Analyses of Continuous Rhythmic Data

MA665

Oct 2012

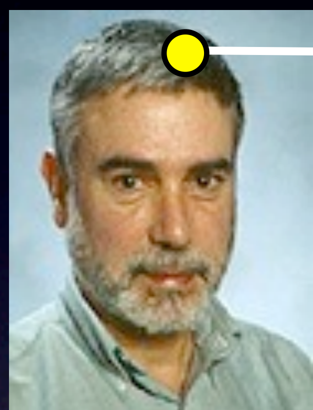
Outline

- Rhythms in neuroscience.
  - They’re everywhere . . .
- Motivates the study of rhythms, particularly . . .
  - Characterize rhythms in data
- An introduction . . .
- Hands on MATLAB examples

An experiment

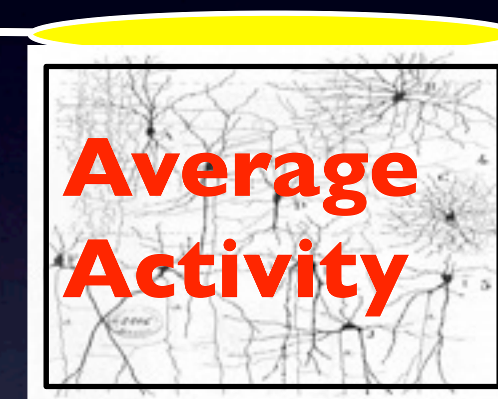
Electroencephalogram (EEG)

Rhythms or oscillations

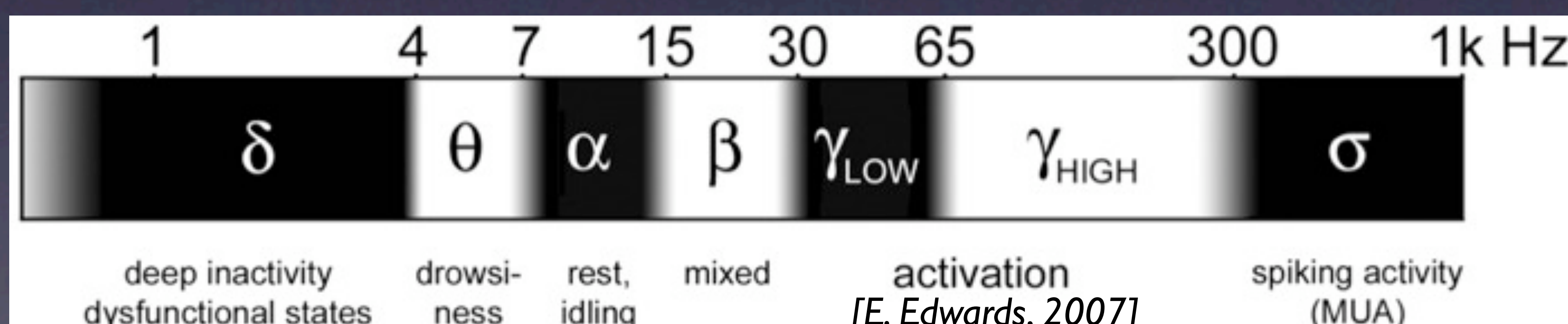


v

Time [10 s]



Q: What produces EEG rhythms?



Rhythms are everywhere . . .

Examples

1. Title: From Prestimulus Alpha Oscillation to Visual-evoked Response: An Inverted-U Function and Its Attentional Modulation
Author(s): Rajagovindan Rajasimhan; Ding Mingzhou
Source: JOURNAL OF COGNITIVE NEUROSCIENCE Volume: 23 Issue: 6 Pages: 1379-1394 DOI: 10.1162/jocn.2010.21478 Published: JUN 2011
Times Cited: 7 (from All Databases)
FIND BU [View abstract]

2. Title: The role of phase synchronization in memory processes
Author(s): Fell Juergen; Axmacher Nikolai
Source: NATURE REVIEWS NEUROSCIENCE Volume: 12 Issue: 2 Pages: 105-U1500 DOI: 10.1038/nrn2979 Published: FEB 2011
Times Cited: 6 (from All Databases)
FIND BU [View abstract]

3. Title: Thalamic Dysfunction in Schizophrenia Suggested by Whole-Night Deficits in Slow and Fast Spindles
Author(s): Ferrarelli Fabio; Peterson Michael J.; Sarasso Simone; et al.
Source: AMERICAN JOURNAL OF PSYCHIATRY Volume: 167 Issue: 11 Pages: 1339-1348 DOI: 10.1176/appi.ajp.2010.09121731 Published: NOV 2010
Times Cited: 6 (from All Databases)
FIND BU [View abstract]

4. Title: Oscillatory Synchronization in Large-Scale Cortical Networks Predicts Perception
Author(s): Hipp Joerg F.; Engel Andreas K.; Siegel Markus
Source: NEURON Volume: 69 Issue: 2 Pages: 387-396 DOI: 10.1016/j.neuron.2010.12.027 Published: JAN 27 2011
Times Cited: 5 (from All Databases)
FIND BU [View abstract]

5. Title: Nonuniform High-Gamma (60-500 Hz) Power Changes Dissociate Cognitive Task and Anatomy in Human Cortex
Author(s): Gaona Charles M.; Sharma Mohit; Freudenburg Zachary V.; et al.
Source: JOURNAL OF NEUROSCIENCE Volume: 31 Issue: 6 Pages: 2091-2100 DOI: 10.1523/JNEUROSCI.4722-10.2011 Published: FEB 9 2011
Times Cited: 5 (from All Databases)
FIND BU [View abstract]

6. Title: Neuronal Dynamics Underlying High- and Low-Frequency EEG Oscillations Contribute Independently to the Human BOLD Signal
Author(s): Scheeringa Rene; Fries Pascal; Petersson Karl-Magnus; et al.
Source: NEURON Volume: 69 Issue: 3 Pages: 572-583 DOI: 10.1016/j.neuron.2010.11.044 Published: FEB 10 2011
Times Cited: 4 (from All Databases)
FIND BU [View abstract]

Search “oscillation & EEG” in Web of Knowledge: 353 publications in 2011

Search “gamma oscillation & EEG”: 104 publications in 2011

- How can we quantify rhythms in data?
  - Power spectrum

Get the data

- Download example data and code:

  http://makramer.info/MA665

Week 6
Lecture and Lab: Analysis of rhythmic data. Lecture slides as pdf.
Download the lecture data set 6_data.mat and the M-file that includes MATLAB code to analyze these data.
This week's Challenge Problems.
Other data sets for challenges: lfp1.mat, lfp2.mat.
Reading:

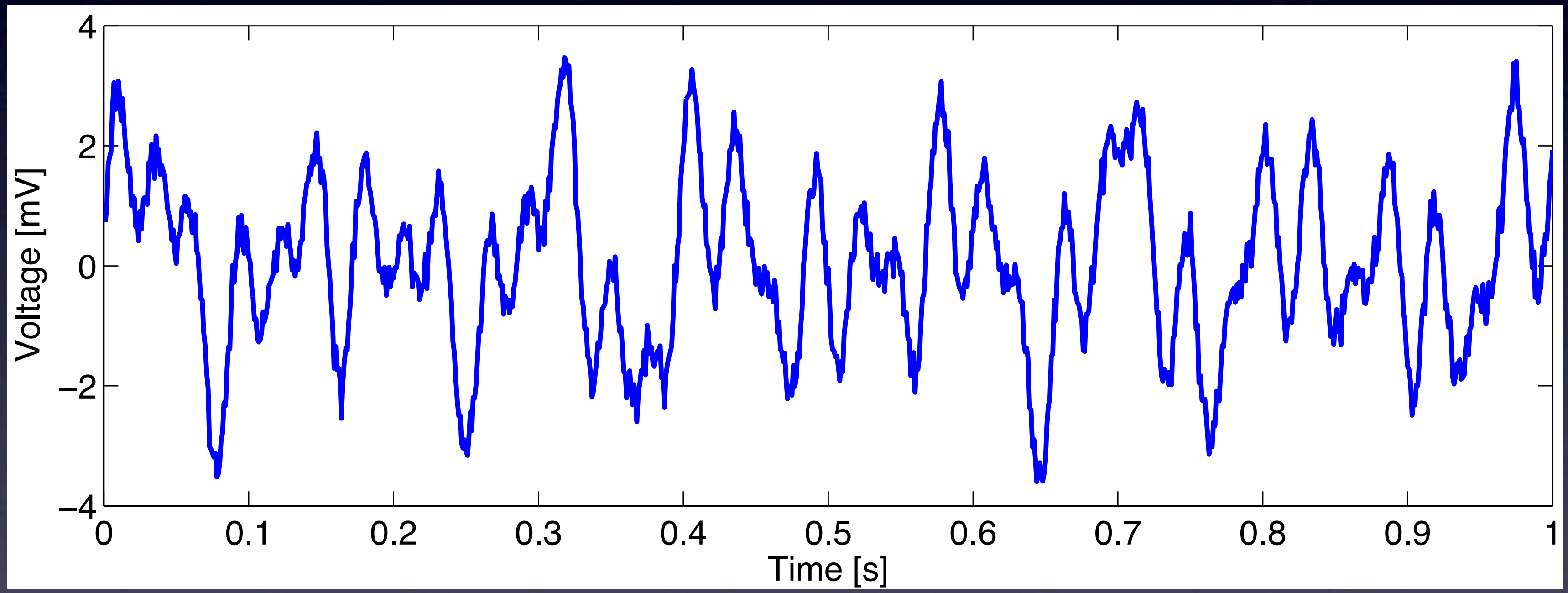
- *MATLAB for Neuroscientists, Ch 7, 8*

Load data & visualize

Download example data: http://makramer.info/MA665

```
>> load 6_data.mat
>> plot(t1,v1)
```

