

Signals, Sampling & Filtering

Scientific Computing, Fall 2019

- Representation of Signals in Time vs Frequency Domain
- Fast Fourier Transform (FFT)
- Sampling
- Spectrum
- Filtering
- Quantization

Market Summary > Apple Inc.

NASDAQ: AAPL

262.02 USD **-0.18 (0.071%)** ↓

Nov. 12, 12:28 p.m. EST · Disclaimer

1 day

5 days

1 month

6 months

YTD

1 year

5 years

Max



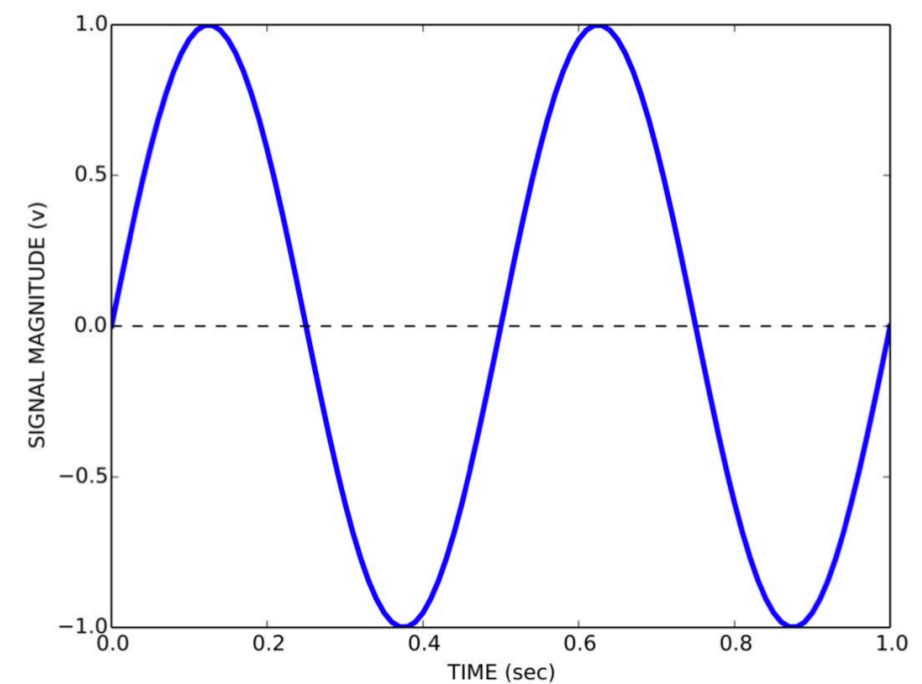
Open	261.55	Div yield	1.18%
High	262.68	Prev close	262.20
Low	260.92	52-wk high	262.68
Mkt cap	1.16T	52-wk low	142.00
P/E ratio	22.11		

→ [Financial news, comparisons and more](#)

