Hiding an Ear in Plain Sight: On the Practicality and Implications of Acoustic Eavesdropping with Telecom Fiber Optic Cables

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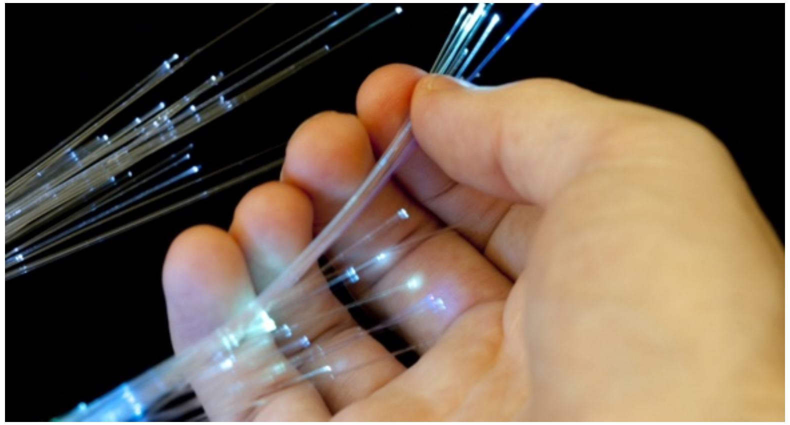
Optical Fibers

- Telecom optical fibers:
  - Transparent medium made from glass.
  - Transmitting light across long distances with minimal loss.
  - Forming the backbone of high-speed internet.
- Compared with electrical cables, optical fibers:
  - Immune to external interference.
  - No Radio-Frequency (RF) emission.
  - Pose fewer side-channel risks.



Source: Submarine Cable Map, updated on 12 Feb 2026

Optical Fibers are Mechanical Sensitive

- Acoustic waves can cause micro-deformation.
- The deformation will result in phase shift in Rayleigh backscattering.
- Phase shift will become recoverable sound signal.
- Distributed Acoustic Sensing (DAS).

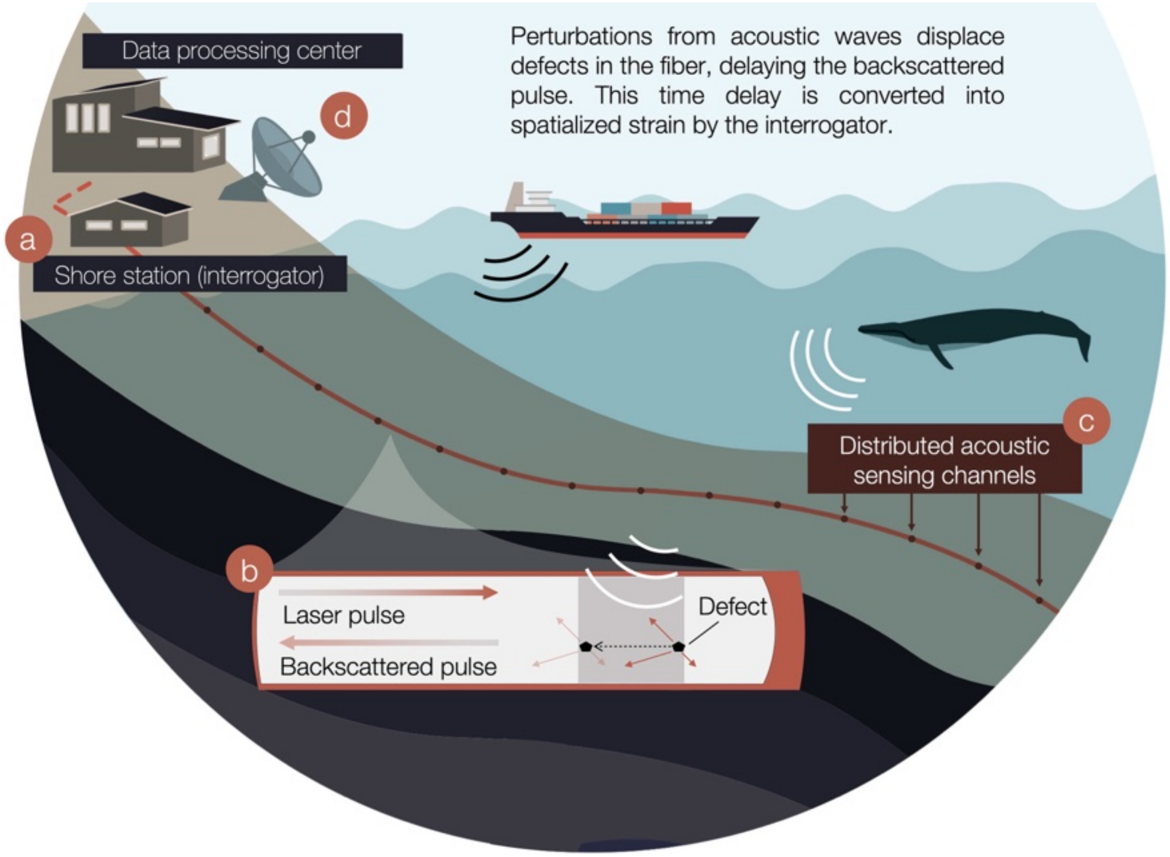
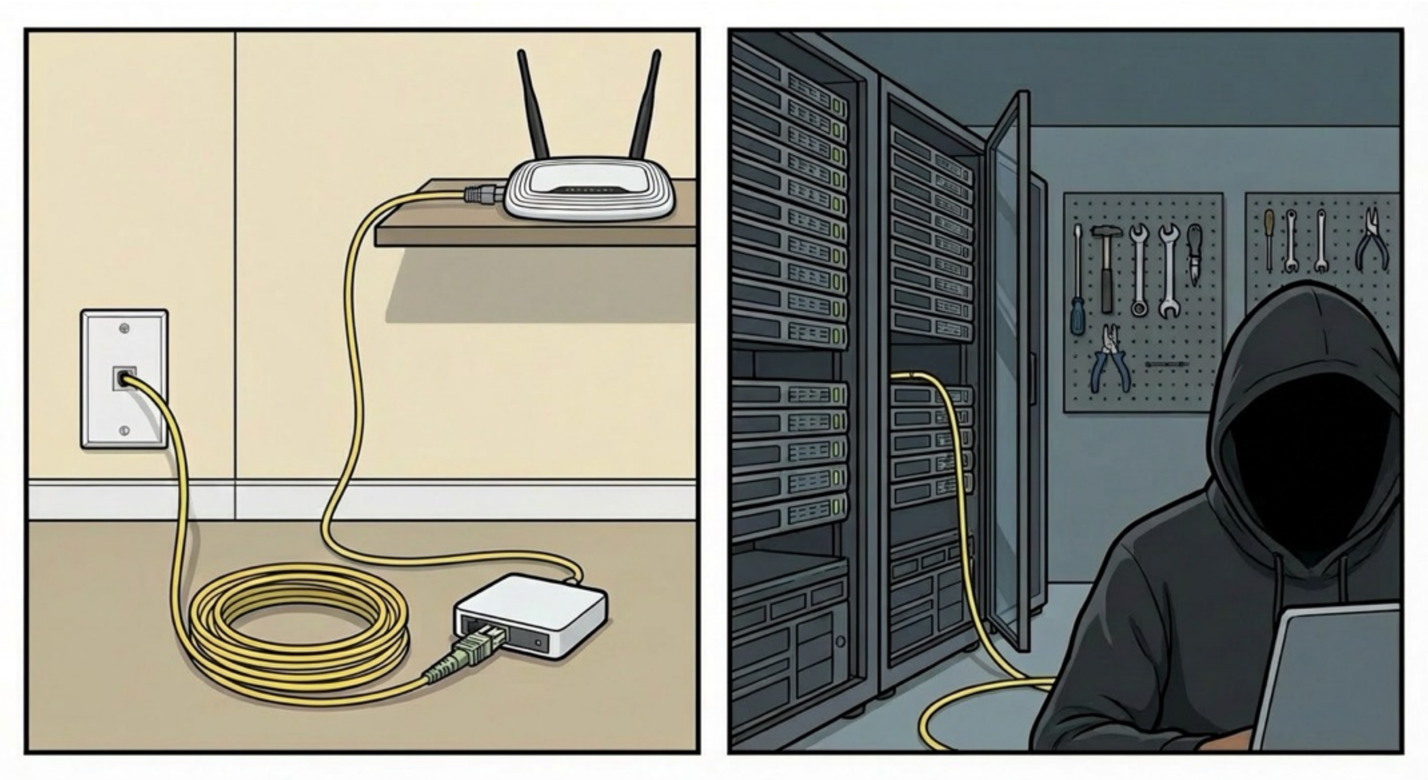


Image Source: Bouffaut, L., et al. *"Eavesdropping at the Speed of Light: Distributed Acoustic Sensing of Baleen Whales in the Arctic," Frontiers in Marine Science, vol. 9, 2022.*

Optical Fiber for Acoustic Eavesdropping?

