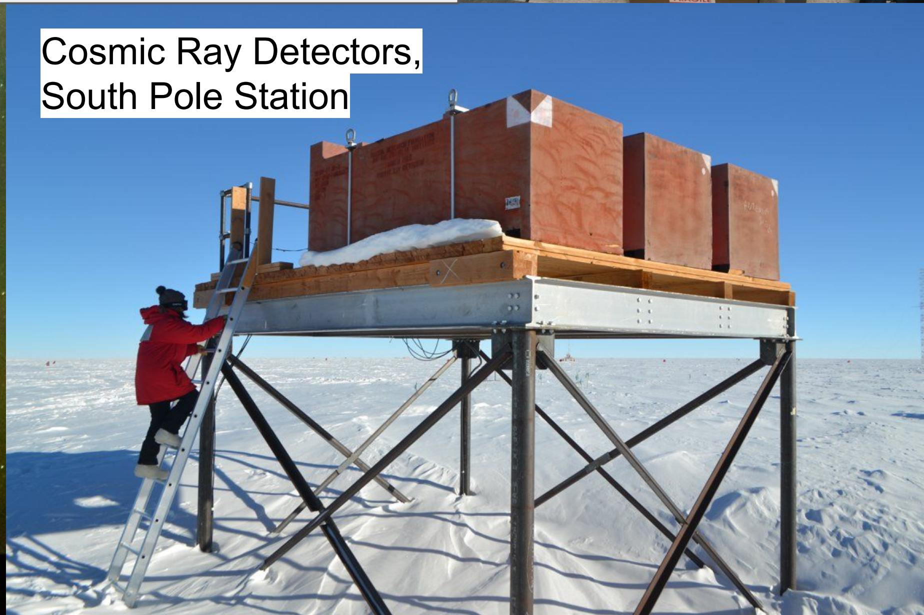
Signal Processing

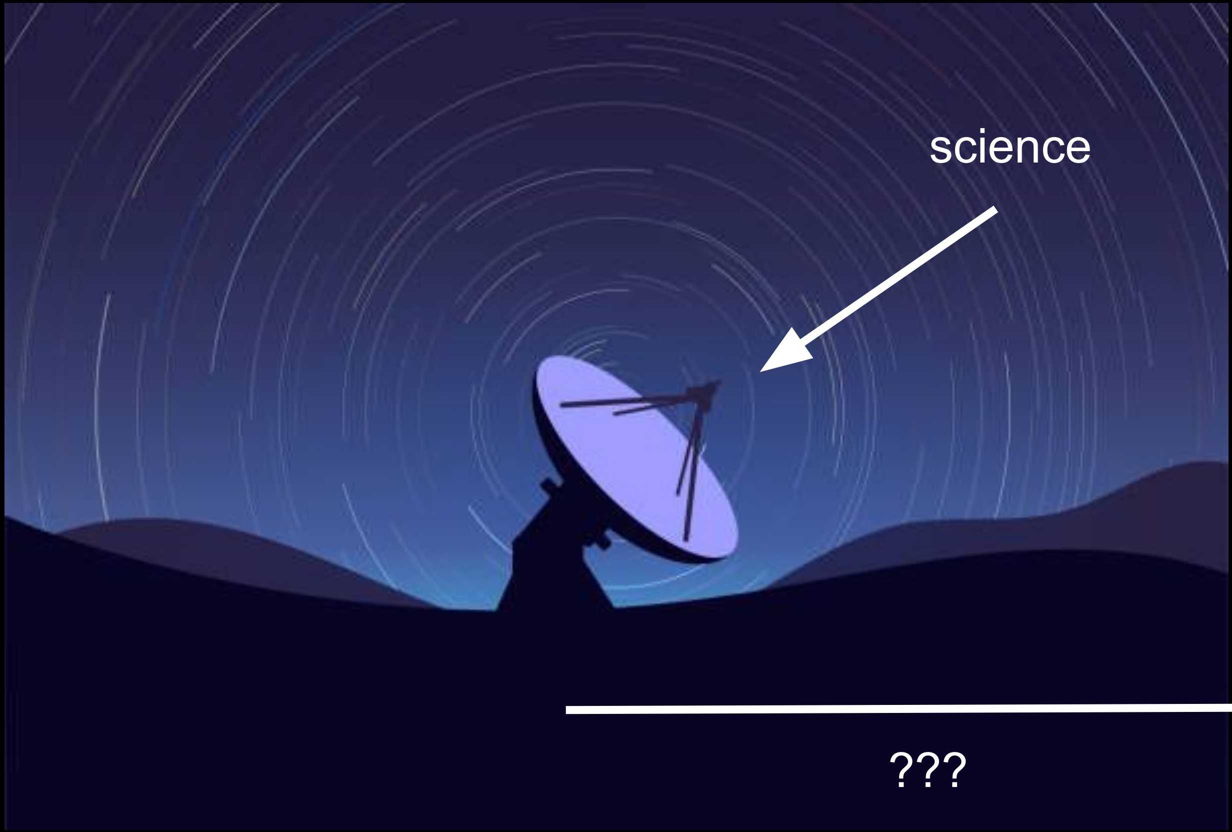
CRASIES 5/26

Libby

- Current TSI postdoctoral fellow
- PhD at ASU in Exploration Systems Design (Instrumentation)
- B.S in Astronomy & Astrophysics from UChicago

