阿里安全
ALIBABA SECURITY

SONIC GUN TO SMART DEVICES

YOUR DEVICES LOSE CONTROL UNDER ULTRASOUND/SOUND

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CAICT
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About Us

- Who are we:
  A research team of Alibaba security.

- Our research interests:
  Security issues about IoT, AI and their combinations.

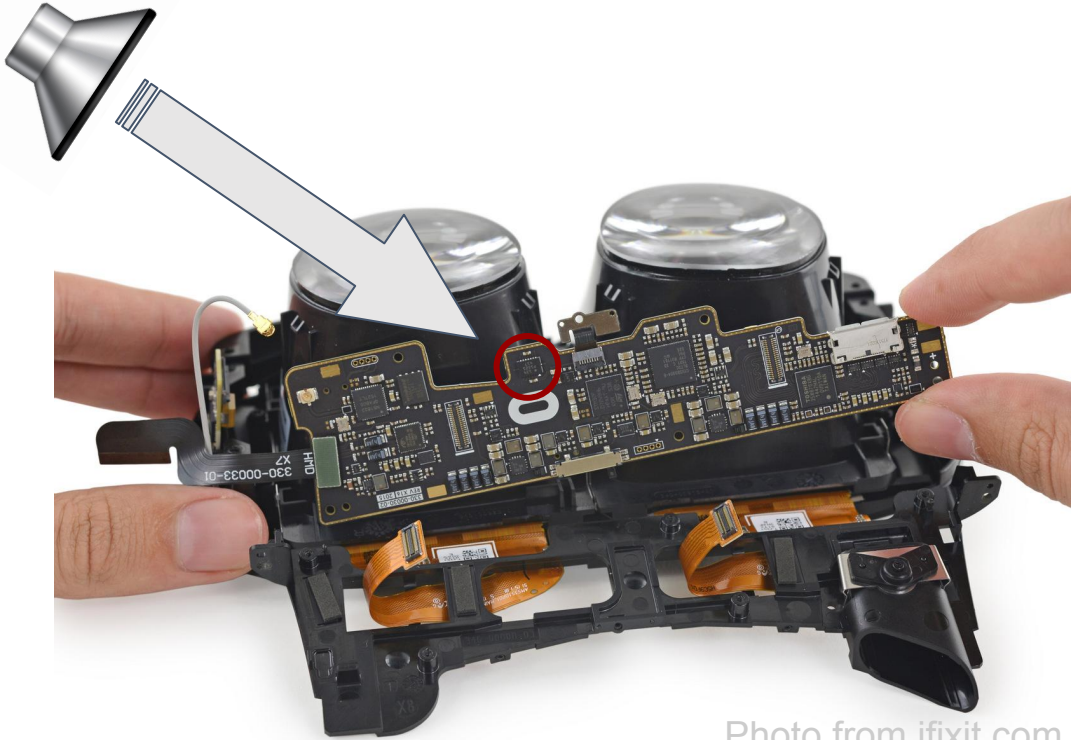
- Previous briefing:
  Time and Position Spoofing with Open Source Projects
  Blackhat Europe 2015

Outline

- An attack demo of Oculus headset
- Physical Principle of MEMS
- Other attack attempts on VR devices
- Attack attempts on drones
- Attack attempts on self-balanced vehicles -
- Countermeasures

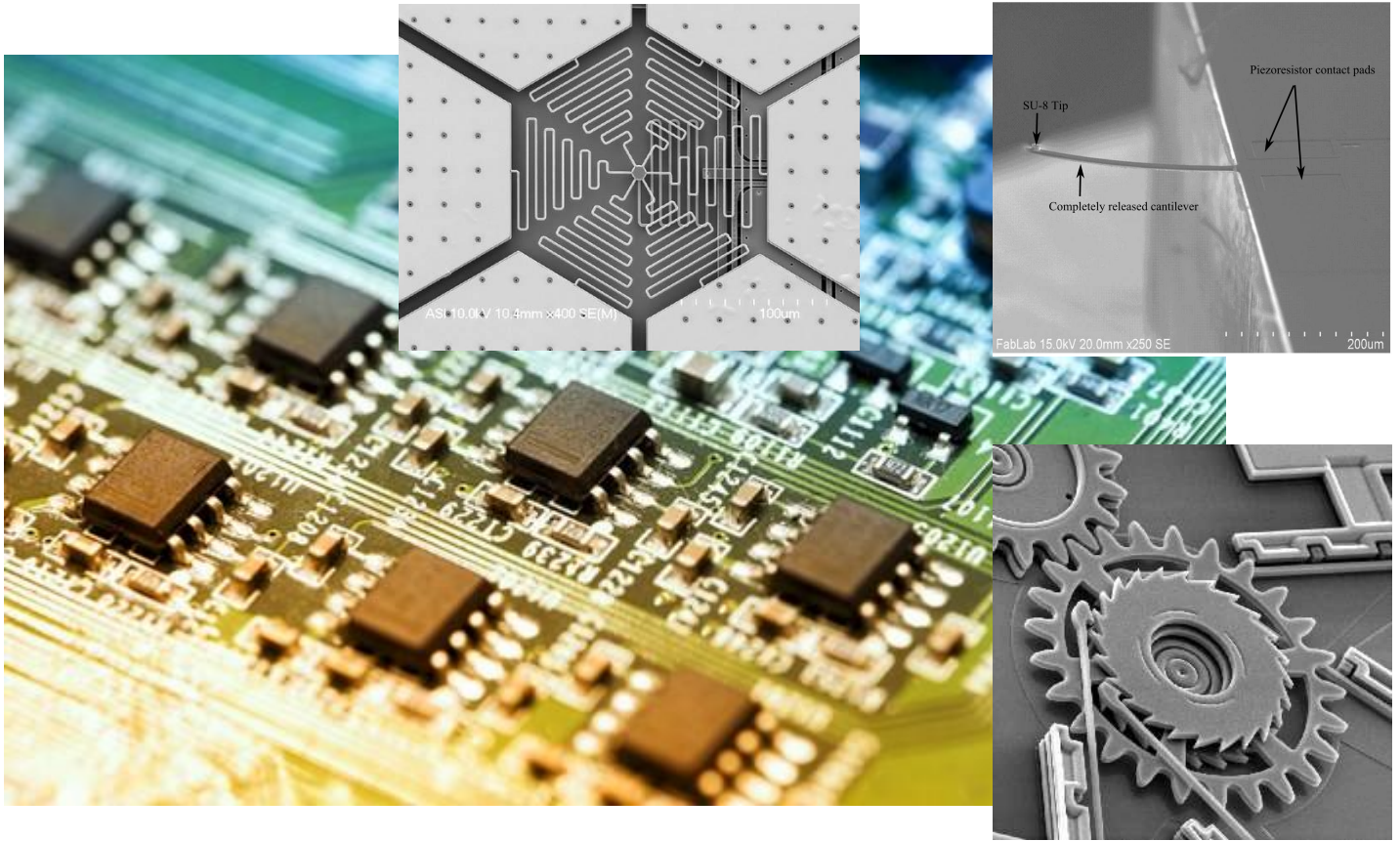
Attack Demo on Facebook Oculus

How This Happens?