Short $$$ on XXX

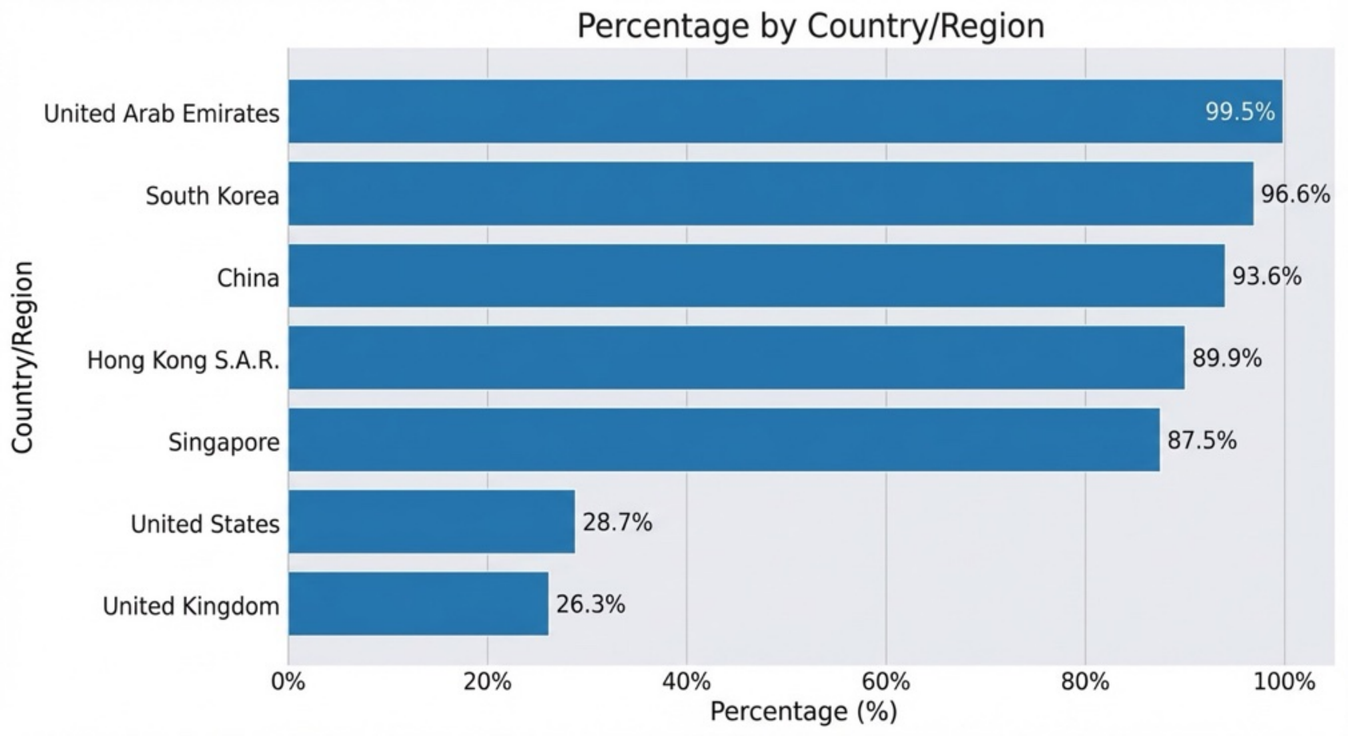


Short $$$ on XXX

The image is partially generated by Nano-Banana-Pro.

Why This Matters Today?

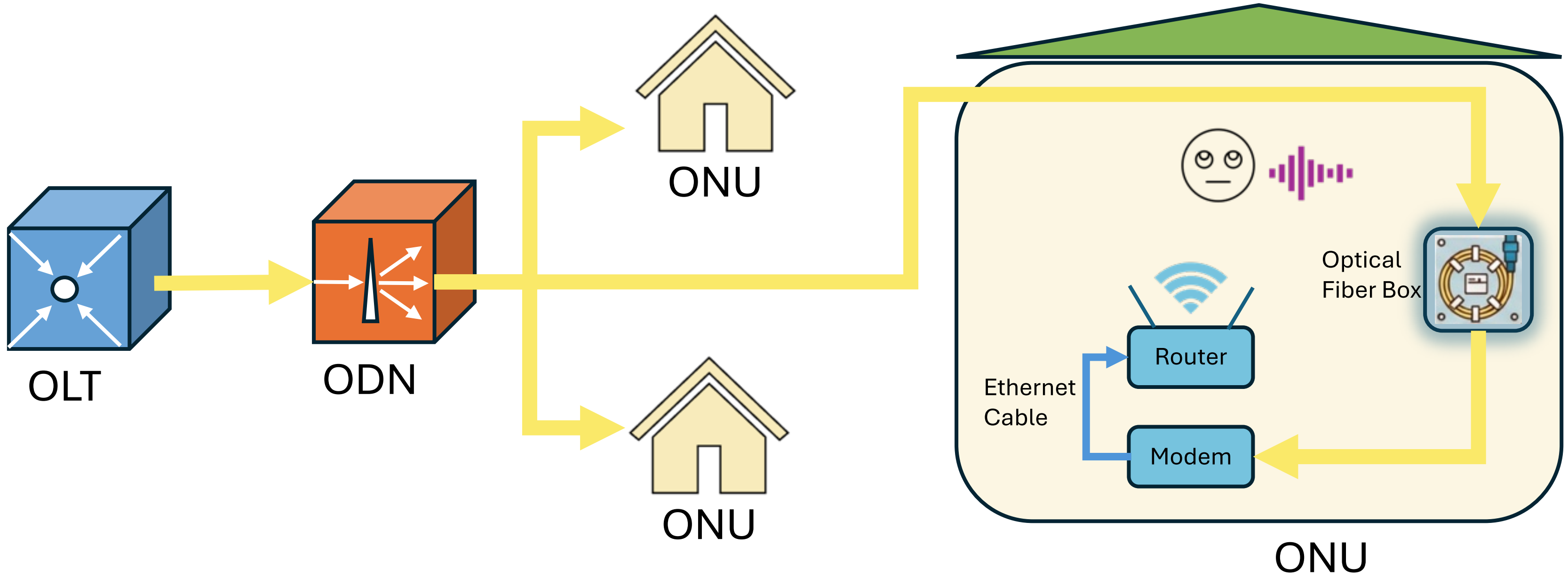
- In 2024, Fiber-to-the-Home (FTTH) deployment is massive.
- Multiple optical fibers are installed:
  - Each belonging to an Internet Service Provider (ISP).
  - Unused "dark fibers".
- The attacker can connect one end of these optical fibers to conduct acoustic eavesdropping: home, offices, and meeting rooms.



Data source: R. Montagne and D. Dichiarante, "FTTH/B Global Ranking," FTTH Council Europe, 2024.