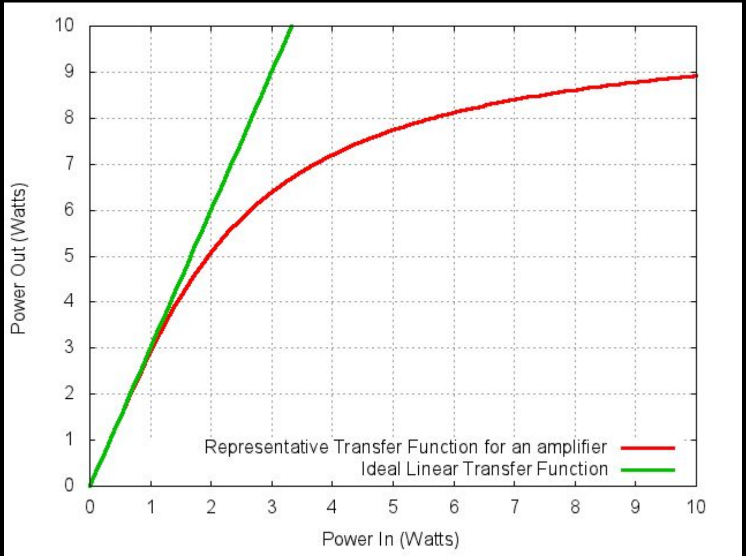
- Primarily work on instrumentation and signal processing
- Do cool stuff with cool equipment in cool places

