JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Open Source Audio Platform: Ultrasound Dosimeter

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Motivation

- Recent news articles suggest illness in diplomats caused by ultrasound
  - News media descriptions of the issue are muddled and difficult to assess

Germany investigates possible sonic attack on U.S. Embassy staff in Berlin

BY AMY CHENG

German police confirmed Friday an investigation into an "alleged sonic attack" targeting U.S. Embassy staffers in Berlin, who are among the roughly 200 cases of a mysterious illness reported by U.S. diplomats and intelligence officers stationed around the world.

As of August, at least two U.S. government employees based in Germany have logged symptoms such as dizziness, nausea and severe headaches, according to numerous media reports. These are among the signs of "Havana Syndrome," an affliction named after the Cuban capital where such cases were first reported.

The U.S. Embassy in Berlin could not immediately be reached for comment early Saturday. A State Department spokesman declined to discuss specific cases but said that various government agencies were "actively working to identify the cause of these incidents and whether they may be attributed to a foreign actor," and that the department "is focused on providing care for those affected."

Berlin police did not release further information about their probe.

On Friday, President Biden signed into law a bipartisan bill to financially support U.S. government personnel believed to be suffering from Havana Syndrome.

"We are bringing to bear the full resources of the U.S. Government to make available first-class medical care to those affected and to get to the bottom of these incidents, including to determine the cause and who is responsible," he said in a statement.

Cases of Havana Syndrome have been reported across the globe, in Russia, China, Colombia, Uzbekistan and even the United States. Two cases were reported in the Washington area, and in July, Austrian authorities said they were working with American officials to investigate about 20 cases among U.S. Embassy staffers in Vienna, reportedly the biggest cluster of cases outside Cuba.

Current and former intelligence officials have increasingly pointed a finger at Russia, which has staged brazen attacks on adversaries and diplomats overseas. No evidence against Moscow has been made public, however, and Russia has denied involvement in the incidents.

After facing criticism for a slow response, CIA Director William J. Burns tasked a top agency official in July with leading the investigation into Havana Syndrome. The CIA's station chief in Vienna was recalled from the prominent post following what some considered an insufficient response to a growing number of health incidents at the U.S. diplomatic mission there, The Washington Post previously reported.

Havana Syndrome encompasses a wide range of physical and cognitive symptoms, including extensive memory lapses. In the brain scans of some embassy employees in Cuba, damage to tissue resembled that seen after bomb explosions or car accidents.

Since its emergence five years ago, the condition has confounded medical experts. Government officials refer to potential cases as "anomalous health incidents."

When Havana Syndrome was initially reported, scientists were reluctant to characterize the phenomenon as an attack. As more people suffering with the ailment reported episodes of feeling like they had been hit by a beam of energy, the possibility of their having been attacked by radio frequency energy gained traction.

In December, the National Academies of Sciences, Engineering and Medicine released a report after hearing patient testimony and concluded that "directed, pulsed radio frequency energy" appeared to be "the most plausible mechanism." Yet outside experts have also called the theory "scientifically implausible" and amounting to "science fiction."

The National Academies report stated that it could not rule out alternative means as well as the possibility that multiple factors may have contributed to the symptoms.

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Miriam Berger in Washington contributed to this report.

Washington Post, Oct 10, 2021

Motivation

- Loud noise above 15kHz can cause annoyance, headaches, etc, especially in younger listeners
- Others in the same space may not hear it
  - Auditory band differs among individuals
- Sounds up to ~20 kHz can be observed in smartphone apps, but not far above that

Table 1. *Examples of incidental or deliberate exposures from commercial devices*

