

Embedded Security

EECE 5698-08: Special Topics: Cyber-Physical Security of IoT Systems in the Age of AI

**Lecture 3:
Signals and Systems Refresher
Prof. Kevin Fu**

September 21, 2025
<https://spqrlab1.github.io/emsec/>



Northeastern University
College of Engineering



Last Time: Threat Modeling

- What?

A systematic approach to identify, prioritize, and mitigate security risks

- Why?

Prevents and reduces surprise of security vulnerabilities

- How?

Attack trees, STRIDE, etc.

- When?

Incorporate it early and iteratively in your projects

Today's Learning Goals

- Refresher on signals and systems intuition
- Basics of cryptographic fault injection

Cardiac Rhythm Signals (time domain)

Kevin Fu

(Age 49)

Recorded on Sep 15, 2025 at 11:04 AM

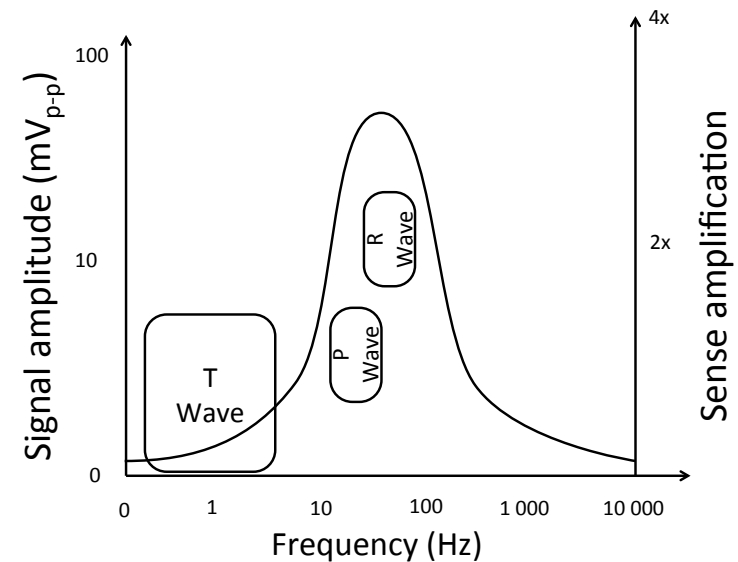
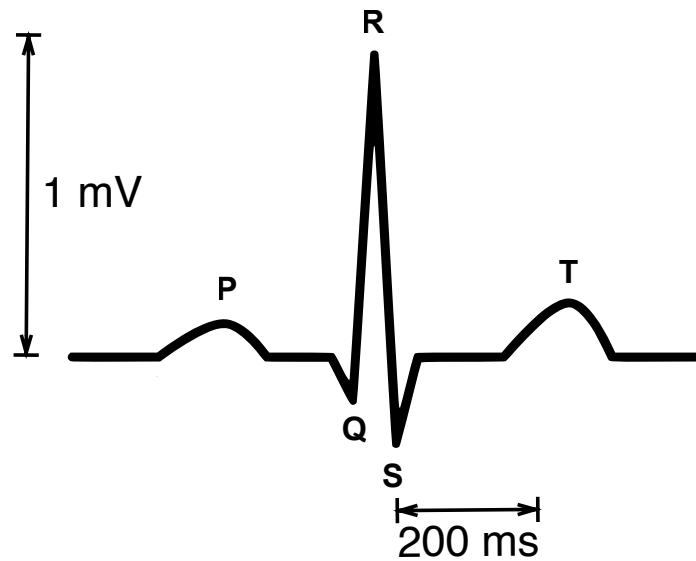
Sinus Rhythm — ❤️ 62 BPM Average

This ECG does not show signs of atrial fibrillation.