Time Domain Representation

$$s(t) = \left(\frac{b}{2}\right) \sin(\omega t)$$

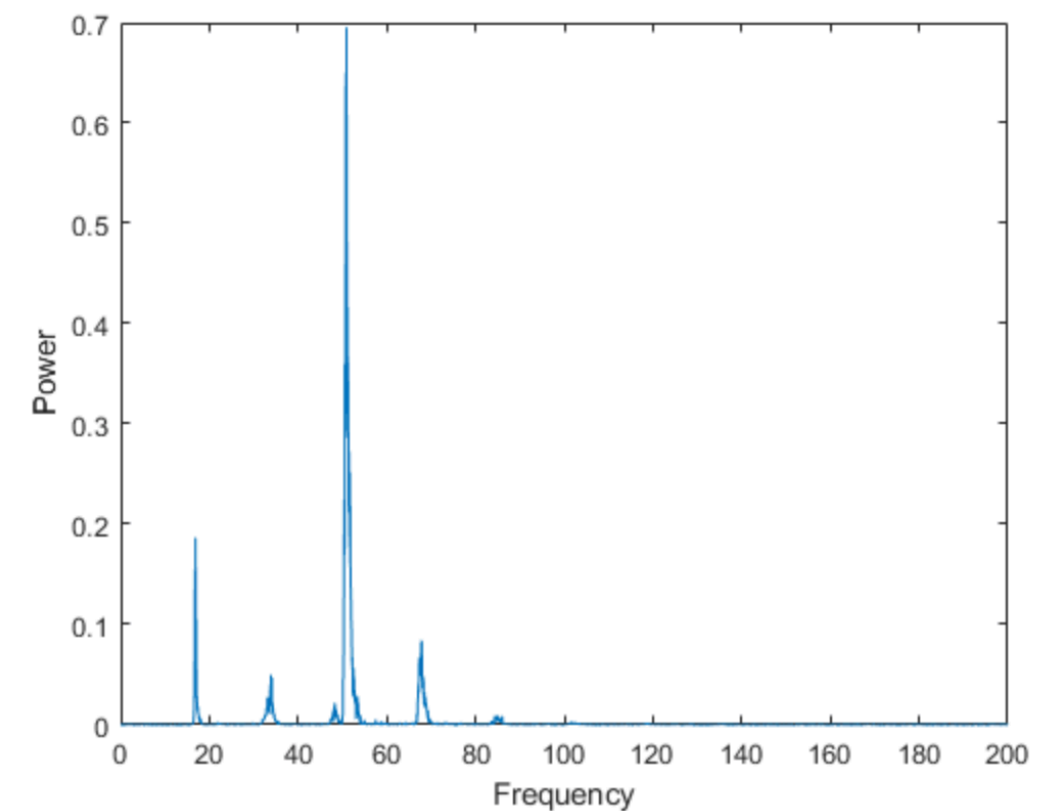
$$\omega = \frac{2\pi}{T}$$



Frequency Domain Representation

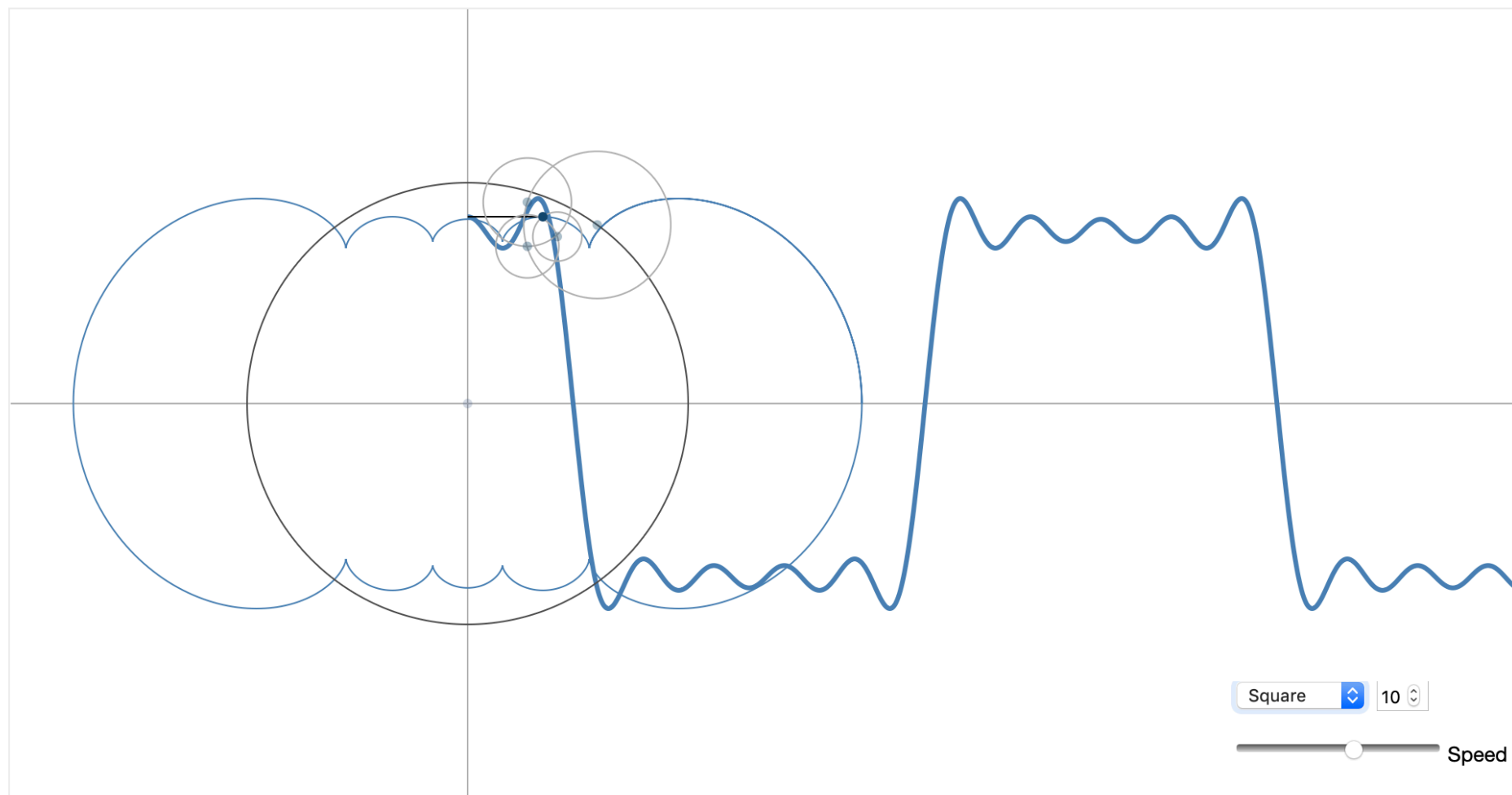
amplitude/power phase

$$s(t) = \frac{a_0}{2} \sum_{n=1}^{\infty} [r_n \cos(n\omega t - \phi_n)]$$