What is MEMS

Micro Electro-Mechanical Systems

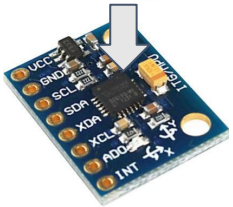


What is MEMS


12:45
75°F


htc

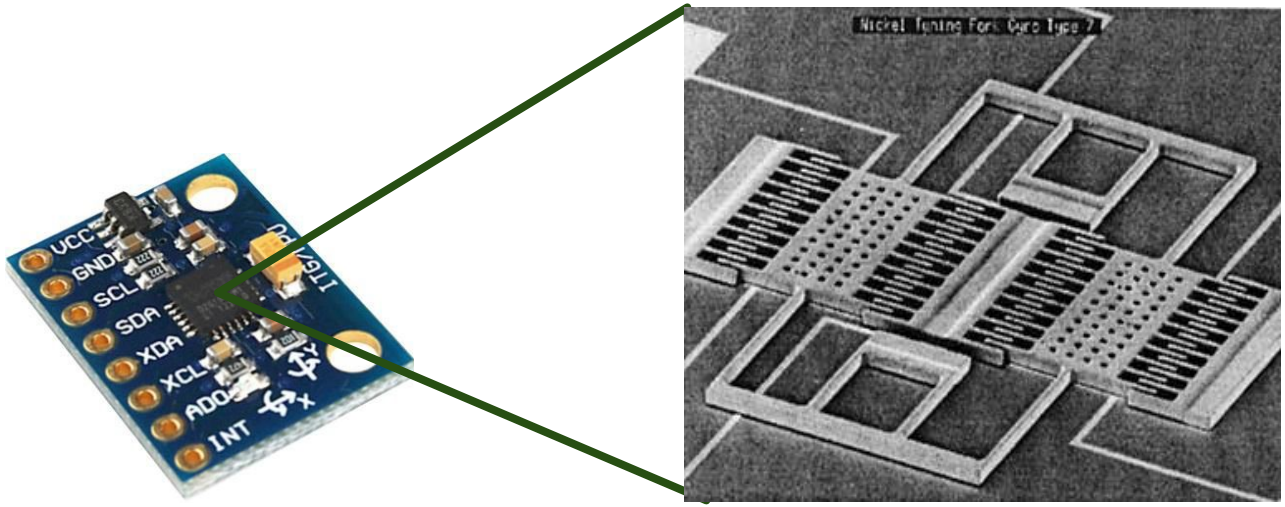

Oculus


VCC
GND
SCL
SDA
XDA
XCL
ADO
INT


htc
SAMSUNG
2:45

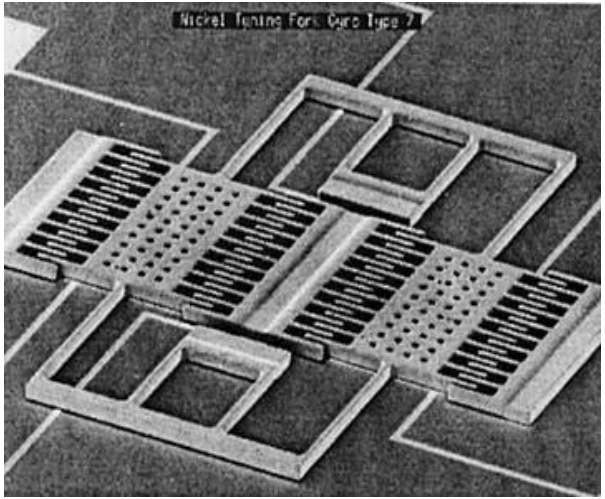
How MEMS Works

