BackDoor: Making Microphones Hear Inaudible Sounds


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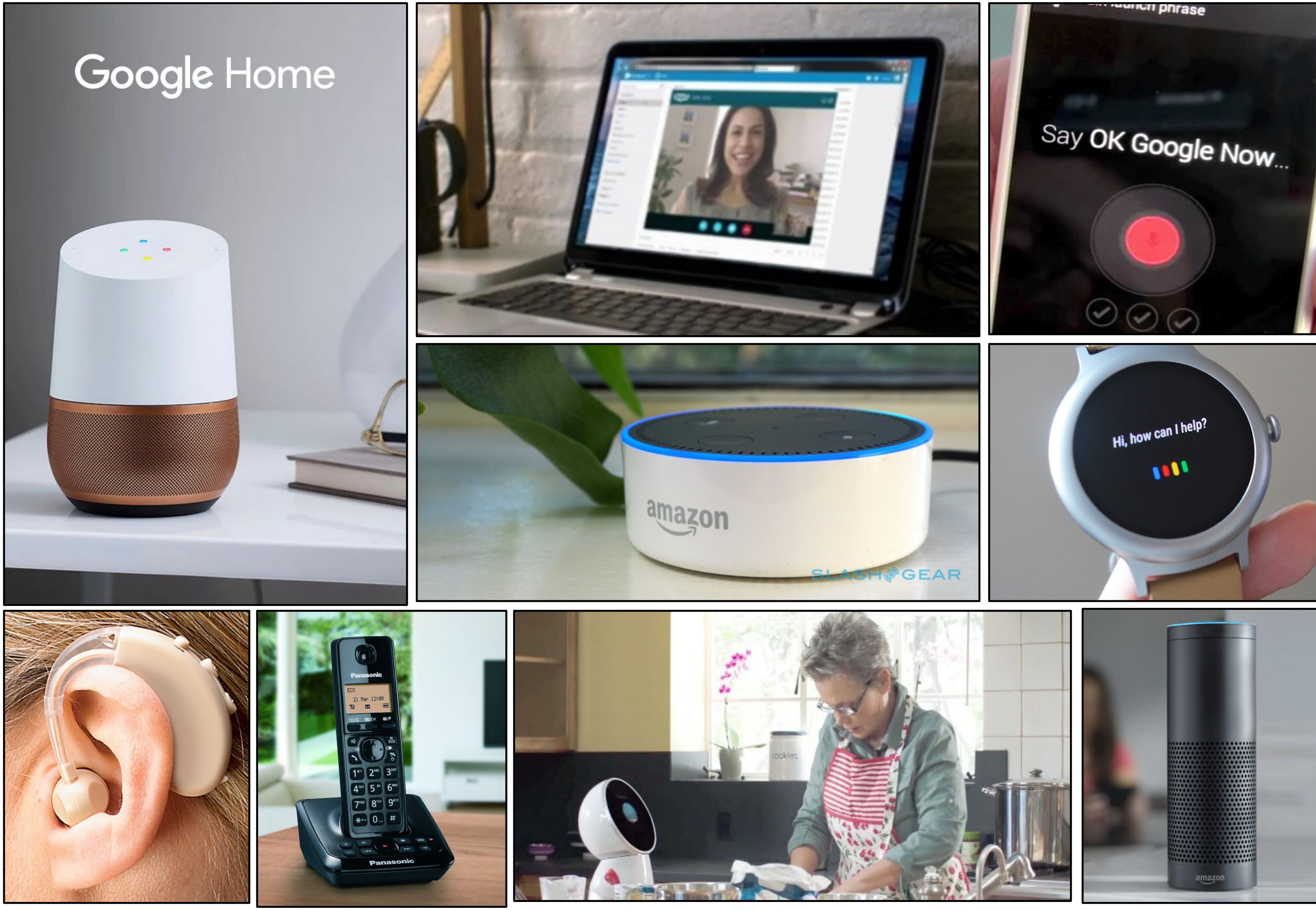
Microphones are everywhere



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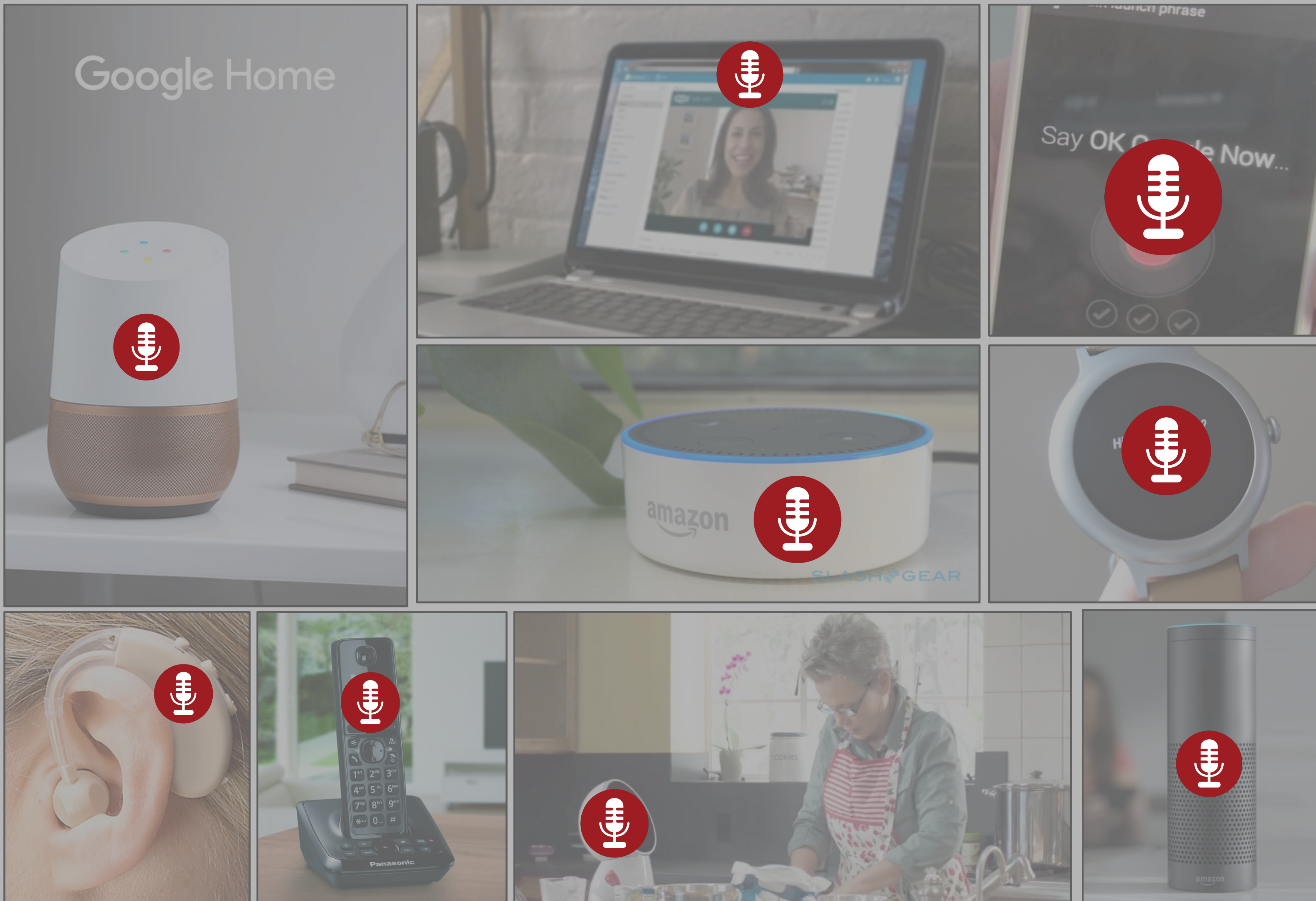
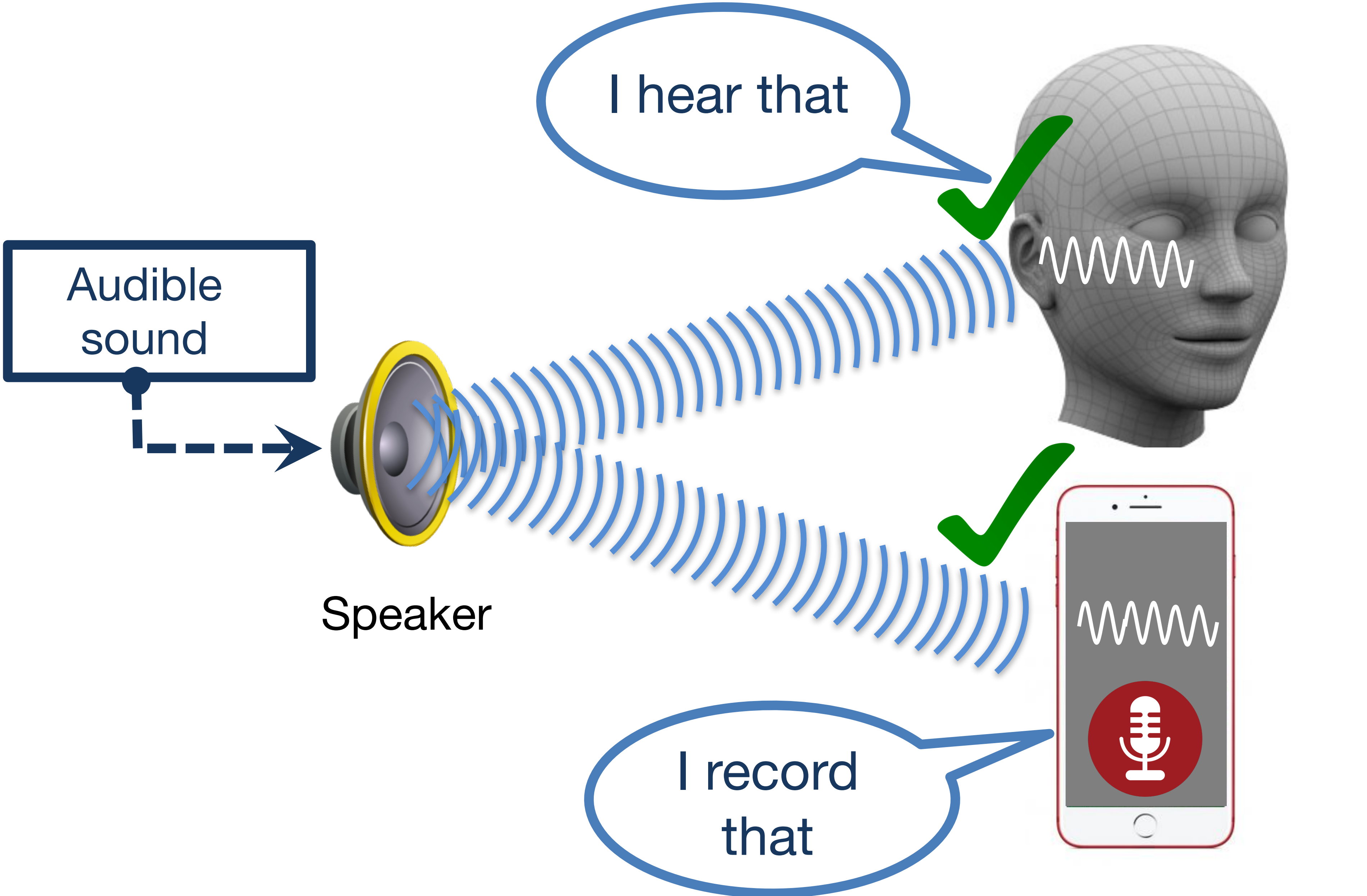
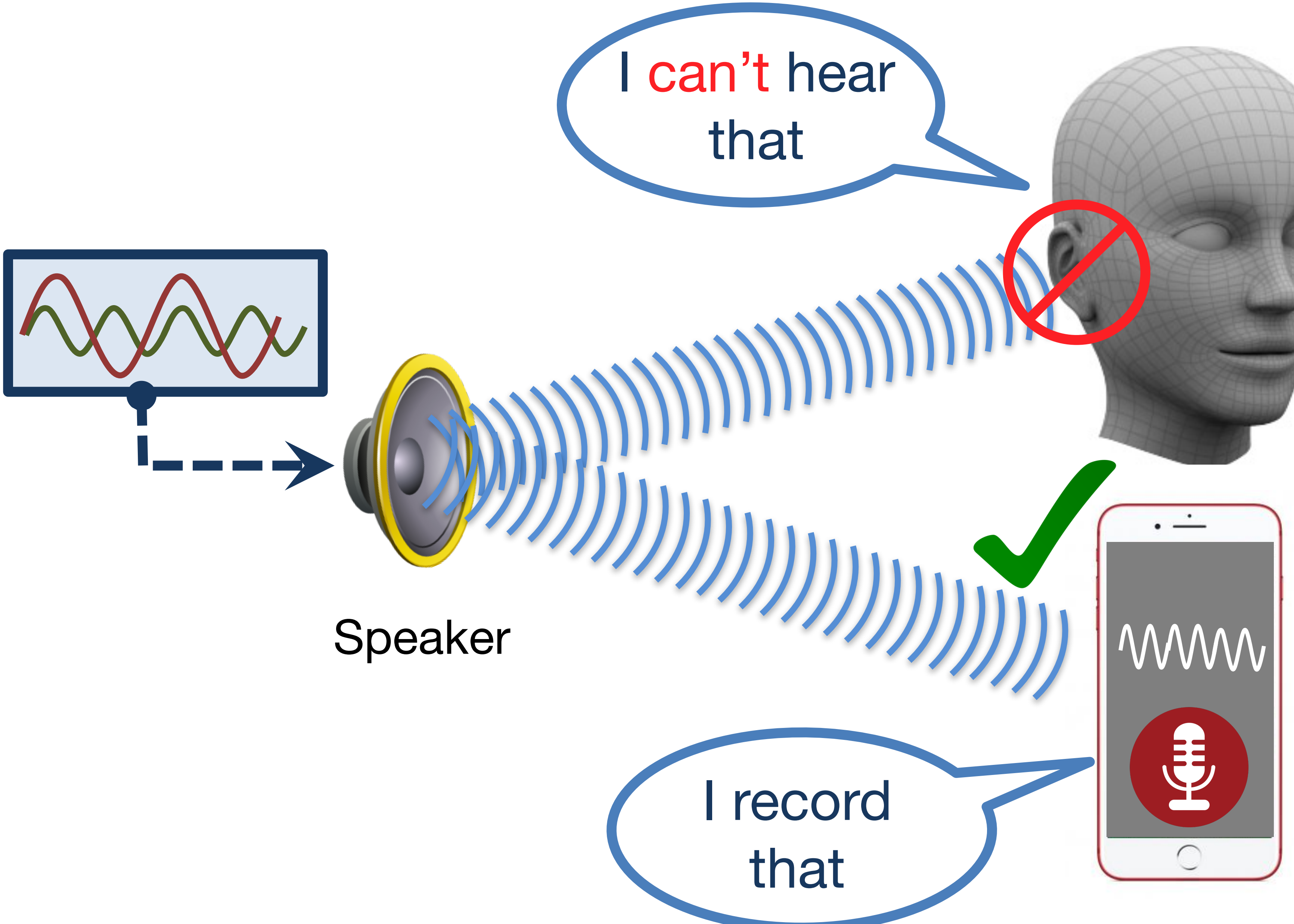


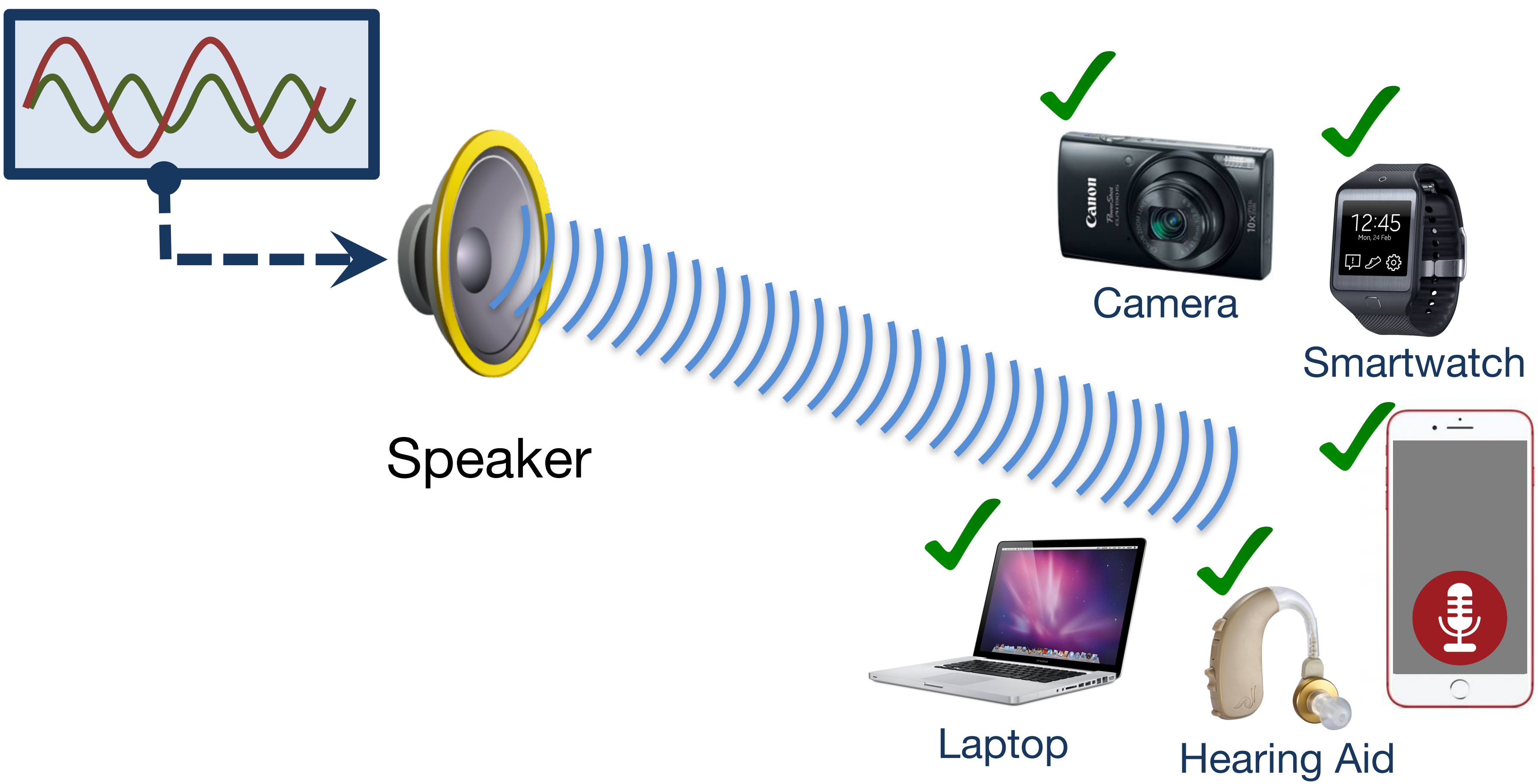
Microphones record audible sounds



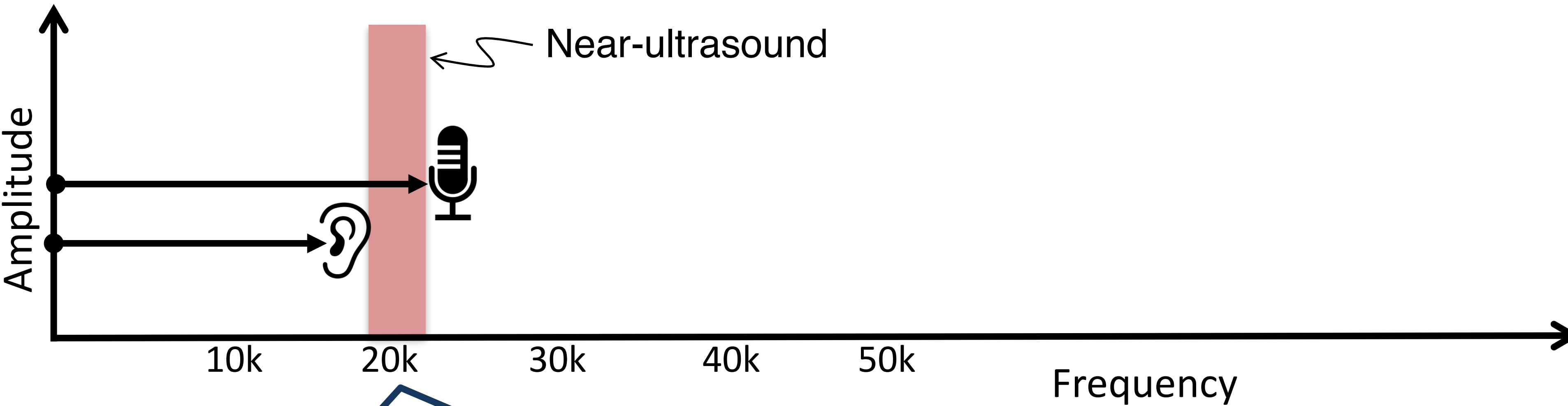
Inaudible, but recordable !