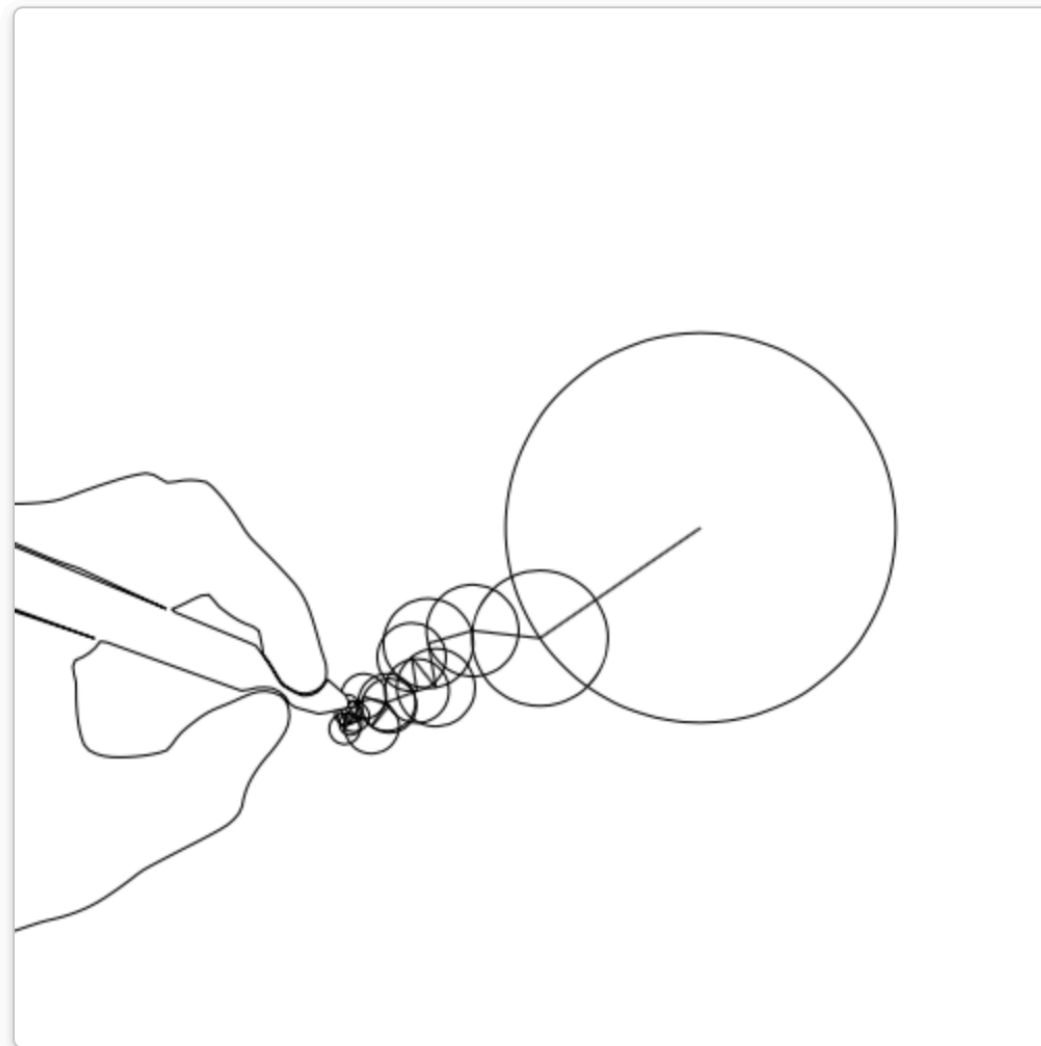
Fourier series visualisation

<https://bl.ocks.org/jinroh/7524988>



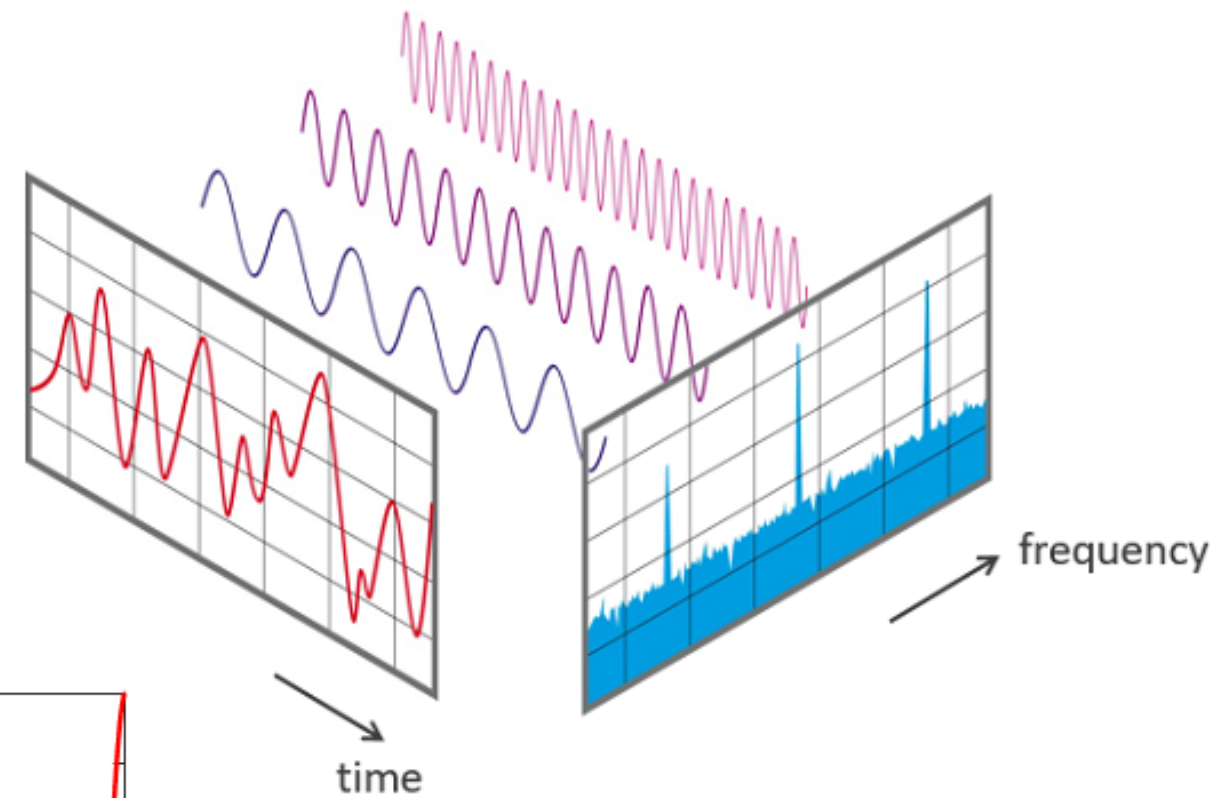
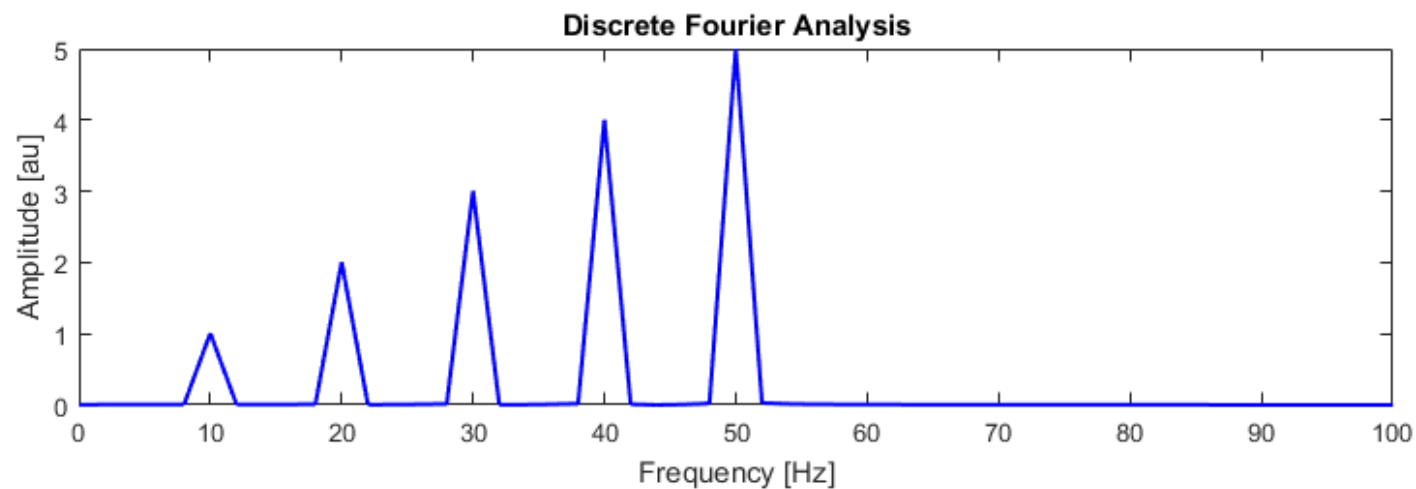
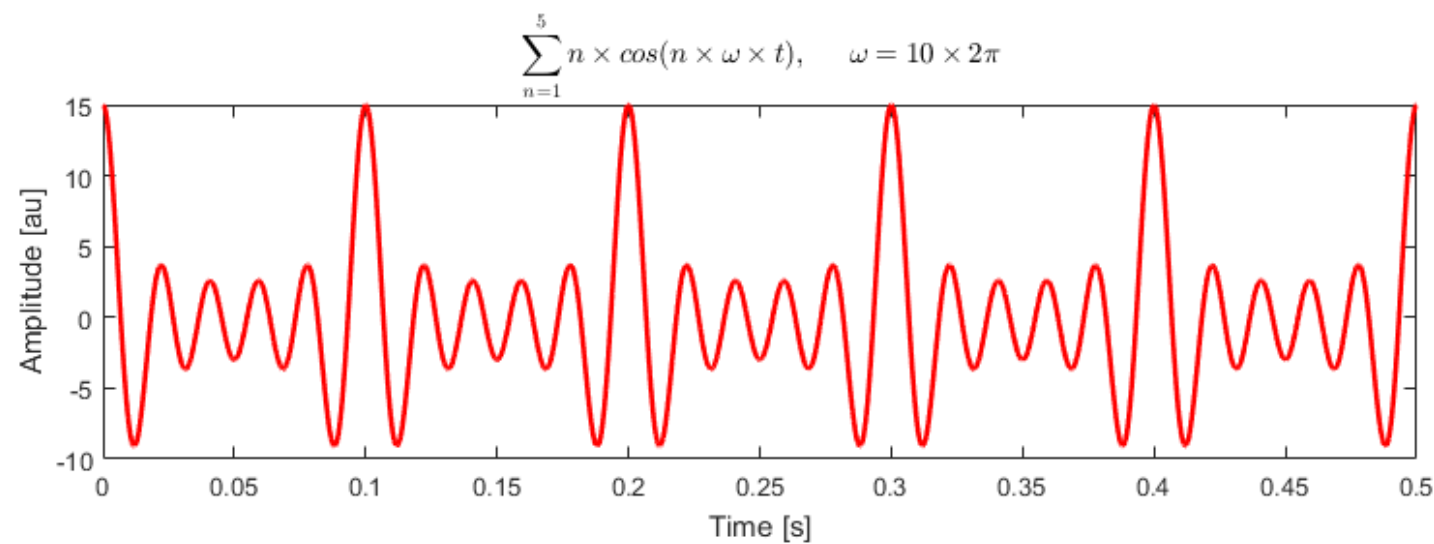
Fourier series visualisation