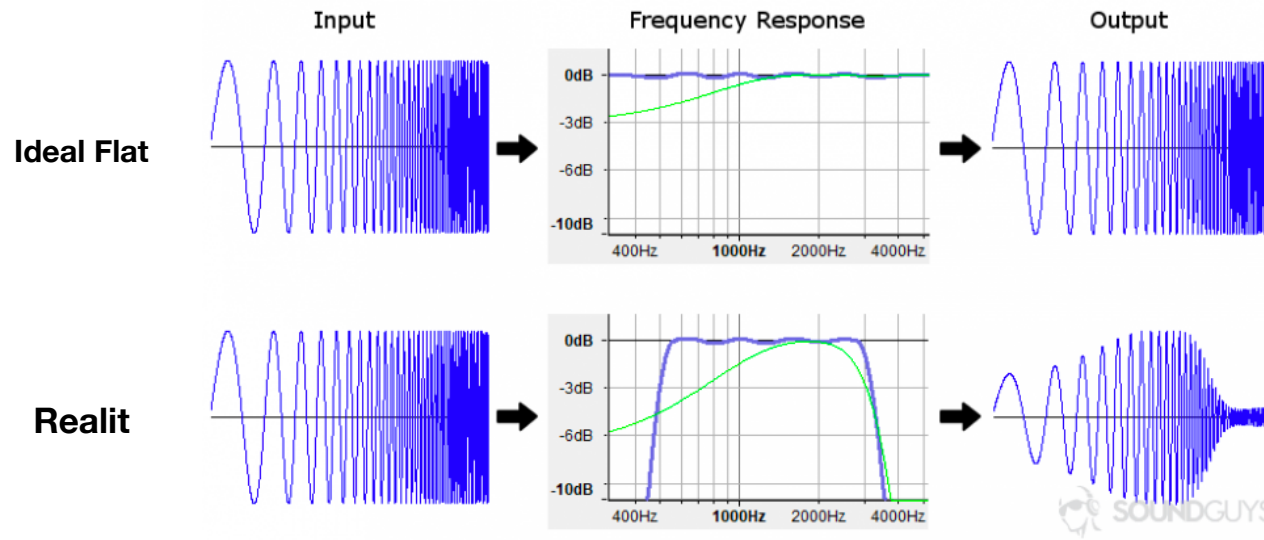
25 mm/s, 10 mm/mV, Lead I, 512Hz, iOS 18.6.2, watchOS 11.6.1, Watch7,9, Algorithm Version 2 — The waveform is similar to a Lead I ECG. For more information, see Instructions for Use.

Cardiac Rhythm Signals (frequency domain)



Cohan et al, 2008

Frequency Response

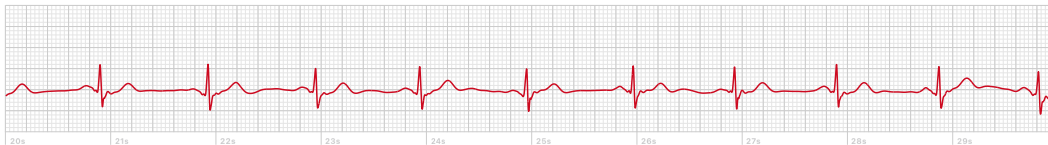


<https://www.soundguys.com/frequency-response-explained-16507/>

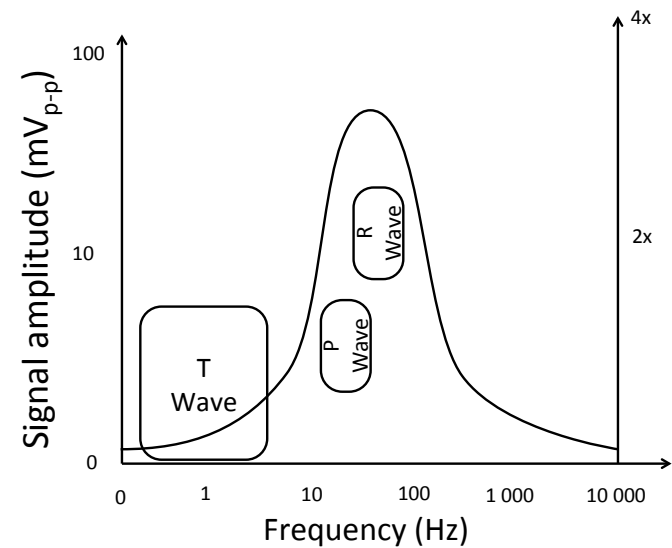
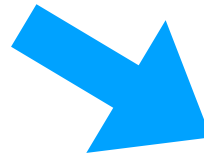
You will often hear a desire for a “flat” frequency response for an ideal reproduction of a signal. An ideal speaker or microphone would have a flat frequency response, but no device is perfectly flat in frequency response, which is why you ought attend to lecture in person to hear the secret exam clues from the 3rd order harmonics.