Lab Example 1

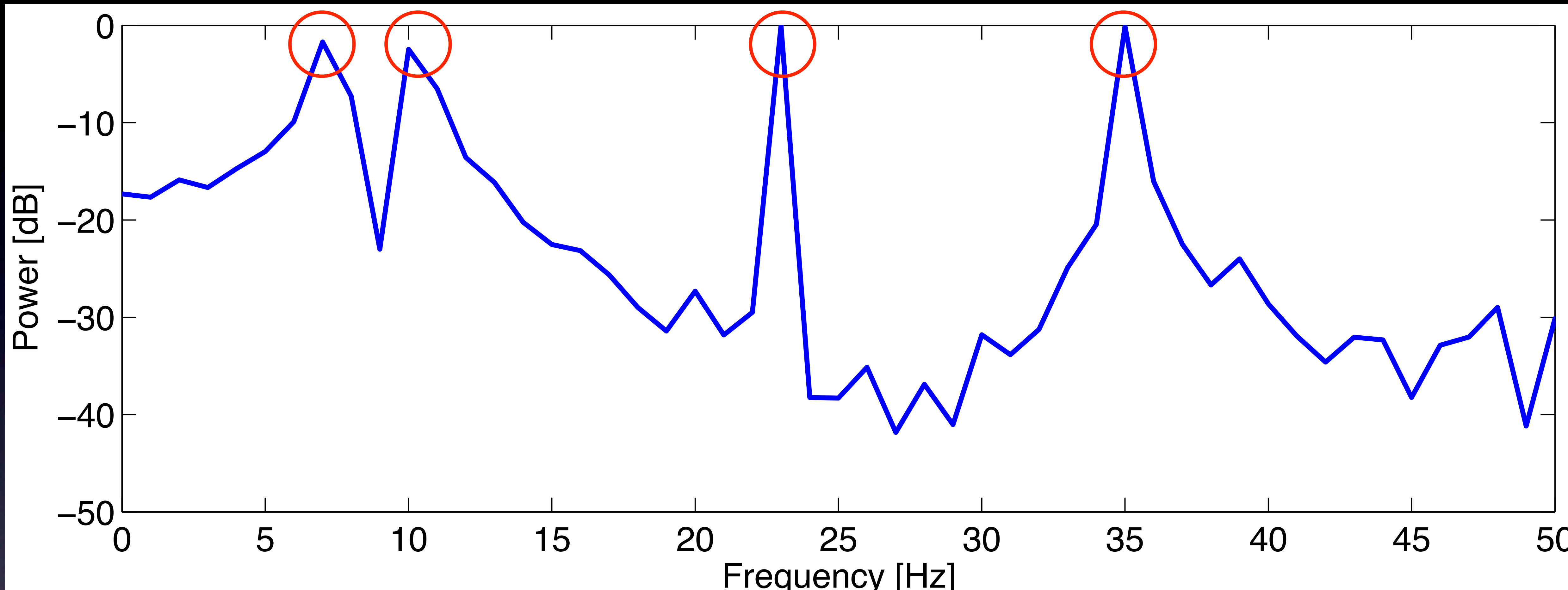


dt = 1ms

Visual inspection:

- Rhythmic
- It's complicated
- How can we simplify?

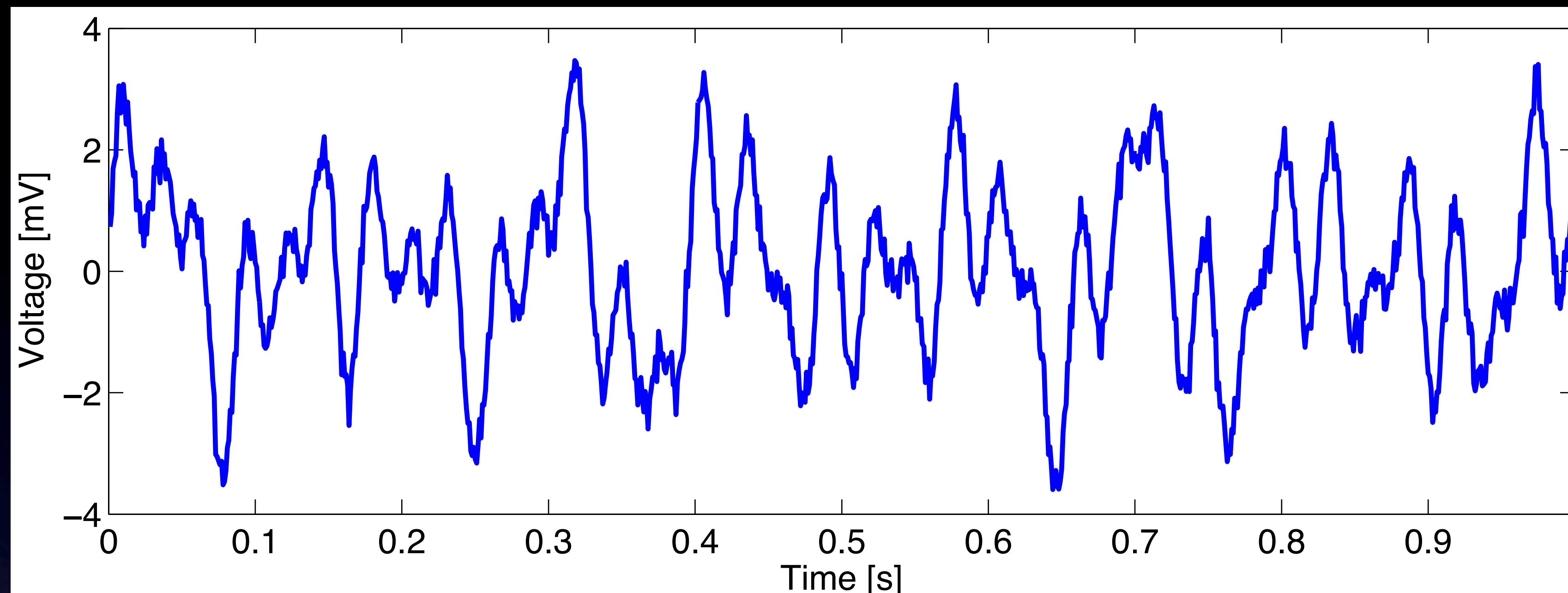
Power spectrum



- Axes: Power [dB] vs Frequency [Hz]
- A simpler representation in frequency domain. Four peaks at {7, 10, 23, 35} Hz
- How do we compute it?

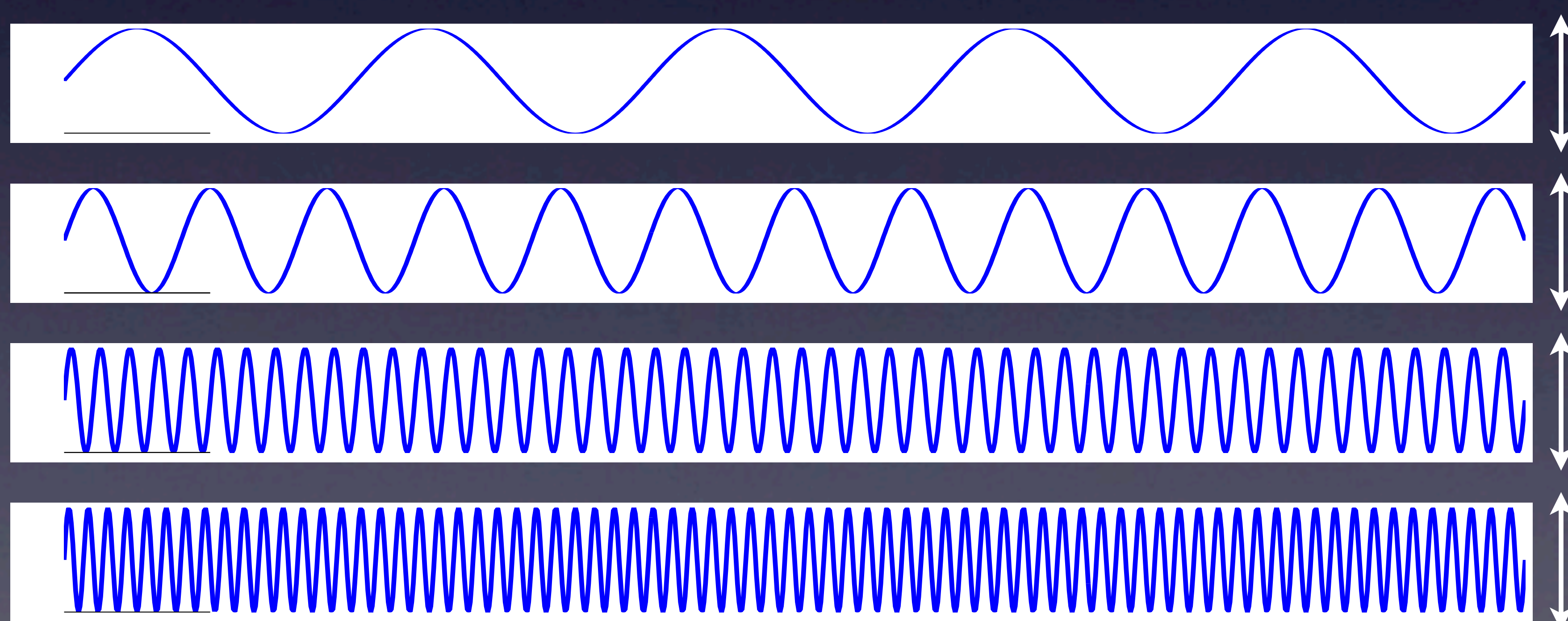
Idea

V =



- Separate signal into oscillations at different frequencies.

