ECE 697 Delta-Sigma Converters Design

Lecture#1 Slides

Vishal Saxena
(vishalsaxena@u.boisetstate.edu)

Course Outline

Instructor : Vishal Saxena

Time : Tuesday and Thursday, 6:30 to 7:45 PM

Course dates : Tuesday, January 19 to Thursday, May 6

Location : MEC 106

Holidays : March 30 and April 1, Spring break.

Office : MEC 202 F

Office hours : Tue. & Thu., 5:00-6:00 pm or walk-in

E-mail : vishalsaxena@u.boisestate.edu

Website : http://cmosedu.com/vsaxena/courses/ece697/s10/ECE697.htm

Course Topics

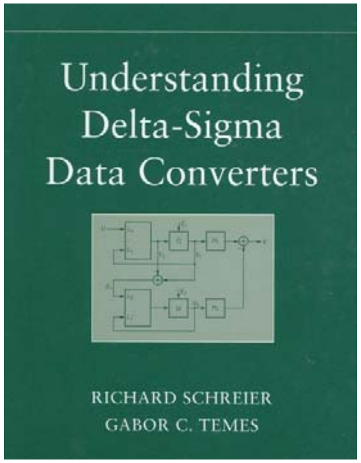
- Data Conversion and spectral estimation fundamentals
- Delta-Sigma modulator (DSM) architectures, decimation filters
- Discrete-time (switched-capacitor) DSM design
  - System level design, noise budgeting, circuit optimization.
- Continuous-time (CT) DSM design
  - Effects of excess-loop delay and clock jitter in CT-DSMs
  - Tuning techniques for CT-DSMs.
- Flash ADCs and DACs employed in the CT-DSMs
- Bandpass and Complex DSMs.
- DAC mismatch error shaping
- Delta-Sigma DAC architectures

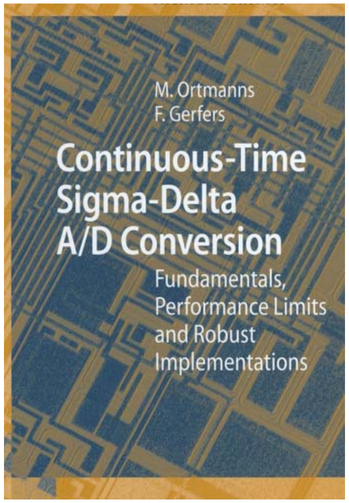
Prerequisites

- Analog IC Design (ECE 511)
  - Op-amps, biasing, small-signal analysis.
- Digital Signal Processing
  - Fourier, DTFT, Laplace, z-transforms, poles and zeros.
- Basic knowledge of circuit simulation using Spice/Spectre and Matlab scripting.
- Preparatory coverage will be provided on
  - Detailed noise and distortion analysis of circuits
  - Signal processing fundamentals

Textbook and References

- Understanding Delta-Sigma Converters – Richard Schreier and Gabor Temes, Wiley-IEEE Press, 2005.
  - ✓ CT Sigma-Delta ADC – Ortmanns
- Matlab Delta-Sigma Toolbox by R. Schreier available for download online. The toolbox manual is here.
- The complete reference list for delta-sigma modulators is available here.