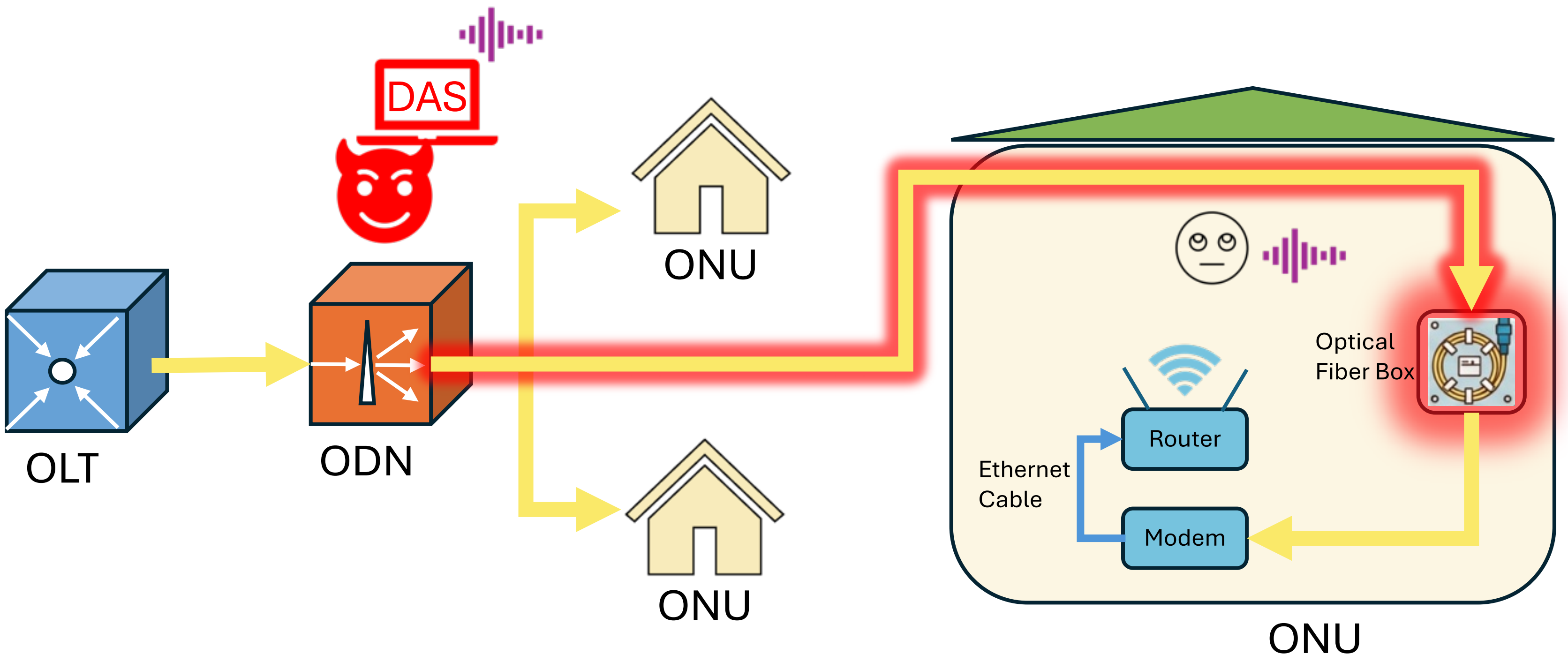
System Model: Passive Optical Network

- Optical Line Terminal (OLT) managed by ISPs.
- Optical Distribution Network (ODN) distributes optical signals to various customers.
- Optical Networking Unit (ONU) is the customer end.



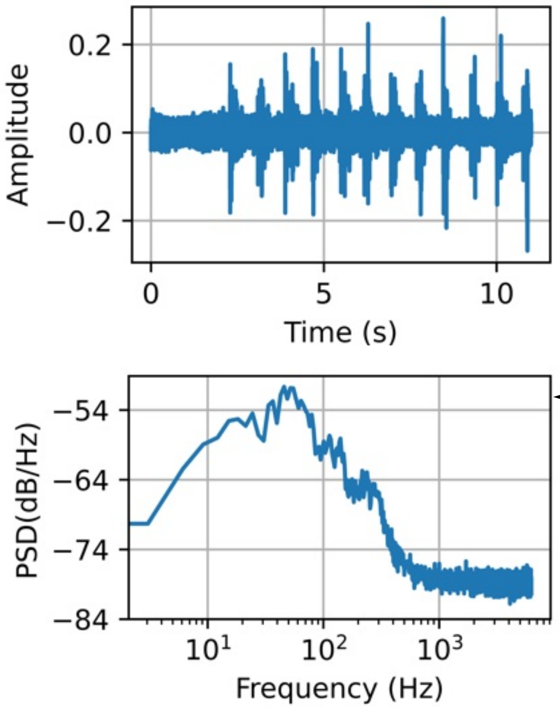
Attacker Model

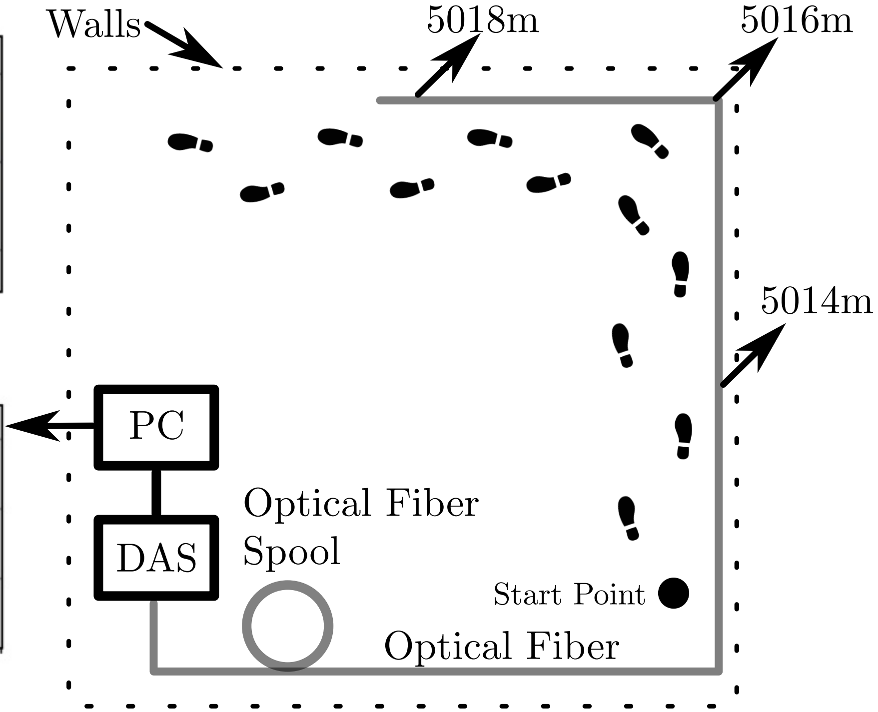
- Access to:
  - ODN and ONU.
- In the ODN:
  - Identify a certain optical fiber.
  - Has a commercial-off-the-shelf DAS equipment.
- In the ONU, to increase the sensitivity to sound:
  - Craft a sensory receptor.
  - The sensor receptor can be camouflaged into optical fiber box.



Can Linearly Laid Optical Fibers Hear Well Enough?

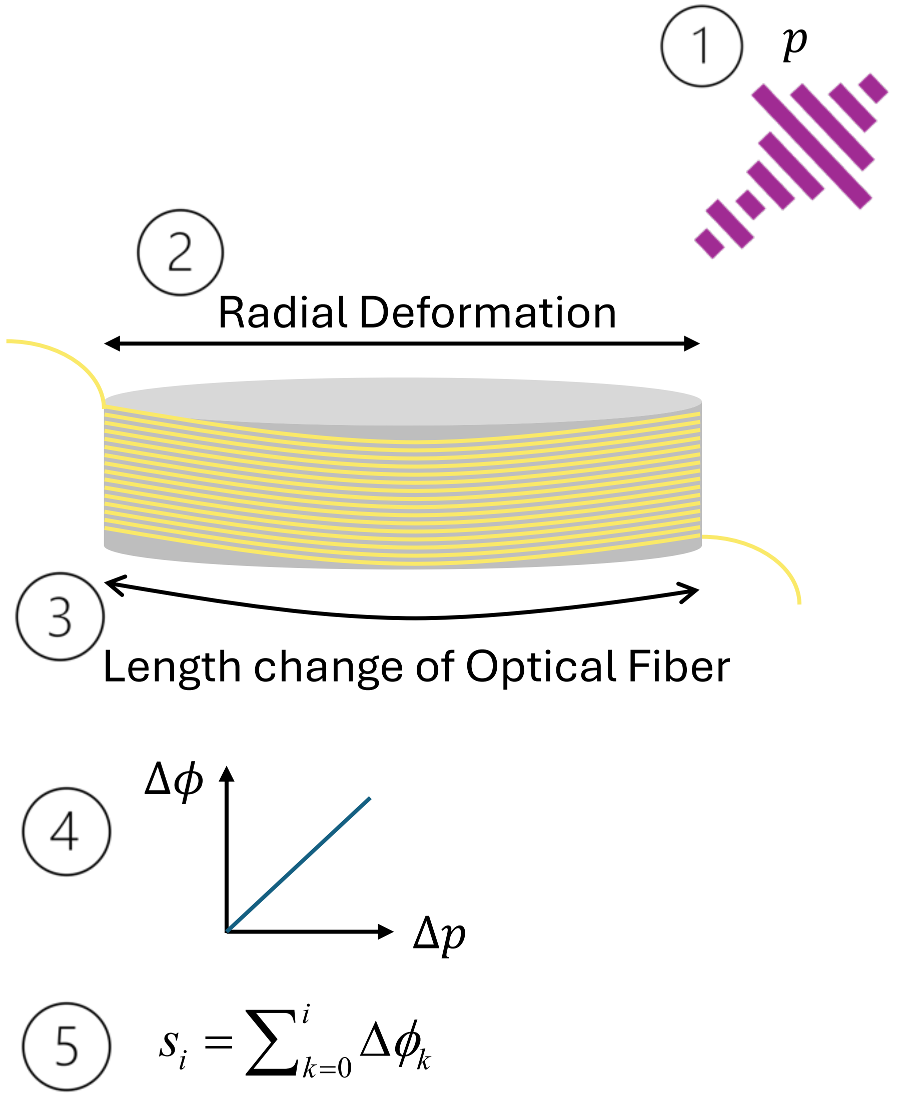
- An optical fiber laid along baseboard.
- A loudspeaker (80dB) playing human speech is placed 1m away from the optical fiber.
  - Acoustic foam under the loudspeaker to prevent structure-borne propagation.
  - Speech not recovered.
- Footsteps (76dB)
  - Steps are detected.