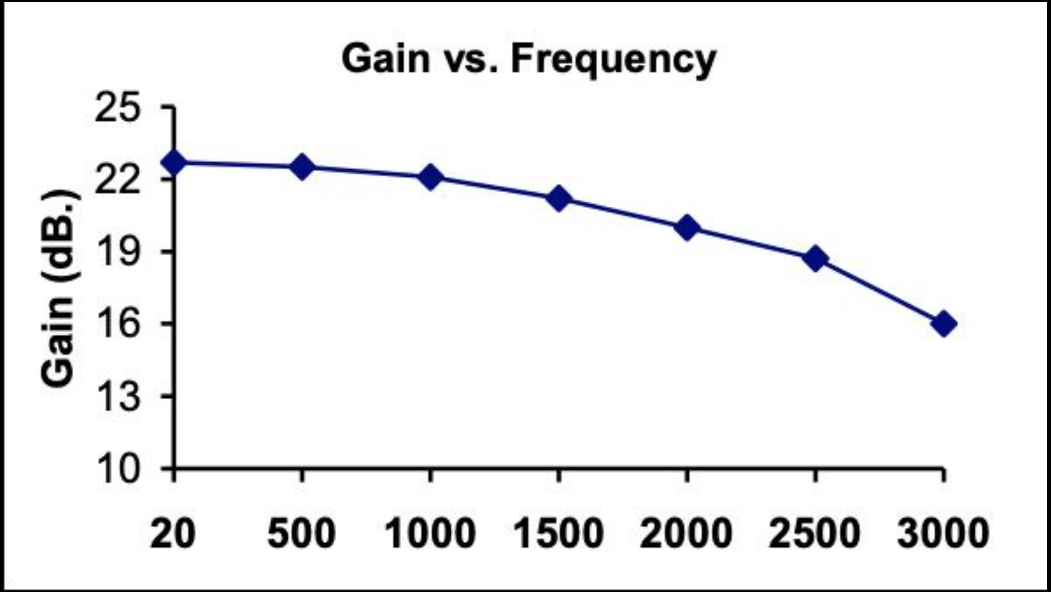


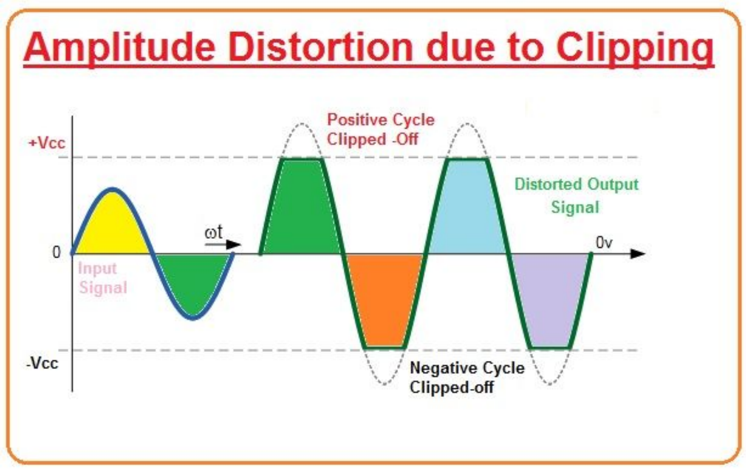


Analyzing science data

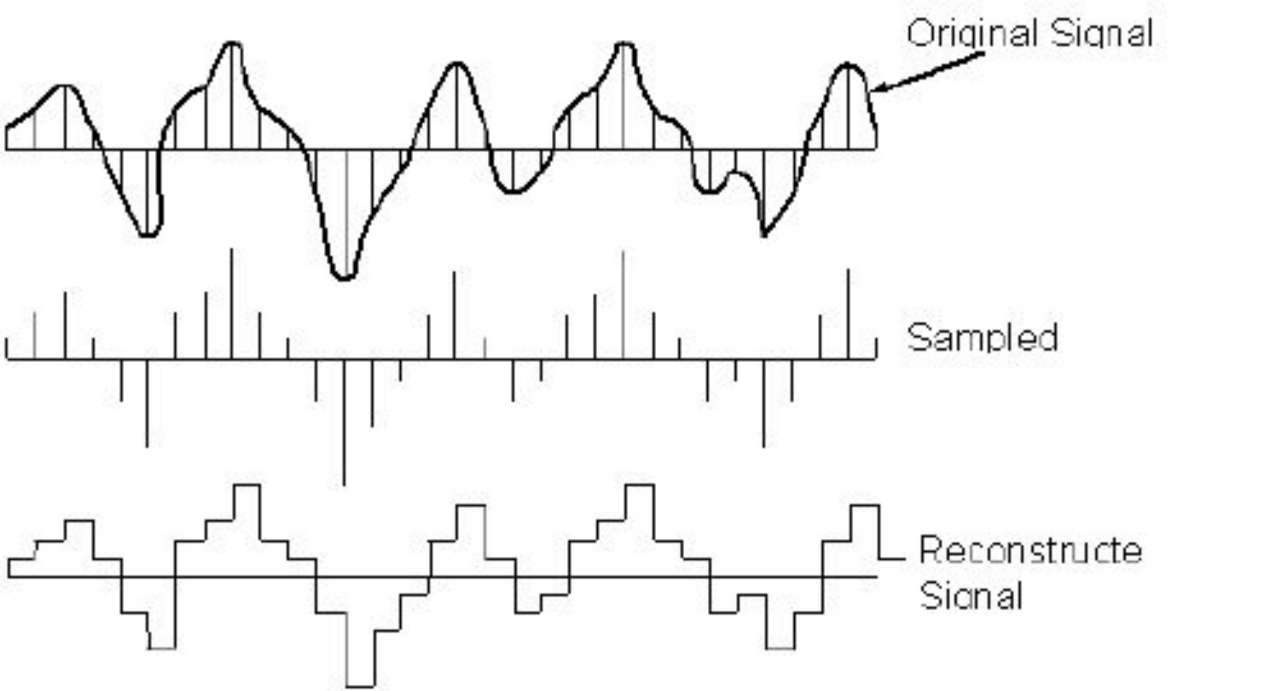
Amplifier response curve





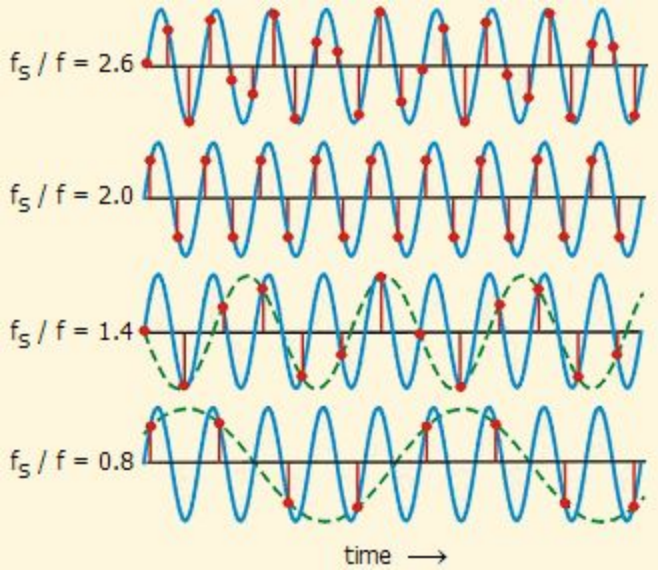


Sampling Theorem

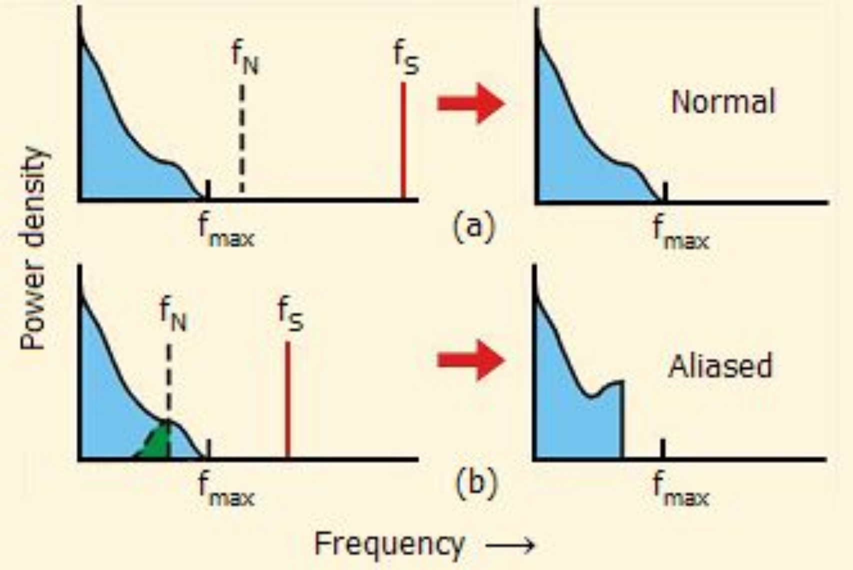


http://www.azimadli.com/vibman/analogtodigitalconversion.html