V =



A_1 f_1

+ A_2 f_2

+ A_3 f_3

+ A_4 f_4

+ . . .

Represent V as a sum of sinusoids (e.g., part 7 Hz, part 10 Hz, . . .)

Orthogonality of sinusoids

In class we said,

$$\int_0^1 \cos(2\pi n t)\,\underline{\sin}(2\pi k t)\,dt = 0$$

Let's check this . . .

Lab Example 2

Idea

We want to decompose data V[t] into sinusoids.

We need to find the coefficients: $A_1, A_2, A_3, \ldots B_1, B_2, B_3, \ldots$

In class:

Complex coefficients

Data Sinusoids

$$V[f] = \int_0^1 \boxed{v[t]}\boxed{e^{-2\pi i f t}} dt$$

~ Fourier transform

$$P[f] \sim |V[f]|^2$$

Power

Complex coefficients squared

Choose sinusoid f to match v[t].

Power largest at frequencies (f) in v[t]

In practice

To compute the power in MATLAB use command:

`fft`

```
>> pow = abs(fft(v)).^2 * 2/length(v);
```

Lab Example 3

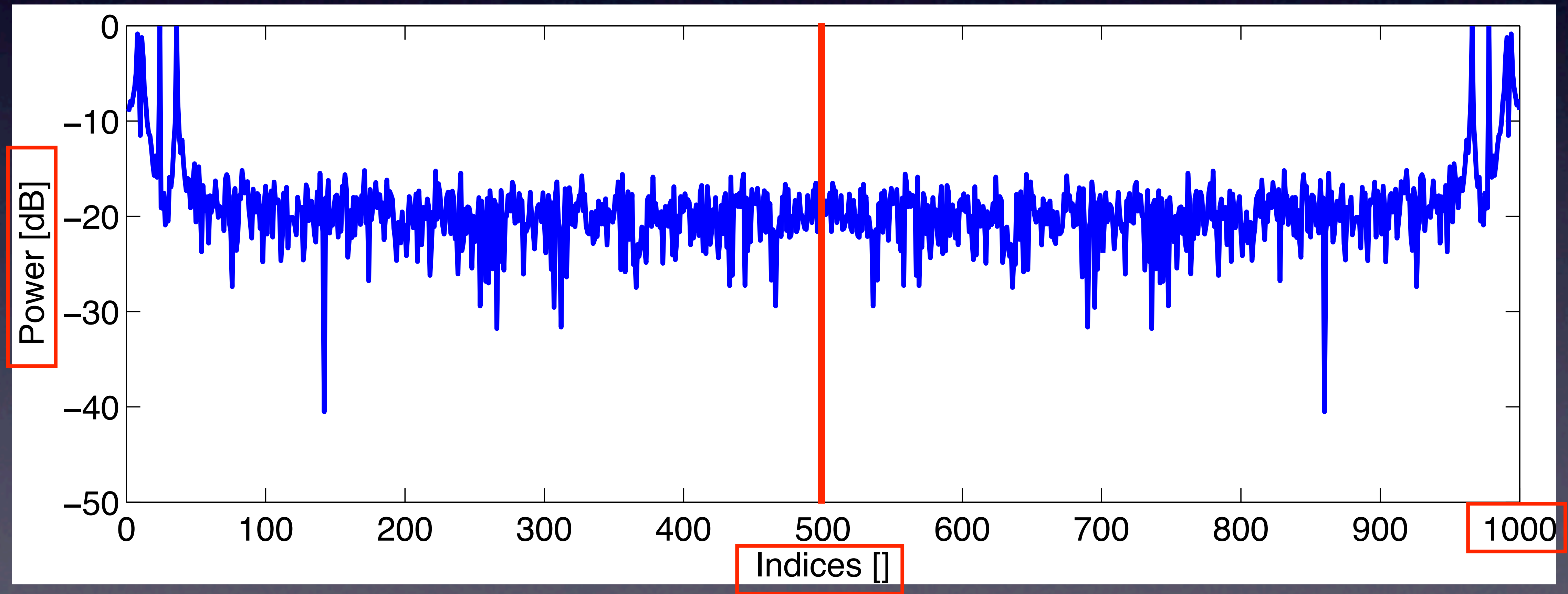
MATLAB code

Lab Example 4

1000 data pts

```
>> pow = abs(fft(v1)).^2*2/length(v1);
>> pow = 10*log10(pow);
>> plot(pow)
```

Clue?



Matches length of v1

Incomplete: Must label the x-axis?

Power spectrum x-axis

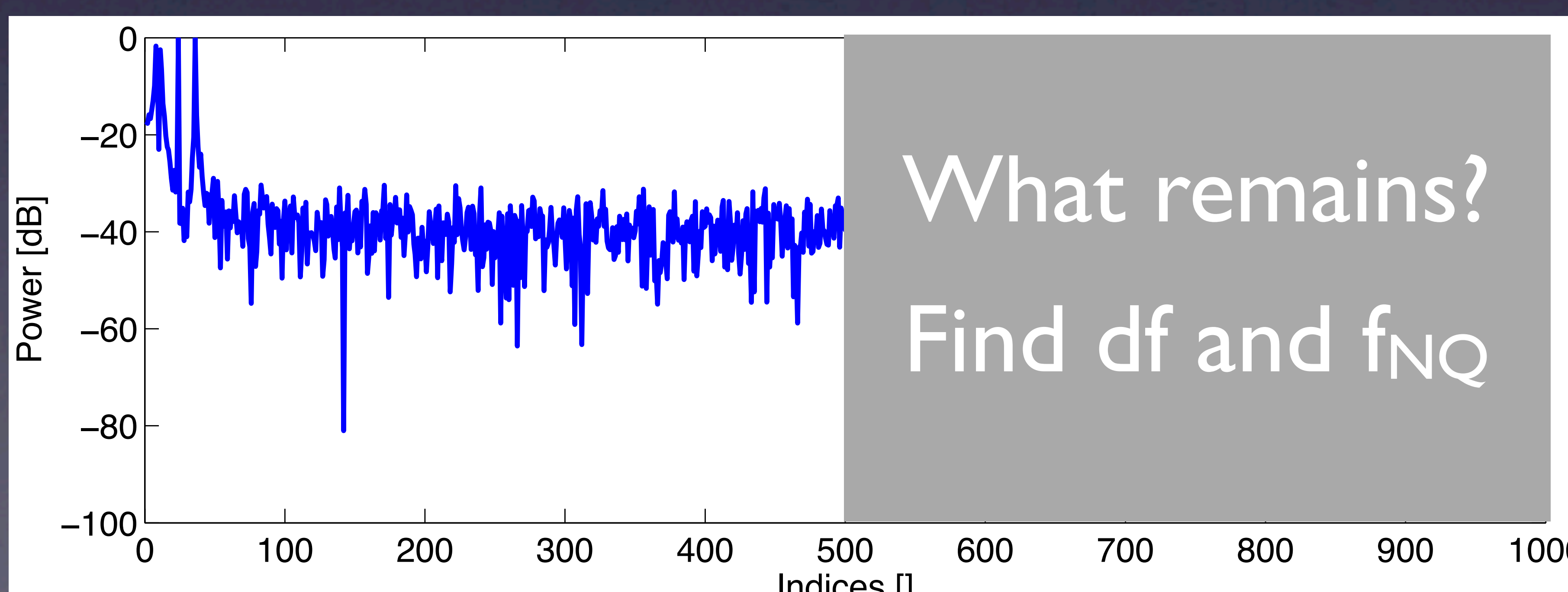
- Indices & frequencies related in a funny way … Examine vector `pow`:

1000

Freq	0	df	2df	…	f_{NQ} - df	f_{NQ}	
Index	1	2	3		500	501	

Frequency resolution f > 0 **Nyquist frequency** f < 0

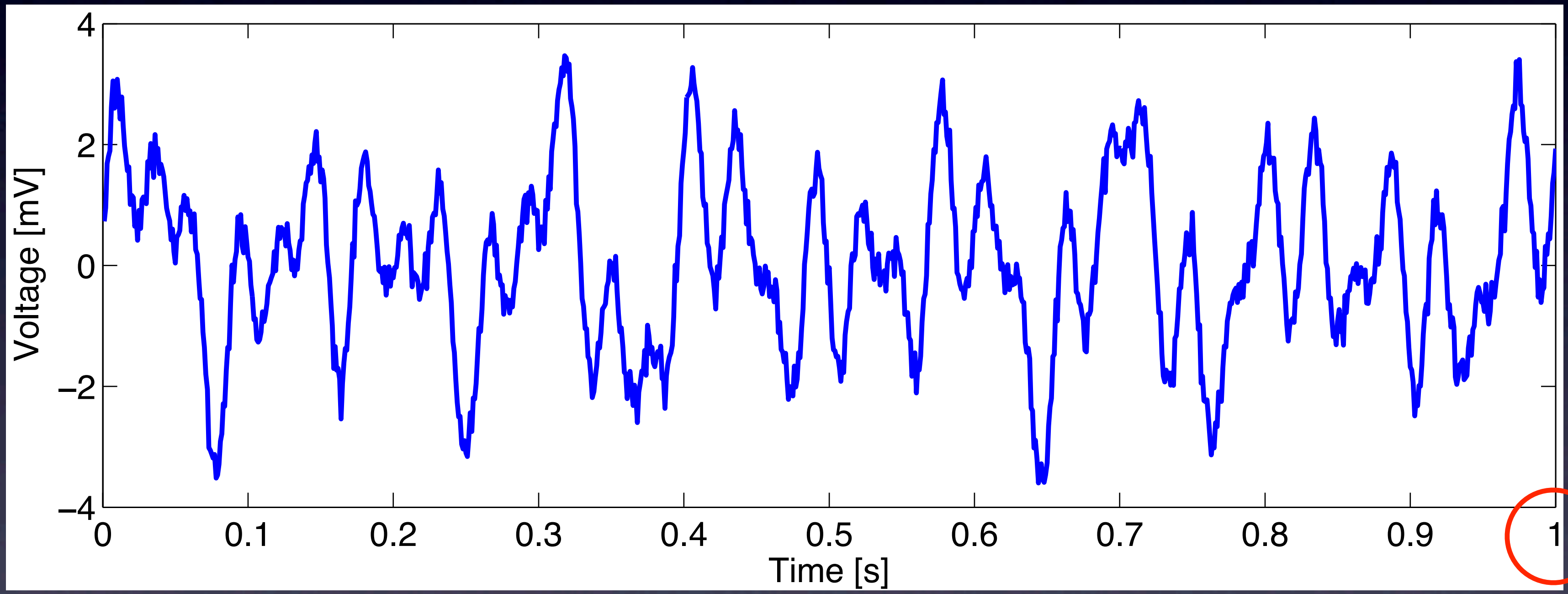
- Because data is real, f < 0 is redundant.



Power spectrum x-axis

- What is df? $$df = \frac{1}{T}$$ where T = Total time of recording.

Ex:

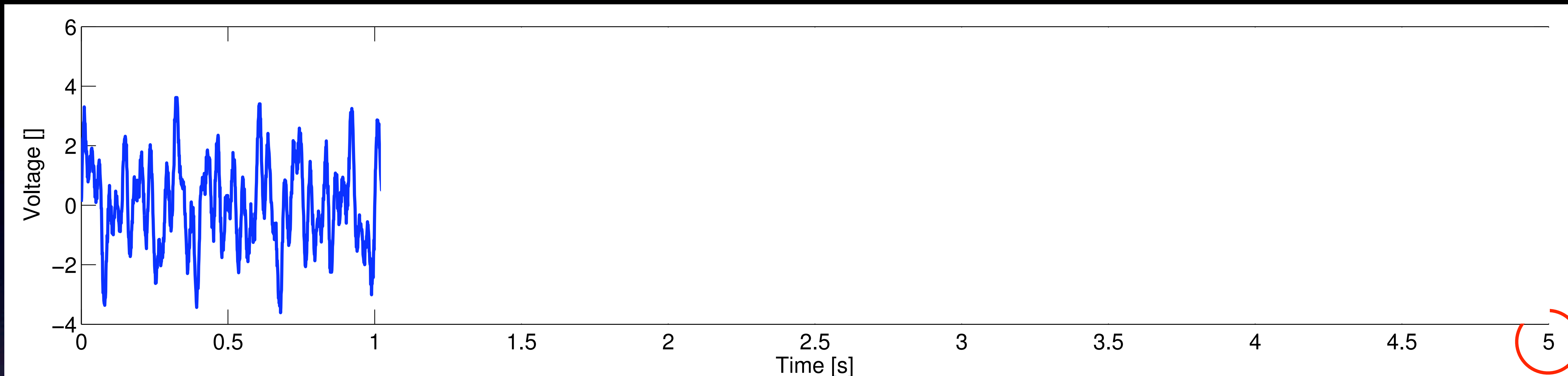


T = 1 s
df = 1 Hz

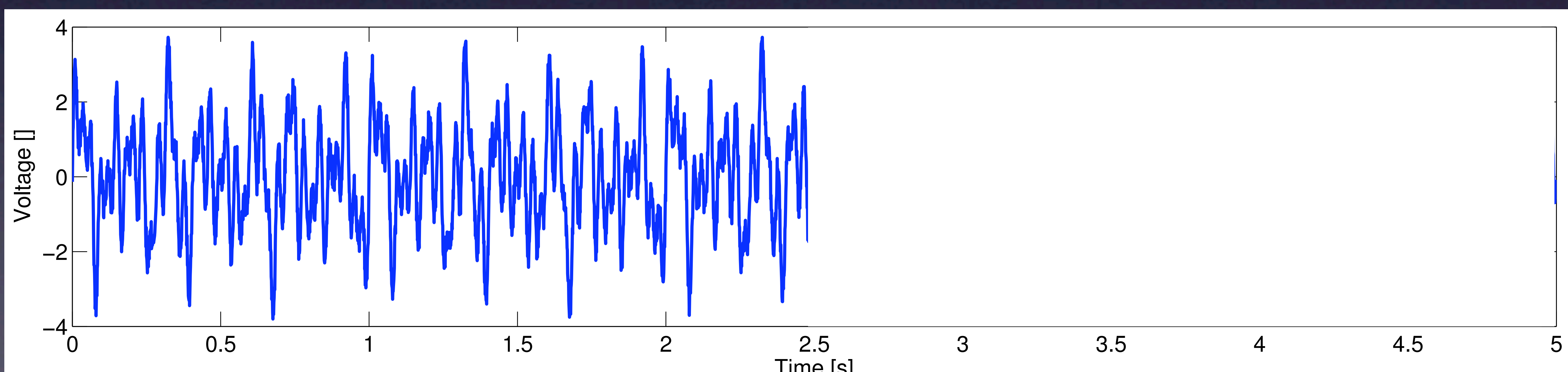
Q: How do we improve frequency resolution?
A: Increase T or record for longer time.

Examples

- Demand 0.2 Hz frequency resolution. df = 1/5s = 0.2 Hz



But, data may change during longer recordings . . .



Different spectra in 1st and 2nd half of data . . .

Balance resolution requirements with consistency in data.

Power spectrum x-axis

- What is f_{NQ}?

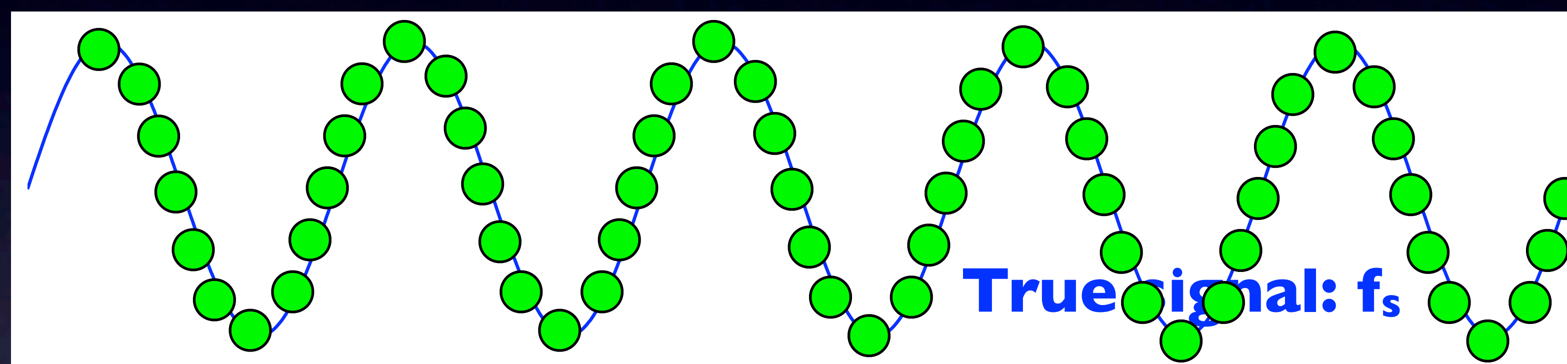
$$f_{\rm NQ} = \frac{f_0}{2}$$

The Nyquist frequency where f_0 = sampling frequency.

The **highest** frequency we can observe.

Sample:

$f_0 >> 2\ f_s$

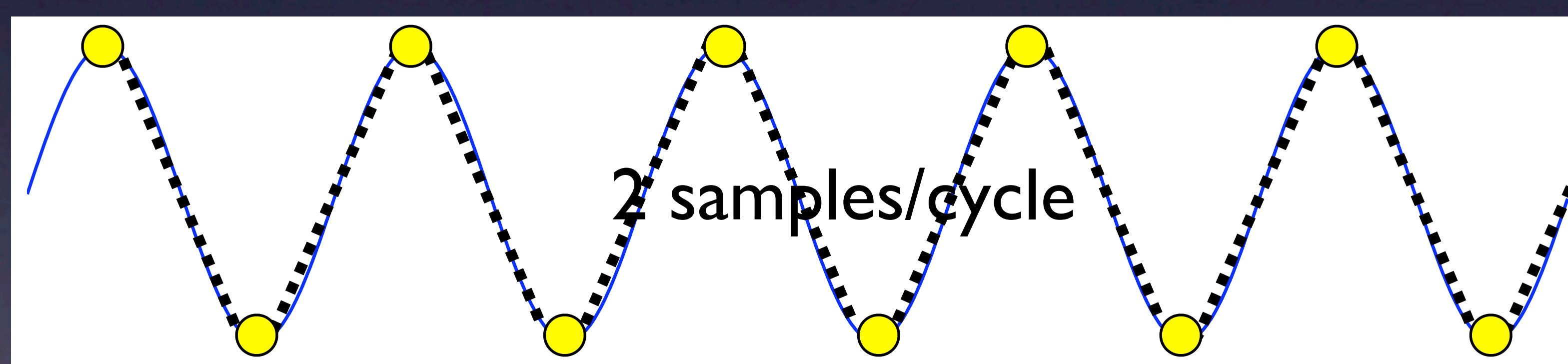


Accurate reconstruction

Too expensive!