<http://www.jezzamon.com/fourier/>

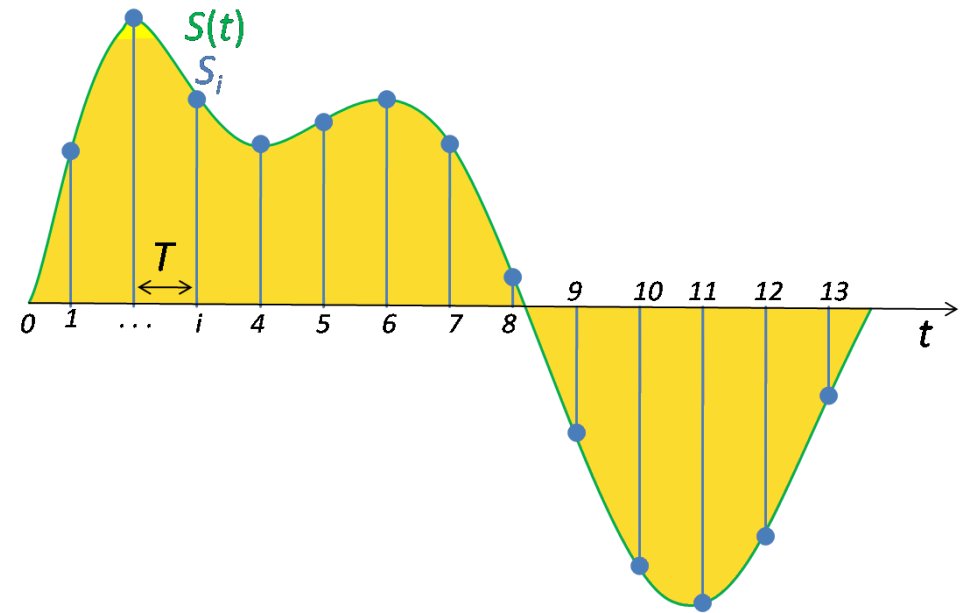


Fast Fourier Transform (FFT) Algorithm

- MATLAB function `fft()`



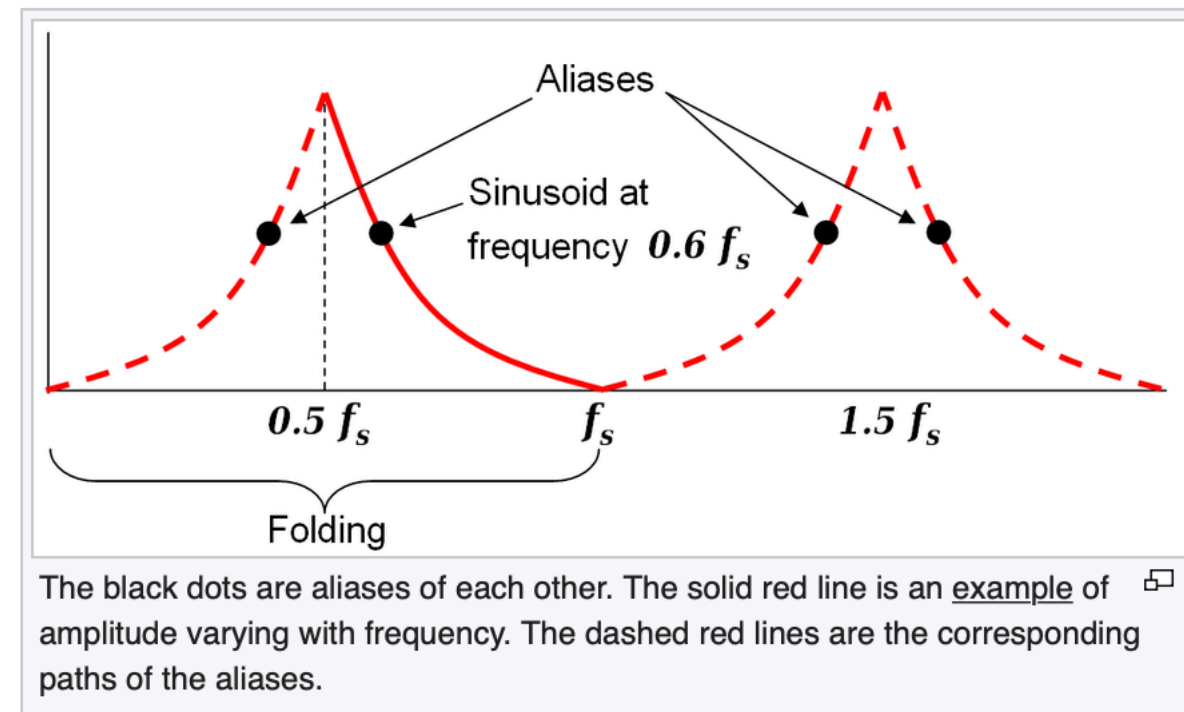
Sampling



- Taking measurements of a continuous (e.g. analog) signal at discrete points in time
- Sampling rate, e.g. 1000 Hz
- Nyquist–Shannon sampling theorem & the Nyquist frequency
- aliasing

Aliasing

- Signal power in frequencies above the Nyquist frequency are aliased down into lower frequencies