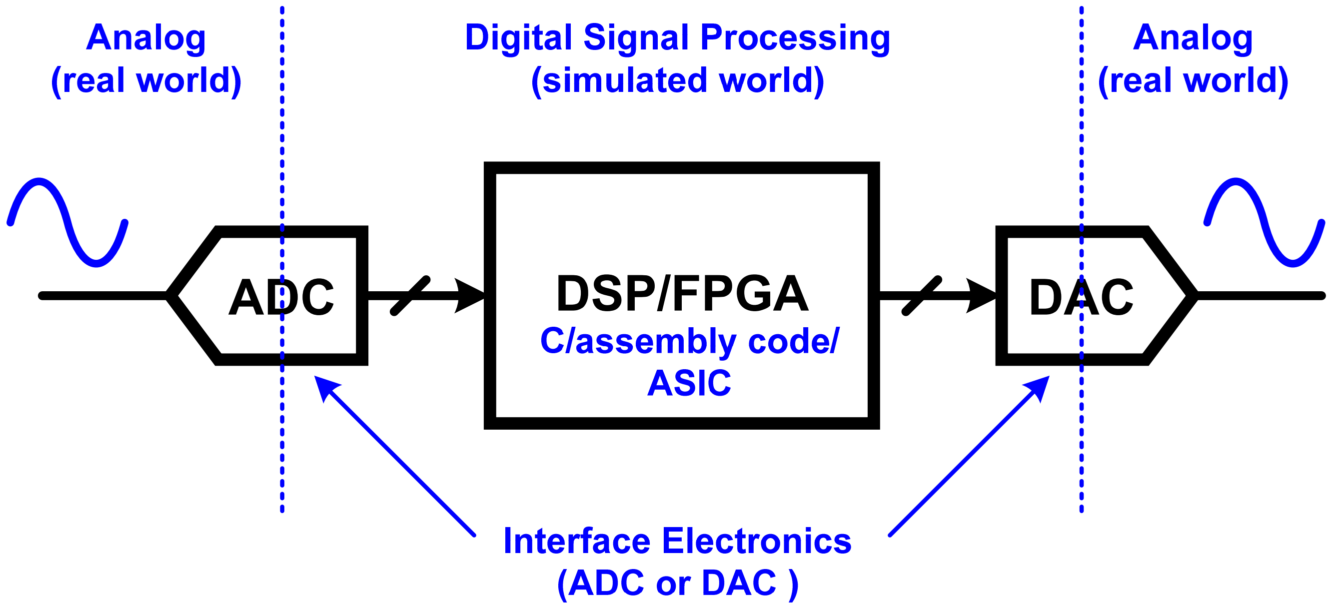




Course Pedagogy, Grading and Policies

- Combination of lecture notes, slides and simulation
  - ✓ Lecture notes will be posted online
  - ✓ Additional slides, Matlab code etc will also be posted.
  - ✓ Regular reading assignments from the textbook and referred papers.
- Workload (Grading)
  - ✓ Homeworks (30%): Weekly assignments combining Matlab and Spectre based design and simulation.
  - ✓ Midterm Exam (20%)
  - ✓ Project 1 (25%): Switched-capacitor delta-sigma modulator design.
  - ✓ Project 2 (25%): Continuous-time delta-sigma modulator design.
- Policies
  - ✓ Maximize learning!
  - ✓ No plagiarism, late work and net surfing in class.

