Introduction

Problem

- Espionage techniques, such as laser microphones, are dangerous to society and can be utilized to compromise private and valuable information.
- Laser microphones are surveillance devices that use projected laser beams to detect sound (Fig. 1 and 2).
- Windows and objects vibrate according to the sound waves in a room. The differences in amount of light, according to the displacement of the laser by sound waves, can be converted back to sound waves to eavesdrop (Wang et. al., 2009).
- The KGB, the main security agency for the Soviet Union used laser microphone to spy on British, French, and US embassies in Moscow (Graham 2008).
- A British intelligence agency feared that if Russian or Chinese agents were unsuccessful in penetrating computer systems, they might try to listen to discussions with a laser microphone (Bryant 2013).

Previous Solutions

- Injecting a sine wave signal into the window vibrations. However, this signal can be filtered out ("Laser Microphone Surveillance Defeater," 2017), the instrumentation is expensive, and there is no scientific research substantiating its effectiveness.
- Utilizing transparent irregular surfaces which cause diffuse reflection and reduce viability of modulated laser signal (Shah, 2016; 2017; 2018). However, these treatments cause an optical distortion in the window and can also be comparatively expensive.
- SCIFs (Sensitive Compartmented Information Facility). These are mostly *windowless* secure rooms that guard against surveillance and suppress data leakage.
  - Emergency SCIFs have to be assembled in unfavorable locations, potentially containing windows, such as hotel rooms, which are susceptible to laser surveillance (Rafferty 2017).

Goal: To quantify the ability of altered oscillations of the reflecting media to alter wavelengths of reflected modulated laser signals while ensuring low audible disruptions and maintaining image clarity.

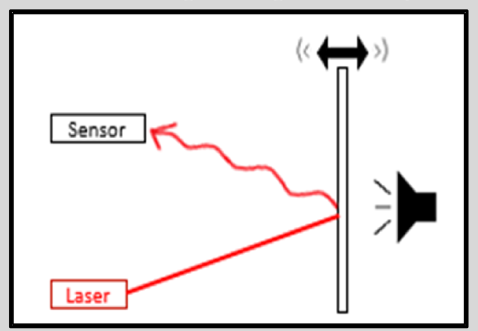

Fig. 1: Modulation of a laser based on vibrations of a window due to sound

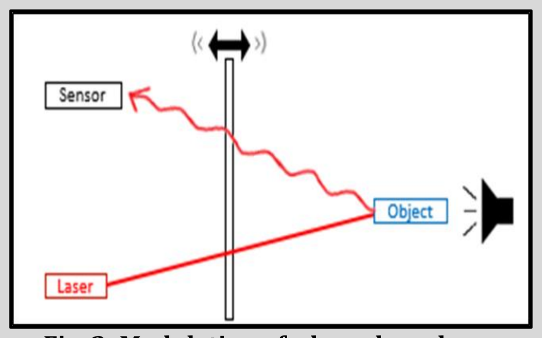

Fig. 2: Modulation of a laser based on vibrations of an inside object due to sound

Methods

Phase I

- Two identical 120W speakers were outfitted with glass cylinders, allowing them to act as transducers capable of injecting signals into the plexiglass window through contact. The window was induced to vibrate by the motion of the speaker.
- Thwarting the signal: Noise cancellation technique
  - An Alpec Class IIIA <5mW HeNe Red Laser was reflected off a plexiglass window and into a spatial filter, photovoltaic cell (PV), amplifying mechanism, and Vernier data logger. The window was first oscillated with a 242Hz frequency, then with the inverse of that signal, and finally with both signals at once.
- Concealing signal with sine wave signal:
  - The same laser microphone setup was utilized. One speaker produced a speech signal susceptible to laser microphone while the other produced an overpowering 242HZ or 129Hz signal.
- Transmitting alternate data (spoofing)
  - The same laser microphone setup was utilized. One speaker outputted the true speech signal, acting as private information vulnerable to laser microphone surveillance. The second speaker produced another speech signal intended to overpower the existing window vibrations.
- Concealing signal with white noise signal:
  - The same laser microphone setup was utilized. One speaker injected a white noise signal using an online sound generator (Pigeon 2013) while the other produced a speech signal.

Phase II

- Optical resolution of window was tested by taking photographs of an image through an oscillating and non-oscillating window.

Phase III

- A Vernier sound level meter was used to measure the decibel levels in a quiet and conversation-filled room with and without the vibrations of the countermeasure.

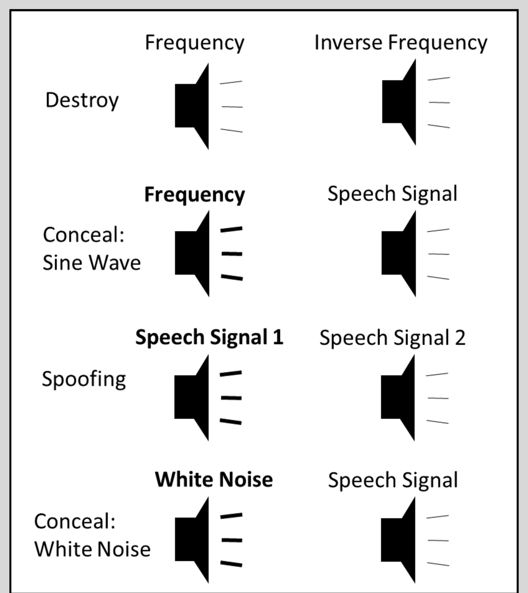

Fig. 3: The four major methods of disrupting a laser microphone setup through oscillation of reflecting media.

Fig. 4: Speaker design with glass cylinder adhered to center with epoxy resin.