Frequency Domain Intuition

- Peaks = “ingredients” of signals



25 mm/s, 10 mm/mV, Lead I, 512Hz, iOS 18.6.2, watchOS 11.6.1, Watch7,9, Algorithm Version 2 — The waveform is similar to a Lead I ECG. For more information, see Instructions for Use.



Time Domain → Frequency Domain

- Sine wave in time domain = oscillation
- Frequency domain = spike in Fourier Transform
- Demo real-time spectrograms aka waterfall plots

Common Signal Filters

Low-pass, high-pass, band-pass, band-stop/notch

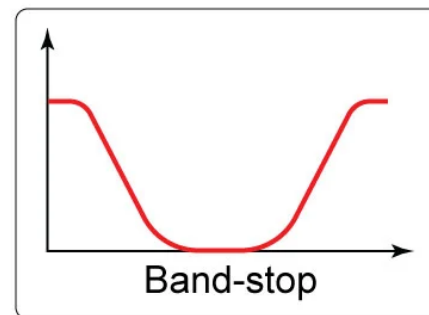
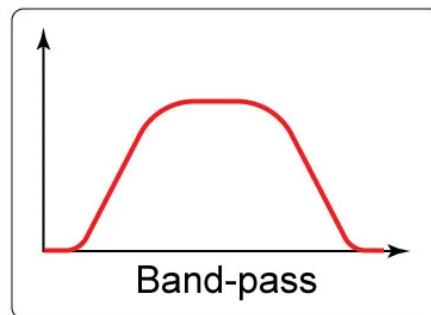
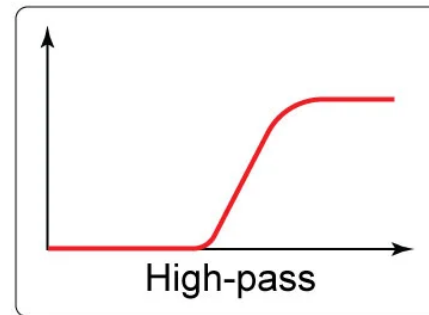
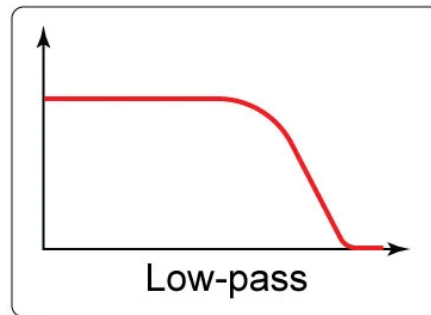
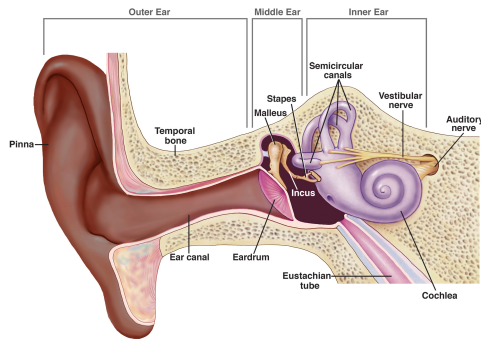


Photo credits: allaboutcircuits.com

Exercise: Filter Examples

Hearing



Laser Safety Goggles



FM Radio Tuner



Tweeter Speaker

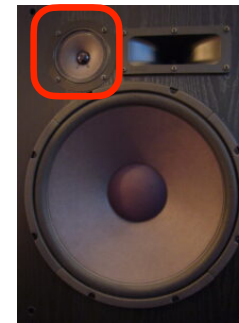


Photo credits: nidcd.nih.gov,
audioengine.com

Resonance

- Draw Fourier Transform of resonance of Green Line track screech in Government Center