Data Converters

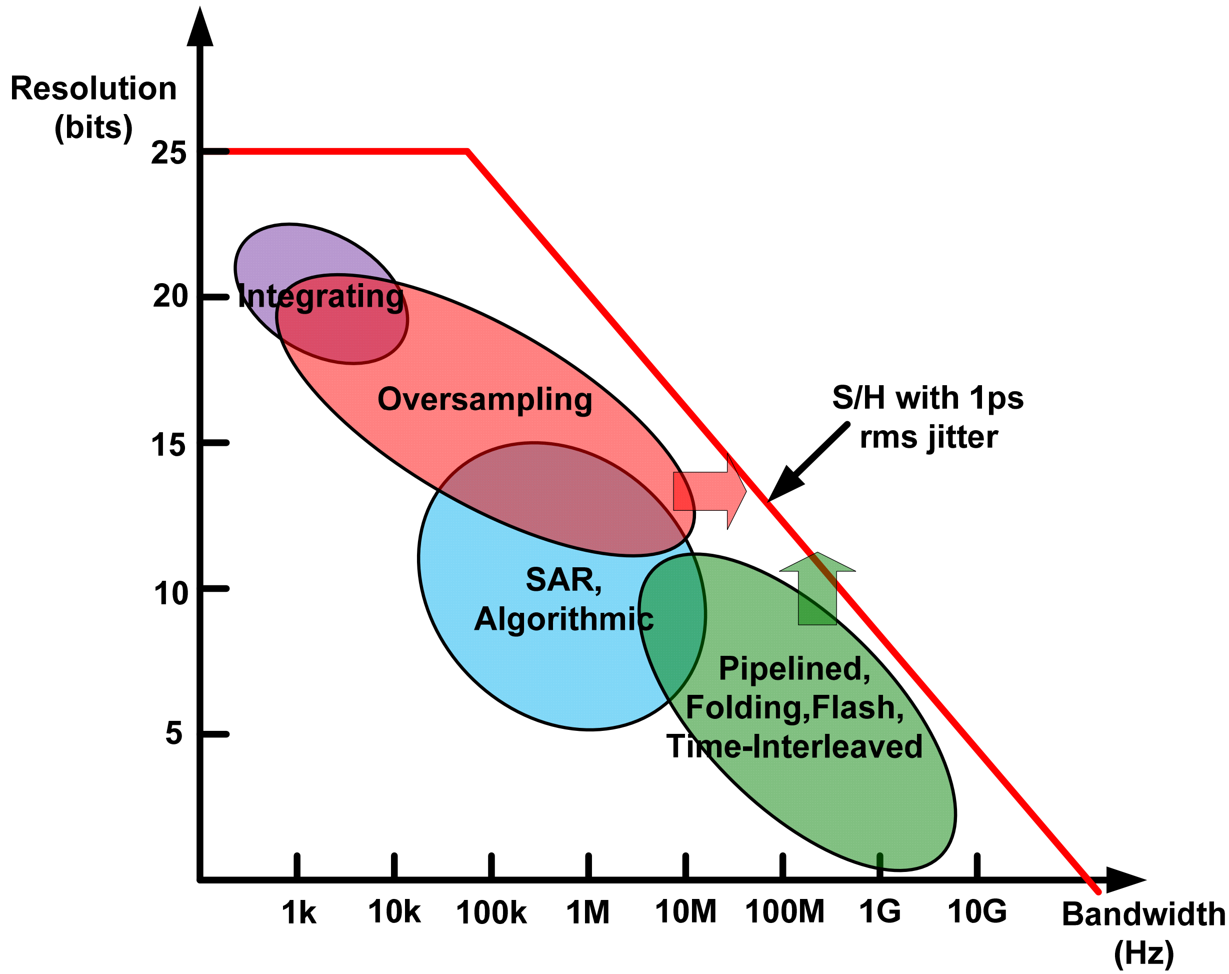


- Real world: Continuous-time, continuous-amplitude signals.
- Digital world: Discrete-time, discrete-amplitude signal representation.
- Interface circuits: ADC and DACs.
  - ✓ Varying speed and precision requirements.