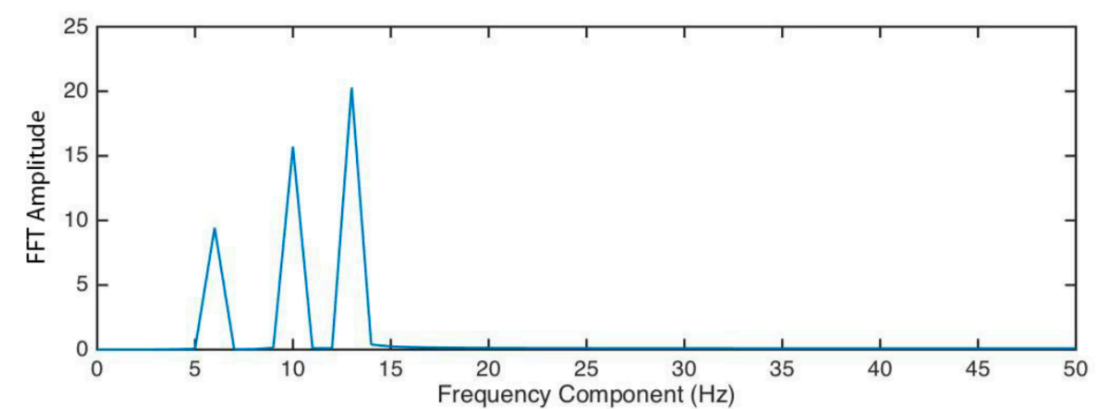
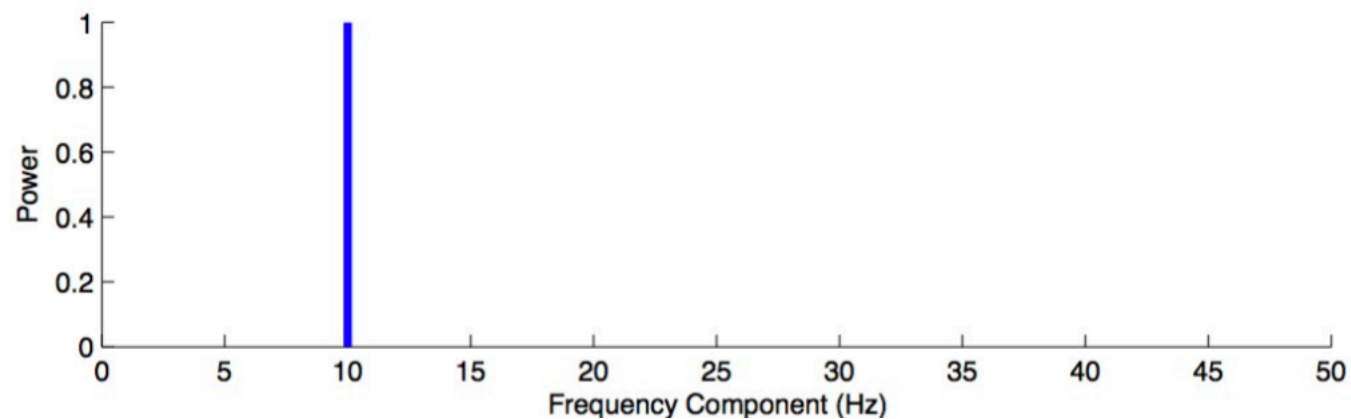
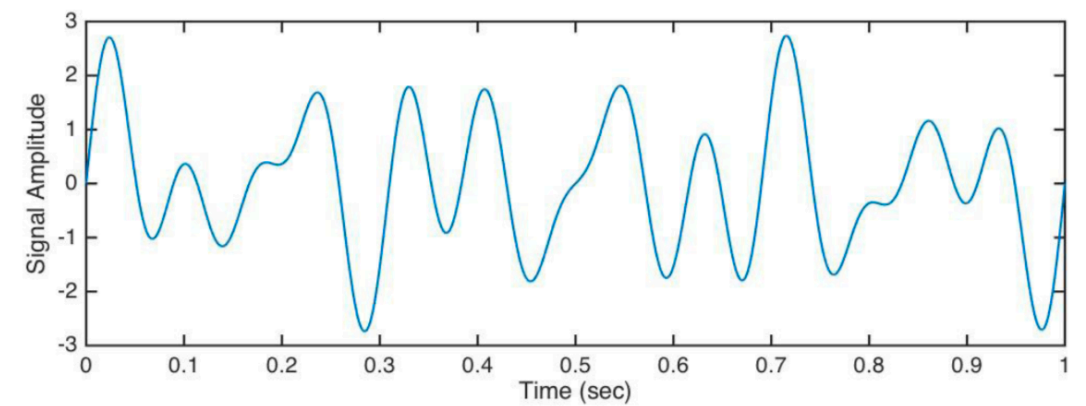
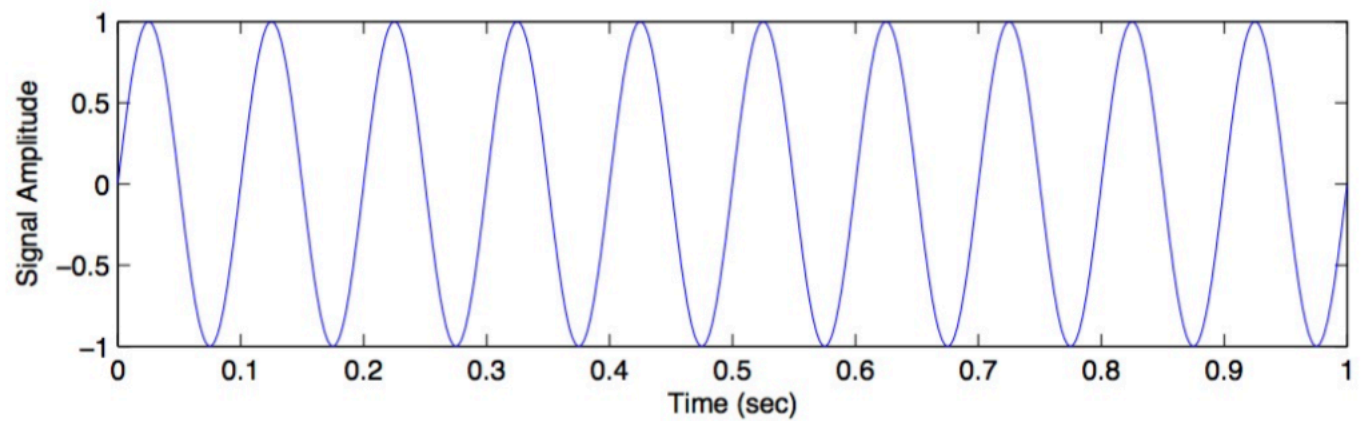