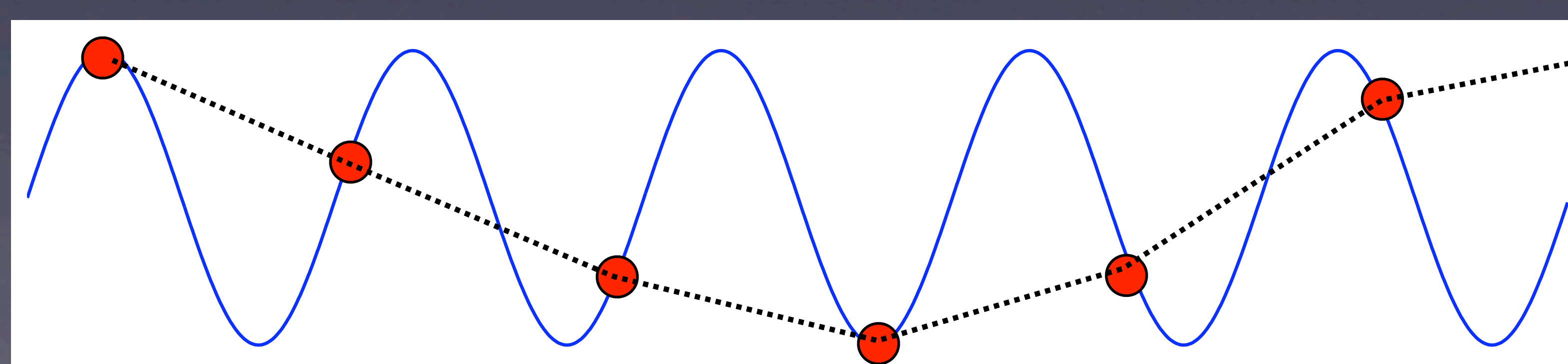
$f_0 = 2\ \boxed{f_s}$

Max freq we can observe at this sample rate!



Enough to reconstruct signal, but just barely.

$f_0 < 2\ f_s$



High frequency (in data) mapped to low frequency (**aliased**).

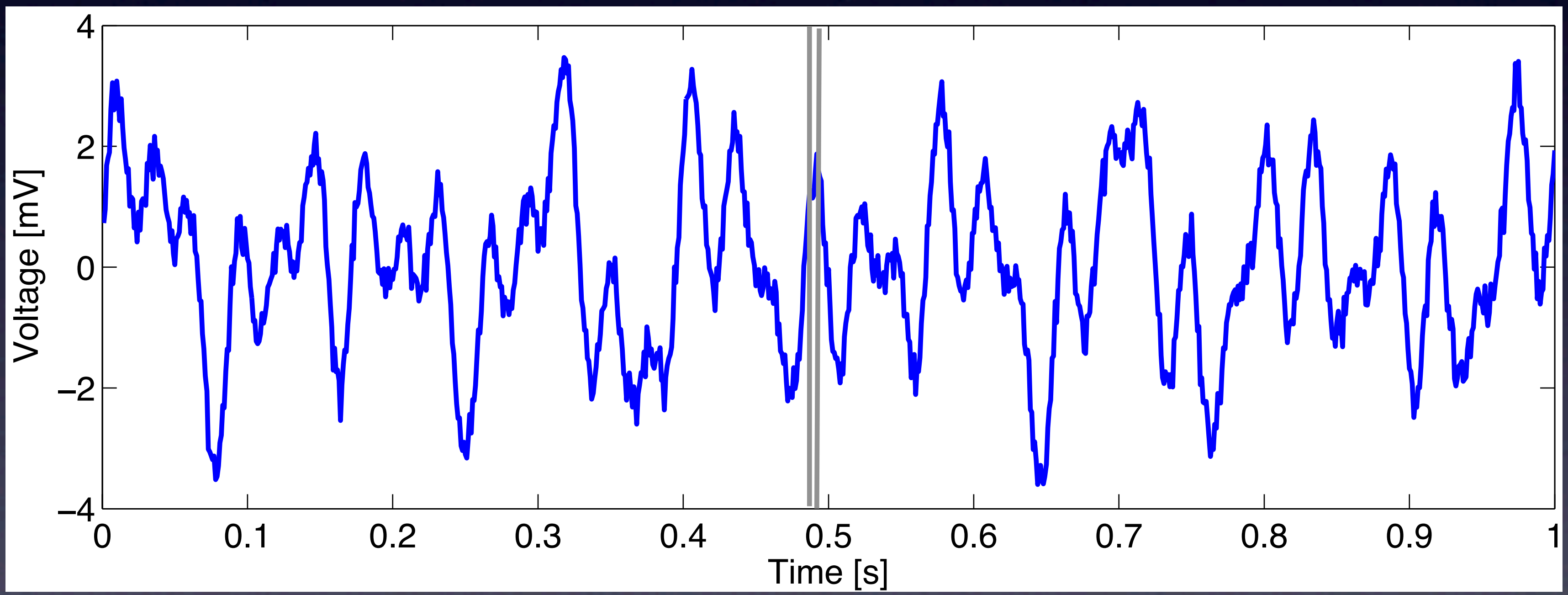
All hope lost! Indistinguishable from true low frequency signals.

Power spectrum x-axis

Moral: Sample fast enough to capture the highest frequency "true" signal.

Sampling interval: $dt = 1$ ms

Ex:



Sampling frequency:

$f_0 = 1/dt$

$f_0 = 1000$ Hz

$f_{NQ} = 500$ Hz

Q: How do we increase the Nyquist frequency?

A: Increase the sampling rate f_0. [Hardware]

MATLAB code

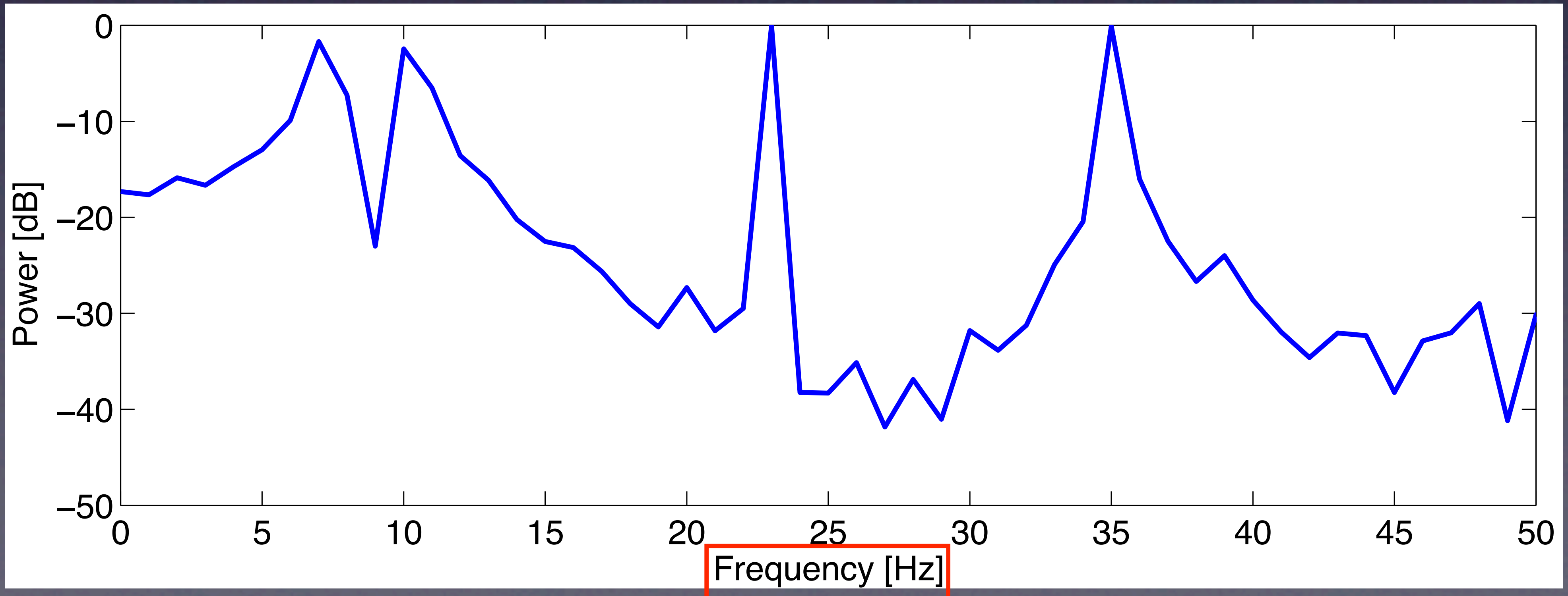
Lab Example 5

```
>> pow = abs(fft(v1)).^2* 2/length(v1);
>> pow = 10*log10(pow);
>> pow = pow(1:length(v1)/2+1);
>> df = 1/max(t1);  fNQ = 1/dt/2;
>> faxis = (0:df:fNQ);
>> plot(faxis, pow);  xlim([0 50]);
```

First half of pow

Define df & f_{NQ}

Frequency axis



Summary

```
>> pow=abs(fft(v1)).^2*2/length(v1);
```

Frequency resolution $$df = \frac{1}{T}$$

Nyquist frequency $$f_{\mathrm{NQ}} = \frac{f_0}{2}$$

- For finer frequency resolution: record more data.
- To observe higher frequencies: increase sampling rate.
- Built-in routines: `>> periodogram(...)`

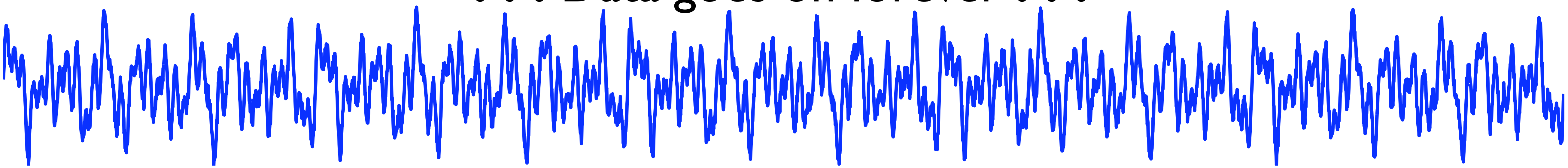
  Requires Signal Processing Toolbox

  Lab Example 6
- Many subtleties . . .