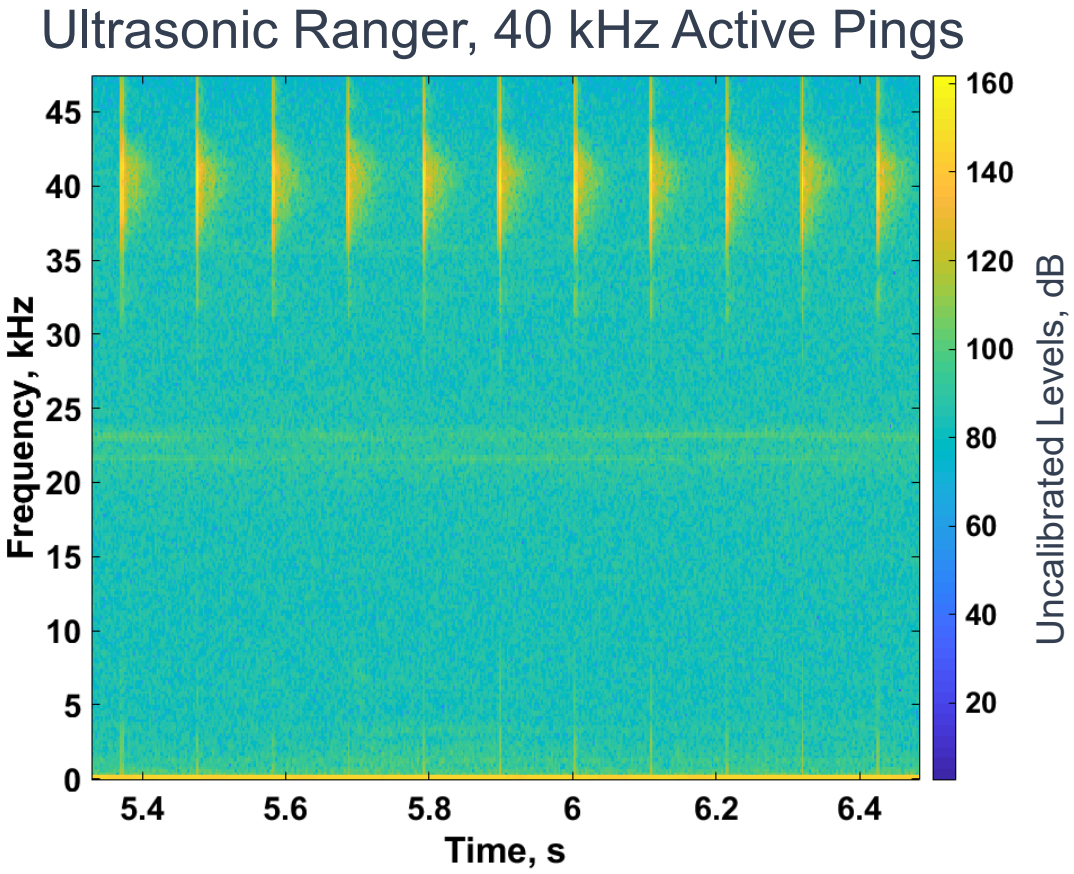
Incidental or Deliberate Exposure?	Commercial Source	Frequency	SPL Levels at the Possible Position of the Human Ear	Reference for Measurement
Deliberate	Pest deterrents: Used to deter birds, rodents, and insects away from locations (barns, homes, and shops)	20-kHz TOB	130 dB at 1.6 m 90 dB at 14 m	Ueda et al., 2014a,b
			92 dB at 1.7 m	Dolder et al., 2018
Deliberate	Teen deterrent: Exploits high-frequency sensitivity of teenagers and children to deter them from shops as age-discriminatory deterrent to make the shop more welcoming to older customers who are assumed to have greater purchasing power and be less likely to steal.	12.5-kHz TOB	72 dB at 1.5 m	Conein, 2006
		16-kHz TOB	92 dB at 1.5 m	
		20-kHz TOB	80 dB at 1.5 m	
Incidental	Public-Address-Voice-Alarm: Speakers, usually set in ceilings or high on walls in public places to alert people, e.g., to evacuate in case of bomb threat or fire; by EU law must be monitored to ensure they are functioning. Many types produce a ~20-kHz tone as a by-product of this monitoring.	~20 kHz	76 dB	Fletcher et al., 2018c
			65 dB	Paxton et al., 2018
			43-82 dB	Mapp, 2018
Incidental	Acoustic spotlights: Two high-intensity ultrasonic beams overlap, and the nonlinear difference frequency produces a low-power audible signal so that listeners to recordings who share a space do not bother one another (for museums, exhibitions, and homes). It is not known whether anecdotal reports of adverse effects, if confirmed, would be due to the fundamental, a subharmonic produced by the source of a nonlinearity in propagation, or when the ear is driven by the signals.	~20 kHz	53 dB at 3.5 m	Dolder et al., 2019 Sapozhnikov et al., 2019
		~40 kHz	118 dB at 3.5 m	
Incidental	Haptic feedback: ultrasonic beams (e.g., above a computer keyboard) produce modulated radiation pressure that gives the sensation resembling "soap bubbles bursting on the skin."	~40 kHz	125 dB at 60 cm	Battista, 2019
			155 dB at 20 cm	Lieber et al., 2019

SPL, sound pressure level, TOB, third-octave band; EU, European Union. See Leighton, 2016a, for details of devices.
Reproduced from Leighton et al., 2020.

Project Overview

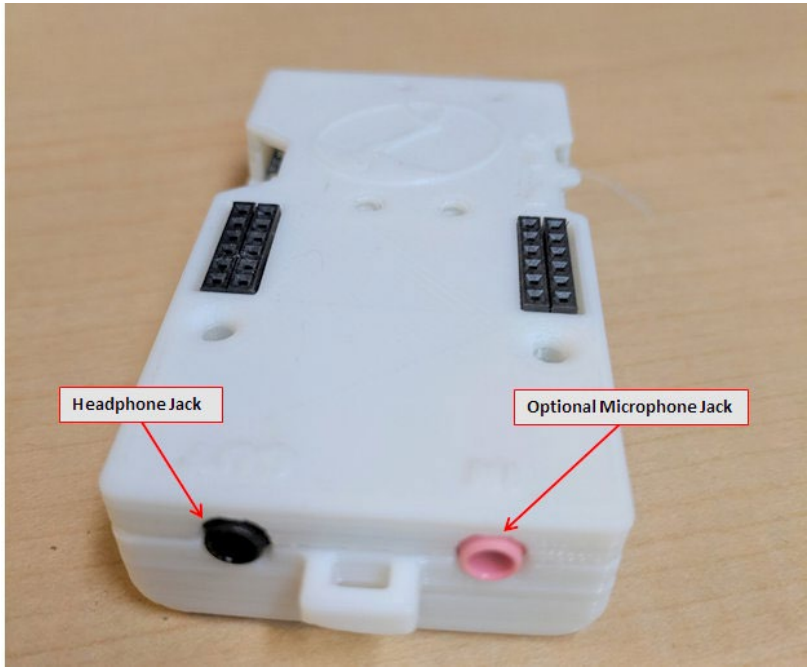
- Create quick, easy, open source way to screen rooms for extraneous ultrasound across entire band
  - Higher frequencies than available on smartphone apps
  - User can listen to frequency shifted audio to help identify sources that are out of the ordinary
  - Would need to follow up with better (calibrated) tools if you found anything

- Other questions we can answer with this work
  - Is my cat disturbed by high frequency sound coming from the TV? Why does he run away?
  - Can we hear bats in the neighborhood (work in progress)
  - Frequency shifted sounds are cool – scare the kids on Halloween!