Aliasing



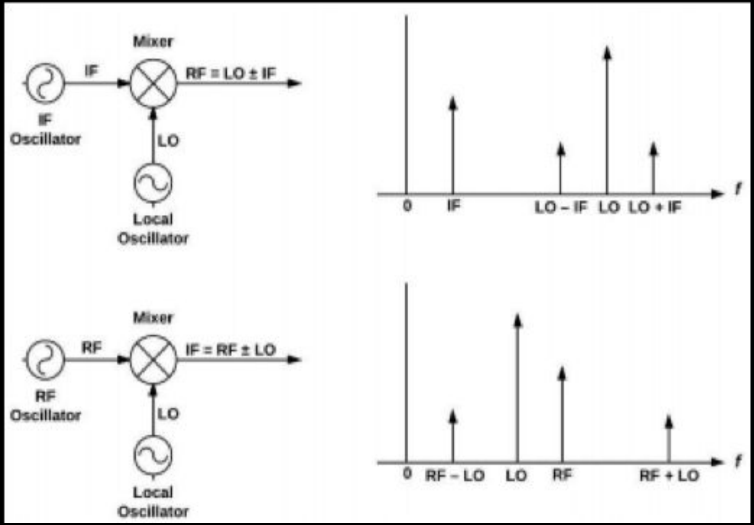
$f_s / f = 2.6$
$f_s / f = 2.0$
$f_s / f = 1.4$
$f_s / f = 0.8$
time ⟶

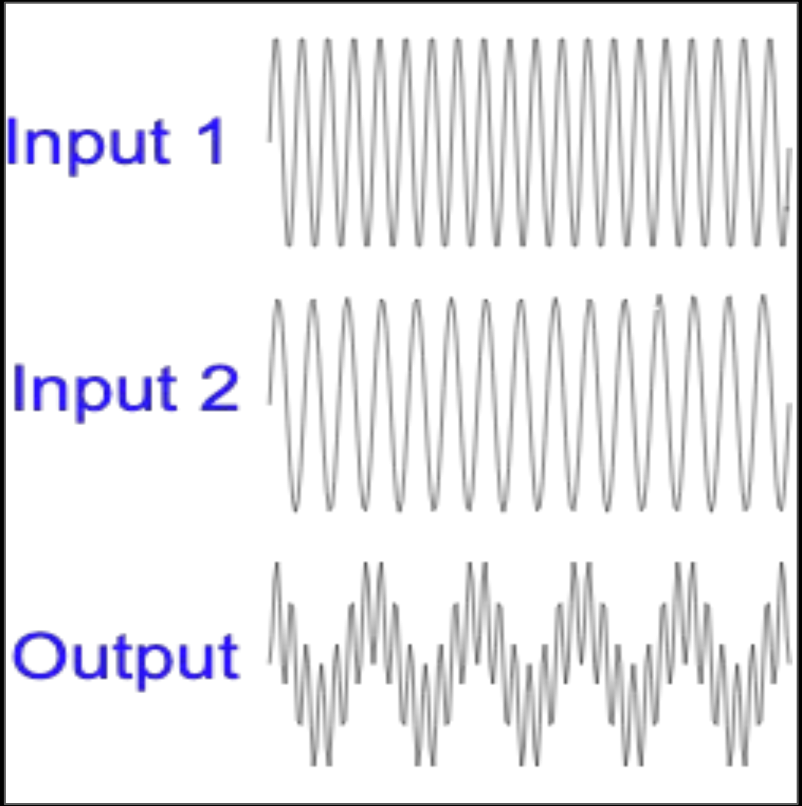


f_N
f_S
Normal
f_{max}
(a)
Power density
Aliased
(b)
Frequency ⟶

Mixing/Tuning

What happens if I want to sample a really high frequency, but low bandwidth?

