Poster: Advanced Ultrasonic Jamming Technology for Privacy Protection: Dynamic Inter-modulation (DIM) Algorithm

Hetian Shi
Tsinghua University
shiht18@tsinghua.org.cn

Shangru Song
Tsinghua University
ssr22@mails.tsinghua.edu.cn

Jianwei Zhuge
Tsinghua University
zhugejw@tsinghua.edu.cn

Xin Liu
Lanzhou University
bird@lzu.edu.cn

***Abstract*—In the digital age, safeguarding privacy against sophisticated eavesdropping technologies is increasingly crucial. We introduce an innovative ultrasonic jamming device enhanced by a novel Dynamic Inter-modulation Modulation (DIM) algorithm, designed to counteract unauthorized audio surveillance. Utilizing nonlinear acoustic effects, the DIM algorithm dynamically varies ultrasonic frequencies to produce complex, shifting harmonic patterns that conventional denoising algorithms struggle to filter. This poster presents the design, implementation, and efficacy of our technology, highlighting its superiority over traditional fixed-frequency jammers in disrupting a wide range of microphone technologies, Electret Condenser Microphones (ECM), Micro-Electro-Mechanical systems (MEMs), and piezoelectric sensors.**

***Index Terms*—Ultrasonic Jamming, Privacy Protection, Dynamic Inter-modulation (DIM), Anti-Eavesdropping Technology, Nonlinear Response Phenomena, Surveillance Countermeasures**

I. Introduction

Eavesdropping technologies have become more pervasive and sophisticated, utilizing advanced signal processing to infiltrate private communications. Traditional countermeasures, such as fixed-frequency ultrasonic jammers as shown in Fig 1, are increasingly found inadequate due to their predictable interference patterns that advanced noise reduction algorithms can easily circumvent [1]. To address these shortcomings, our research has developed a cutting-edge ultrasonic jamming technology that employs a DIM algorithm. This novel approach takes advantage of the nonlinear characteristics of microphones to generate a mutable and complex frequency landscape, substantially enhancing privacy protection across various environments.

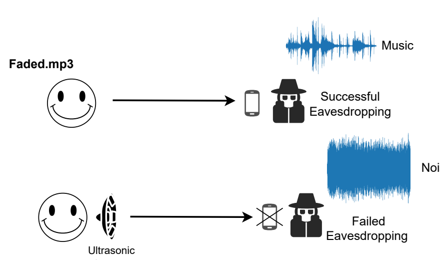


Fig. 1. Anti-eavesdropping through Ultrasonic Jammer

Each method has distinct strengths and challenges in ultrasonic jamming and privacy protection. Traditional jammers use fixed-frequency signals and often fail against sophisticated devices due to susceptibility to standard filtering techniques [1]. Adaptive noise generators combat modern spy device noise cancellation features but struggle against advanced signal processing. Further, research into the microphone nonlinear response phenomenon aids advanced jamming strategy development. At the same time, the effectiveness of signal obfuscation techniques against AI-based tools in real scenarios remains to be fully verified [2].

Our contribution to this domain includes the innovative DIM algorithm and a specially designed ultrasonic speaker array. By dynamically adjusting frequencies to exploit the microphone nonlinear response phenomenon, our solution creates an unpredictable acoustic environment that poses a formidable challenge to even the most advanced eavesdropping technologies, thus offering a comprehensive and flexible solution for enhanced privacy protection.

II. Design

The core innovation of our ultrasonic jammer lies in the DIM algorithm, which dynamically adjusts two primary ultrasonic frequencies. These adjustments result in unpredictable resonant peaks across the spectrum, encompassing the human speech range of 80 to 1100 Hz. The algorithm's effectiveness is underpinned by its ability to generate overlapping harmonic disturbances that significantly degrade the signal-to-noise ratio for any eavesdropping device.

Complementing the DIM algorithm, our design features a modular array of high-frequency ultrasonic transducers. Engineered to produce a dense, impenetrable field of ultrasonic waves, this array maximizes spatial coverage and ensures effective jamming across various environments and through physical obstructions.

A. DIM Algorithm

The cornerstone of our technology is the DIM algorithm, which utilizes two dynamically varying ultrasonic frequencies to exploit the nonlinear characteristics of microphones under high sound pressure. Specifically, the algorithm uses the signal S defined by:

$$S = \cos(2\pi f_1 t) + \cos(2\pi f_2 t) \tag{1}$$

In Equation (1), f_1 and f_2 are the dynamically varying frequencies essential to the DIM process.