Approach

- Use Arduino based open source Tympan platform
  - No circuits to build, just coding
  - Code can be shared for others to build on
- Team includes acousticians and experienced C++ programmer
- Compute 1/3 octave band levels
- Compare high frequencies to lower frequencies
- Alert if energy only at high frequency
- Allow user to listen for themselves



https://github.com/Tympan/Docs/wiki/Getting-Started-with-Tympan

Compute (Uncalibrated) Octave Band Levels Below 20 kHz And 1/3 Octave Band Levels Above 20 kHz

Example Serial Monitor Output

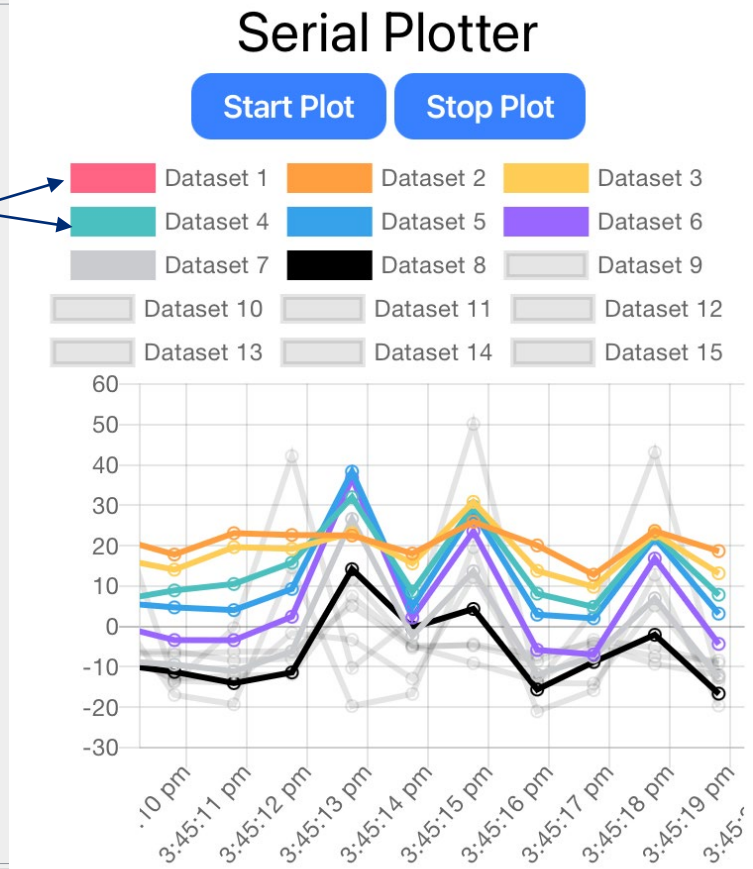
[offline] (Teensy)

```
Ultrasound detected: 18.72 is greater than -8.59
 SPL Level: 47.00, 18.51, 14.35, 3.83, 1.34, -5.65, -11.48, -15.46, -12.34, -8.43, -7.10, -7.50, 25.06, -6.48,
Ultrasound detected: 25.06 is greater than -7.10
 SPL Level: 46.84, 16.91, 18.07, 9.74, 18.37, 14.75, 4.02, 3.28, -0.23, 4.15, -2.92, -6.28, 24.76, -4.25,
Ultrasound detected: 24.76 is greater than -2.92
 SPL Level: 46.19, 12.60, 12.23, 4.76, 11.30, 3.17, -7.90, -12.15, -11.80, -7.77, -5.40, -7.80, 25.76, -7.43,
Ultrasound detected: 25.76 is greater than -5.40
 SPL Level: 47.36, 26.36, 15.90, 10.09, 17.51, 19.57, 13.33, 5.62, 3.93, 7.58, 2.77, -2.27, 14.57, -11.23,
Ultrasound detected: 14.57 is greater than 2.77
 SPL Level: 46.34, 23.07, 9.73, 5.33, -0.37, -2.90, -12.22, -16.14, -14.90, -8.59, -2.37, -5.05, 7.16, -16.55,
Ultrasound detected: 7.16 is greater than -2.37
 SPL Level: 46.51, 15.67, 8.41, 3.23, -0.87, -6.28, -12.23, -15.46, -14.37, -8.20, -2.28, -10.81, -10.39, -22.20,
 SPL Level: 42.91, 29.41, 24.66, 20.17, 31.86, 28.85, 21.40, 12.56, 4.49, 8.48, 5.50, -1.65, -5.03, -12.95,
 SPL Level: 45.42, 14.05, 8.87, 7.01, 3.41, 5.91, -0.03, -8.53, -11.22, -2.35, -4.20, -11.95, -14.30, -18.19,
 SPL Level: 47.23, 16.33, 11.08, -0.99, -2.44, -6.19, -14.21, -15.24, -14.32, -8.60, -5.53, -13.47, -5.55, -21.38,
 SPL Level: 46.33, 18.81, 15.54, 3.67, 2.13, -3.92, -11.09, -14.30, -13.70, -8.78, -6.94, -7.73, 26.46, -1.80,