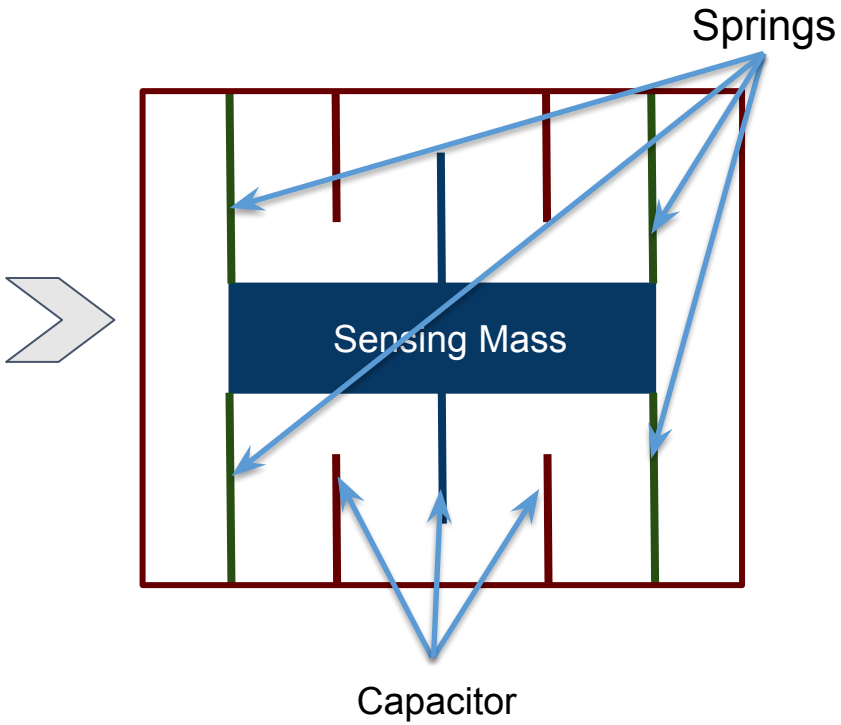
Accelerometer



How MEMS Works

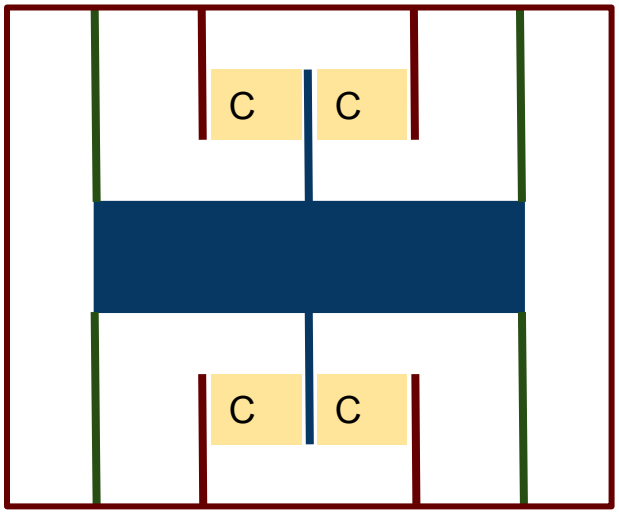
Accelerometer





How MEMS Works

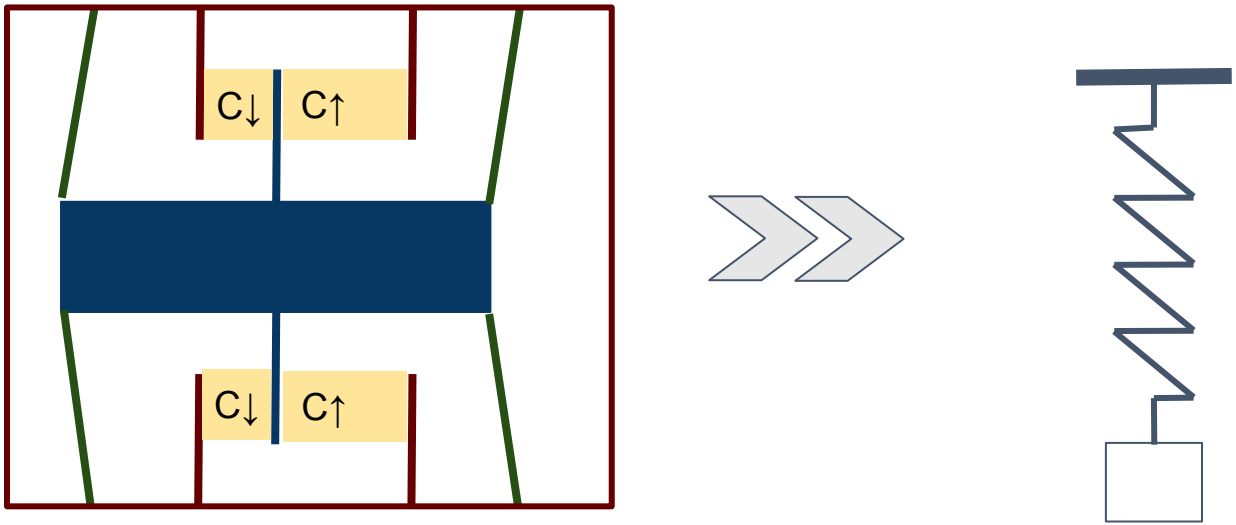
Accelerometer



1 DoF (Degree of Freedom)
Spring-Mass System

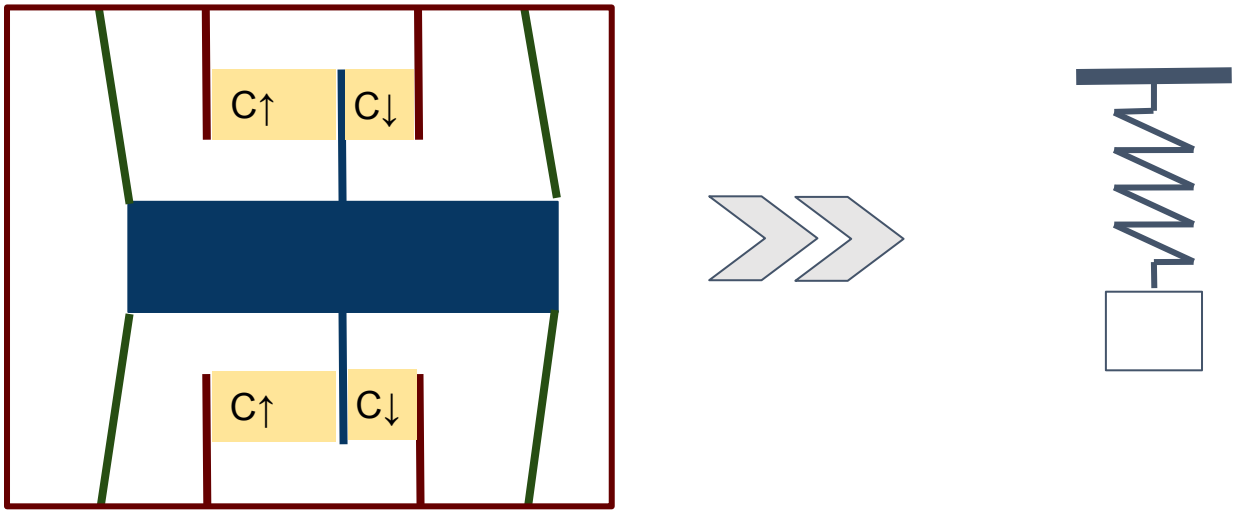