**Downsampled
without first low-pass
filtering**

Moiré pattern

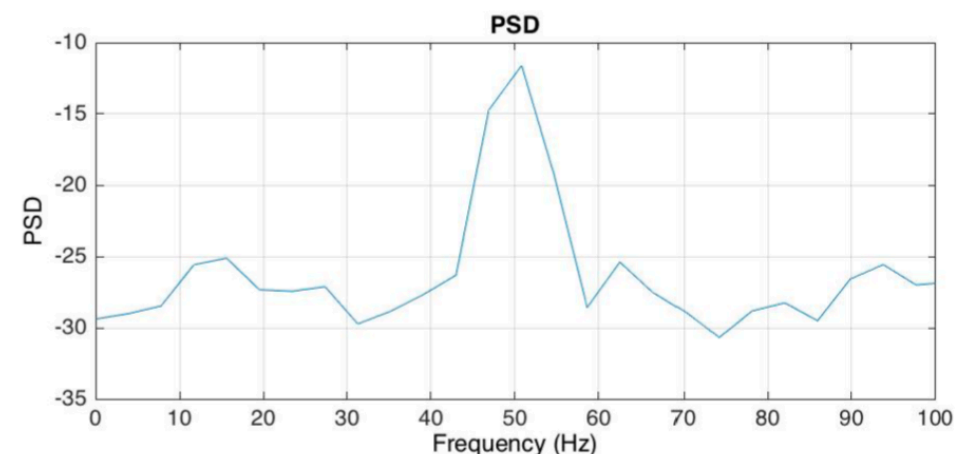
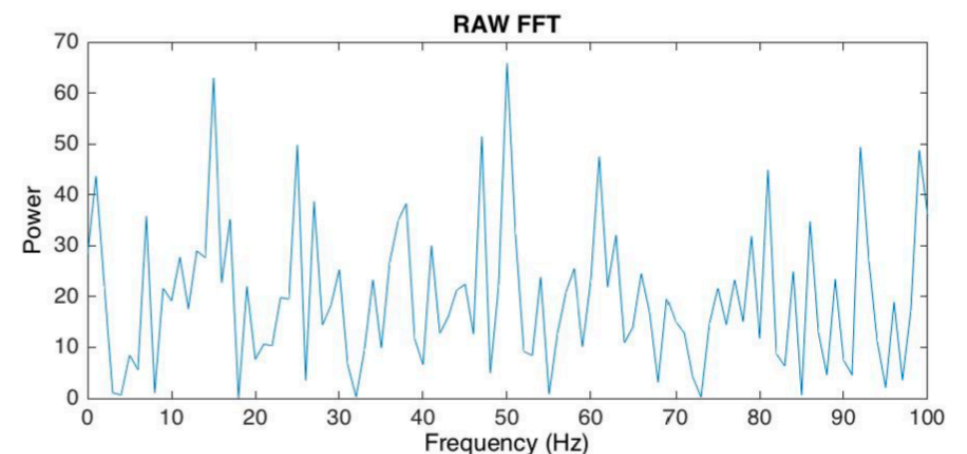
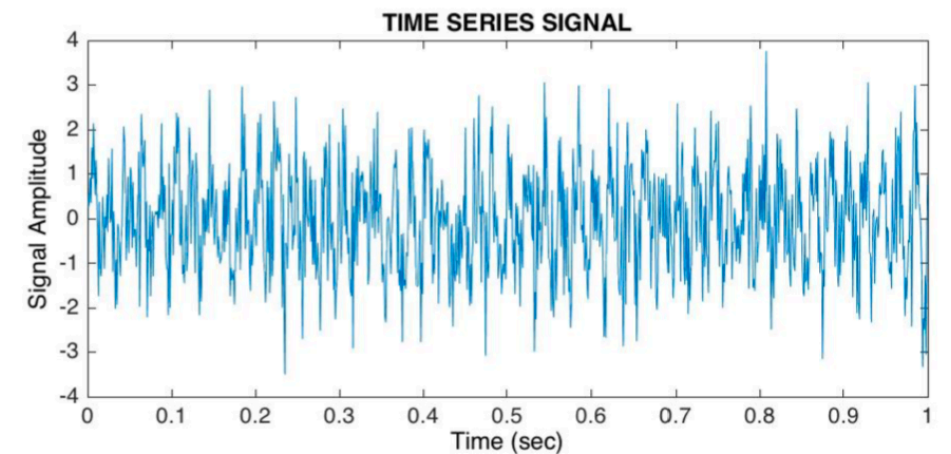
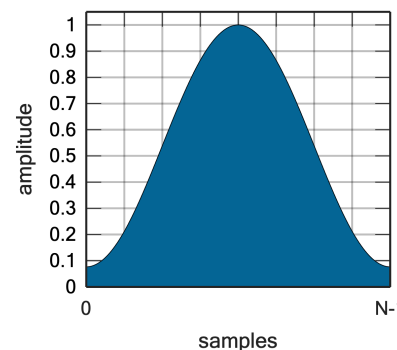
Spectrum

- Signal power at different frequencies



Power Spectral Density (PSD)

- Split signal into overlapping time windows
- Weight each window e.g. using a Hamming window
- FFT each window
- Average all the FFTs to get the PSD estimate



Spectrogram

- Spectrum over time
- MATLAB function spectrogram()