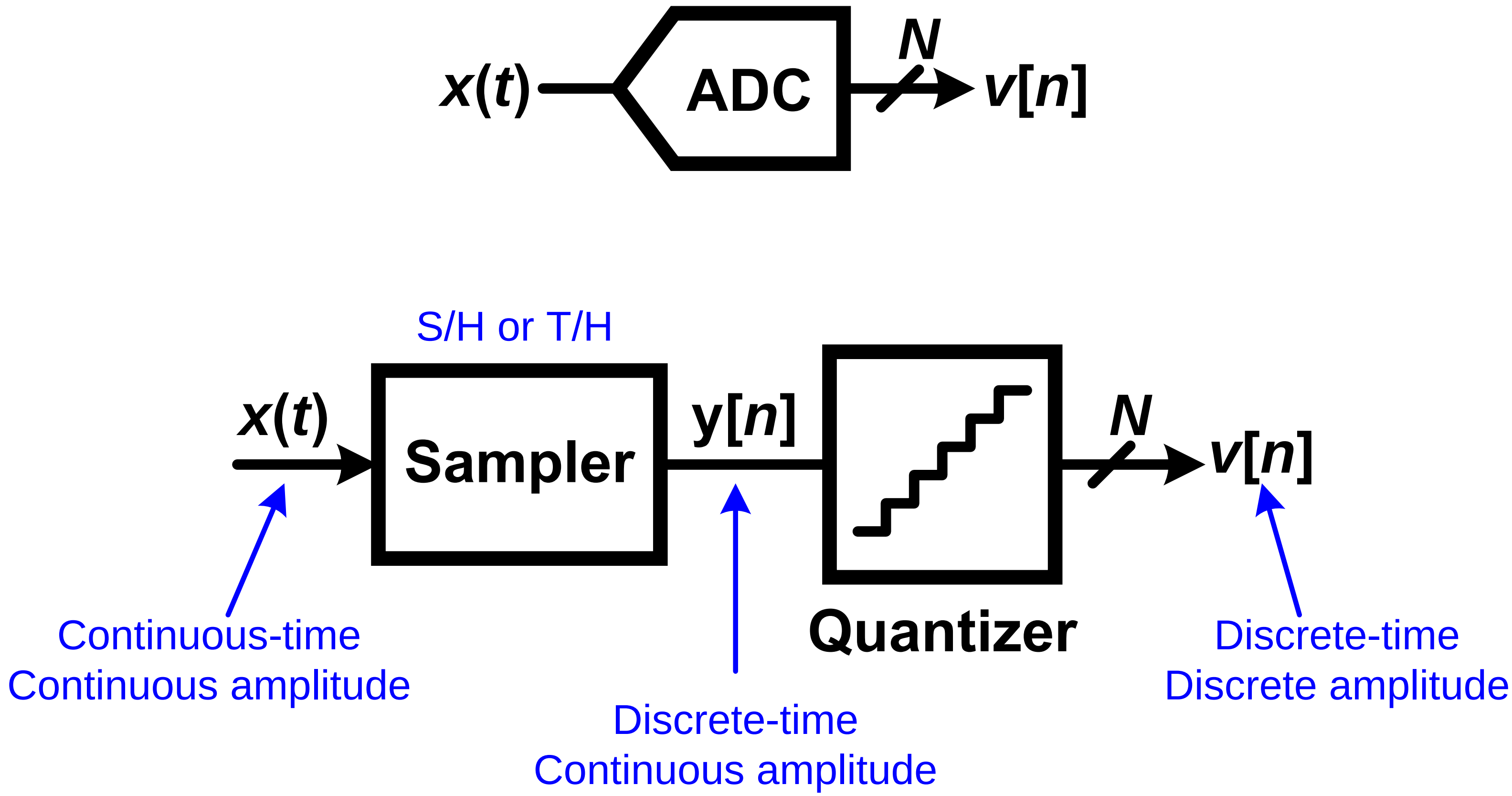
Data Conversion Scenarios

- Any application using a sensor and/or an actuator
  - Wireless: RF Rx and Tx chain
  - Twisted pair: ADSL modem
  - Coaxial: Cable modem
  - Serial/Optical links: 10G+ ADC for modulation and equalization
  - Audio Recording: 24-bit stereo ADCs
  - Audio players: stored data to speaker (audio DAC)
  - HDD read channel: Magnetic disk to microprocessor
  - Biomedical applications (e.g. sensing blood glucose level and actuating the insulin pump),.........
- Speed and resolution requirements vary with the application.

Analog to Digital Converter Architectures



Analog-to-Digital Converter (ADC)



Sampling Process

- Refer to lecture notes.

Signals refresher.

