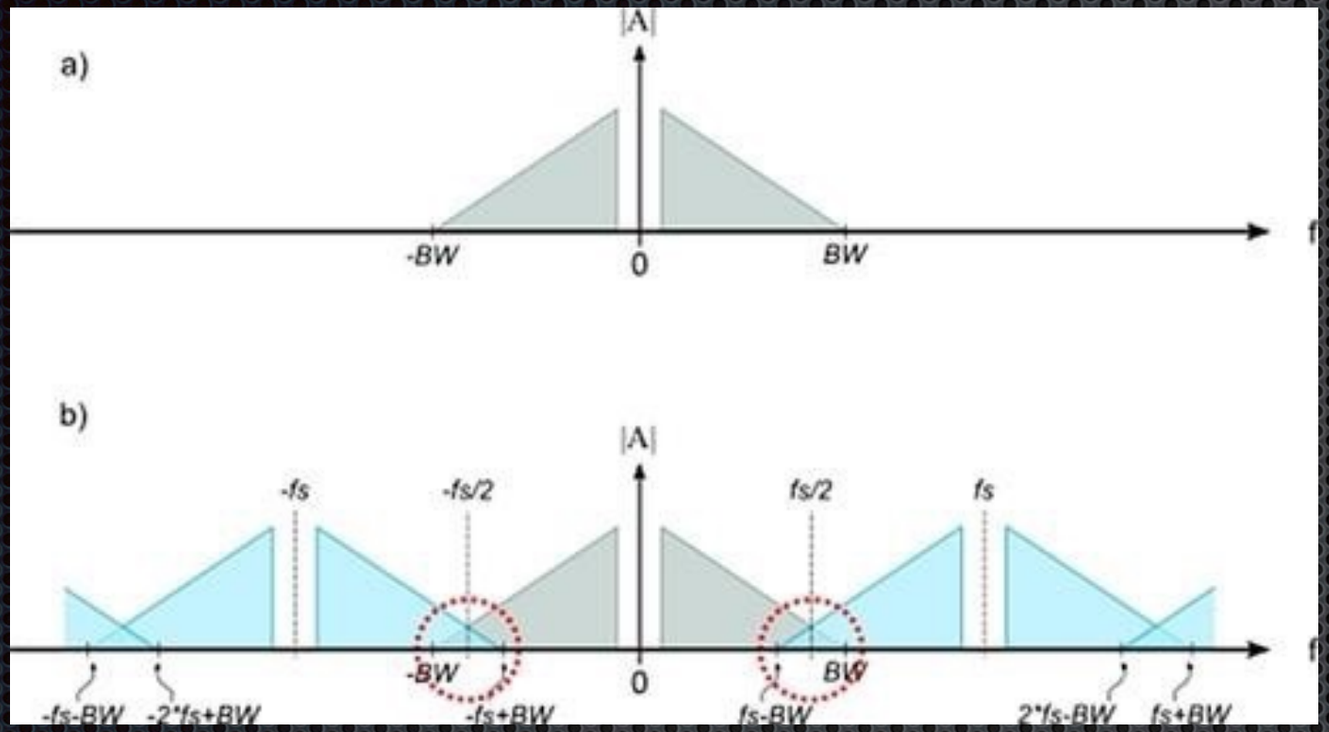
Nyquist rate

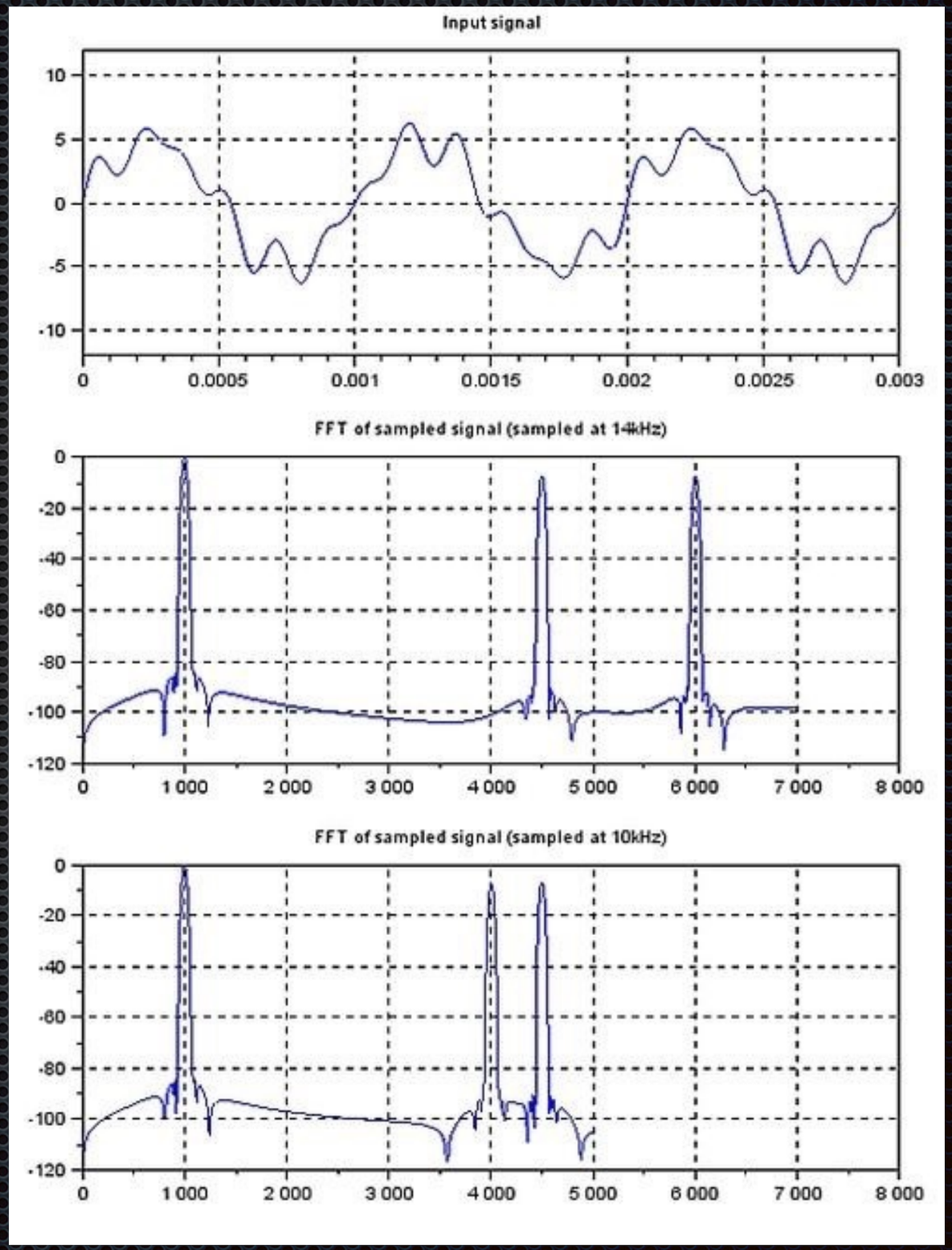


Sampling frequency domain

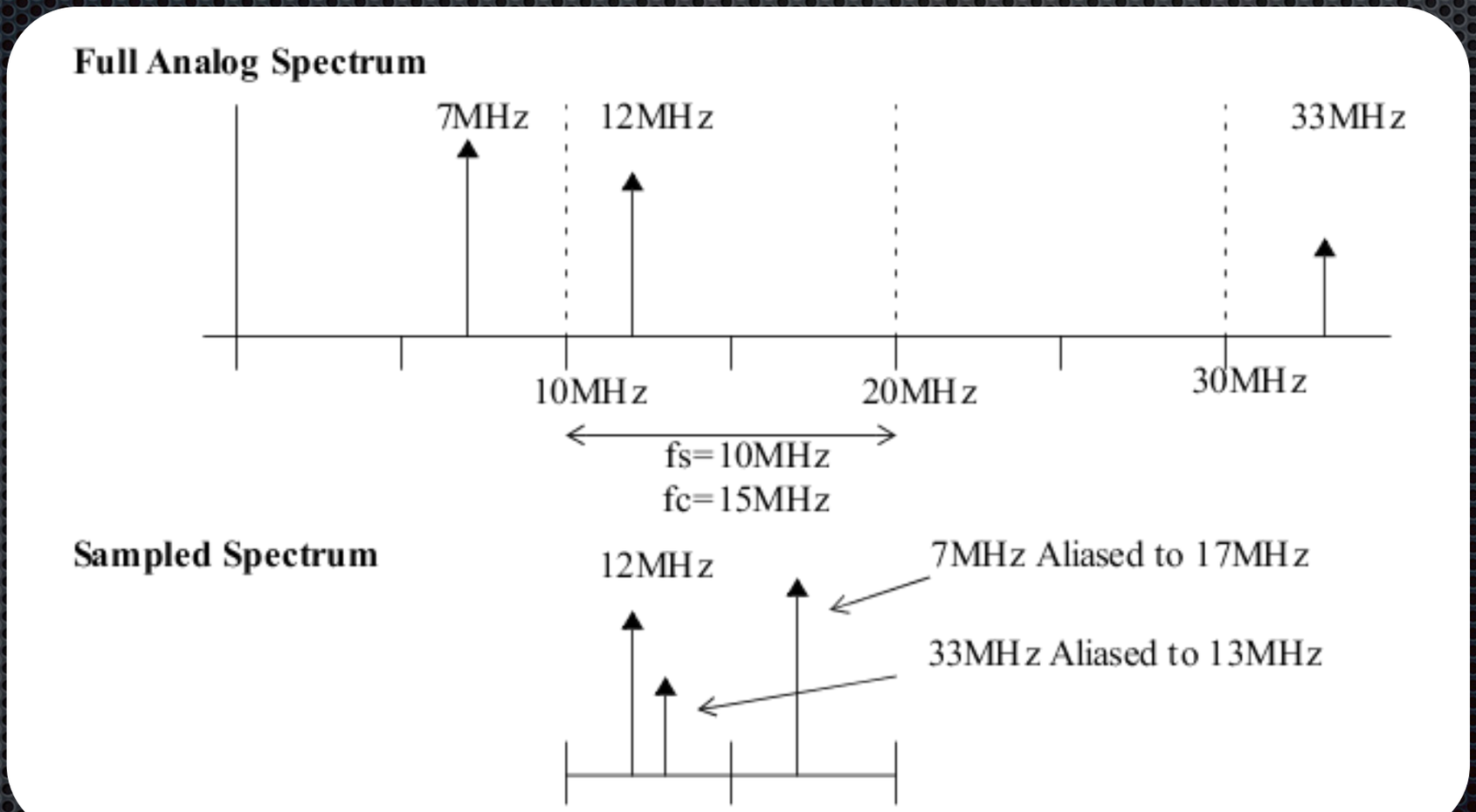


Aliasing


a)
|A|
-BW
0
BW
f
b)
|A|
-fs
-fs/2
fs/2
fs
-BW
0
BW
f
-fs-BW
-2*fs+BW
-fs+BW
fs-BW
2*fs-BW
fs+BW


Input signal
10
5
0
-5
-10
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
FFT of sampled signal (sampled at 14kHz)
0
-20
-40
-60
-80
-100
-120
0
1 000
2 000
3 000
4 000
5 000
6 000
7 000
8 000
FFT of sampled signal (sampled at 10kHz)
0
-20
-40
-60
-80
-100
-120
0
1 000
2 000
3 000
4 000
5 000
6 000
7 000
8 000