The output signal S_{out} is formulated by expanding S into a nonlinear series as follows:

$$S_{out} = A_1 S + A_2 S^2 + A_3 S^3 + \ldots + A_N S^N \tag{2}$$

For practical purposes and clarity in the demonstration, the output signal can be specifically expressed up to the second-order term as $S_{out} = A_1 S + A_2 S^2$ and further expanding is as:

$$\begin{aligned} S_{out} = {} & A_1 \left(\cos(2\pi f_1 t) + \cos(2\pi f_2 t)\right) \\ & + A_2 \left(1 + 0.5 \left(\cos(2\pi(2f_1)t) + \cos(2\pi(2f_2)t)\right)\right. \\ & \left. + \cos(2\pi(f_1 + f_2)t) + \cos(2\pi(f_1 - f_2)t)\right) \end{aligned} \tag{3}$$

The term $\cos(2\pi(f_1 - f_2)t)$ in (3) represents the difference frequency components (in red frame) generated by the nonlinear response phenomenon as shown in Fig 2. The component contributes to a broad and dynamically varying frequency spectrum due to the temporal changes in f_1 and f_2. The dynamic nature of these frequencies ensures that the resultant interference spectrum is not only wide but also continuously shifting, creating complex patterns that are difficult for AI-driven noise reduction algorithms to predict and filter out effectively.

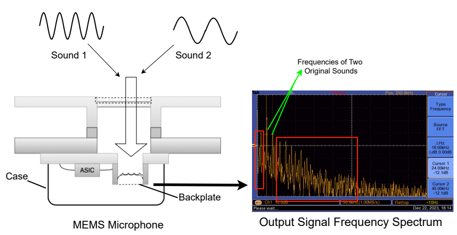


Fig. 2. Inter-modulation & Non-linear Response Phenomenon

B. Speaker Array Design

Complementing the DIM algorithm is an ultrasonic speaker array composed of multiple ultrasonic transducers. This modular array is strategically designed to produce a dense, impenetrable field of ultrasonic waves, covering a comprehensive spatial range and disrupting spying devices across wide areas. The design prioritizes precision, efficiency, and adaptability to diverse environmental conditions.

III. Experimental Evaluation

The experiments are designed to simulate human conversation, evaluate device placement strategies, perform comparative analyses with commercial products, and test speech obfuscation capabilities using advanced technologies.

Different Microphone Types: In a controlled experiment simulating human conversation by playing audio of the numbers '1 to 10', different types of microphones are used as receiving devices connected to an oscilloscope. We conduct comparative tests between our jamming device and commercial anti-eavesdropping equipment under the same conditions.

Device Placement and Scenarios: We strategically place eavesdropping devices in multiple configurations and environments to simulate realistic conditions including office spaces, residential settings, and public areas with potential physical barriers.

Comparative Analysis: Performance is benchmarked against leading commercial devices to evaluate our jammer's disruption rate and effectiveness in neutralizing espionage equipment.

Speech Obfuscation Tests: We conduct rigorous tests using advanced Speech-to-Text (STT) models, such as iFLYTEK and Otter.ai, to determine if the jammer could render speech indecipherable.

Results: Our ultrasonic jammer demonstrates superior performance, with a disruption rate nearing 100% under simulated conditions with MEMs microphone module ADMP401 as shown in Fig 3, outperforming existing alternatives. The sections marked in red indicate the phase when jammers are activated. Using the commercial jammer does not effectively interfere with the STT analysis of the counting sounds '1 to 10' being played.

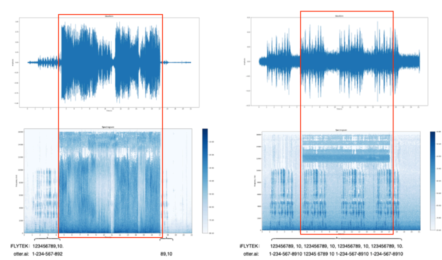


Fig. 3. **Left:** Our Jammer **Right:** Commercial Jammer

IV. Ethic Consideration

All ultrasonic jammer experiments were conducted legally with necessary authorizations to ensure regulatory compliance. Our devices were designed for minimal interference, affecting only targeted test environments and not other communications. We also confirmed that our jammers enhance counter-surveillance without affecting normal device operations.