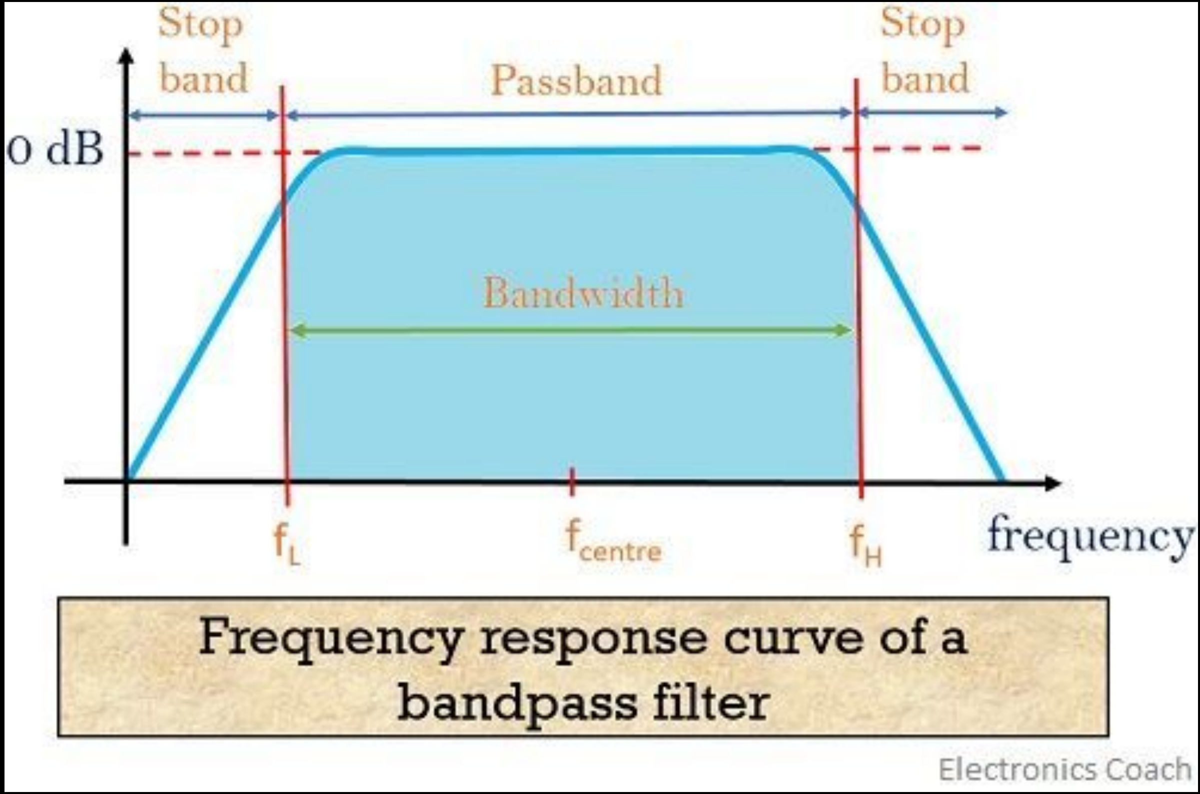




https://coppermountaintech.com/rf-mixer-characterization/

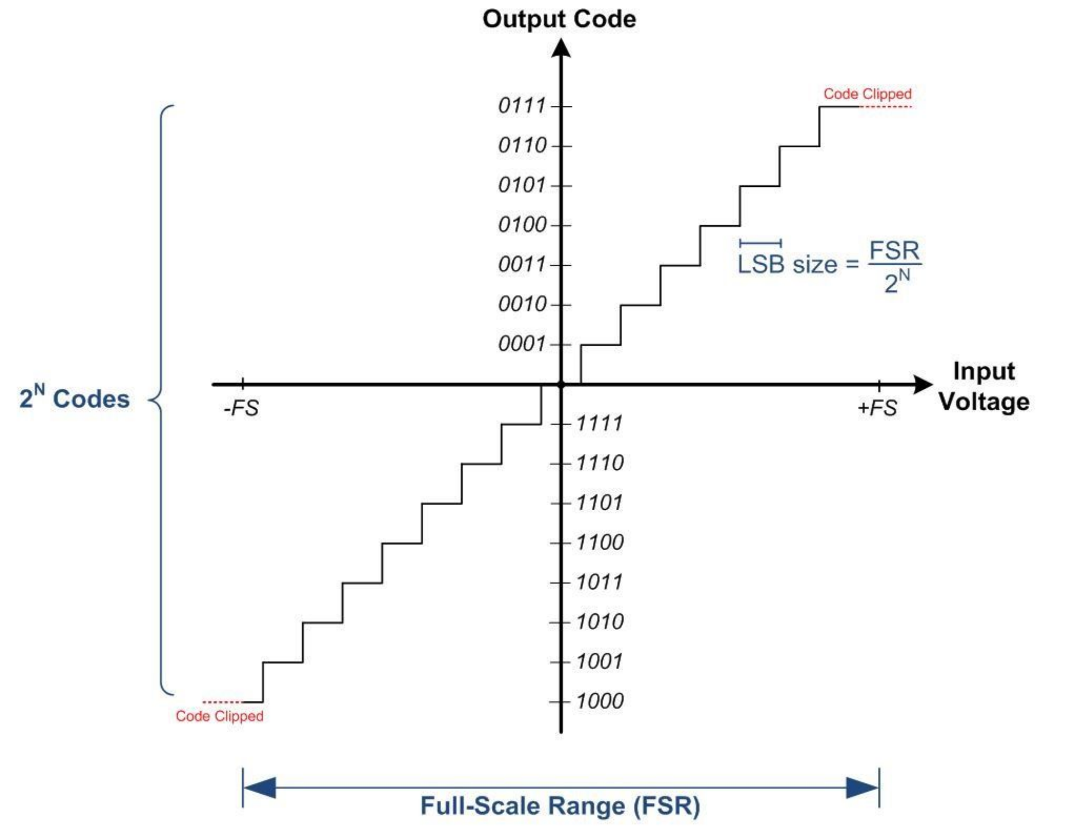
https://academo.org/demos/wave-interference-beat-frequency/