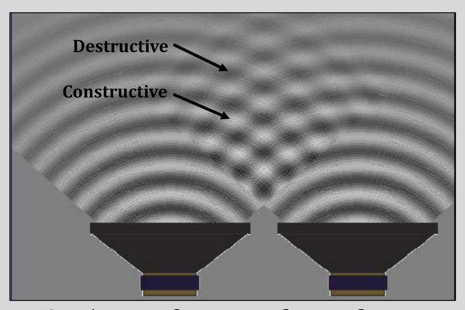

Fig. 5: Interference of sound waves.
Source: https://phet.colorado.edu/en/simulation/legacy/sound

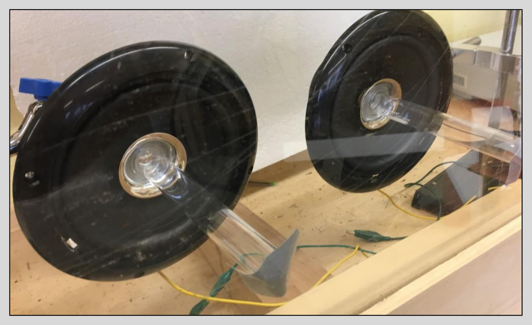

Fig. 6: Two speakers with glass cylinders that are tangent to the window .

Methods

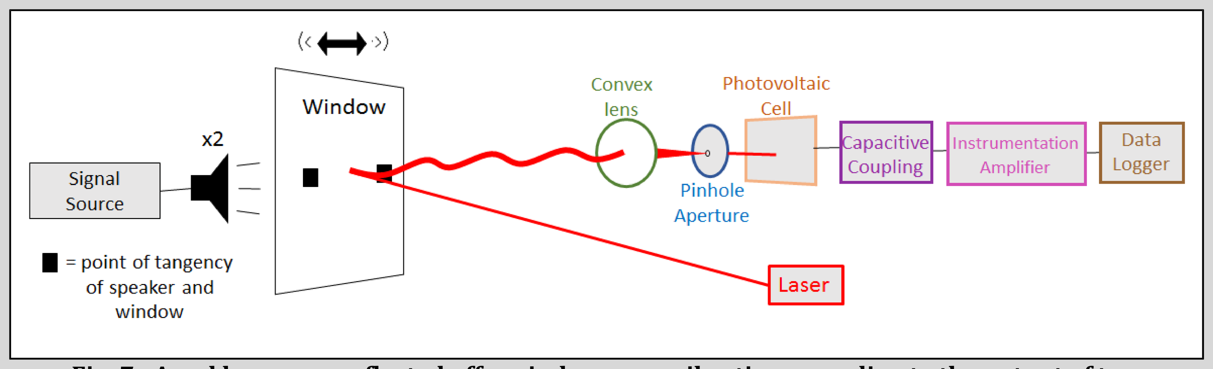

Fig. 7: A red laser was reflected off a window pane vibrating according to the output of two speakers. The reflection of the laser was directed through a spatial filter (convex lens and pinhole), PV, and an amplifying mechanism into a data logger.

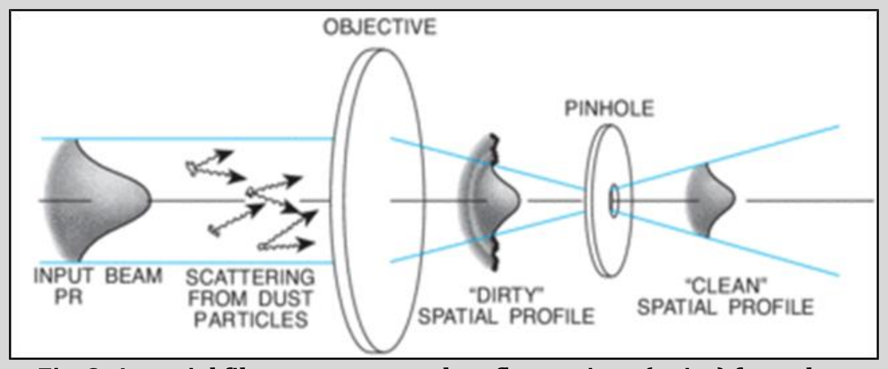

Fig. 8: A spatial filter removes random fluctuations (noise) from the intensity curve of a laser. The lens refocus the laser beam and pinhole blocks most noise.
Source: https://www.newport.com/medias/sys_master/images/images/hcc/hb4/8798836359198/SPATIALF-S-600w.gif

Fig. 9: Experimental setup with (from left to right) spatial filter, PV, capacitive coupling, and instrumentation amplifier.

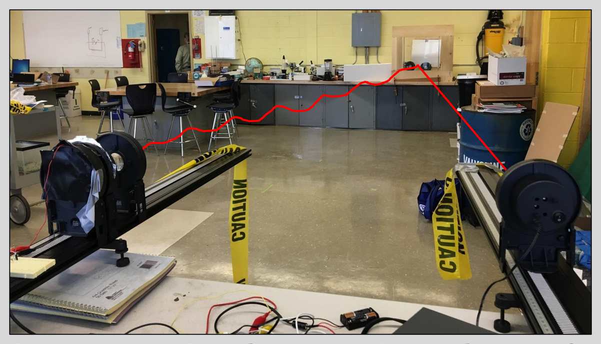

Fig. 10: Laser microphone experimental setup of Figure 7.