Ultrasound detected: 26.46 is greater than -6.94
 SPL Level: 47.36, 19.80, 10.63, 3.65, 1.17, -8.59, -13.06, -15.50, -15.09, -8.32, -6.76, -14.19, -14.50, -22.06,
 SPL Level: 47.07, 23.55, 17.36, 3.59, 1.97, -5.79, -11.96, -14.18, -13.98, -7.96, -6.15, -13.95, -0.03, -20.78,
Ultrasound detected: -0.03 is greater than -6.15
 SPL Level: 46.03, 32.59, 27.00, 25.51, 22.89, 18.45, 8.24, 1.18, -6.18, -1.61, -3.15, 10.55, 48.47, 21.68,
Ultrasound detected: 48.47 is greater than -3.15
 SPL Level: 46.29, 25.91, 16.59, 17.05, 14.14, 15.60, 7.64, -6.77, -10.96, -4.18, -5.81, -14.84, -12.87, -19.72,
 SPL Level: 47.36, 20.01, 9.68, 1.32, 0.53, -3.61, -10.63, -11.30, -13.32, -7.22, -7.01, -14.03, 3.43, -20.89,
Ultrasound detected: 3.43 is greater than -7.01
 SPL Level: 46.82, 14.91, 8.70, 7.01, 0.28, -6.58, -11.32, -12.19, -8.62, 1.07, -3.88, -13.03, -14.69, -20.97,
 SPL Level: 46.67, 14.60, 10.55, -0.53, -3.09, -8.06, -13.69, -15.05, -13.92, -8.91, -7.05, -14.00, -16.05, -22.81,
 SPL Level: 46.76, 15.27, 12.21, 2.59, -2.05, -7.02, -13.74, -15.18, -14.16, -8.68, -6.24, -14.69, -16.11, -21.95,
 SPL Level: 47.08, 20.65, 11.42, 6.63, -1.74, -7.42, -12.99, -15.46, -14.20, -8.65, -6.57, -14.22, -15.67, -22.22,
 SPL Level: 47.07, 17.97, 6.80, 7.85, -0.74, -6.47, -14.72, -16.47, -14.51, -7.94, -7.75, -14.36, -15.84, -23.42,
 SPL Level: 46.85, 17.09, 12.15, 8.67, -3.07, -6.55, -12.47, -15.90, -15.04, -9.66, -6.88, -14.34, -15.25, -22.38,
 SPL Level: 47.54, 18.31, 9.31, 3.20, -1.51, -7.72, -14.91, -15.17, -13.85, -9.06, -7.04, -13.65, -15.85, -22.71,
 SPL Level: 47.11, 18.30, 11.31, 2.67, -0.88, -5.76, -9.92, -12.98, -13.07, -8.57, -6.15, -14.23, -15.27, -21.04,
 SPL Level: 46.98, 13.26, 13.48, 7.50, -0.76, -3.40, -9.32, -15.09, -13.93, -8.28, -6.95, -14.72, -14.51, -21.85,
 SPL Level: 46.77, 12.93, 9.85, 23.13, 17.61, 11.49, 3.54, -6.01, -2.05, 3.68, -3.65, -13.64, -15.34, -20.45,
Command Received: setting frequency downshift to 25kHz
SerialManagerBase: sending: STATE=BTN:ShiftA:0
```

