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Deaf-Aid: Mobile IoT Communication Exploiting Stealthy Speaker-to-Gyroscope Channel

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Presented by Chenpei Huang

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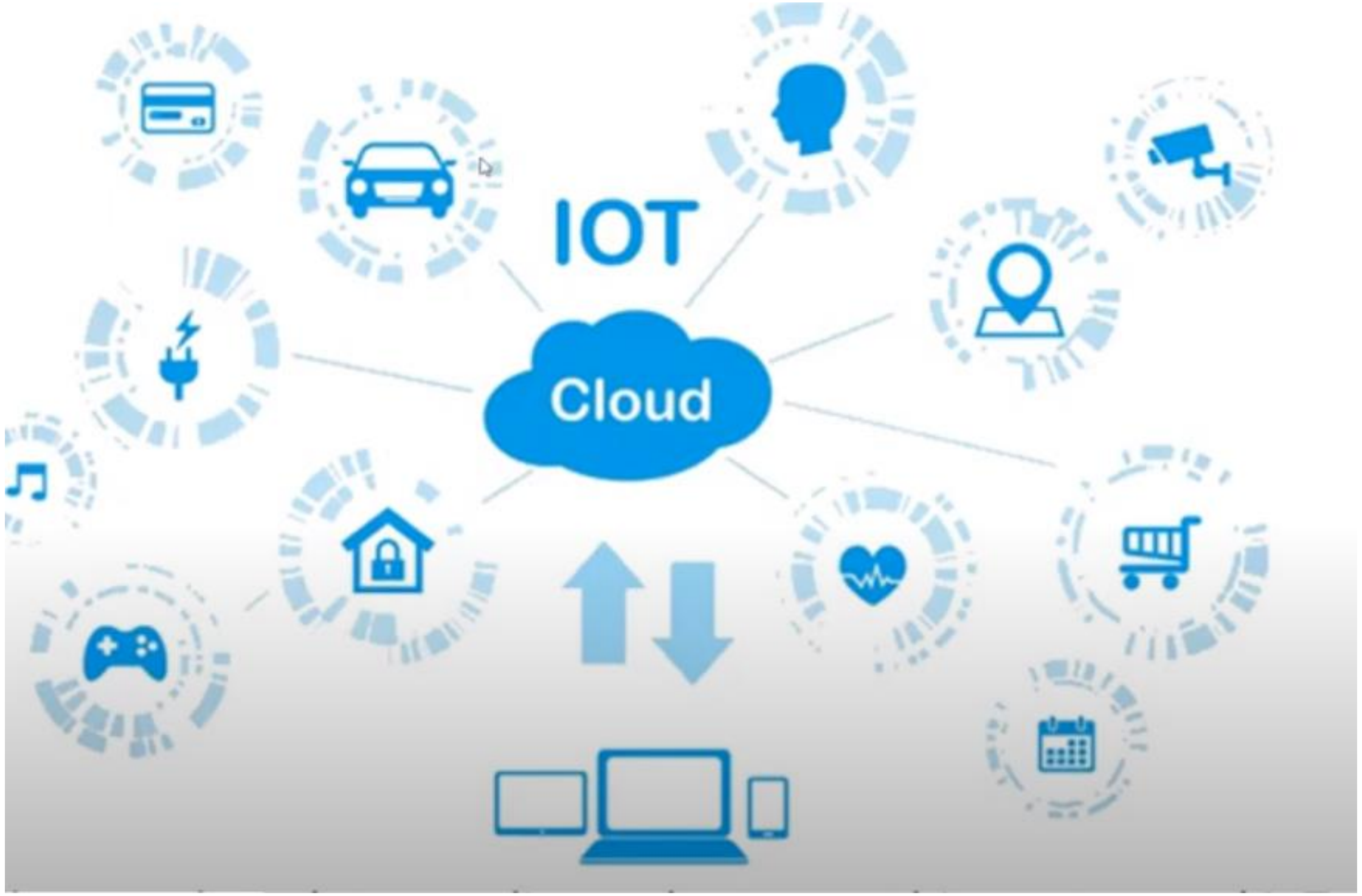
Outline