V. Conclusion

Our DIM algorithm uses dynamic frequency modulation and an advanced speaker array to enhance privacy protection, effectively countering sophisticated eavesdropping and noise reduction techniques in various environments. Future enhancements will focus on broadening its operational frequency spectrum and improving portability, optimizing it for both personal and commercial use.

VI. Demonstration

All audio results, spectral figures, and the poster are available for viewing at the following link: https://github.com/Moriartysherry/Ultrasonic_Jammer. Jianwei Zhuge is the corresponding author.

References

[1] P. Huang, Y. Wei, P. Cheng, Z. Ba, L. Lu, F. Lin, F. Zhang, and K. Ren, "InfoMasker: Preventing Eavesdropping Using Phoneme-Based Noise," in Proc. NDSS, 2023.

[2] Y. Chen, H. Li, S. Nagels, Z. Li, P. Lopes, B. Y. Zhao, and H. Zheng, "Understanding the Effectiveness of Ultrasonic Microphone Jammer," arXiv preprint arXiv:1904.08490, 2019.

Poster #7: Advanced Ultrasonic Jamming Technology for Privacy Protection: Dynamic Inter-modulation (DIM) Algorithm

Hetian Shi[1] Shangru Song[1] Jianwei Zhuge[1] XinLiu[2]
[1]Tsinghua University [2]Lanzhou University
shiht18@tsinghua.org.cn ssr22@mails.tsinghua.edu.cn zhugejw@tsinghua.edu.cn bird@lzu.edu.cn

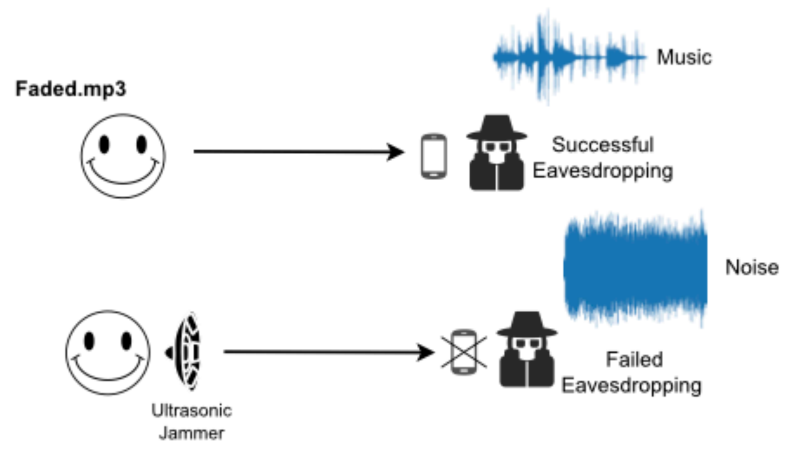
Abstract

✳ We proposed a novel **Dynamic Inter-modulation Modulation (DIM)** algorithm combats unauthorized audio surveillance by generating complex harmonic patterns.

✳ The DIM algorithm demonstrates enhanced efficacy over traditional fixed-frequency jammers, disrupting a **wide range** of microphone technologies.

Motivation

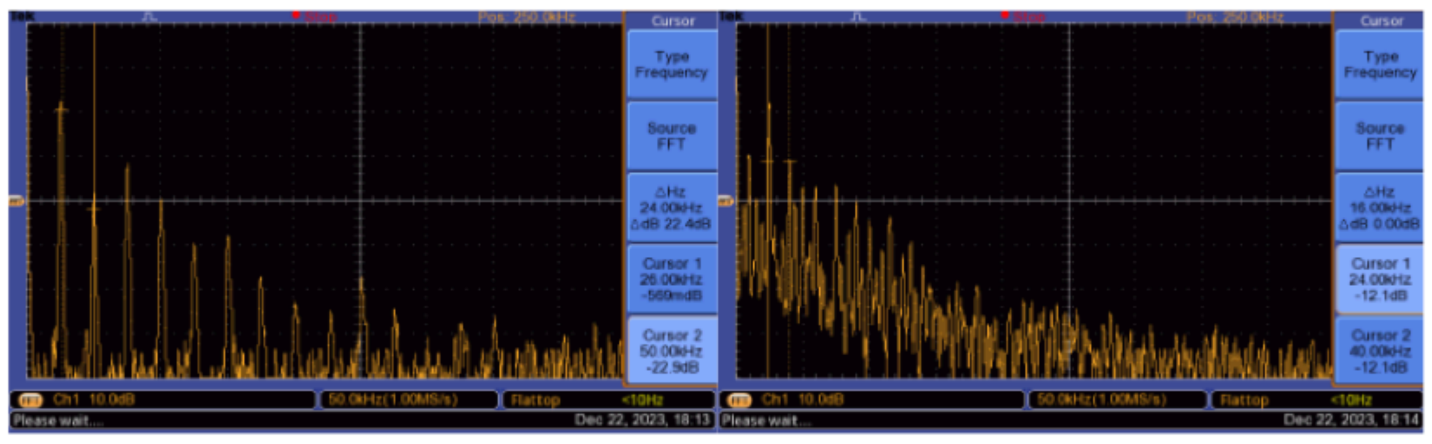
- DIM algorithm aims to create mutable and complex frequency patterns to counter sophisticated eavesdropping [1].
- With advanced nonlinear acoustic effects, we craft more effective countermeasures against AI-based signal processing to enhance eavesdropping protection [2], as shown in figure below.