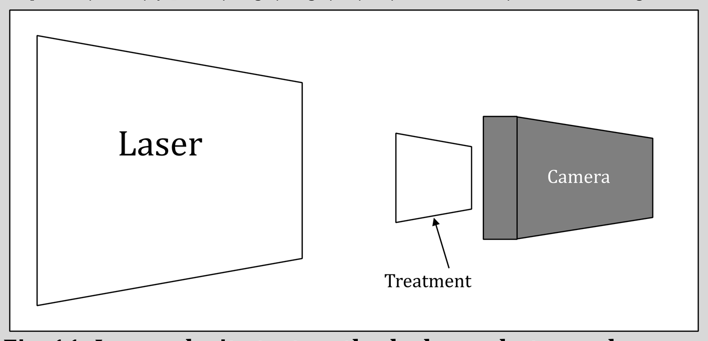

Fig. 11: Image clarity test method where photographs were taken through a vibrating and non-vibrating window.

Discussion

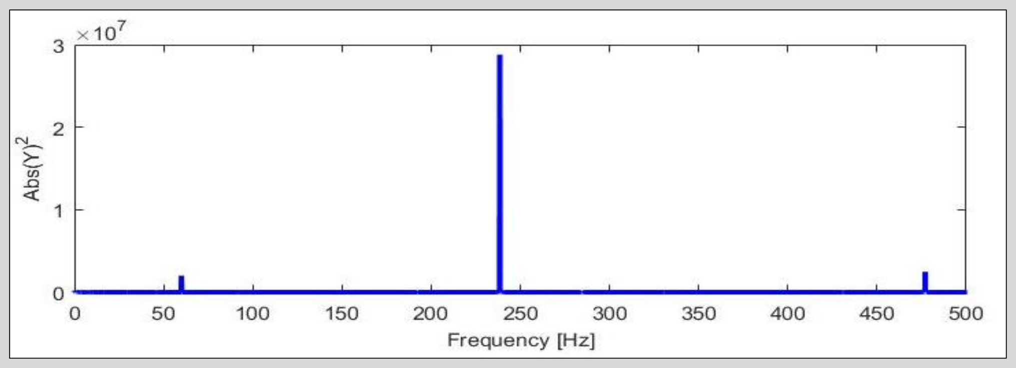

Fig. 27: FFT of 242Hz signal; noise is present at 60Hz.

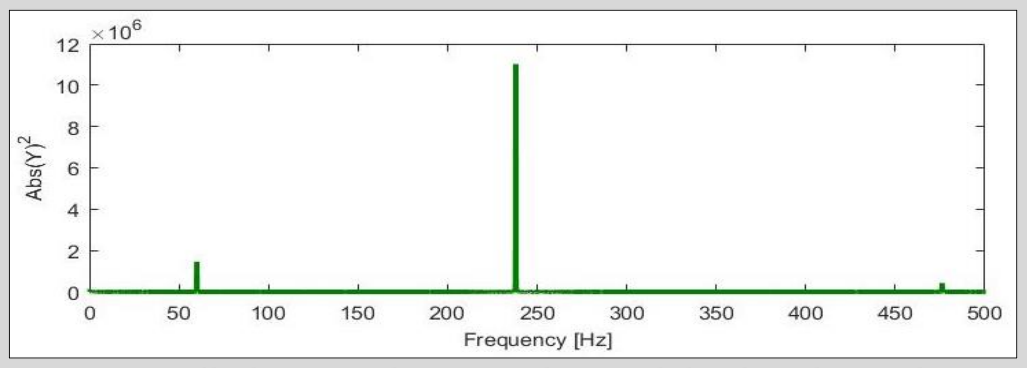

Fig. 28: FFT of both 242Hz and voice recording signal played simultaneously. Sine wave signal is overpowering voice signal. Voice signal is not visible at this scale.

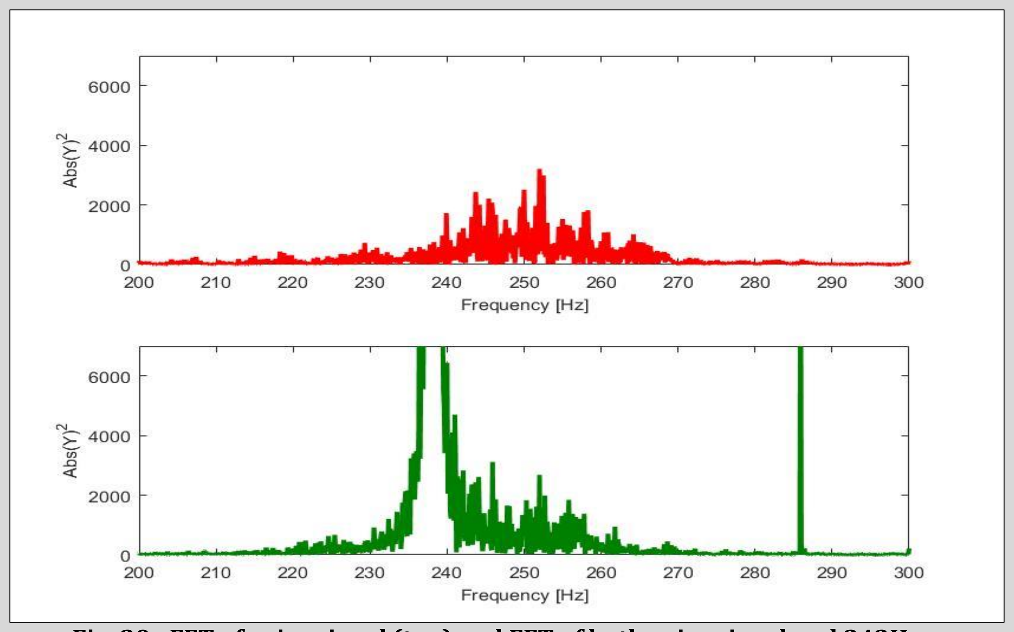

Fig. 29: FFT of voice signal (top) and FFT of both voice signal and 242Hz played simultaneously (this graph is scaled down to visualize frequency spectrum of voice) . Filtering out the 242 Hz frequency would also filter out a portion of the voice spectrum.