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

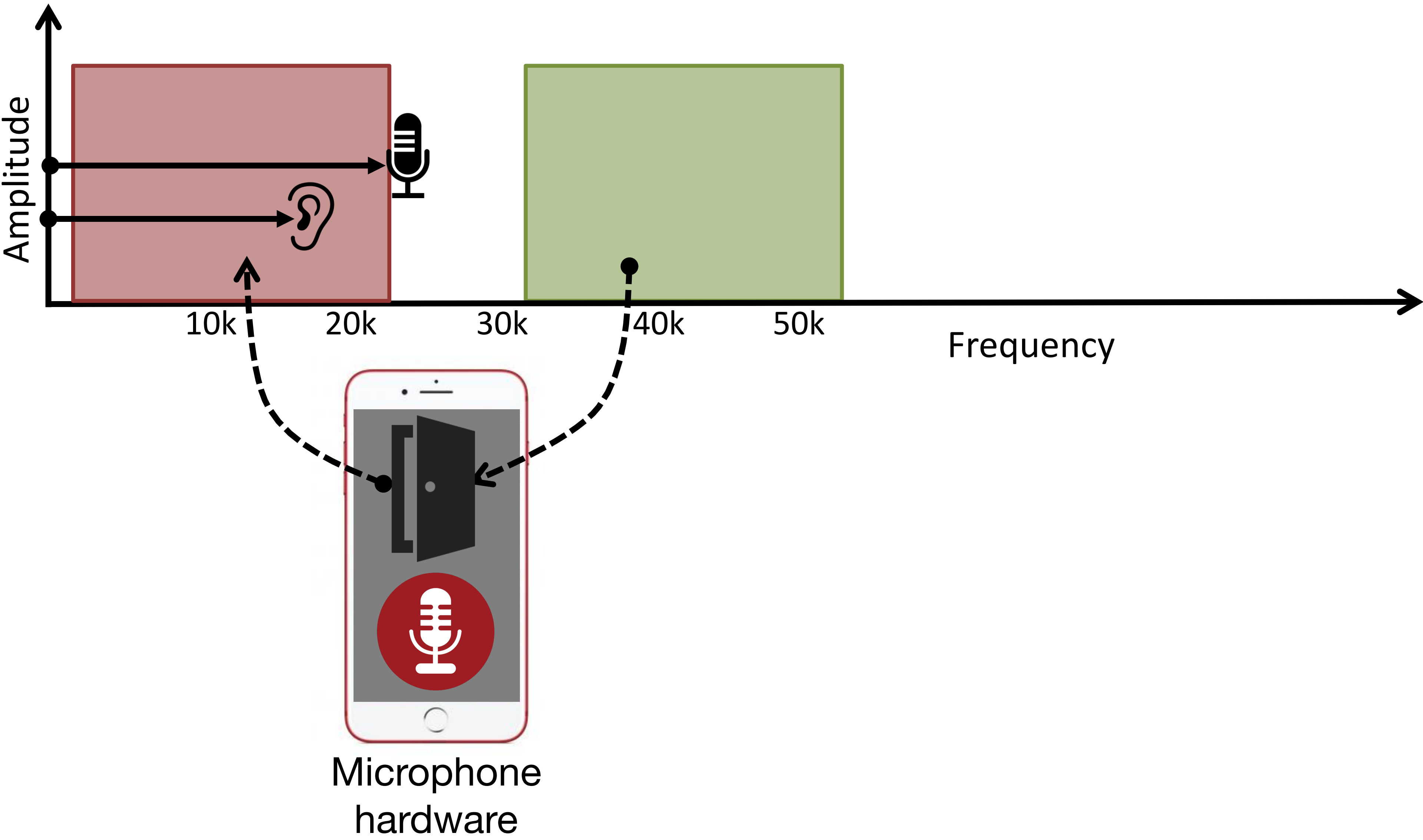
AAMouse
MobiSys'15

AirLink
UbiComp'14

Spartacus
MobiSys'13

Crowd-counting
SenSys'12

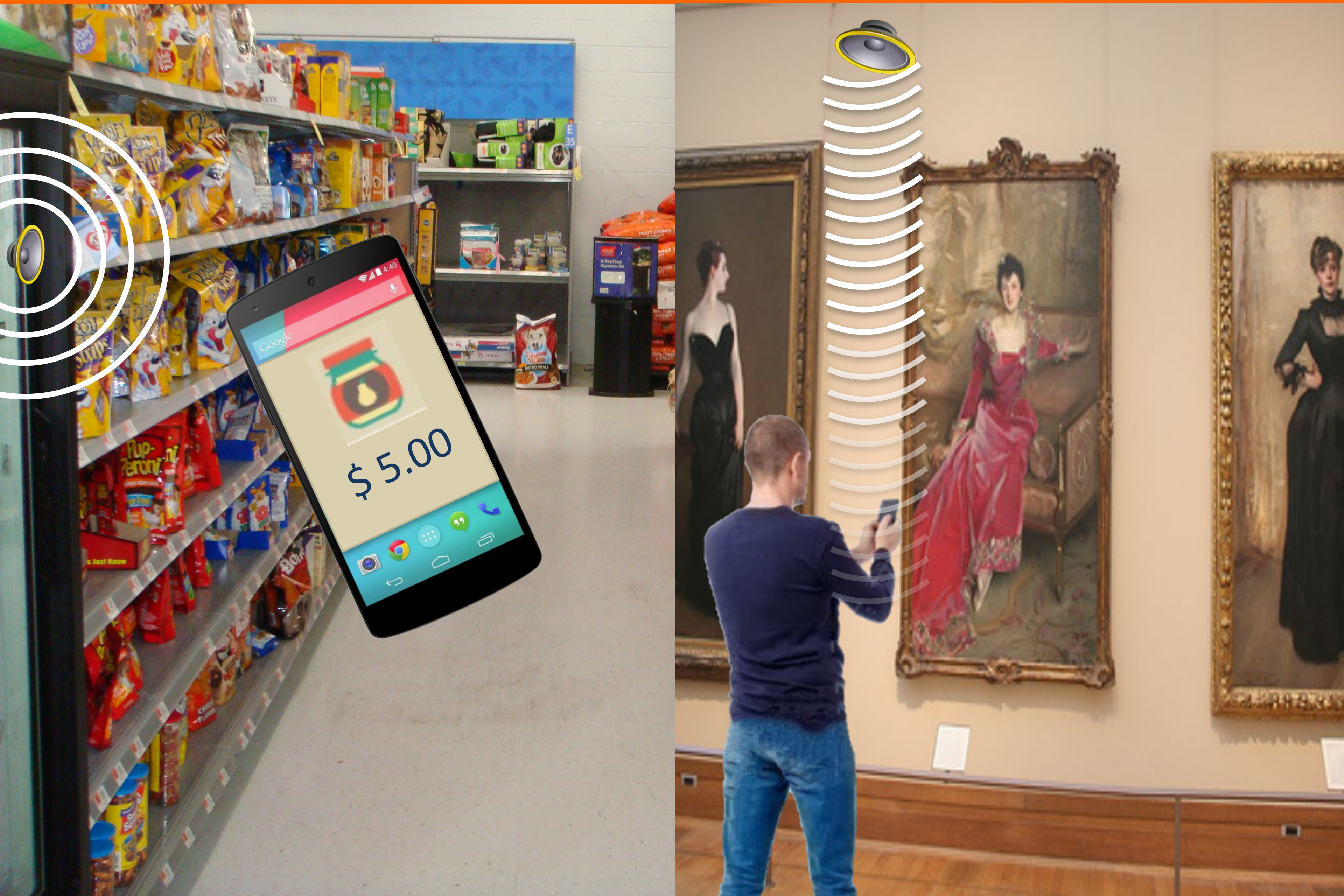
Exploiting fundamental nonlinearity



What can we do with it?