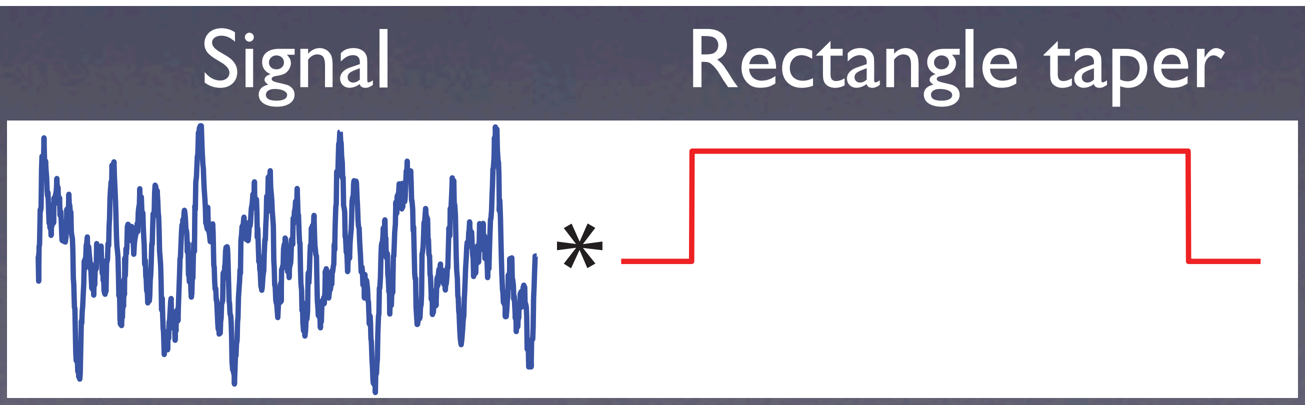
Tapers

- Doing nothing, we make an implicit taper choice . . .

. . . Data goes on forever . . .



What we're observing:

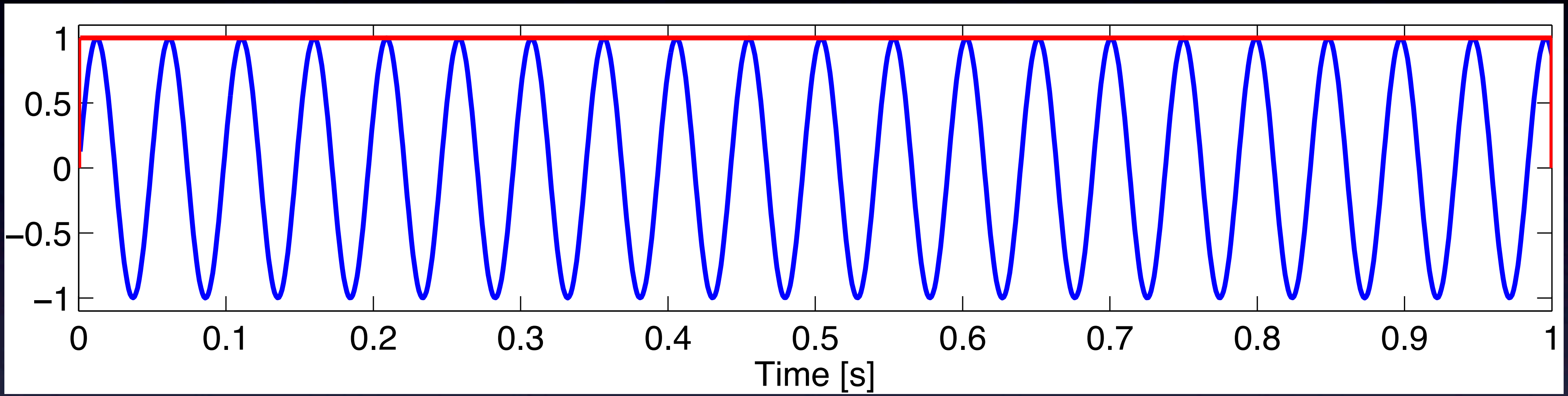


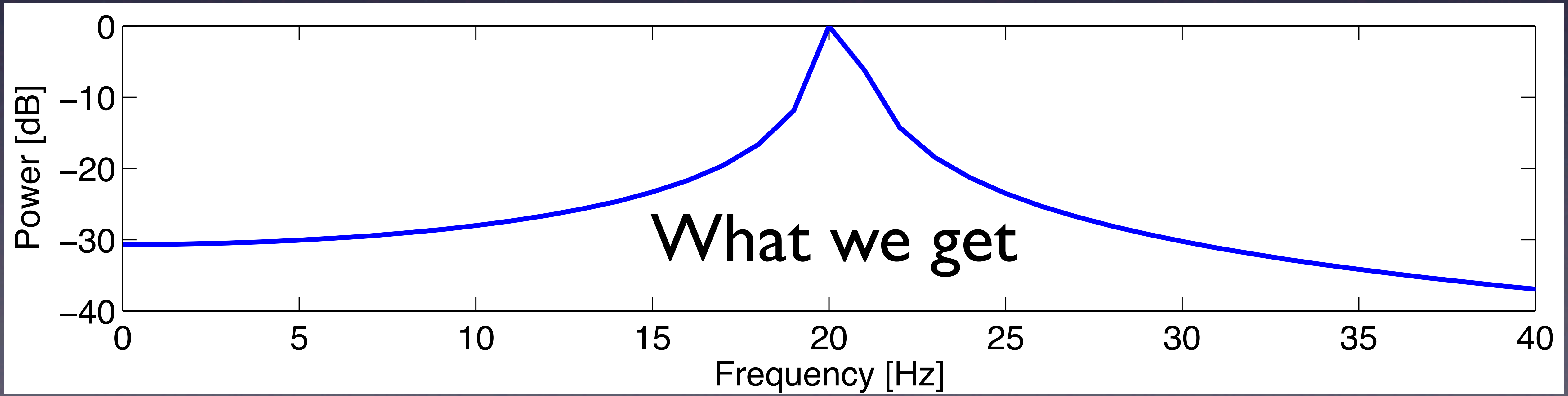
Tapers

- The rectangle taper *blurs* the power spectrum.