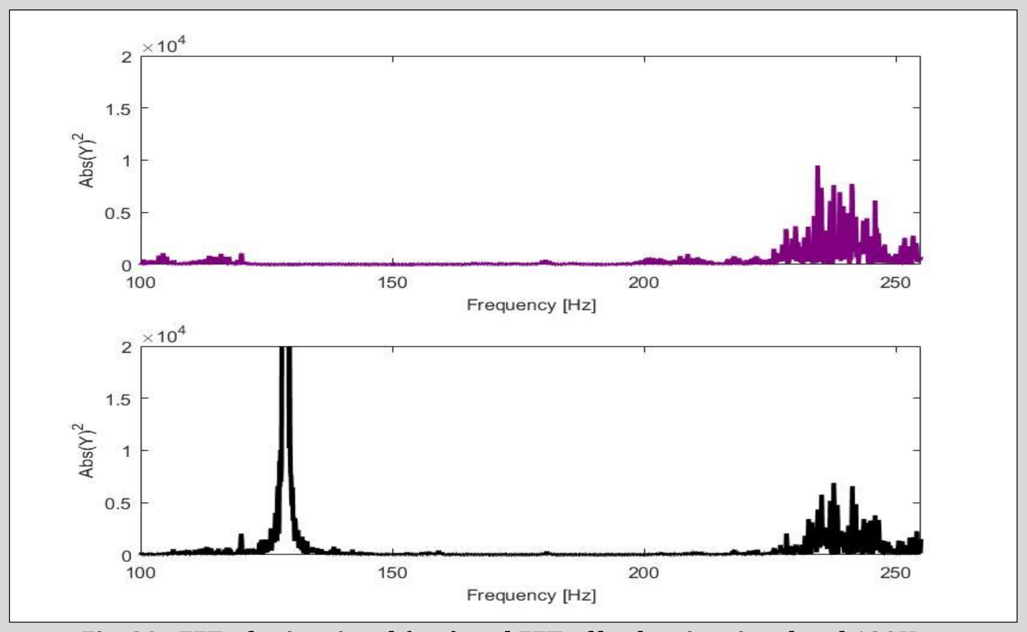

Fig. 30: FFT of voice signal (top) and FFT of both voice signal and 129Hz played simultaneously (this graph is scaled down to visualize frequency spectrum of voice). Note that filtering out the 129Hz sine wave signal will not affect the integrity of the original voice spectrum.

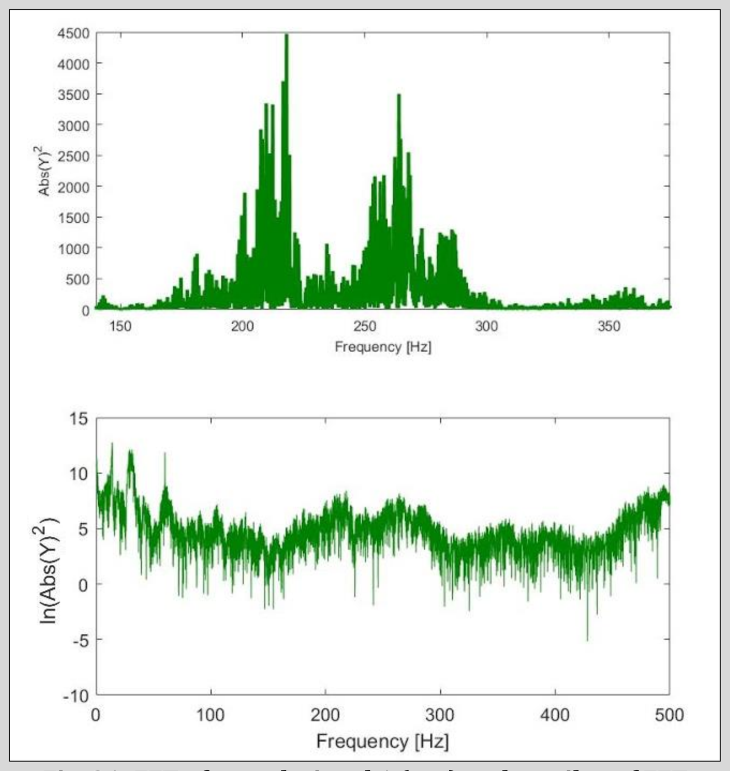

Fig. 31: FFT of speech signal 1 (top) and semilog of FFT (bottom).