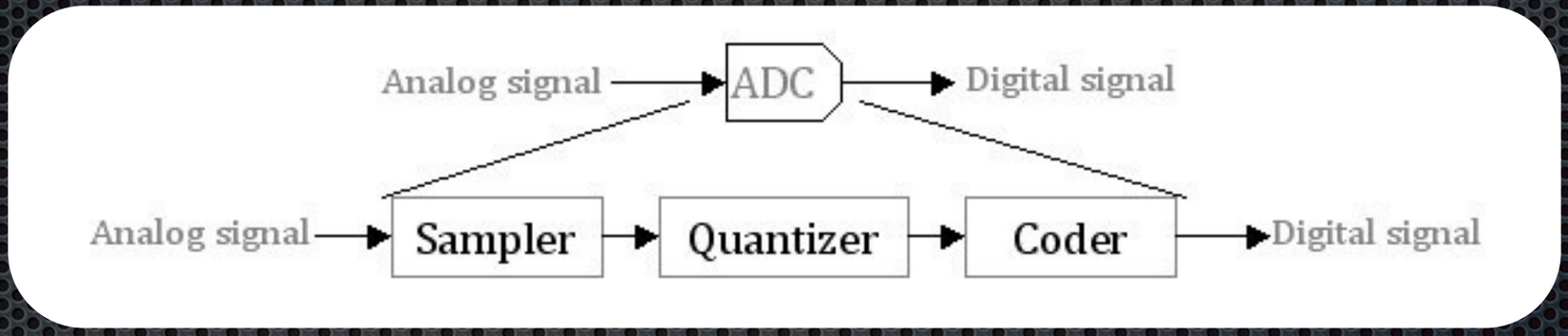
Passband Aliasing



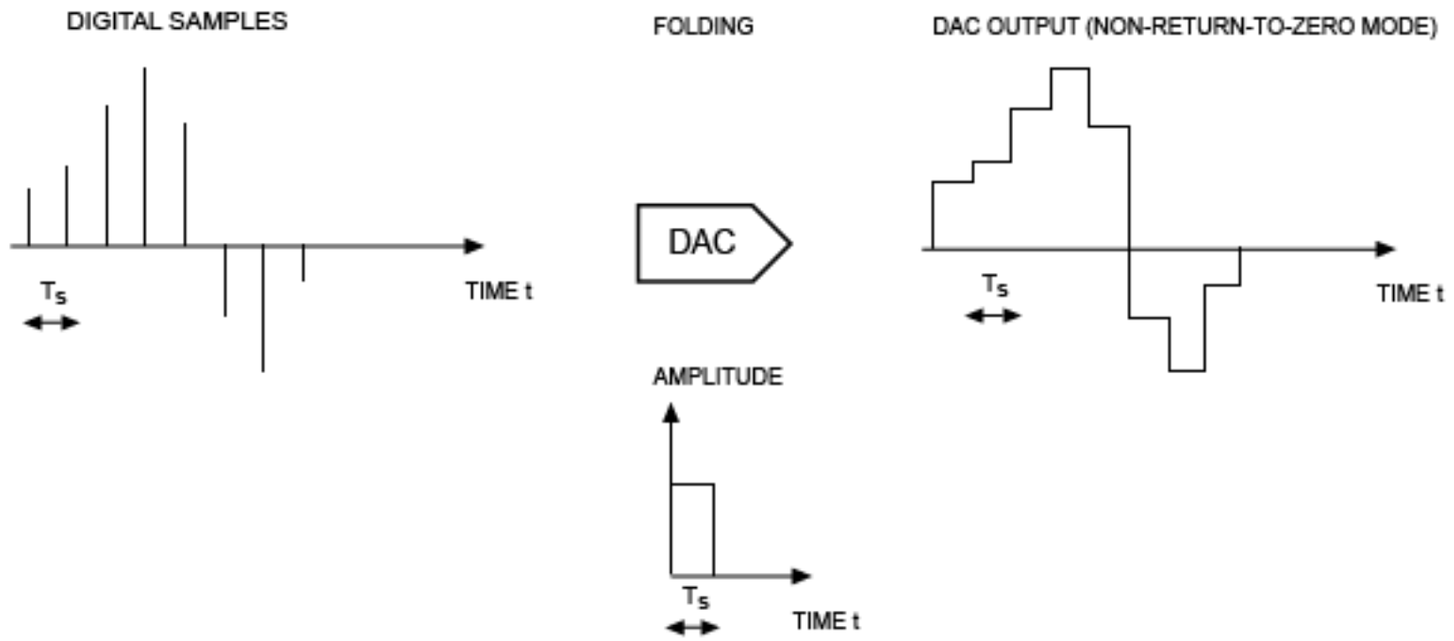
Aliasing in images

Aliasing in videos

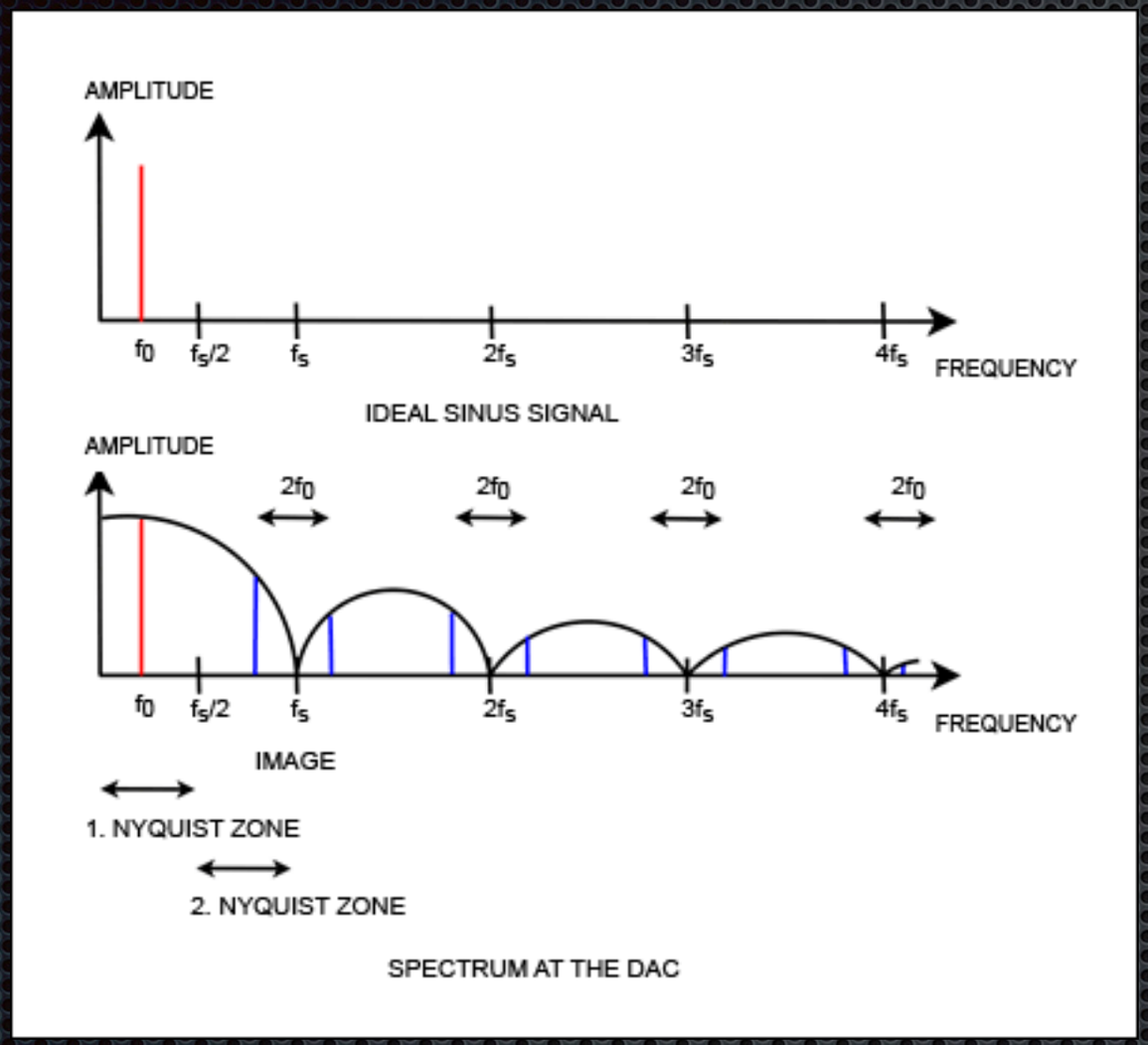
ADC

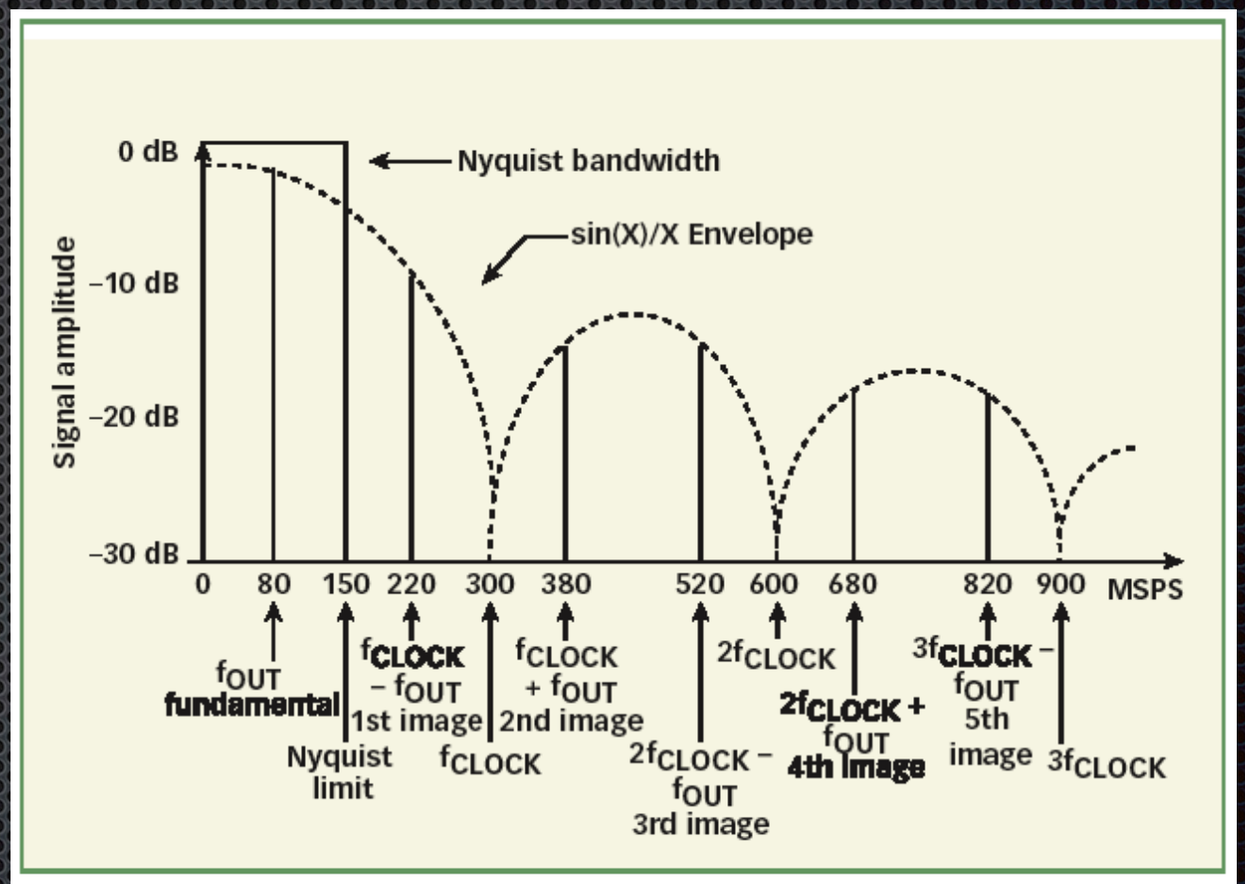

Analog signal
ADC
Digital signal
Analog signal
Sampler
Quantizer
Coder
Digital signal

DAC


DIGITAL SAMPLES
FOLDING
DAC OUTPUT (NON-RETURN-TO-ZERO MODE)
DAC
T_S
TIME t
T_S
TIME t
AMPLITUDE
T_S
TIME t

DAC


AMPLITUDE
f0
fs/2
fs
2fs
3fs
4fs
FREQUENCY
IDEAL SINUS SIGNAL
AMPLITUDE
2f0
2f0
2f0
2f0
f0
fs/2
fs
2fs
3fs
4fs
FREQUENCY
IMAGE
1. NYQUIST ZONE
2. NYQUIST ZONE
SPECTRUM AT THE DAC


0 dB
−10 dB
−20 dB
−30 dB
Signal amplitude
Nyquist bandwidth
sin(X)/X Envelope
0
80
150
220
300
380
520
600
680
820
900
MSPS
fOUT fundamental
Nyquist limit
fCLOCK − fOUT 1st image
fCLOCK
fCLOCK + fOUT 2nd image
2fCLOCK − fOUT 3rd image
2fCLOCK
2fCLOCK + fOUT 4th image
3fCLOCK − fOUT 5th image
3fCLOCK