Bits over the Air: Pre-Lab 4

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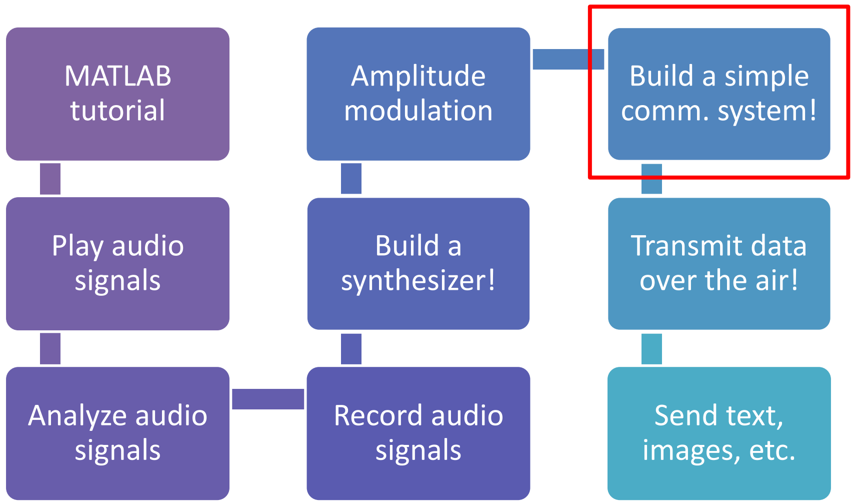
Wednesday overview

Bits over the air

Today's goals:



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

- Some of you still have to finish Module 7

Remember: this is group work!

- Try to help each other (also with the other group you are supposed to collaborate)
- Module 9 has an inter-group activity!
  - Synchronization of a receiver to a transmitter
  - Find the longest distance for which synchronization still works reliably

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Module 8

Design of a digital amplitude modulation (AM) receiver

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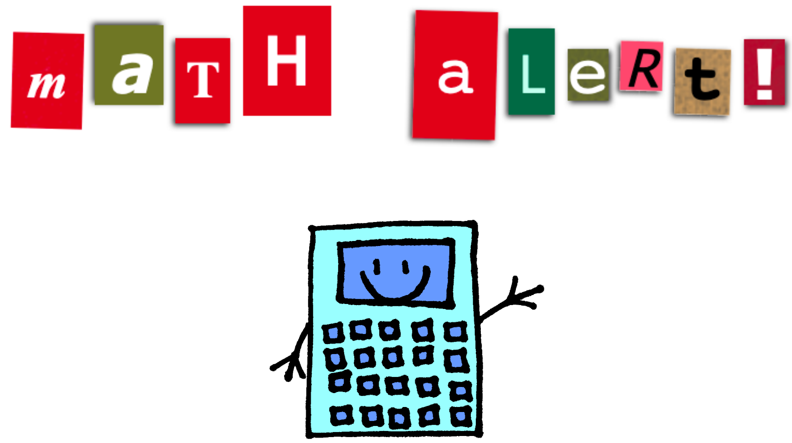

Engineering = a lot of math!

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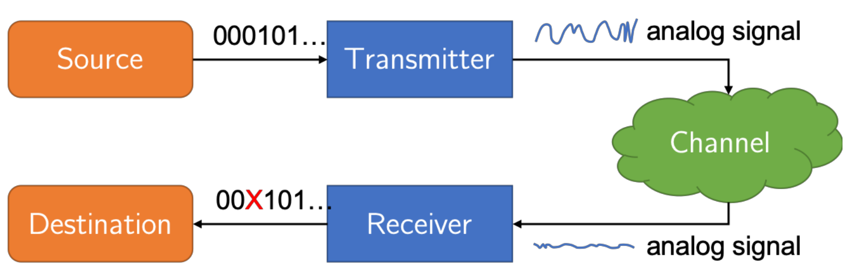
Remember: communication system