MBTA Boylston Station Wheel Squeal

14K views 8y ago ...more



WBUR 27.9K

Subscribe

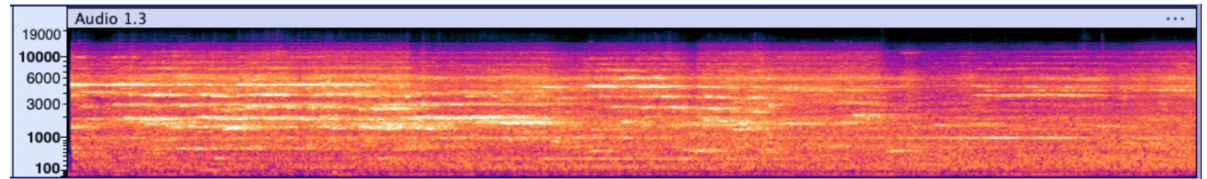
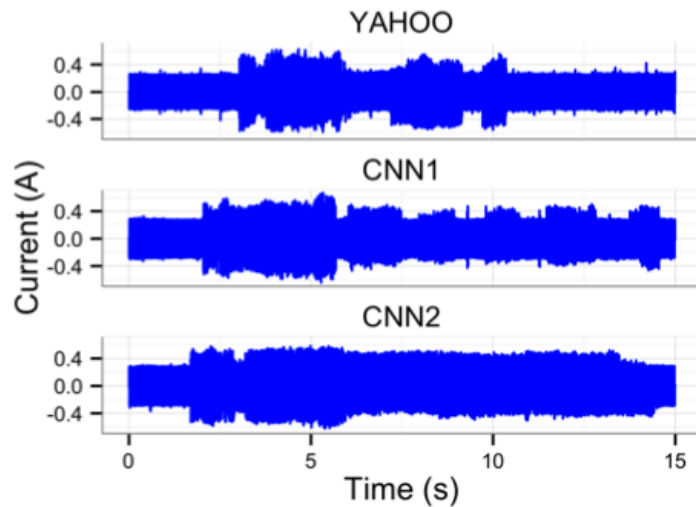