Fourier Series: for a periodic signal $g(t)$, with period to

$$g(t) = \sum_{k=-\infty}^{\infty} a_k e^{j2\pi k f_0 t}$$

where $a(k) = \frac{1}{T_s}\int_0^{T_s} g(t) e^{-j2\pi k f_0 t} dt$

for LTI systems only

Fourier Transform:

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi f t} dt$$

$$x(t) = \int_{-\infty}^{\infty} X(f) e^{j2\pi f t} df$$

FT properties:

Linearity: $a x(t) + b y(t) \xleftrightarrow{\mathcal{F}} a X(f) + b Y(f)$

time delay: $x(t - t_0) \xleftrightarrow{\mathcal{F}} X(f) e^{-j2\pi f t_0}$ ← Linear phase

frequency translation: $e^{j2\pi f_0 t} x(t) \xleftrightarrow{\mathcal{F}} X(f - f_0)$

$x(-t) \xleftrightarrow{\mathcal{F}} X(-f)$

Scaling: $x(at) \xleftrightarrow{\mathcal{F}} \frac{1}{|a|} X\left(\frac{f}{a}\right)$

Convolution $x(t) \circledast y(t) \xleftrightarrow{\mathcal{F}} X(f) \cdot Y(f)$

Multiplication $x(t) \cdot y(t) \xleftrightarrow{\mathcal{F}} X(f) \circledast Y(f)$

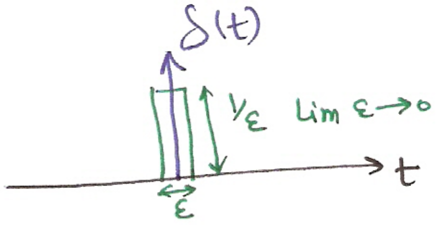
Duality: $X(t) \xleftrightarrow{\mathcal{F}} x(-f)$

Parseval's Theorem (Energy conservation)

$$\int_{-\infty}^{\infty} x(t) x^*(t) dt = \int_{-\infty}^{\infty} X(f) X^*(f) dt$$

Delta function (?)

$$\int_{-\infty}^{\infty} \delta(t)\, dt = 1$$



$x(t) \cdot \delta(t) = x(0) \cdot \delta(t)$ ← picks the value at $t=0$

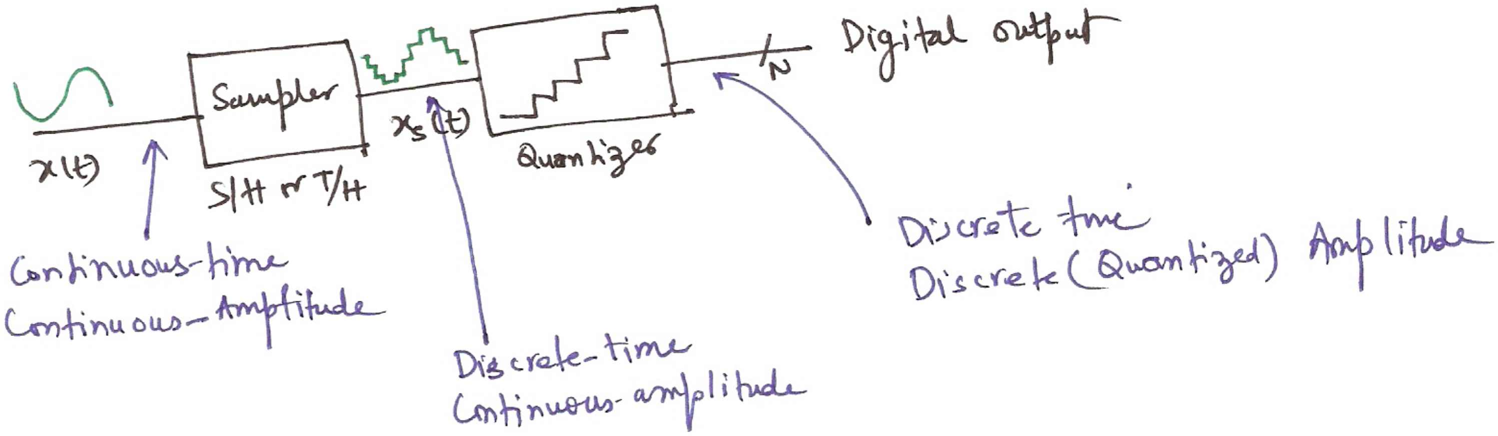
$x(t) \cdot \delta(t-t_0) = x(t_0)\, \delta(t-t_0)$