Anti-eavesdropping via Ultrasonic Jammer

Jamming Effects

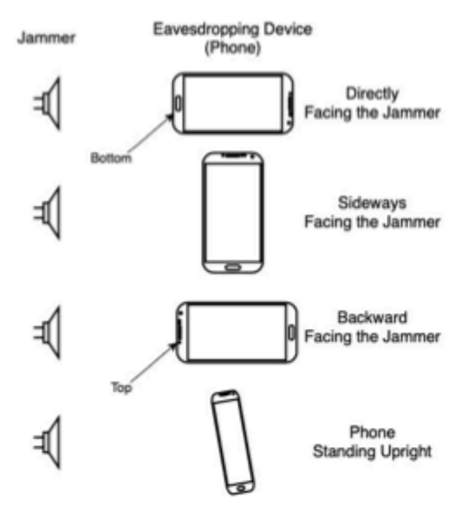
- Here illustrates the responses captured by the oscilloscope between the fixed frequency intermodulation algorithm and the DIM algorithm.
- As shown, the DIM exhibits more complex and stronger energy components at the baseband, resulting in more effective interference.



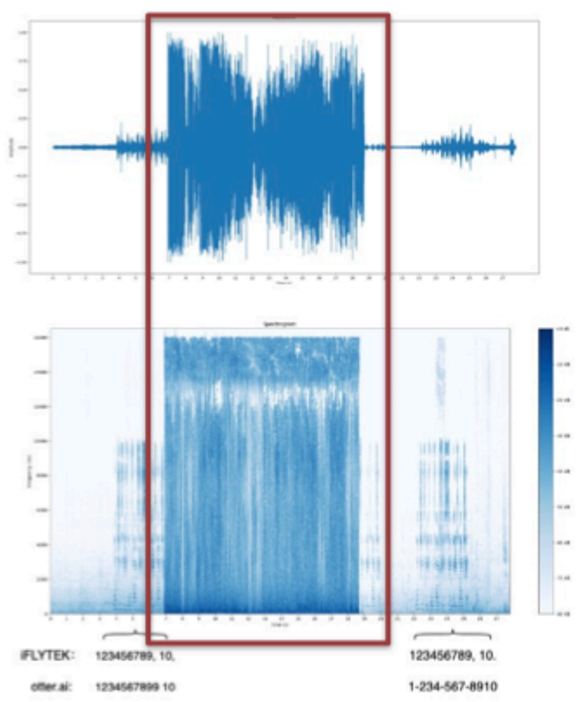
Fixed Frequency Intermodulation V.S. DIM
Testing microphone model: MEMs ADMP 401