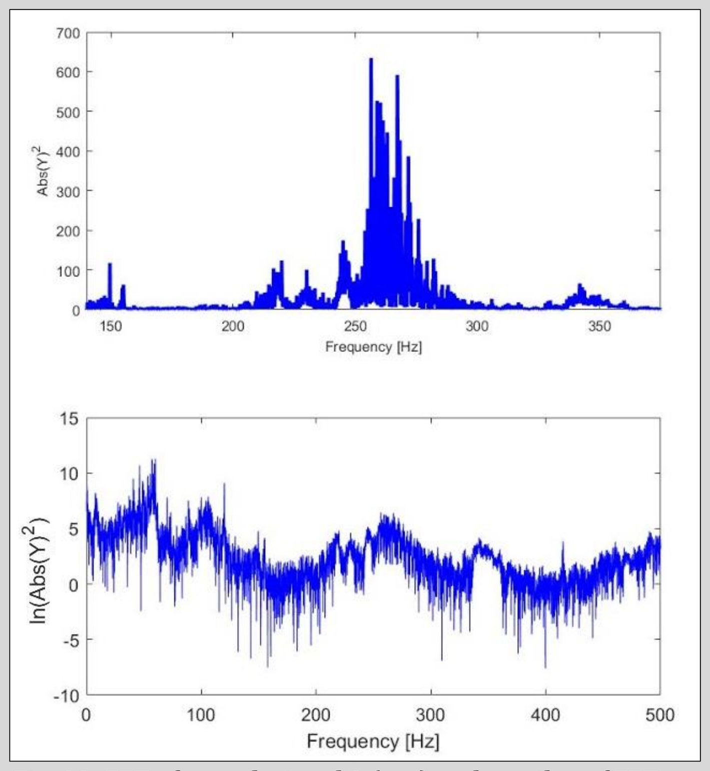

Fig. 32: FFT of speech signal 2 (top) and semilog of FFT (bottom).

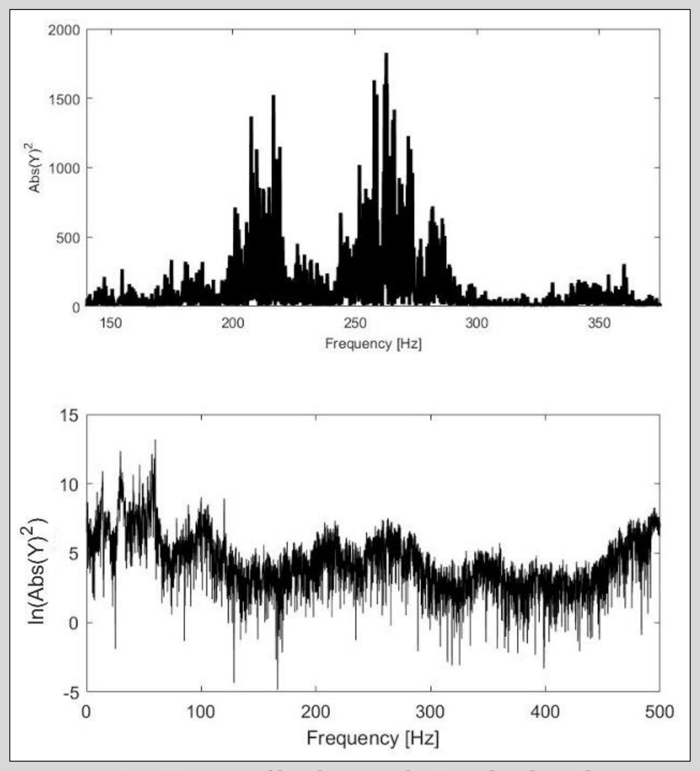

Fig. 33: FFT of both speech signals played simultaneously (top) and semilog of FFT (bottom). Both plots show many similarities with plots of the overpowering signal (Fig. 31).

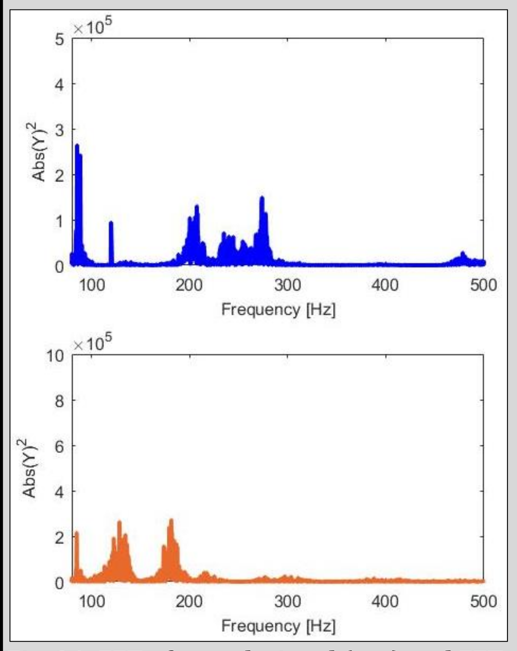

Fig. 34: FFT of speech signal (top) and FFT of white noise signal (bottom). Resonant frequencies of around 130Hz and 170Hz appear in the bottom spectrum.

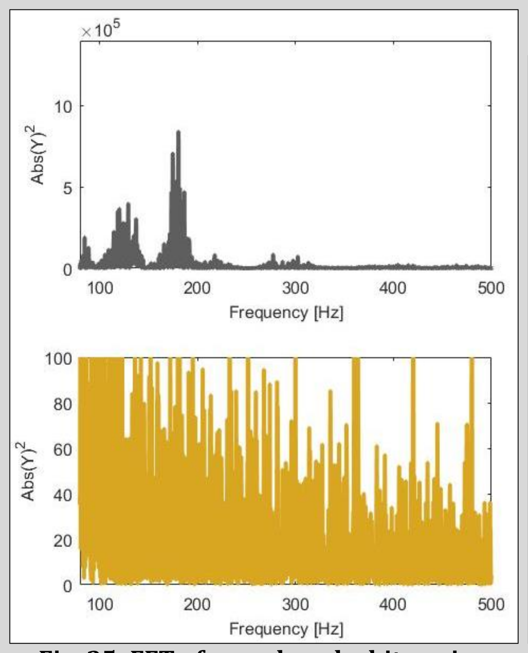

Fig. 35: FFT of speech and white noise signal played simultaneously (top) and FFT of white noise signal acquired directly from the speaker (bottom).