Pure sinusoid

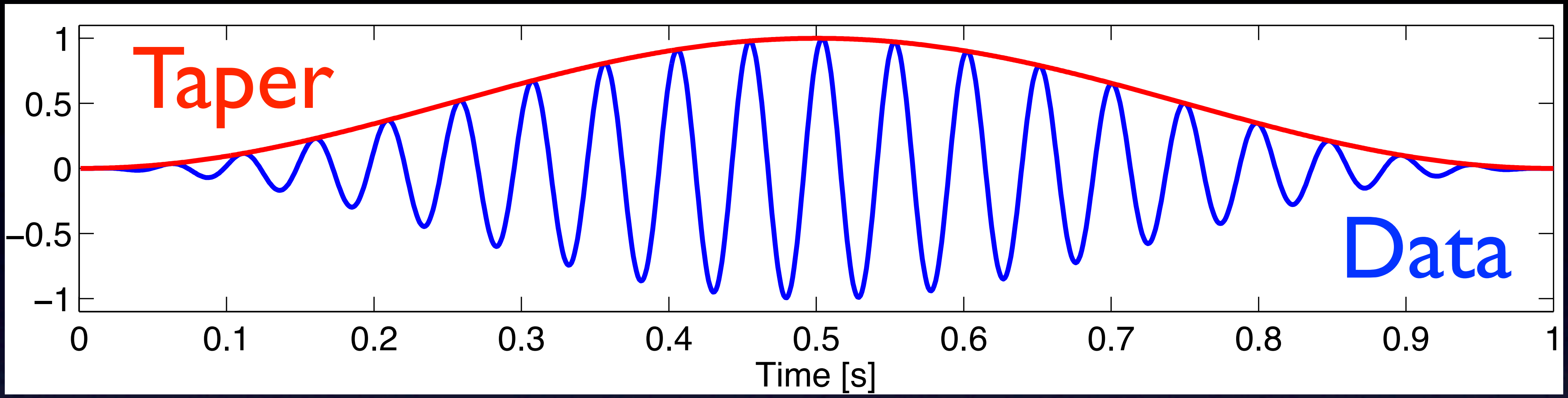
near 20 Hz





Hann taper

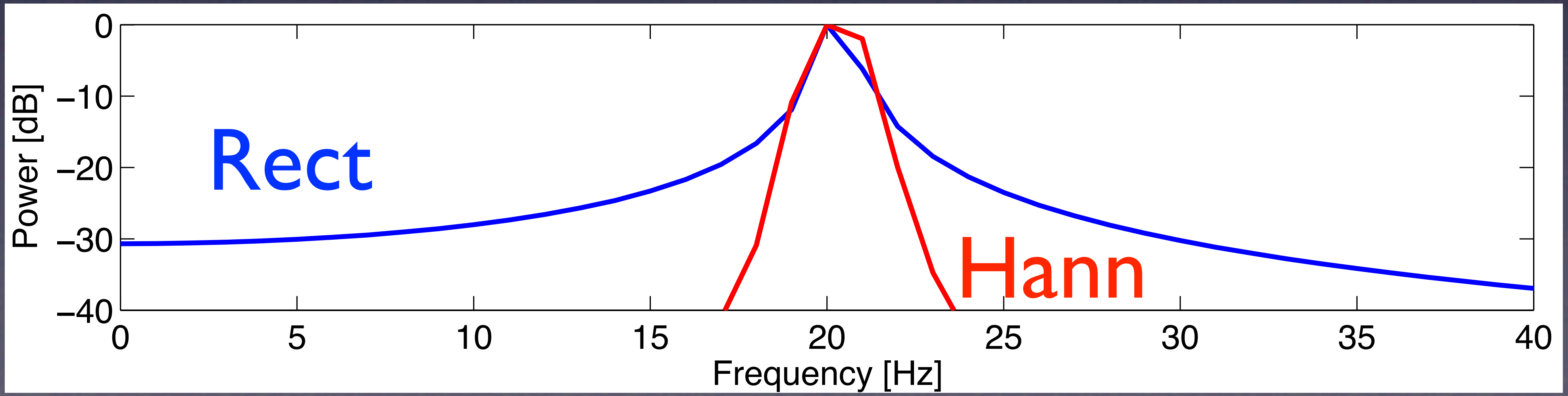
- Idea: smooth the sharp edges of rectangle taper.




```
>> st = s .* hann(length(s))' ;
```

Requires Signal Processing Toolbox

- Compute power spectrum of tapered data.

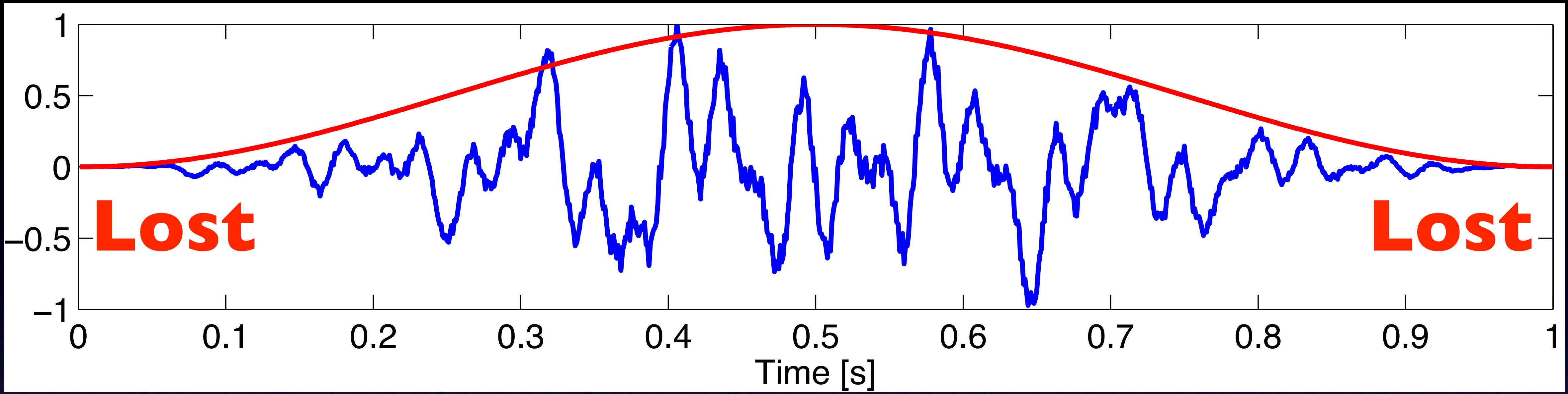


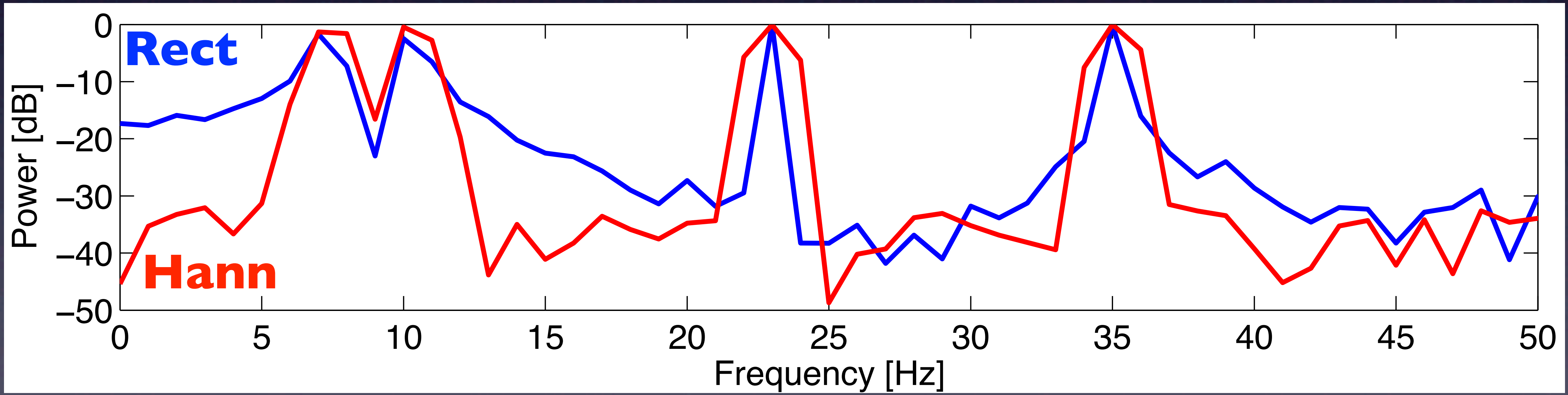
Taper reduces the “sidelobes”.

Ex: Hann taper

Lab Example 7

v1:





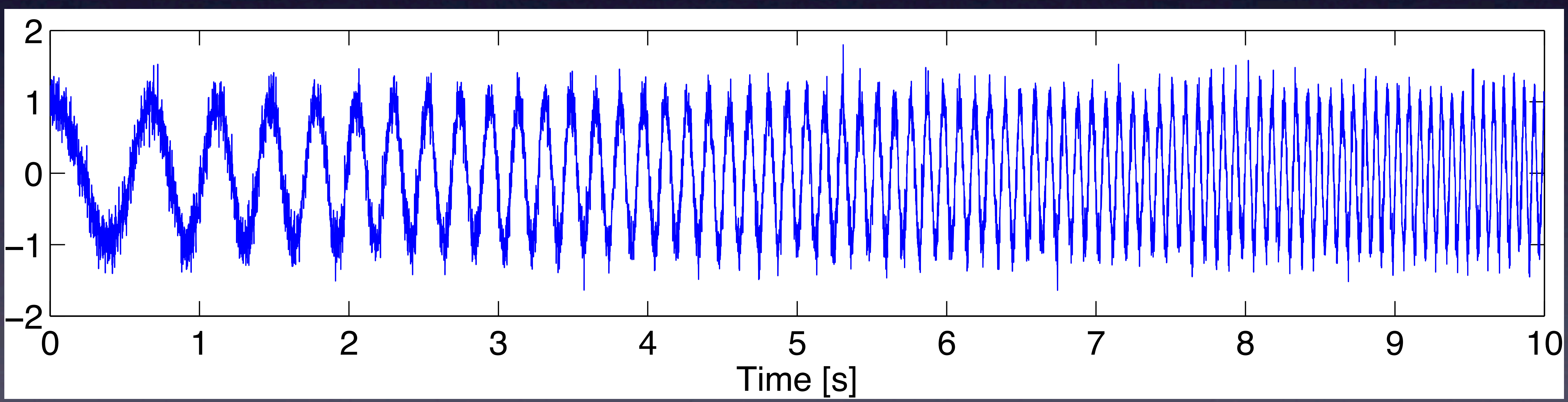
- Good: Deeper baseline
- Bad: Broader peaks & lose data at edges.