DIM Jammer V.S. Commercial Jammer with Different STT(Speech-to-text) Models

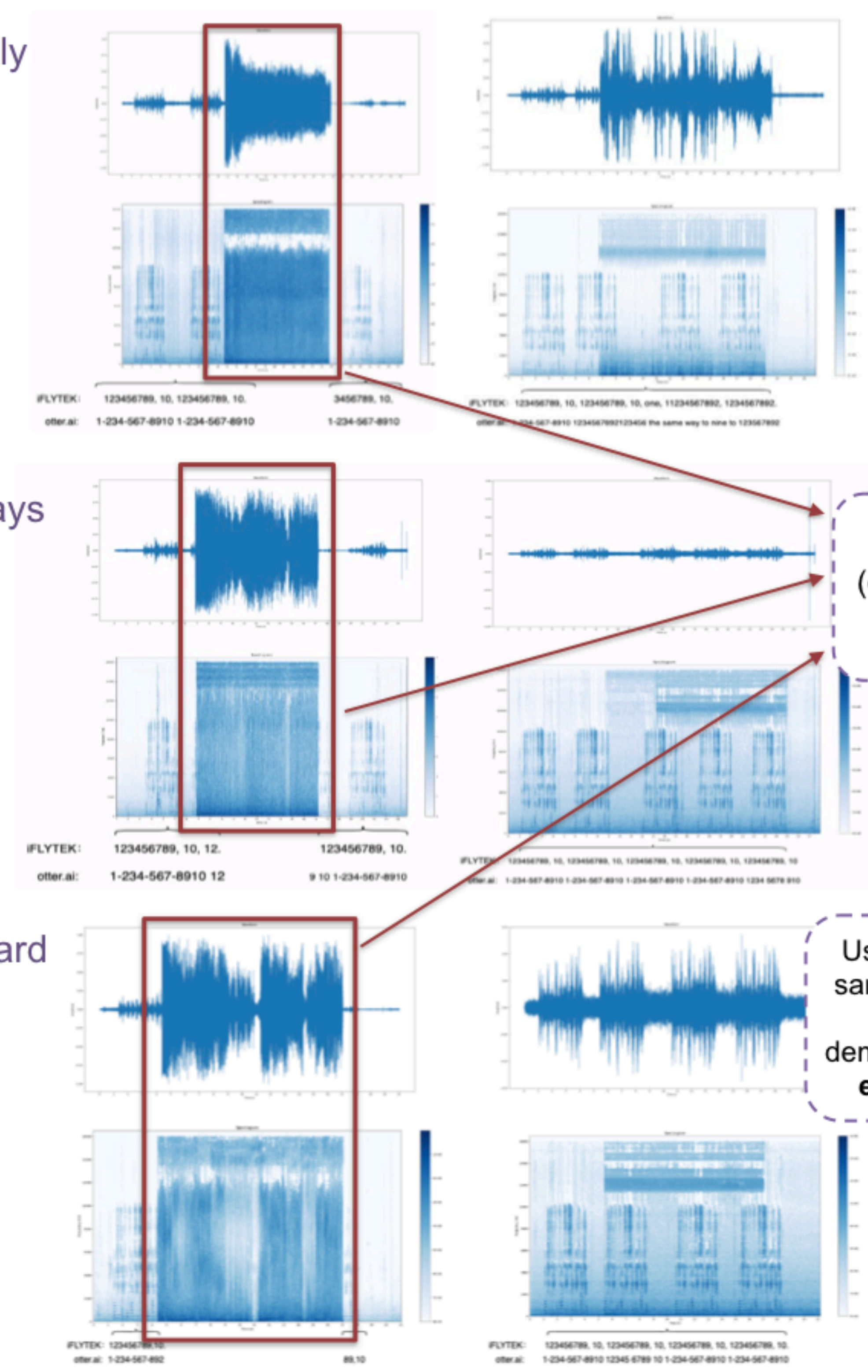
Left : Our Jammer
Right: Commercial one



Test with Different angles



Phone Standing Upright

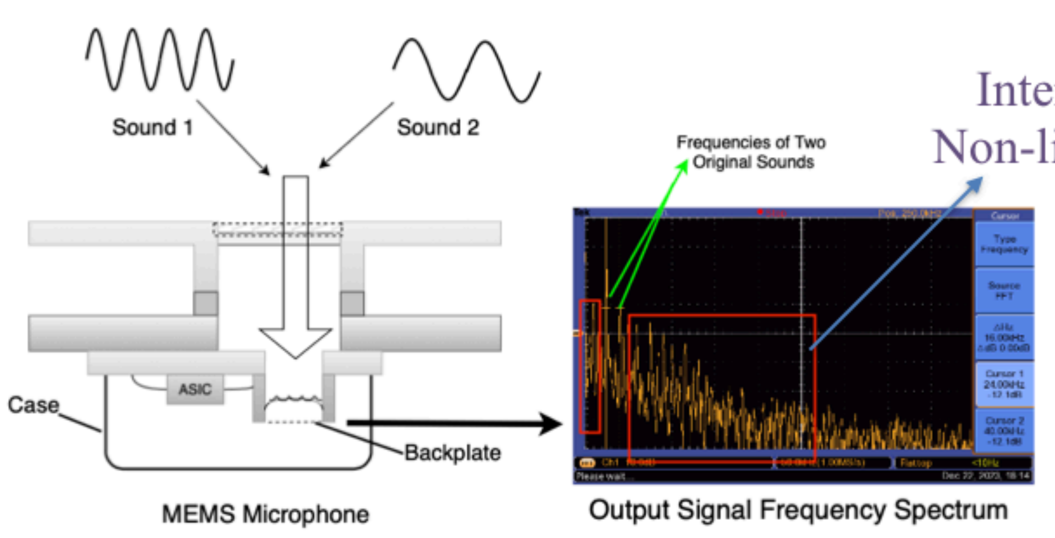


- We utilize two AI speech-to-text (STT) models, **iFLYTEK** and **Otter.ai**, to transcribe audio under various conditions.
- The background audio consistently features a repeating sequence of numbers from '**1 to 10**'.

As depicted in the figures, when our jammer is activated (**components in the boxed area**), **neither** of the models can recognize the sound meaning.

Using **commercial jammer** under the same conditions, both STT models can still recognize the information, demonstrating that **our jammer is more effective at causing interference.**

DIM Algorithm



✦ Non-linear phenomena occur because the interference signal frequency exceeds the microphone diaphragm's designed capture frequency, resulting in abnormal deformation

Non-linear Response : $S_{out} = A_1 S + A_2 S^2 + A_3 S^3 + \ldots + A_N S^N$

$$S_{out} = A_1(\cos(2\pi f_1 t) + \cos(2\pi f_2 t)) + A_2(1 + 0.5(\cos(2\pi 2 f_1 t) + \cos(2\pi 2 f_2 t)) + \cos(2\pi(f_1 + f_2)t) + \cos(2\pi(f_1 - f_2)t))$$

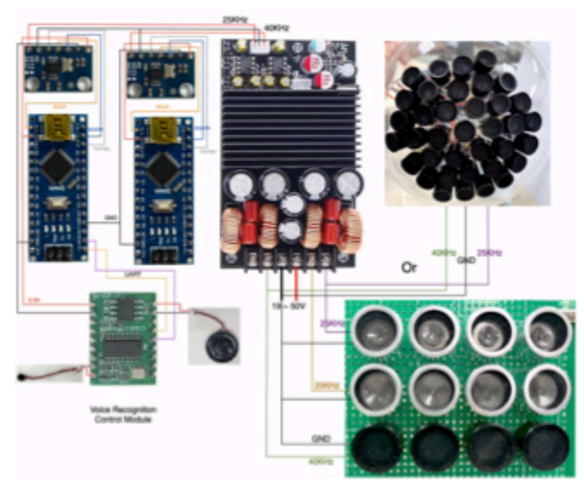