How MEMS Works

Accelerometer



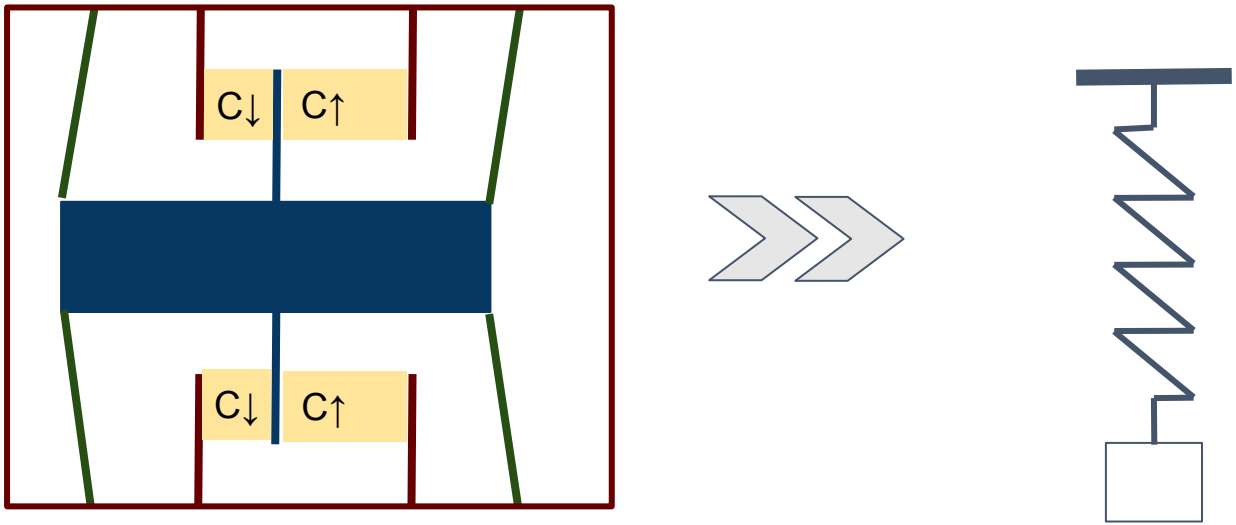
How MEMS Works

Accelerometer



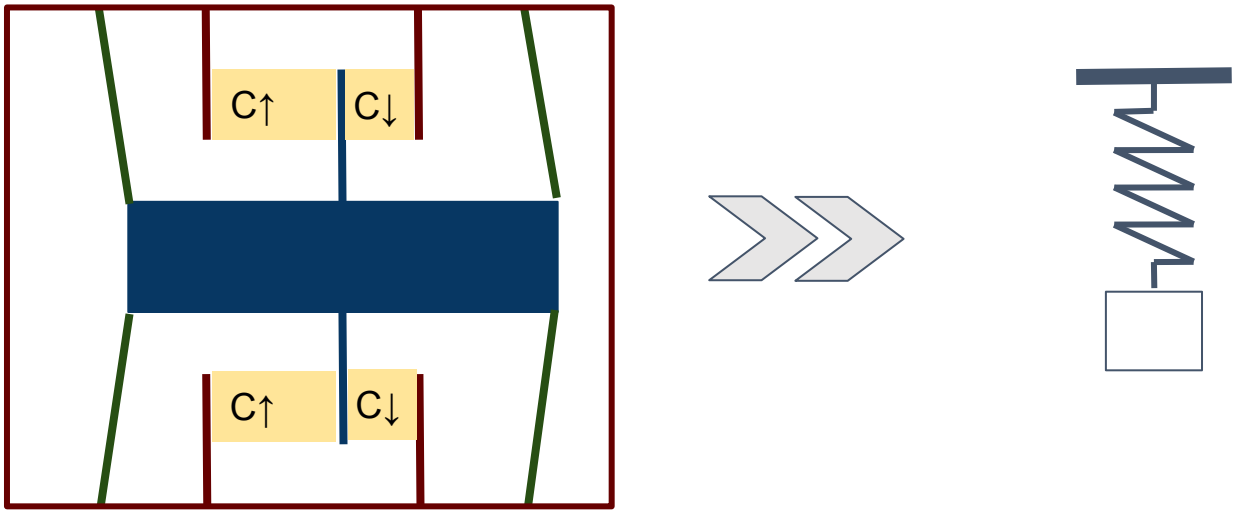
How MEMS Works

Accelerometer



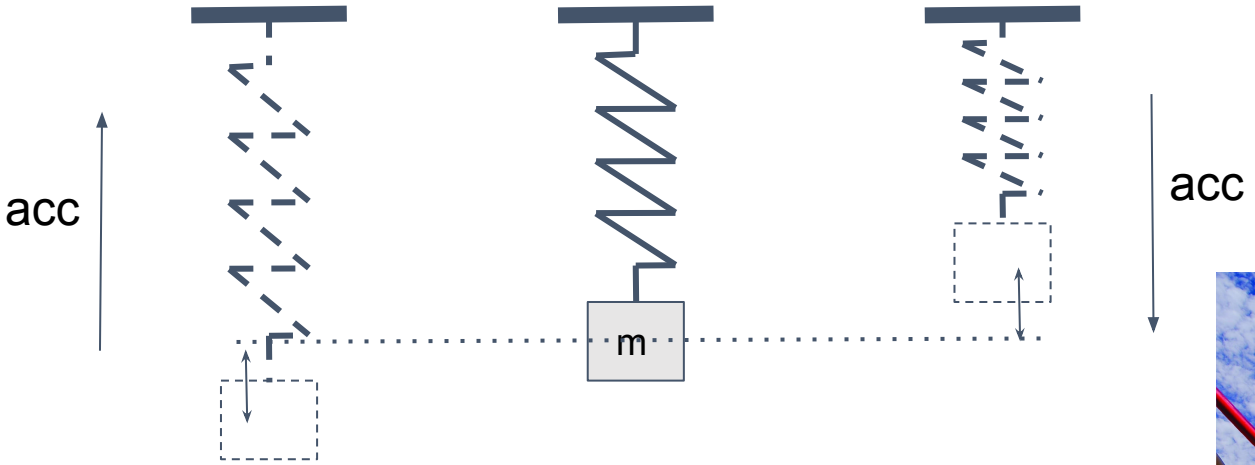
How MEMS Works

Accelerometer



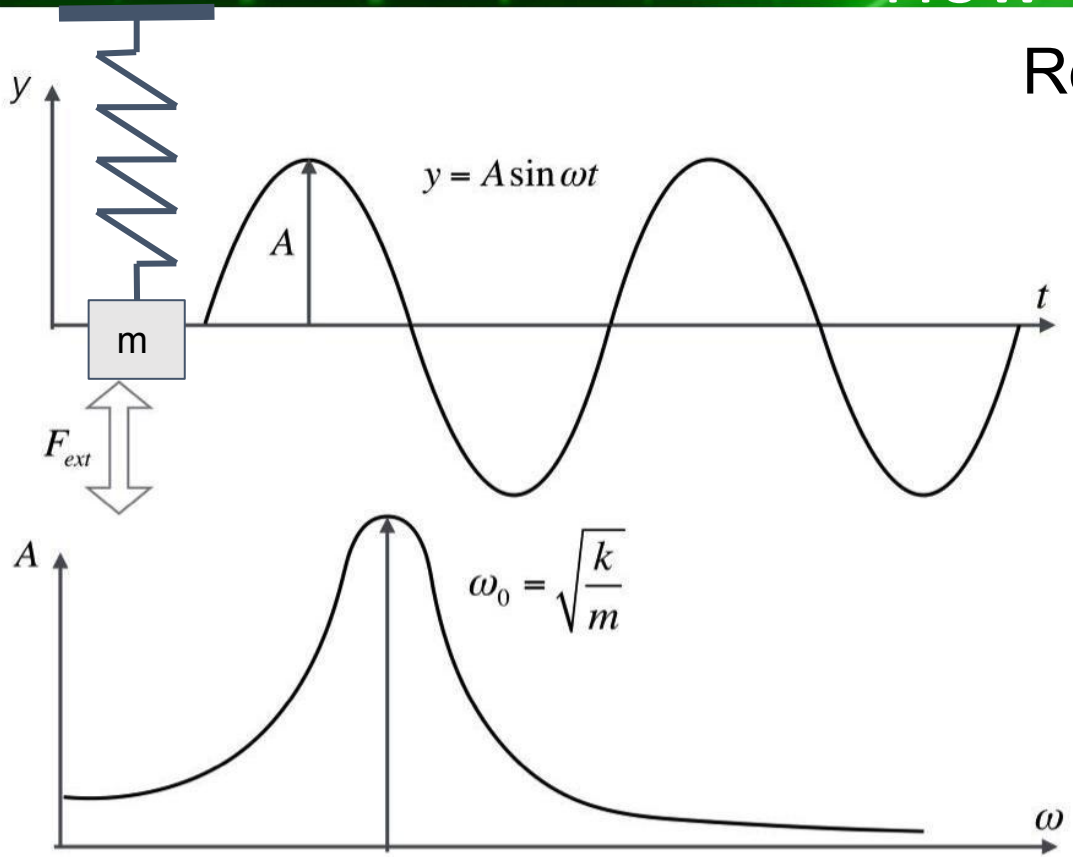
