Bits over the Air: Pre-Lab 2

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- You can always ask questions (during pre-labs and labs, or via email* after the labs)
- During the labs, you can also ask us if you want to know more about a specific aspect!

- We are here to help!

*studer@cornell.edu

Tuesday overview

Bits over the air

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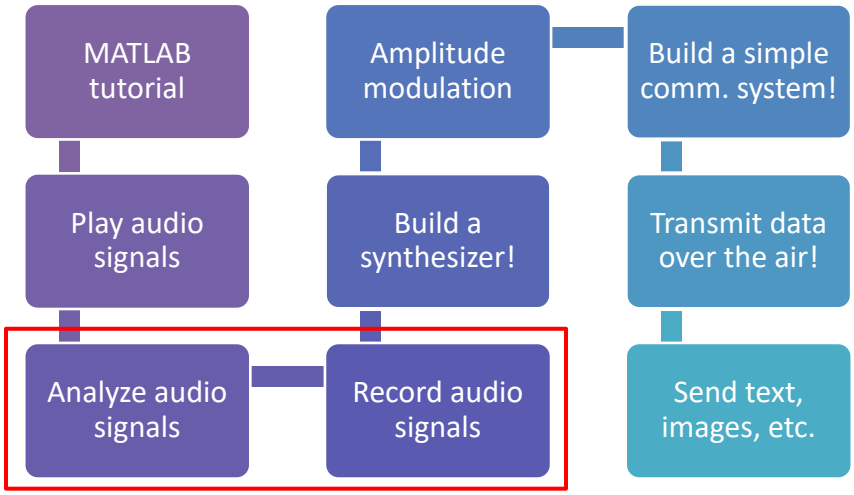
Today's goals:



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Project schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
1pm-2pm	Pre-Lab 1: Introduction to MATLAB and digital communication	Pre-Lab 2: Signal processing, time-domain, spectrum, and spectrogram	Pre-Lab 3: Generating music with MATLAB and communication system basics	Pre-Lab 4: Communication via amplitude modulation and synchronization	Pre-Lab 5: Bits over the air: transmitting text and images over the air (reliably!)
2pm-3pm	Module 1: MATLAB basics 1	Complete previous modules	Complete previous modules	Complete previous modules	Complete previous modules
	15min break	15min break	15min break	15min break	15min break
3pm-4pm	Module 2: MATLAB basics 2	Module 4: Spectrum and spectrogram	Module 6: Generating music in MATLAB	Module 8: Simple communication system 2	Module 10: Transmitting bits over the air
4pm-5pm	Module 3: Play audio in MATLAB	Module 5: Record audio in MATLAB	Module 7: Simple communication system 1	Module 9: Synchronization	Work on presentations

- Scheduled break from 3:15pm to 3:30pm

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Remember: this is group work!

- Groups of 2-3 students
  - Wish to switch group? → studer@cornell.edu
- Try to help each other (within group)
- Today: Module 5 has a component where you have to work with another group
  - Collaborating group assignments announced after this pre-lab

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Module 4

Spectrum and spectrogram

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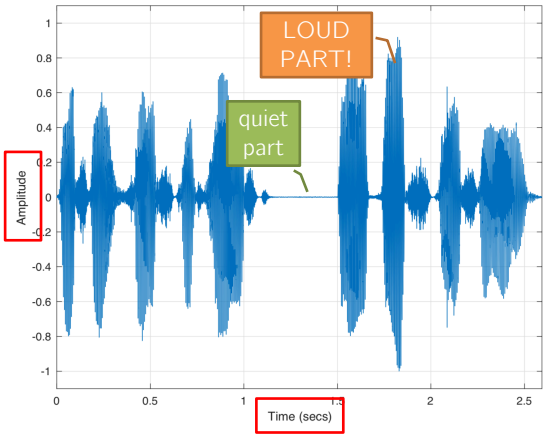
Signals in the time-domain

- Signals are naturally represented in time-domain



- Tells us what amplitude appears at what time instant
- Reveals silence and loud parts

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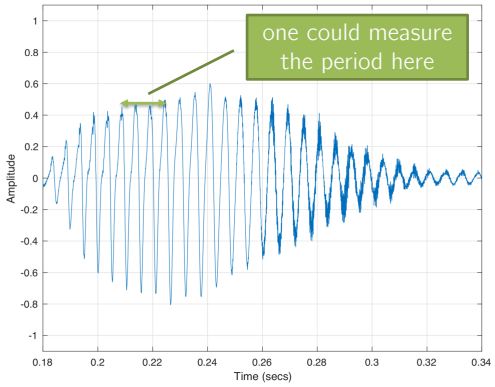
Time-domain zoom