Photo credits: Wikipedia

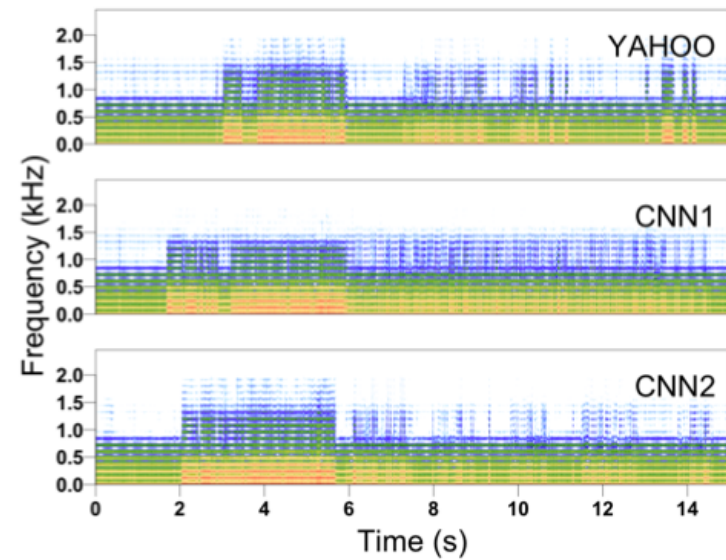
Shannon Nyquist Sampling Theory

- Why must sample at twice the frequency?
- Need two volunteers

Example: Reactive Power



(a) Time-domain plots



(b) Spectrogram plots

Example: Reactive Power

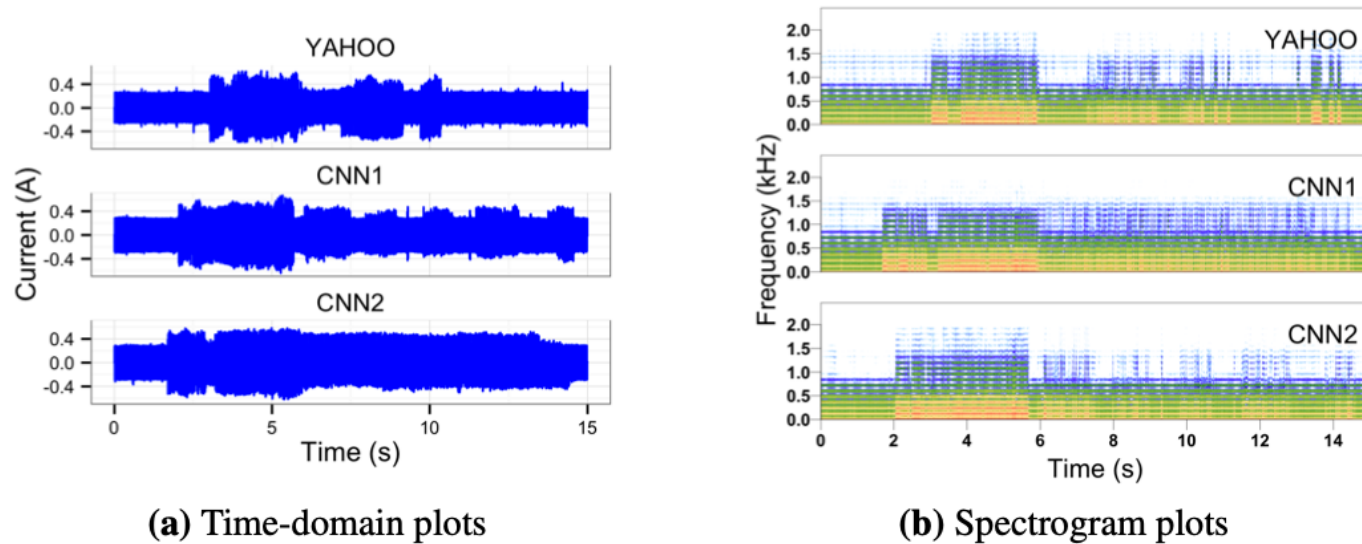


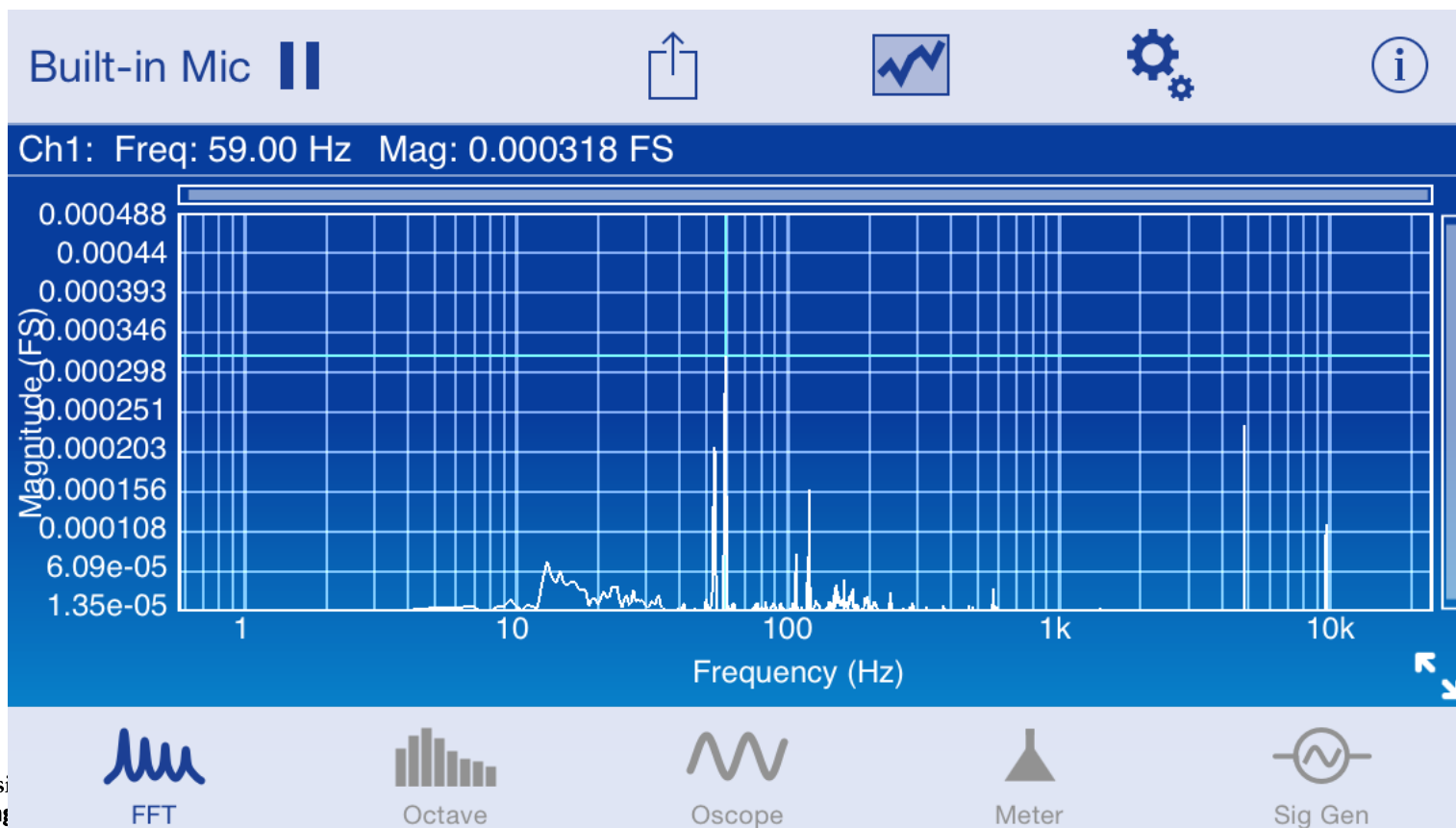
Fig. 1: Time- and frequency-domain plots of several power traces as a MacBook loads two different pages. In the frequency domain, brighter colors represent more energy at a given frequency. Despite the lack of obviously characteristic information in the time domain, the classifier correctly identifies all of the above traces.