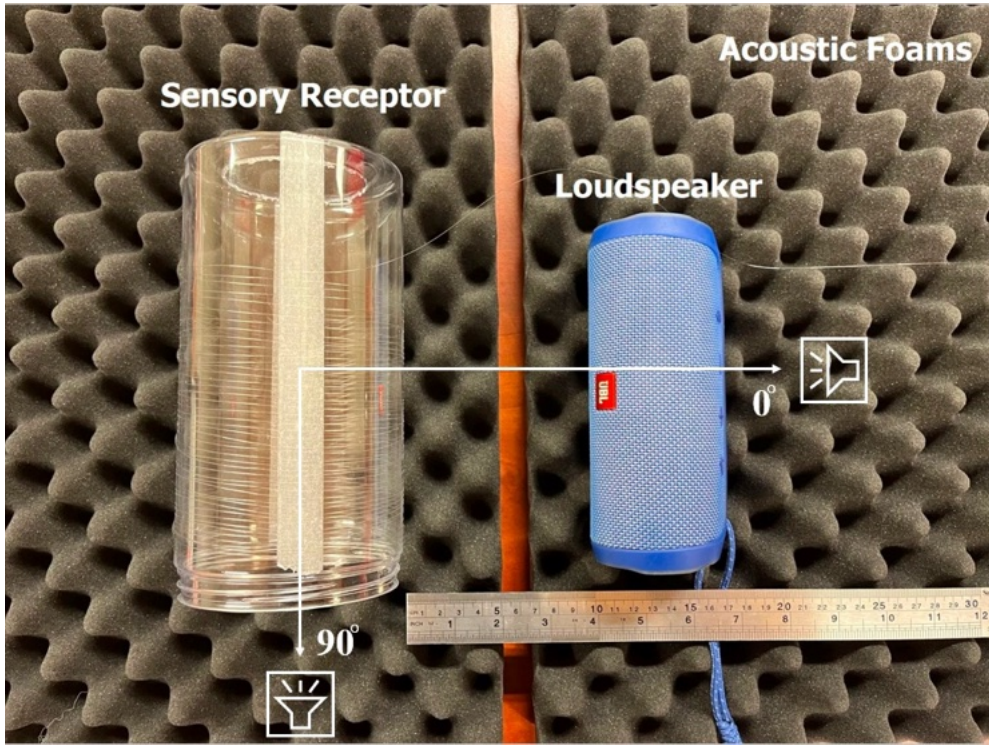
Design of Sensory Receptor

- Idea:
  - Wind standard telecom optical fiber around a hollow cylinder.
- Converts:
  1. Sound pressure to radial deformation of the hollow cylinder.
  2. Radial deformation to longitudinal strain of the optical fiber.
  3. Strain change to the length change of the optical fiber.
  4. Length change to phase shift ϕ.
  5. Phase shift to audio signal s.
- Cumulative sum of the incremental phase changes over time.

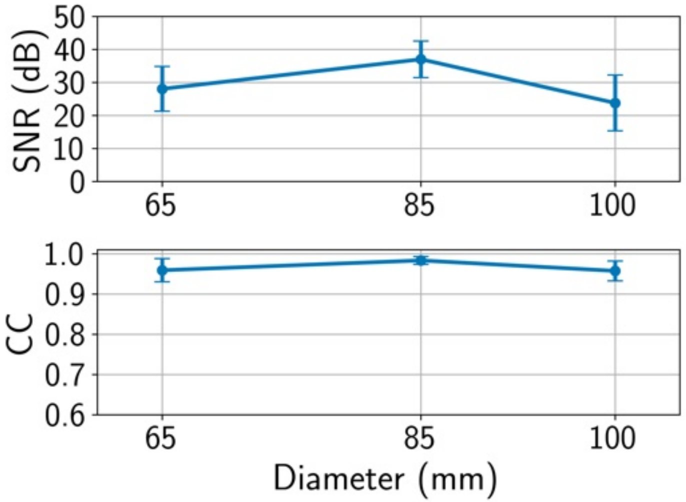


Characterizing Sensory Receptor

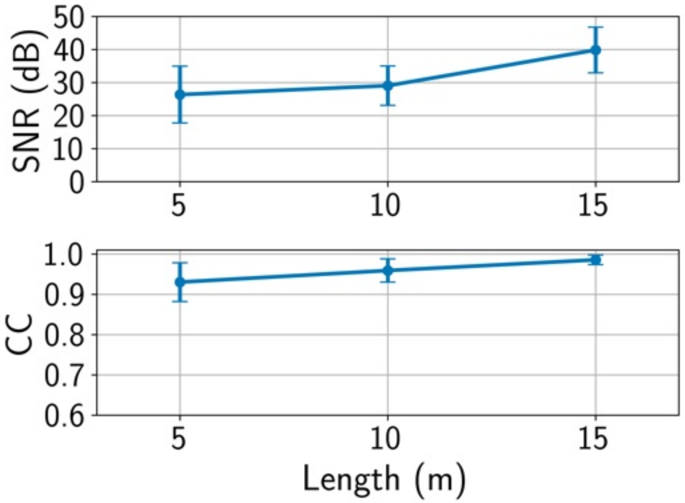
- Metrics for Evaluation
  - Signal-to-Noise Ration (SNR).
  - Correlation Coefficient (CC).
- Materials of the Sensor Receptor:
  - **PET**, resin, PA, etc.
- Intrinsic Parameters:
  - Outer Diameter: 65, 85, 100mm (thickness is 0.2mm).
  - Length of Wrapping Optical Fiber: 5, 10, 15m.
- External Parameters (sound source):
  - Volume: 60, 70, 80, 90dB.
  - Distance: 10, 100, 200cm.
  - Angle: 0, 30, 60, 90 degree.
  - Frequency: 100, 250, 500, 750, 1000 Hz.



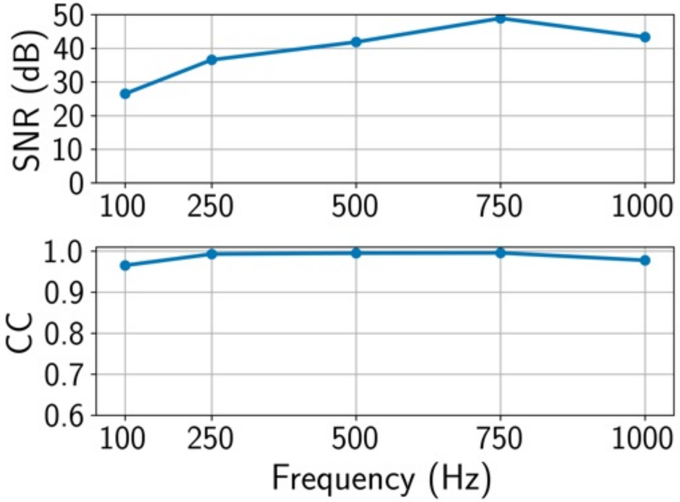
Impacts of Parameters (Examples)



(a) Outer Diameter of the Sensory Receptor.