- Transmitter takes information bits and creates analog (continuous) waveforms
- Receiver takes output of channel and tries to estimate transmitted information bits

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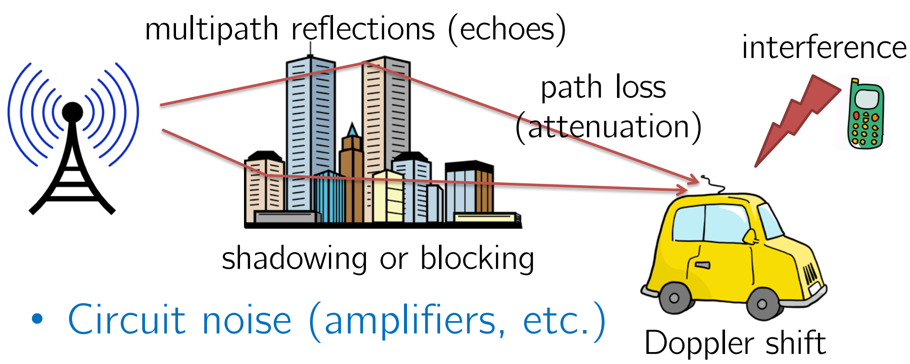
Typical wireless channel*

- Wireless channels distort transmit signals in many ways (echoes, noise, interference,…)



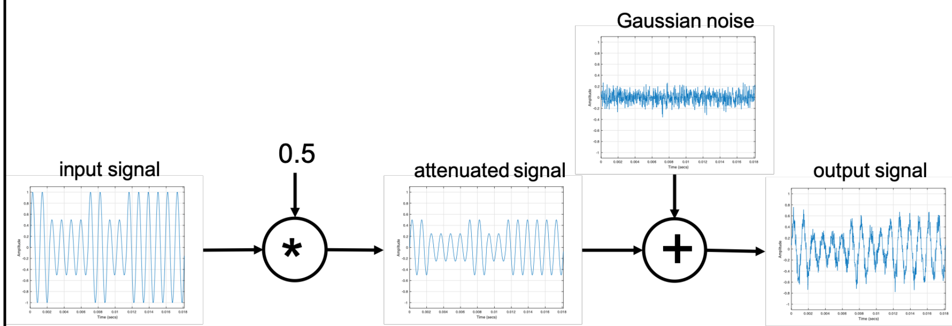
- Circuit noise (amplifiers, etc.)

*also applies to acoustic channels

Test channels

- Before one tries communication over real channels, engineers use test channels and software simulations (with MATLAB)
- Test channels simplify testing and performance optimization of system:
  - Full control over parameters
  - Experiments can be reproduced
- We do the same → simple test channel!

Additive white Gaussian noise (AWGN)



- Attenuate input signal (models path loss)
- Add Gaussian noise (models noise/interference)
- Output signal is distorted

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Impact of signal and noise levels

- Noise level (relative to signal level) influences how many errors will happen
  - High noise level → many errors
  - Low noise level → few errors
  - High signal level → few errors
  - Low signal level → many errors
- Number of errors also strongly depends on how the receiver is implemented!

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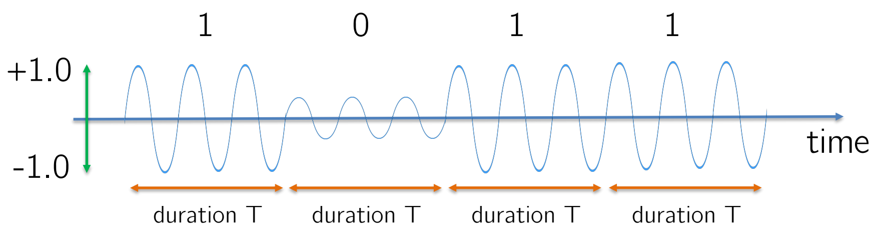
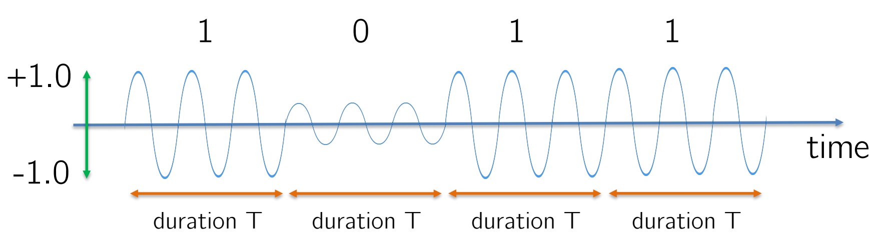
Remember: Digital AM transmission