- Introduction
- Background and Model
- System Design
- Evaluation
- Conclusion

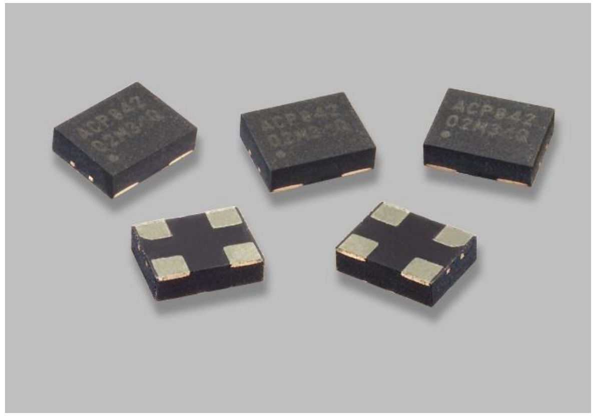
Introduction



Introduction

Introduction

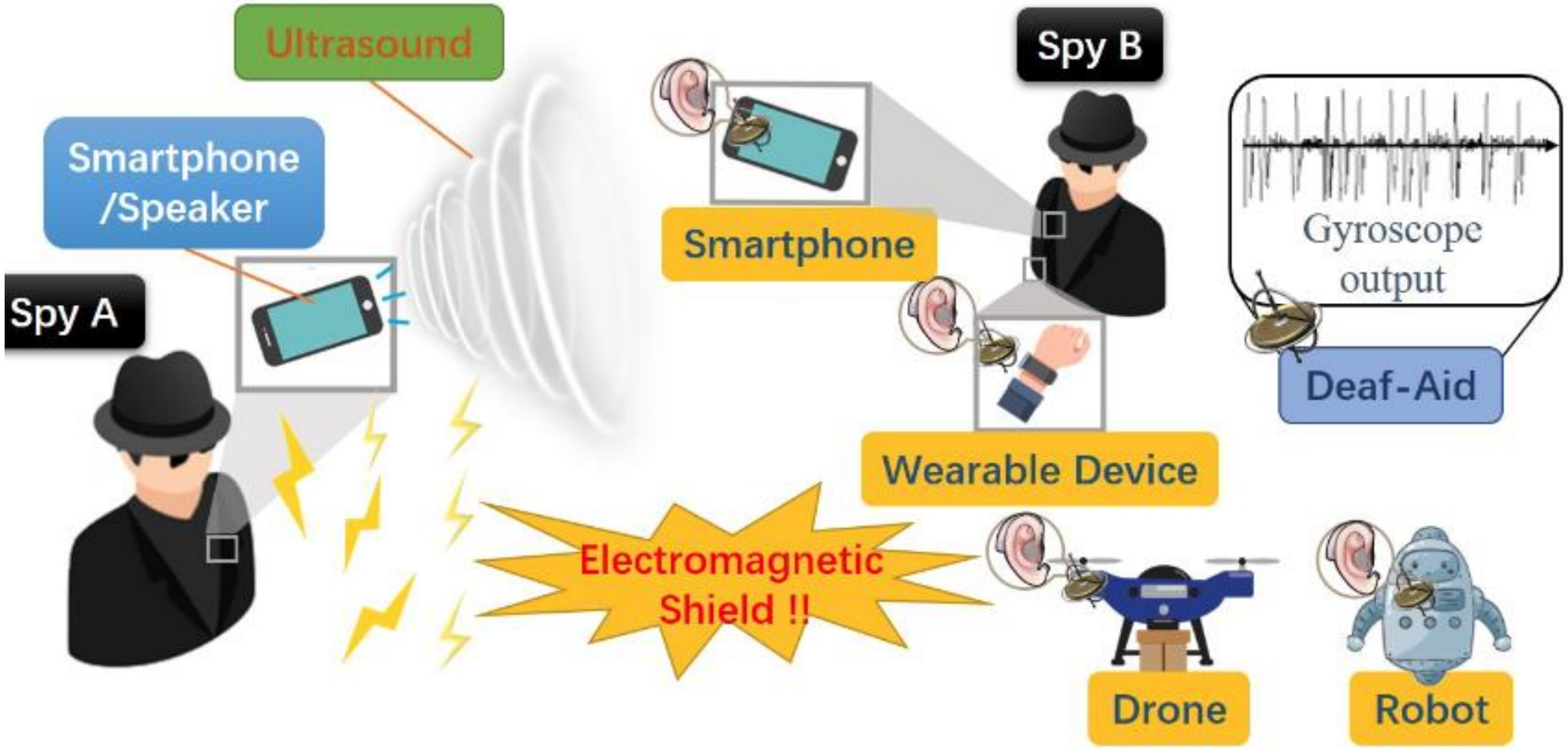
Micro-electro-mechanical system (MEMS)



MEMS is vulnerable to the ultrasonic injection! But can it be used for communication purpose?

Become indispensable…

Application



Contribution

1. Investigate a stealthy speaker-to-gyroscope channel without the restriction of peripheral, contact, fixed placement, etc.

2. Analyze the relationship among axes in a gyroscope under resonance.

3. Develop a robust communicating system for a mobilizable IoT network.

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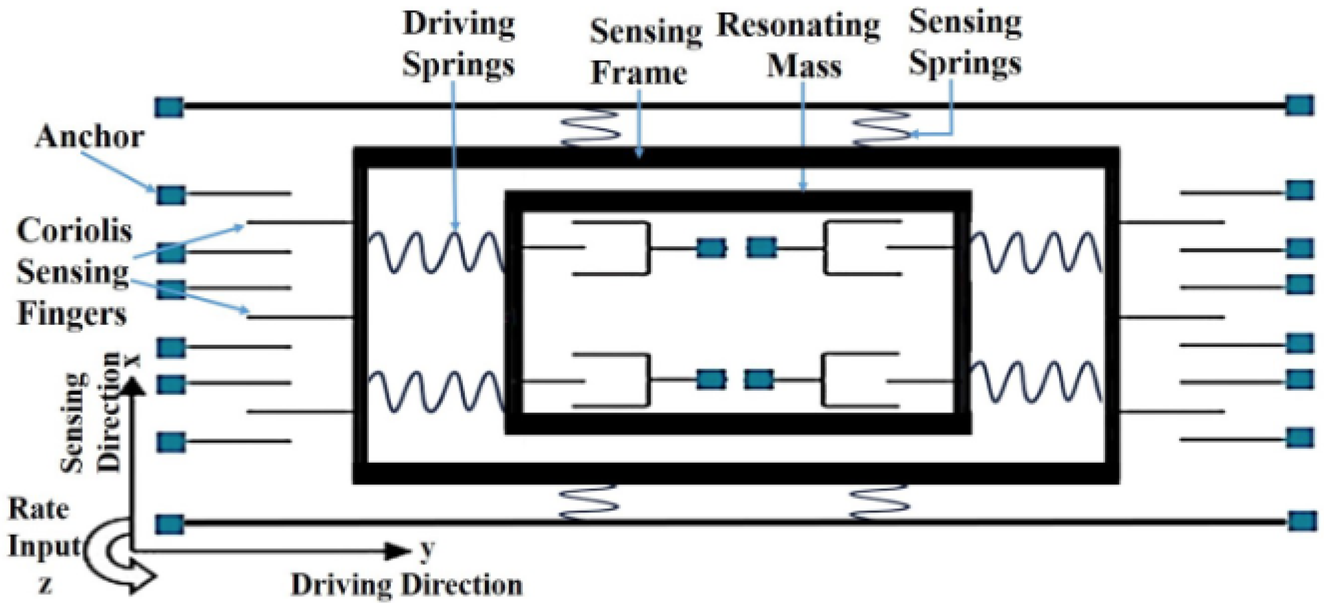
Background: Gyroscope Structure