Two signals of different frequencies are combined

$(f_1 - f_2)$ represents the primary disruptive component in the baseband (20~20,000 Hz)

f_1 and f_2 are **dynamically** changing, resulting in the interference having **more complex** characteristics

Implementation

✤ Here is our implementation of the **DIM** with a **spherical** microphone array, which supports voice-controlled interference modes.



Jammer Device
Connection Diagram

Ethical Considerations

- Verify the legality of ultrasonic jammers in your jurisdiction, ensuring all operations are authorized and comply with relevant regulations.
- Respect and protect individual privacy rights, informing all affected parties about the use and intentions of the ultrasonic jamming devices.

Demonstration

All audio results, spectral figures and draft poster are available for viewing at the following link: https://github.com/Moriartysherry/Ultrasonic_Jammer .

Reference:
[1] P. Huang, Y. Wei, P. Cheng, Z. Ba, L. Lu, F. Lin, F. Zhang, and K. Ren, "InfoMasker: Preventing Eavesdropping Using Phoneme-Based Noise," in Proc. NDSS, 2023.
[2] Y. Chen, H. Li, S. Nagels, Z. Li, P. Lopes, B. Y. Zhao, and H. Zheng, "Understanding the Effectiveness of Ultrasonic Microphone Jammer," arXiv preprint arXiv:1904.08490, 2019.