- Example: bits = [1,0,1,1]



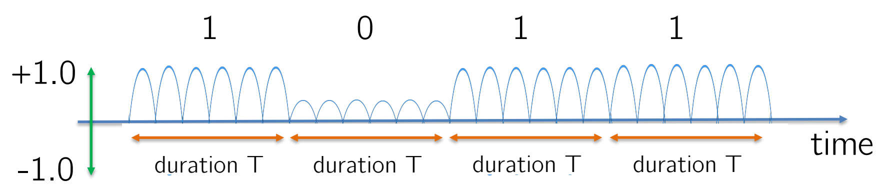
- The receiver must distinguish amplitudes
  - If noise level is low, super easy
  - if noise level is high, difficult to distinguish

How can we estimate amplitudes?



- Remember analog AM demodulation:
  - Rectify the signal
  - Low-pass filtering
- But we now also need to recover the bits!

Rectify receive signal



- Mathematical operation:

absolute value

$$y_{\text{rect}}(t) = |y(t)|$$

- Easier to estimate the amplitudes!

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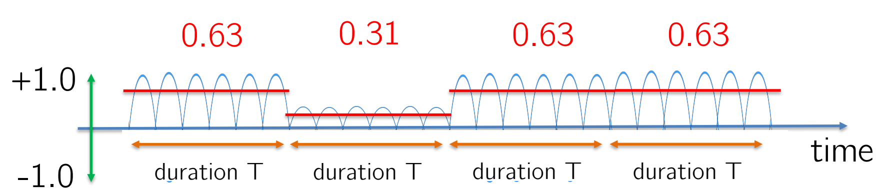
Low-pass filter: estimate amplitudes



- Mathematical operation:

average amplitude over period of T seconds

$$y_{\text{avg}}(n) = \frac{1}{T}\int_{T(n-1)}^{Tn} y_{\text{rect}}(t)\mathrm{d}t$$

- Need to know amplitude of bit 1 and of bit 0

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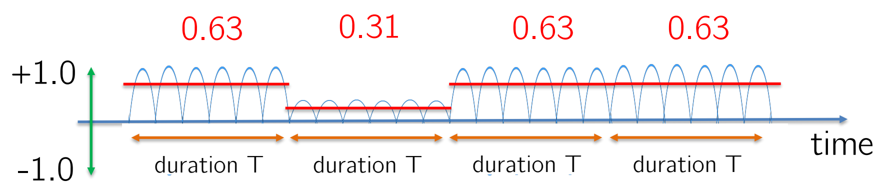
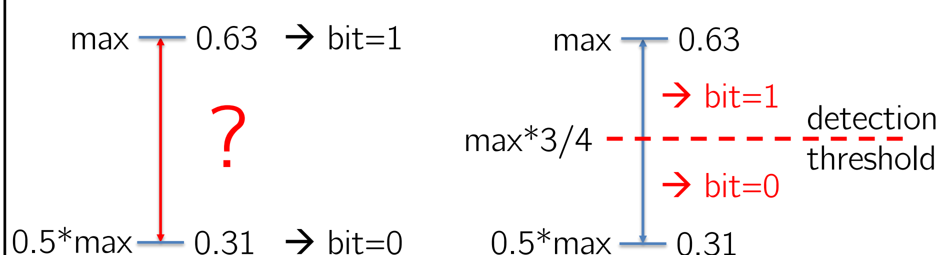
Estimation of bits