Autoscroll Newline

1 Octave Frequency bands

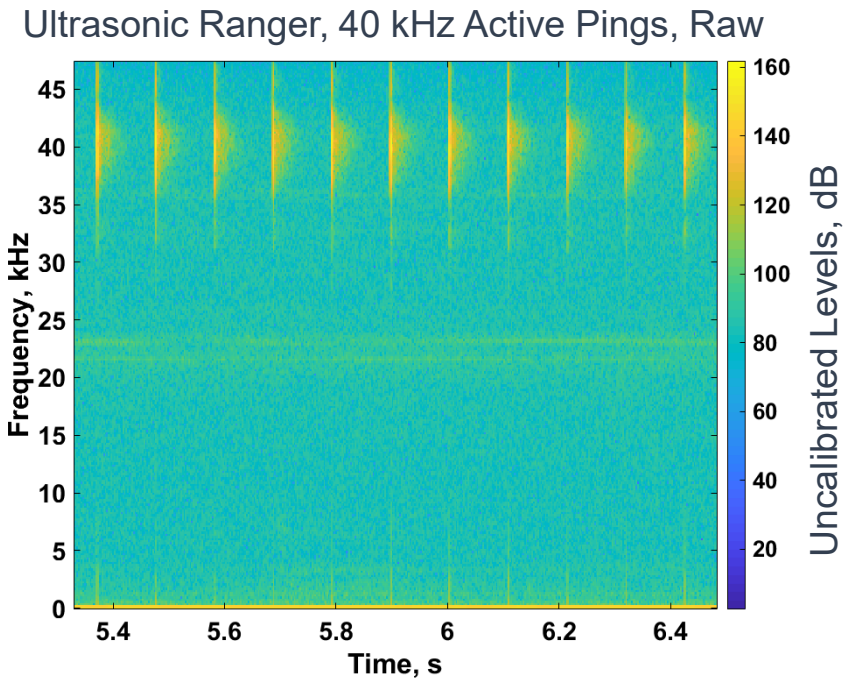
Example Bluetooth App Plotter

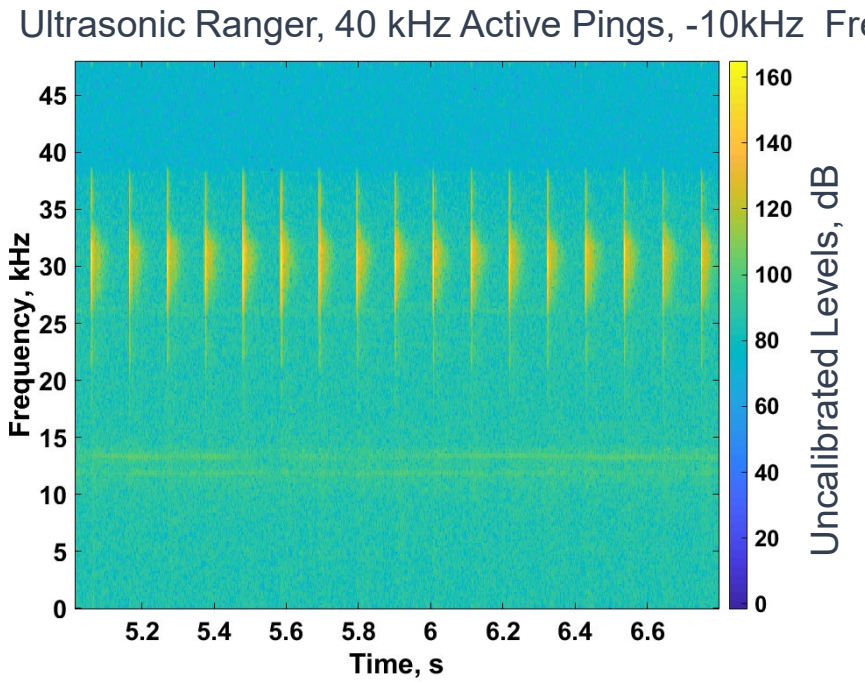


Play Back Through Headphone Jack

- Ultrasound shifted down to audible in left channel and audio with low pass filter in the right channel

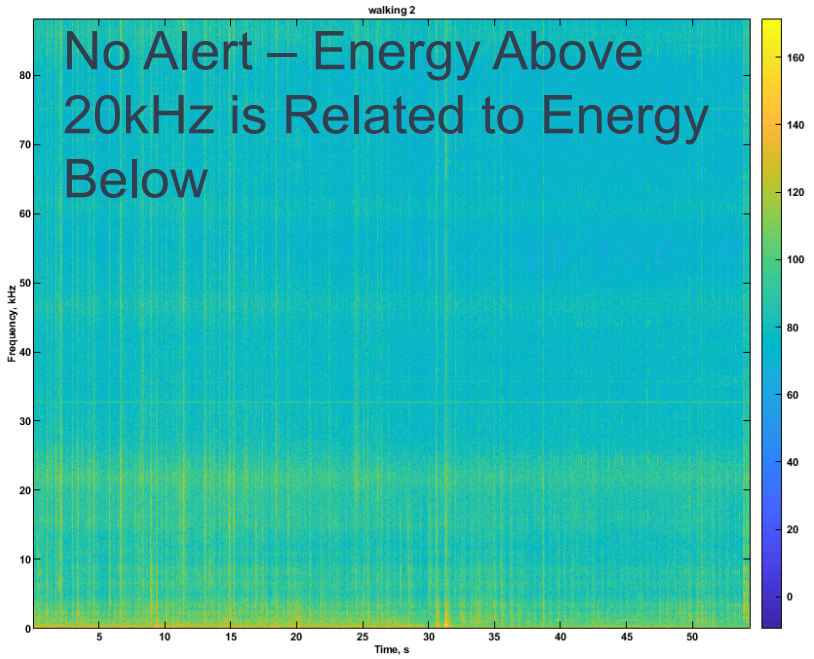
- Record frequency shifted and raw audio to SD card (one on each channel in the .wav file) when user selects