Application: Acoustic jammer

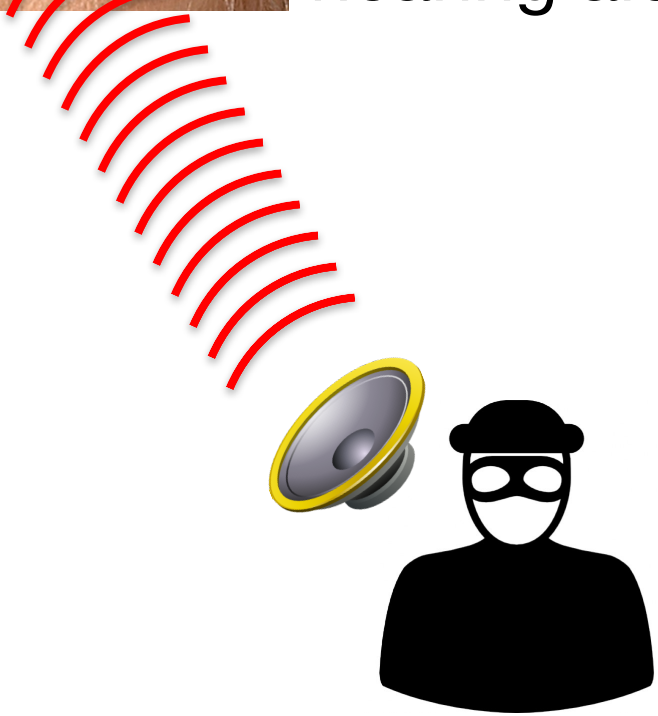
Application: Acoustic communication



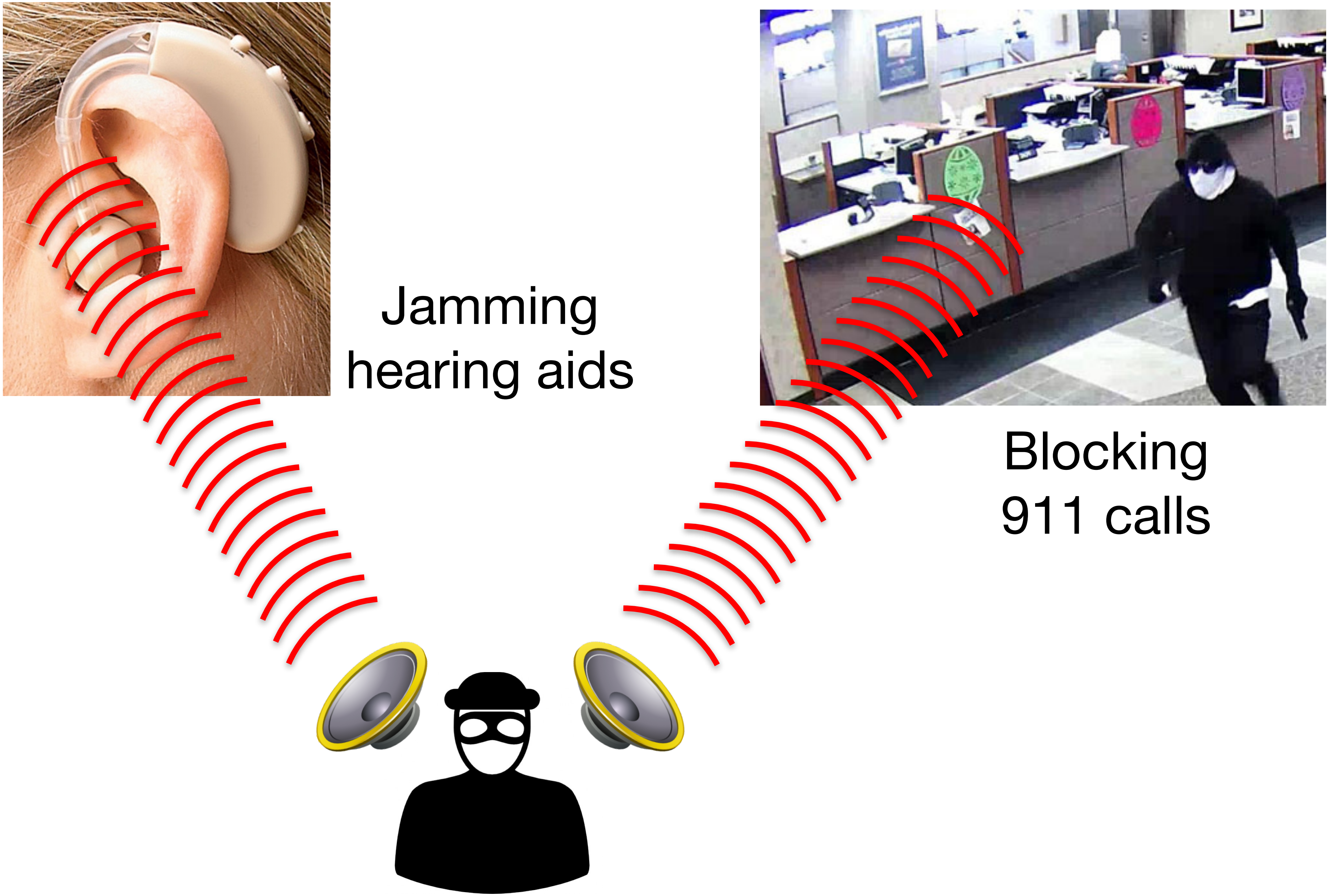
Threat: Acoustic DOS attack

Threat: Acoustic DOS attack

Jamming
hearing aids



Threat: Acoustic DOS attack



Talk outline

① Microphone Overview

② System Design

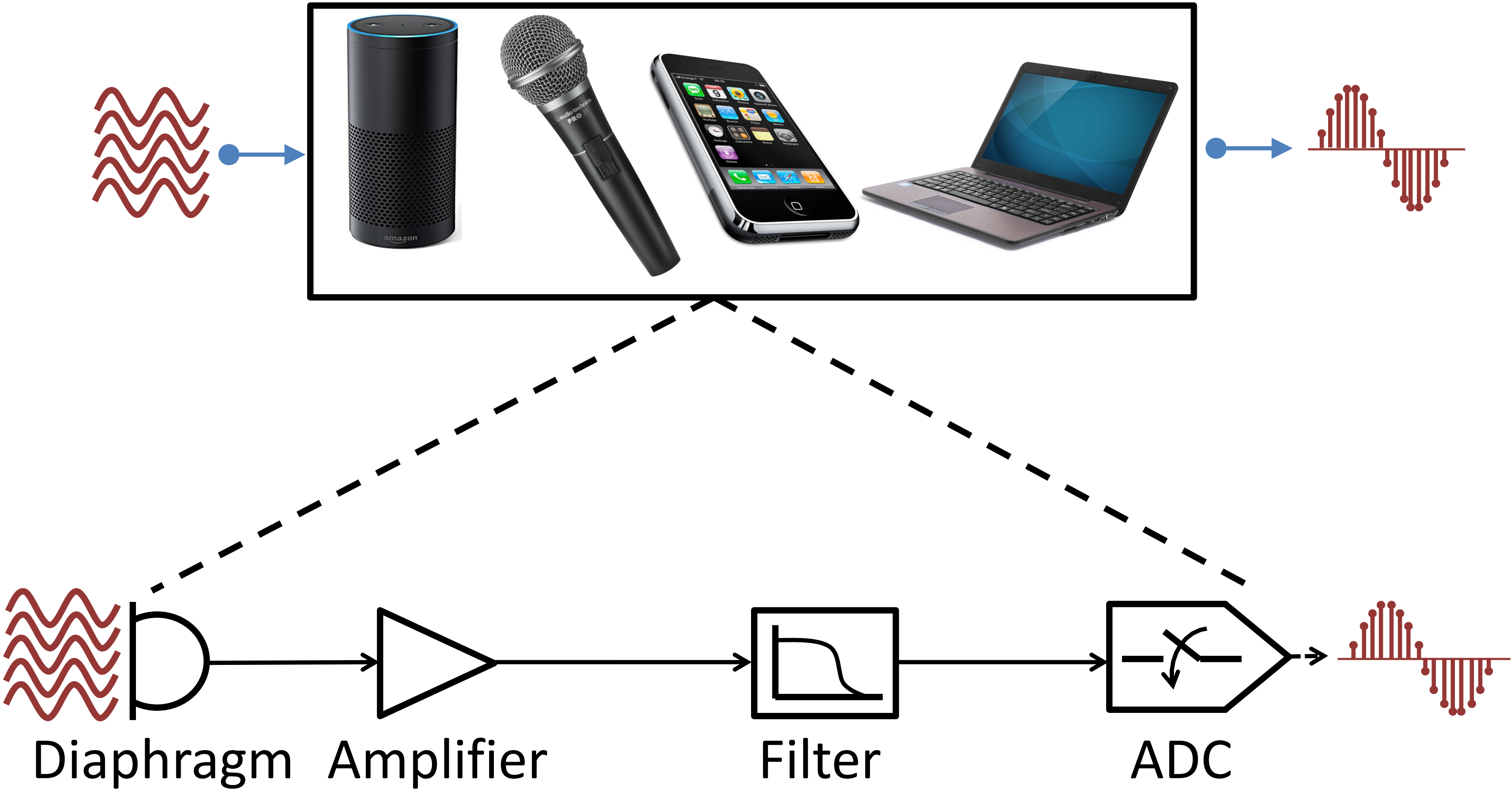
③ Challenges

④ Evaluation

Talk outline

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

Microphone working principle



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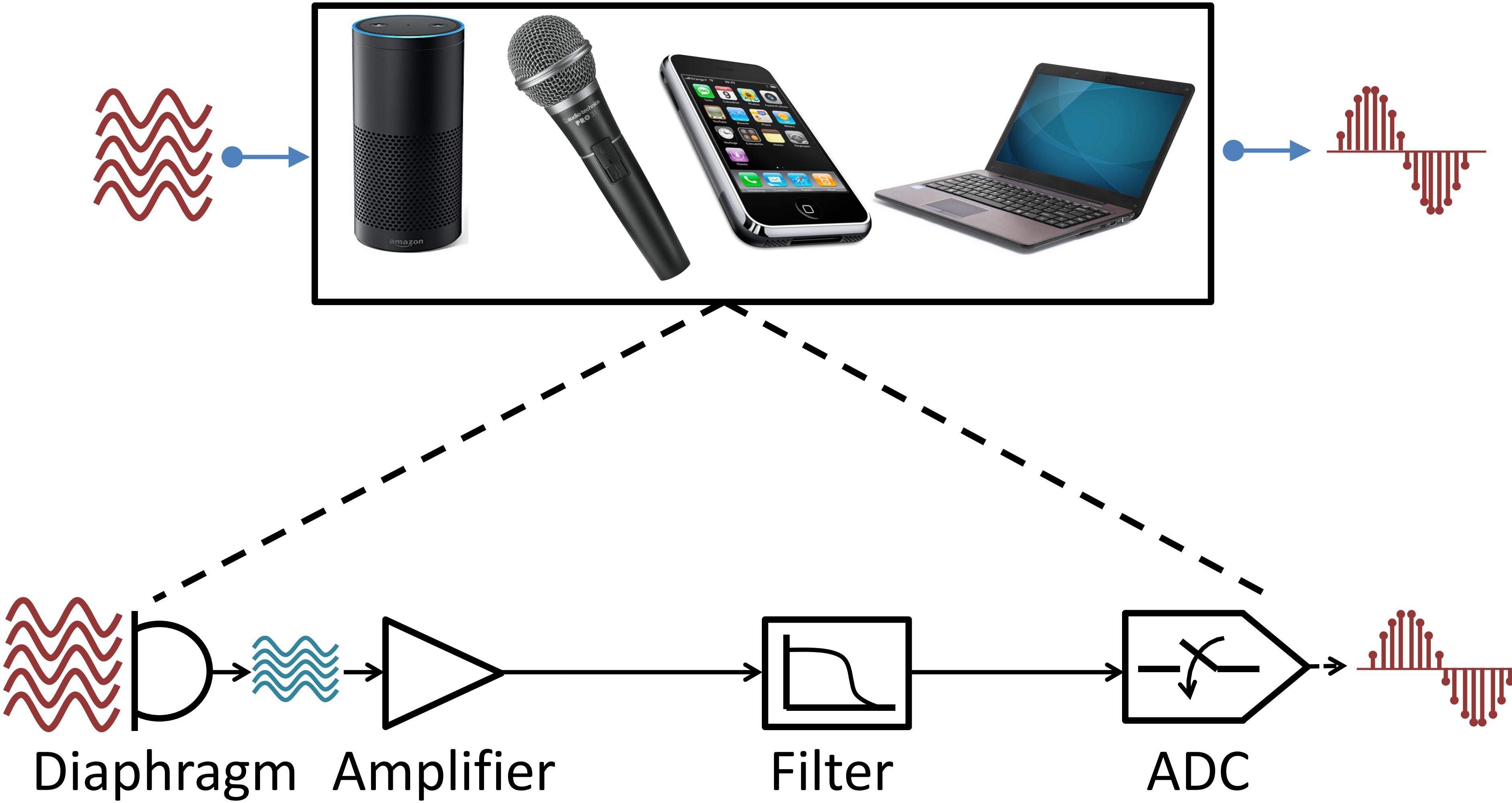

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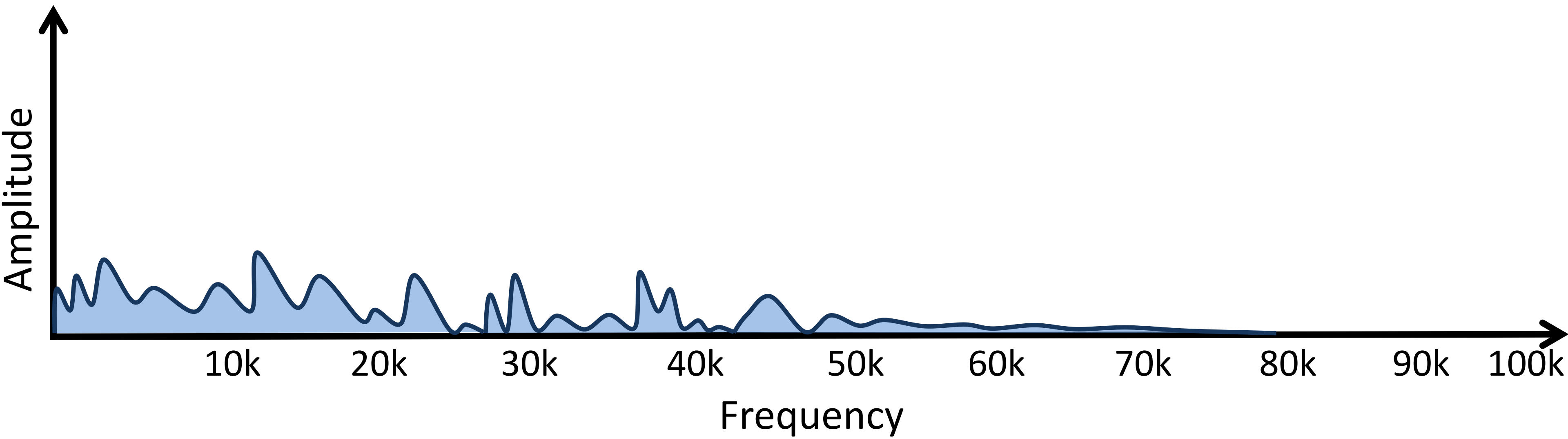

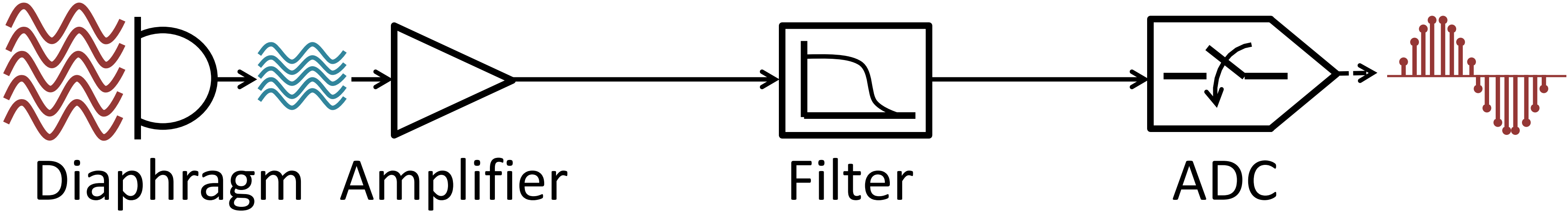

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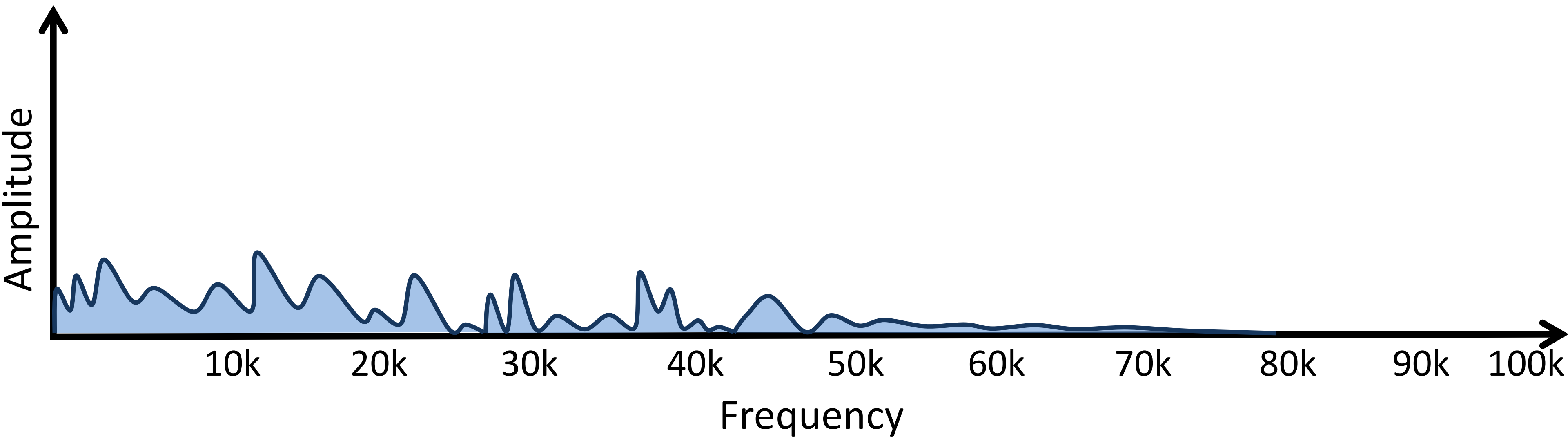

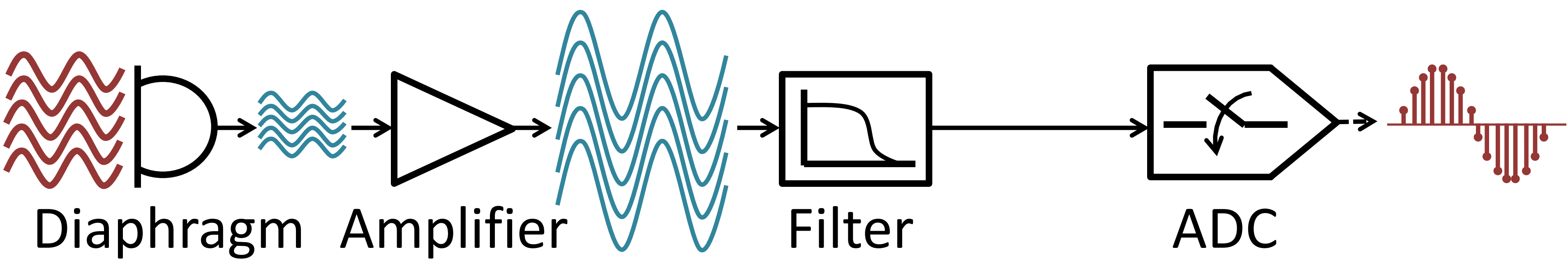

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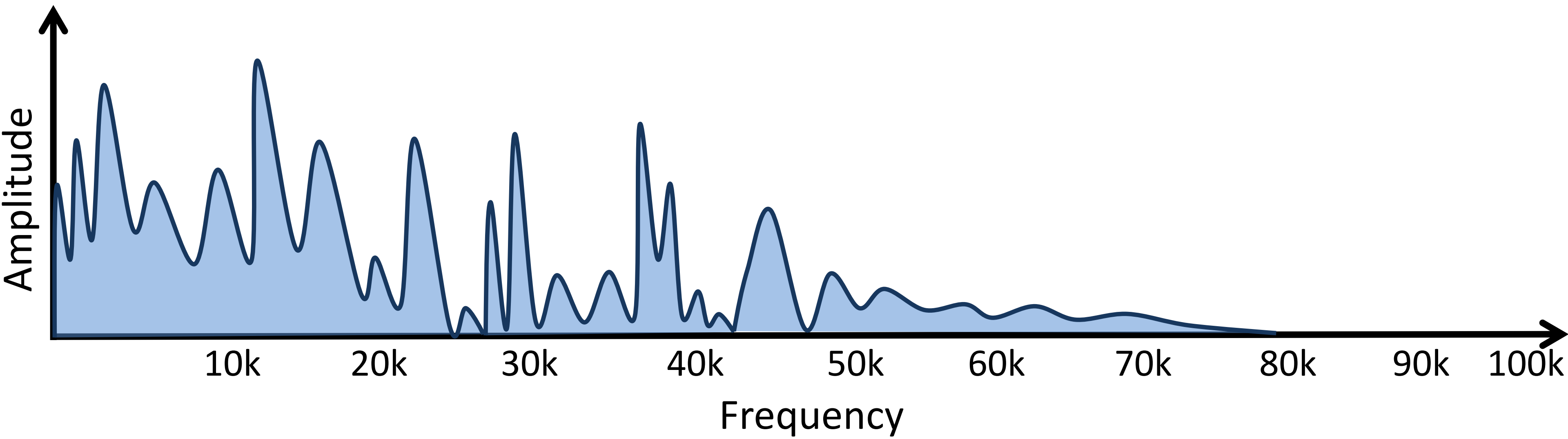

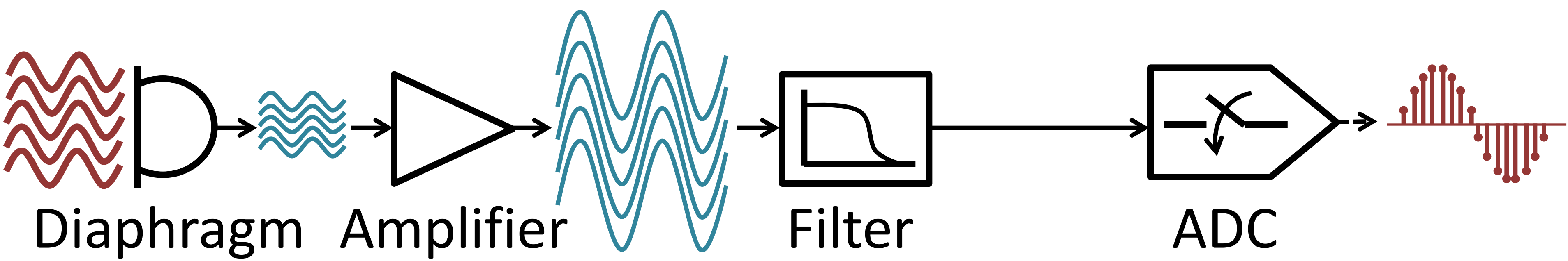

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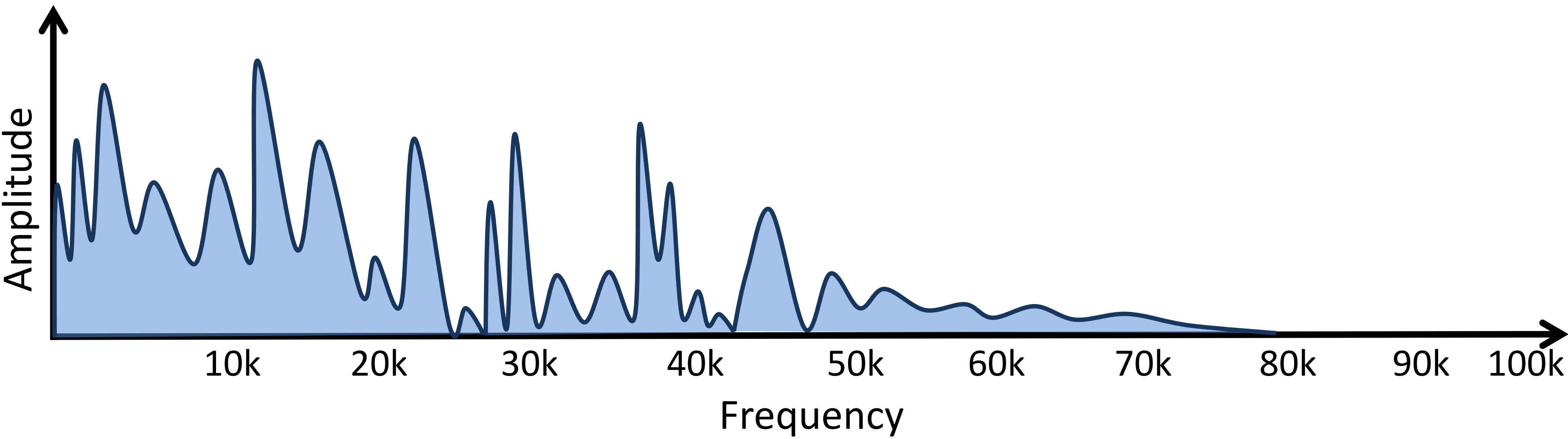