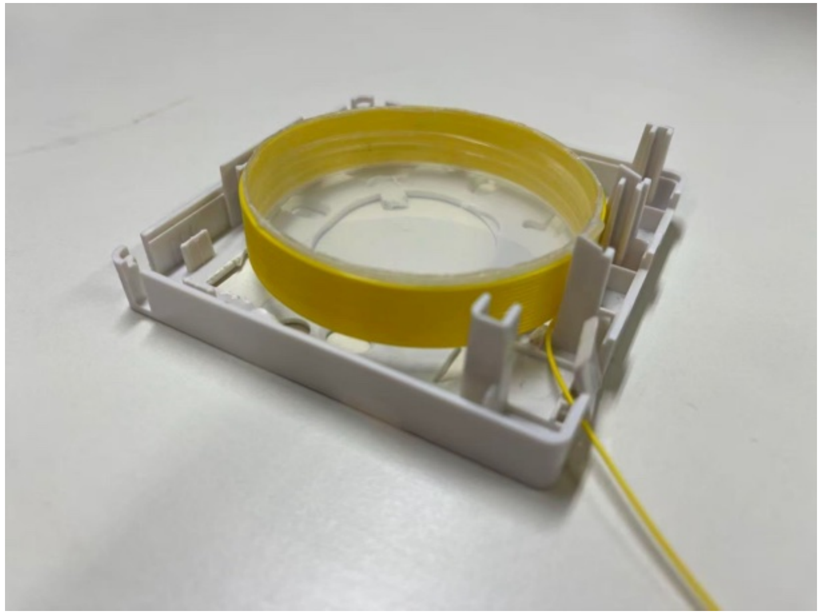
(b) Length of Optical Fiber on the Sensory Receptor.

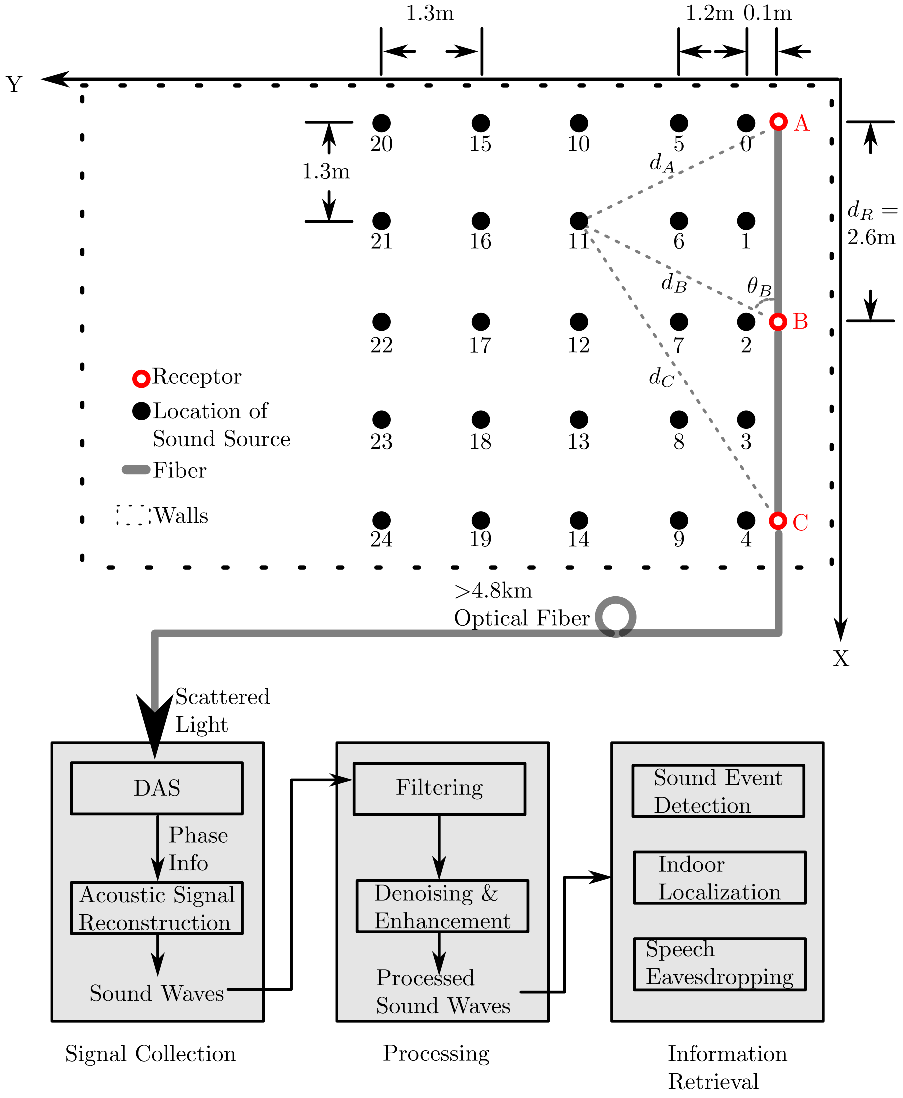


(c) Frequency of the Single-Tone Sound Source.

Experiments of Eavesdropping

- Sound Event Classification.
- Indoor localization.
- Speech Eavesdropping.





Sound Event Classification

- 14 types of sound events: e.g., clock alarming, coughing, keyboard typing, etc.

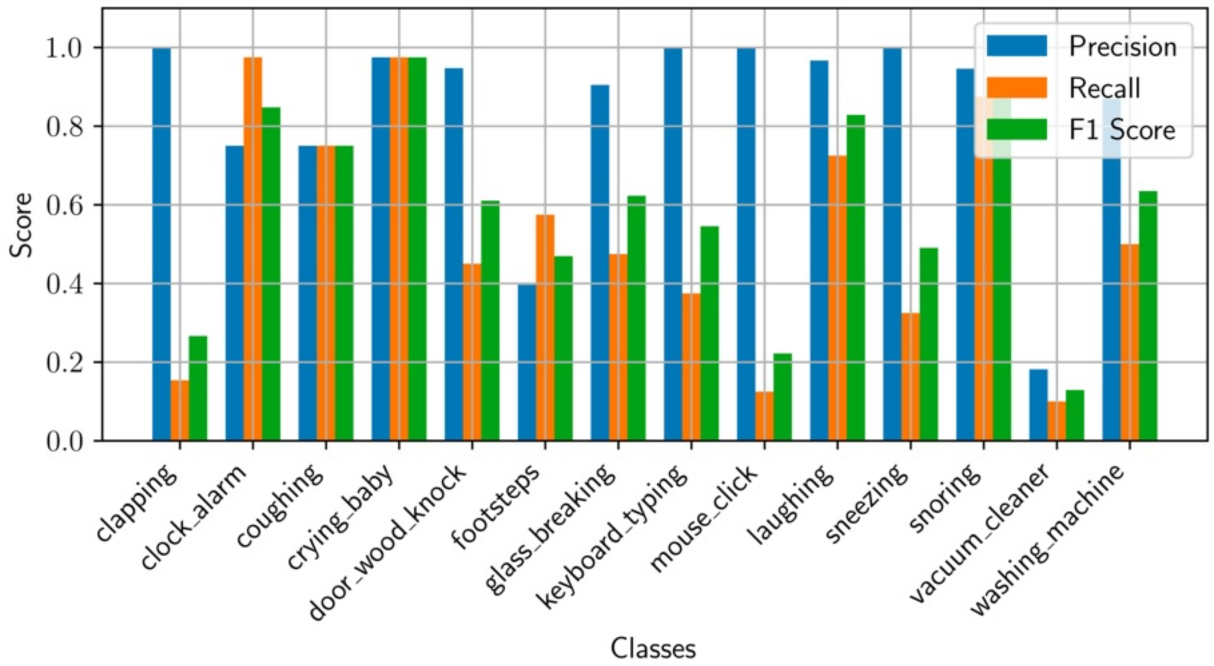


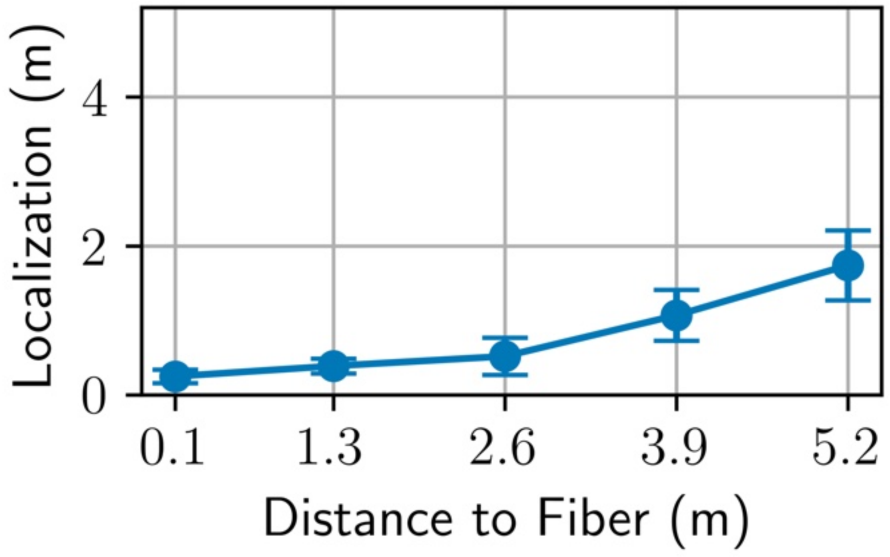
TABLE I: Sound Event Detection Accuracy of Different Models at Different Distances

Models	Accuracy			
	Ref	0.1 m	1 m	2 m
BEATs [42]	0.96	0.53	0.11	0.06
HTS-AT [43]	0.97	0.39	0.06	0.05
Efficient-AT [45], [46]	0.97	0.44	0.11	0.07
Our Fine-tuned	0.97	**0.83**	**0.50**	**0.43**

Better than a random guessing probability of 0.07.