Filtering

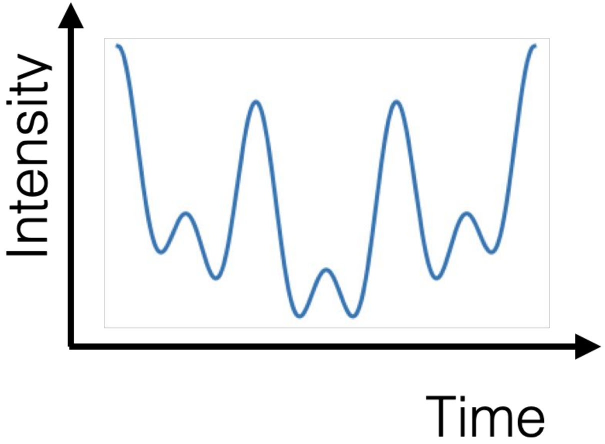


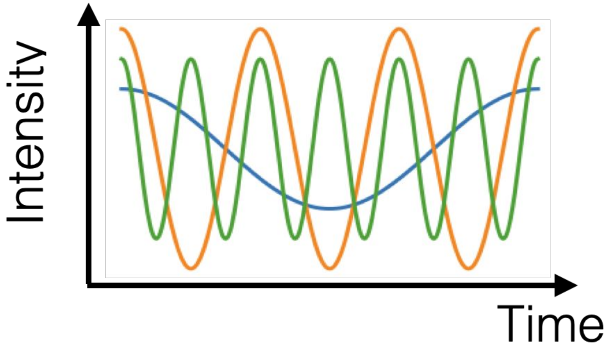
https://electronicscoach.com/bandpass-filter.html/frequency-response-curve-of-bandpass-filter