- A closer look reveals additional information



- Shows us when periodic signals happen
- Example: vowels (a, e, i, o, u, ä, ö, ü)

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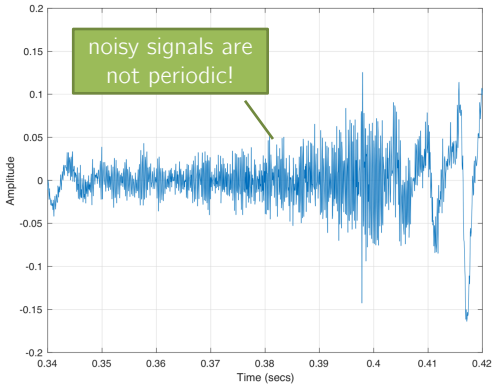
More time-domain zoom

- A closer look reveals additional information



- Shows us when "noise" happens
- Example: sibilants (s, z, sh, zh)

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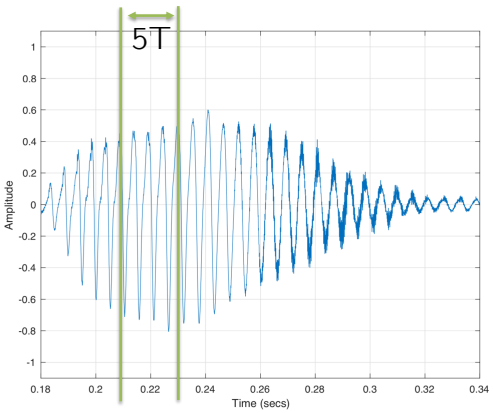
Other representations exist

- Assume that you would like to know what frequencies are present in a signal



- Example: this part of the speech signal consist of one dominant frequency:
  T=0.0055s
  f=1/T=181Hz

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Frequency-domain representation

- Every signal can be represented as a superposition (sum) of sine/cosine functions with different frequen

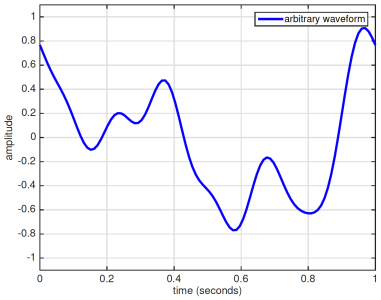
$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} (a_n \cos(2\pi n t) + b_n \sin(2\pi n t))$$

for any function $f(t)$
in the interval $t \in [0, 1]$

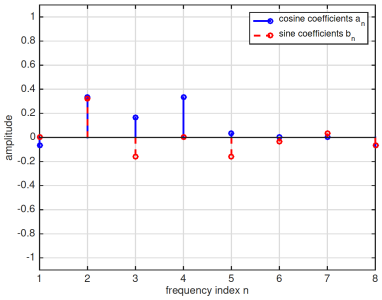
Jean-Baptiste Joseph Fourier

Example

time-domain signal



Fourier coefficients



- Fourier coefficients tell us which frequencies are how strongly represented in a signal

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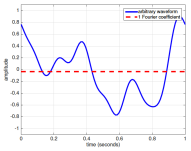
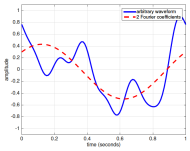
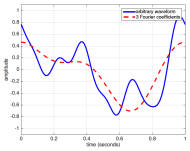
More terms, better approximation



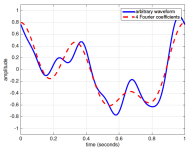
(a) 1 coefficient.



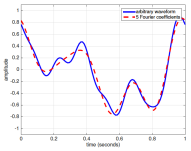
(b) 2 coefficients.



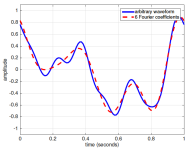
(c) 3 coefficients.



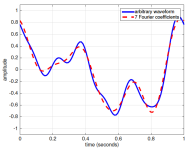
(d) 4 coefficients.



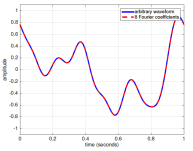
(e) 5 coefficients.



(f) 6 coefficients.



(g) 7 coefficients.



(h) 8 coefficients.