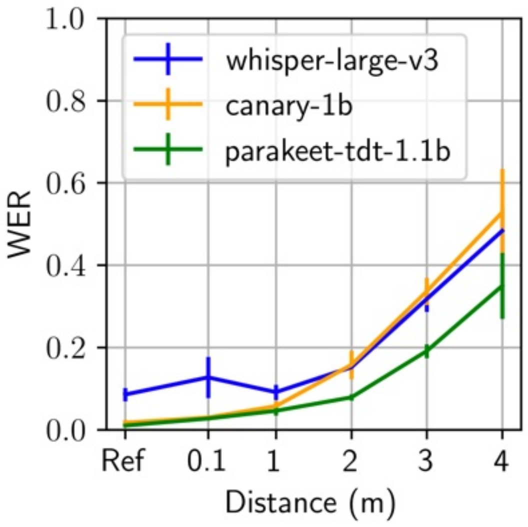
Indoor Localization

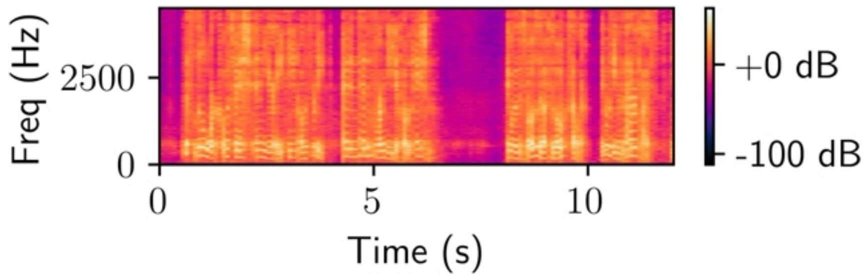
- Locating the sound source with three sensory receptors using time difference of arrival.
- Localization error metric: Euclidean distance between estimated position and ground truth.
- Averaged estimation of error in a room of 27.04 m^2 is 0.77m$\pm$0.17m.



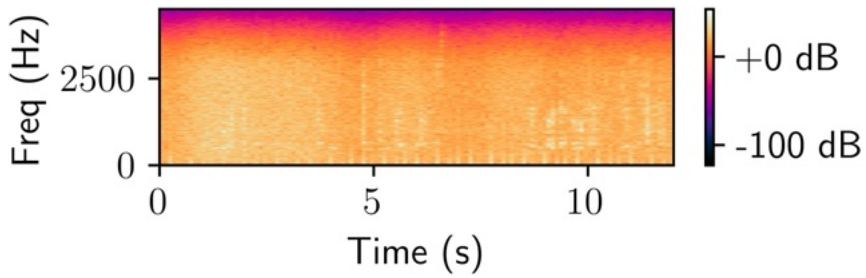
Speech Eavesdropping

- Human speech: 30 male and 30 female speech clips from LibriSpeech dataset.
- Metric: Word Error Rate (WER).

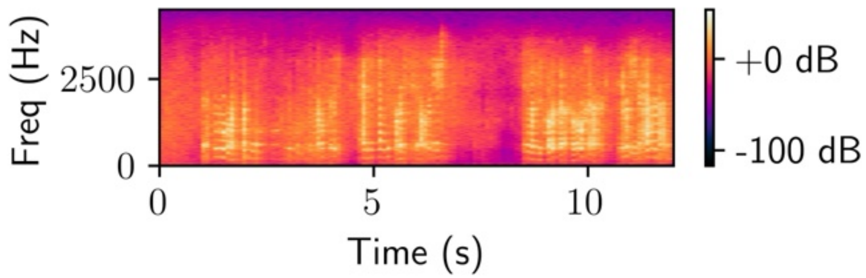




(a) Ground Truth



(b) Recovered Sound

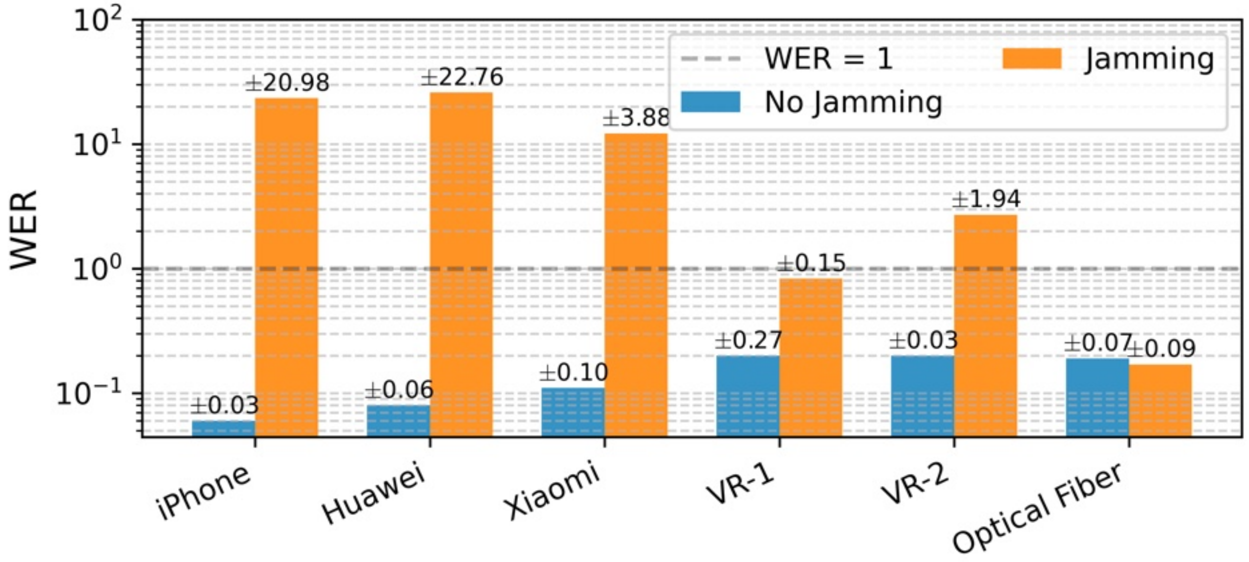


(c) Recovered Sound after Denoising

Ultrasound Jamming

- Compared with iPhone 13, Huawei Mate 30, Xiaomi Note 9 Pro, and two mini voice recorder.

(a) Ultrasound Jammer.

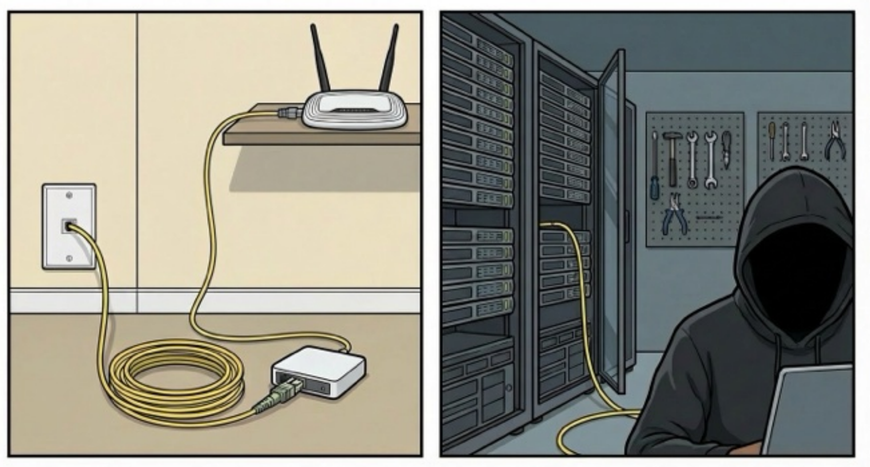


(b) Under Jamming.

Conclusion

- Standard telecom optical fiber can be exploited for acoustic eavesdropping.
- It is resistant to ultrasonic jammers.
- Call for the attention to the side-channel threats of optical fiber.