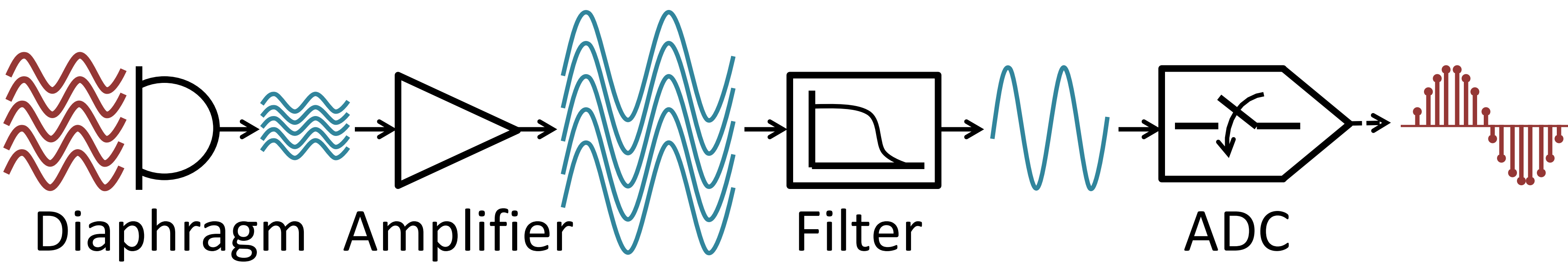

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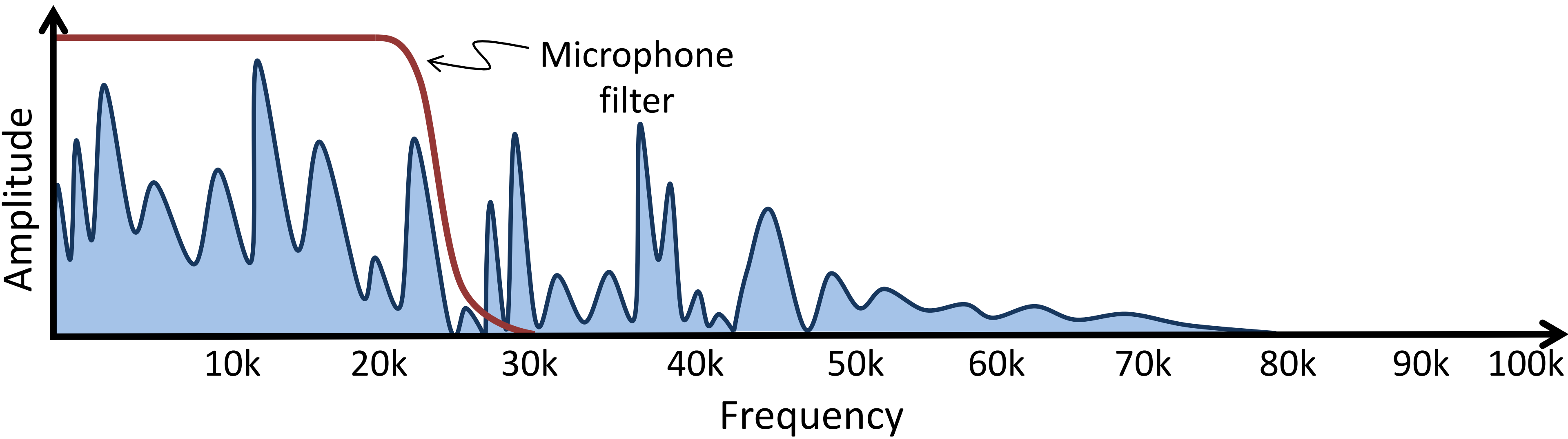

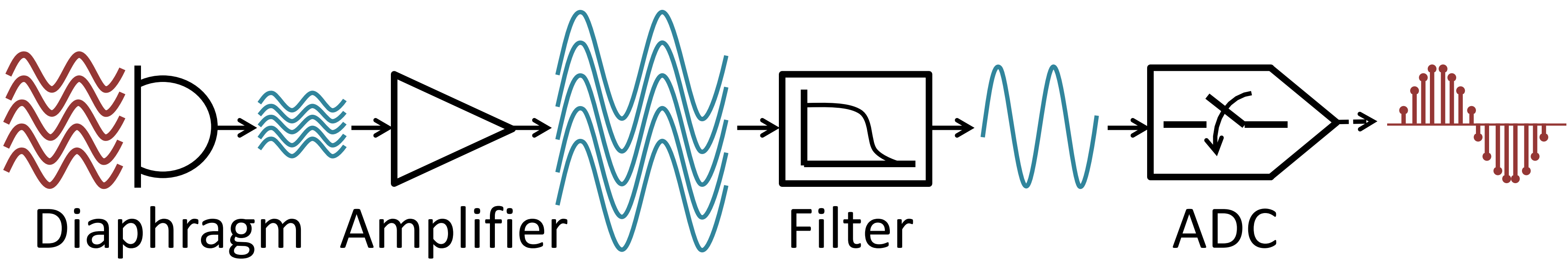

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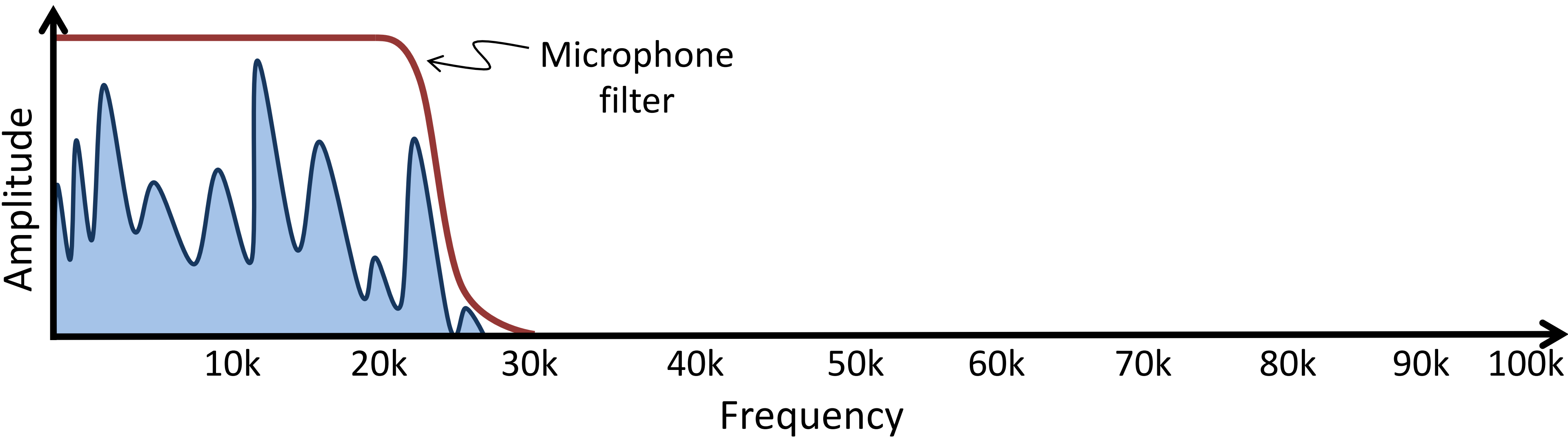

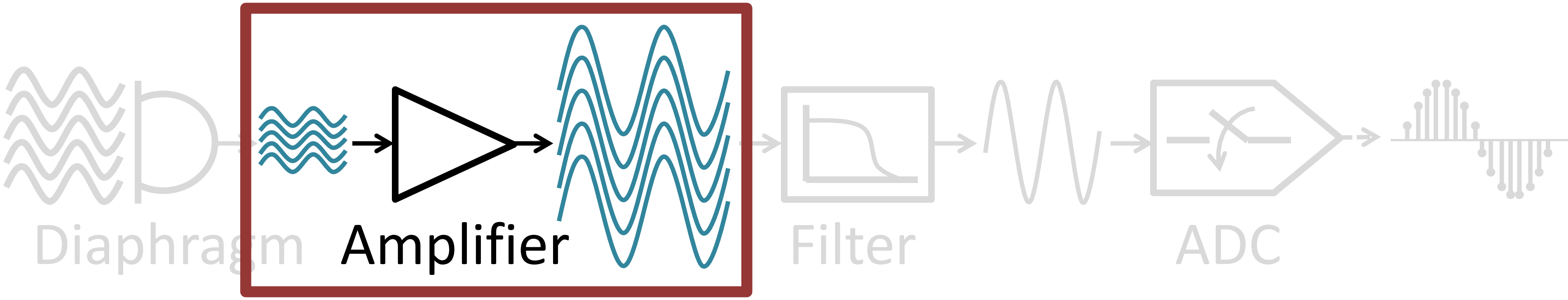

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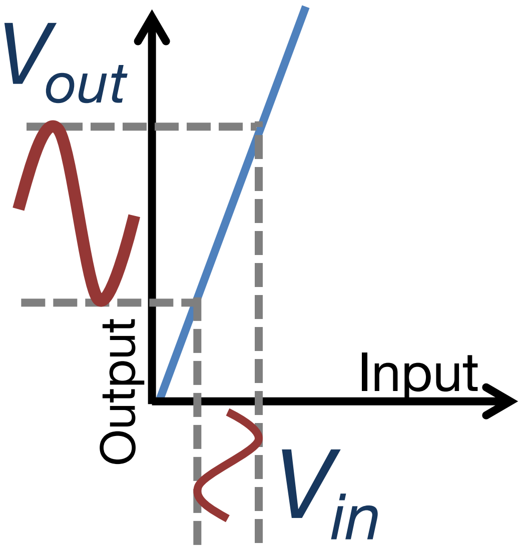
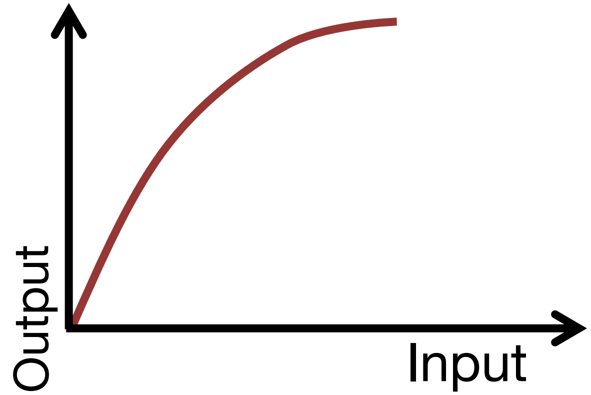
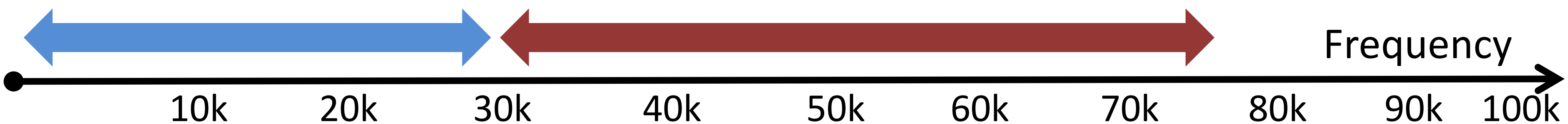
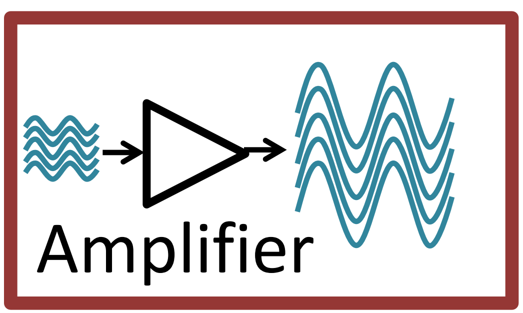




$$V_{out} = a_1 V_{in}$$

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





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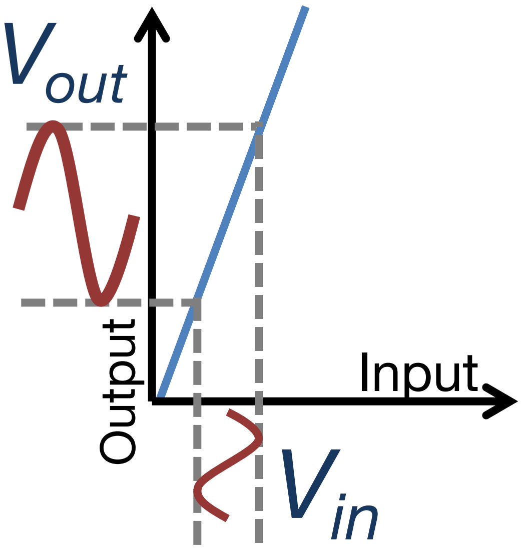

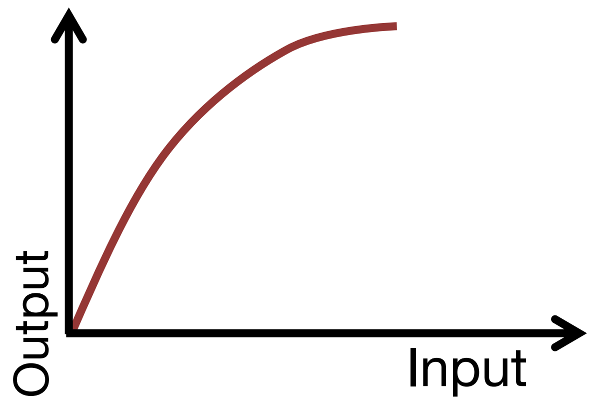

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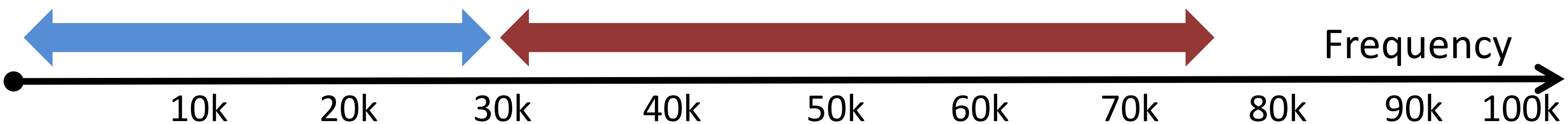

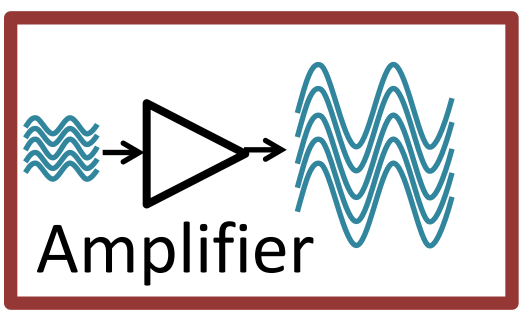

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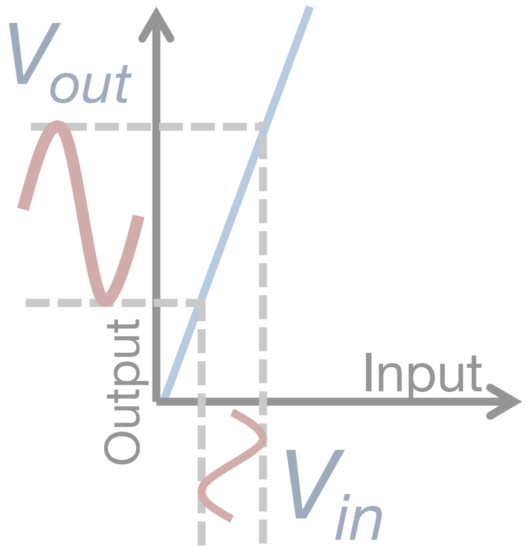

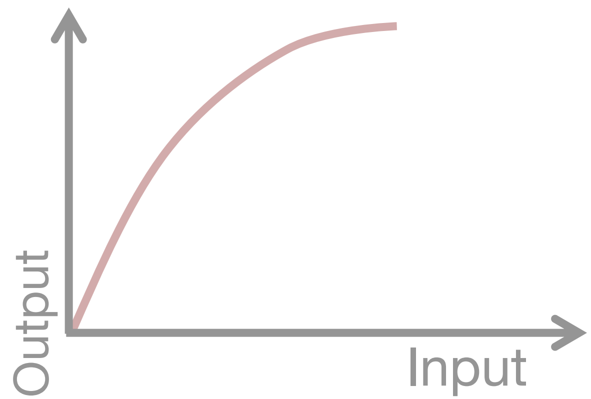

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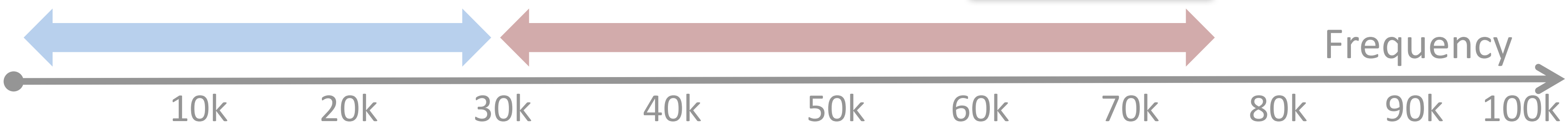

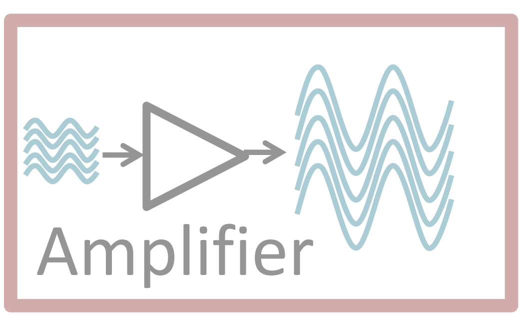

Talk outline

1. Microphone Overview
2. System Design
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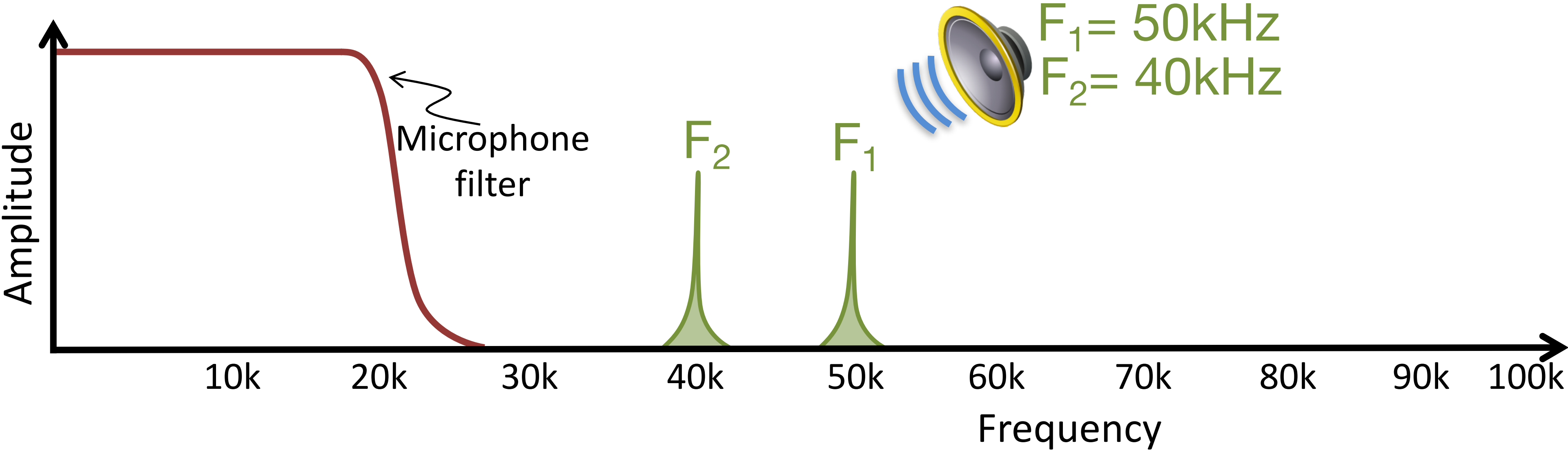
4. Evaluation

Exploiting amplifier non-linearity



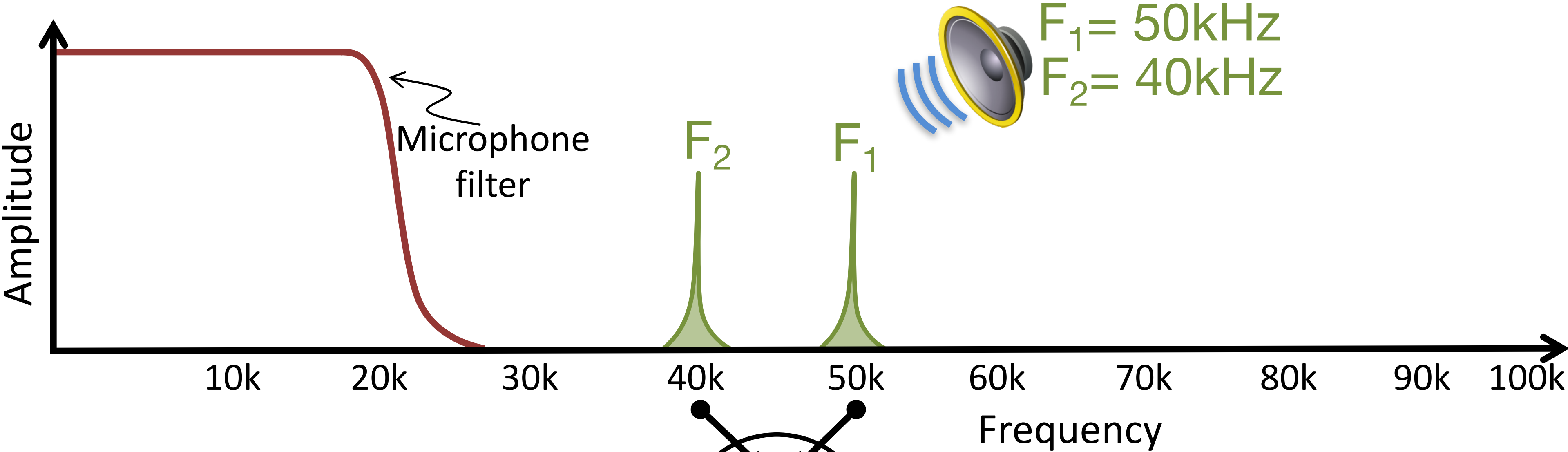
$$S_{out} = A_1(S_1 + S_2) + A_2(S_1 + S_2)^2$$

$$= A_1\{Sin(\omega_1 t) + Sin(\omega_2 t)\} \; + A_2\{Sin^2(\omega_1 t) +$$

$$Sin^2(\omega_2 t) + 2Sin(\omega_1 t)Sin(\omega_2 t)\}$$

where $\omega_1 = 2\pi 40$ and $\omega_2 = 2\pi 50$.