Concept of MEMS gyroscope structure

Acceleration data:

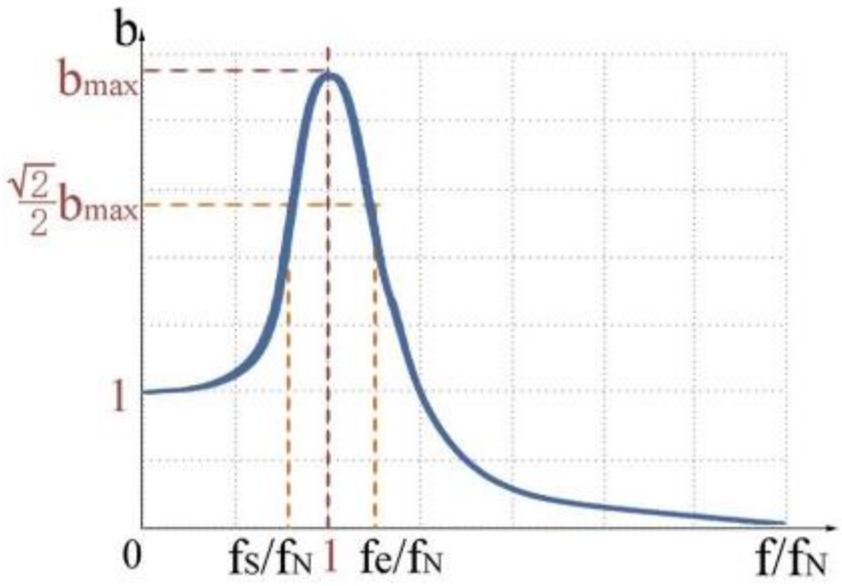
$$a_x = -2\omega\dot{y},$$

- Multi-dimension ACC data
- Amplification
- Filtering
- Analog-to-digital Conversion