Sound Sample



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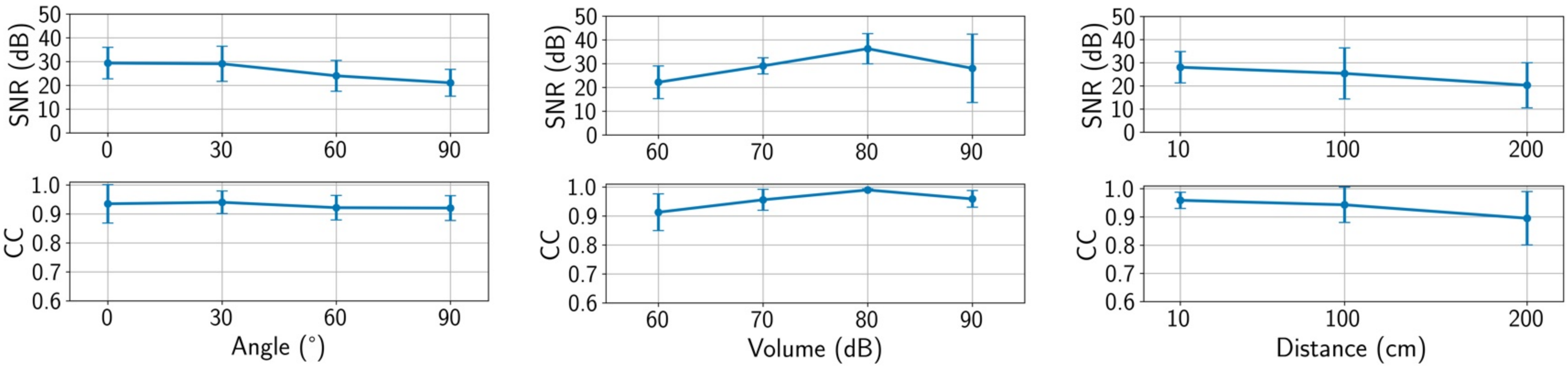
Presenter: Youqian Zhang (you-qian.zhang@polyu.edu.hk)

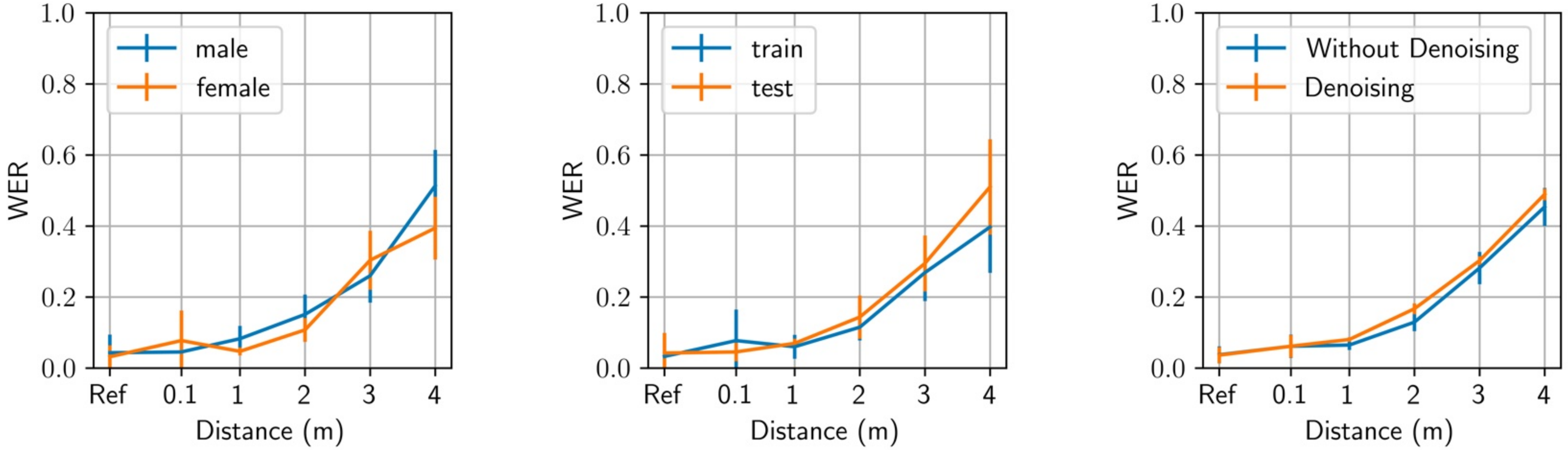
Supplementary – Potential Mitigation Methods

- Using polished connectors to introduce significant Fresnel reflection that will saturate DAS.
- Using optical isolator, allowing light to travel in one direction only, preventing scattering.
- Users should ensure the optical fiber cables are installed in a way that avoids excess length or keeps them from looping around or touching objects, which may unintentionally amplify vibration.