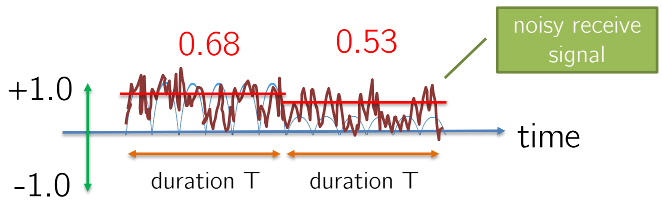
- Assume that largest value belongs to bit 1
  - In this example max=0.63
  - This is known as channel estimation
- Since we used 0.5*sine to transmit bit 0, we assume that level of bit zero is 0.5*max=0.31

Detection: decide for bit 1 or bit 0

- We have two levels: max=0.63 and 0.5*max
  - Magnitude max=0.63 maps to bit=1
  - Magnitude 0.5*max=0.31 maps to bit=0
- What about other magnitude values?



Reason why errors can happen



- 0.53 is larger than max=0.68*3/4=0.51
  - Detection threshold was 0.51
  - Average amplitude of second bit exceeded 0.51 and bit would be mapped to 1 (but was 0!)
- Detector makes an error ☹

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Bit error rate

- Bit error rate (BER) is a key performance metric of a communication receiver
- Definition: number of wrong bits divided by total number of transmitted bits

we want this to be zero!

$$BER = \frac{\#\ \text{errors}}{\#\ \text{transmitted bits}}$$

- Noise stronger than signal → more errors
- Signal stronger than noise → fewer errors

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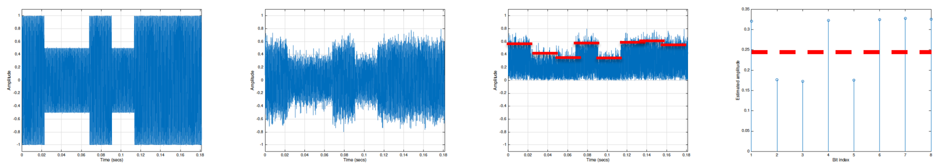
Example of digital AM receiver



(a) Transmit signal. (b) Received signal. (c) Rectified signal. (d) Estimated amplitudes.

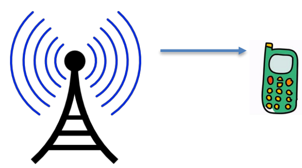
- bits = [1,0,0,1,0,1,1,1]
- Received: noisy but amplitudes visible
- Rectified signal: helps for average amplitude
- Estimated amplitudes → detector (BER=0)

Module 9

Synchronization

What is synchronization?

- Receiver does not know when transmission starts but it needs to know this
  - If transmission missed → all bits wrong ☹
- Receivers constantly sense antenna input (=microphone) and detect transmission start



- Only if transmission occurs, demodulation and detection is performed

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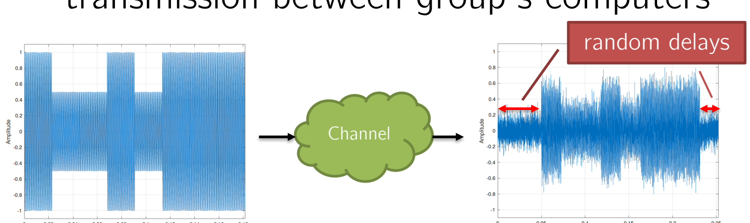
Test channel for synchronization

- To design a synchronization method, we will use a new test channel
- Our test channel introduces random delay before and after transmission
  - Similar to manually start recording and transmission between group's computers



