2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #53785

SHARE: Fourier Detectives: A Math-Free, Hands-On Introduction to Spectral Analysis for Biomedical Engineering Students

Dr. Uri Feldman, Wentworth Institute of Technology

Uri Feldman is an Associate Professor of Biomedical Engineering in the School of Engineering at Wentworth Institute of Technology in Boston. He received a Ph.D. from the Massachusetts Institute of Technology's Media Lab, a B.S. in Electrical Engineering from Case Western Reserve University in Cleveland, and an M.S. in Electrical Engineering from University of Illinois at Urbana Champaign. As a Postdoctoral Fellow at Harvard Medical School at Brigham and Women's Hospital in Boston, Dr. Feldman developed informatics metrics to quantify performance of clinicians when using digital diagnostic tools. He has published in Radiology, Academic Radiology, IS&T, SPIE, and RESNA. At Wentworth, Dr. Feldman is focused on project-based instruction, hands-on simulations, experiential learning approaches, and first year curriculum. Dr. Feldman is one of the lead instructors for Introduction to Engineering courses, with enrollments in the hundreds each fall. His research and teaching interests, in addition to first year engineering, include telemedicine, health informatics, rehabilitation engineering, medical robotics, and engineering pedagogy. Dr. Feldman has collaborated with researchers and engineers from organizations including Tufts School of Veterinary Medicine, Boston Children's Hospital, Vecnacares, and Restoreskills. He is a 2025 KEEN Engineering Unleashed Fellow, and co-PI on a $4.5M NSF NRT grant 2025-2030.

SHARE: Fourier Detectives: A Math-Free, Hands-On Introduction to Spectral Analysis for Biomedical Engineering Students

Motivation

Fourier analysis is central to biomedical engineering, yet students often struggle to connect its abstract mathematics to physical reality [1]. While instructors commonly use applications such as heart rate analysis, optics, and IR spectroscopy, these examples are usually presented after the formal mathematics have been introduced, limiting opportunities to build intuition first [2–7]. "Fourier Detectives" reverses this sequence. By exploring WiFi, audio, and physiological signals before the math lecture, students develop a mental model of time and frequency representations and recognize common principles across modalities. This exposure primes them for the formal mathematical treatment that follows, allowing instructors to later anchor equations to observations, such as broadband spectra from a clap versus narrow band for a whistle. In future lectures, the instructor references student observations, such as, "Remember when your clap created spikes? That is because…"

Learning Objectives-After completing activity students will be able to:

1. Recognize that everyday signals are composed of multiple frequency components, strengthening pattern recognition skills that prepare them for formal spectral analysis.
2. Explain how the same physical event appears in both the time and frequency domains, building an intuitive foundation for the mathematical development of Fourier analysis.
3. Articulate a unifying analytical principle across communications, acoustics, and physiology, positioning Fourier analysis as tool for understanding many real-world systems.

Practical Implementation Details

The activity requires almost **no prerequisites**, making it accessible for students ranging from first-year engineering to upper-level students (where the math will be developed further).
Time required: 50-60 minutes, delivered before formal Fourier analysis is introduced.
Groupings: Students work in pairs (larger groups could work also)
Materials and Preparation: Smartphones with the free apps installed in advance: spectrum analysis app *Phyphox*, and a heart rate app such as *Welltory.* Polygraph waveform printouts.

Activity Flow

Step 1: The Invisible WiFi Spectrum Mystery (20 minutes at-home, 10 minutes in class)
At home students review: https://howiwifi.com/2020/07/03/spectrum-analysis-phys-and-interferers/
When the session begins students put their phones in airplane mode, then turn WiFi back on. The instructor gives a "hook" and asks, "How many networks do you see? Now imagine all of them transmitting at once. How does your phone separate them?" This prompts students to generate their own hypotheses about overlapping signals and shared communication channels, creating a natural need for the idea of frequency spectrum before it is formally introduced. Students answer the following question: *"If many signals share the same physical space, what must a mathematical tool / electronic device be able to do in order to separate them?"*

Step 2: Audio Spectrum Detective Work (15 minutes)
Students use Phyphox, or a similar app to visualize sounds in real time. They produce different sounds by whistling, humming, and clapping, and capture a screenshot of their spectrum. These audio examples show that steady behaviors produce focused frequency patterns, while rapid or irregular changes spread energy across frequencies. Students describe the screen-shots of time-

domain representations of a sustained whistle and a clap, and write a brief explanation of how time behavior affects frequency distribution.

