BackDoor: Making Microphones Hear Inaudible Sounds

Nirupam Roy

Haitham Hassanieh

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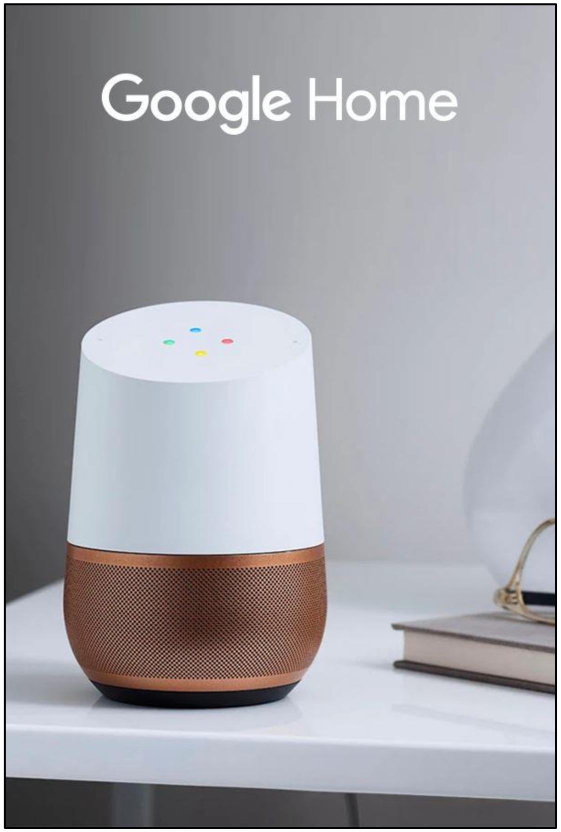
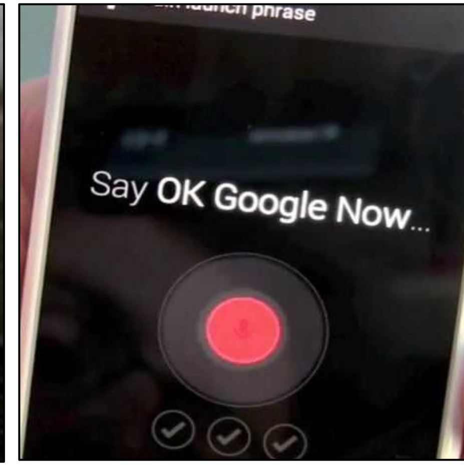
University of Illinois at Urbana-Champaign

Microphones are everywhere





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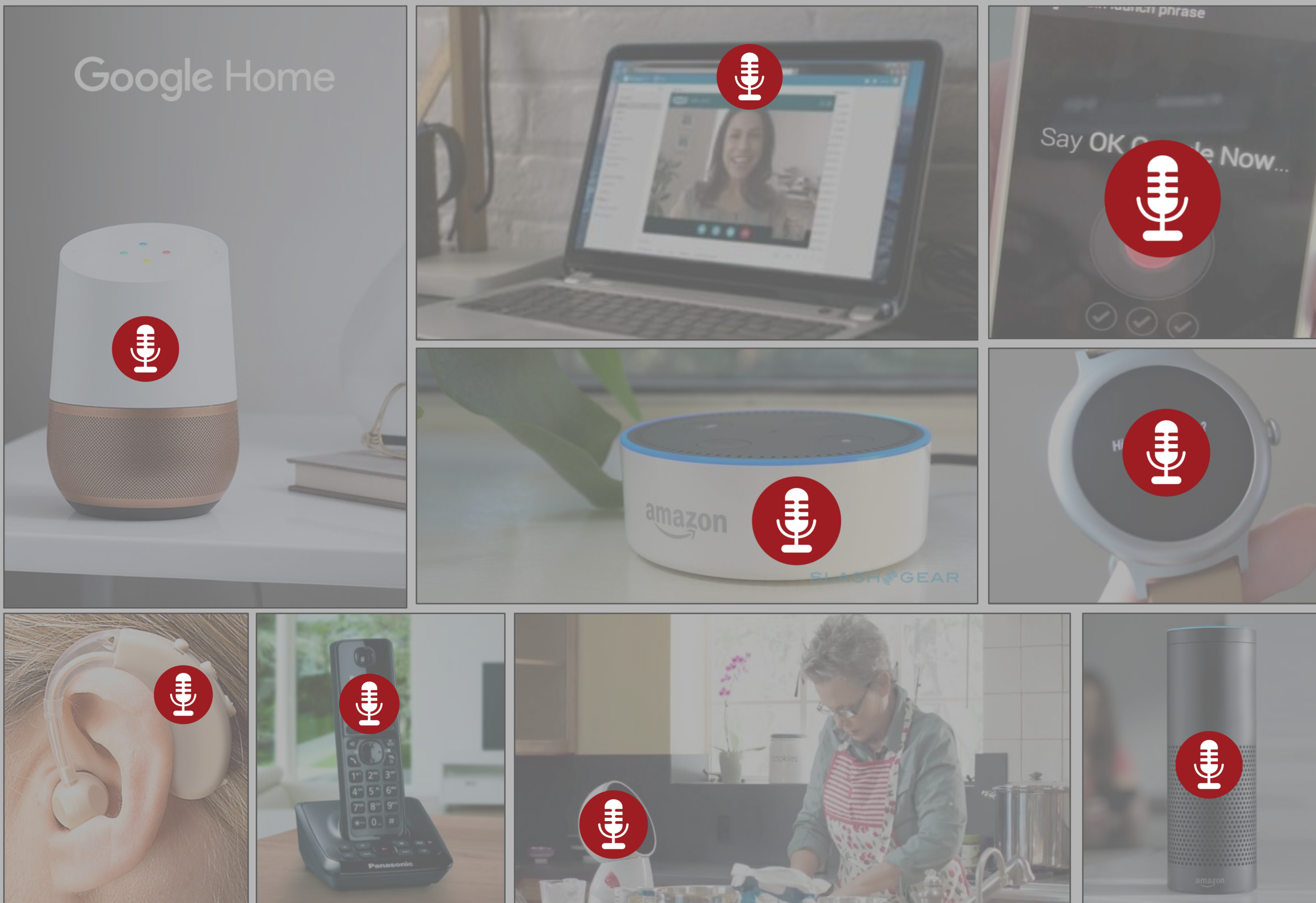
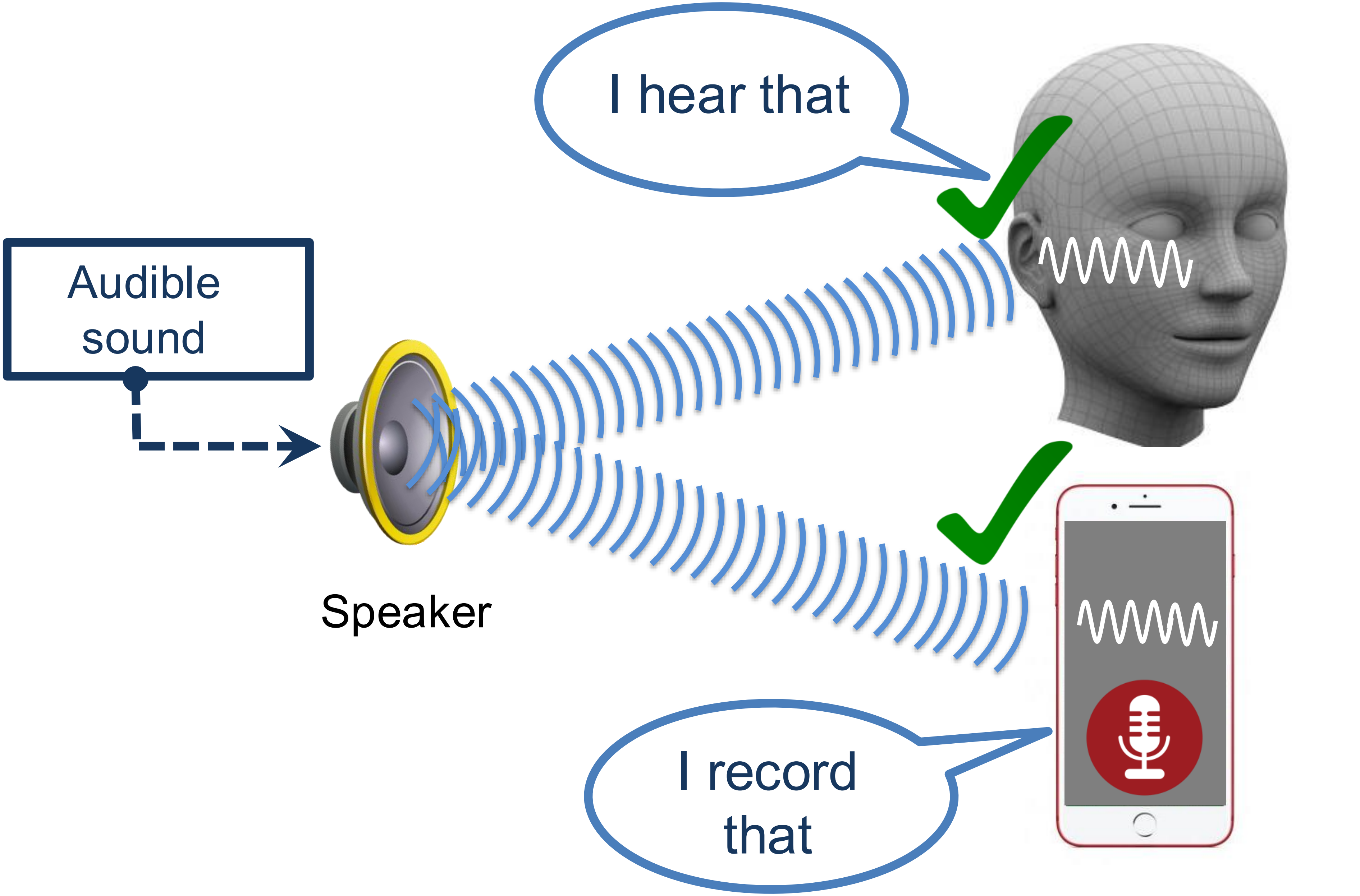
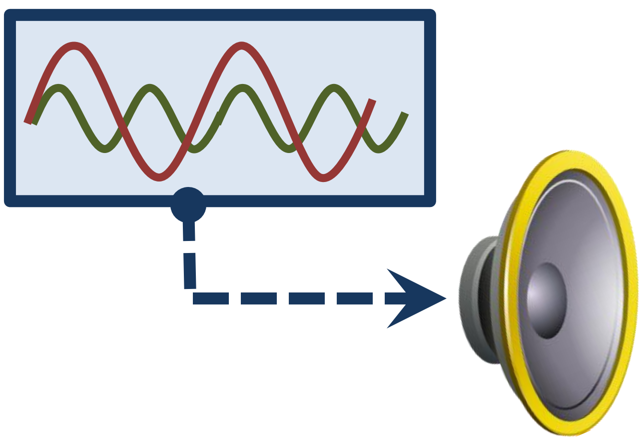


Microphones record audible sounds

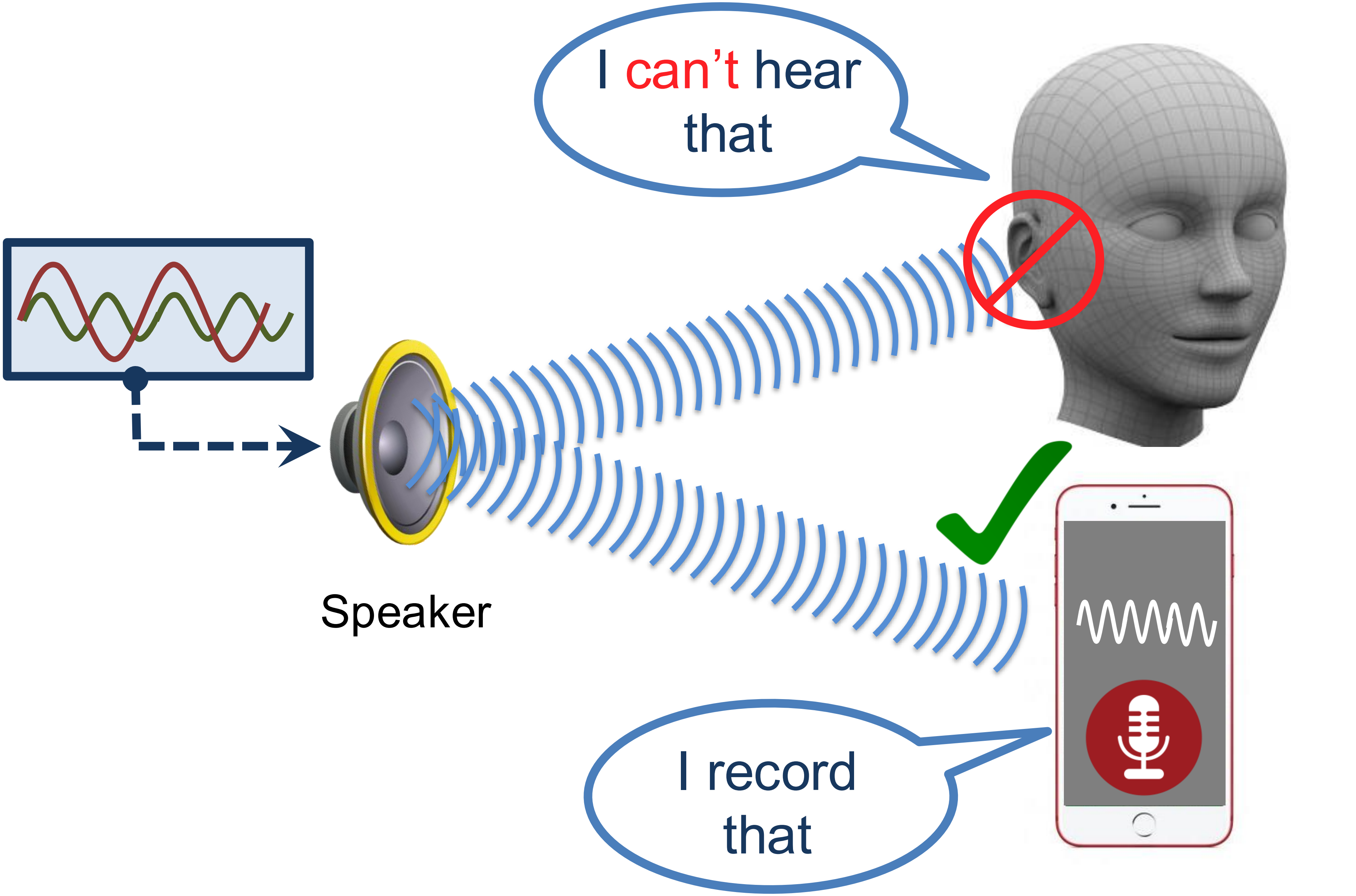


Inaudible, but recordable !