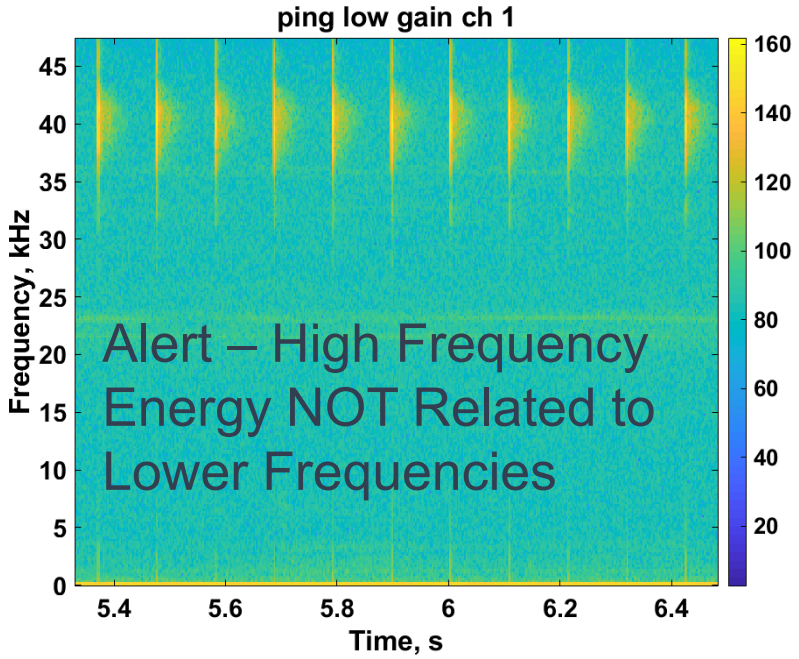




Alert If Irregular Ultrasonic Energy Is Observed

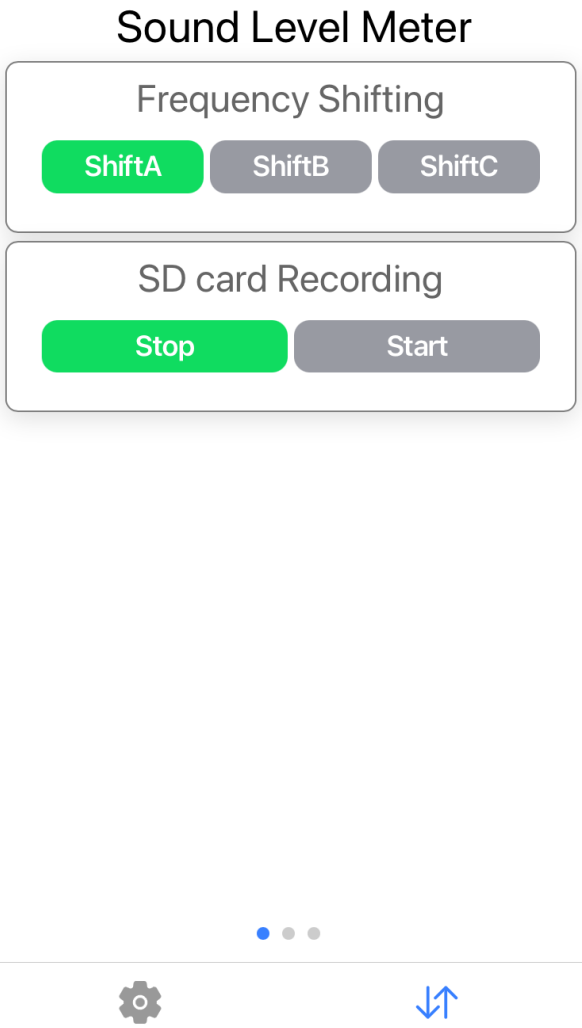
- Alert = Flash the light and report to serial monitor
- Threshold: level in any of the ultrasound 1/3 octave bands exceeds the level in the band just below 20kHz
- Levels are averaged over the band and corrected back to spectral level units (dB/Hz)
- Still uncalibrated, but the relative levels should be accurate