Step 3: Polygraph Test Analysis (15 minutes)
3.1 Watch introductory video (~4 minutes):
https://mass.pbslearningmedia.org/resource/nvsn6.sci.tech.polygraph/how-does-a-polygraph-test-work/?student=true&focus=true
3.2 Examine sample polygraph waveforms showing respiration, galvanic skin response, and cardiovascular signals (Appendix A). Instead of looking at the entire data stream at once, students are instructed to select a "window" or portion of the signal to analyze. Students look for repeating patterns, correlations between signals, and changes during questioning. The focus is on recognizing how polygraphers assess variations across multiple physiological signals, building pattern recognition skills through observation rather than math. Students annotate the waveform by circling repeating patterns, labeling at least two distinct rhythms or timescales [8].

Step 4: The Connection Reveal and Artifact Creation (10 minutes)
The instructor makes the connection explicit: students have already applied the central idea of Fourier analysis by decomposing complex signals into simpler components. The class briefly discusses what becomes visible in the frequency domain that was not obvious in the time domain, and what new insights and questions this perspective enables.
Students then generate three short artifacts tied directly to the three contexts:

- **WiFi artifact:** A brief written explanation describing how separating signals by frequency allows multiple network transmissions to coexist and be selectively identified.
- **Audio artifact:** A sketch or annotated spectrum predicting how a whistle, clap, or voice would appear in the frequency domain, with a short note explaining what this reveals about pitch, tone, or noise.
- **Physiology artifact:** An annotated physiological waveform identifying distinct rhythms or timescales, with a short explanation of what frequency differences might indicate.

Step 5: Assessment and Readiness Check (10 minutes plus post-activity)
The WiFi explanation, audio sketch, and physiological annotation serve as the primary assessment artifacts and are evaluated using a rubric that measures students' ability to link time- and frequency-domain behavior, recognize multiple signal components, and articulate the shared decomposition principle. The results provide evidence of conceptual readiness for transitioning to the formal Fourier transform equations and document students' intuitive understanding prior to the mathematical development. Appendix B provides a student reporting handout and rubric.

Suggestions for Instructors

Encourage students to explore and let insights surface as they experiment with the apps. Try not to explain everything too early; save the full synthesis for Step 4. Use examples that connect to their interests, such as biomedical devices, audio, or wireless systems, and then explicitly link their observations to the mathematics in the next lecture. For example, revisit why a clap produces a broad spectrum and show how the equations formalize what they already noticed.

Situational Factors and Solutions

Student curiosity may naturally extend the activity, so plan flexibly and adjust timing as needed. In larger classes, consider using breakout groups or a gallery-walk format to keep students engaged and ensure broad participation. If students do not have phones or reliable internet access, provide access to online analyzers or distribute preloaded screenshots for analysis. In the event of technical difficulties, demonstrate the tools on the projector and guide a full-class discussion instead.

IRB Statement on Data Usage

The data utilized in this study was anonymized and aggregated and was deemed as "exempt" by our university's IRB committee.

References

[1] U. Feldman and G. D. Ricco, "WIP: A methodology for developing a 'signal detective' mindset in biomedical engineering students," ASEE Annual Conference. [Online]. Available: https://peer.asee.org/55532

[2] M. A. C. Potenza, "An extremely simplified optics laboratory for teaching the fundamentals of Fourier analysis," European Journal of Physics, vol. 42, no. 2, p. 025301, 2021.

[3] P. B. Siegel, A. Urhausen, J. Sperber, and W. Kindermann, "Putting your heart into physics," American Journal of Physics, vol. 72, no. 3, pp. 324–332, Mar. 2004.

[4] Q. S. Hanley, "Fourier transforms simplified: Computing an infrared spectrum from an interferogram," Journal of Chemical Education, vol. 89, no. 3, pp. 391–396, 2012.

[5] D. Choudhury, "Teaching the concept of convolution and correlation using Fourier transform," in Proceedings of the 14th Conference on Education and Training in Optics and Photonics (ETOP), 2017, p. 104520Y.