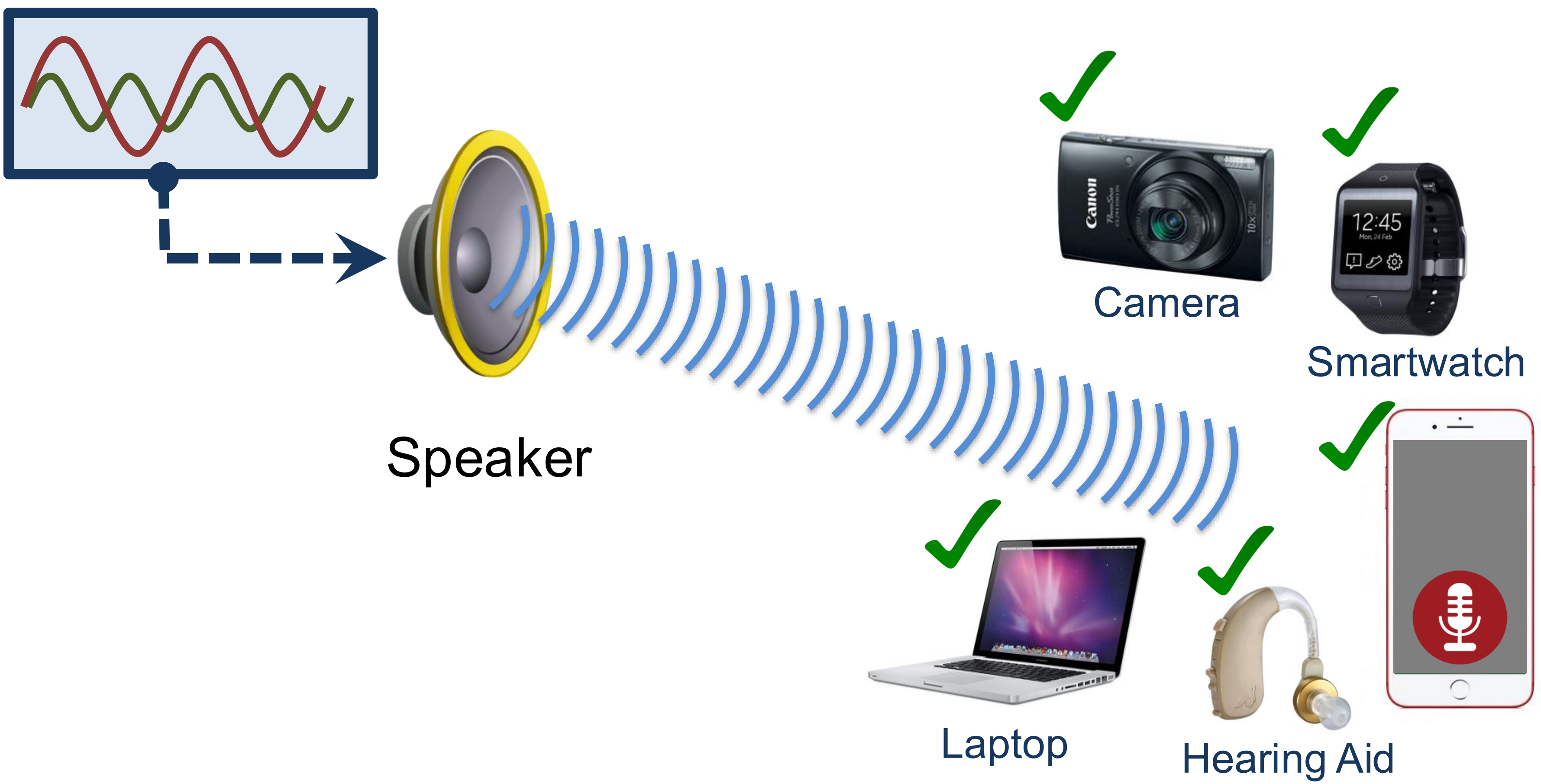


Speaker

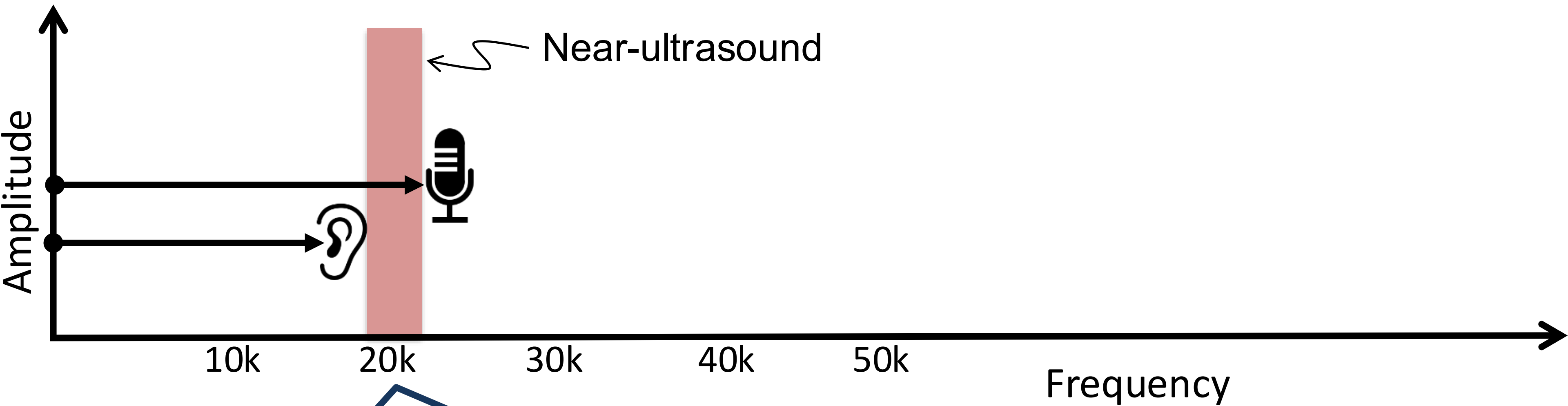
Inaudible, but recordable !



Works with unmodified devices



It's not "near-ultrasound"



chirp.io

Pseudo-ranging
SenSys'12

ApneaApp
MobiSys'15

DopLink
UbiComp'13

SoundWave
CHI'12

lisnr.com

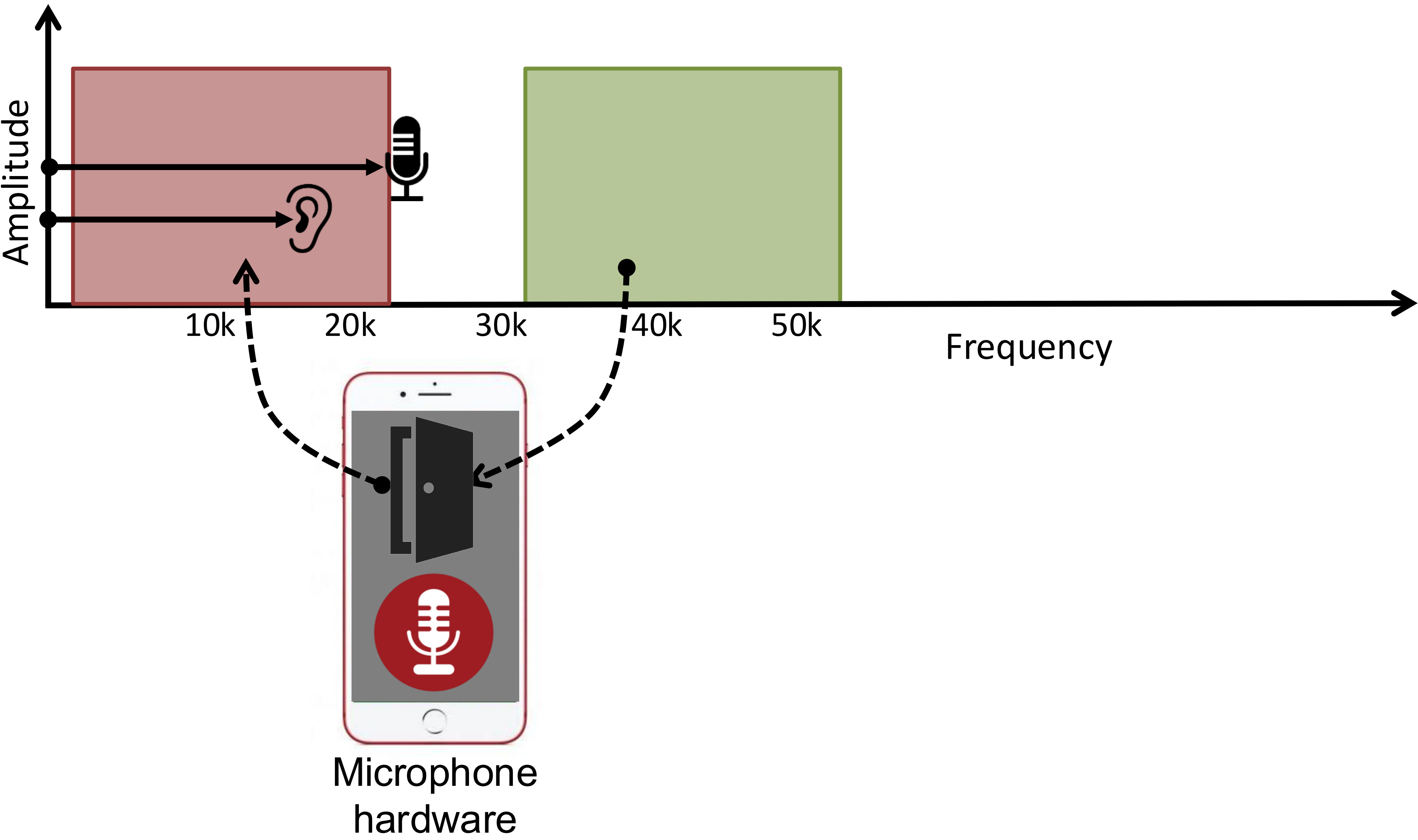
AAMouse
MobiSys'15

AirLink
UbiComp'14

Spartacus
MobiSys'13

Crowd-counting
SenSys'12

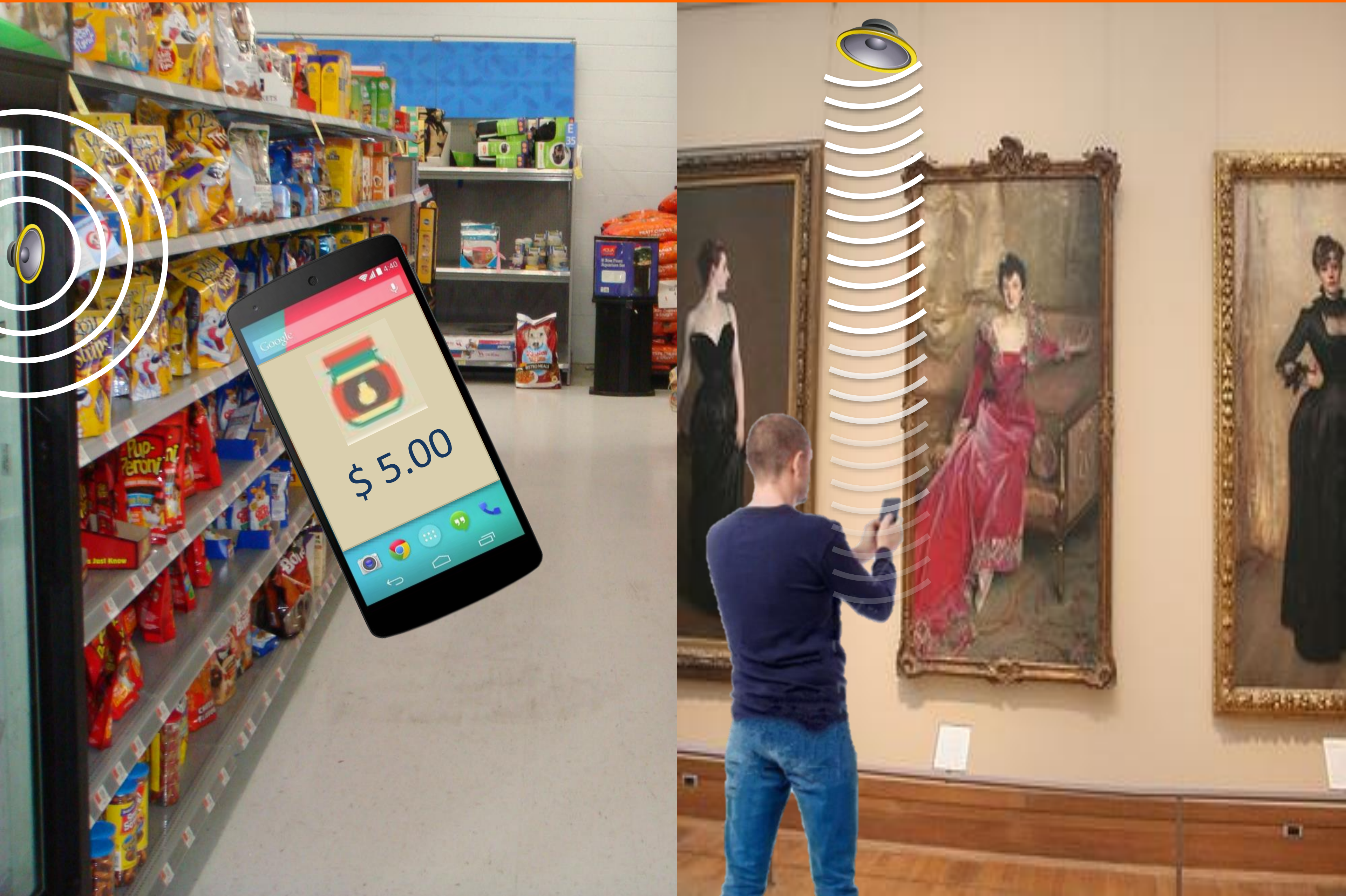
Exploiting fundamental nonlinearity



What can we do with it?

Application: Acoustic jammer

Application: Acoustic communication



Threat: Acoustic DOS attack

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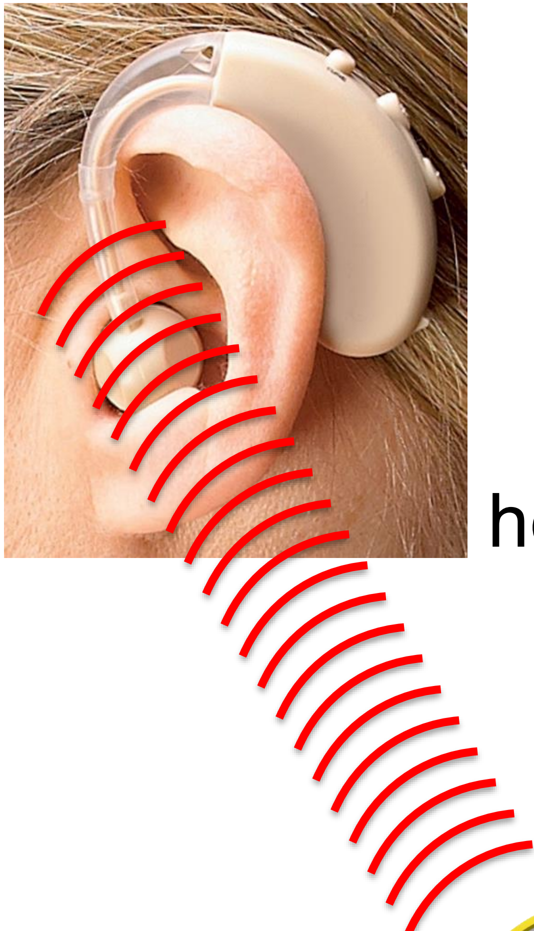
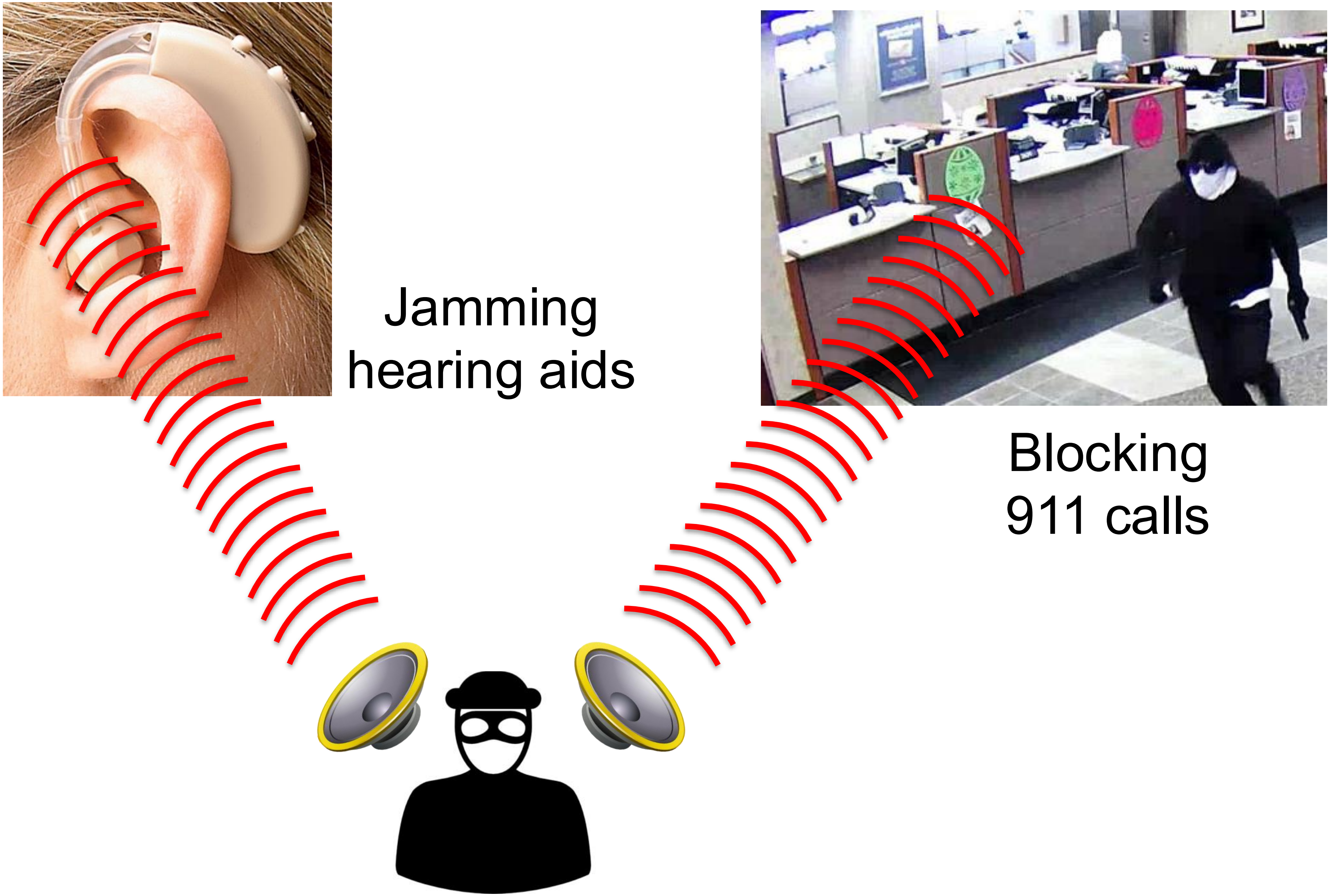