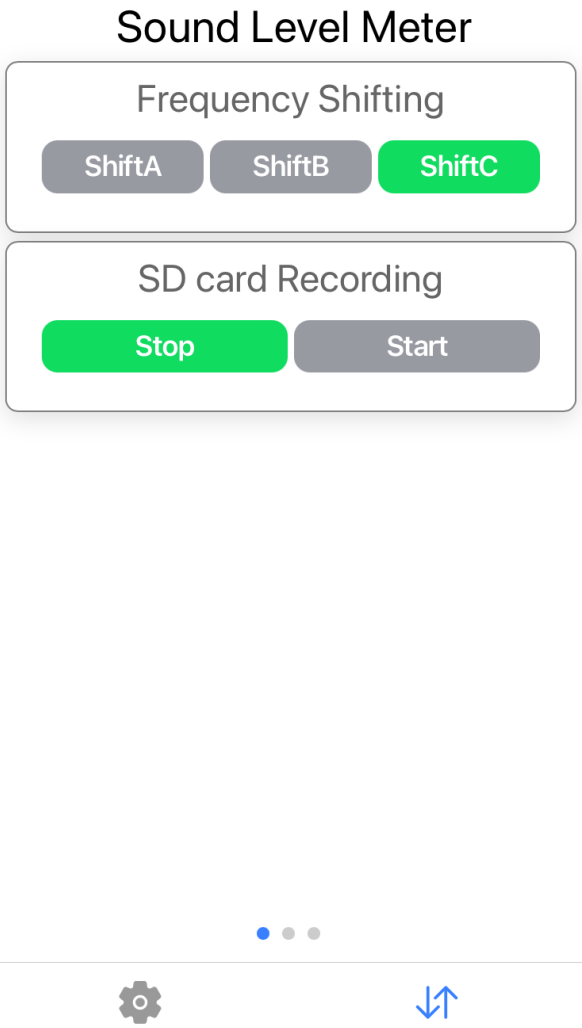




Bluetooth Controls

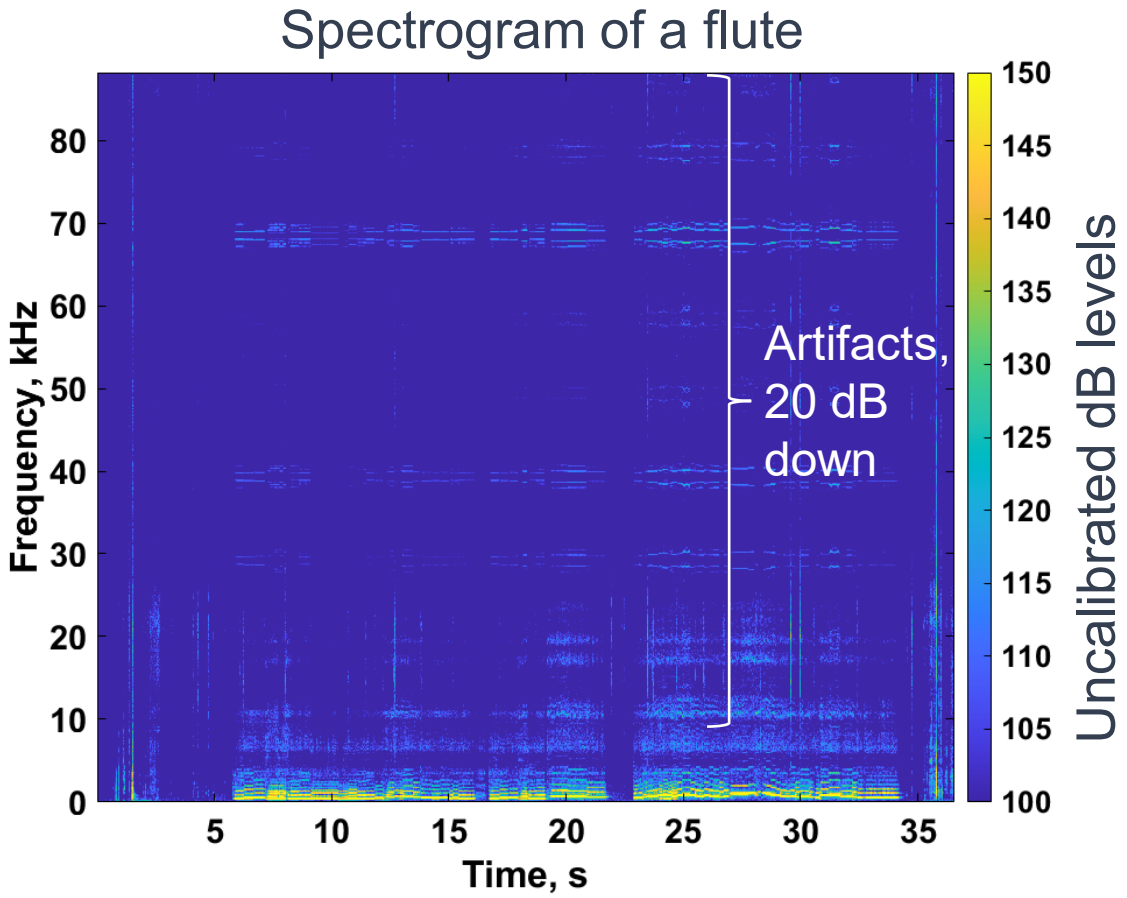
Tympan App on smartphone allows control over frequency shift (10, 20, 25 kHz) and SD card recording





Lessons Learned

- The Tympan has a configurable sample rate, enabled by sigma-delta ADC
  - But at sample rates > ~110kHz, it can't really keep up, and spectral content is splattered