- This is possible for every signal $f(t),\ t \in [0, 1]$

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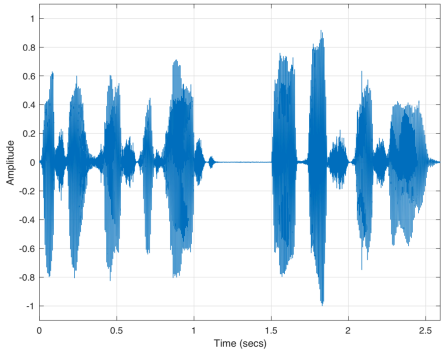
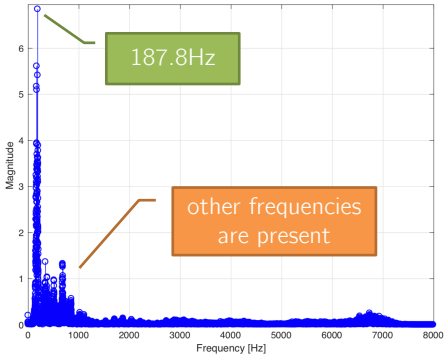
Time- vs. frequency-domain

time-domain signal



spectrum



- Fourier transform: convert signal from time-domain to frequency-domain (spectrum)

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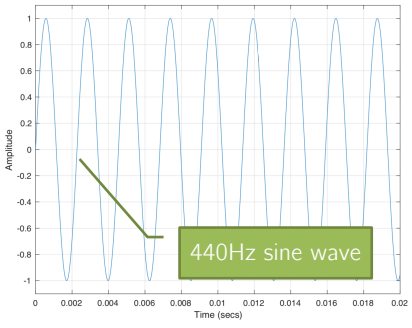
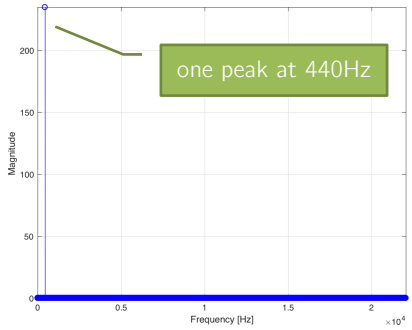
How about a simple signal?

time-domain signal



spectrum



- Signals in time-domain and frequency-domain contain same amount of information!

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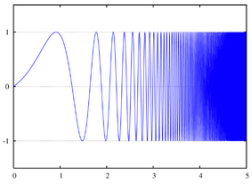
"Problem"

- The frequency-domain signal does not tell us when certain frequencies are active
  - Think about it as a summary of existing frequencies over the entire time interval
- Equivalently, the time-domain does not tell us what frequencies are present



Example: A chirp signal sweeps its frequency over time…

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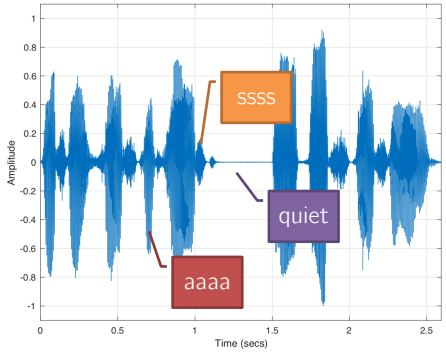
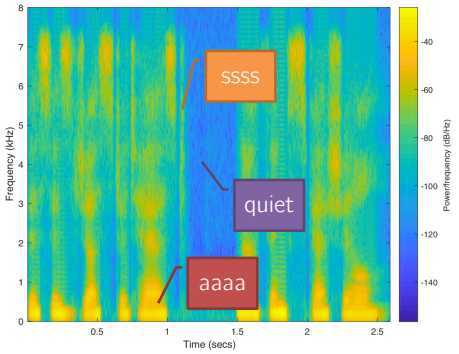
"Solution:" the spectrogram

time-domain signal



spectrogram



- The spectrogram shows which frequencies are present at what time instant

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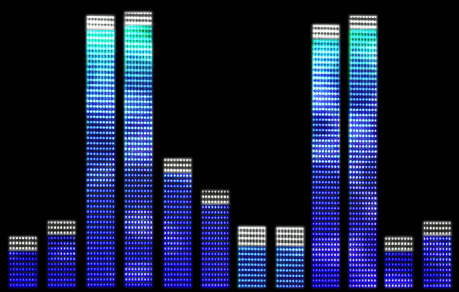
Everybody has seen these



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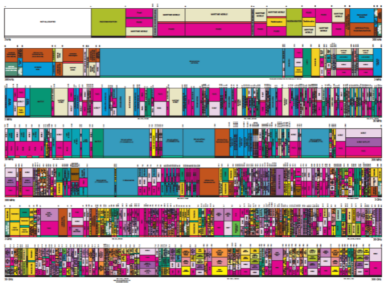
Why is this important???