Jamming
hearing aids

Threat: Acoustic DOS attack



Talk outline

1. Microphone Overview
2. System Design
3. Challenges
4. Evaluation

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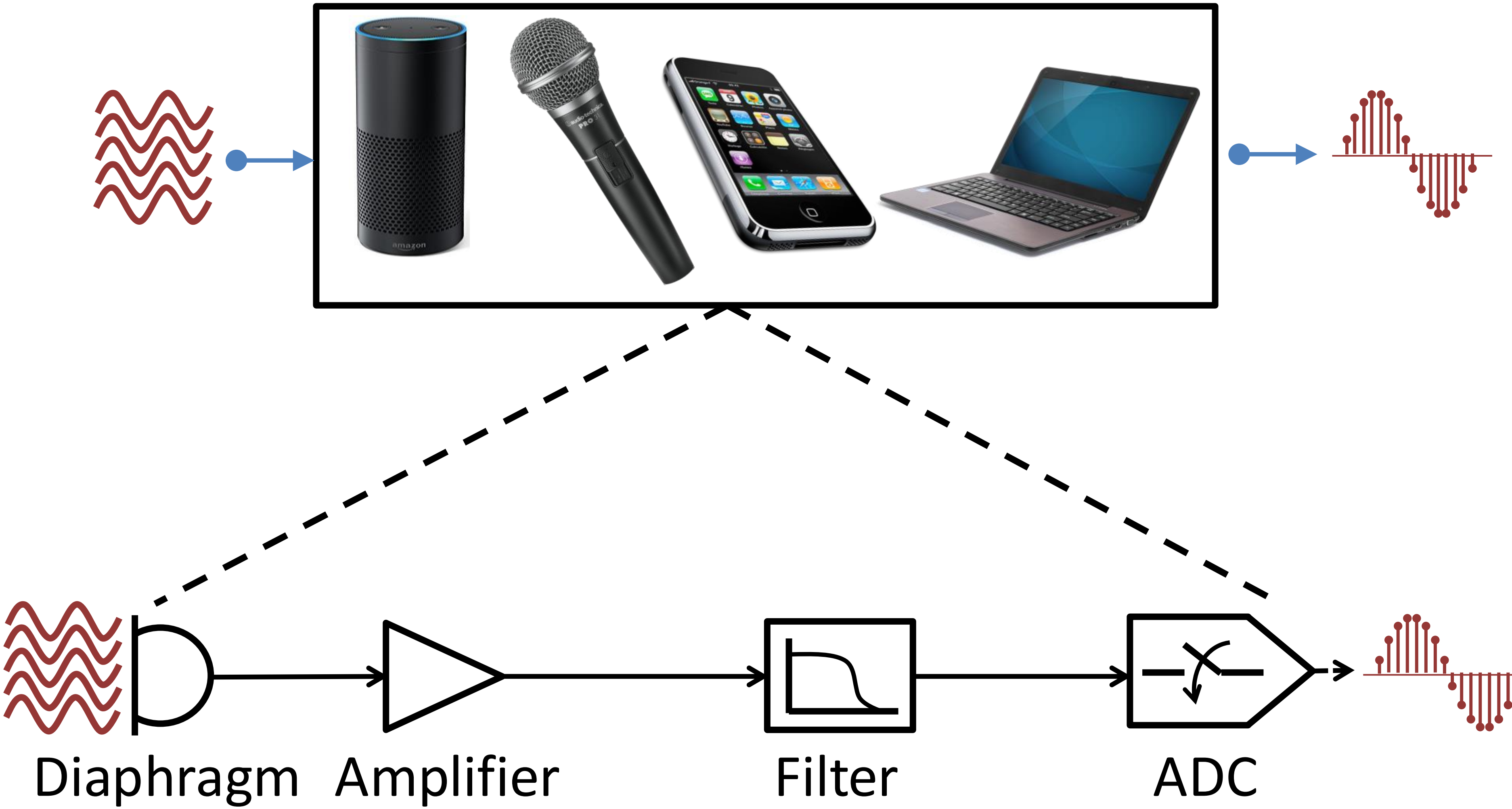
Microphone working principle



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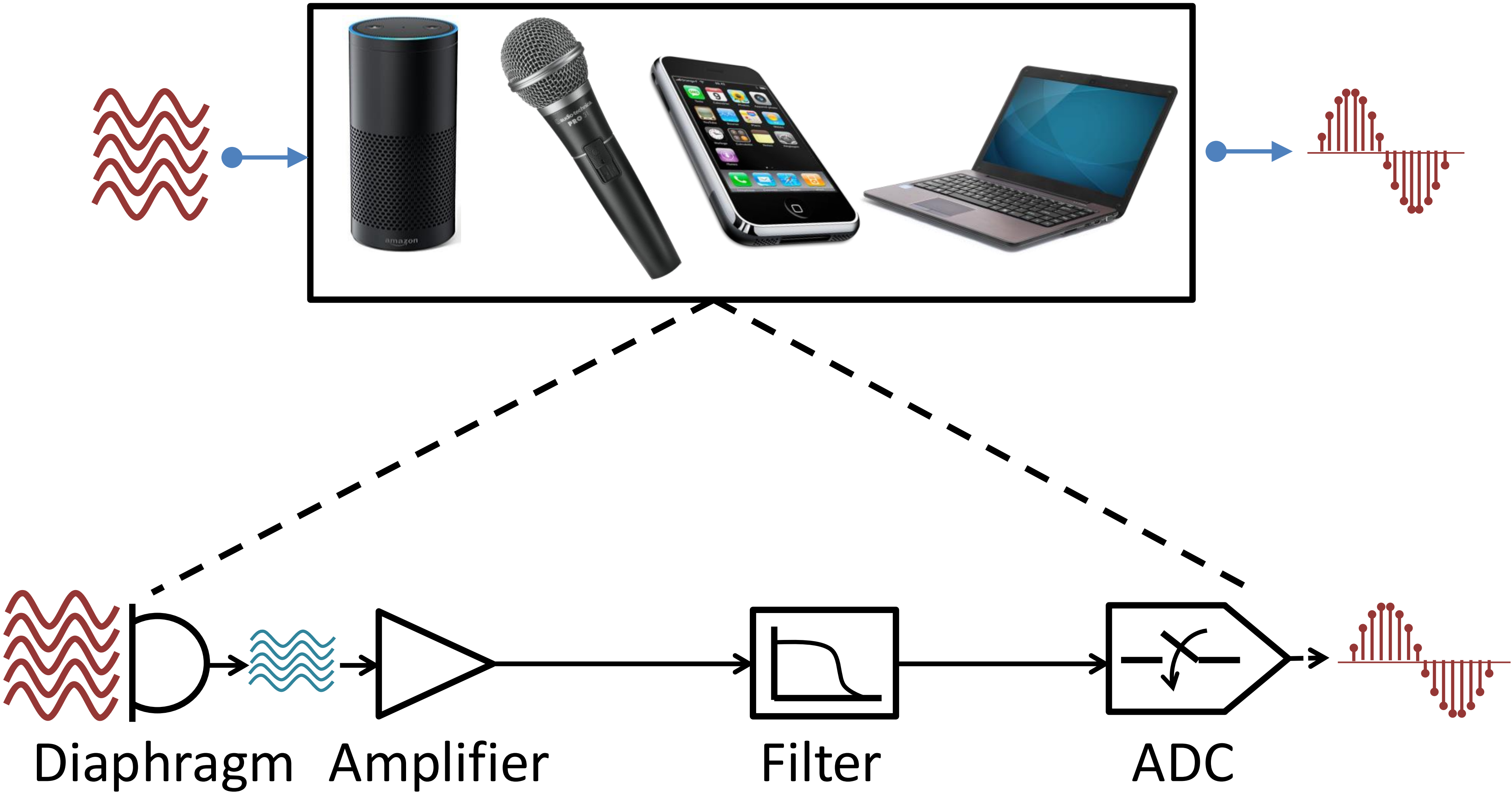

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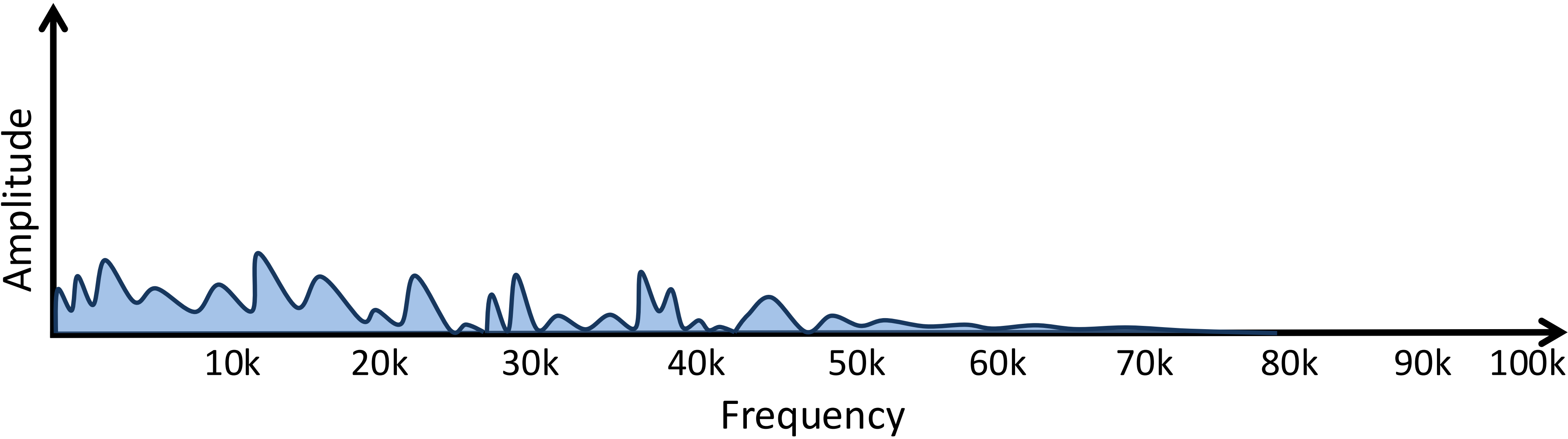

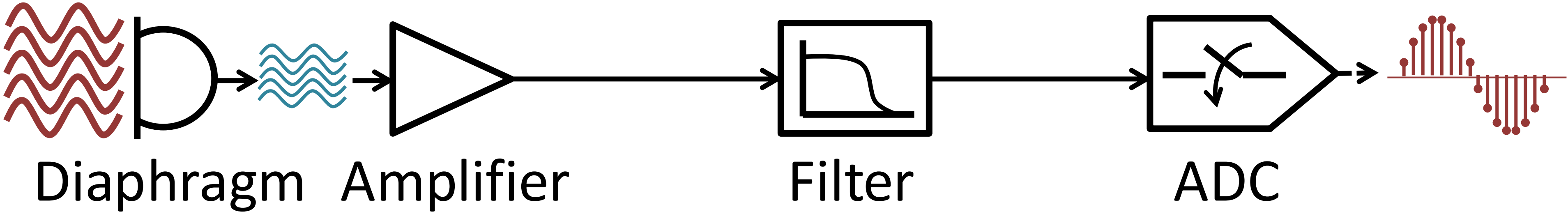

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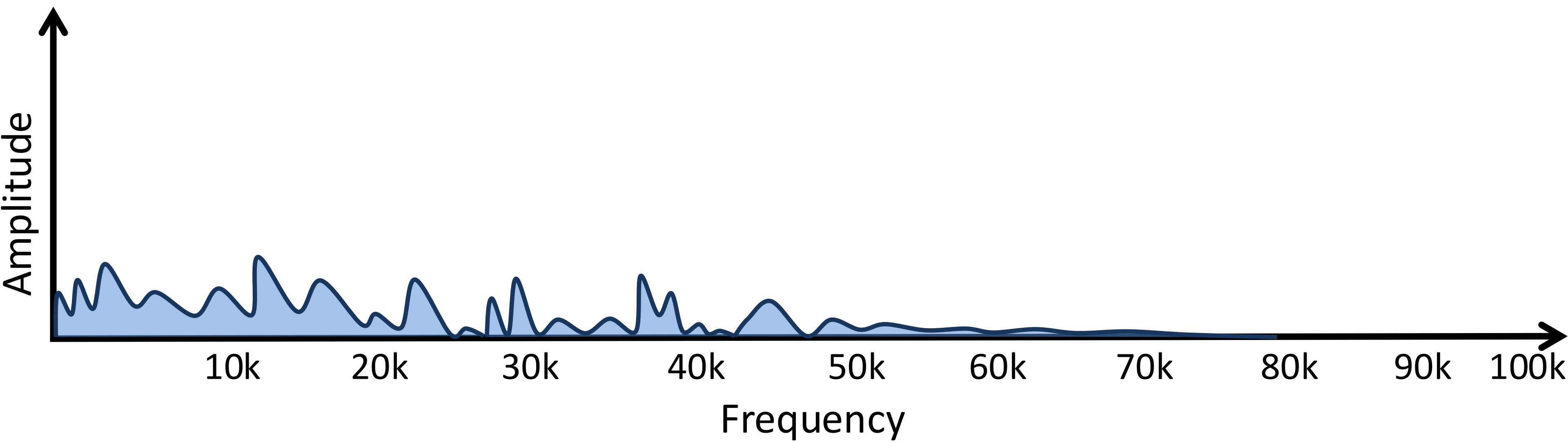

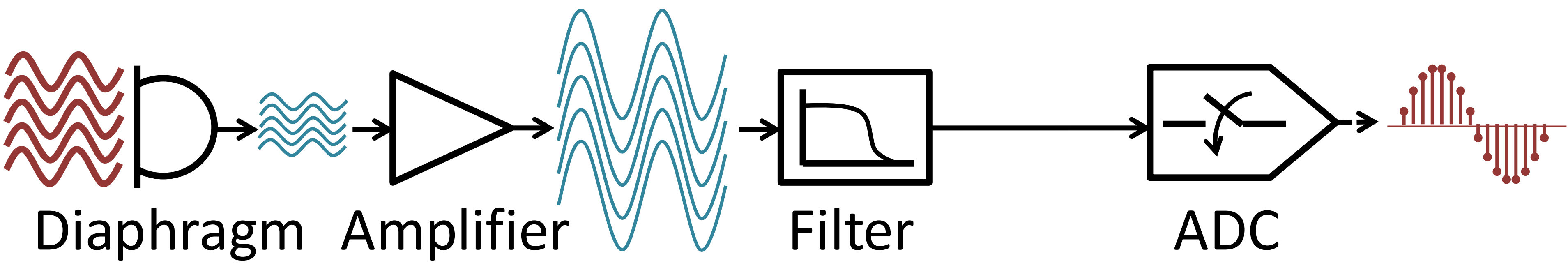

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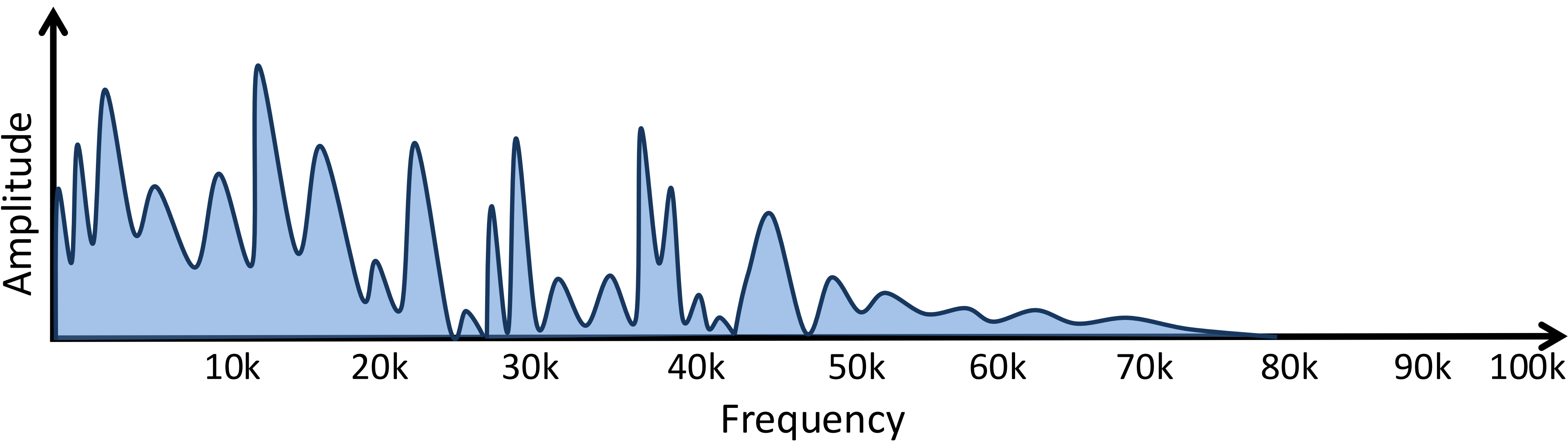

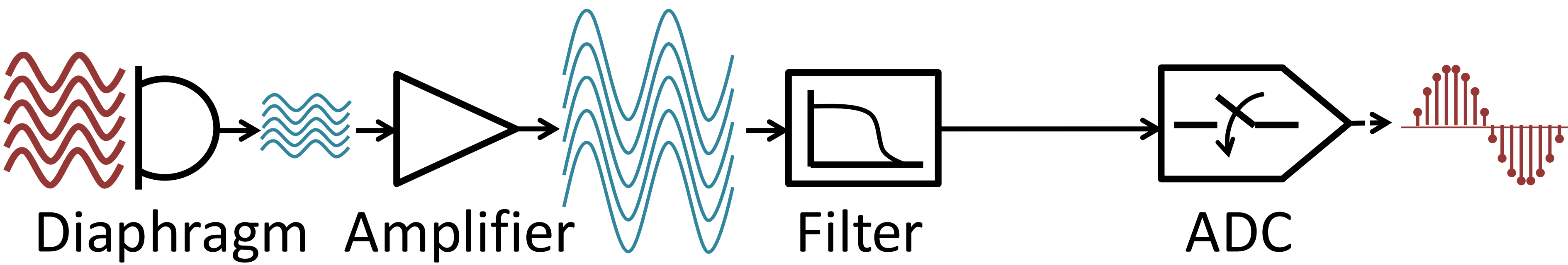

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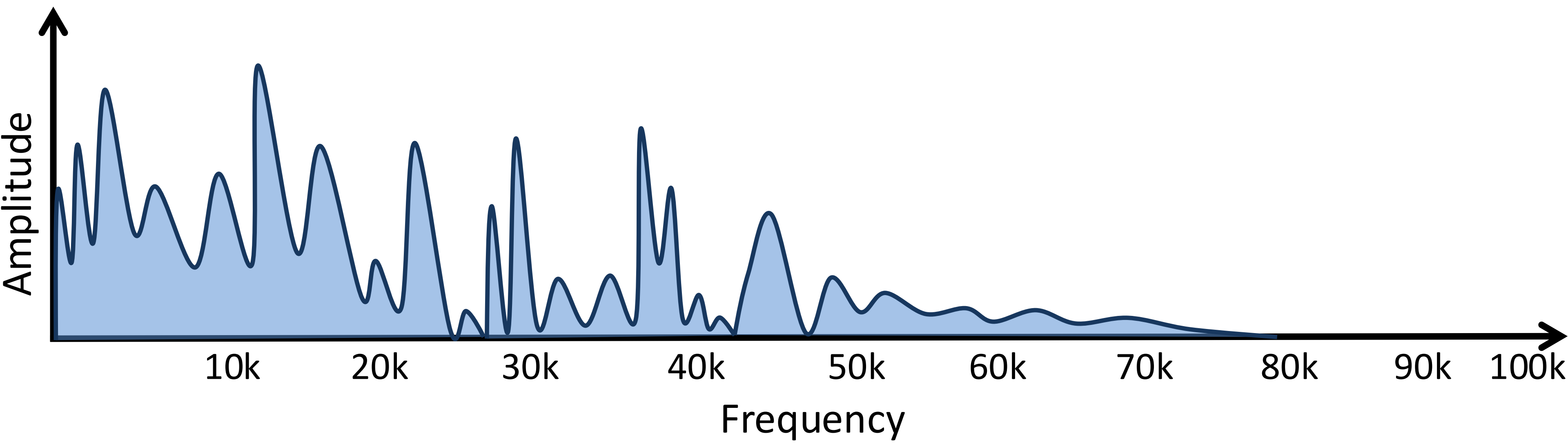