Exploiting amplifier non-linearity

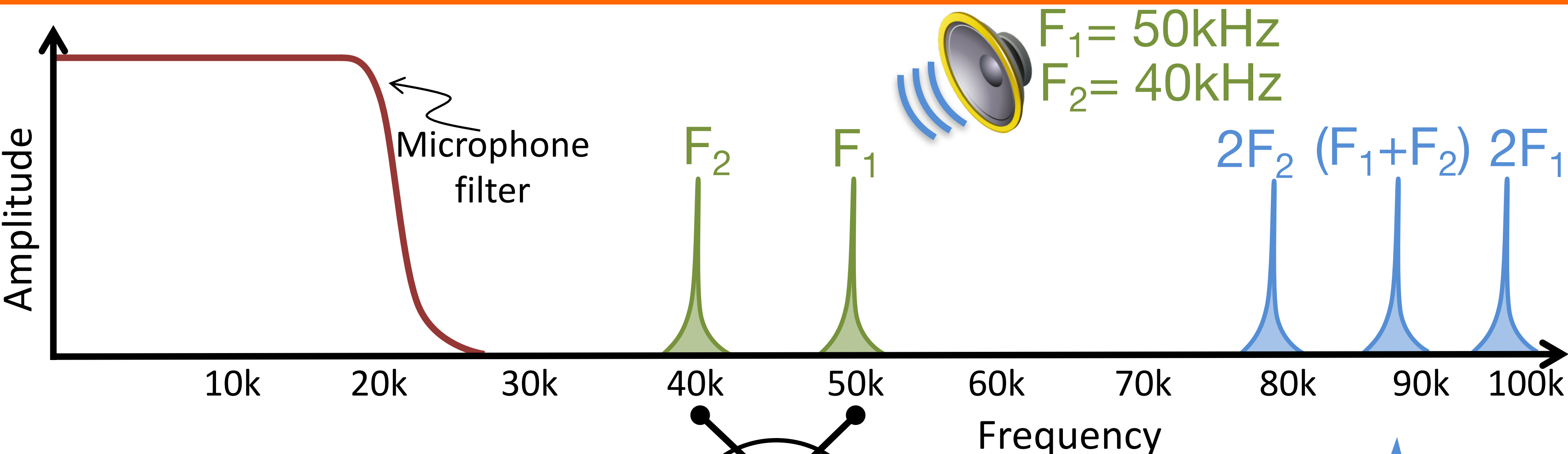


$$V_{out} = a_1 V_{in} + a_2 V_{in}^2$$

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

$$A_2(S_1+S_2)^2 = 1 - \frac{1}{2}Cos(2\omega_1 t) - \frac{1}{2}Cos(2\omega_2 t) + Cos((\omega_1 - \omega_2)t) - Cos((\omega_1 + \omega_2)t)$$

Exploiting amplifier non-linearity



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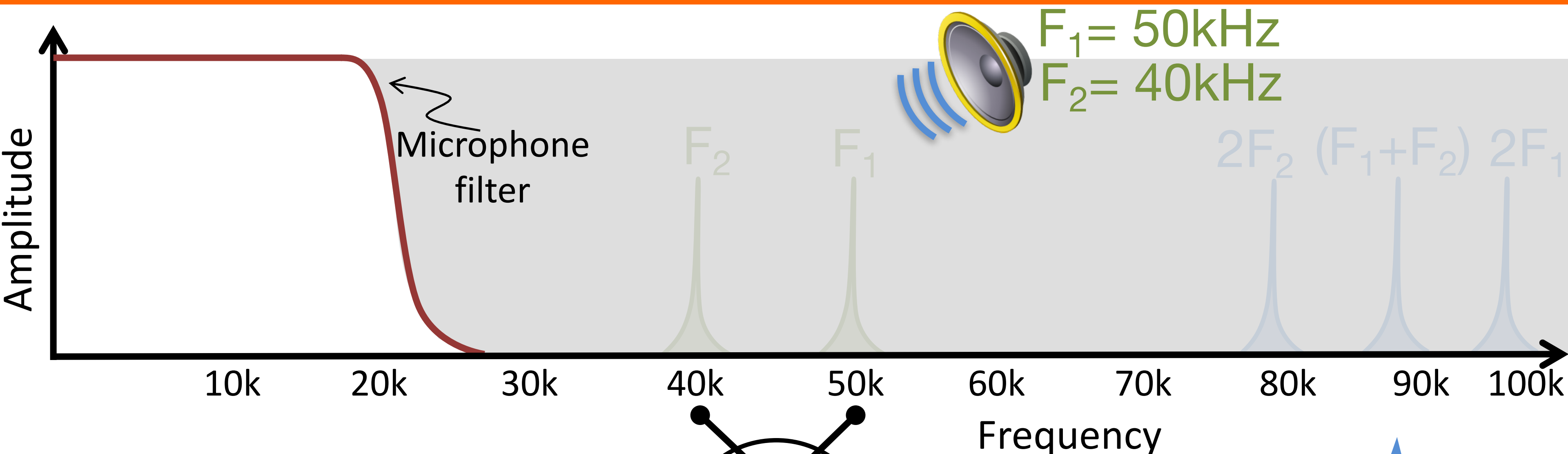

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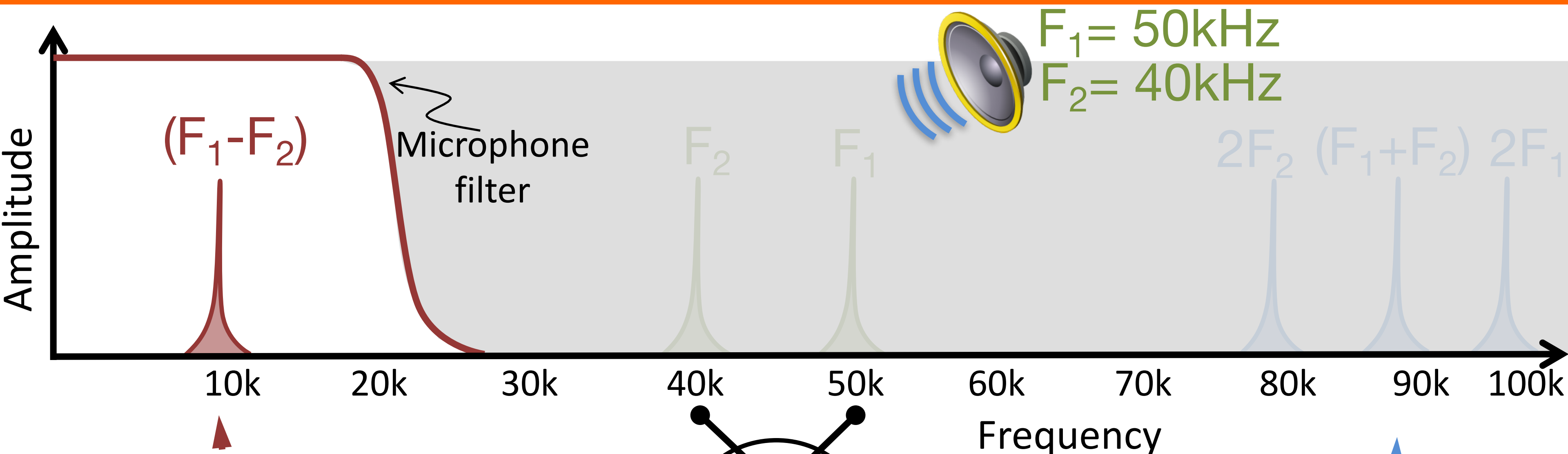

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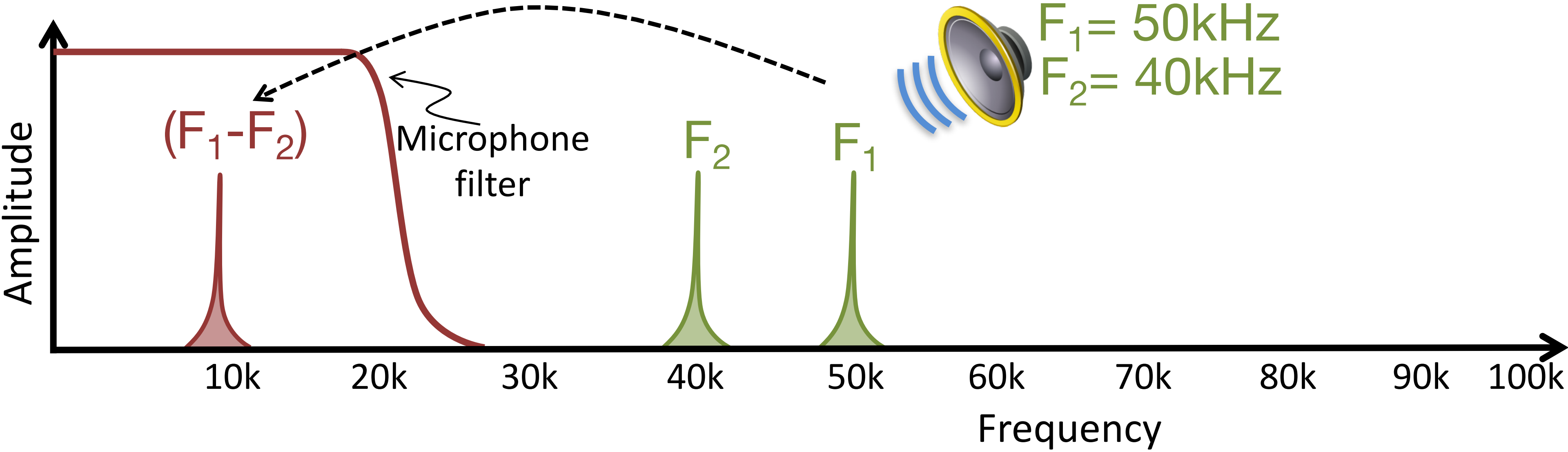
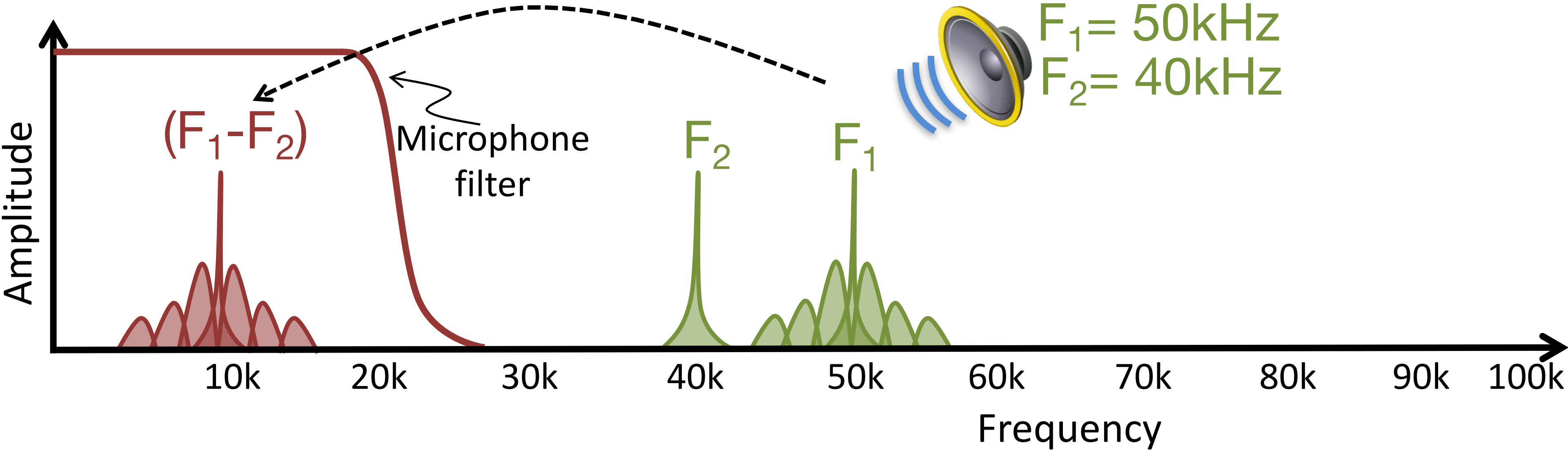


Exploiting amplifier non-linearity



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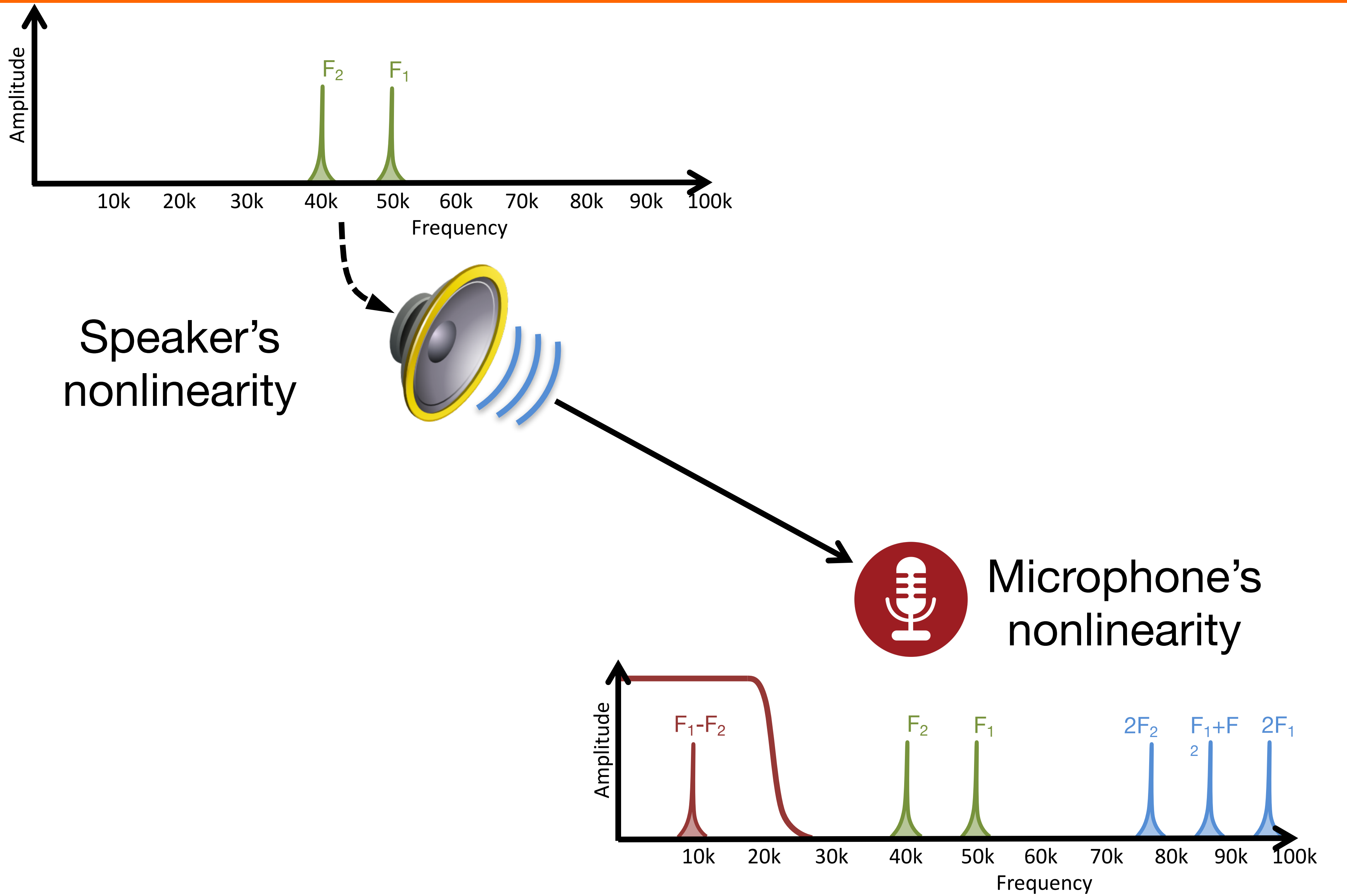
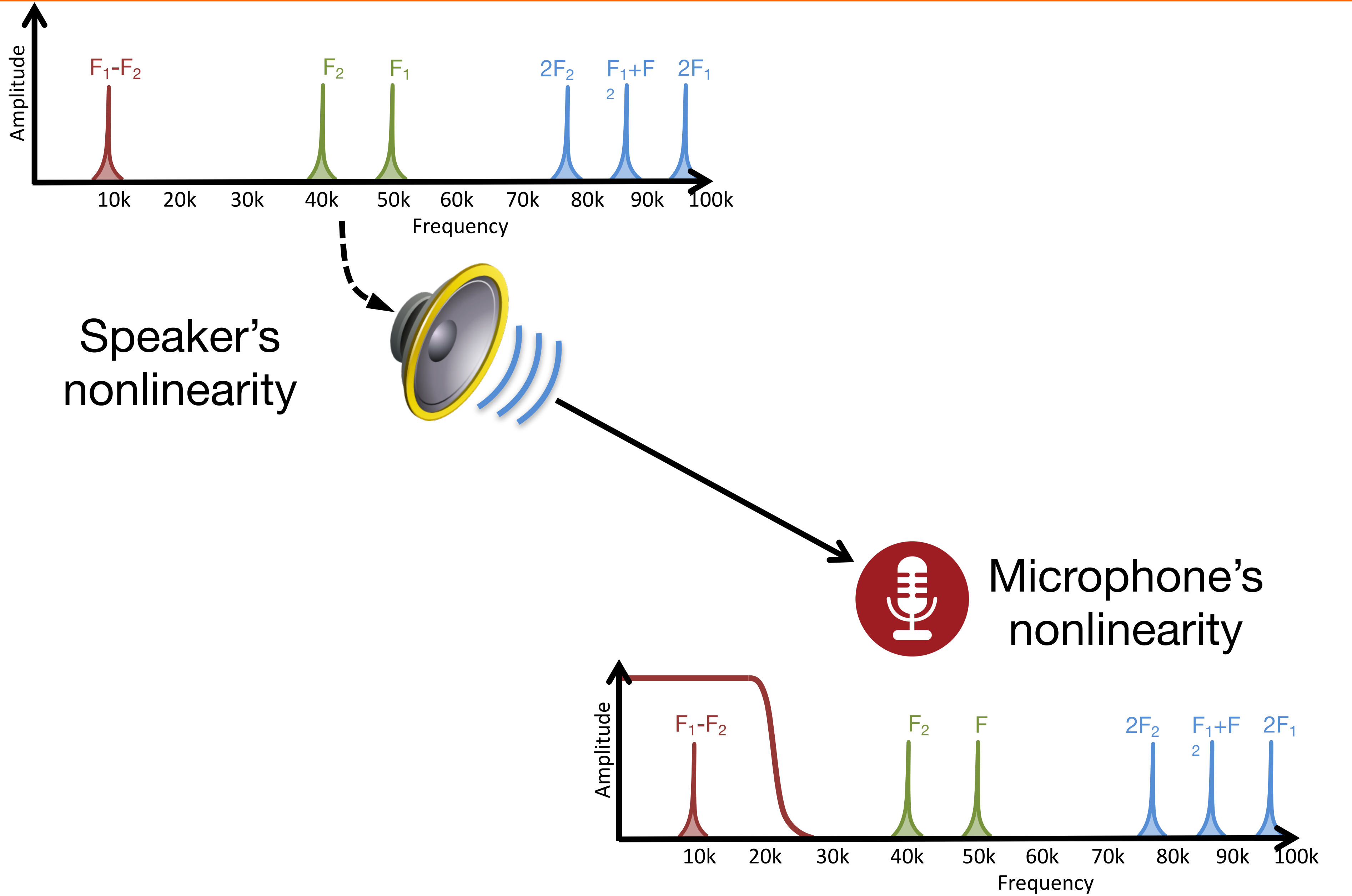
Challenges