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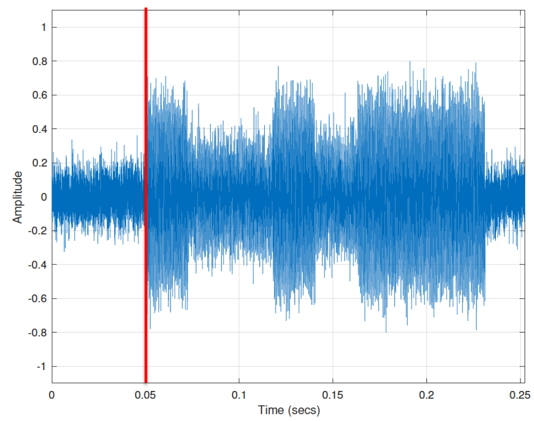
How would you detect transmission?



- Easy to do by eye, but how would you program a computer to do that?

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Synchronization algorithm

- Algorithm: "A process or set of rules to be followed in calculations or other problem-solving operations, especially by a computer"
- Our synchronization algorithm:
  - Rectify receive signal (we do that anyway)
  - Find maximum received value: max
  - Index of first sample that exceeds max*threshold

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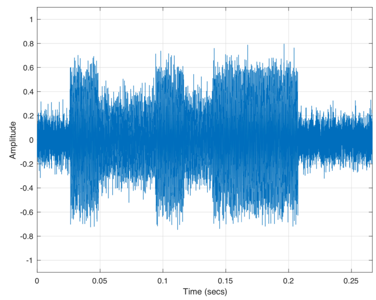
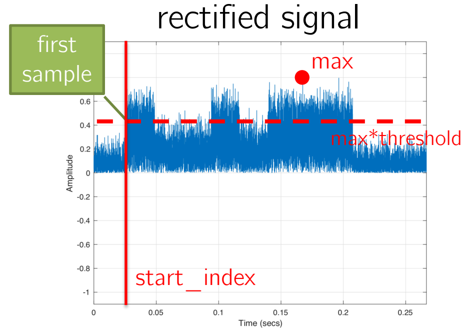
Example

received signal

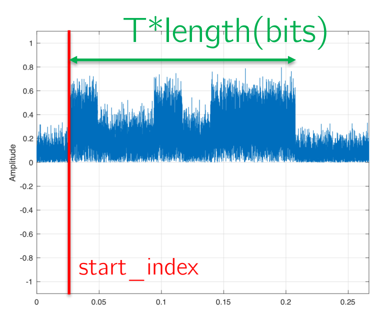


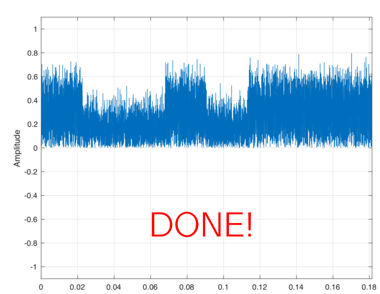
rectified signal



- Find largest sample: max
- Find first sample larger than max*threshold
- Index of that sample is transmission start

We are not done yet!





- You know length of transmission: number of bits B times duration T
- Trim signal and then, use your receiver

Synchronization is important!

- Performance of practical systems, such as Wi-Fi, LTE-A, and Bluetooth is limited by sensitivity of synchronization method
- To be reliable, these systems use extremely advanced synchronization algorithms:
  - Transmitter sends a specific sequence of bits
  - Receiver “looks” for this particular sequence

Some updates

Organization

Research presentations

- Saturday from 9:30am to 11:30am in RPCC
- Group presentation together with assigned team (see list at end; no changes)
- 10 teams in 2 hours → 10 minutes presentation plus 2 minutes Q&A
- Present what you have done this week
  - Music synthesizer, transmitter/receiver, achieved data rate, special tricks used, etc.
  - About 7-8 slides (only 10 minutes time)

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To do

- Some of the groups did NOT upload their music ☹ → do that today!
- Remember your group number and your assigned collaborating team!
- Then, we walk to the ACCEL labs
- Important:
  - Finish Module 6 if you haven't done that yet
  - Only start with Module 9 after you talked to us

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