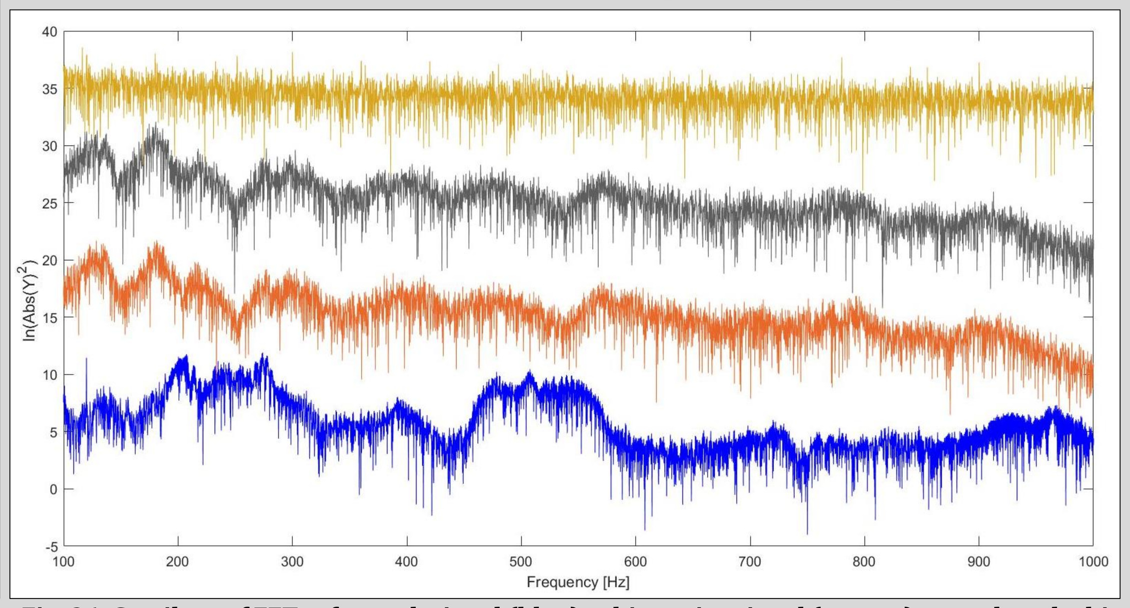

Fig. 36: Semilogs of FFTs of speech signal (blue), white noise signal (orange), speech and white noise signal (gray), and direct white noise signal (yellow). Data sets are offset by an arbitrary factor for comparison purposes. White noise signal (orange) and white noise with speech (gray) show similar structure, but voice spectrum alone (blue) shows a decidedly different structure.

- Window vibrations are only thwarted through noise cancellation at certain points on the window.
- Single frequency oscillations succeed in disrupting laser microphone when frequency used is in the frequency spectrum of voices in the room.
- Oscillating the reflecting media with broadband noise including random voice signals and white noise signals is able to disrupt the laser microphone signal. The overpowering voice signals can be used for conveyance of false information, or spoofing, to allow perpetrators to believe that they received important intel.
- Window oscillations created insignificant optical distortions (At 1 m p=0.89) and insignificant auditory distortions(p=0.33; p=0.11).
- Added voice signal and white noise signal oscillations in the reflecting media are capable of masking a modulated laser signal without causing large audible and optical distortions.
- This countermeasure can be implemented everywhere from corporate offices to the average household to SCIFs for privacy and security.

Future Studies: Further comparisons between previously researched treatments and oscillatory countermeasures.
Optimizing the volume of overpowering signal necessary to thwart the device.

Results

Phase I

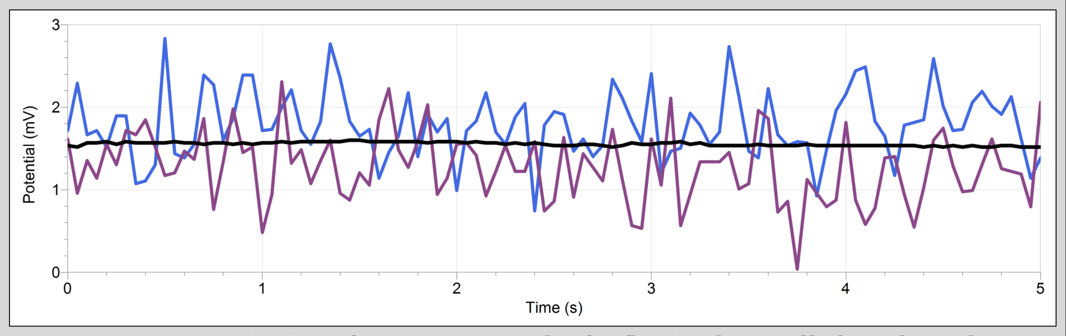

Fig. 12: Destructive interference as a result of reflecting laser off of window where inverse sine wave signals played simultaneously.

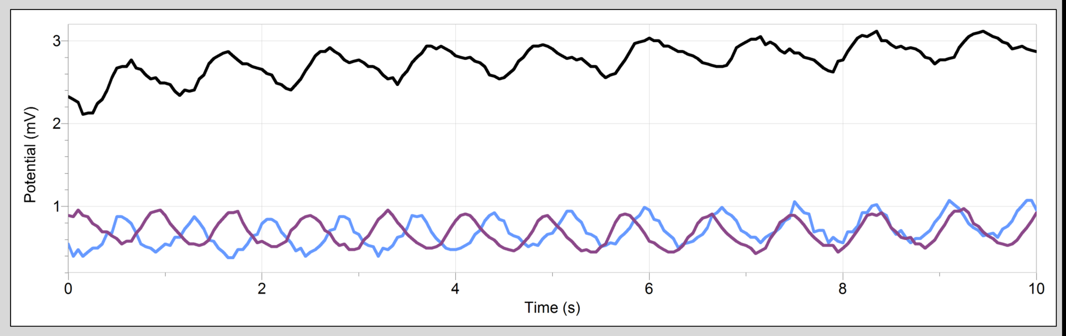

Fig. 13: Constructive interference as a result of reflecting laser off of window where in-phase sine wave signals played simultaneously