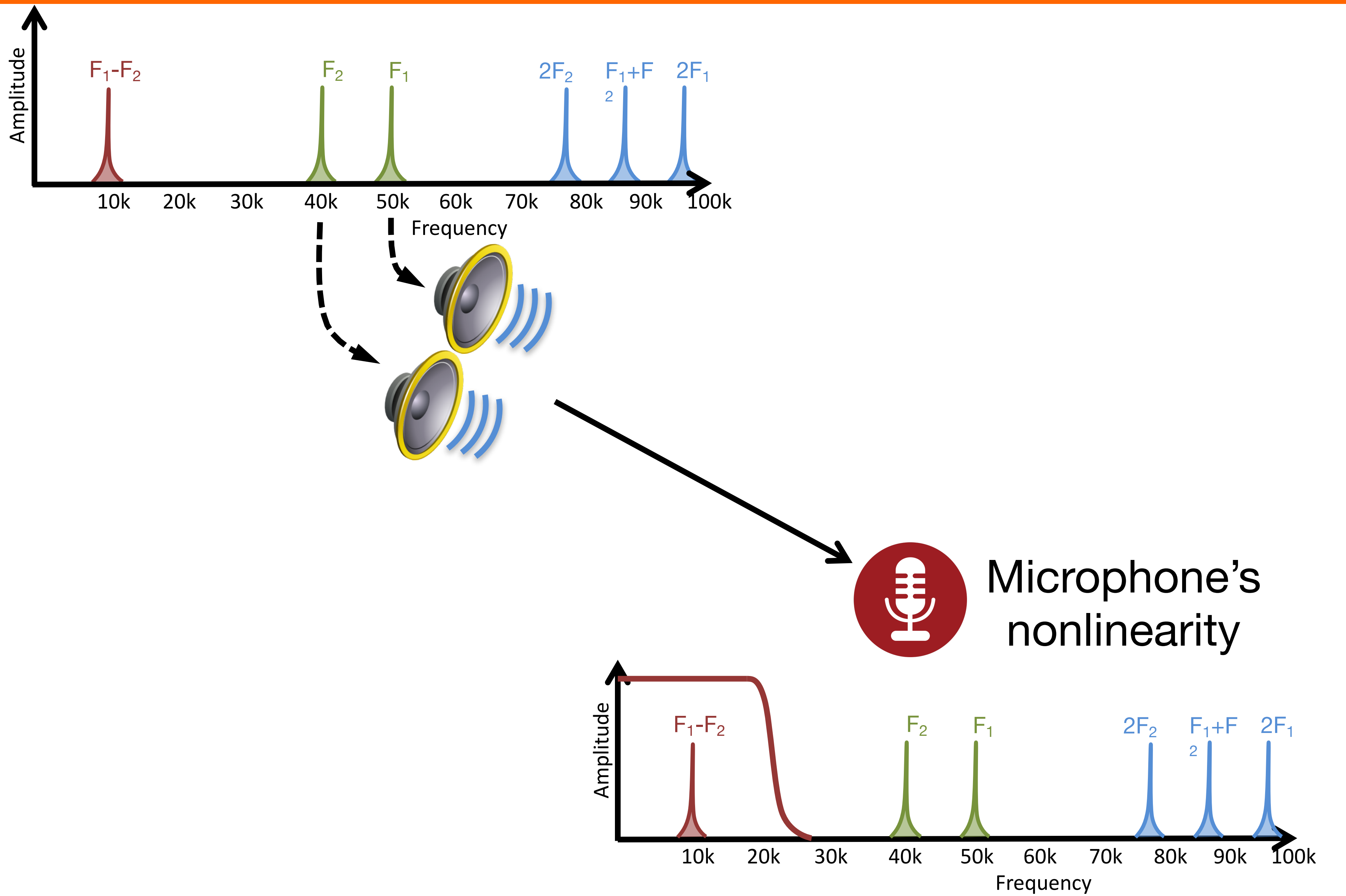
Amplitude
F2
F1
10k
20k
30k
40k
50k
60k
70k
80k
90k
100k
Frequency
Speaker's nonlinearity
Microphone's nonlinearity
Amplitude
F1-F2
F2
F1
2F2
F1+F2
2F1
10k
20k
30k
40k
50k
60k
70k
80k
90k
100k
Frequency

Challenges



Amplitude
F_1-F_2
F_2
F_1
$2F_2$
F_1+F_2
$2F_1$
10k 20k 30k 40k 50k 60k 70k 80k 90k 100k
Frequency
Speaker's nonlinearity
Microphone's nonlinearity
Amplitude
F_1-F_2
F_2
F
$2F_2$
F_1+F_2
$2F_1$
10k 20k 30k 40k 50k 60k 70k 80k 90k 100k
Frequency

Challenges


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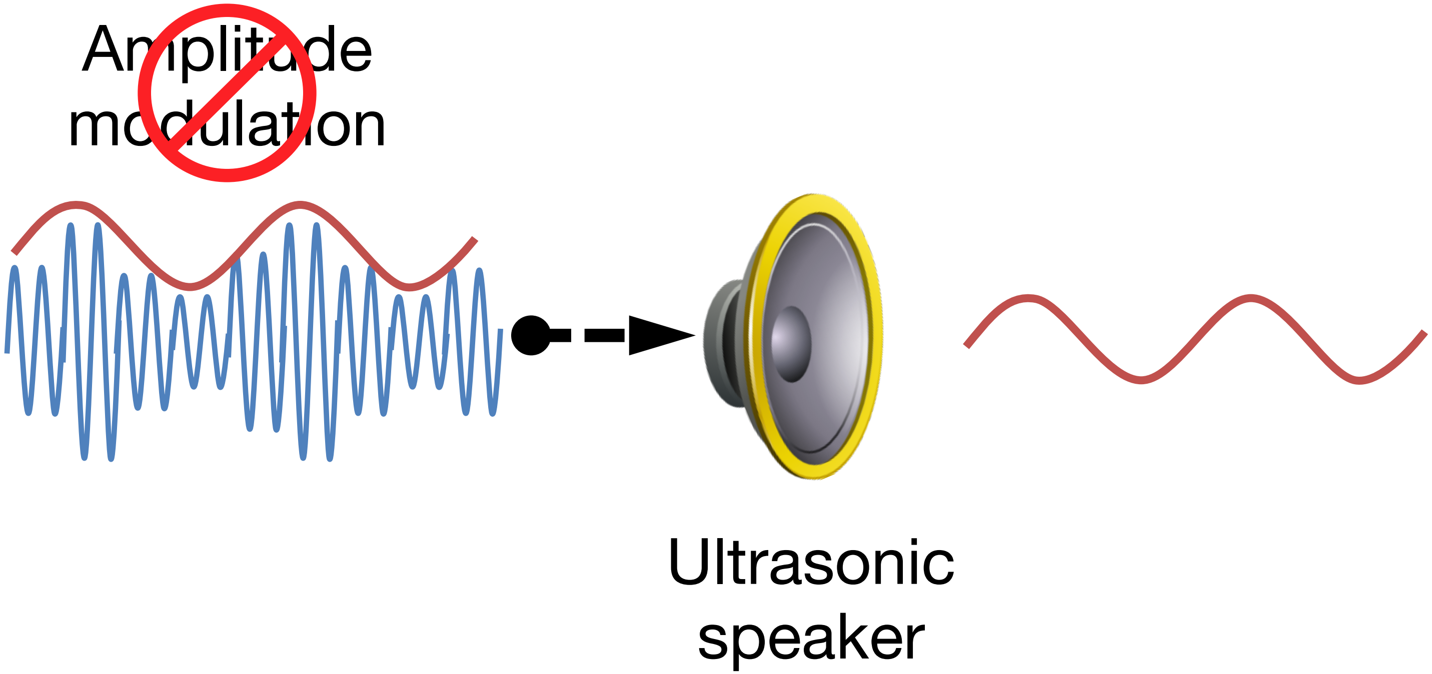
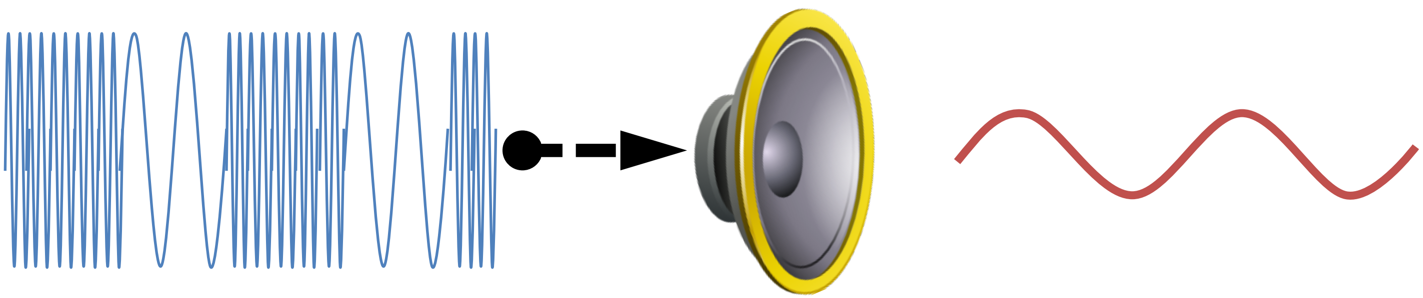
Challenges



Challenges

Frequency modulation



Ultrasonic speaker

Challenges

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

Measurements and Validation

Sensitivity to High Frequencies:

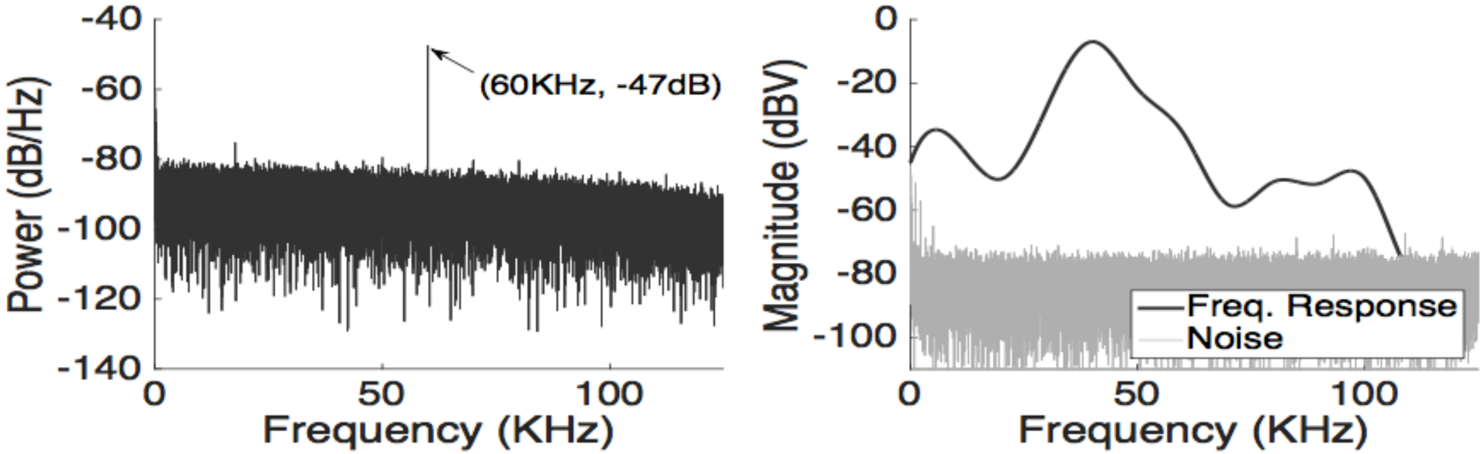


Figure 4: (a) Microphone signals (measured before the LPF) confirm the diaphragm and pre-amplifier's sensitivity to ultrasound frequencies. (b) Full freq. response at the output of the amplifier.

60kHz sound was played through an ultrasonic speaker and recorded with a programmable micro- phone circuit.