$x(t) \circledast \delta(t) = x(t)$

$x(t) \circledast \delta(t-t_0) = x(t-t_0)$

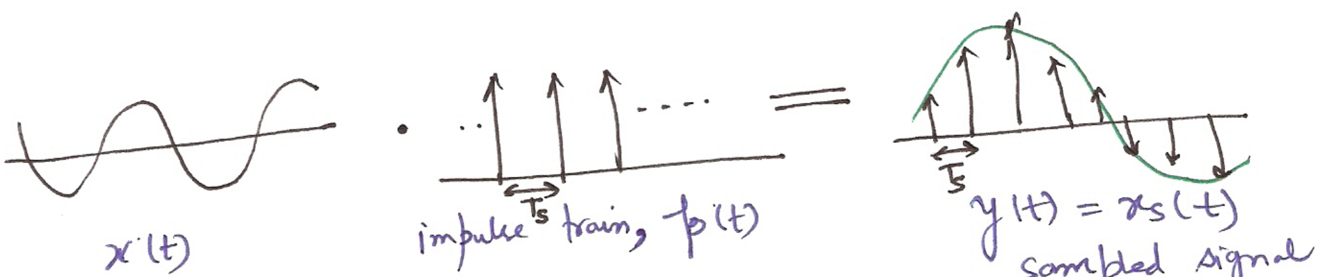
$\delta(t) \overset{\mathcal{F}}{\longleftrightarrow} 1$

ADC (Analog-to-Digital Converter)



Using continuous-time representation of signals to keep S/H analysis simple. $\Rightarrow y(t) = x_s(t) \Rightarrow x(nT_s)$ is held

Ideal sampling (impulse sampling)



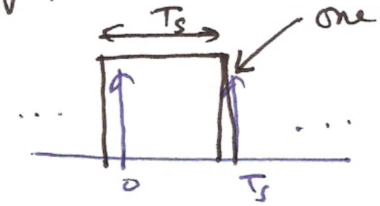
$$y(t) = x(t) \cdot \sum_{n=-\infty}^{\infty} \delta(t - nT_s) = x(t) \cdot p(t)$$

$$\Rightarrow Y(f) = X(f) \circledast P(f)$$

How to find $P(f) = ?$

$p(t) \leftarrow$ periodic function
↳ express as fourier series
↳ easy to find spectrum of $p(t)$

$$p(t) = \sum_{k=-\infty}^{\infty} a_k e^{j2\pi k f_s t}$$



$$\Rightarrow \quad a_k = \frac{1}{T_s}\int_0^{T_s^-} p(t) e^{-j2\pi k f_s t} dt = \frac{1}{T_s}\int_0^{T_s^-} \delta(t) e^{-j2\pi k f_s (0)} dt$$

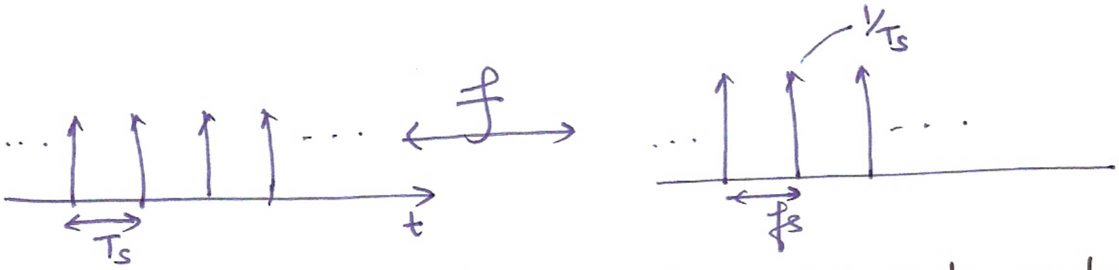
$$\boxed{f_s = \frac{1}{T_s}}$$

$$= \frac{1}{T_s}\int_0^{T_s^-} \delta(t) dt = 1/T_s \quad \leftarrow \text{Same amplitude for all harmonics}$$