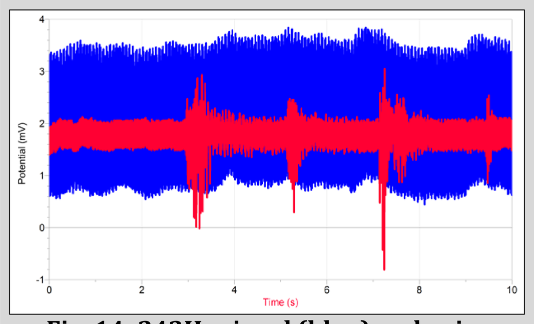

Fig. 14: 242Hz signal (blue) and voice recording signal (red).

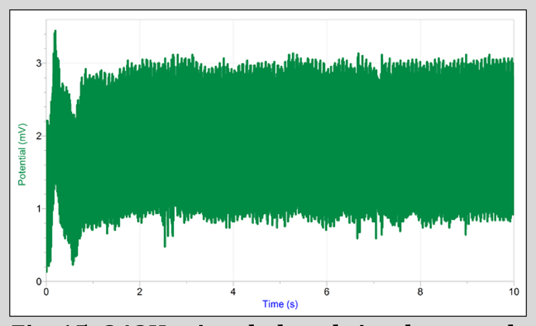

Fig. 15: 242Hz signal played simultaneously with voice recording signal.

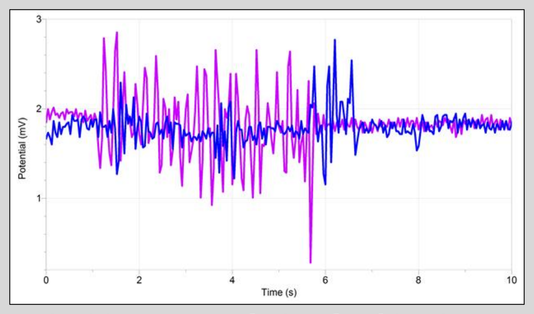

Fig. 16: Two speech signals of 4 unique words played separately.

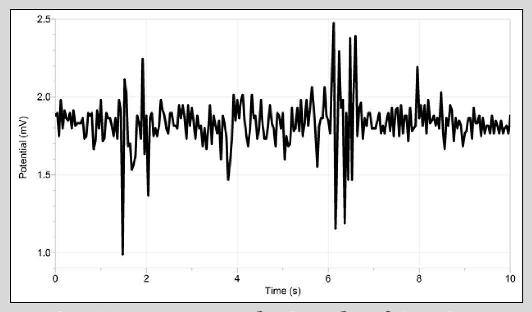

Fig. 17: Two speech signals of 4 unique words played simultaneously.

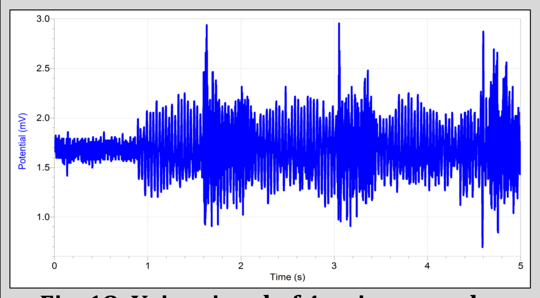

Fig. 18: Voice signal of 4 unique words taken at a sampling rate of 10,000Hz.

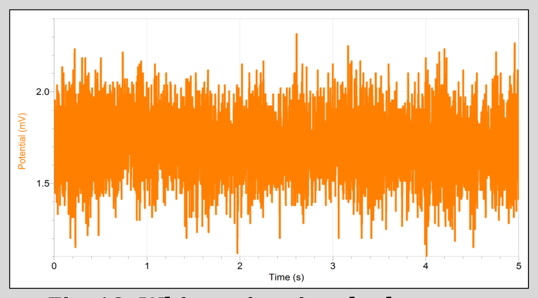

Fig. 19: White noise signal taken at a sampling rate of 10,000Hz

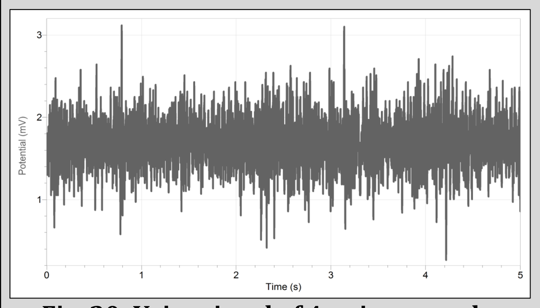

Fig. 20: Voice signal of 4 unique words and white noise signal played simultaneously and taken at a sampling rate of 10,000Hz.

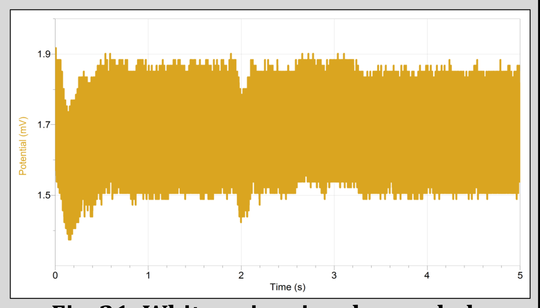

Fig. 21: White noise signal recorded directly from speaker for comparison.