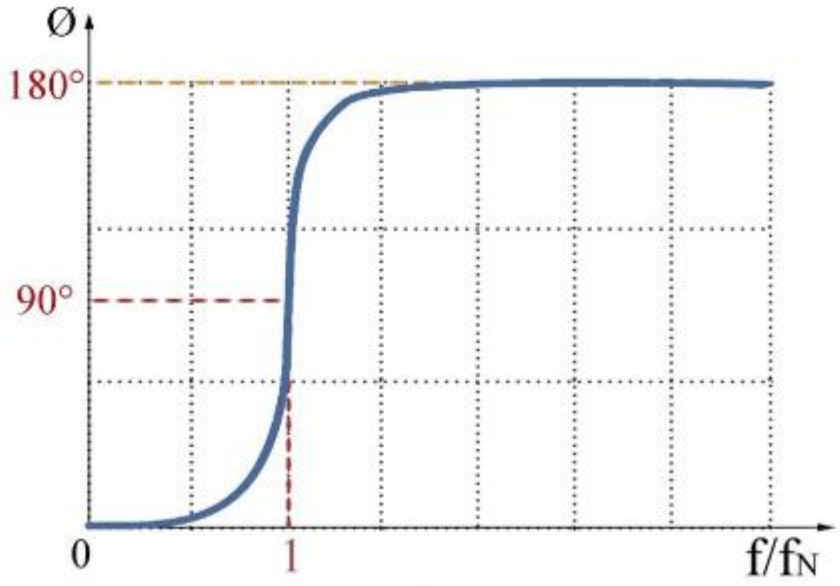
Background: Resonance Principle

Single-degree-of-freedom system with high-damping

- Natural Frequency: f_N
- Inter-individual discrepancy among gyroscopes



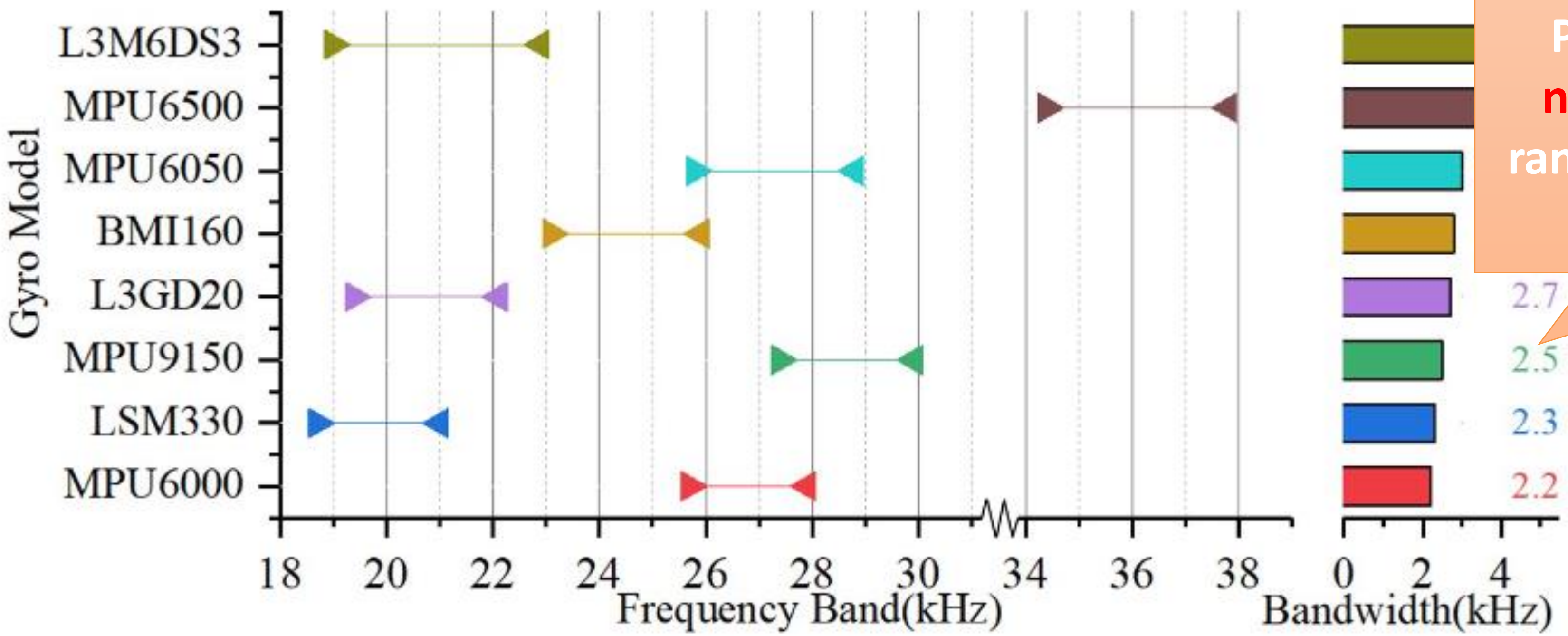
(a) Amplitude-frequency



(b) Phase-frequency

Background: Resonance Principle

- Natural Frequency: f_N
- Inter-individual discrepancy among gyroscopes



Popular gyroscopes have a **narrow** resonant frequency range **above human audibility!**

Feasibility Investigation

- Inaudibility
  The resonant frequency of gyroscopes tends to exceed 18kHz, which is ignored by human hearing and speech recognition system.

- No peripheral
  For transmitter: commercial speakers (up to 24kHz), Hi-Fi speakers (32-bit/384kHz) could cover the band of interest without peripherals.

- Little interference
  Other ultrasound application prefer bands above 40kHz.

Model: from forced vibration to digitized signal

1. Sinusoid force imposed on one axis and its response

$$F(t) = A \cdot sin(2\pi f_0 t + \phi_0), \longrightarrow R_0(t) = bA \cdot sin(2\pi f_0 t + \phi_0 + \phi_1),$$

2. Amplifier and filter introduce gain and phase shift

3. AD conversion with much lower sampling rate (few hundreds)

$$f_0' = n \times Fs + f_1, \quad (-\frac{Fs}{2} < f_1 < \frac{Fs}{2})$$

$$R[k] = bLA \cdot sin(2\pi f_1 \frac{k}{Fs} + \Phi).$$

Sounds good! But…

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System Design: Sample rate drift

Unpredictable deviation of output frequency

$$f_0' = n \times Fs + f_1, \quad (-\frac{Fs}{2} < f_1 < \frac{Fs}{2})$$

$$R[k] = bLA \cdot sin(2\pi f_1 \frac{k}{Fs} + \Phi).$$

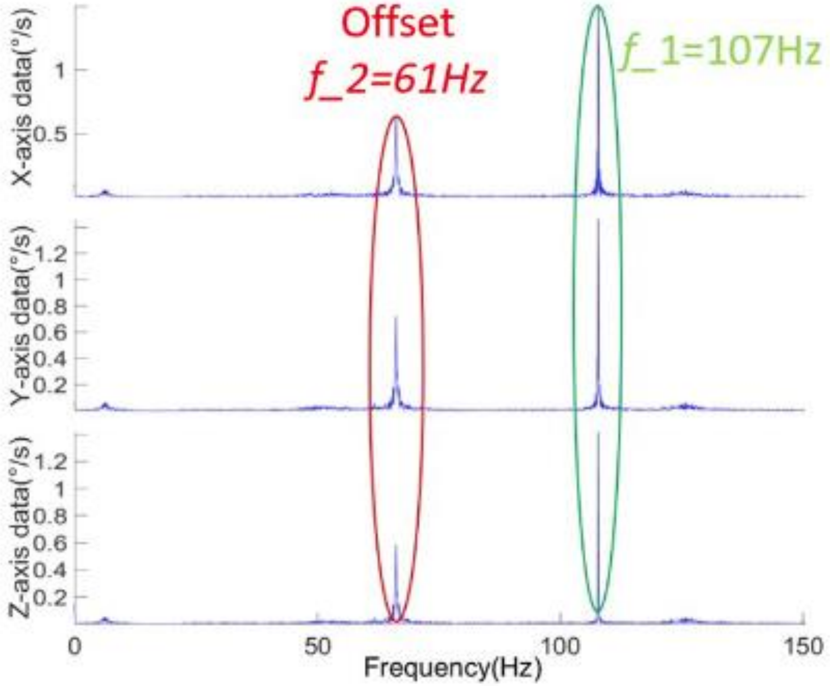
$$f_0' = n \times (Fs + \Delta Fs) + f_2,$$