$\Rightarrow$ Now, $$p(t) = \sum_{k=-\infty}^{\infty} 1/T_s \, e^{j2\pi k f_s t}.$$

$\Rightarrow$ Taking fourier transform

$$\boxed{P(f) = \frac{1}{T_s}\sum_{k=-\infty}^{\infty} \delta(f - k f_s)}$$



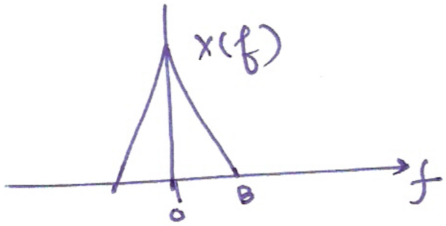
$\Rightarrow$ Impulse train signal is invariant under Fourier Transform.

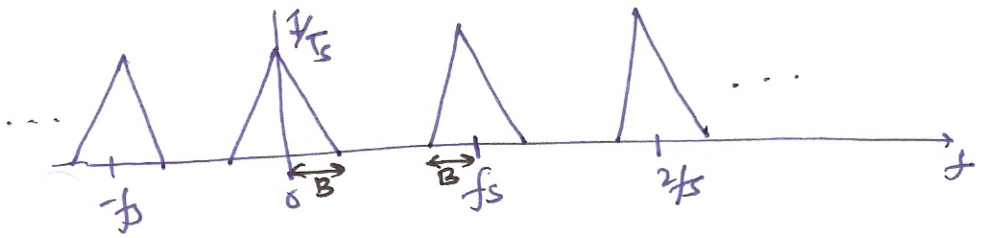
Now,

$$Y(f) = X(f) \circledast P(f)$$

$$= X(f) \circledast \frac{1}{T_s}\sum_{k=-\infty}^{\infty} \delta(f - kf_s)$$

$$\Rightarrow \boxed{Y(f) = \frac{1}{T_s}\sum_{k=-\infty}^{\infty} X(f - kf_s)}$$



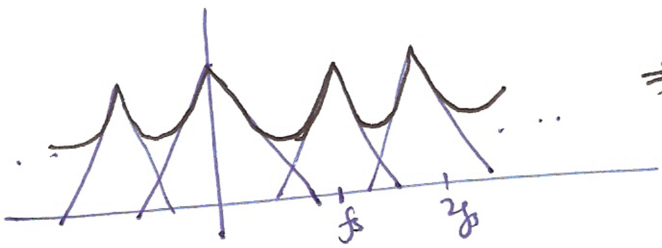


$\Rightarrow$ To avoid aliasing

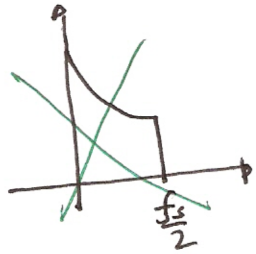
$$\boxed{f_s > 2B}$$

Nyquist Sampling Theorem

If $f_s < 2B$

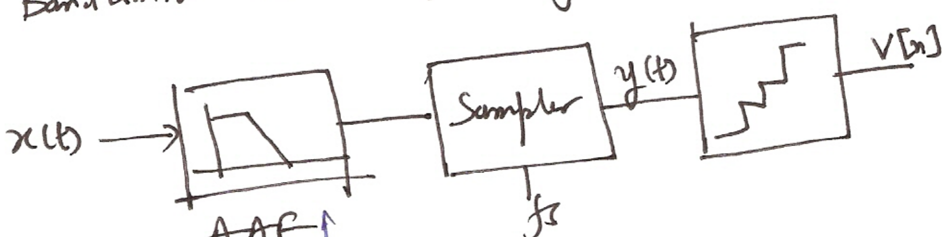


$\Rightarrow$



instead of

$\Rightarrow$ Bandlimit the input signal to the Sampler.