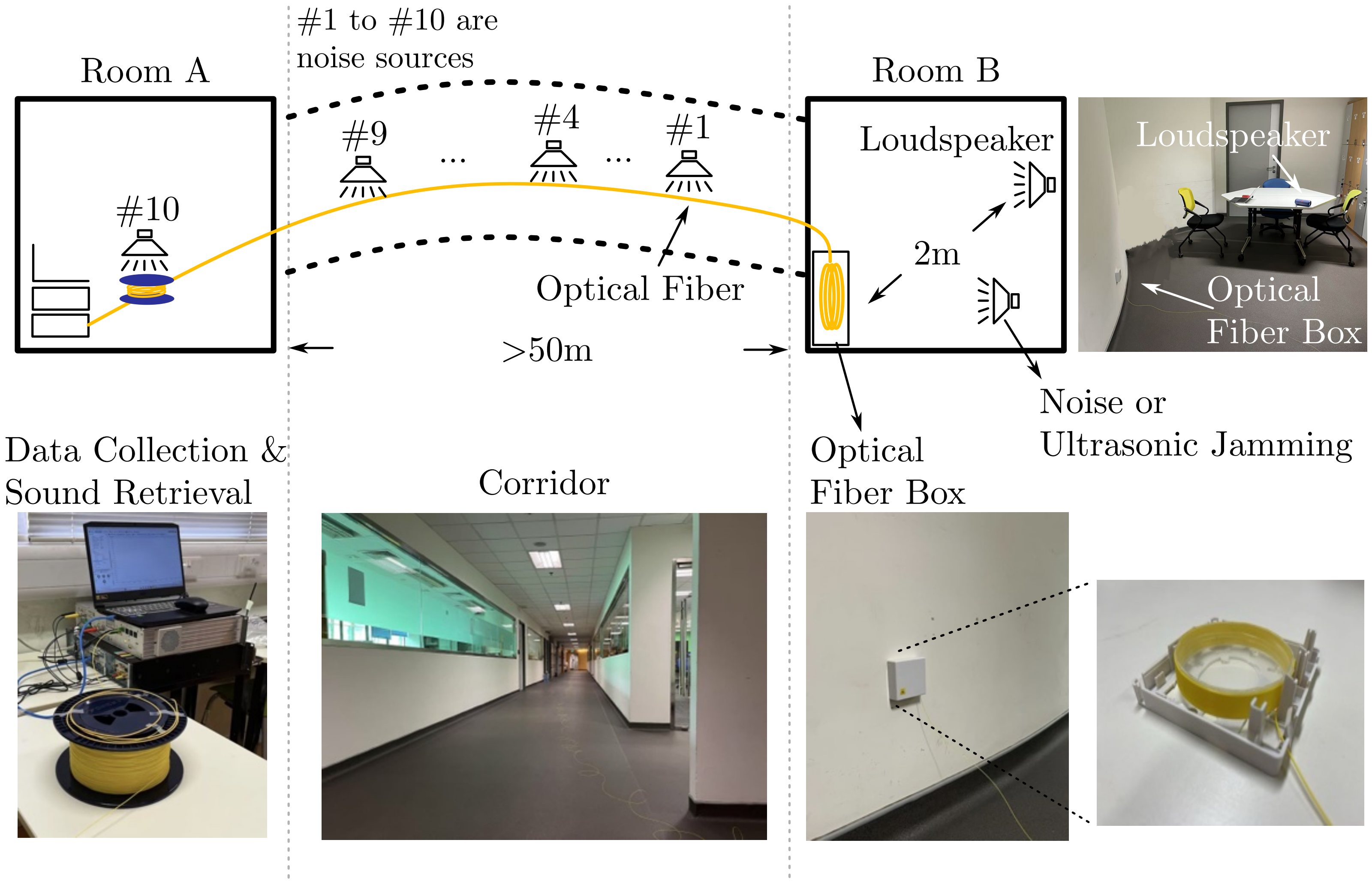
Supplementary – Other Parameters



Supplementary – Speech Eavesdropping

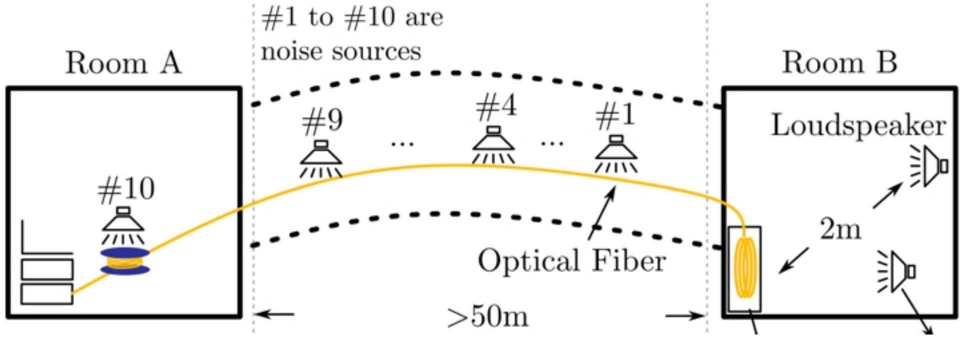


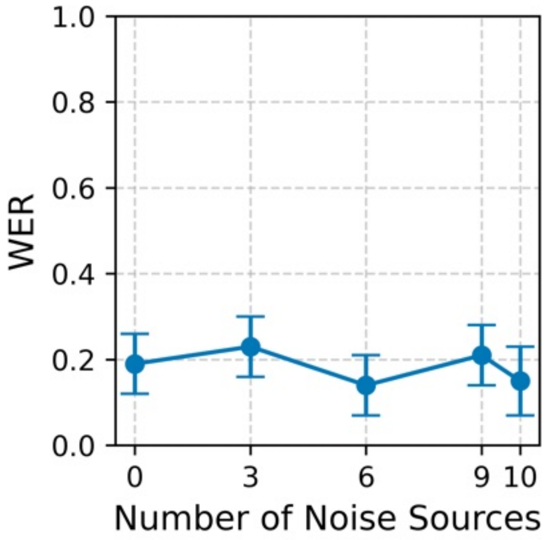
Supplementary - Case Study: Office Scenario



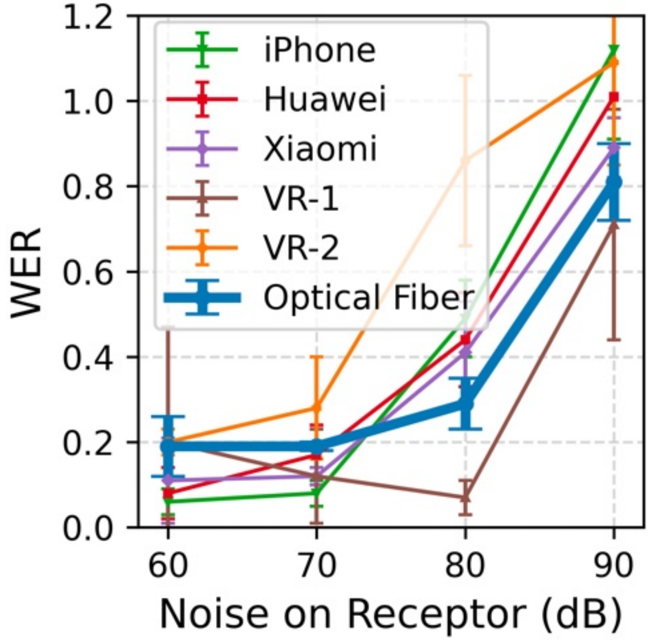
Supplementary - Impacts of Noise Along the Optical Fiber as Conduit

- 10 Noise sources >90 dB.
- Activate noise sources in groups:
  - First, (#1, #4, #7);
  - Then, (#2, #5, #8);
  - Next, (#3, #6, #9);
  - Finally #10.





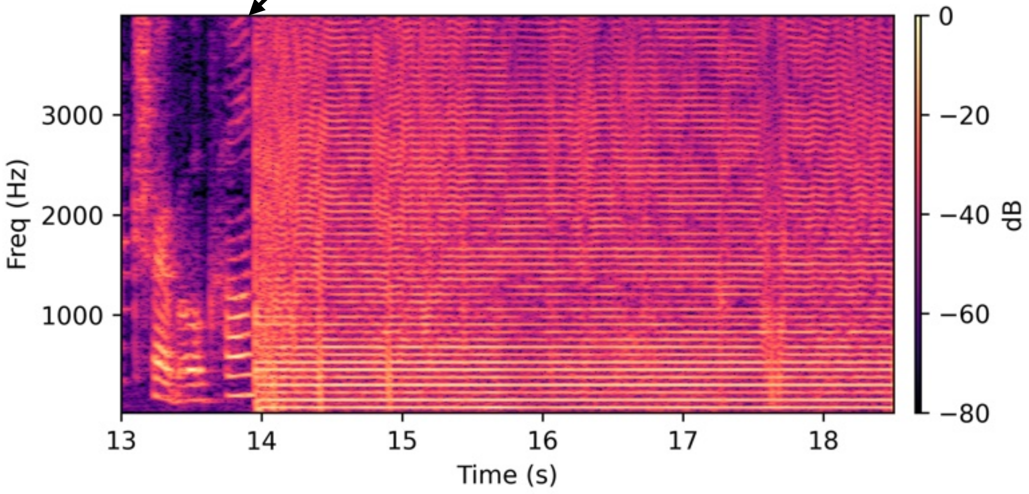
Supplementary – White Noise around the Sensory Receptor

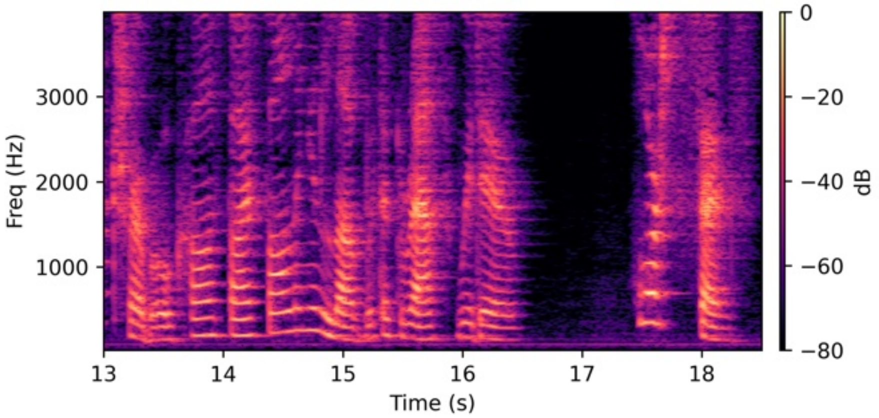


Supplementary - Impacts of Ultrasonic Jamming

Jamming is on from 14s.

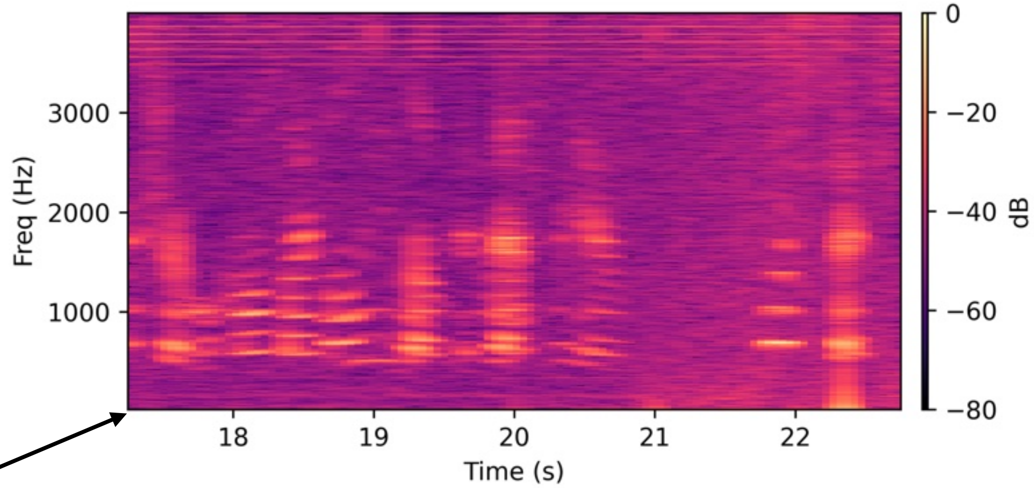
Microphone





Ground Truth

Optical Fiber



Jamming is always on.