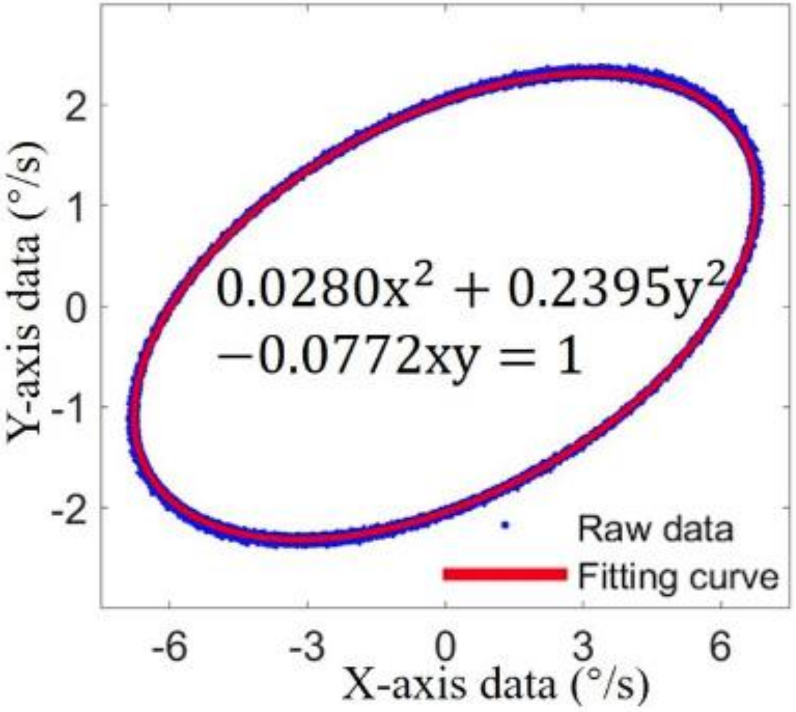
$$R[k] = bLA \cdot sin(2\pi f_2 \frac{k}{Fs + \Delta Fs} + \Phi),$$

Remarkable offset!

System Design: Sample rate drift

Key Observation: The sampling drift happens simultaneously among axes





System Design: Sample rate drift

Solution: Apply a multiplier and mean filter

$$S_{cor}[k] = R_x[k] \times R_y[k]$$
$$= \frac{1}{2} A_x A_y [cos(\Phi_x - \Phi_y) - cos(4\pi \frac{f_0'}{Fs} k + \Phi_x + \Phi_y)],$$

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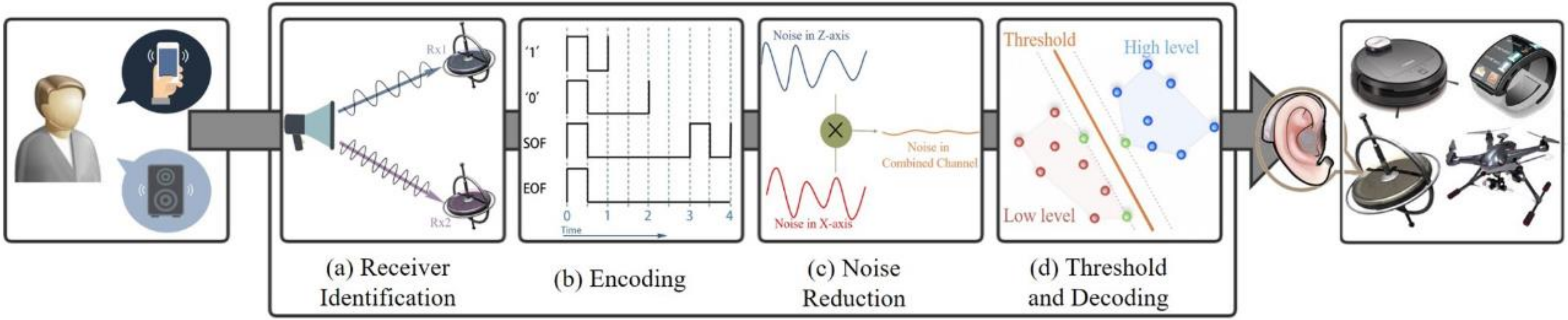
System Design

Overview:



Deaf-Aid, a speaker-to-gyroscope channel for mobile IoT communication

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System Design

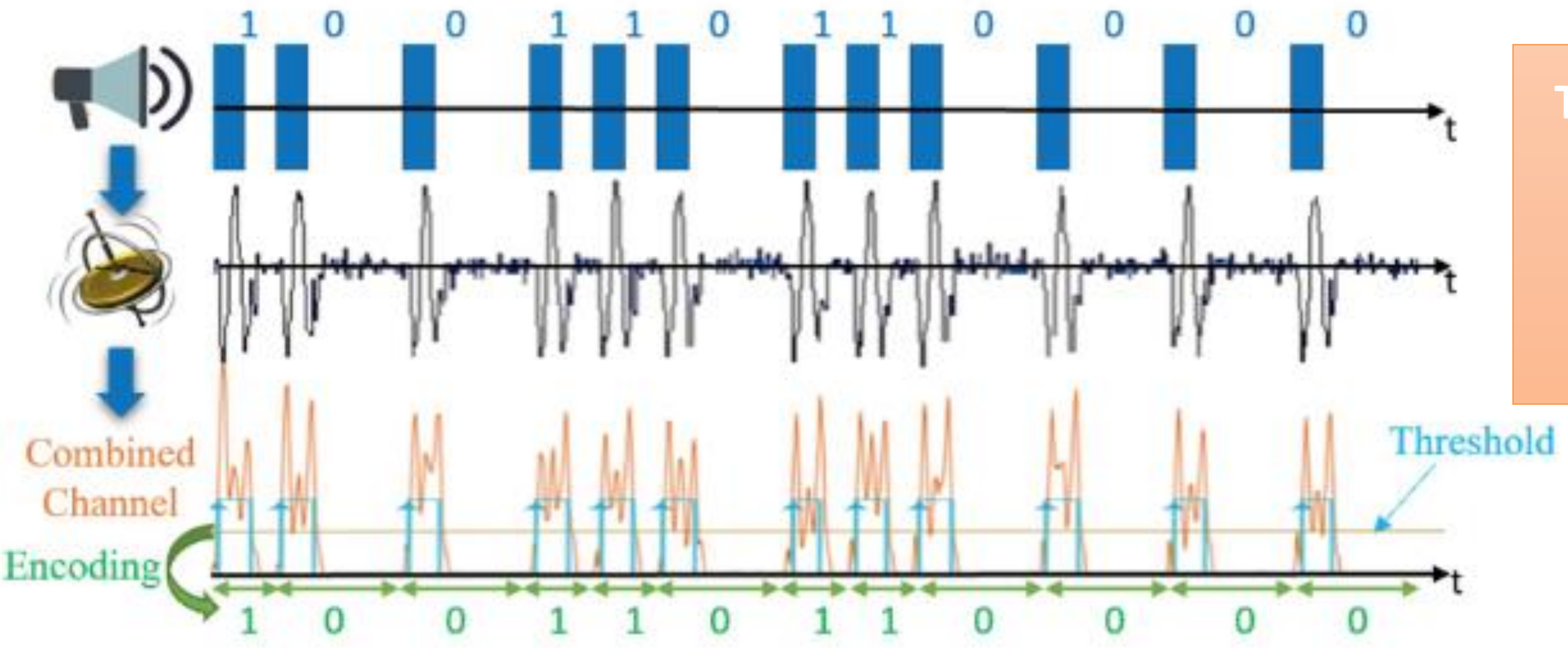
(a) Receiver Identification: Different gyroscopes have various resonant frequency ranges. Transmitter will send a chirp and the target should receive the full range signal.

(b) Encoding: pulse interval encoding (PIE)

(c) Noise Reduction: average filtering after multiplication

(d) Threshold and Decoding: maximum entropy threshold method

System Design



Transceiver movement can be filtered out after some transform (e.g., Fourier/Wavelet transform, EMD)

An Example of signal transmission

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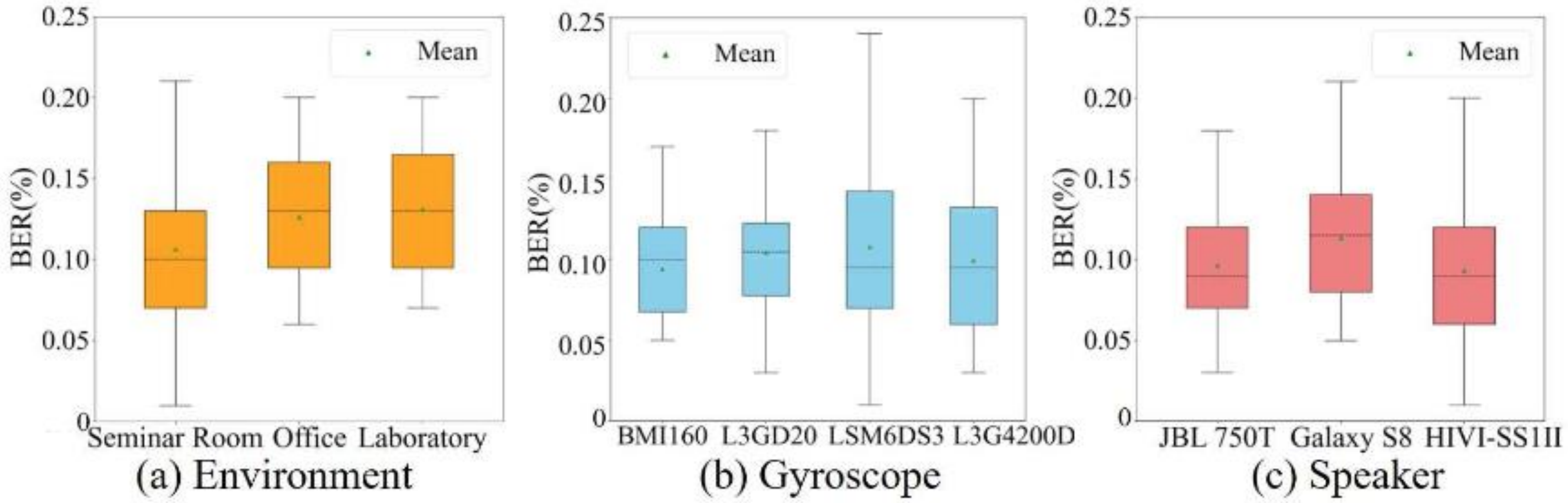
Evaluation: parameters