Spectrogram

- What if signal characteristics change in time?

```
>> load 6_data.mat
>> plot(t2,v2)
```

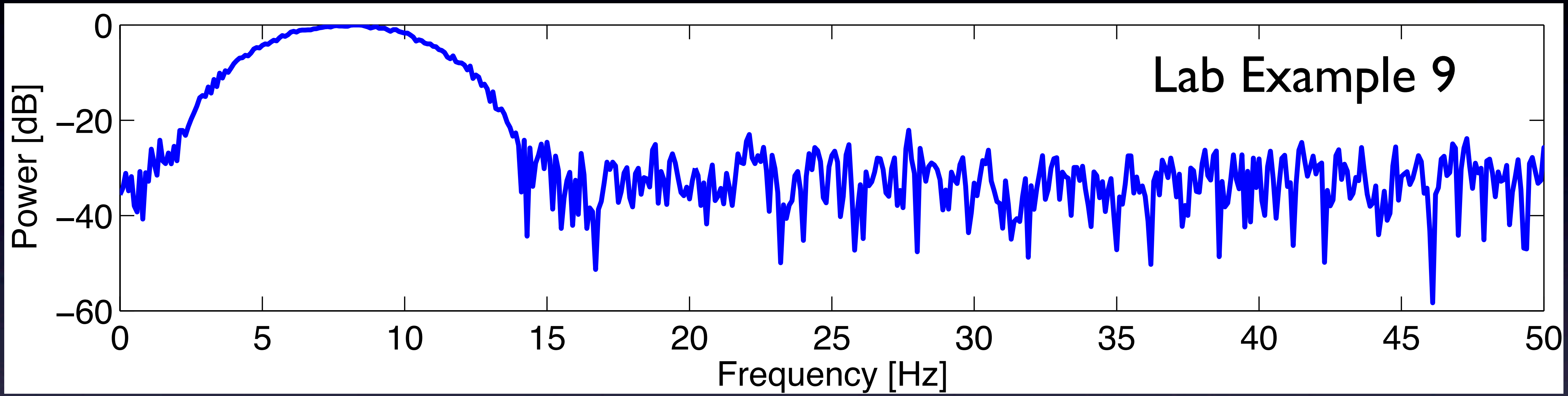
Lab Example 8



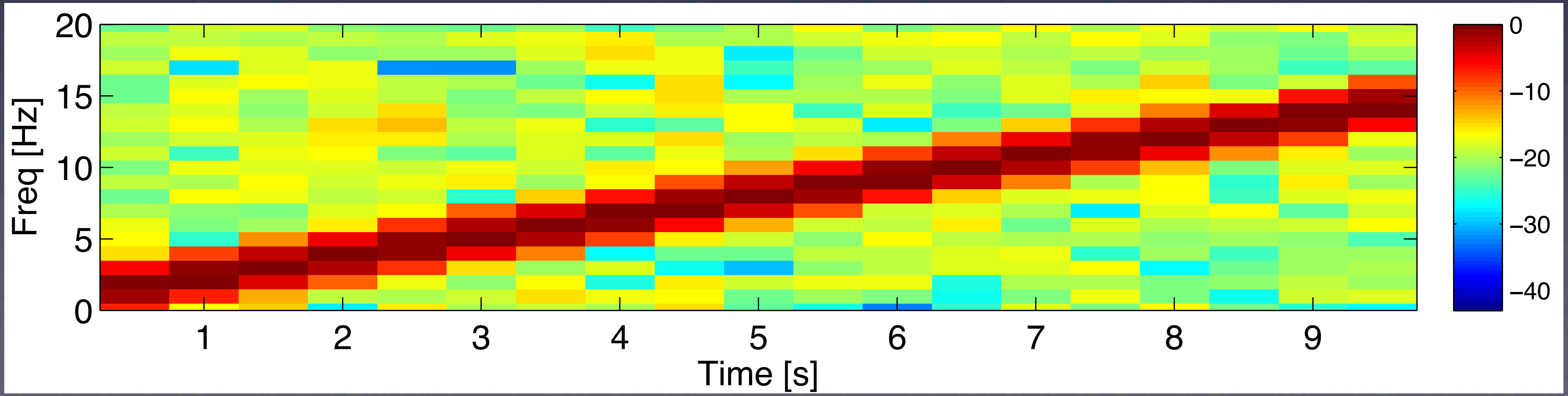
- Visual inspection
- Data characteristics change in time.

Spectrogram

- Compute the spectrum (Hann taper) of all data

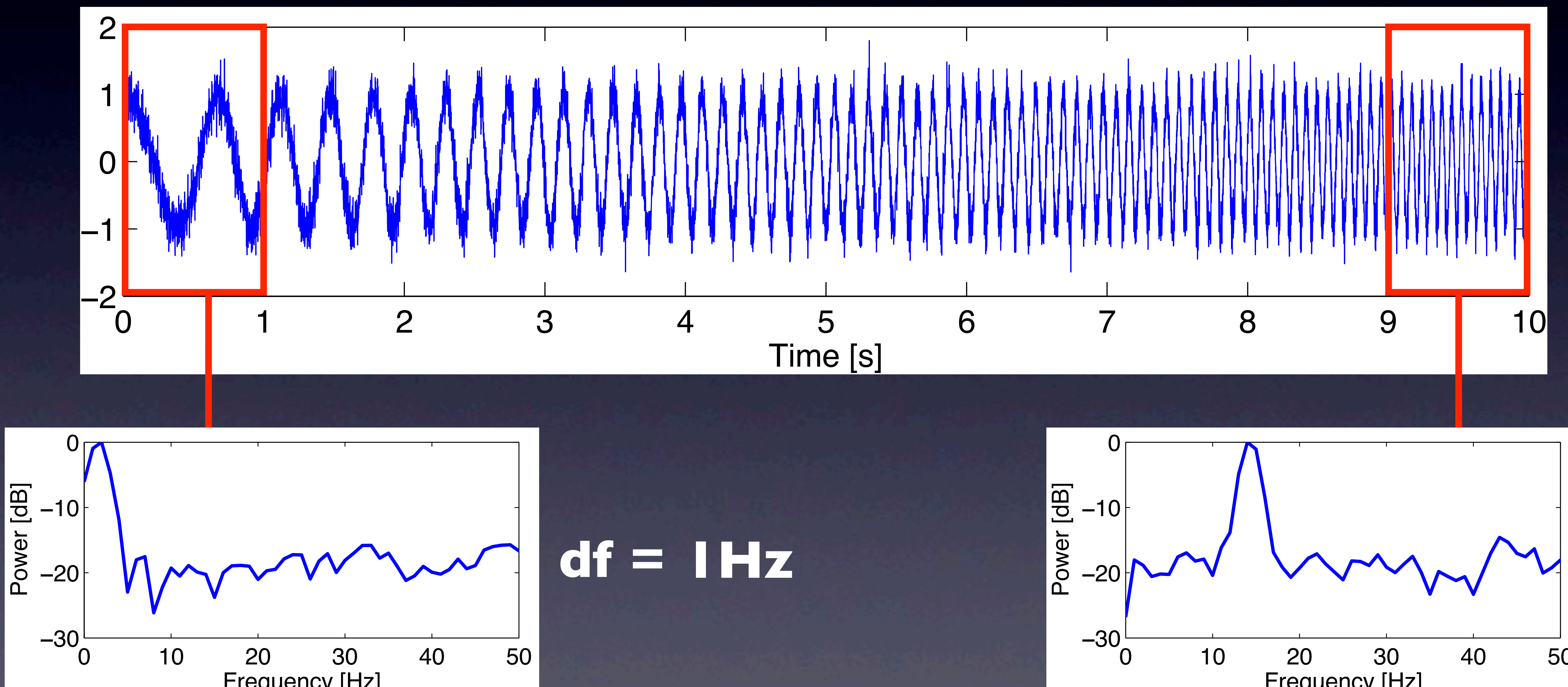


Q: Is this a good representation of the data?



Spectrogram

- Idea: Split up the data into windows & Compute spectrum in each.



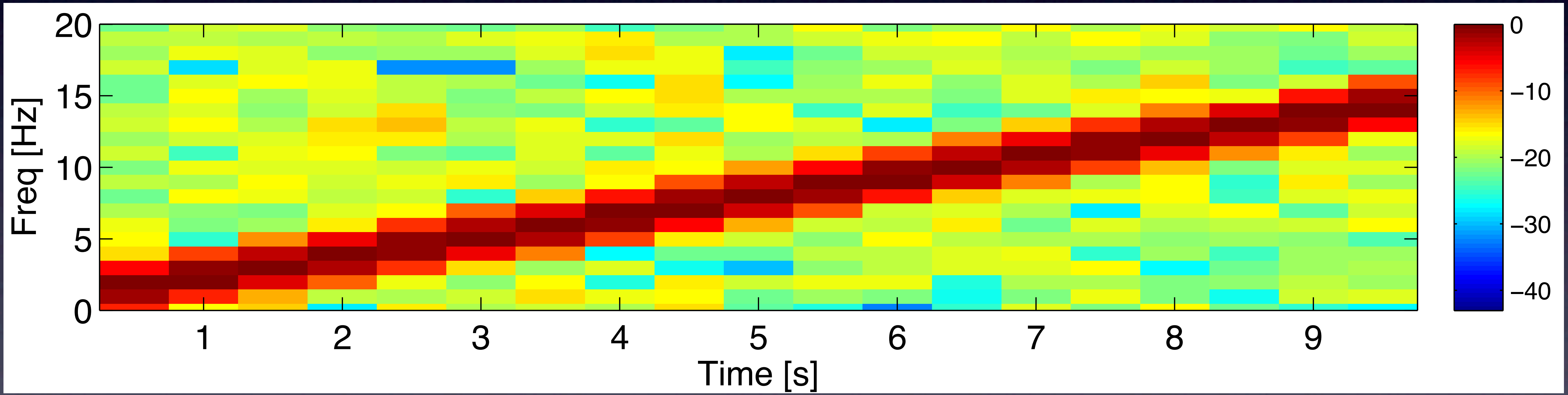
Different spectra at beginning and end of signal.
Repeat for many overlapping windows . . .

MATLAB code

Lab Example 10

Requires Signal Processing Toolbox

```
                                  Window       Padding
>> [S,F,T]=spectrogram(v2,1s,0.5s,1s,1kHz)
                                       Overlap        f0
>> S = abs(S);
>> imagesc(T,F,10*log10(S/max(S(:))));
```



Plot power [color] vs frequency and time

A better representation of the data?

Conclusions & Refs

- We focused on power spectrum: what rhythms appear in EEG/MEG/LFP data?
- Defined *df* and f_{NQ}.
- Explored tapers and spectrograms.

References

MATLAB for Neuroscientists, Numerical Recipes in C

Chronux.org and Neuroinformatics Summer Course

EEGLab