How MEMS Works

Accelerometer



How to Attack

Resonance



Previous Work

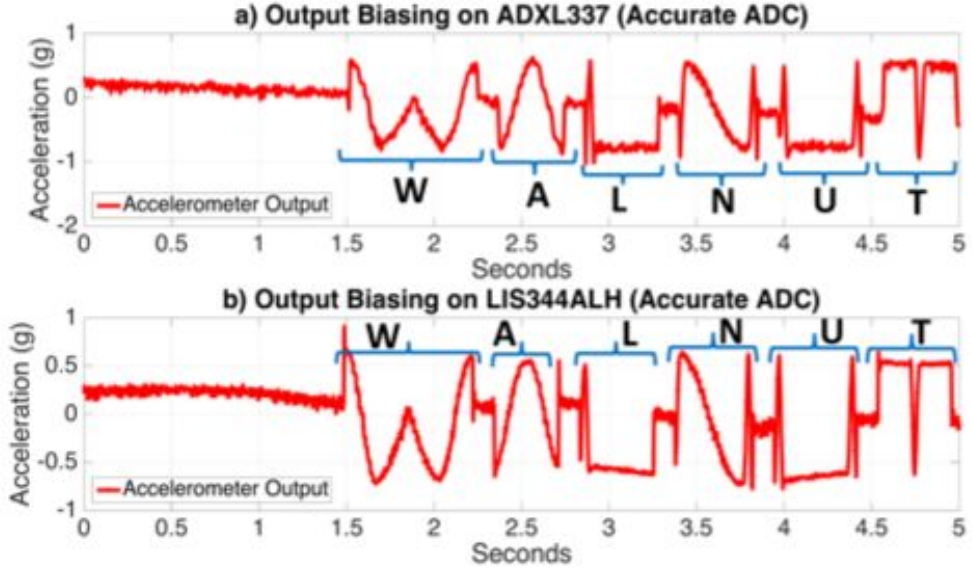
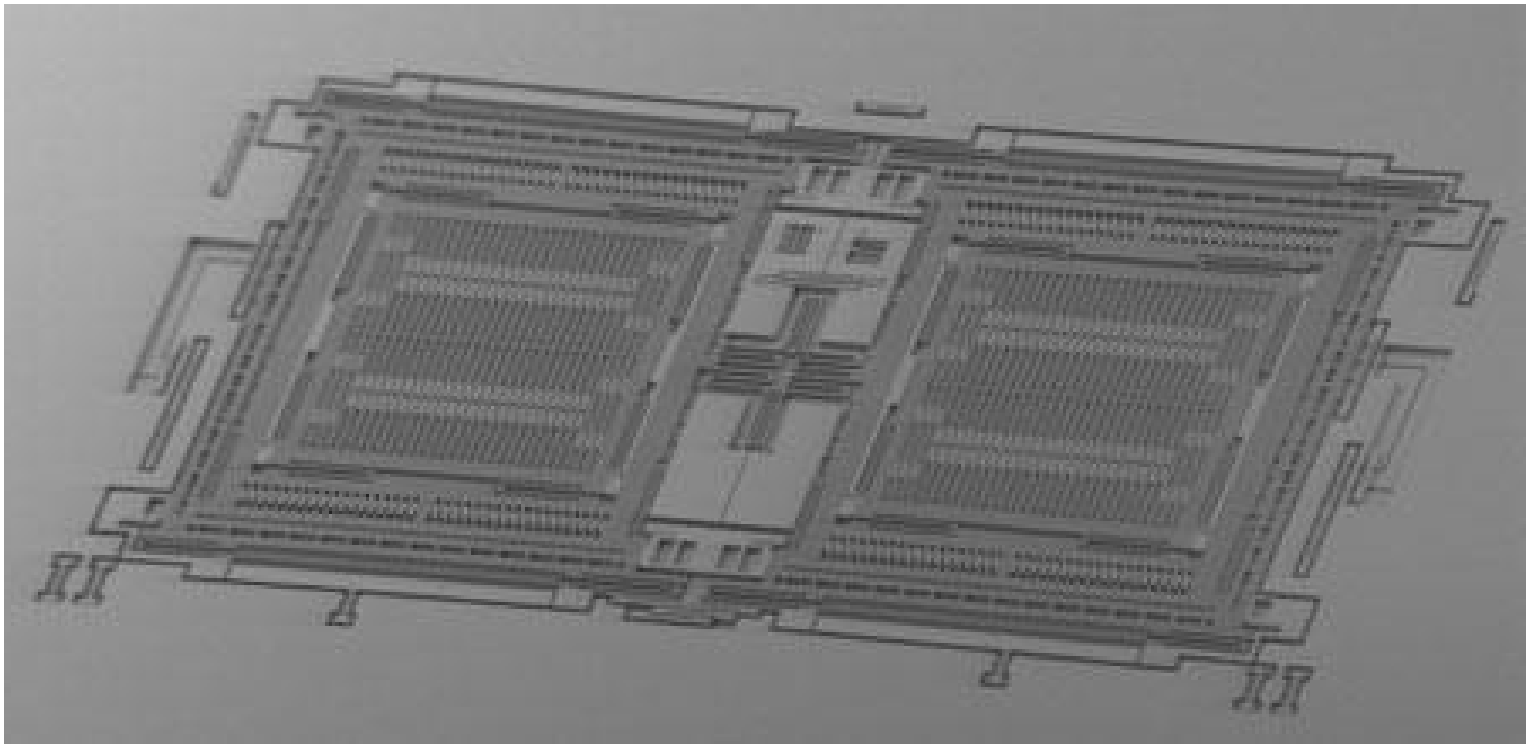


Figure 11. **Spelling WALNUT: Output Biasing Attack on Sensors with Accurate ADCs**. We demonstrate the output biasing attack can control