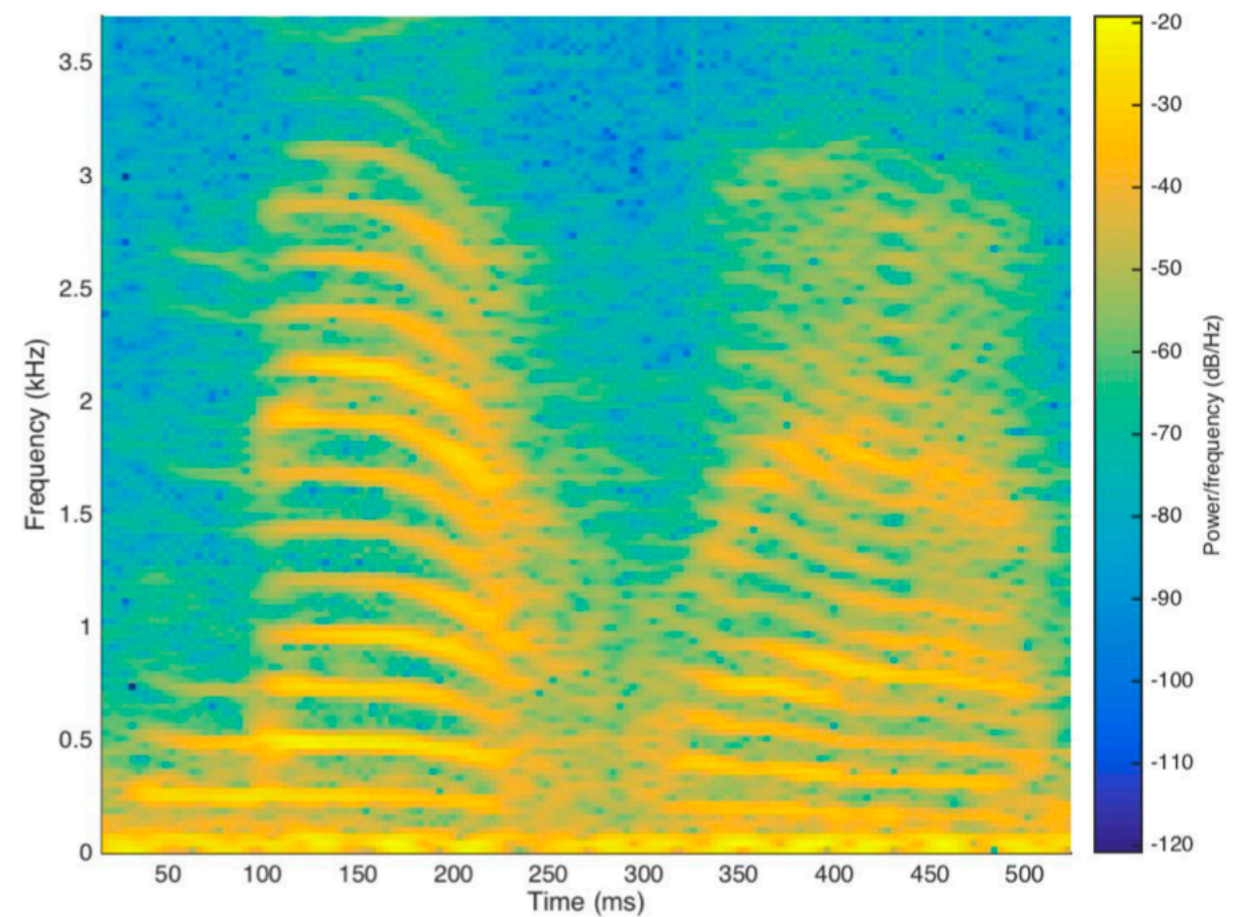
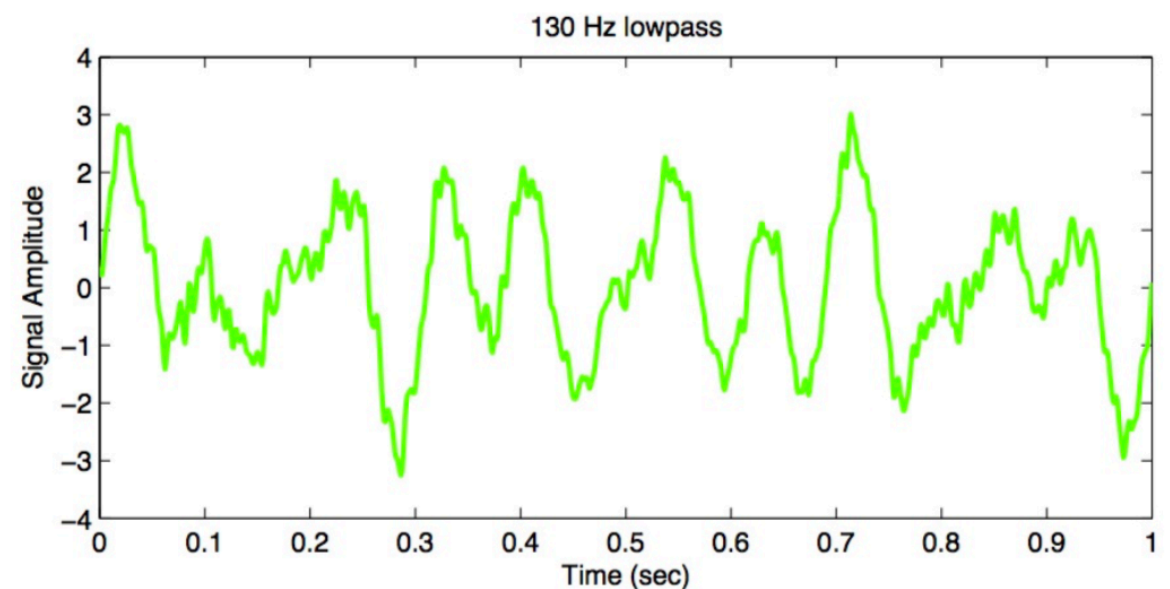
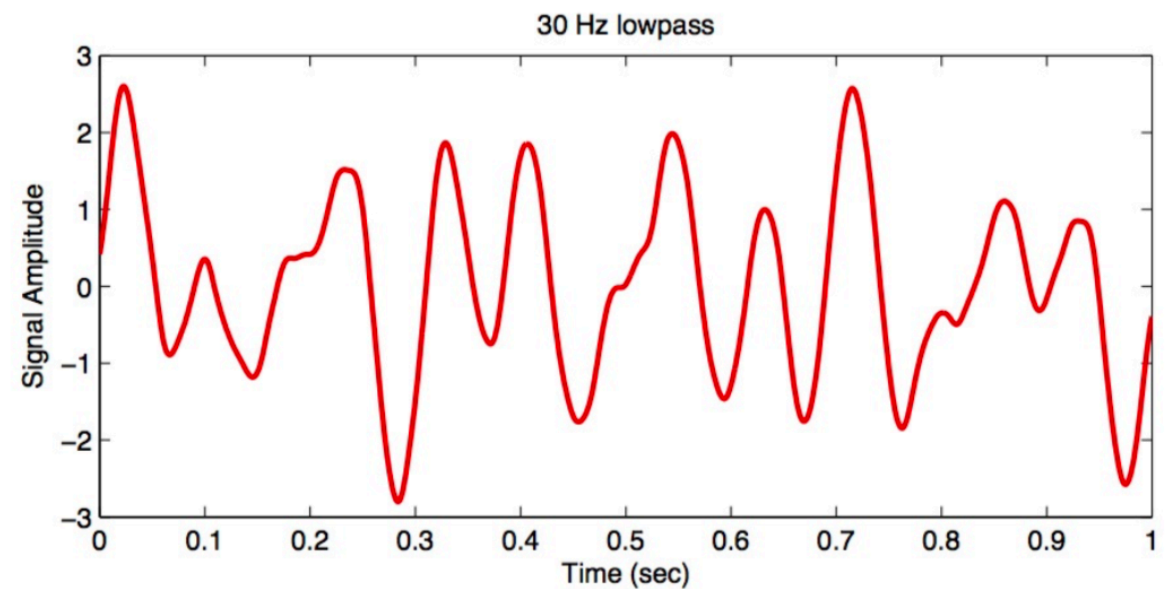
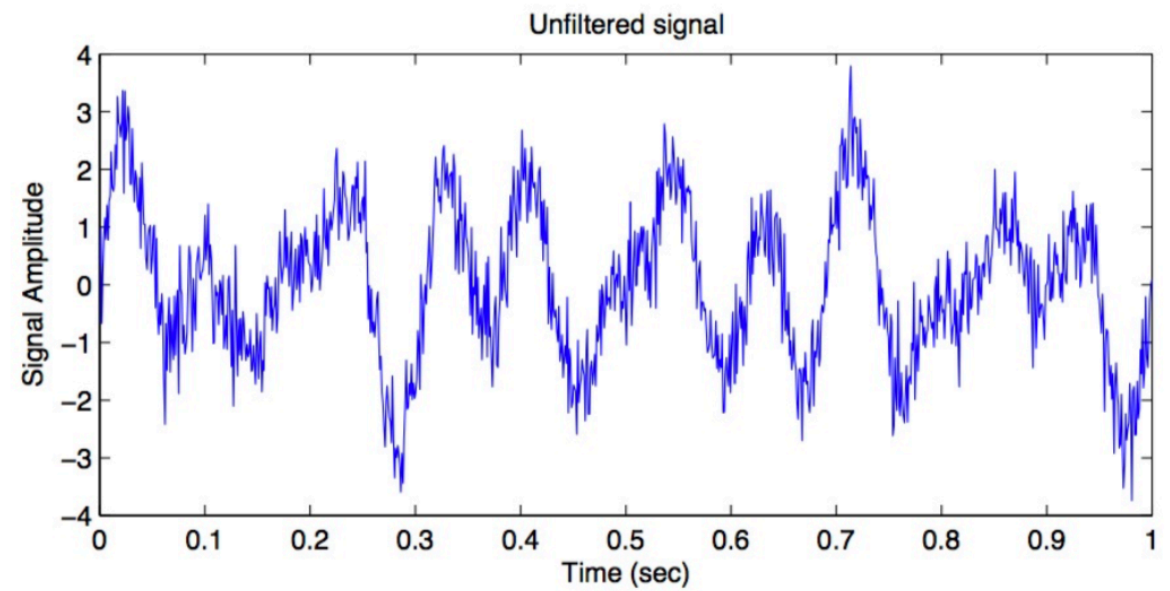


Figure 7: Spectrogram of the sound "MATLAB".