- Sampling rate: 200Hz
- Pulse width: 50ms

- Distance: 15cm
- Tx power: <5W



The impact of environment and device

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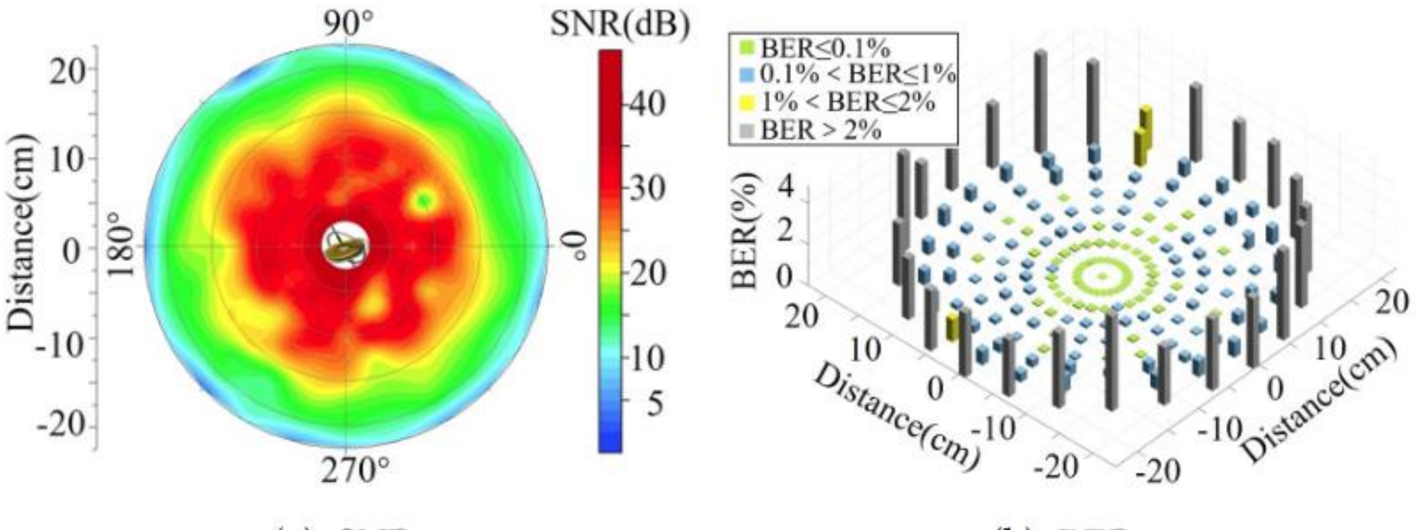
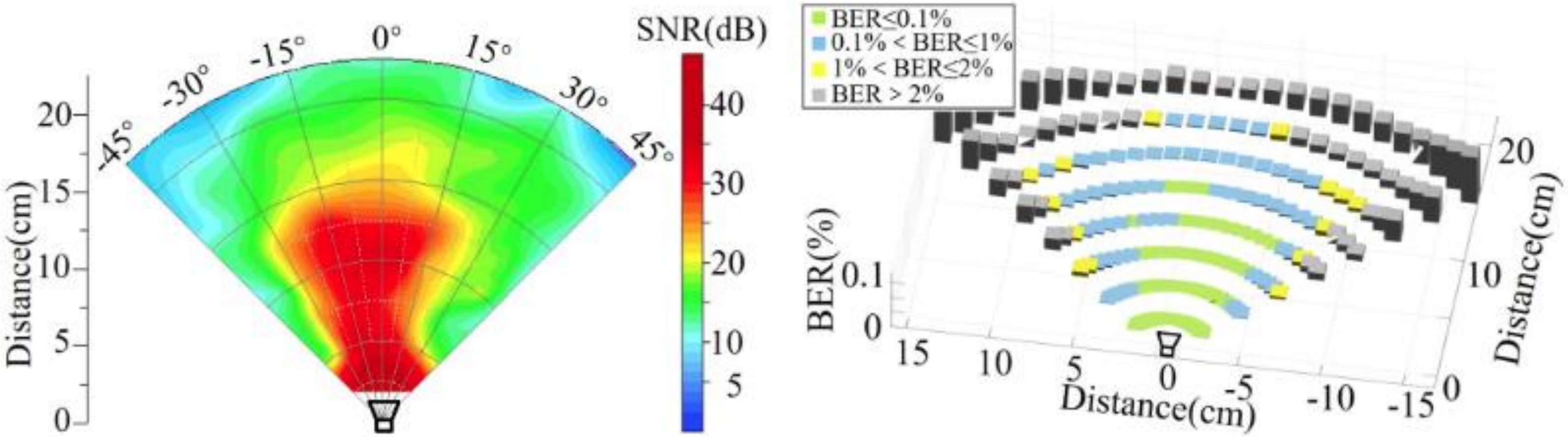
Evaluation: Orientation