The wireless spectrum is crowded!



2011 US frequency allocation chart

- Wireless systems must generate their transmit signals to occupy only the designated spectrum

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Module 5

Record audio with MATLAB

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Let's use the microphone!

- The microphone will be our receive antenna

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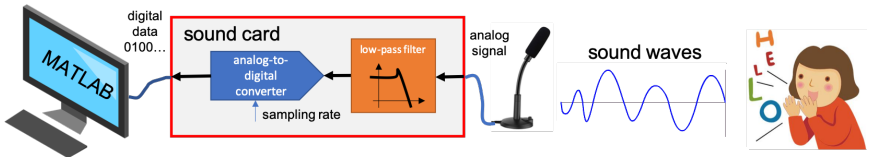
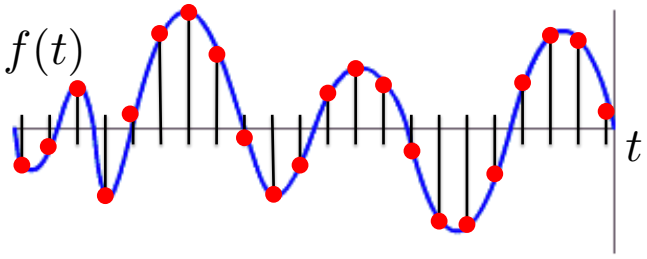
Recording = sampling!





- Low-pass filter removes high frequencies
- Why do we filter the signal before sampling?

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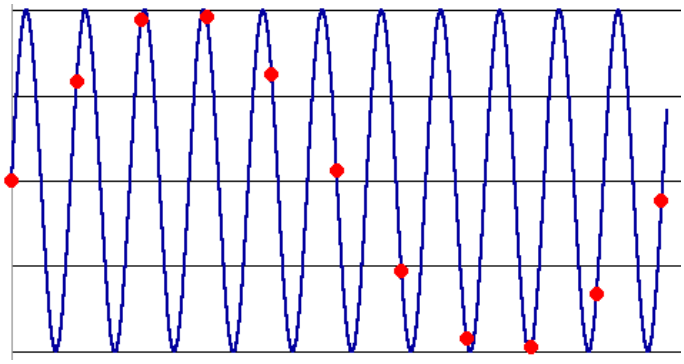
Sampling rate > 2x highest frequency

- We have to filter the signal at $f_s/2$
- Higher frequencies could not be represented



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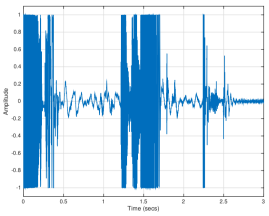
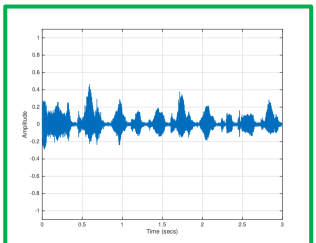
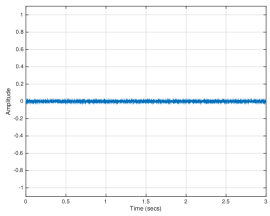
Signal must be loud "enough"



(a) Signal too loud.



(b) Signal level acceptable.



(c) Signal too quiet.

- In MATLAB signals must have amplitudes between -1 and +1
- Signals that exceed [-1,+1] are clipped
- Make sure that signal level is acceptable

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You will do three experiments

- Record your own voice
- Play sound from one group's computer and record with another group's computer
  - Will be used that to transmit data wirelessly!
  - Pairs of groups will be announced at the end
- Simultaneously play and record sound from same computer
  - Will be used to design, test, and optimize your wireless communication system

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Some updates

Organization

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Project website: catalyst2019.github.io

- Updated modules
- Added presentations (introduction and old pre-labs)
- MATLAB files (in a zip-folder)

You need to save your data

- The computers in the ACCEL labs erase all data when logging out (after 30min idle…)
- We will use box.com for storage

- We invited you to join a folder
- Sign up (create an account)
- Move your files to folder with your group number → try it out before it is too late!

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To do

- We slightly shuffled the groups
  - One late student, rooms were filled unevenly
- Get your group number and the number of the group you will collaborate with
  - Used for playback from one computer and record on other computer…
- Then we walk to the ACCEL labs
- Get free earplugs (if you want)
- If you think you are done with Module 5 talk to us → more work ☺

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