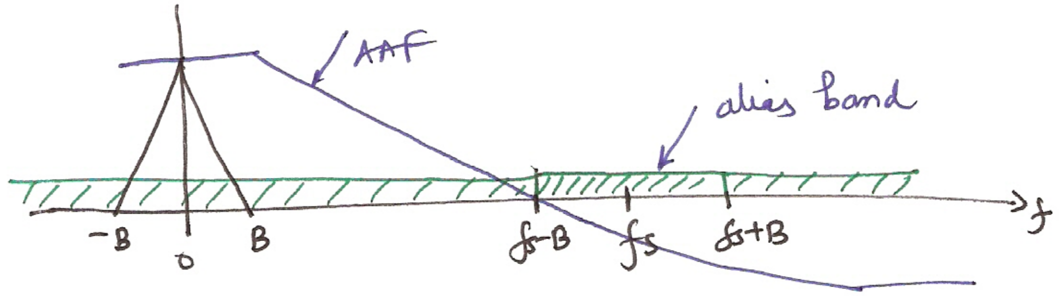


Anti-aliasing filter

↳ Always CT filter

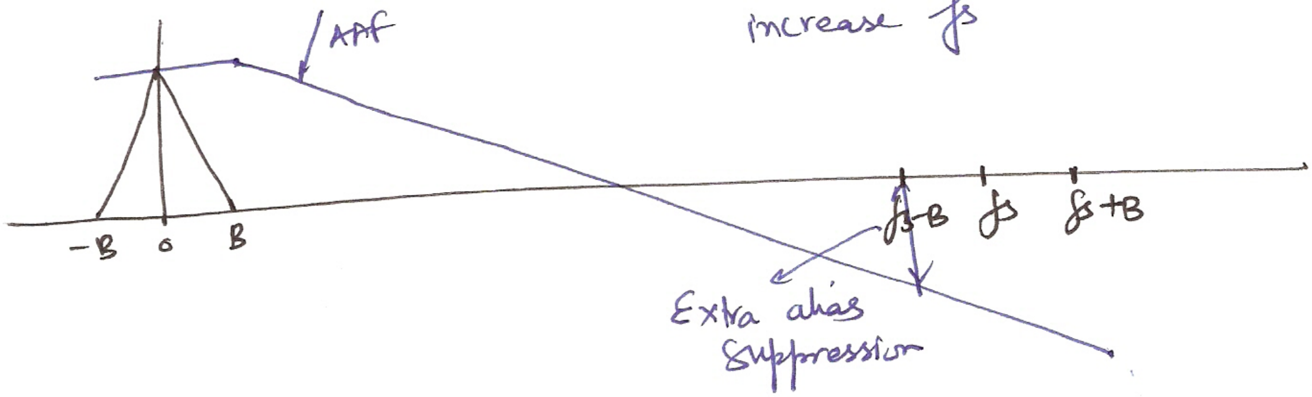
Can't use switched-capacitor filter here!

But what about thermal/wideband noise present at the input of the sampler?



* Even if the signal was bandlimited, the noise will alias from $kf_s + [-B, B]$ to the baseband.
* AAF ~~limits the~~ suppresses the noise in the alias bands.
  ⇒ AAF is always a must before a sampler.

* Ideal brickwall AAF is not realizable



⇒ Oversampling results in
  ↳ better alias rejection with the same AAF.
  ↳ lower order AAF for same amount of alias rejection.

⇒ Oversampling relaxes the requirements on AAF.

$$\text{Oversampling ratio} = \frac{f_s}{f_{s,Nyquist}} = \boxed{\frac{f_s}{2B} = OSR}$$