[6] H. S. Barrows, "Problem-based learning in medicine and beyond: A brief overview," New Directions for Teaching and Learning, no. 68, pp. 3–12, 1996.

[7] M. J. Prince and R. M. Felder, "Inductive teaching and learning methods: Definitions, comparisons, and research bases," Journal of Engineering Education, vol. 95, no. 2, pp. 123–138, 2006.

[8] "Understanding the polygraph chart: A deep dive into lie detection," Lie Detector Test, Polygraph Examiner. [Online]. Available: https://liedetectortest.com/polygraph-examiner/understanding-the-polygraph-chart-a-deep-dive-into-lie-detection

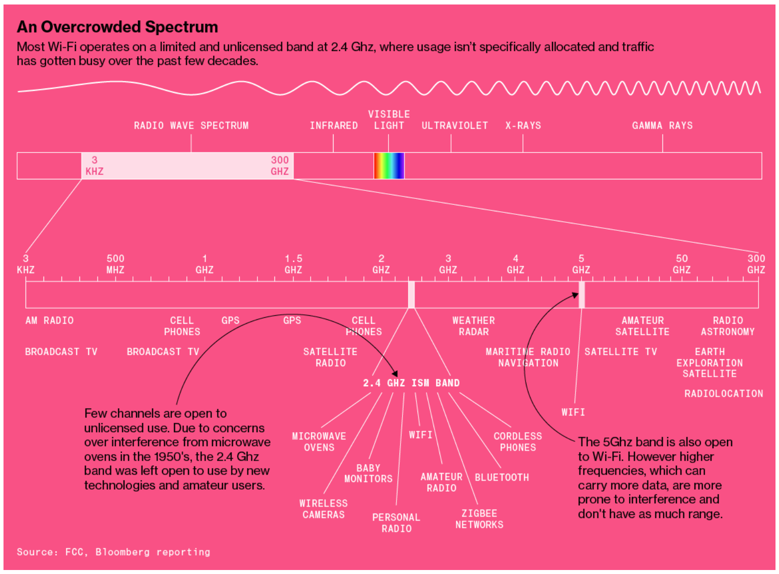
Appendix A

Graphics to illustrate waveforms and signals used in Activity

For audio Spectrum

https://apps.apple.com/us/app/spectrumview/id472662922

Wifi Spectrum (with source links)



Useful links with WIFI spectrum

https://community.tablotv.com/t/wifi-routers-spectrum-neat-article-graphics/10697