T. Trippel, et al. EuroS&P, 2017.

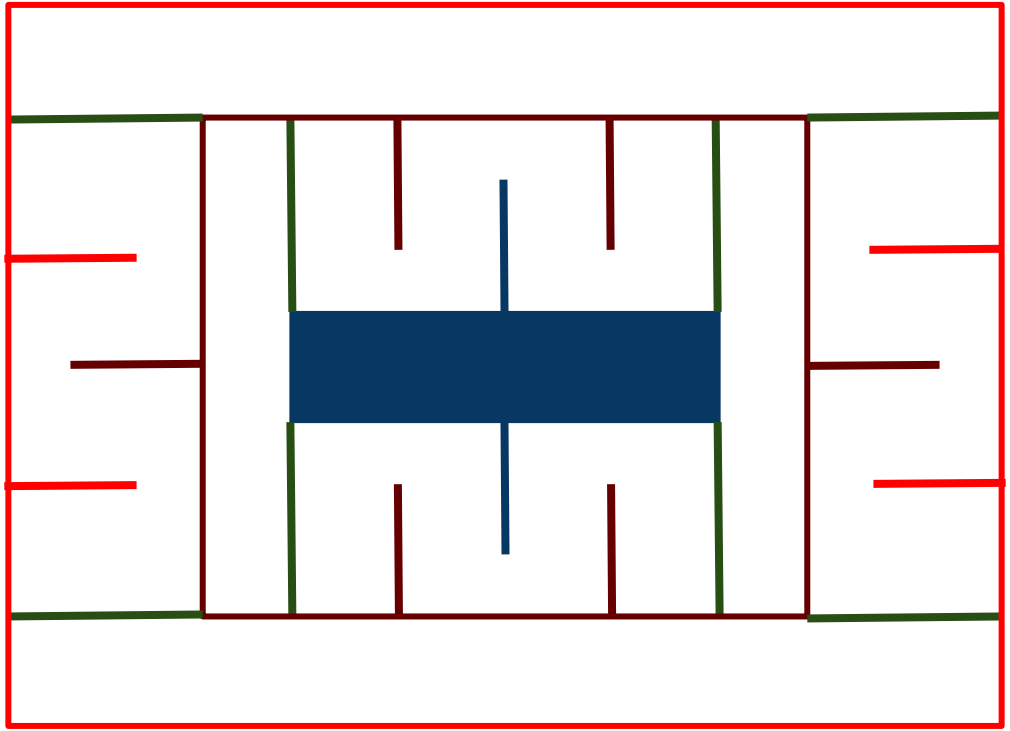
How MEMS Works

Gyroscope



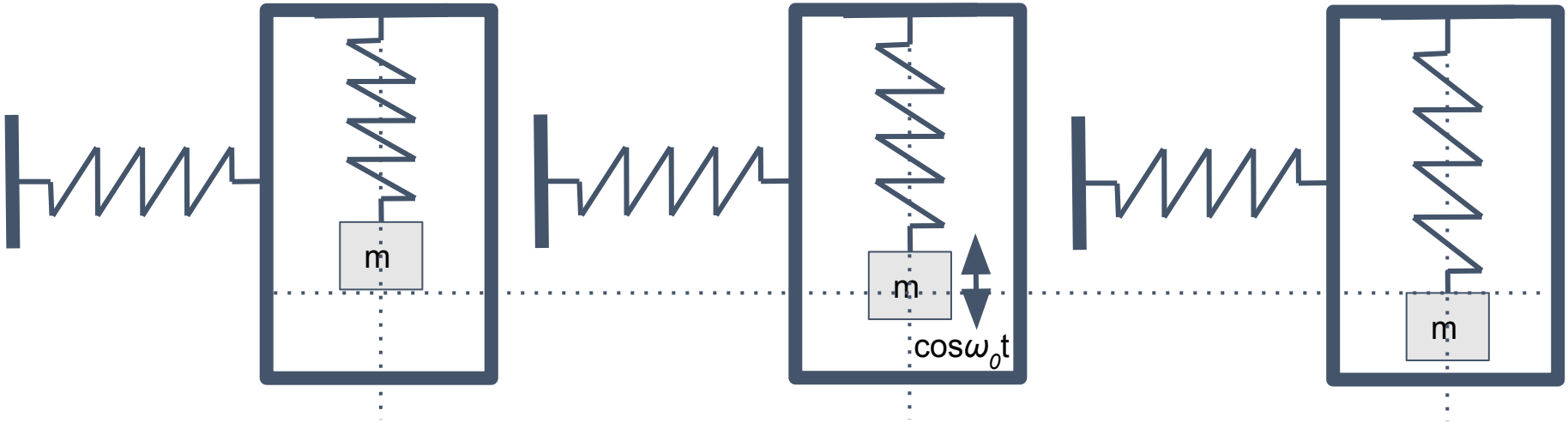
How MEMS Works

Gyroscope



How MEMS Works

Gyroscope

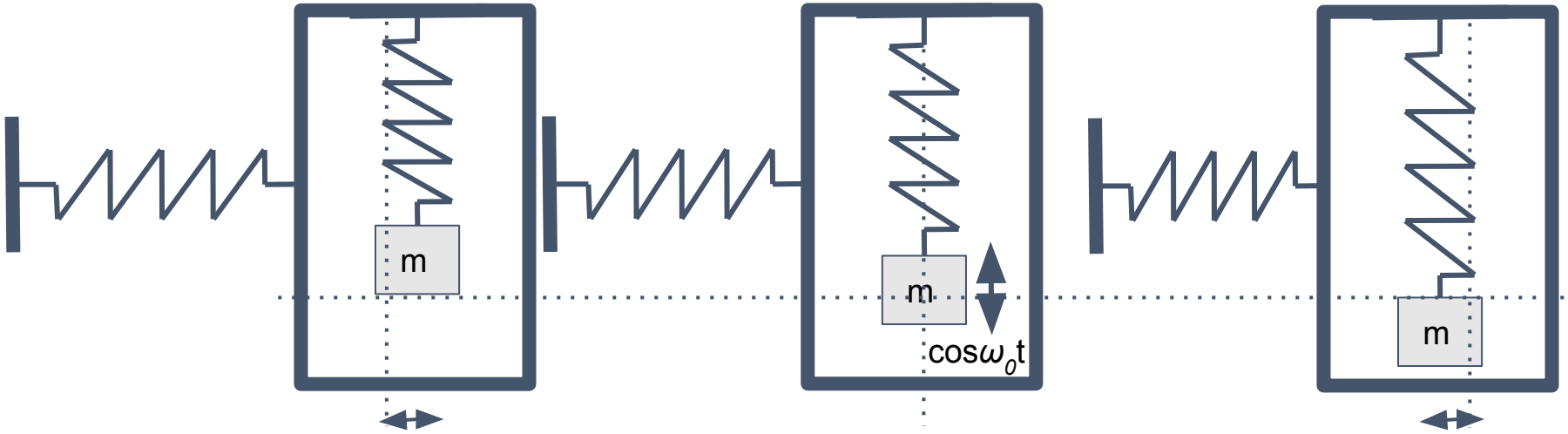


No Rotation

2 DoF (Degree of Freedom)
Spring-Mass System

How MEMS Works

Gyroscope



How MEMS Works

Gyroscope

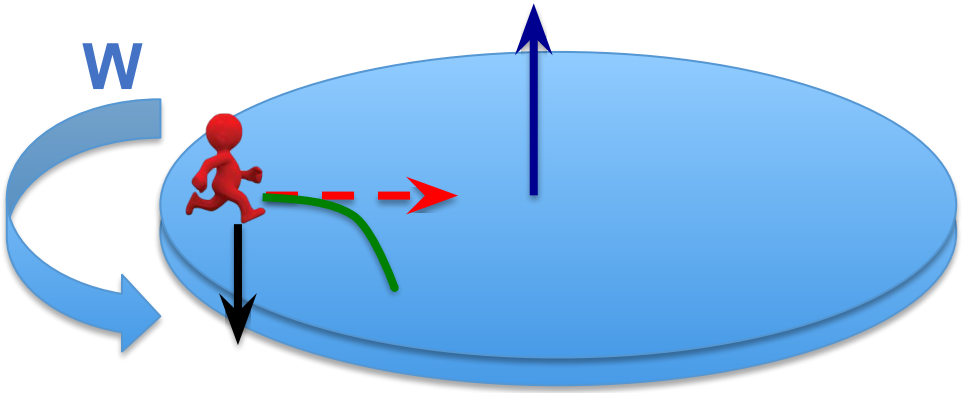
$$F_c = 2m\mathbf{v}\times\mathbf{W}$$

F_c - Coriolis force

m - vibratory mass

v - linear velocity

W - angular rotation



How MEMS Works

Gyroscope

$$F_c = 2m\mathbf{v}\times\mathbf{W}$$

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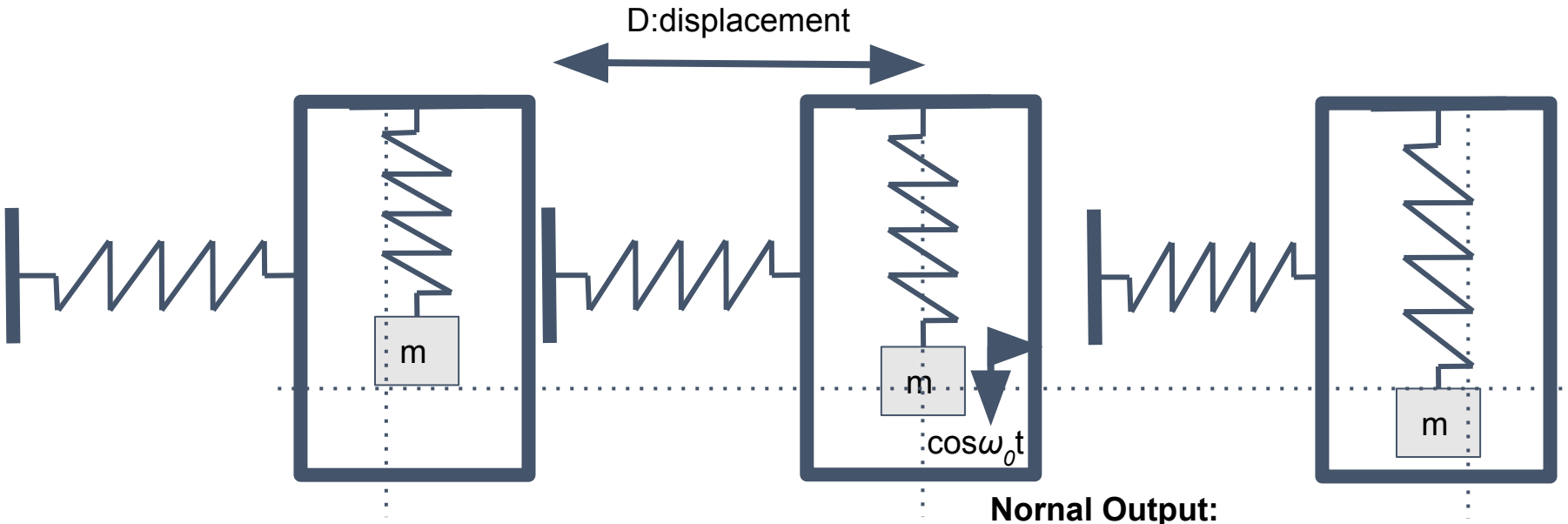