Current Events: Identifying Webpages by Tapping the Electrical Outlet

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ESORICS 2013



Turned out to be the HVAC system. The AC conduit line had been mechanically coupled to a ceiling joist near an incandescent lightbulb. The sounds came from the lightbulb. Solved by opening the ceiling, duct taping the AC conduit line. The motor ran at 60hz presumably, causing 60hz sound. Not sure where the 5khz came from. The 10khz is probably the 2nd harmonic.

Signal-to-Noise

- SNR

- * = signal to noise ratio

- * = survival of signal in noise

- Could you inject whistling signal from 10 miles away? In theory, yes; in practice, no.
- Reality check: path loss makes attacks harder

What is cryptographic fault injection

- Outputs resulting from injected faults can reveal unintended information
- A fault can turn an ordinary output into a security “signal”
- RSA signatures
 - Message = x
 - Public modulus = $n = p \cdot q$ where p, q prime
 - Public exponent = e
 - Secret exponent = d where $e \cdot d \equiv 1 \pmod{(p-1)(q-1)}$
 - Signature = $x^d \pmod{n}$
 - Verification: Check that $\text{signature}^e \pmod{n} = x$

What is cryptographic fault injection (2)

- Signature = $x^d \bmod n$
- Verification: Check that $\text{signature}^e \bmod n = x$
- Fault can corrupt the computation associated with one factor while leaving the other correct
- The faulty output reveals information about one of the secret factors, p or q
- The GCD algorithm extracts that shared factor (fancy math)

What is cryptographic fault injection (3)

Take home message

- Check a cryptographic result before outputting it
- If the result is incorrect, discard it
- A simple correctness check prevents a faulty output causing an information leak

Signals and Fault Injection Summary

- An error is not necessarily just noise
- An error can contain information about the internal state of a system
- In security, the error itself can become the revealing signal

Homework and Next

- Homework

1. Prelab #1: Already past due
2. Lab #1: Due Monday, Sep 24

- Next

- A. Thursday: Lab #2 Acoustic Injections Against Accelerometers Exploiting Signal Aliasing
- B. Monday lecture: Transductions Attacks and Electromagnetic Injection
- C. Read: FuXu, "Risks of Trusting the Physics of Sensors," CACM, 61(2), February 2018.