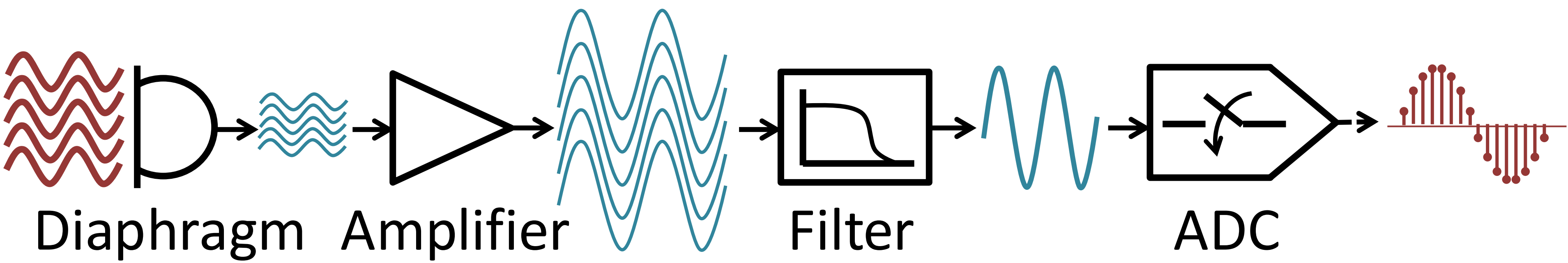

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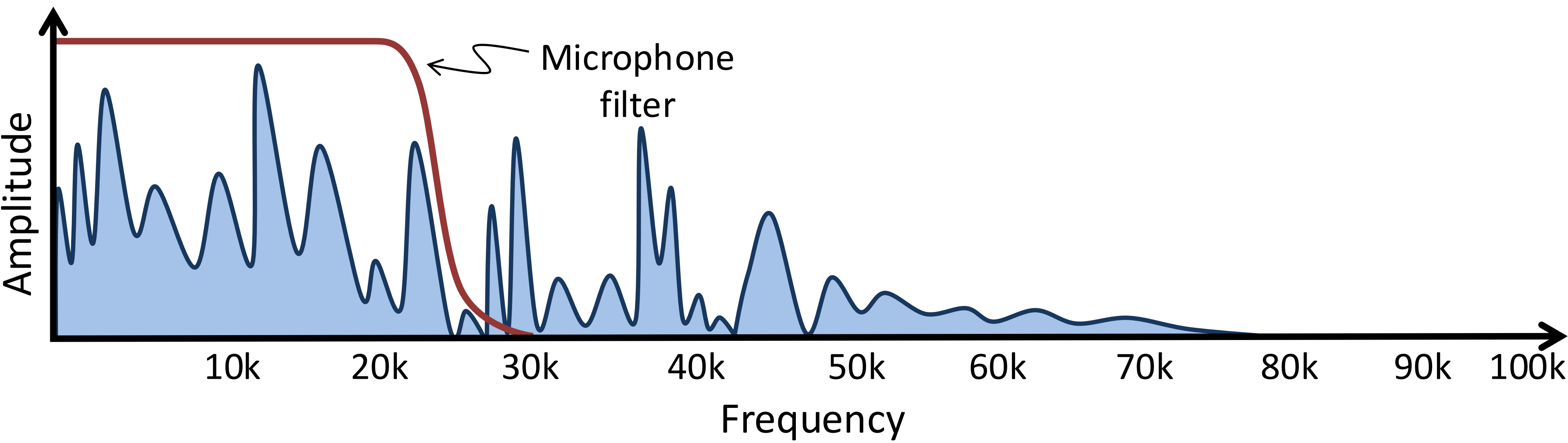

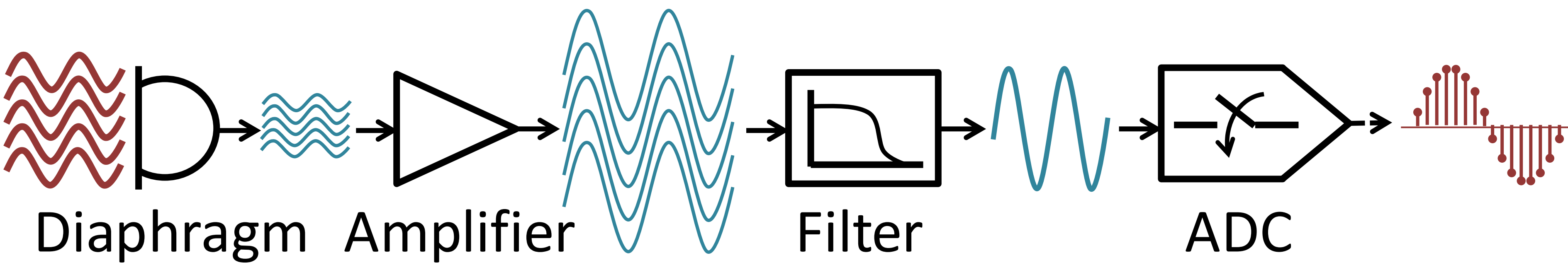

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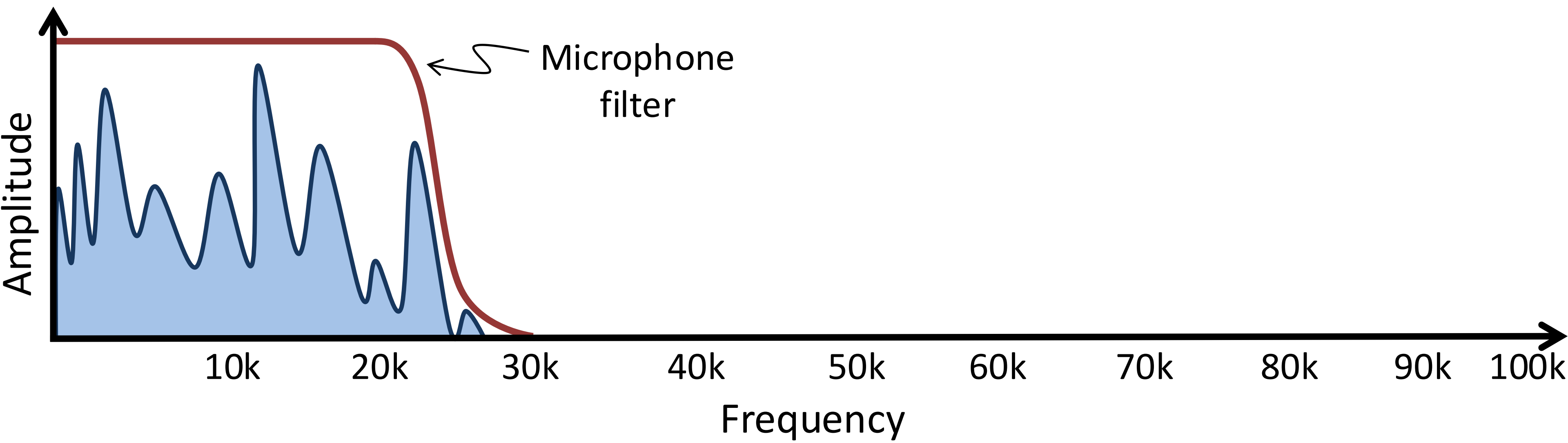

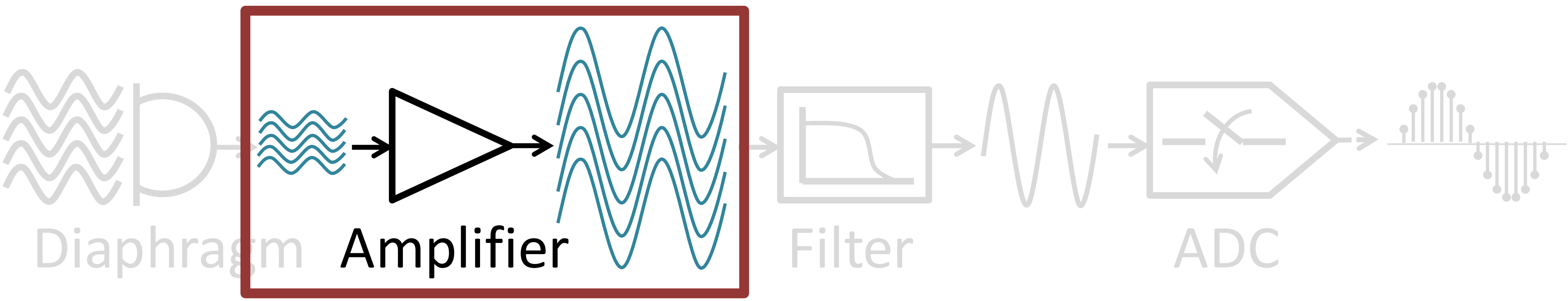

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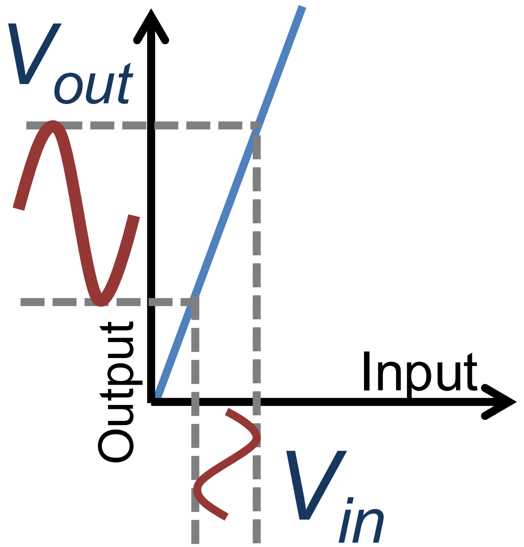
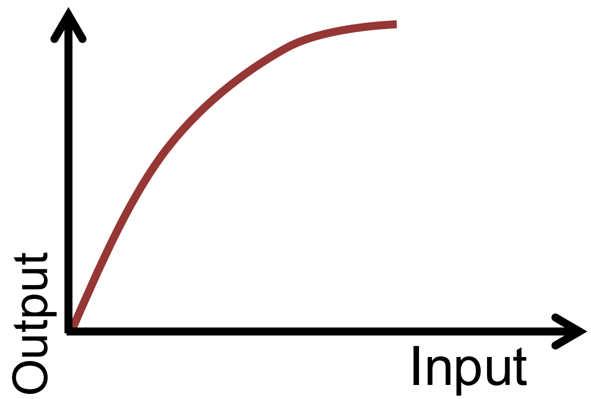
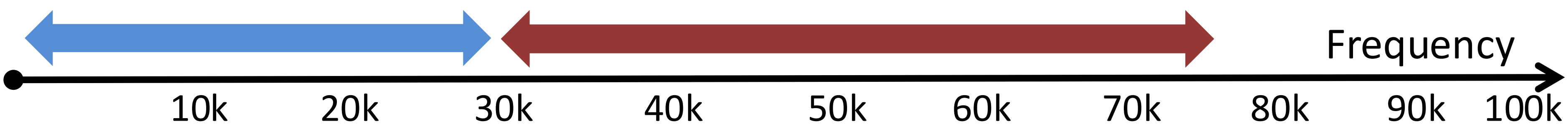
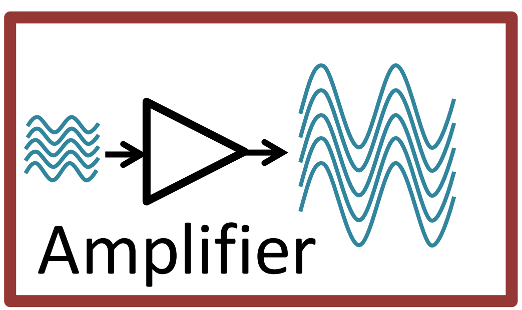




$$V_{out} = a_1 V_{in}$$

$$V_{out} = a_1 V_{in} + a_2 V_{in}^2 + a_3 V_{in}^3 + \ldots$$





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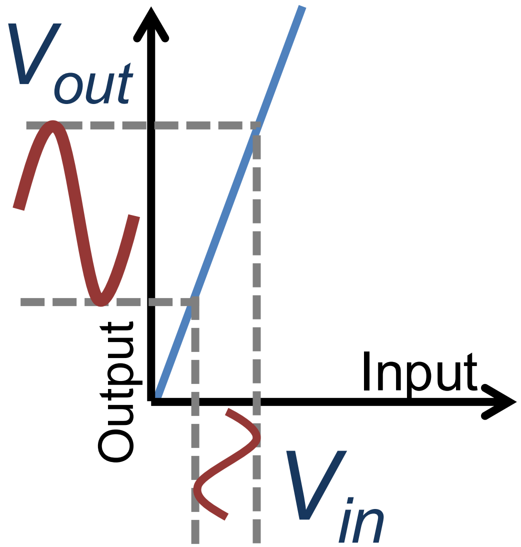

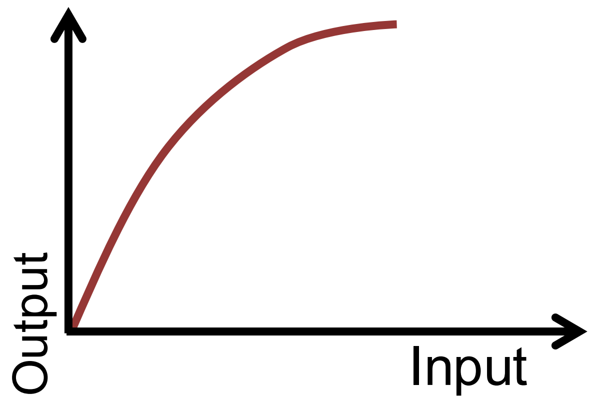

$$V_{out} = a_1 V_{in}$$

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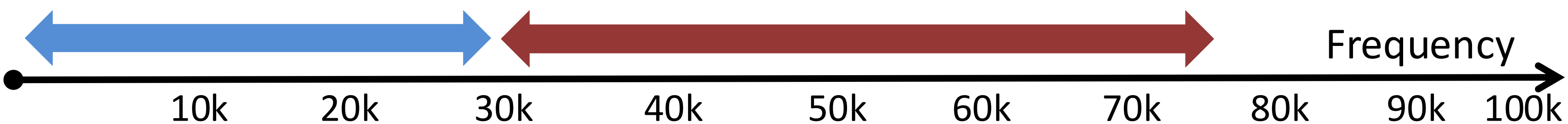

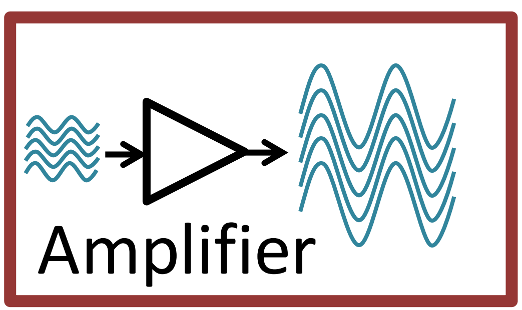

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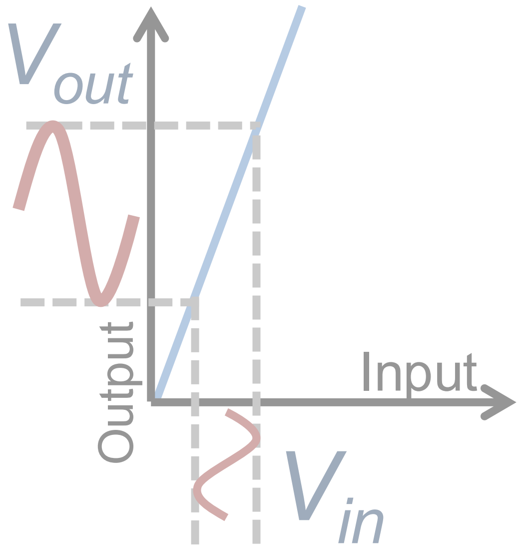

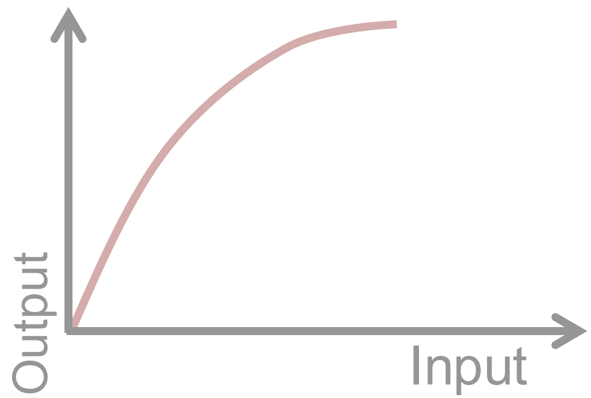

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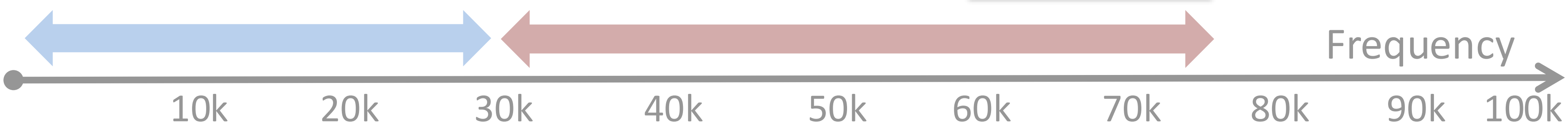