Measurements and Validation

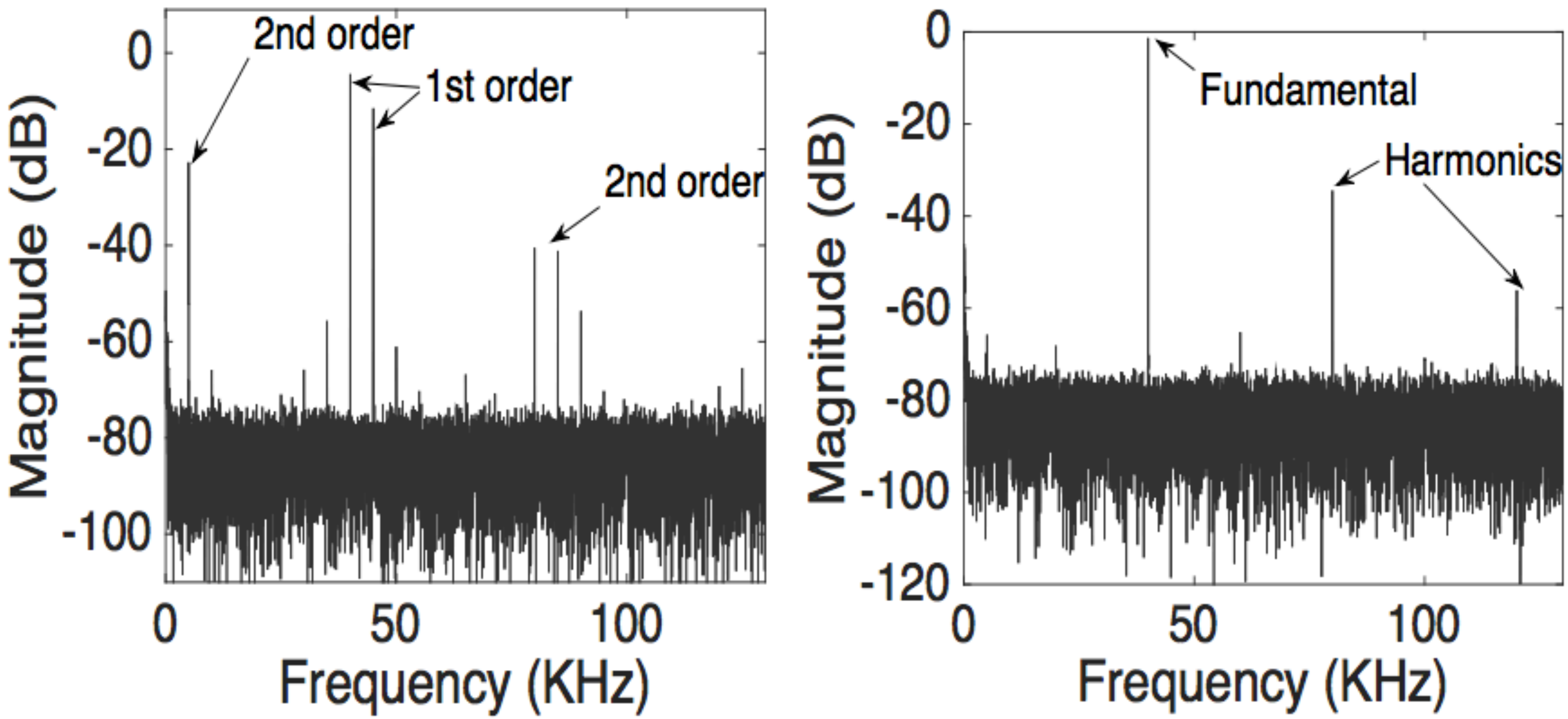
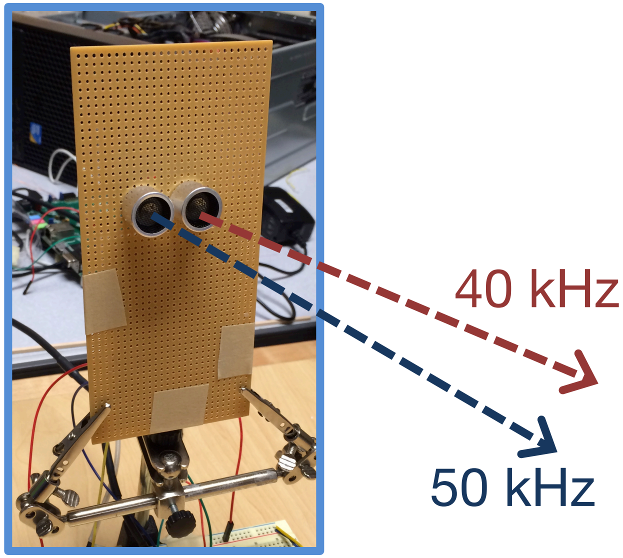
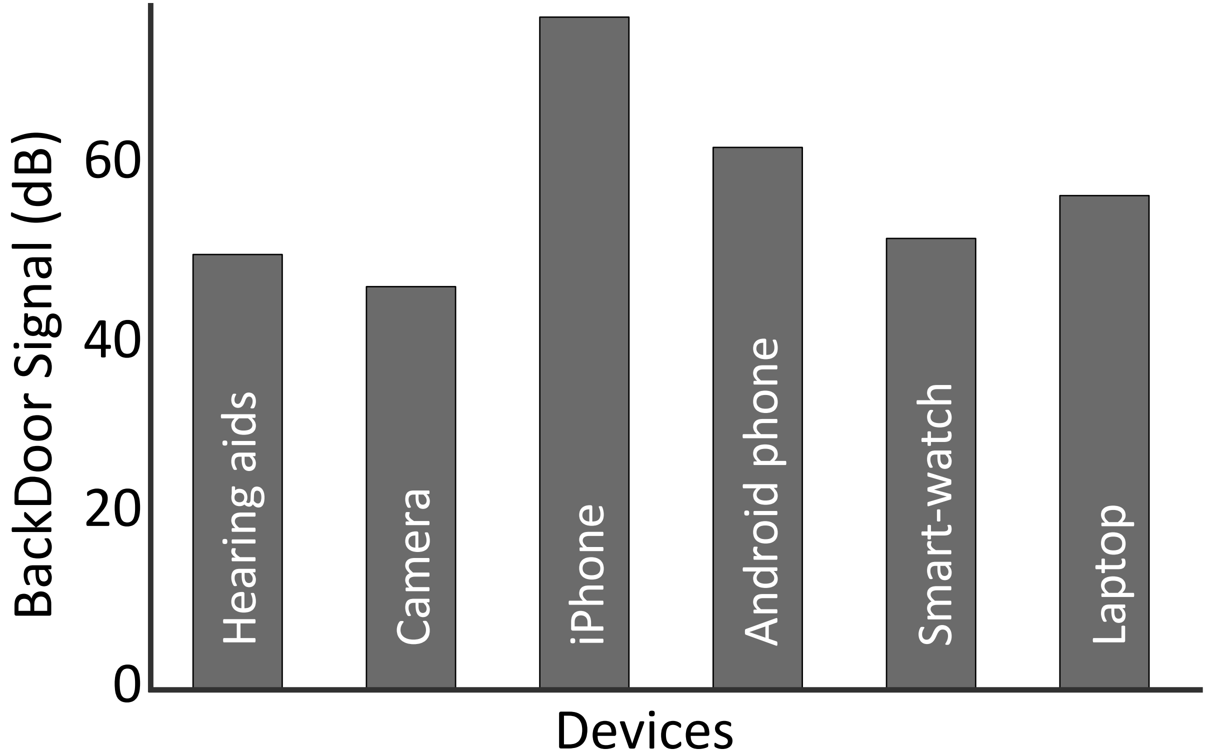


Figure 5: (a)The intermodulation distortion of signal (b) Harmonic distortion.

Hardware generalizability





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

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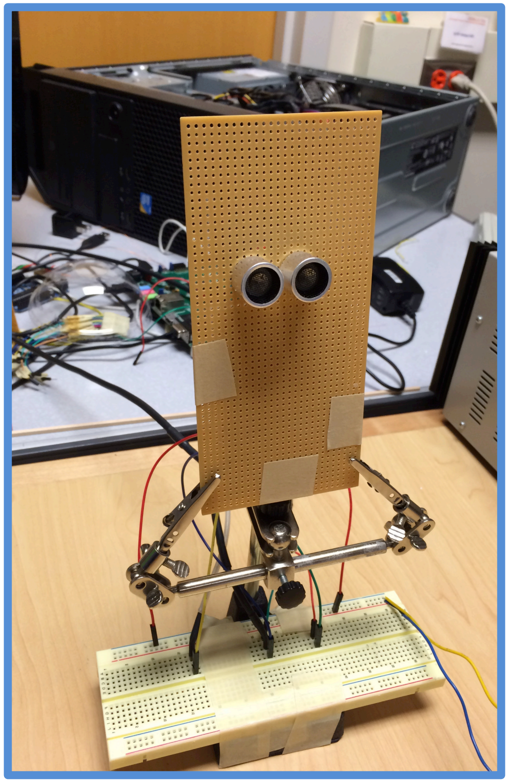
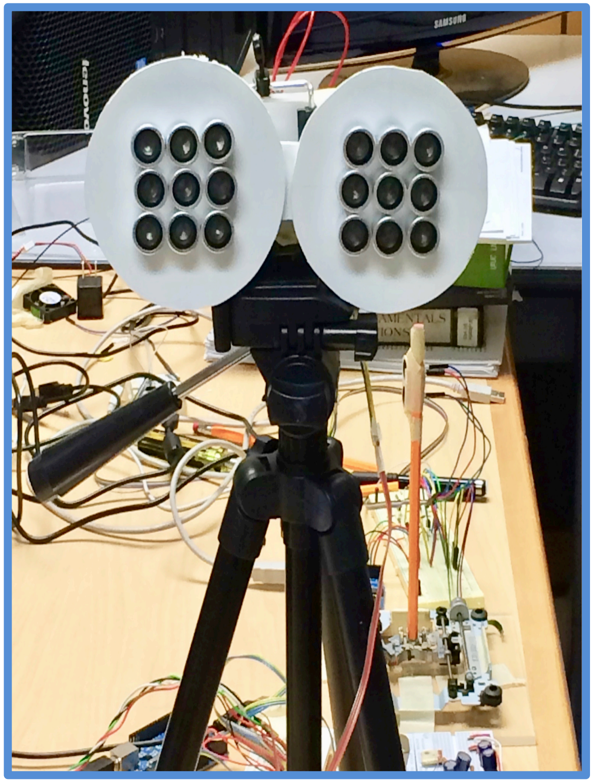
Implementation