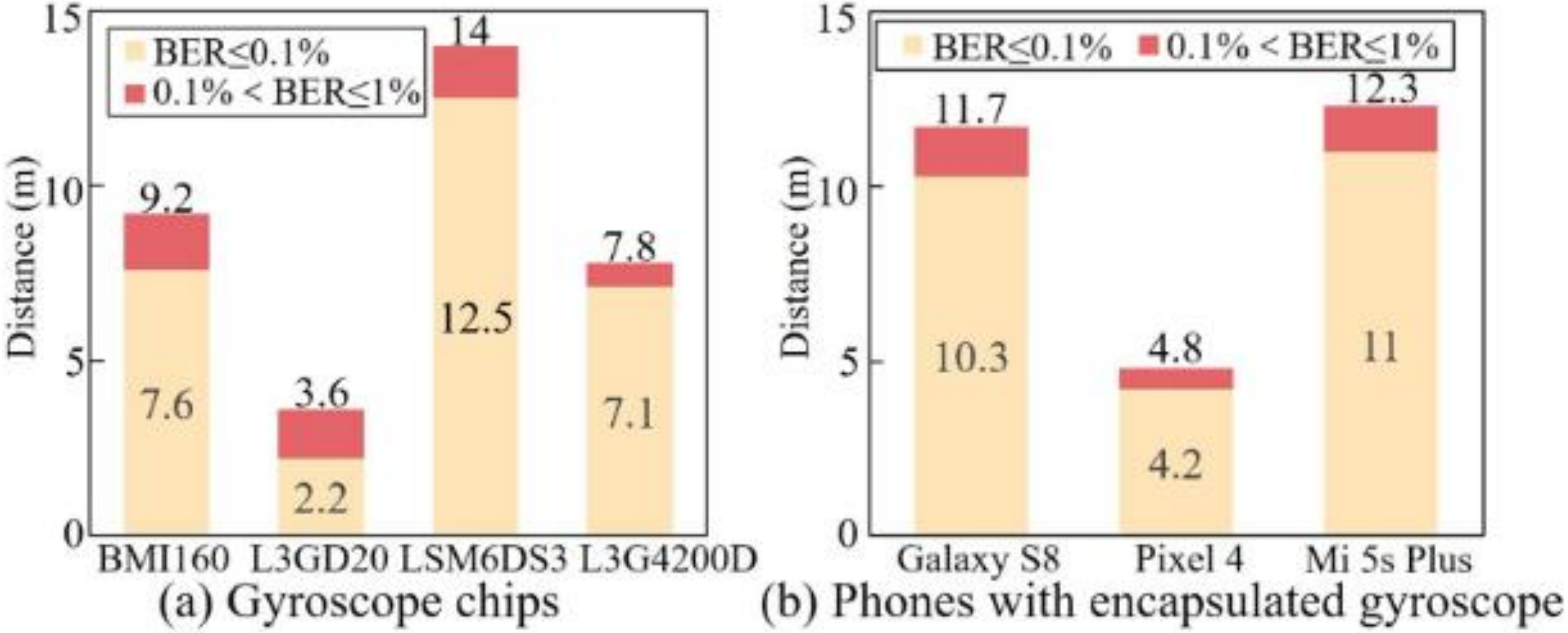
(a) SNR (b) BER



(a) SNR (b) BER

Evaluation: Distance

- Raise Tx power to 30W



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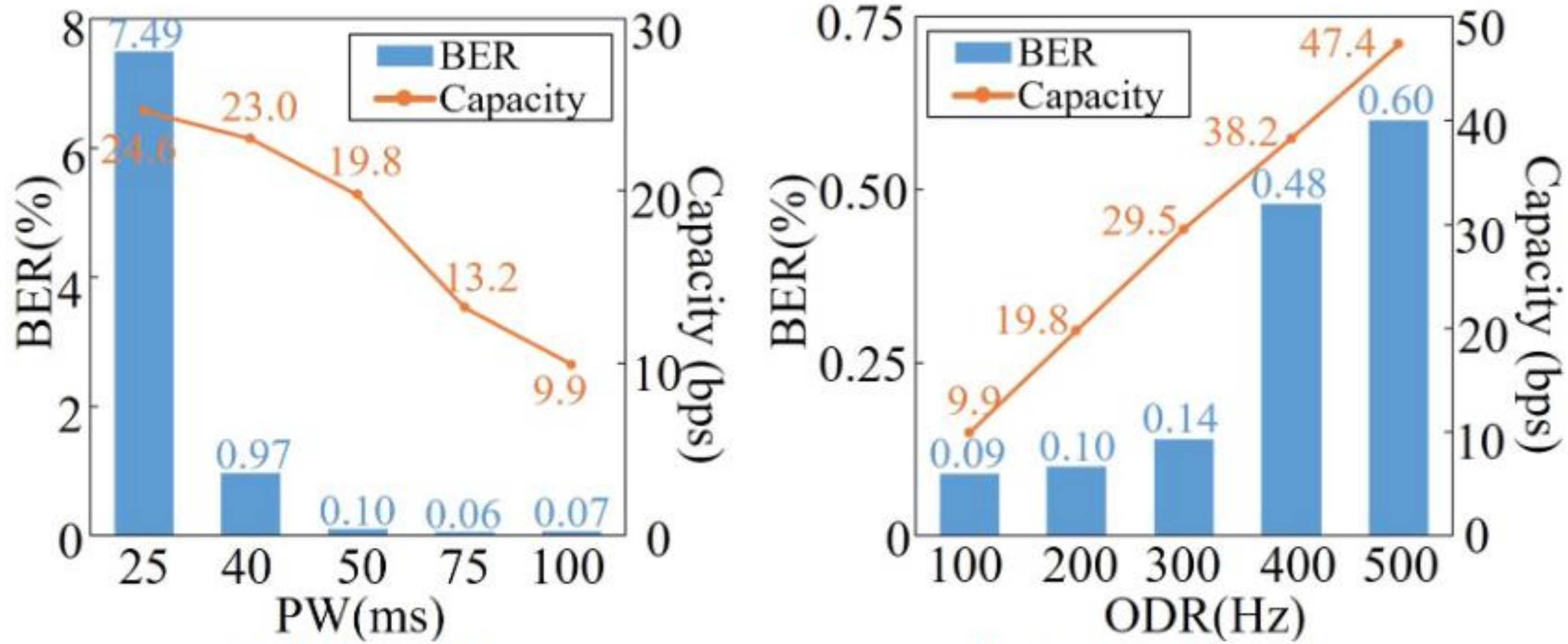
Evaluation: Transmission Capacity

- The channel capacity in a binary symmetric channel

$$C = \frac{1}{PW}\left[1 + BER \times log_2 BER + (1 - BER) \times log_2(1 - BER)\right],$$



(a) Pulse width

(b) Output-bit-rate

*maintain the product PW×ODR at 0.01

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Conclusion

1. They first probe the relationship among axis in a gyroscope under resonance.

2. They use the diversity of resonant frequency range as fingerprint for receiver identification.

3. Deaf-Aid reaches up to 47bps with a low BER even under motion interference


THANK YOU
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