How MEMS Works



Rotation

Nornal Output:

OUT = LPF{2 D cos $\omega_0 t$}
= LPF{2 A cos $\omega_0 t$ cos $\omega_0 t$}
= LPF{A + A cos $2\omega_0 t$}
= A

How to Attack

Gyroscope

Displacement Under Attack:

$D = A_u \cos(\omega_u t + \Delta\Phi)$

A_u : ultrasound induced amplitude

ω_u : ultrasound frequency

$\Delta\Phi$: ultrasound phase shift

Attack Output:

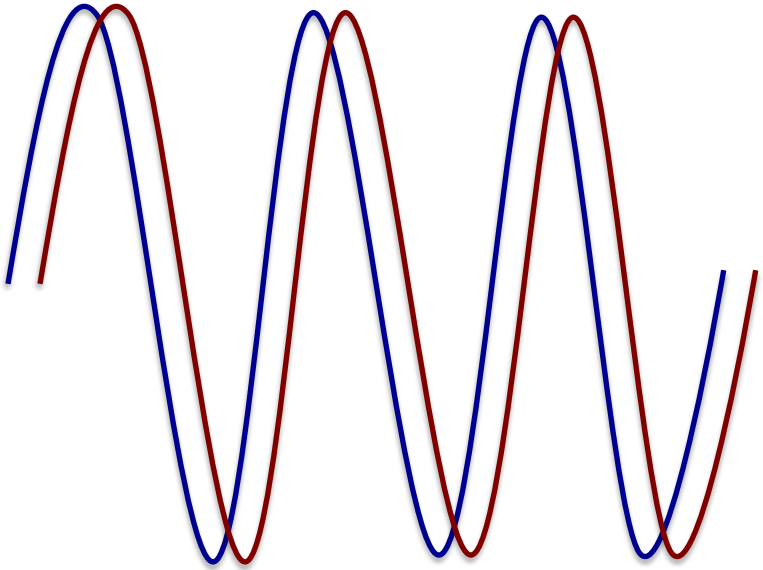
$OUT = LPF\{2\ D \cos \omega_0 t\}$

$= LPF\{A_u \cos [(\omega_0-\omega_u)t - \Delta\Phi] + A_u \cos [(\omega_0+\omega_u)t + \Delta\Phi]\}$

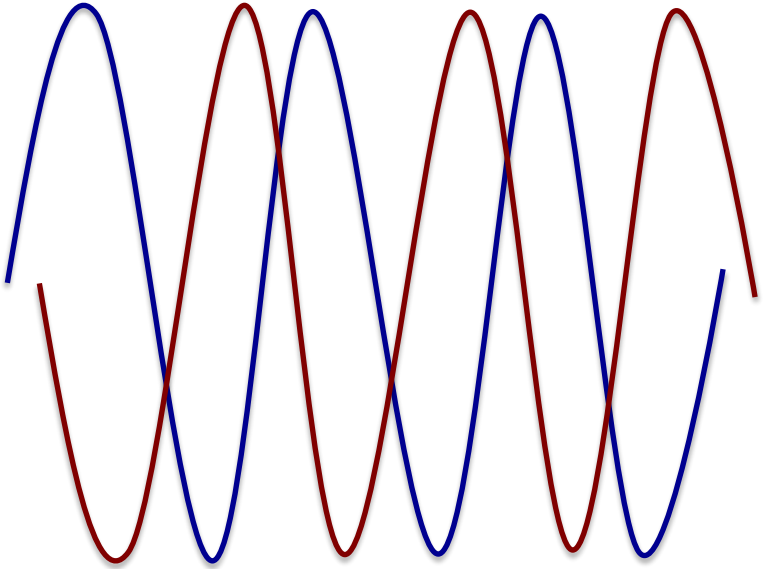
$= A_u \cos [(\omega_0-\omega_u)t - \Delta\Phi]$