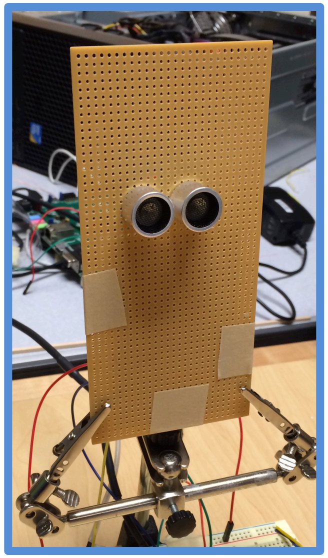


Communication prototype



Jammer prototype

Communication performance

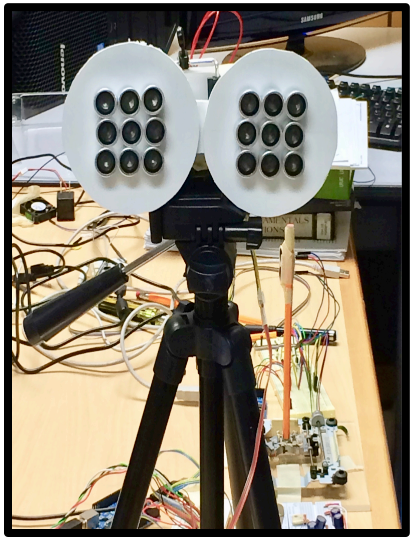


FM data packets

4kbps
up to 1 meter

More power can increase the distance

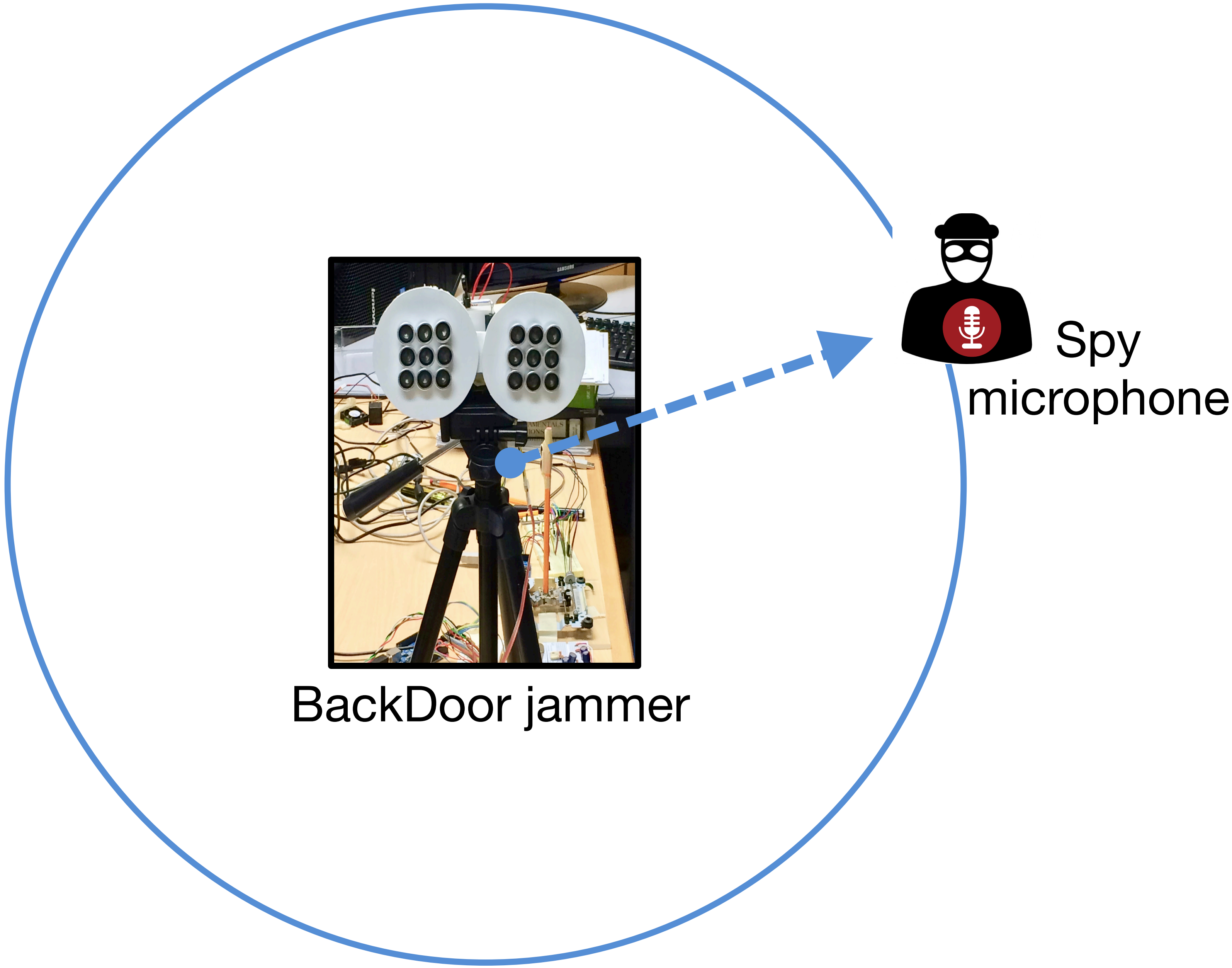
Jamming performance



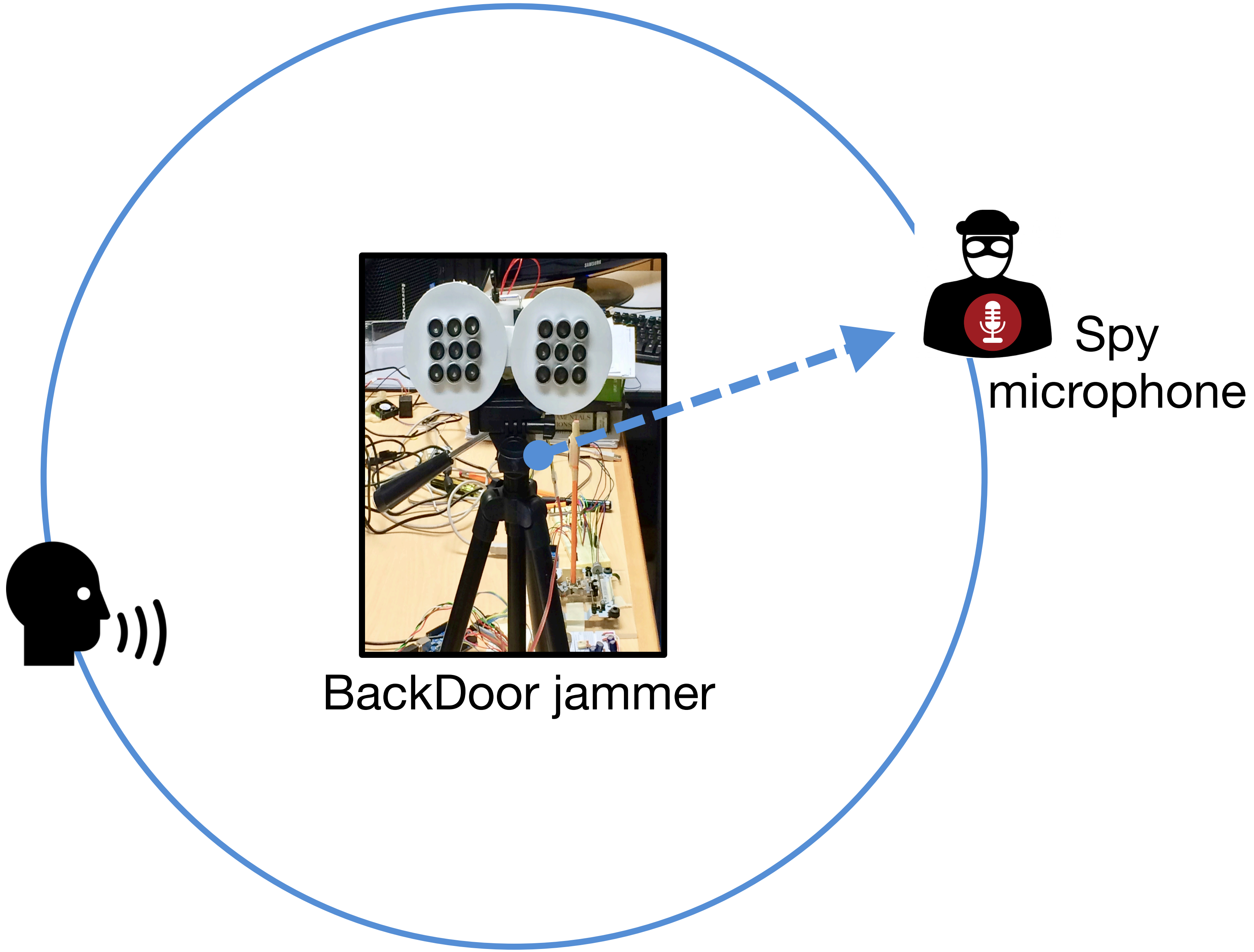
BackDoor jammer

Spy microphone

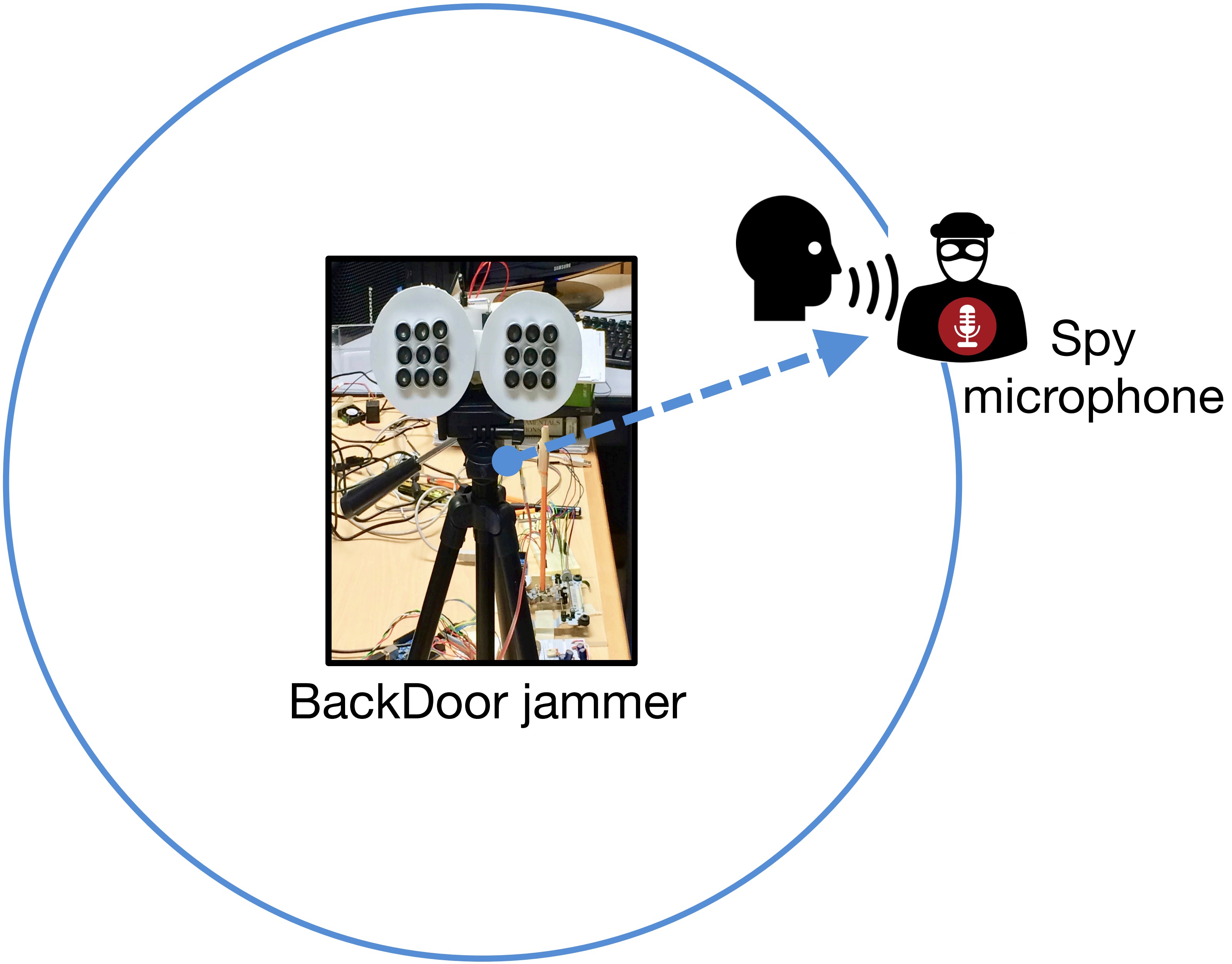
Jamming performance



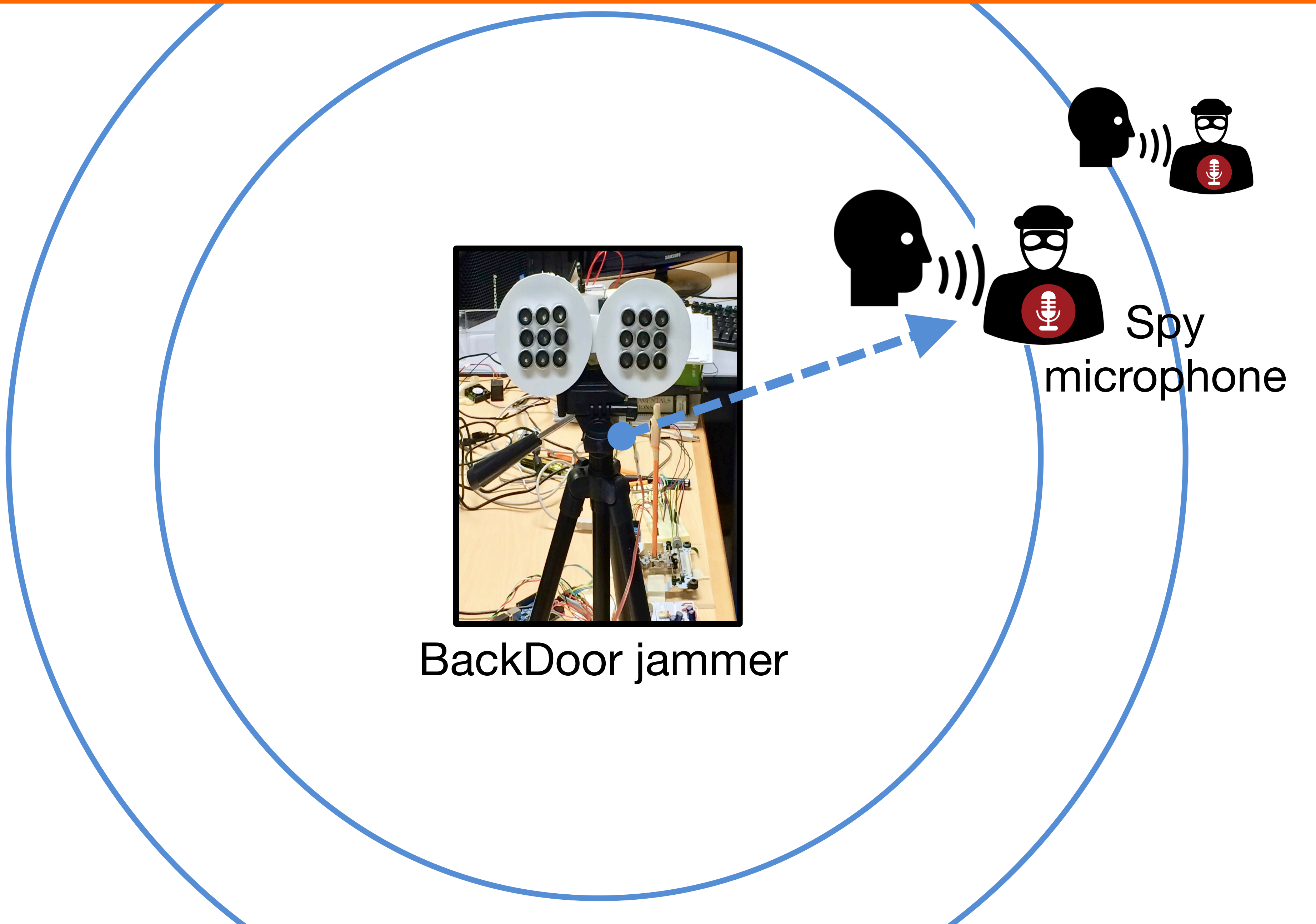
Jamming performance



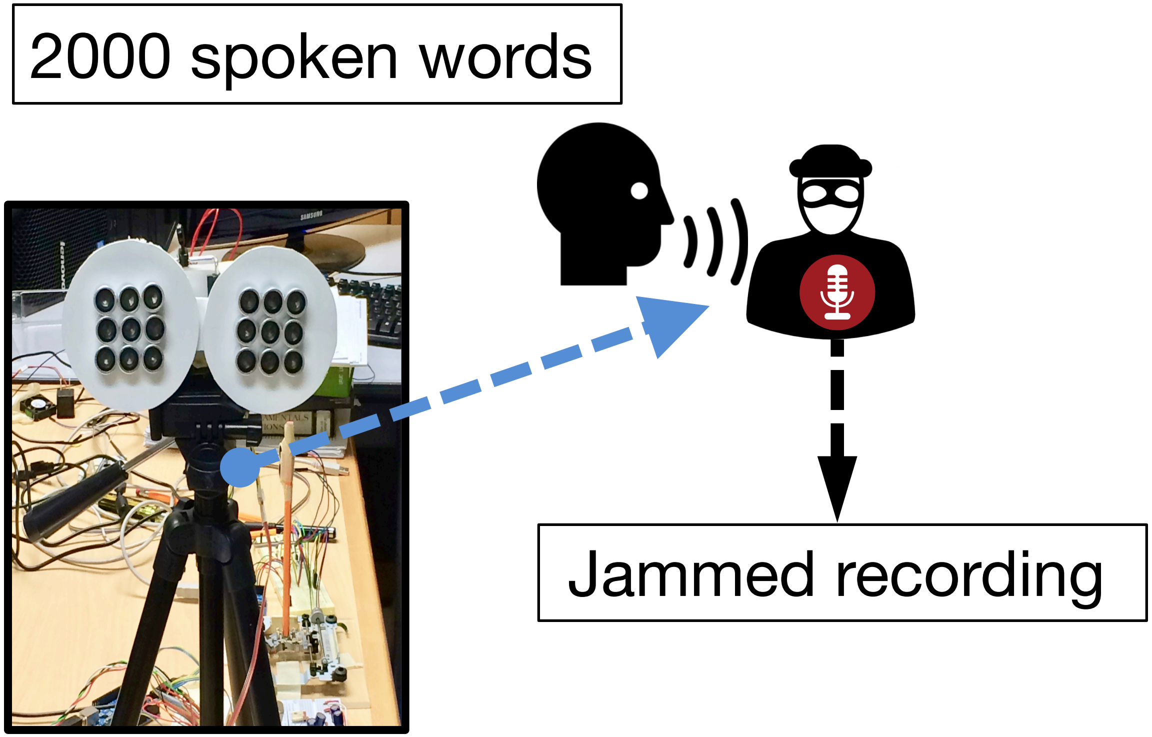
Jamming performance



Jamming performance

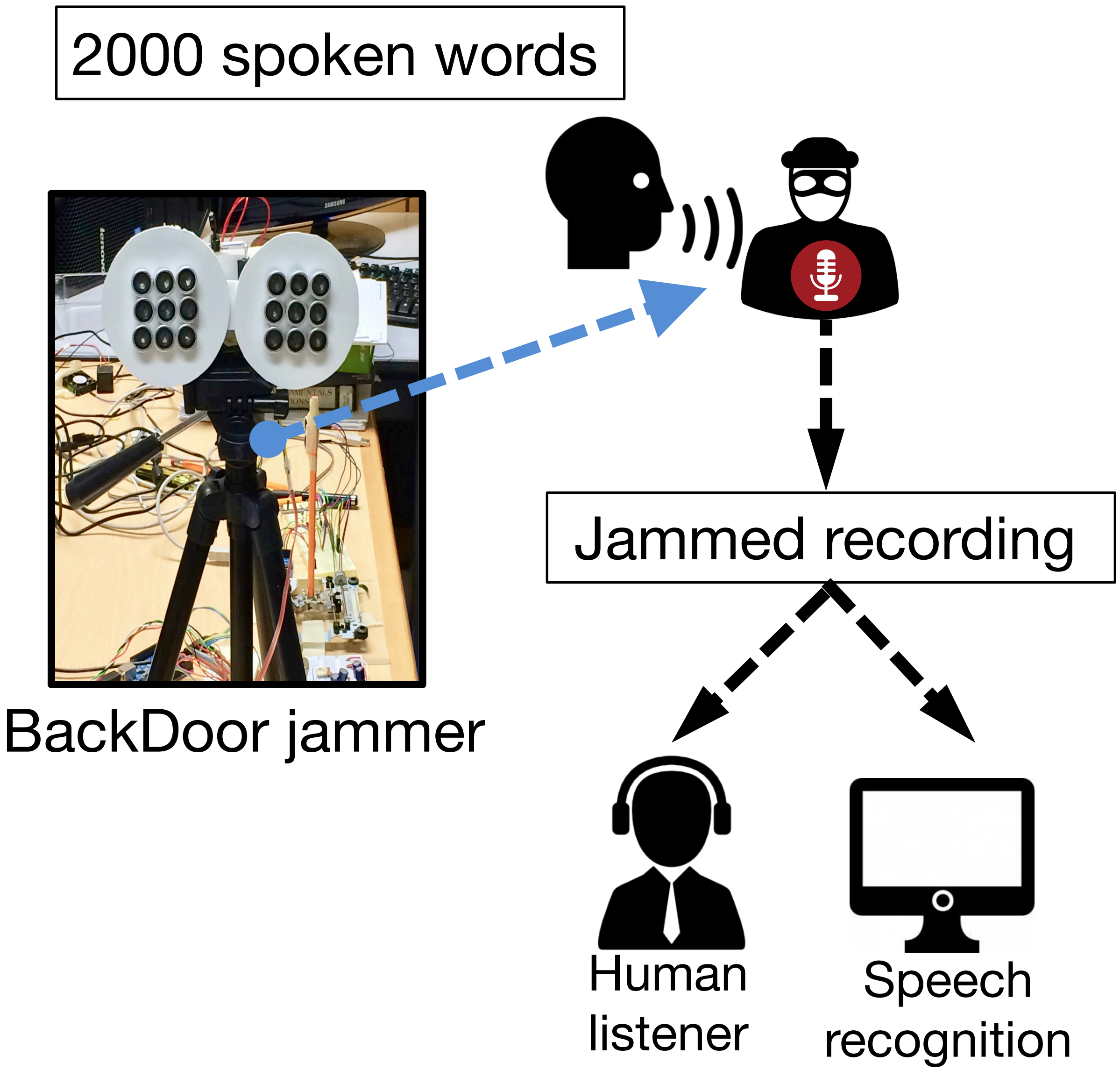


Jamming performance



BackDoor jammer

Jamming performance



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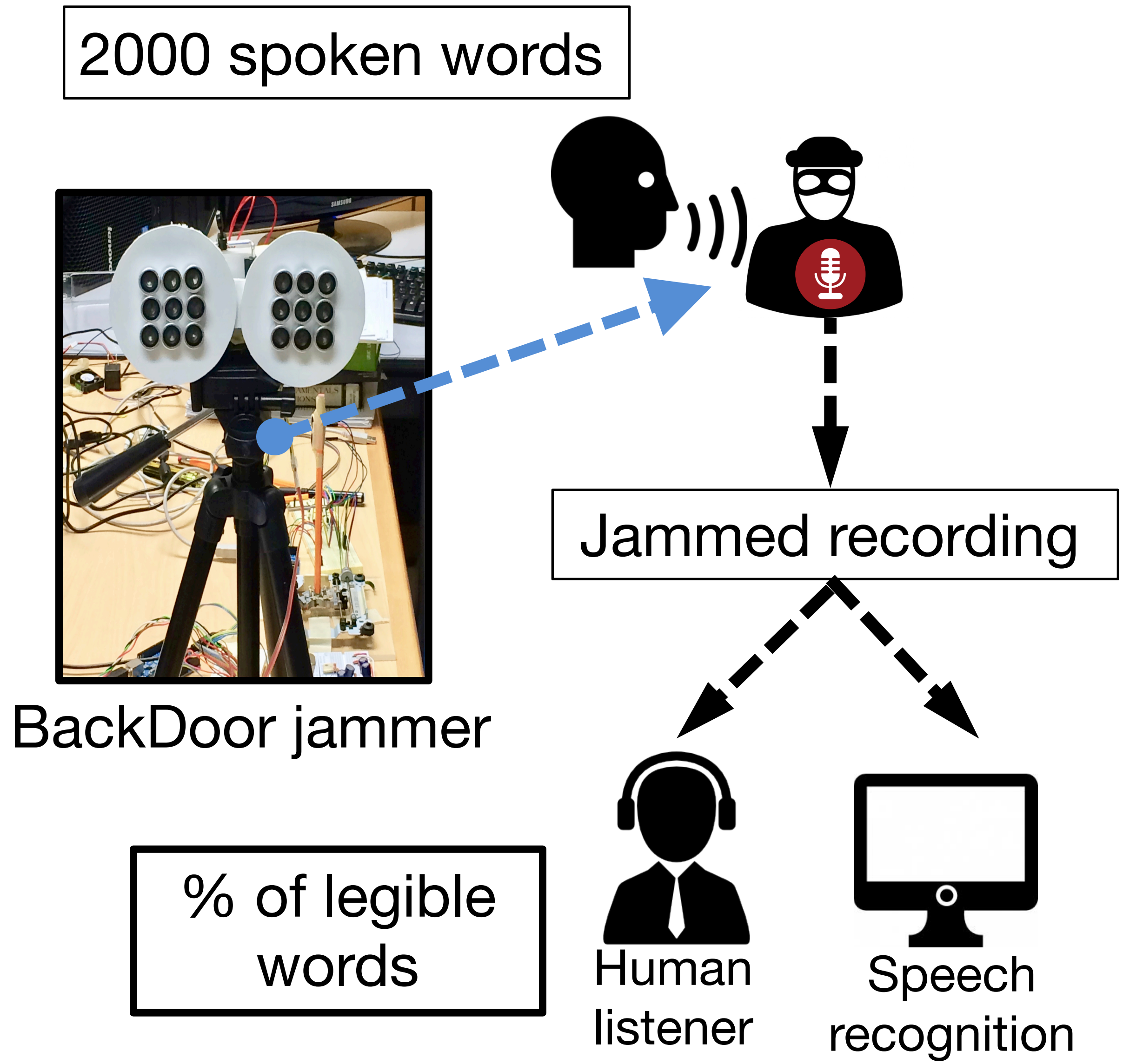

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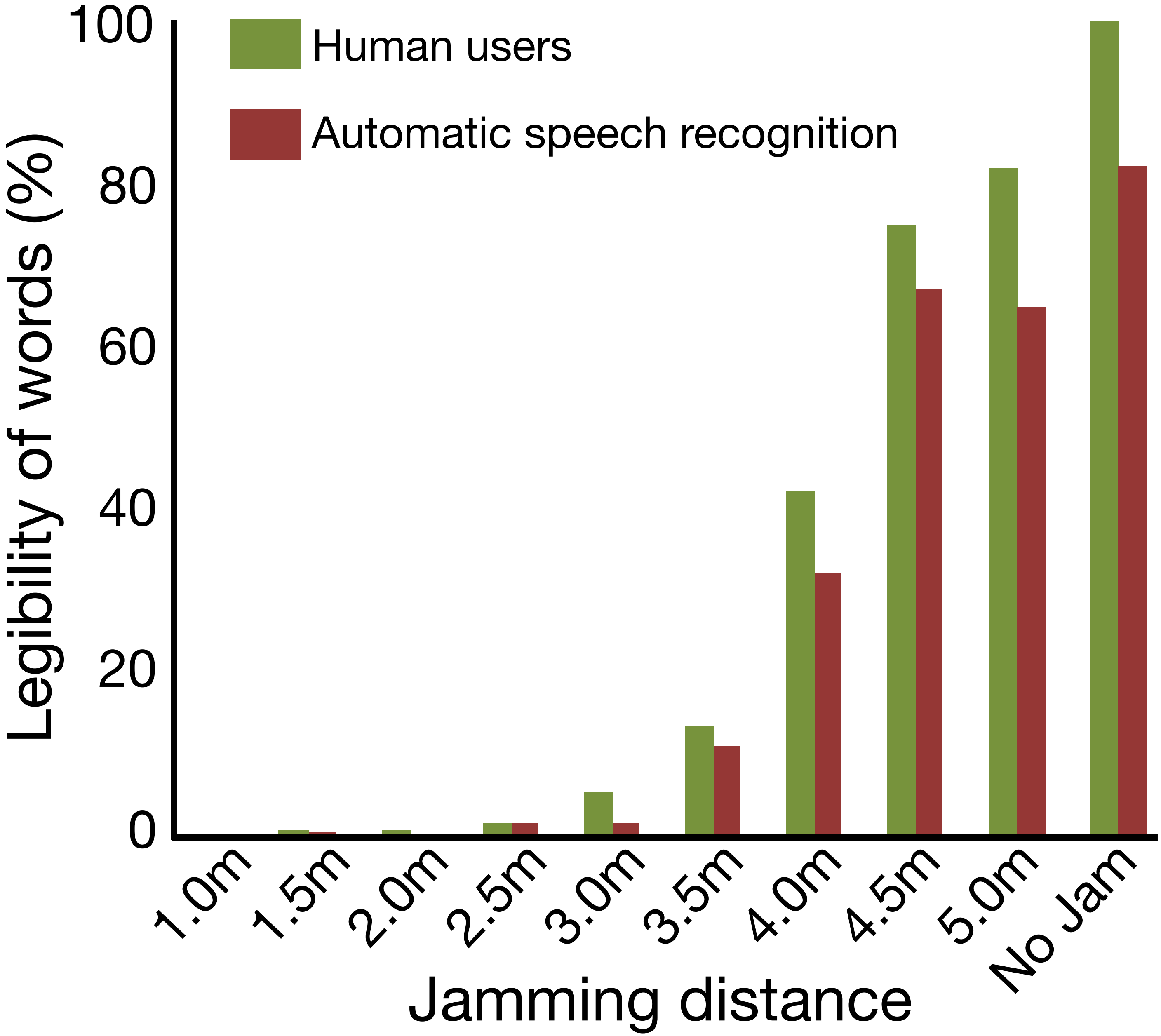

Jamming performance

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