Phase II

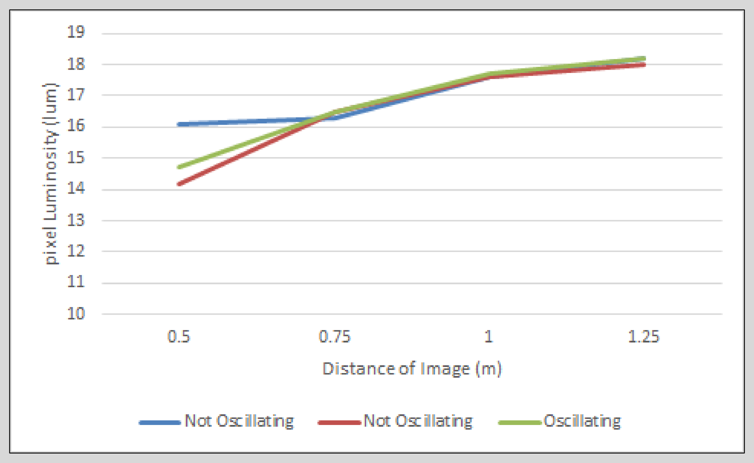

Fig. 22: Distance from Image vs Pixel Luminosities of Photographs; quantifying image quality through oscillating window (at 1 m p=0.89).

Fig. 23: Image quality through non-oscillating window at 0.5m.

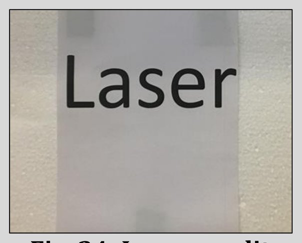

Fig. 24: Image quality through oscillating window at 0.5m.

Phase III

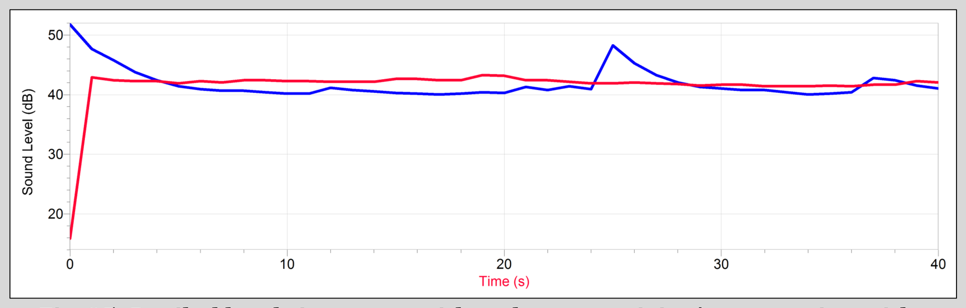

Fig. 25: Decibel levels in a room with no human activity/conversation with (red) and without (blue) added oscillations (p=0.11).

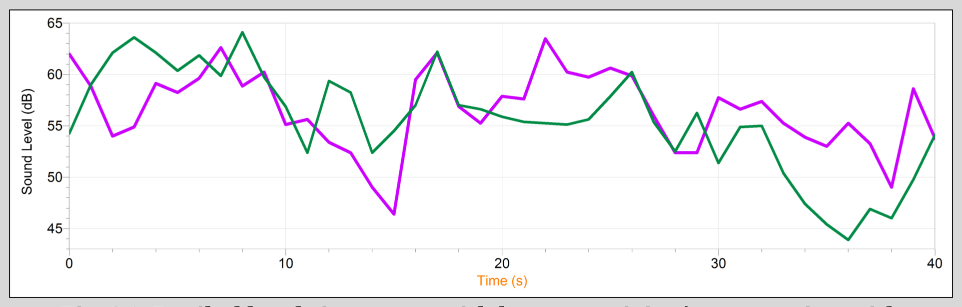

Fig. 26: Decibel levels in a room with human activity/conversation with (green) and without (purple) added oscillations (p=0.33).

Literature Citations

Bryant, Chris. "Q&A: Laser Microphone Surveillance." *The World*. N.p., n.d. Web. 01 Mar. 2018. <http://blogs.ft.com/the-world/2013/08/qa-laser-microphone-surveillance/>.

Graham, Brad. "Build the LASER SPY DEVICE," 2008. *LucidScience*.

"Laser Mic Surveillance Defeater Laser Countermeasure Surveillance Protection Device."*Laser Mic Surveillance Defeater Laser Countermeasure Surveillance Protection Device*, 2017, www.spyville.com/laser-mic-surveillance-defeater.html.

Pigeon, Stephanie. "The Ultimate White Noise Generator • Design Your Own Color." *The Ultimate White Noise Generator • Design Your Own Color*, 2013, mynoise.net/NoiseMachines/whiteNoiseGenerator.php.

Rafferty, Andrew. "What Is a SCIF and Who Uses It?" *NBCNews.com*, NBCUniversal News Group, 7 Apr. 2017, www.nbcnews.com/politics/politics-news/what-scif-who-uses-it-n743991.

Shah, Sharmi. "Transparent Irregular Surfaces as sound-Modulated Laser Transmittance Countermeasures." NJRSF Rutgers University, March 2016

Shah, Sharmi. "Analysis of Reflected Laser Signal Disruption via Transparent Irregular Surfaces." NJRSF Rutgers University, March 2017

"Technical Note: Spatial Filters." *Modular Integrating Spheres*, www.newport.com/n/spatial-filters.

Wang, Chen-Chia, Sudhir Trivedi, Feng Jin, V. Swaminathan, Ponciano Rodriguez, and Narasimha S. Prasad. "High Sensitivity Pulsed Laser Vibrometer and Its Application as a Laser Microphone." AIP Scitation. American Institute of Physics, n.d. Web. 6 Feb. 2018.<http://scitation.aip.org/content/aip/journal/apl/94/5/10.1063/1.3078520>.