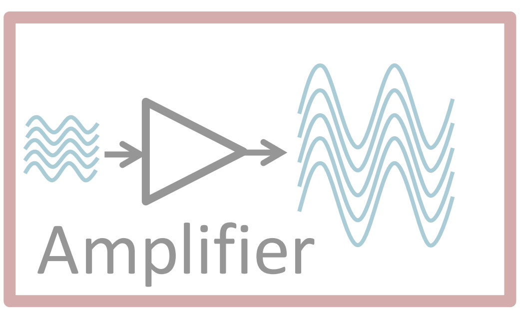

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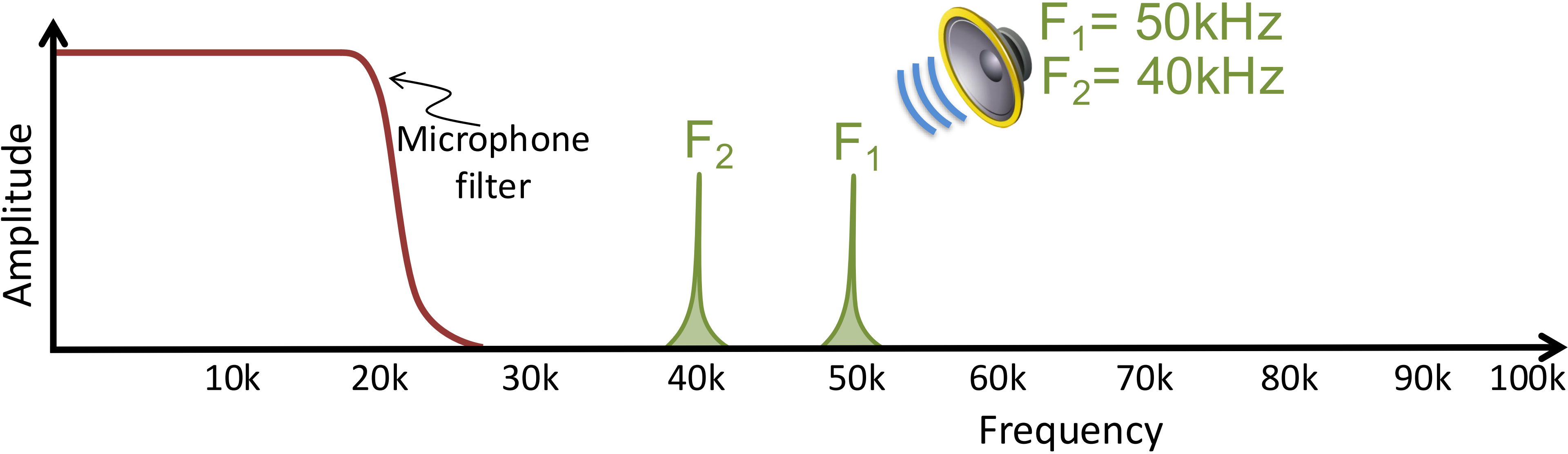
Exploiting amplifier non-linearity



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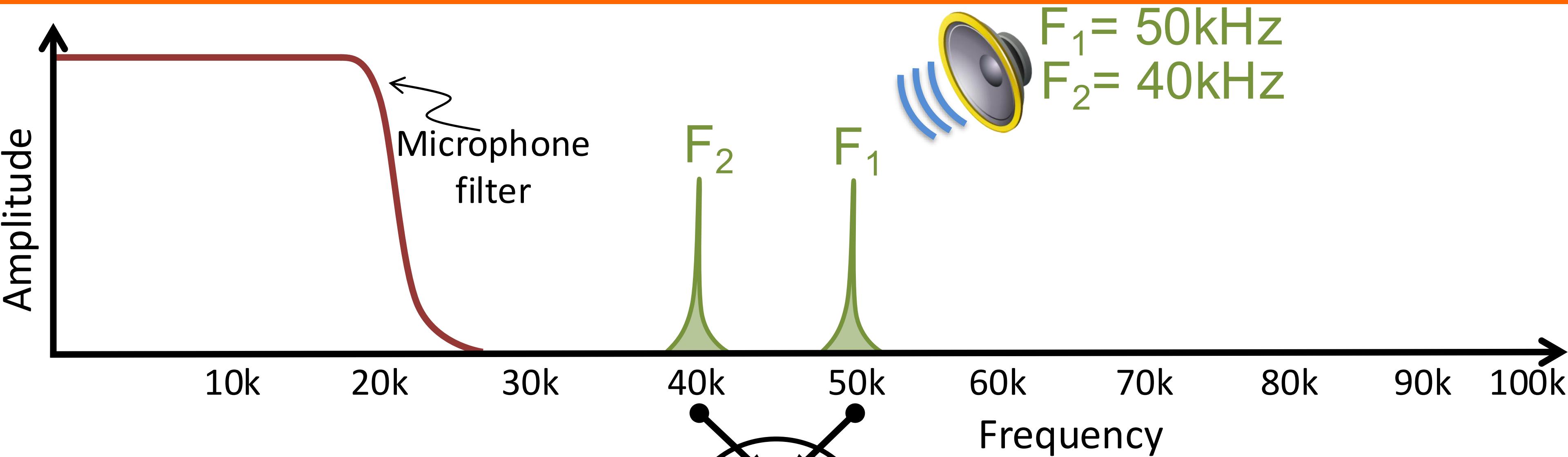

$$V_{out} = a_1 V_{in} + a_2 V_{in}^2$$

$$(\sin F_1 + \sin F_2)^2 = \cos 2F_1 + \cos 2F_2 + \cos (F_1+F_2) + \cos (F_1 - F_2)$$

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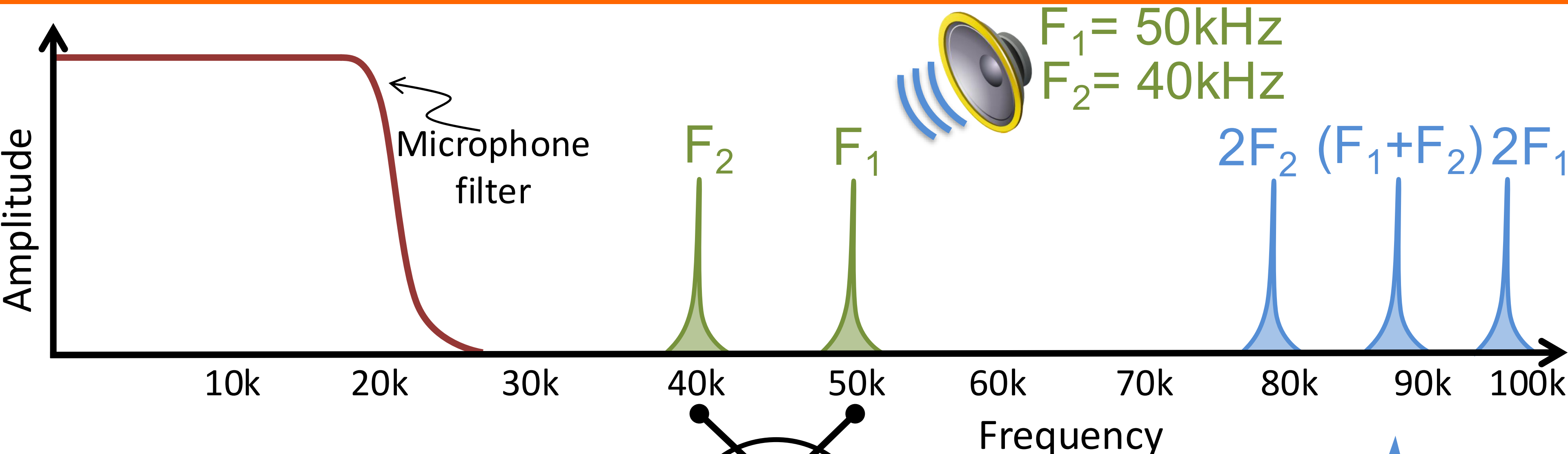

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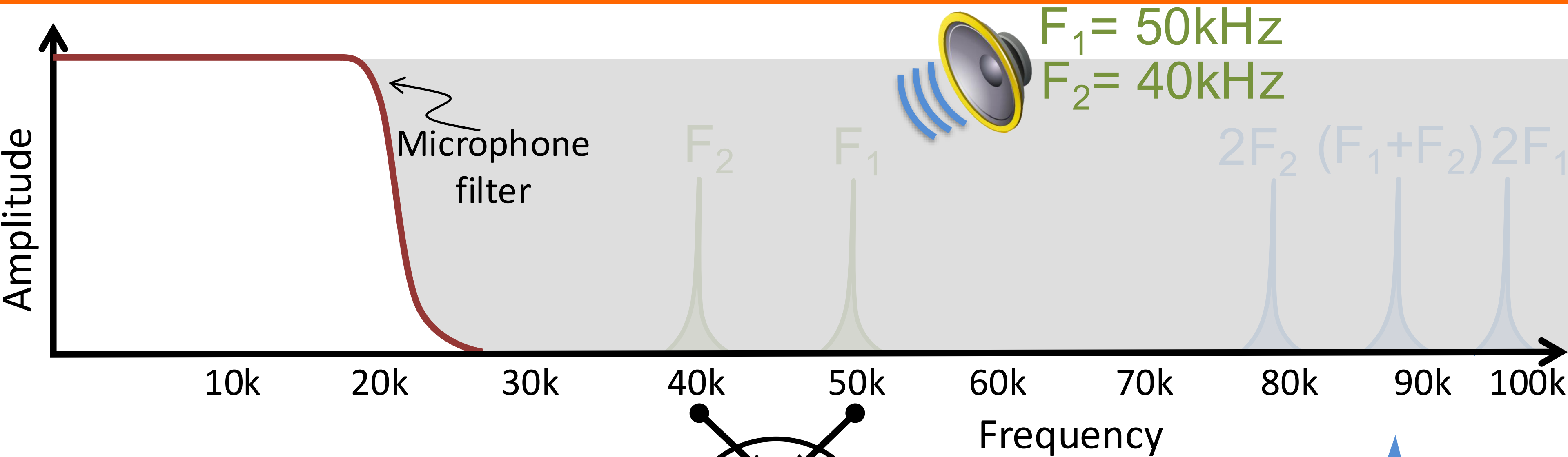

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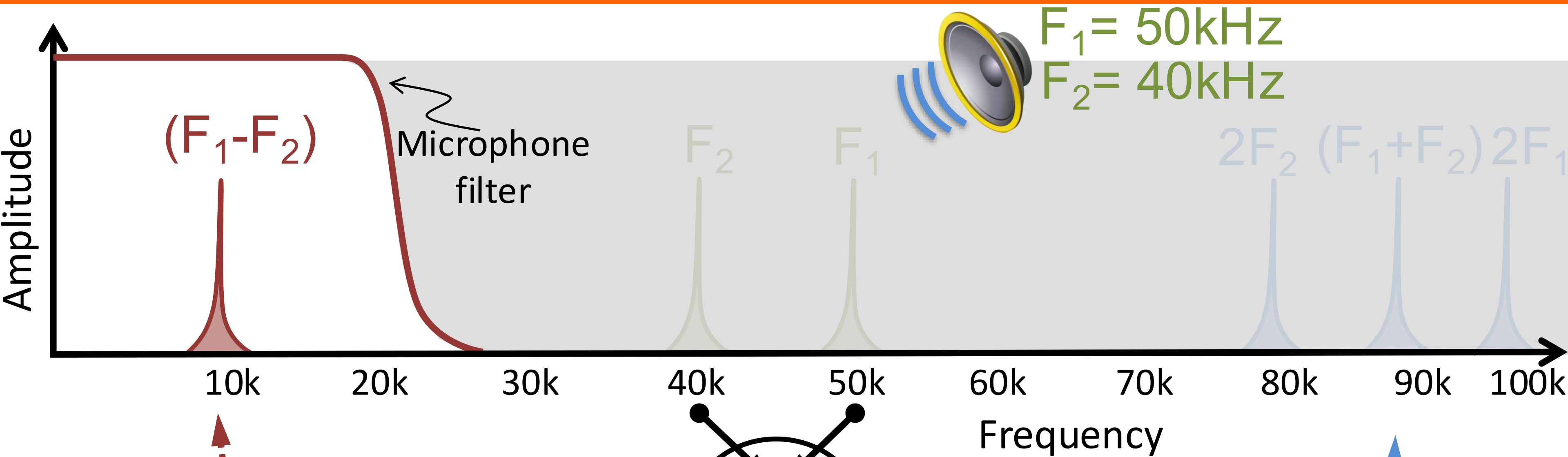

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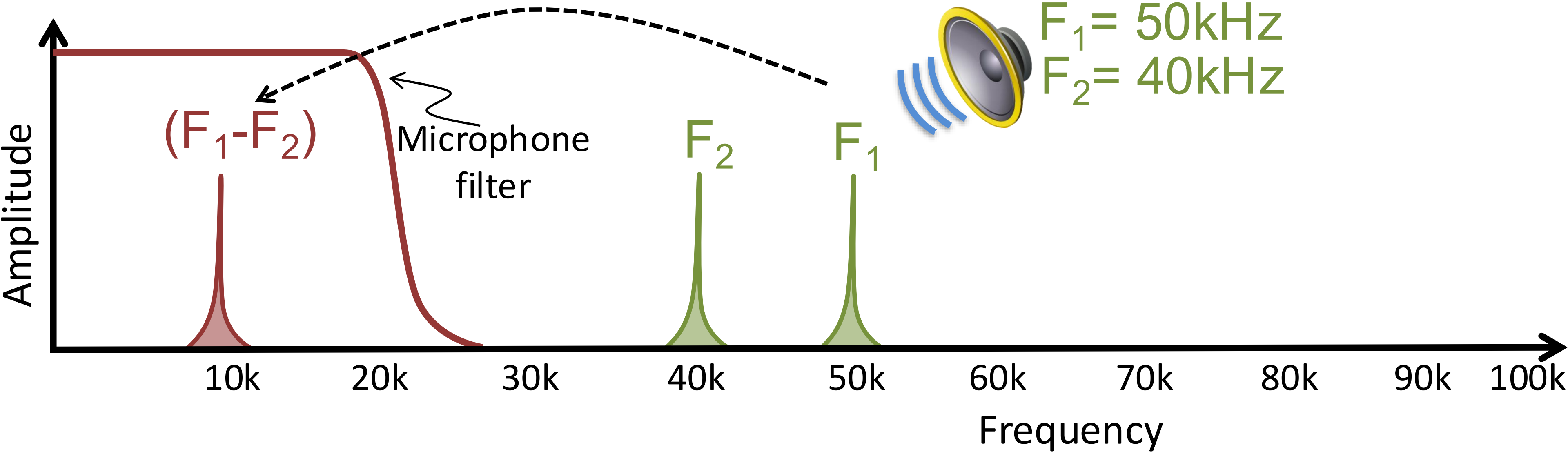

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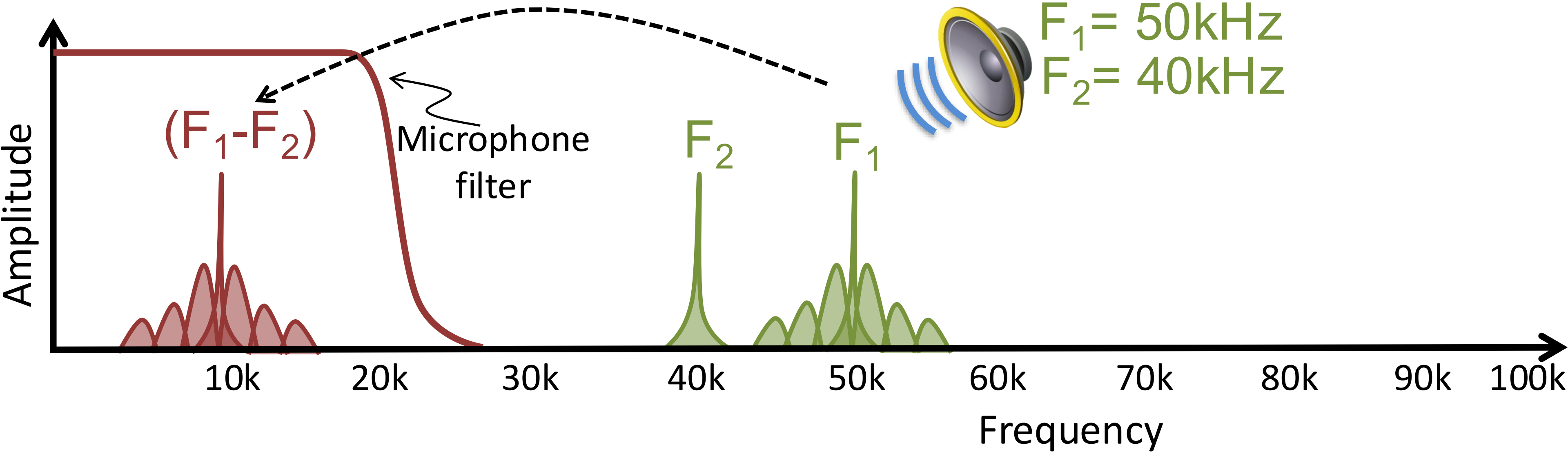