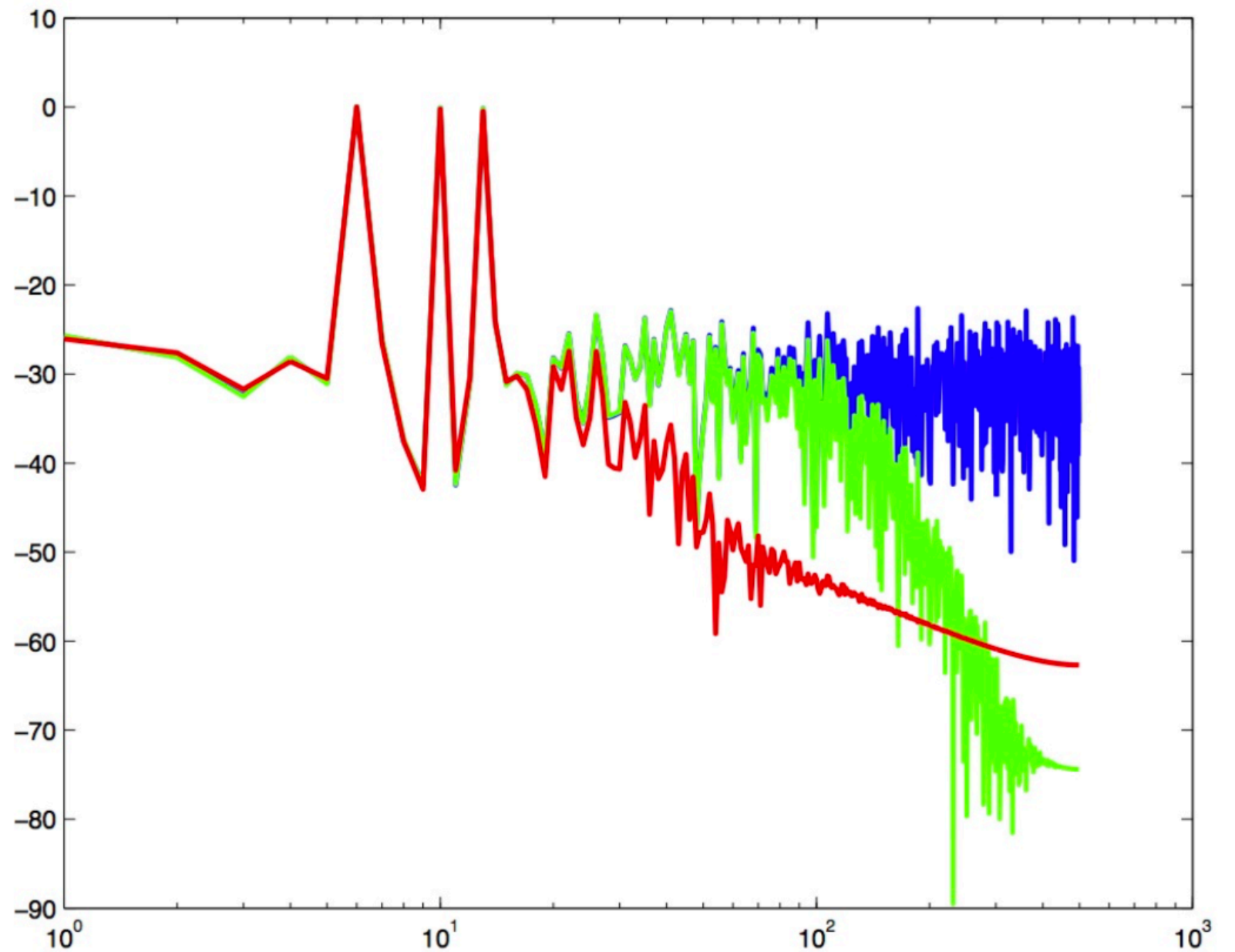
Filtering

- lowpass
- highpass
- bandpass
- bandstop



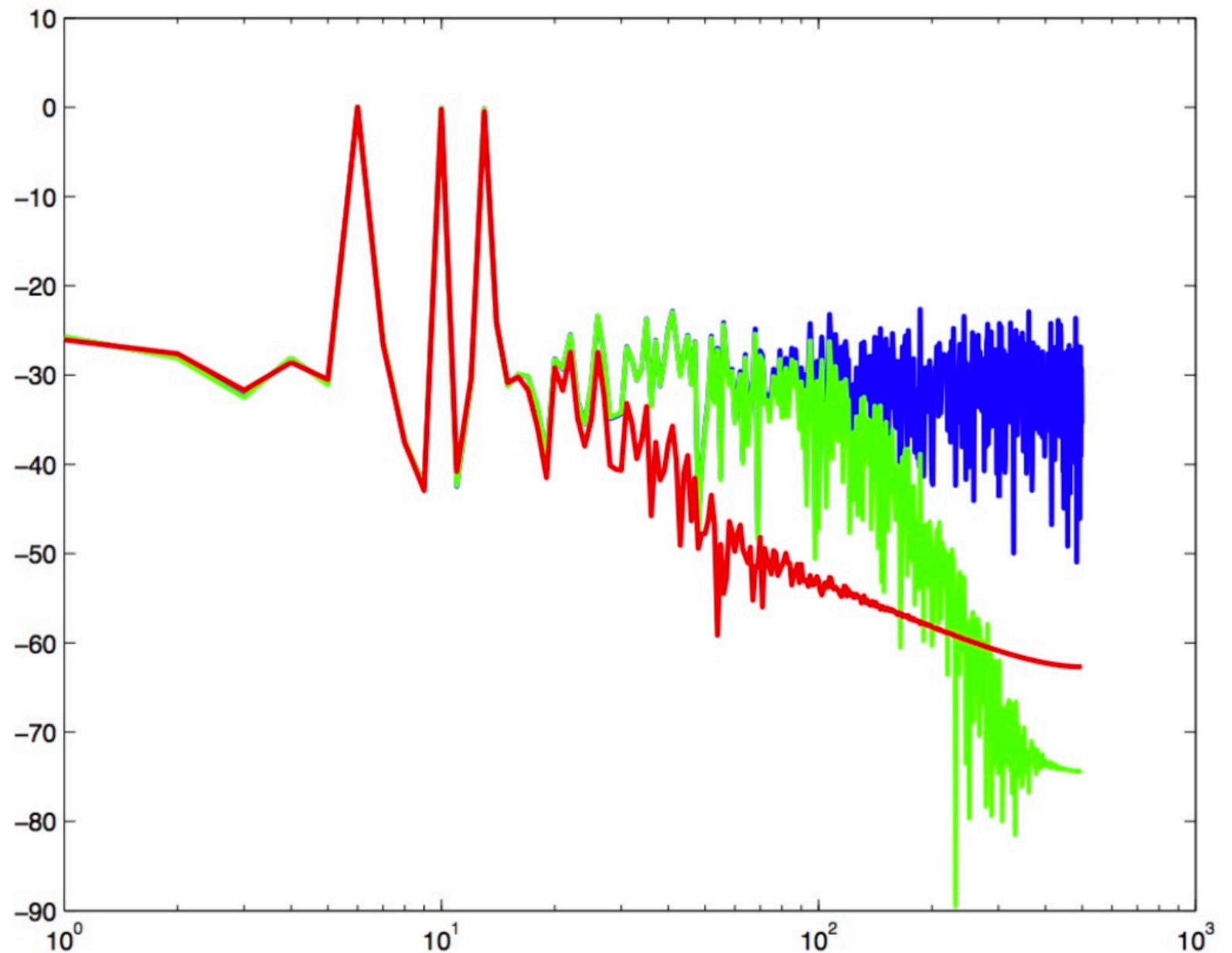
Filtering

- lowpass
- highpass
- bandpass
- bandstop



Filtering

- cutoff or corner frequency
- pass band, stop band
- rolloff



Quantization

- like a sampling rate but not over time, but over the range of the input signal
- usually expressed in number of **bits** over input range in **Volts**
- 12-bit vs 16-bit A/D board