https://community.hubitat.com/t/new-router-and-modem/112830

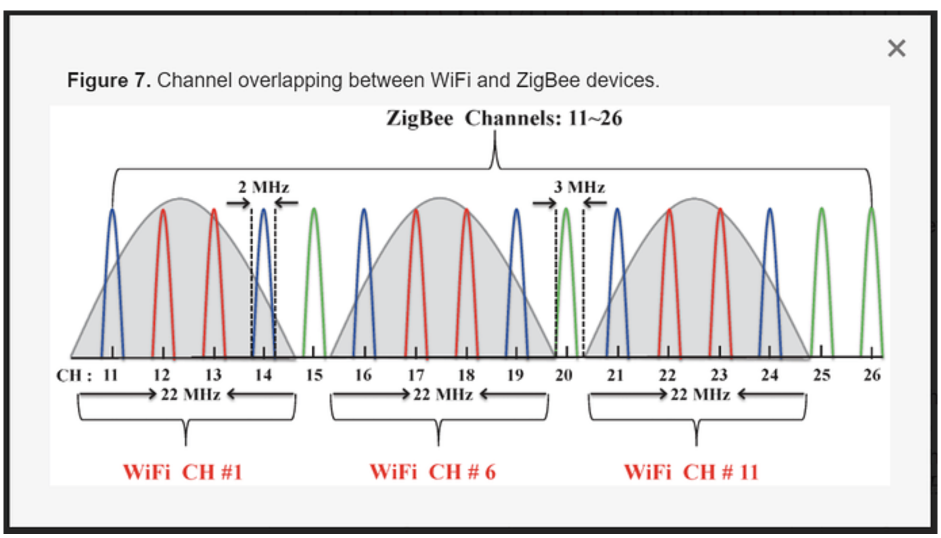
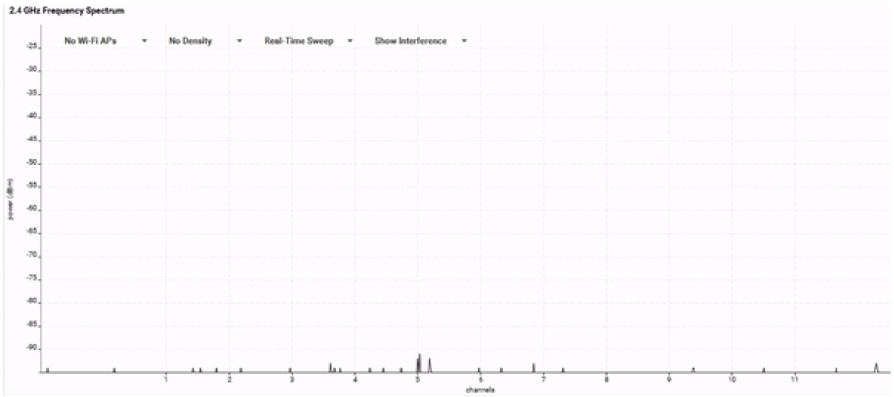
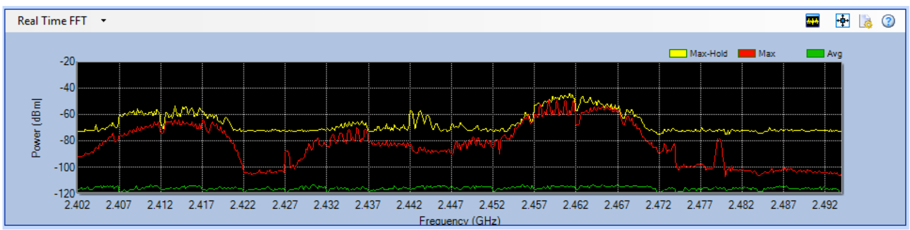


Figure 7. Channel overlapping between WiFi and ZigBee devices.

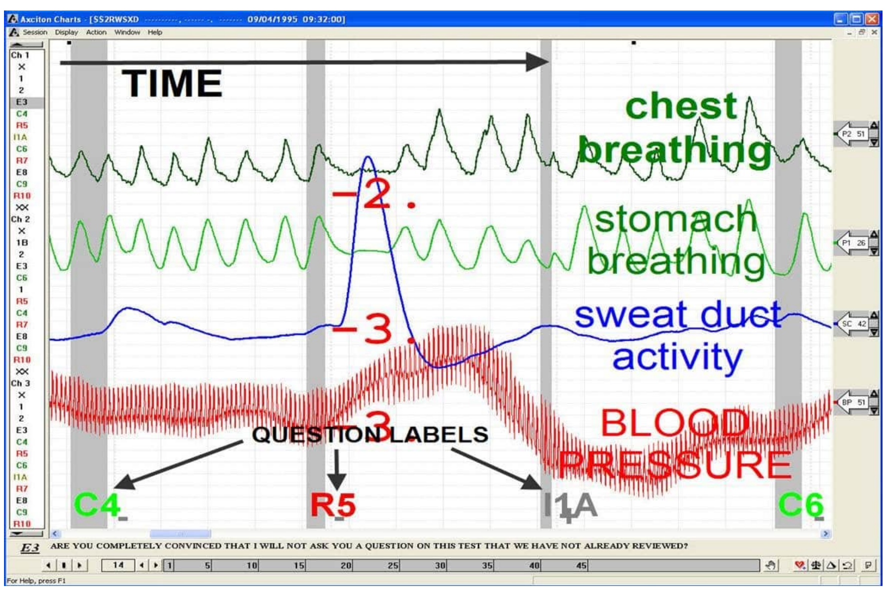
WIFI Real time: https://howiwifi.com/2020/07/03/spectrum-analysis-phys-and-interferers/





For Polygraph

https://liedetectortest.com/polygraph-examiner/understanding-the-polygraph-chart-a-deep-dive-into-lie-detection



Optional Project: Polygraph DIY

https://youtube.com/watch?v=8ogMm94AH80&si=YNl6r7M2viOZg5wD

Appendix B: Fourier Detective Reporting Worksheet

🔍 Fourier Detectives

A Hands-On Introduction to Spectral Analysis

Name: ________________________ Date: ____________ #: _______

Team members: ____

> **Overview.** In this activity you will explore WiFi signals, sounds, and physiological waveforms, all before any equations. Your job is to act as a signal detective: look carefully, describe what you see, and start building intuition about how signals can be broken into simpler components. Keep your observations handy, your instructor will refer back to them throughout the semester.