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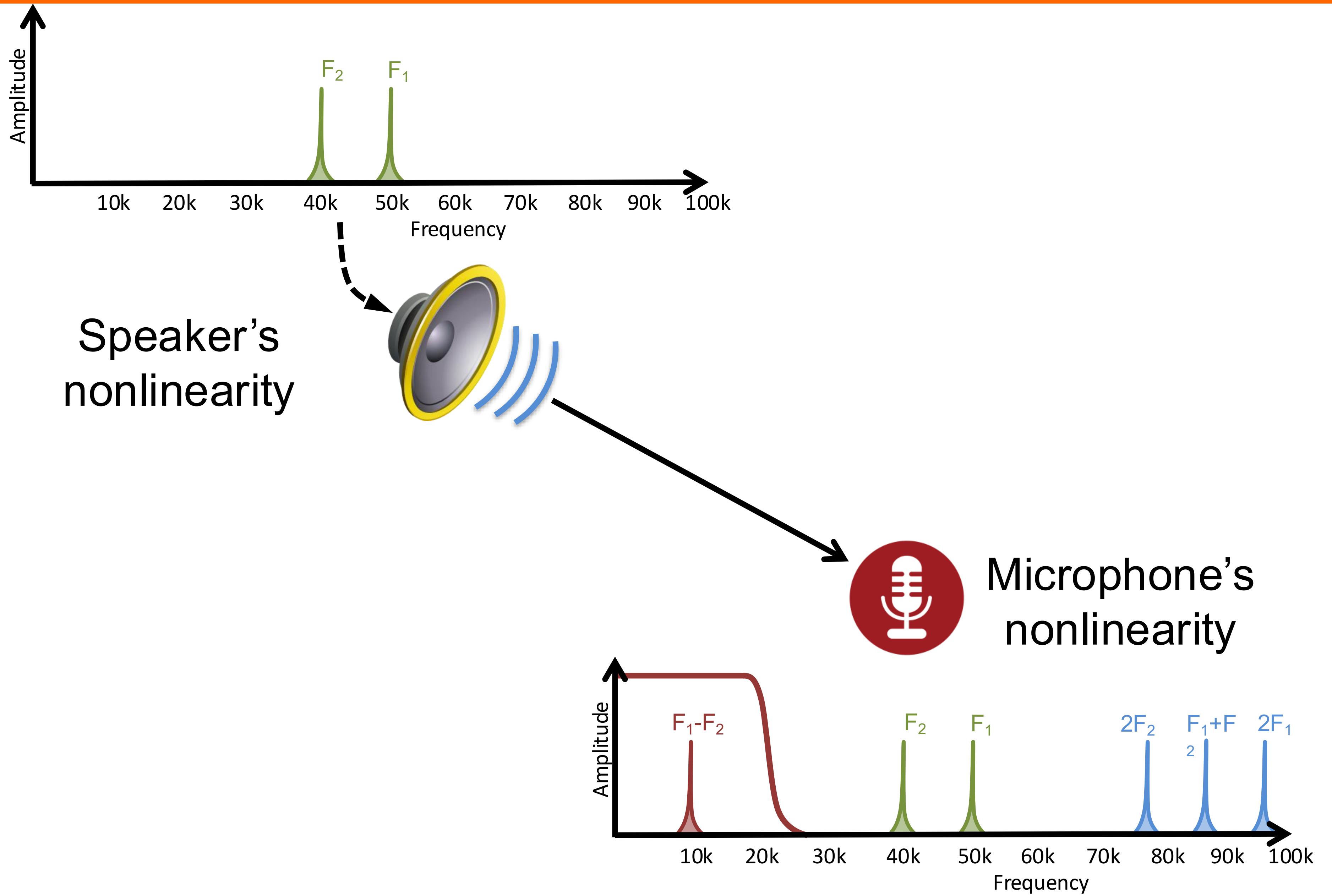
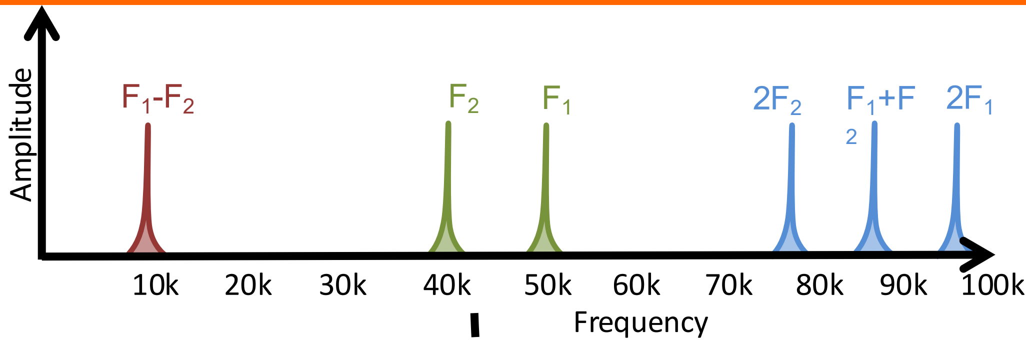
Challenges

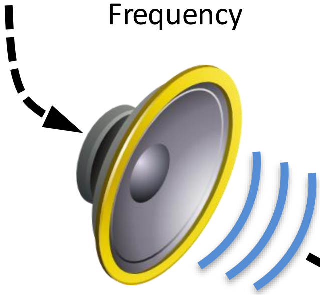


Amplitude
F2
F1
10k
20k
30k
40k
50k
60k
70k
80k
90k
100k
Frequency
Speaker's nonlinearity
Microphone's nonlinearity
Amplitude
F1-F2
F2
F1
2F2
F1+F2
2F1
10k
20k
30k
40k
50k
60k
70k
80k
90k
100k
Frequency

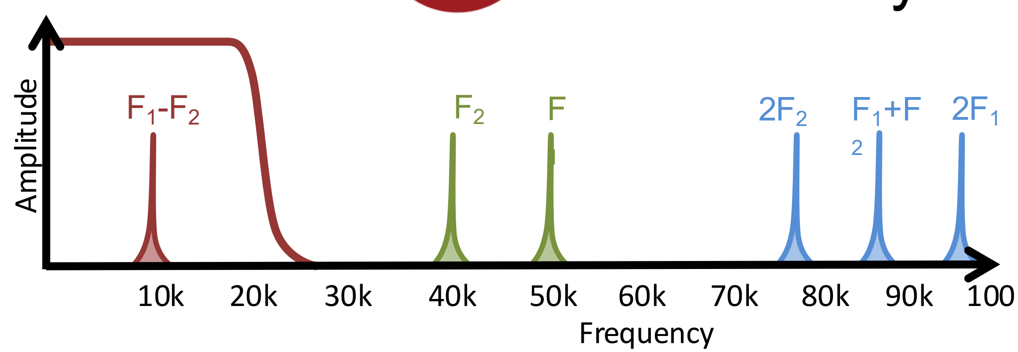
Challenges



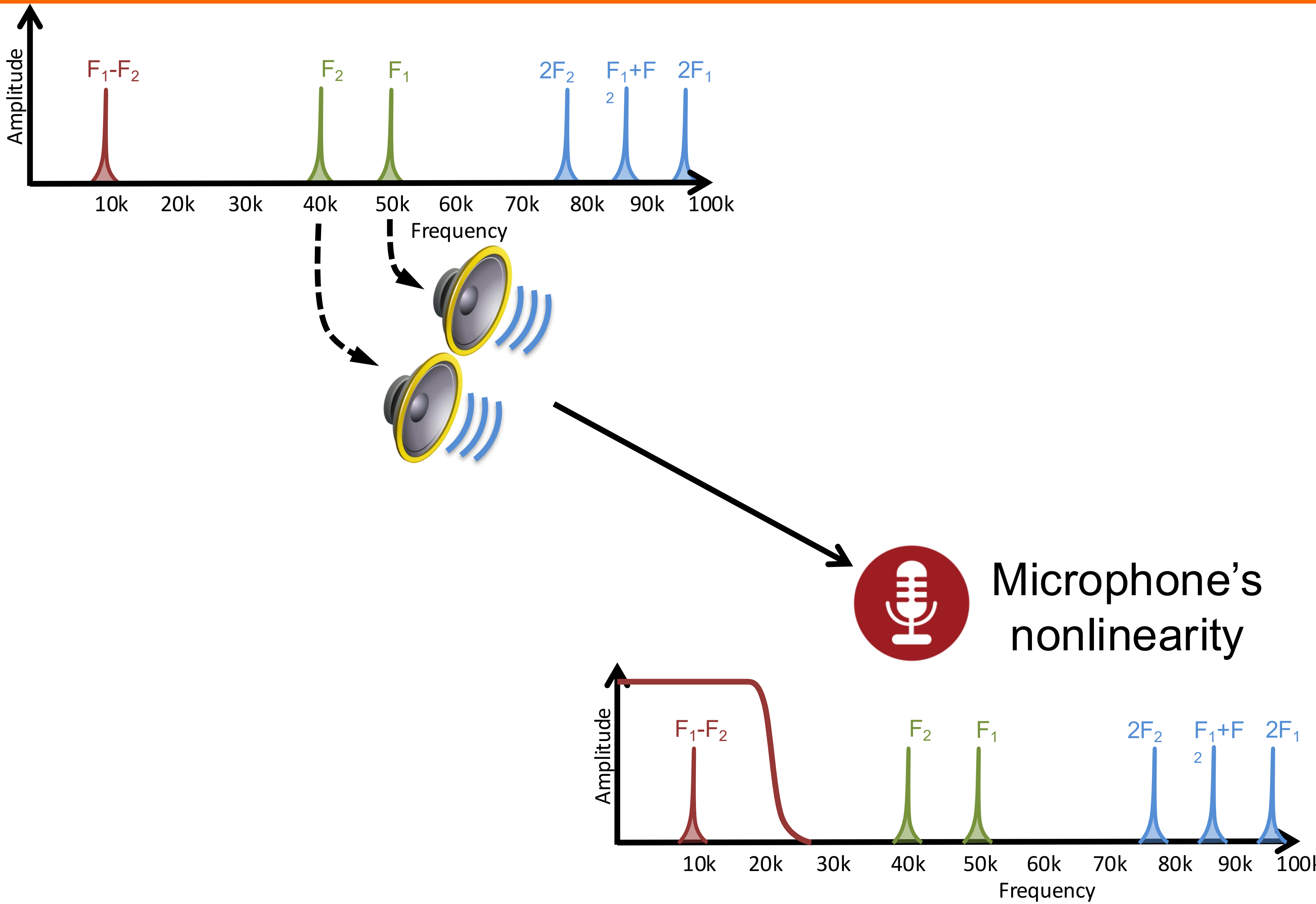
Speaker's nonlinearity



Microphone's nonlinearity



Challenges


Amplitude
F1-F2
F2
F1
2F2
F1+F2
2F1
10k
20k
30k
40k
50k
60k
70k
80k
90k
100k
Frequency
Microphone's nonlinearity
Amplitude
F1-F2
F2
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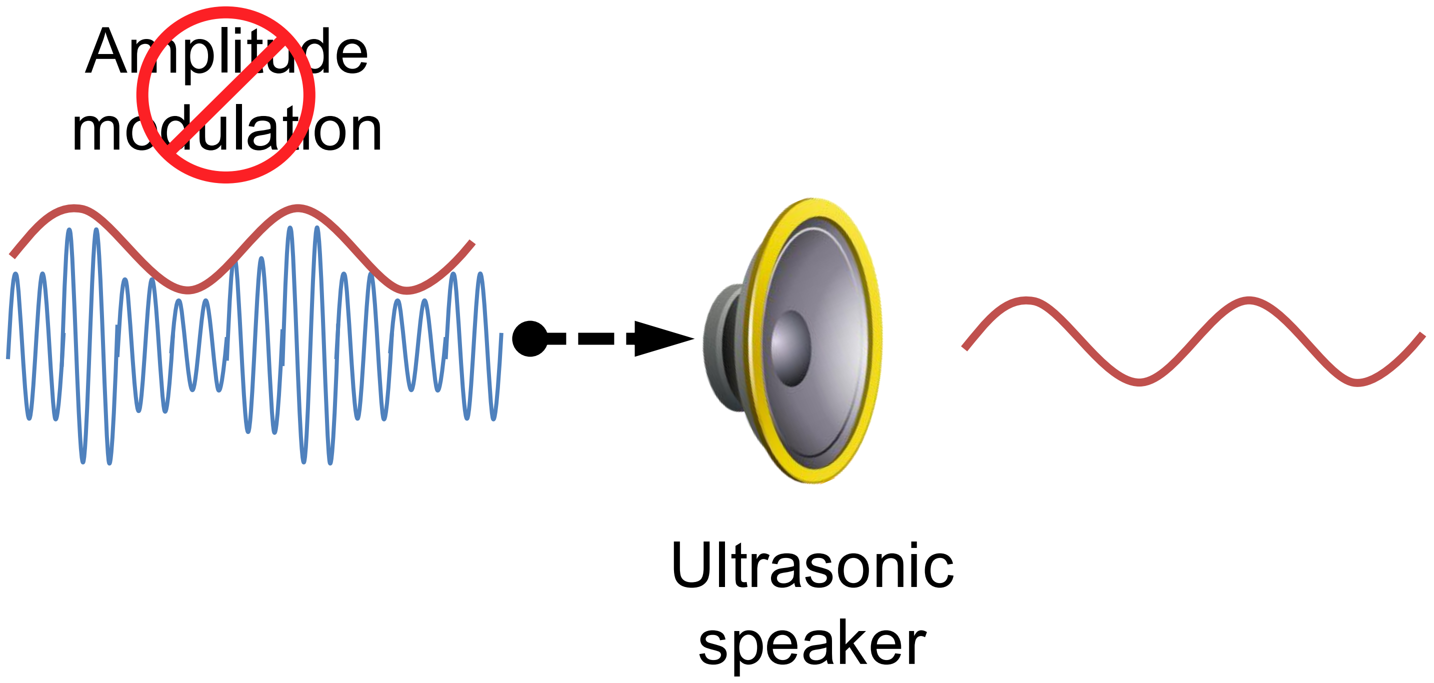
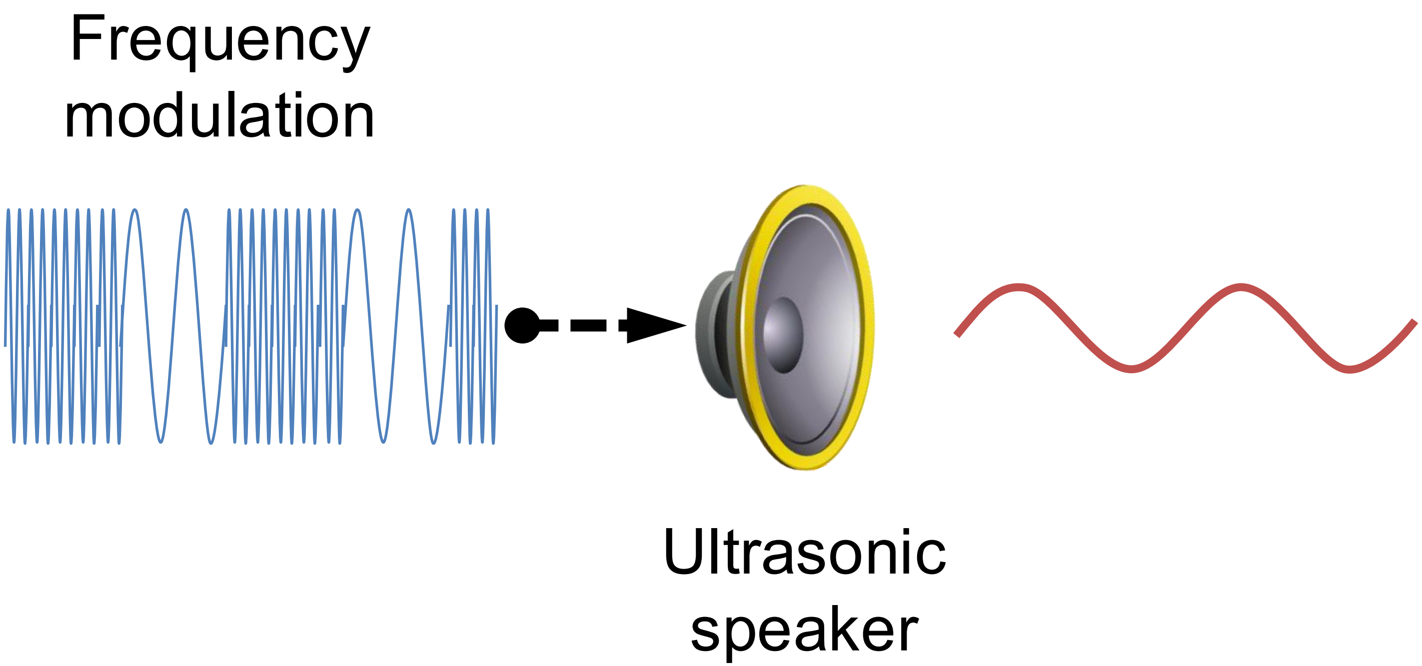
Challenges



Challenges



Challenges

- Signal self-demodulation
- Piezoelectric ringing effect
- Carrier intermixing
- Spectrum inversion
- Carrier power allocation