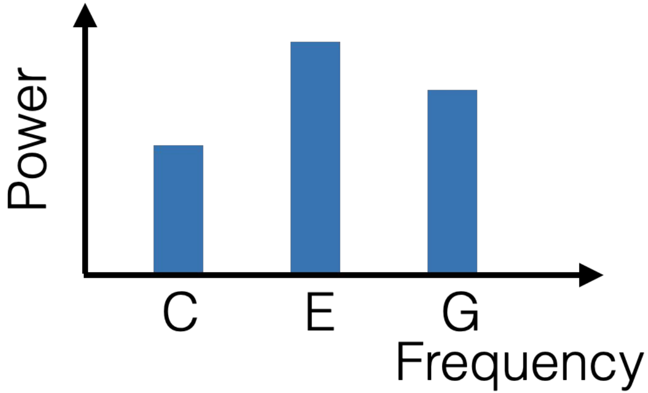
Analog to Digital Conversion



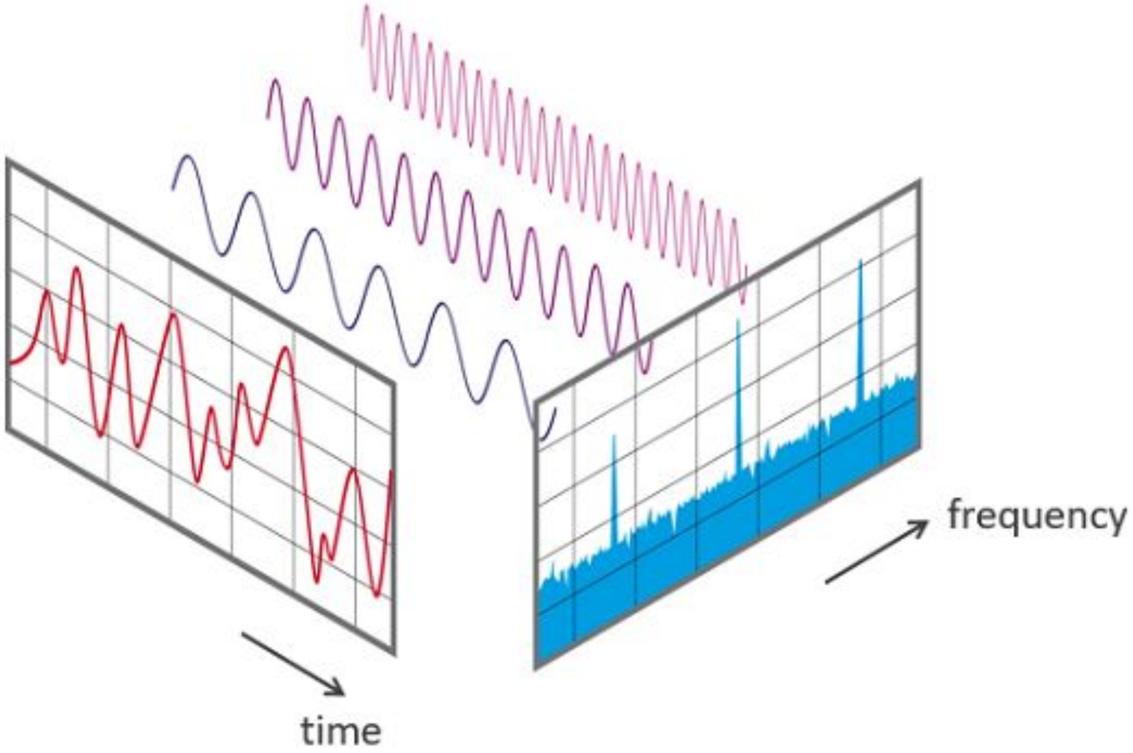
Fourier Transform







Fourier Transform to Spectra



https://www.nti-audio.com/en/support/know-how/fast-fourier-transform-fft

Fourier Series

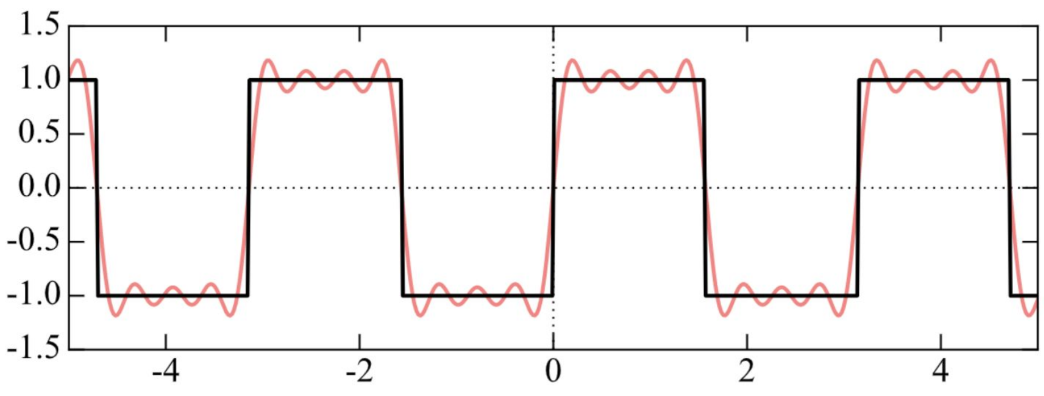


Figure 1: A square wave (black) approximated by a sum of cosines (red).

If you'd like some intuition for the Fourier Series:

https://phet.colorado.edu/sims/html/fourier-making-waves/latest/fourier-making-waves_en.html

Fourier transform

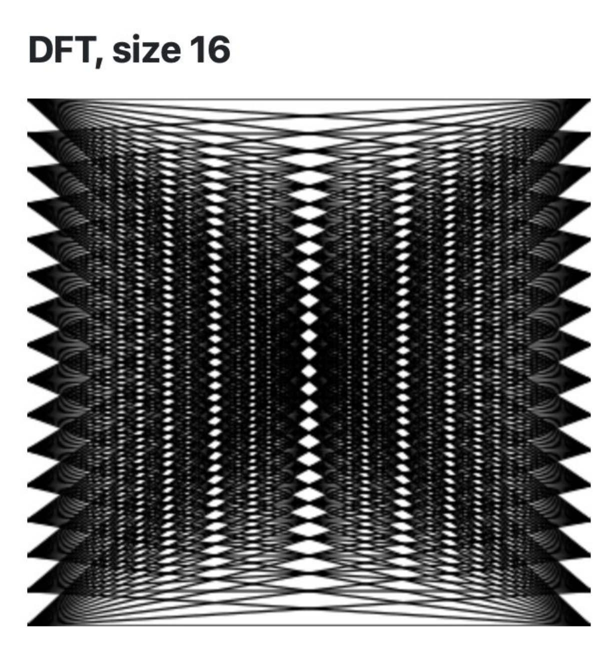
$$\widehat{f}(\xi) = \int_{-\infty}^{\infty} f(x)\, e^{-i2\pi\xi x}\, dx, \quad \forall \xi \in \mathbb{R}.$$

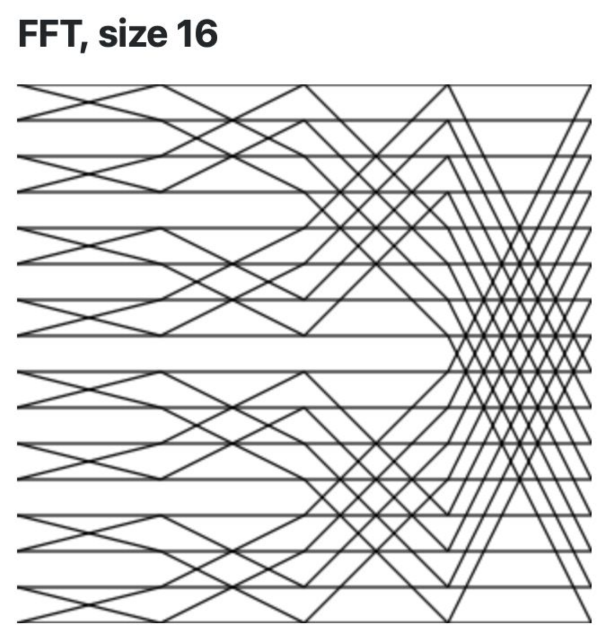
Discrete Fourier transform

$$X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-i2\pi \frac{k}{N} n}$$

Fast Fourier Transform

- Efficient technique to calculate DFT
- Computations are faster compared to DFT definition
- "Divide and Conquer" → compute DFT of smaller chunks of data and combine them ⇒ lower number of computations
- Most commonly used numerical tool to compute DFT of real signals