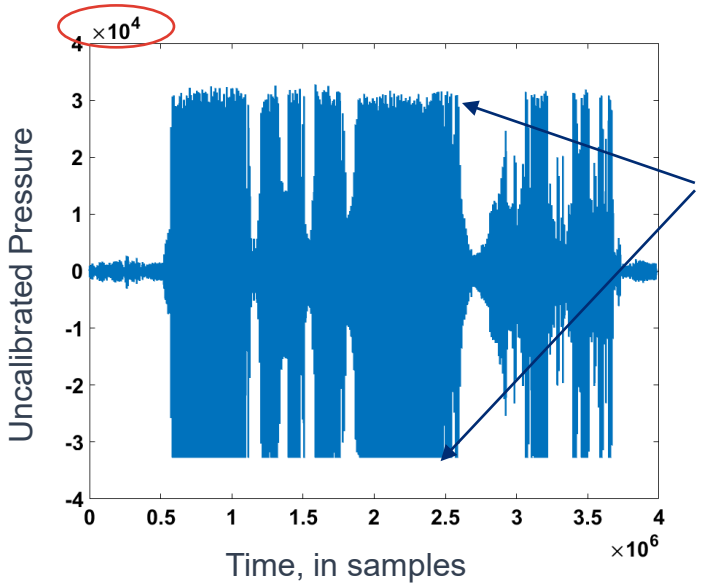


recorded at 176.4 kHz sample rate

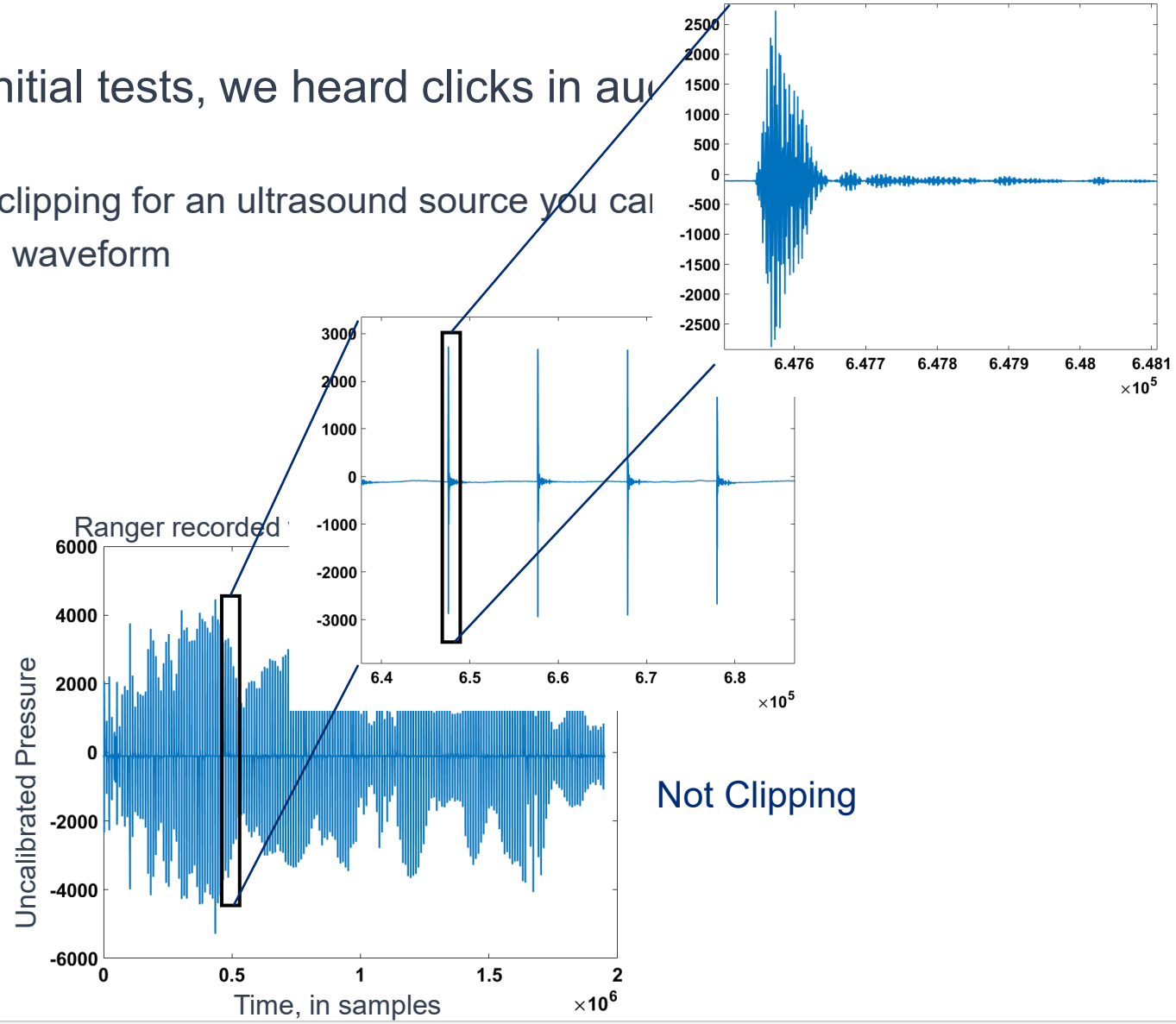
Lessons Learned

- Using ultrasonic ranger for Arduino in initial tests, we heard clicks in au
  the Tympan but not with our ears.
  - Adjusting the input gain to avoid saturation/clipping for an ultrasound source you ca
  - It was evident when looking at the recorded waveform

Ranger recorded with 25 dB input gain



Clipping evident from the flat max level



Not Clipping

*Note difference in yaxis limits

Next Steps

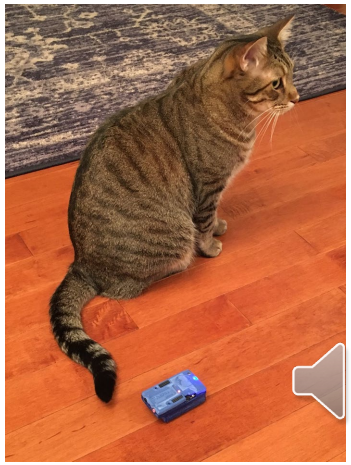
- Improve the threshold for questionable ultrasound levels
  - Ideally, would need access to something that looks like “ultrasonic weapons” to test against
- Calibrate the built-in mic at ultrasound frequencies or use an external calibrated mic
  - Resonance peak typical in 20-40 kHz band for mics intended for audio
  - Need to adjust the threshold for alerting afterward
- Improve the responsiveness
  - Processing in blocks means that if a transient sound does not align with the block, it may not register fully – energy will be split between blocks
  - Arduino works in a continuous loop, only acting on the blocks periodically. Again some transients will be missed

Fun With Frequency Shifting

Mild Mannered Scientist Becomes Feared Monster

Safety Pins Sound Awesome

Officemate Enhancement



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