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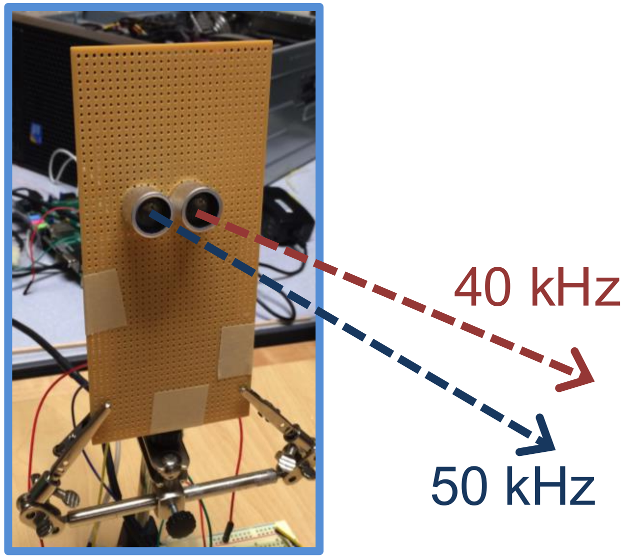
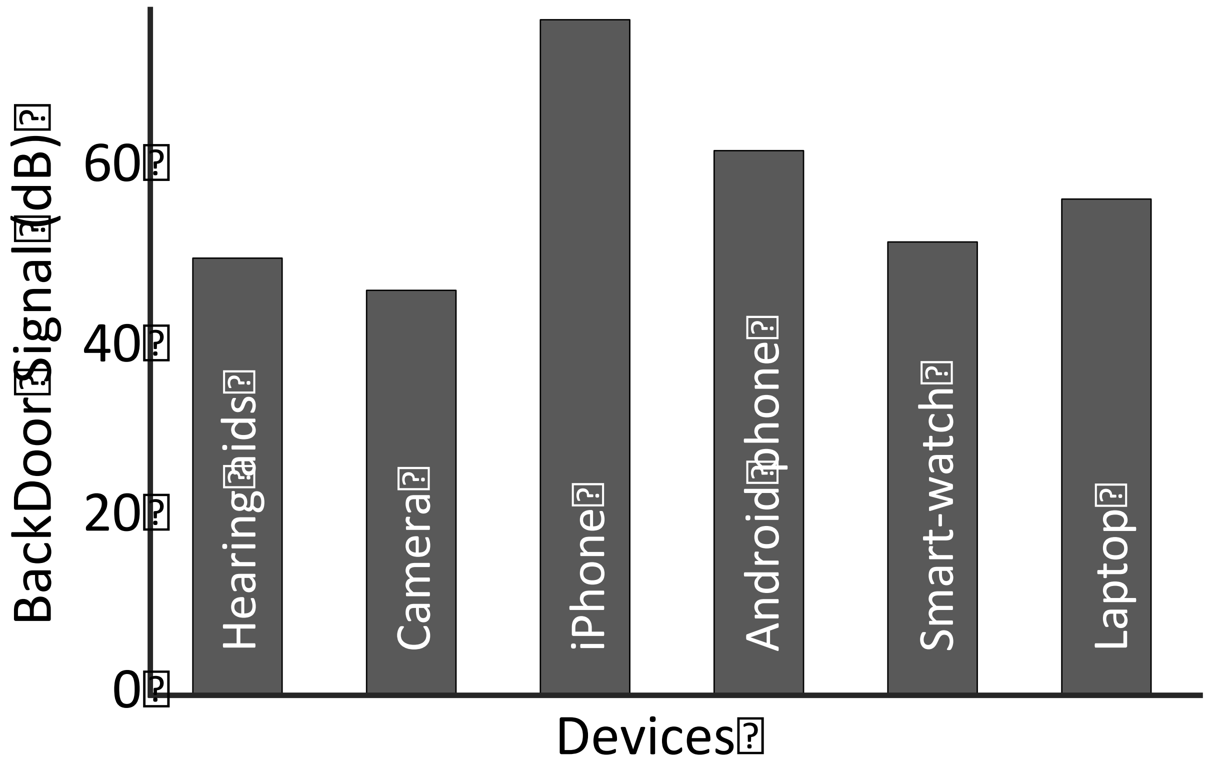
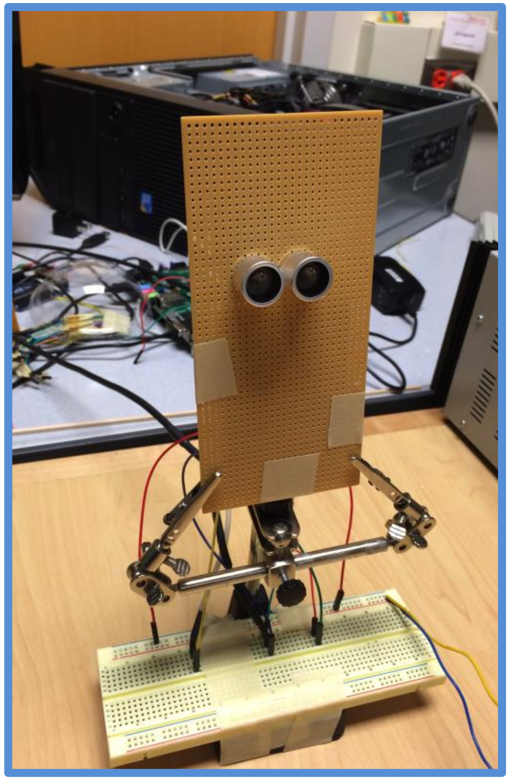
Hardware generalizability