Step 1 — The Invisible WiFi Spectrum Mystery (10 min)

Before class: Read the following article at home and come prepared to discuss:

https://howiwifi.com/2020/07/03/spectrum-analysis-phys-and-interferers/

In class: Put your phone in airplane mode, then turn WiFi back on.

Paste or sketch your WiFi spectrum screenshot below:

Q1. How many networks do you see?

Q2. Imagine all of those networks transmitting at the same time, through the same environment. How do you think your phone separates them?

Q3. *"If many signals share the same physical environment, what must a mathematical tool or electronic device be able to do in order to separate them?"* Write your best hypothesis; there is no wrong answer here.

Useful links with WIFI spectrum
https://community.tablotv.com/t/wifi-routers-spectrum-neat-article-graphics/10697
https://community.hubitat.com/t/new-router-and-modem/112830

Step 2 — Audio Spectrum Detective Work (15 min)

Download Phyphox or SpectrumView (iOS) and open the audio spectrum tool. Produce each sound below and capture a screenshot.

Screenshot 1 — Sustained whistle

Q4. Describe the spectrum. Is it narrow or spread out? Where is most of the energy concentrated?

Screenshot 2 — Single clap

Q5. Describe the spectrum. How does it differ from the whistle? [Hint: Pay particular attention to the spread of the spectrum.]

Screenshot 3 — Your choice (another sound you recorded, or instructor might produce sounds). Explain what it is : ______________________________

Q6. What does this spectrum tell you about the relationship between how a sound behaves over time and how its energy is distributed across frequencies?

Step 3 — Polygraph Analysis (15 min)

3.1 Watch the short video (~4 min):

How Does a Polygraph Test Work?

https://liedetectortest.com/polygraph-examiner/understanding-the-polygraph-chart-a-deep-dive-into-lie-detection

3.2 Examine the polygraph waveforms in Appendix A. Select a window (a portion of the signal) to focus on [Hint: sweat activity changes]; do not try to analyze the entire recording at once. Annotate the waveforms by circling repeating patterns and labeling at least two distinct rhythms or timescales.

Q7. Signal Pattern Matrix — Complete the table based on your observations:

Signal Type	Pattern You Observe	What Does the Pattern Reveal?
Respiration		
Galvanic Skin Response (sweat)		
Cardiovascular		

Q8. Which signal shows the slowest repeating pattern? Which shows the fastest?

Q9. Based on your observations, how would the frequency content of the slowest signal differ from that of the fastest?

Step 4 — The Connection Reveal (10 min)

Your instructor will now make an explicit connection across all three activities. Then complete the three artifacts below.

WiFi Artifact: Write a brief explanation (~2–3 sentences) describing how separating signals by frequency allows multiple WiFi networks to coexist and be identified independently.

Audio Artifact: Sketch or describe how a whistle, a clap, and a speaking voice would each appear in the frequency domain. Add a short note explaining what this reveals about pitch, tone, or noise.

Physiology Artifact: Using your annotated polygraph waveform, identify the distinct rhythms you found and explain what differences in frequency content might indicate clinically.

Big Idea: In one sentence, state the unifying principle you observed across all three domains:

How did this idea appear in each domain?

WiFi:

Audio:

Polygraph:

What are you most curious about once we introduce the math of Fourier analysis?

Assessment Rubric for Worksheet above

3-Tier Quick Check

Ready for Math (3 points)
Student shows ALL three:

- **Audio section:** Connects time to frequency (e.g., "long whistle = narrow spike, short clap = broad spread")
- **Polygraph section:** Predicts slow pattern = low frequency, fast pattern = high frequency
- **Big Idea:** States that signals can be broken into frequency components and gives examples from all 3 domains

Partially Ready (2 points)
Student shows TWO of the above

Not Ready (1 point)
Student shows ONE or NONE of the above