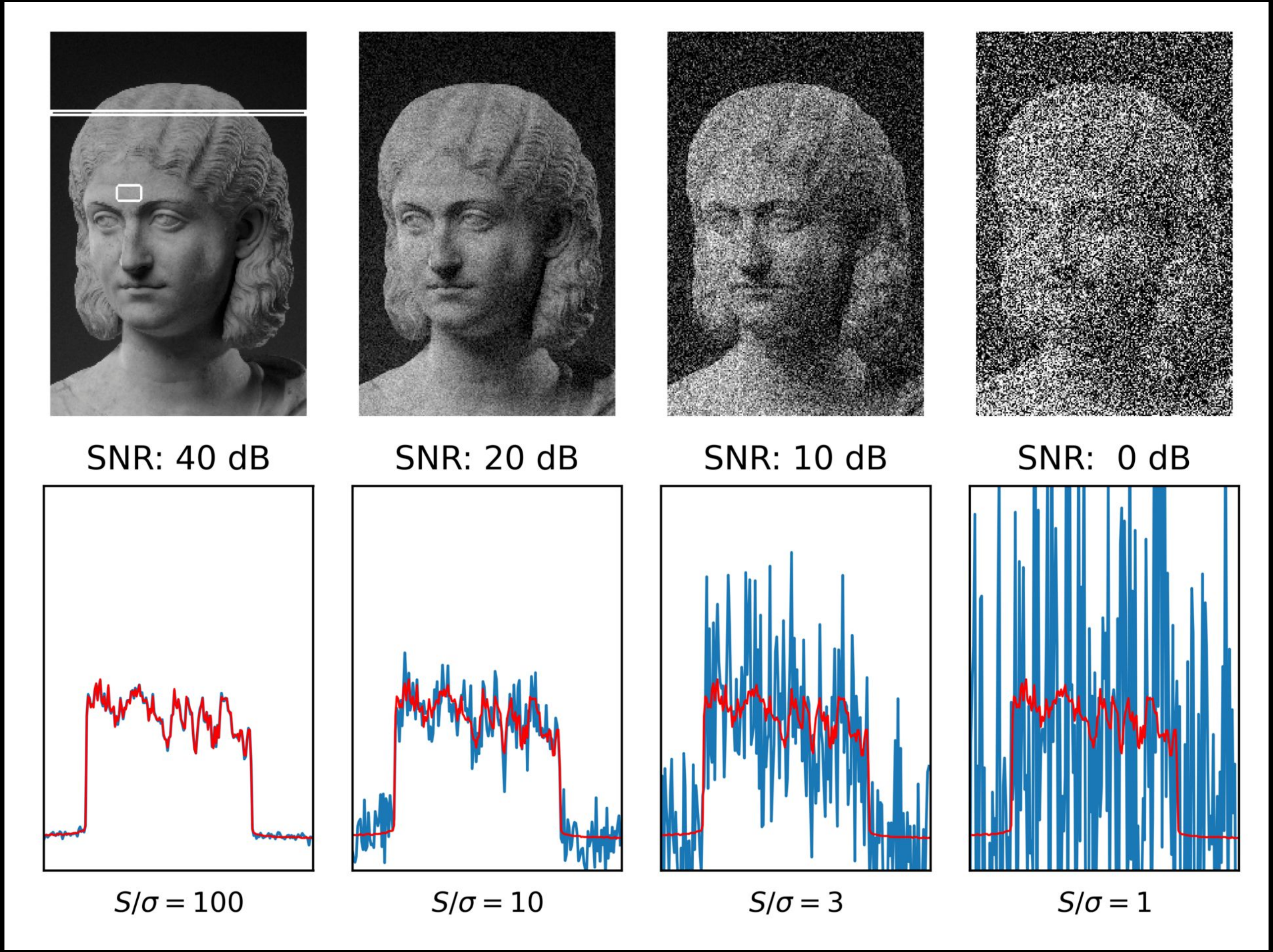




Stack Exchange

Integration Time

- CHORD will produce 4 + 4 bit samples, at 3.2 GSPS, over 512 dual polarization antennas = 3.3 terabytes/sec
- We cannot store this for extended periods of time, so we either have to:
  - Trigger on events for short timescale capture (i.e, FRBs)
  - Integrate the data down (cosmology)
- We also need to integrate for many science applications to get the required Signal to Noise ratio



https://en.wikipedia.org/wiki/Signal-to-noise_ratio#/media/File:SNR_image_demonstration.png

How long do I integrate for?

- Do you want to survey the whole sky, or stare at a single location for a long time?
- Can your telescope point, or does it just survey the sky as it goes overhead?
- What is the required SNR for your science target?
- What is your telescope's field of view?
- Do you need to be able to exclude certain data (i.e, RFI, jacknife testing)
- Etc…
    - For a cosmology telescope that wants to survey a large period of the sky, and does not track (driftscan), often you need hundreds/thousands of hours to meet science goals
    - Sky motion through the beam limits feasible integration to second timescales, and most integration is done offline