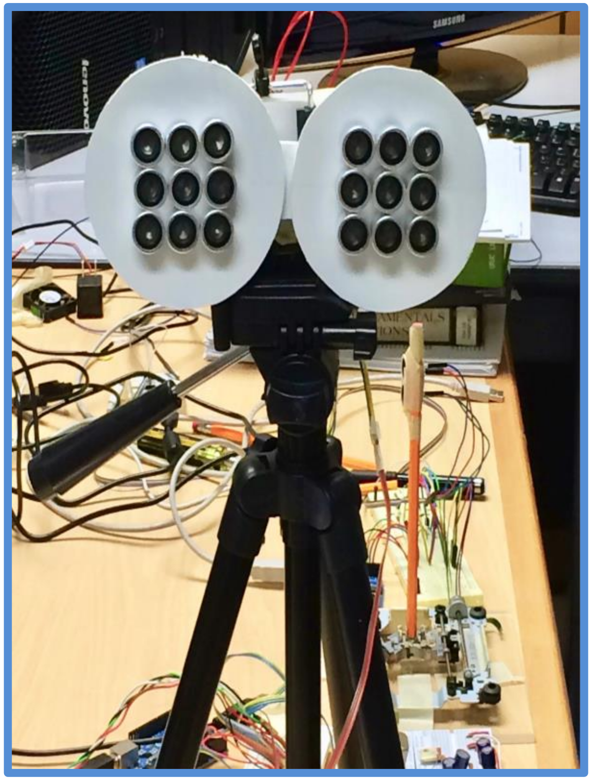


Hearing Aid | Camera | iPhone | Android phone | Smartwatch | Laptop

Implementation

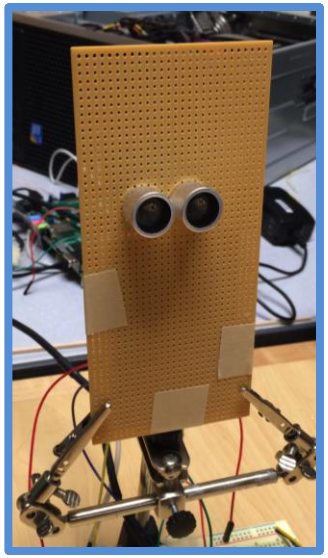


Communication prototype



Jammer prototype

Communication performance

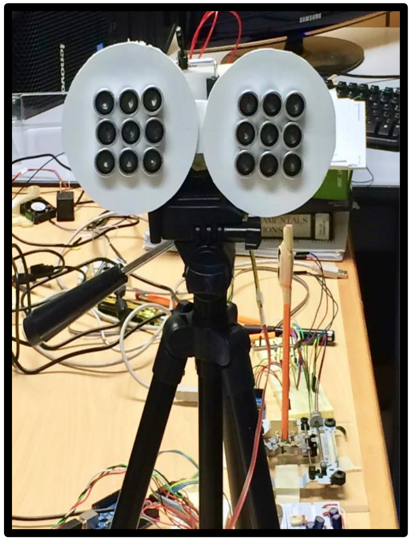


FM data packets

4kbps
up to 1 meter

More power can increase the distance

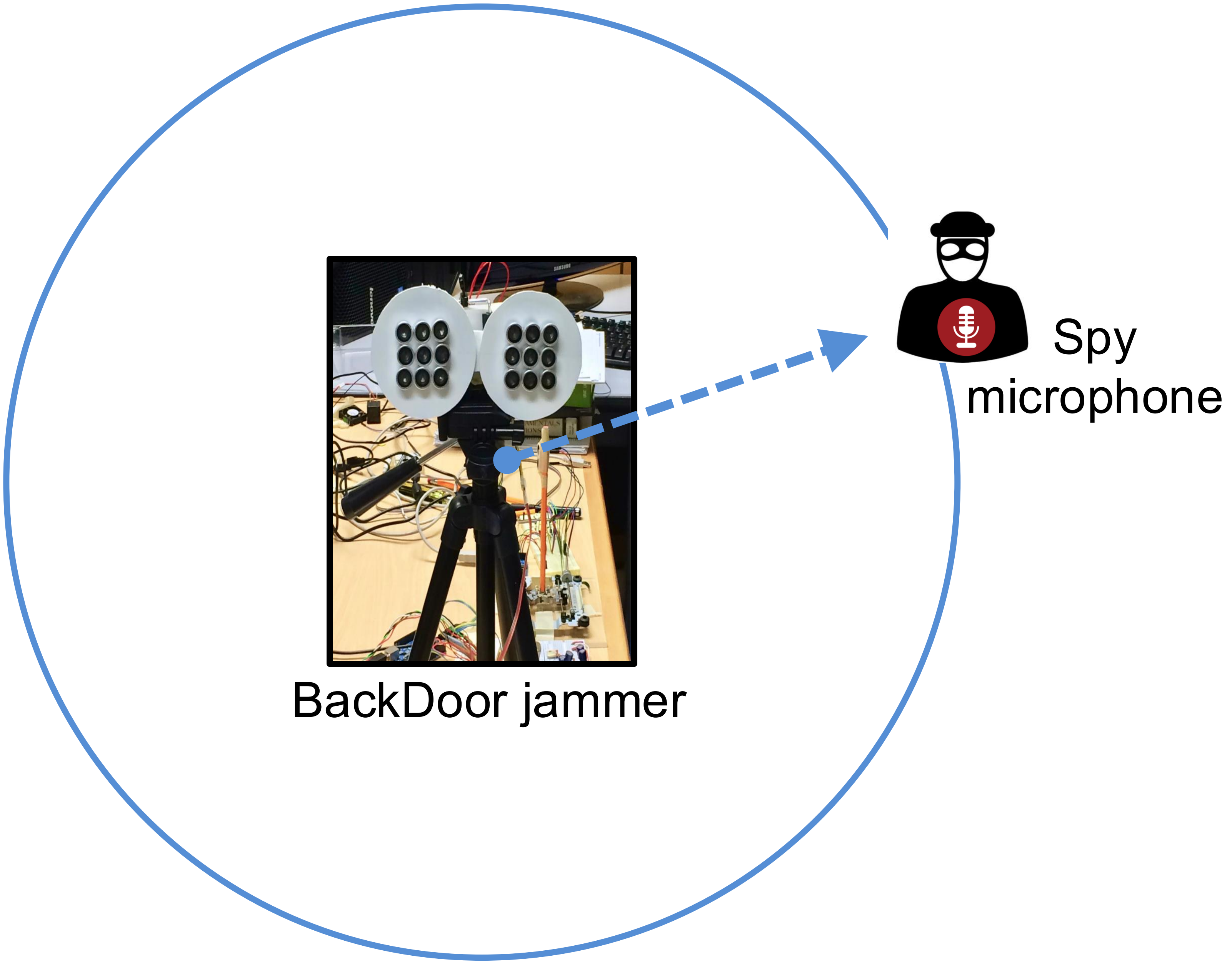
Jamming performance



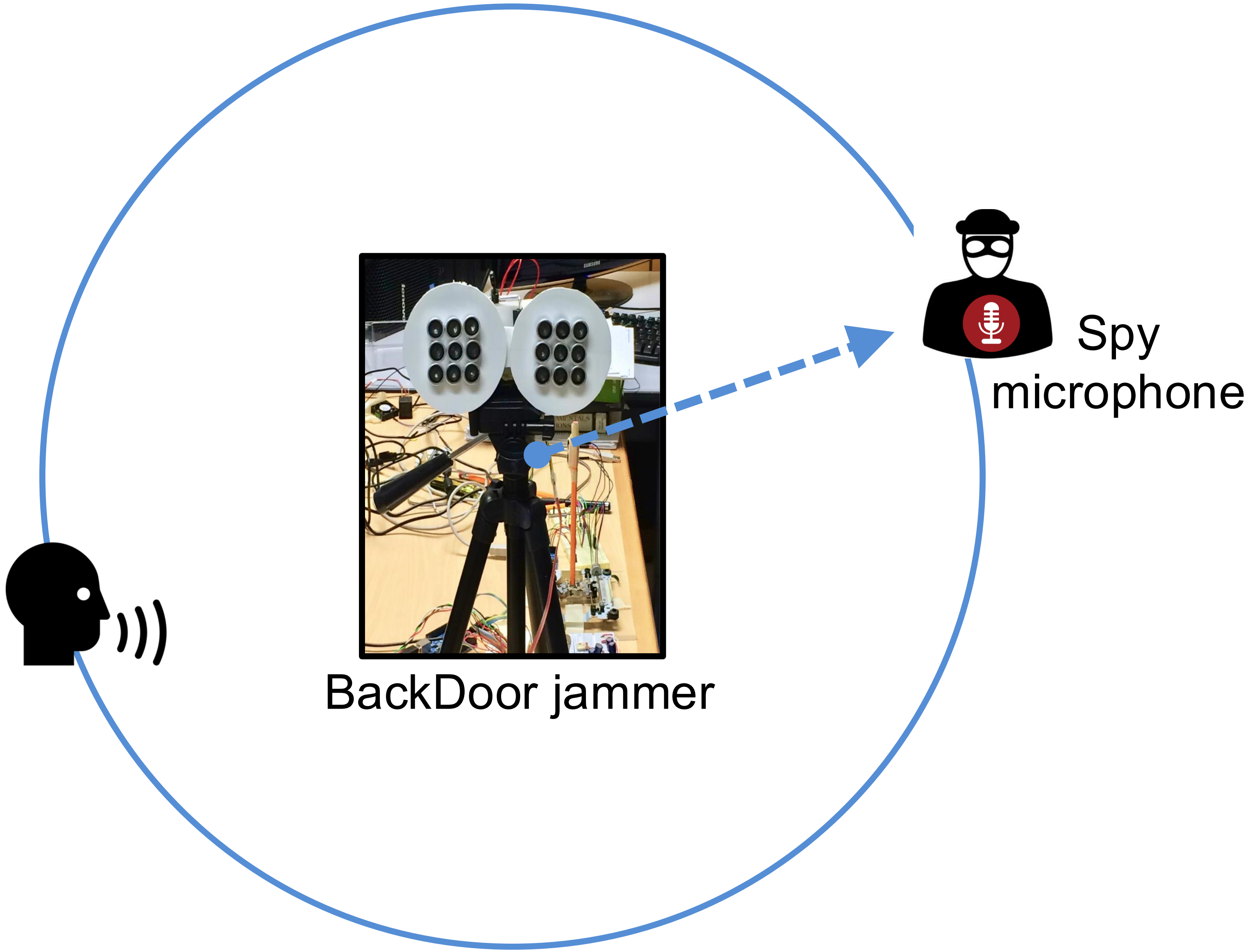
BackDoor jammer

Spy microphone

Jamming performance



Jamming performance



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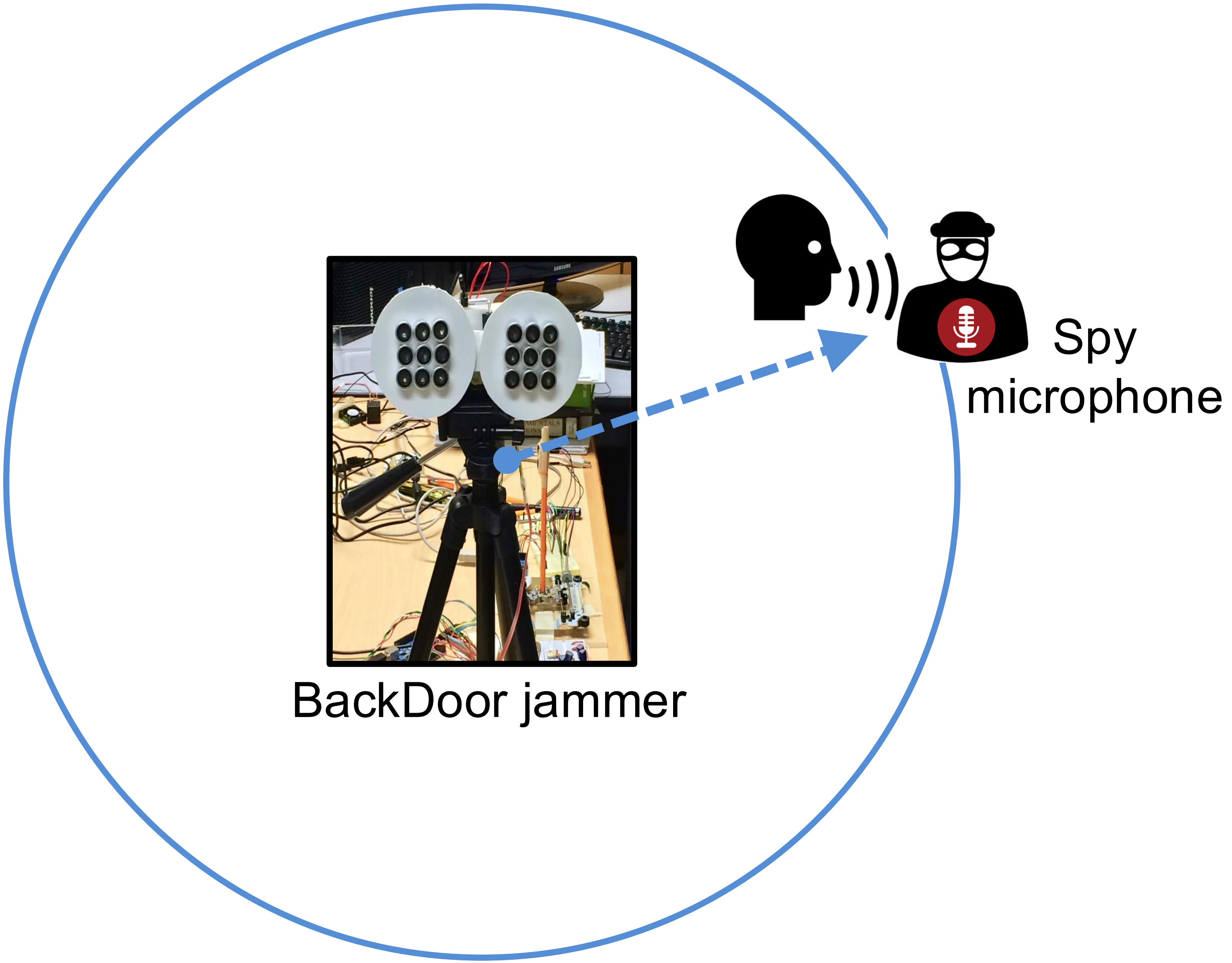
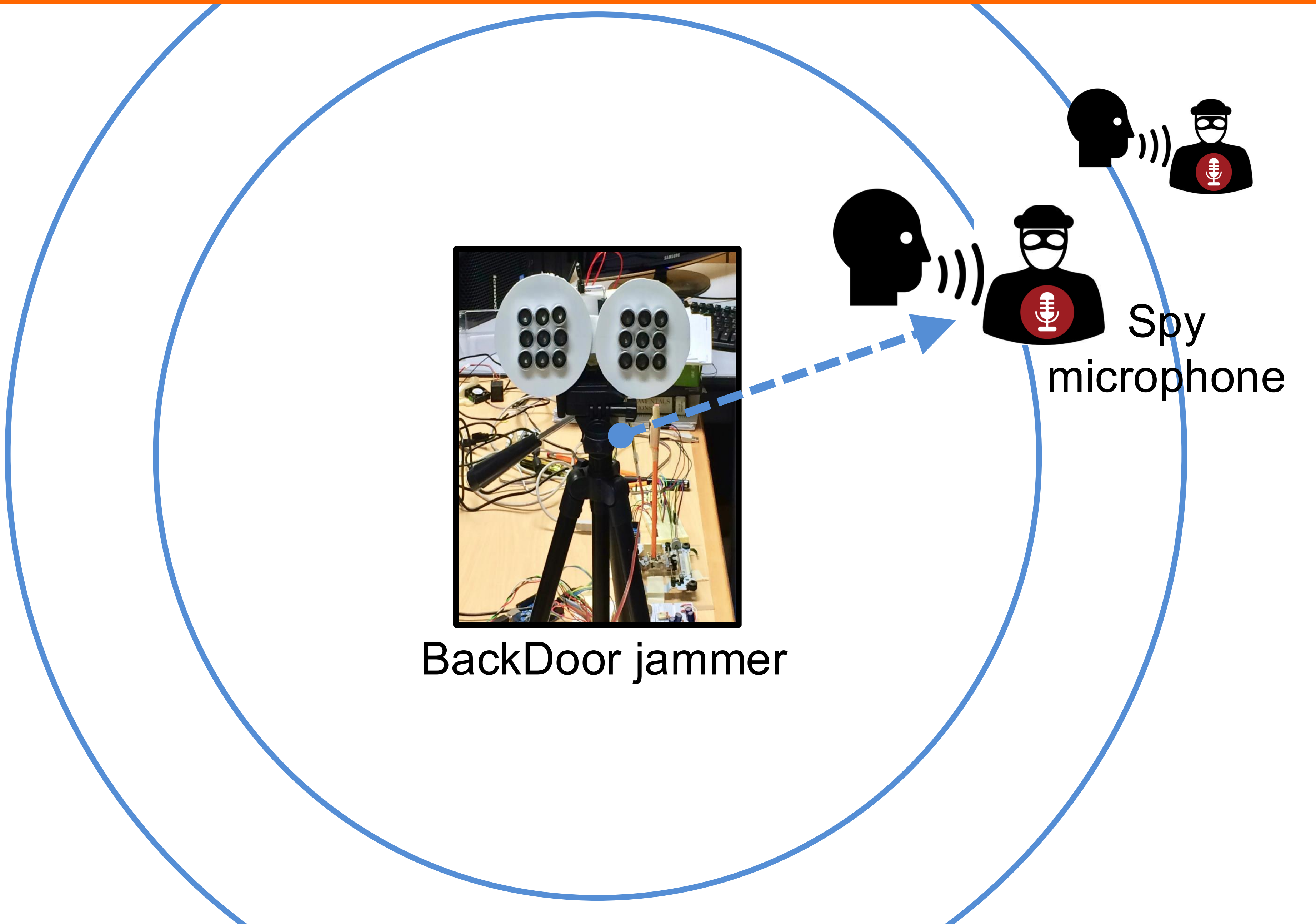
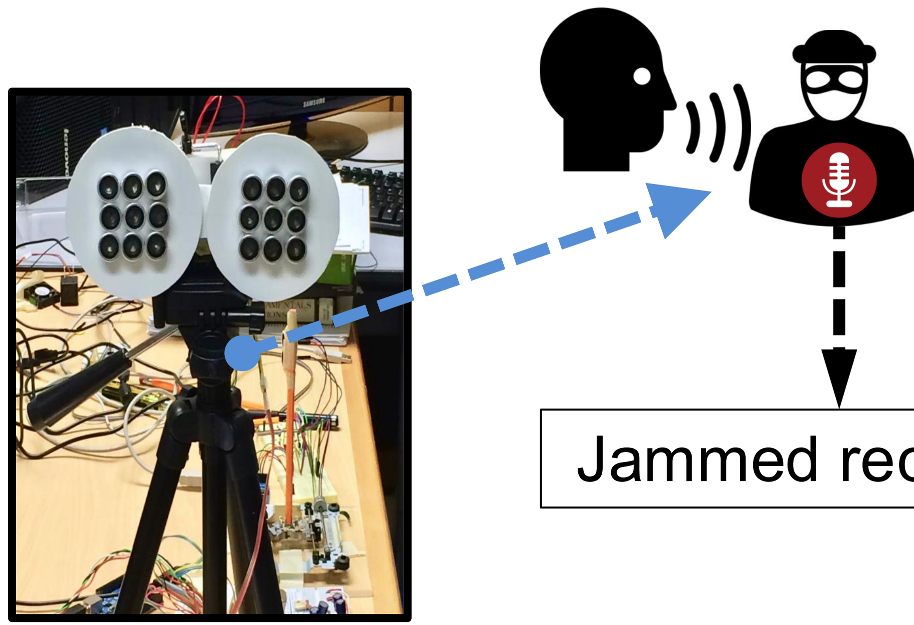


Jamming performance



Jamming performance

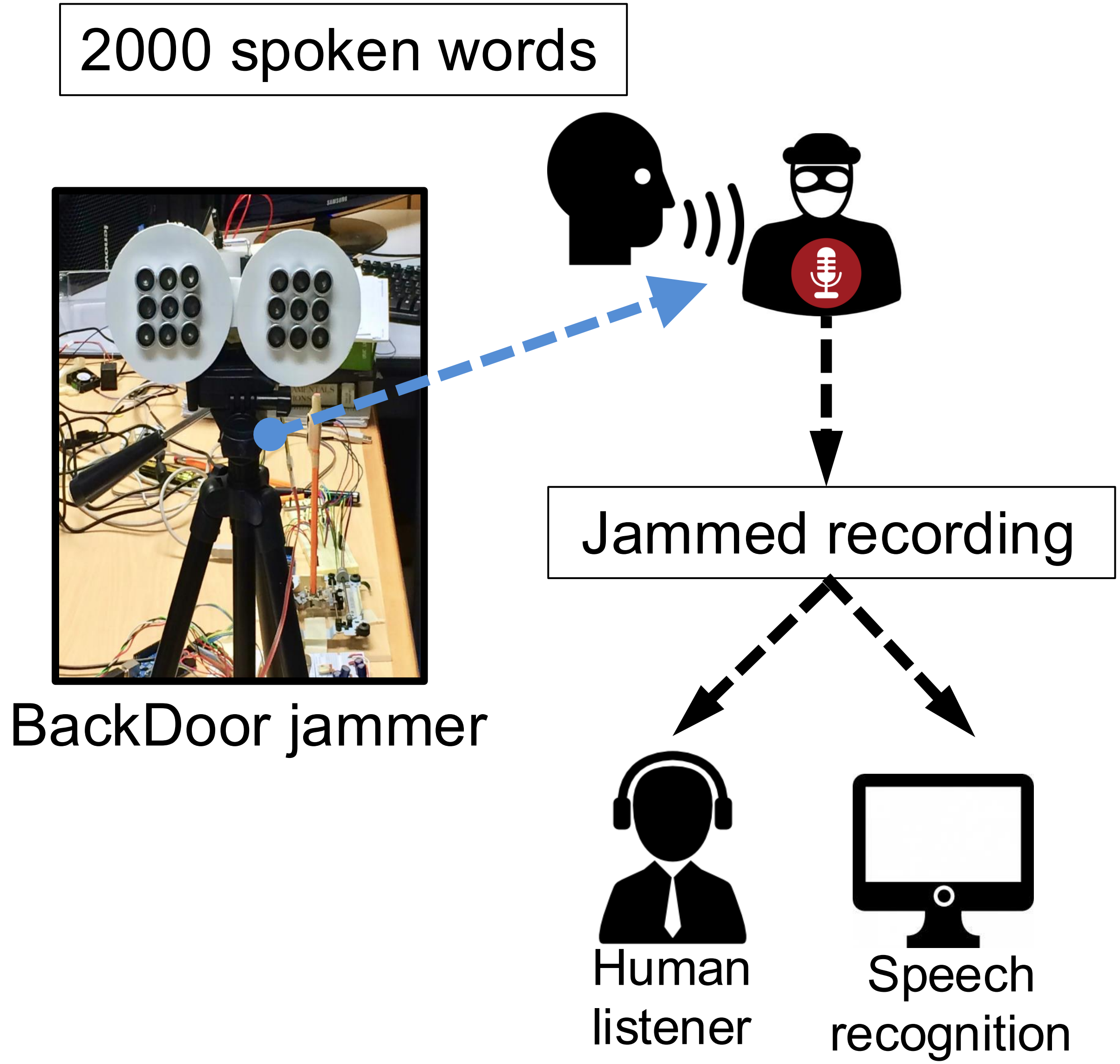
2000 spoken words



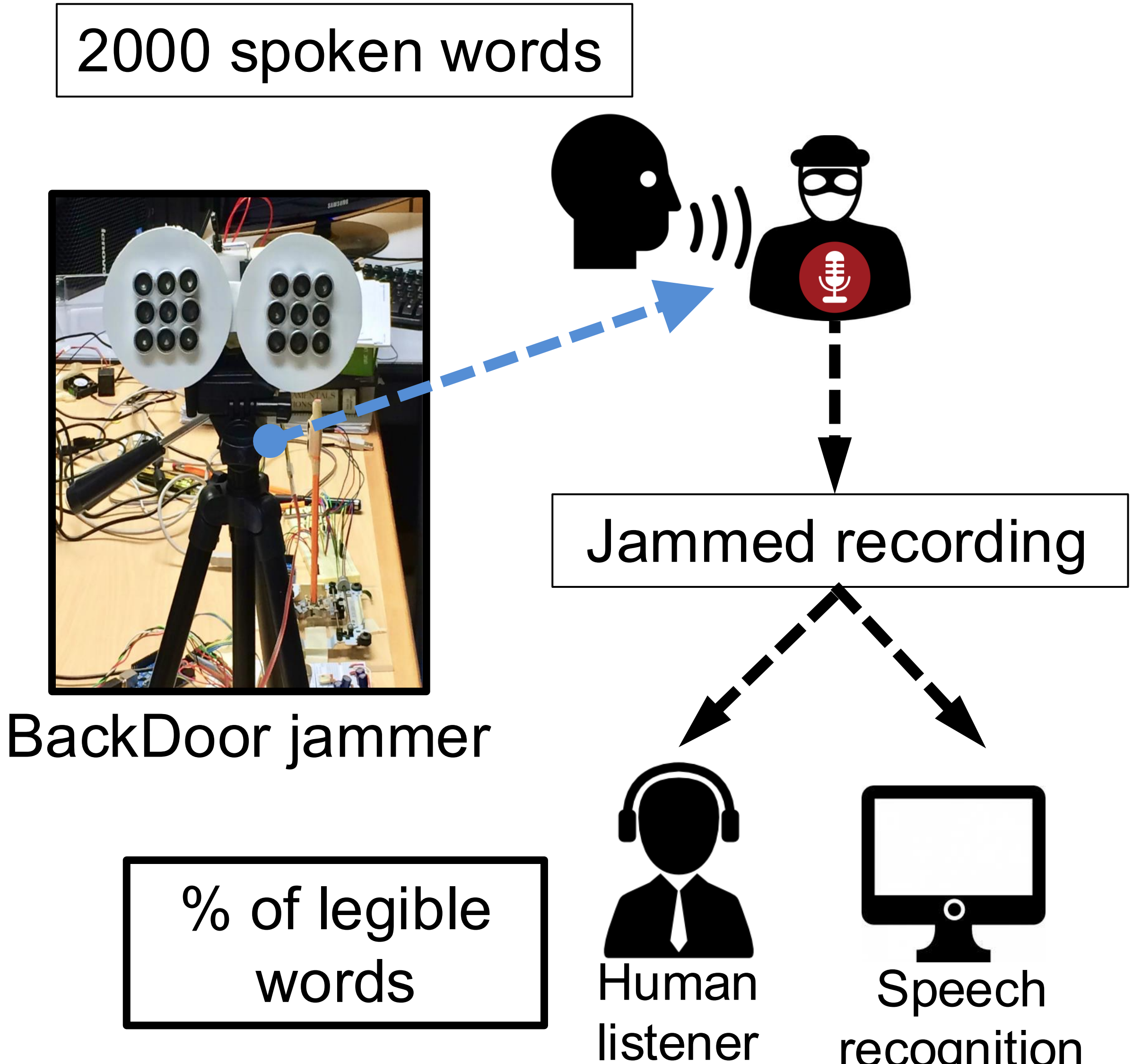
BackDoor jammer

Jammed recording

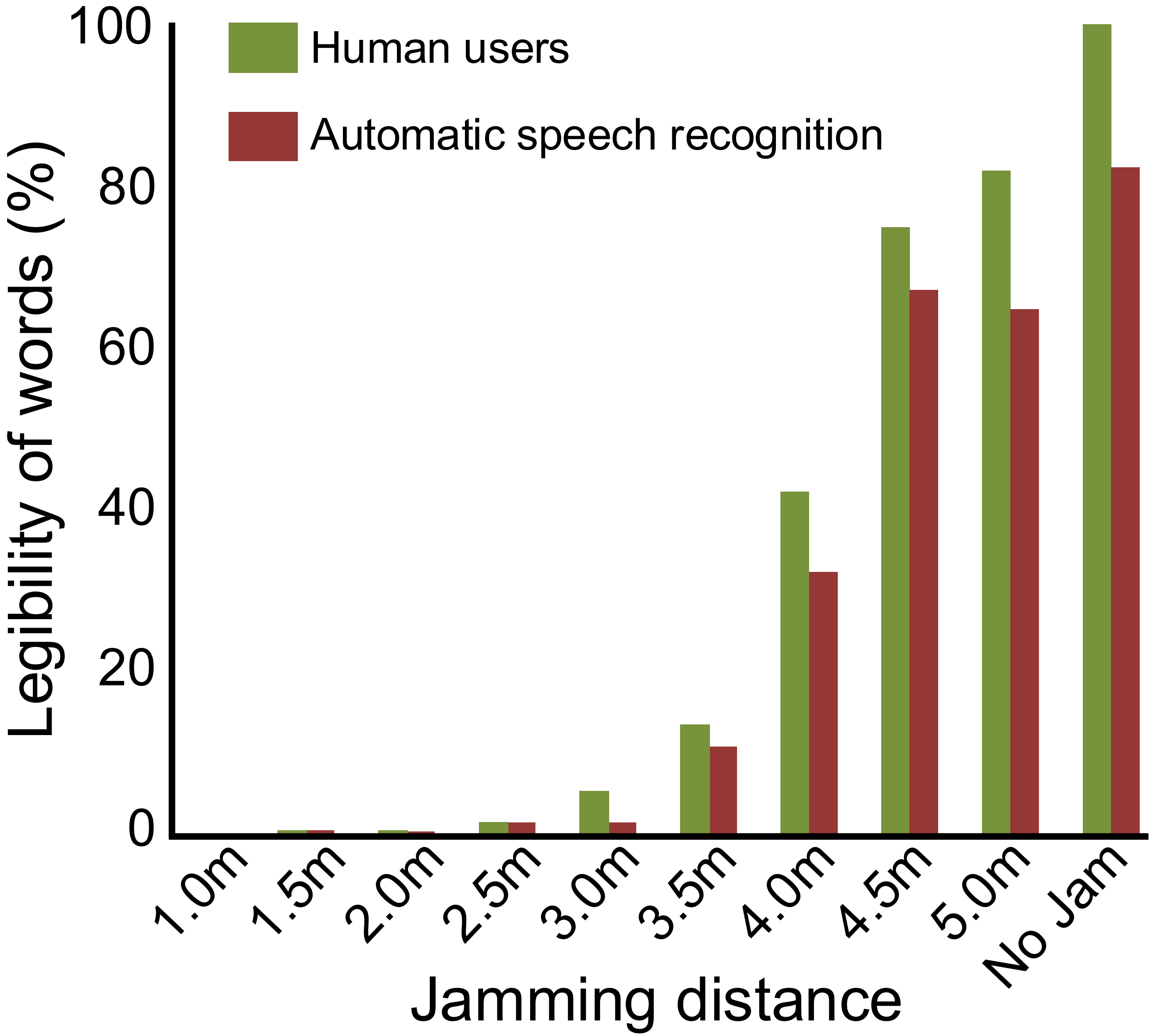
Jamming performance



Jamming performance



Jamming performance



Jamming performance

Takeaways

① Specially designed inaudible sound can be recorded with unmodified microphone

② It can make acoustic jammer possible and also can be a communication channel

③ It also uncovers threats like acoustic Denial-of-Service attacks

Thank You

SyNRG group website: http://synrg.csl.illinois.edu

Jamming performance