How to Attack

Gyroscope



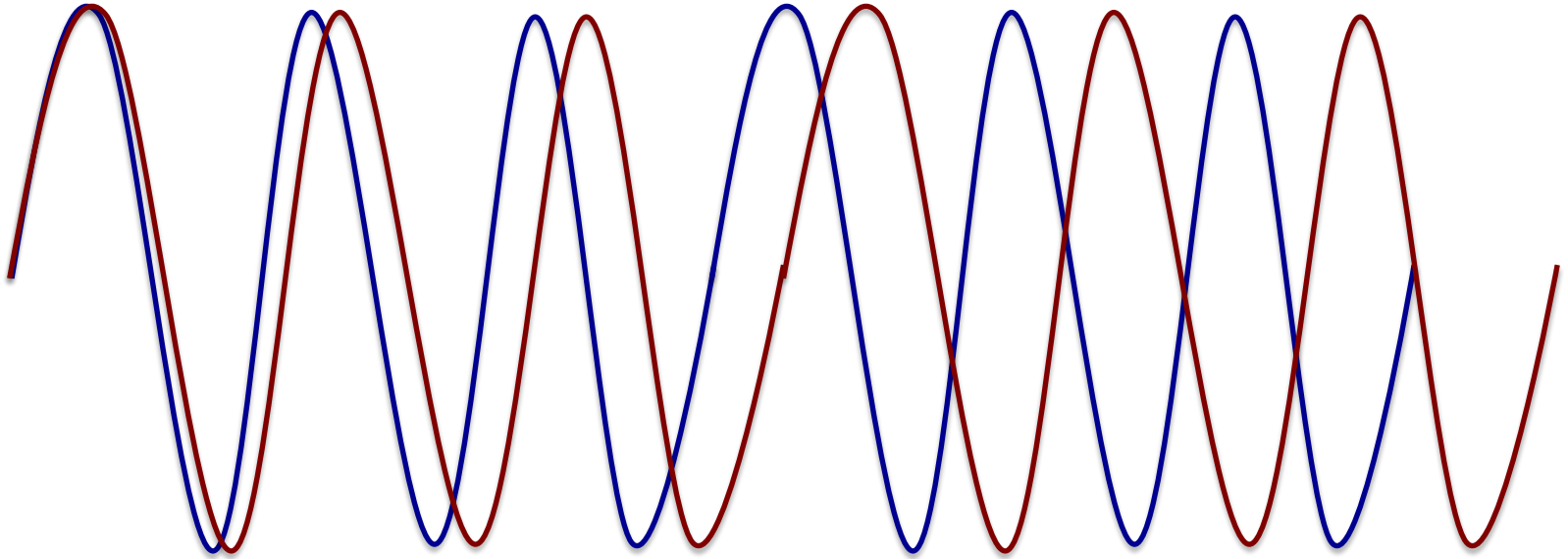
$0 < \Delta\varphi < \pi$
OUT > 0



pi $< \Delta\varphi < 2\pi$
OUT < 0

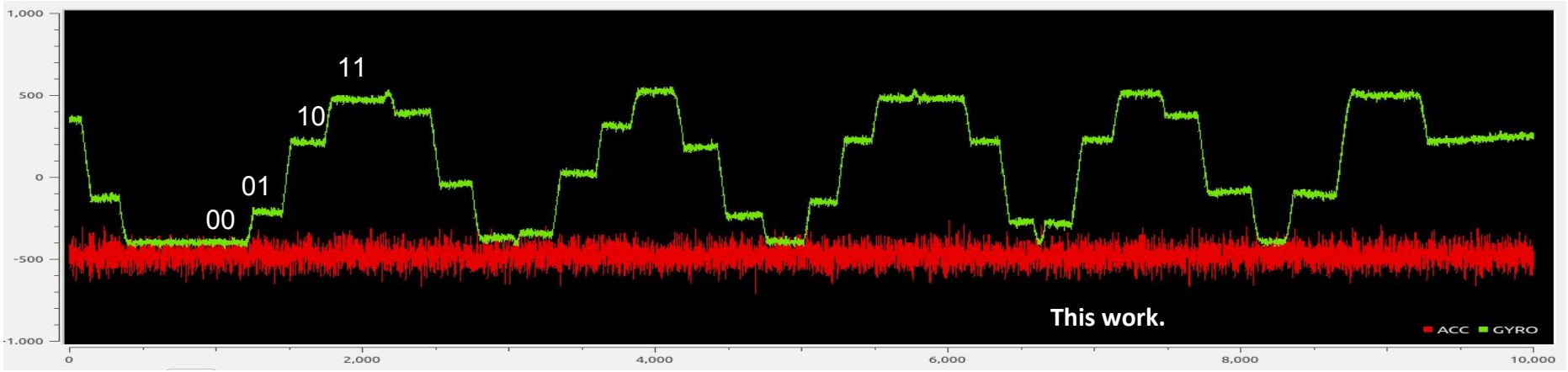
How to Attack

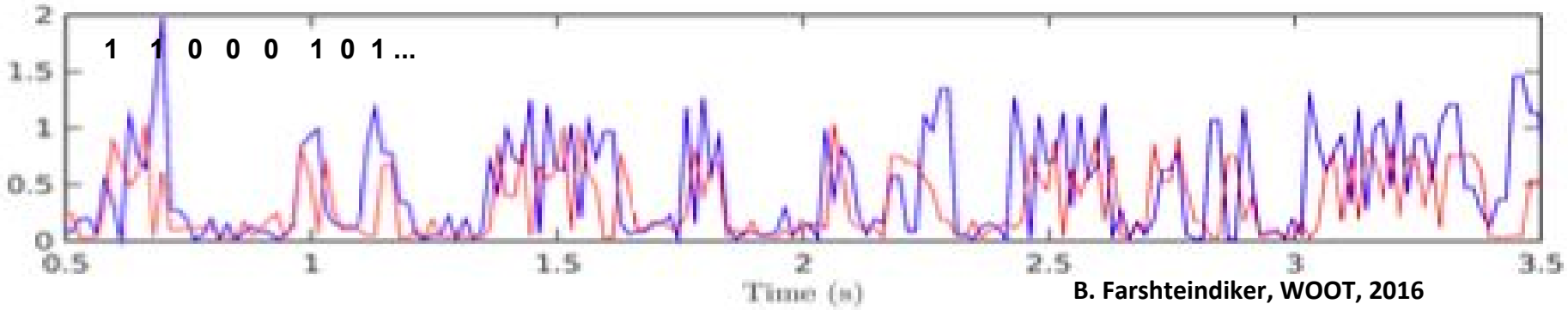
Gyroscope



$\Delta\varphi$: 0 → π

Modulation Demo





B. Farshteindiker, WOOT, 2016

Attack Attempts

VR Devices(including Phones)

- Facebook Oculus Rift CV1
- HTC Vive + Controller
- Microsoft HoloLens
- iPhone 7
- Samsung Galaxy S7

Drone

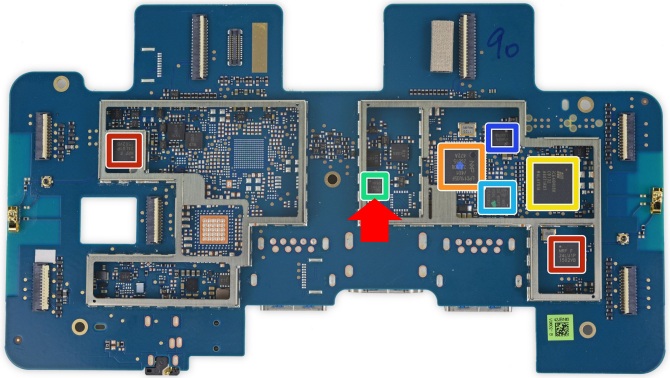
- DJI phantom 3

Self Balancing Vehicles(including Toys)

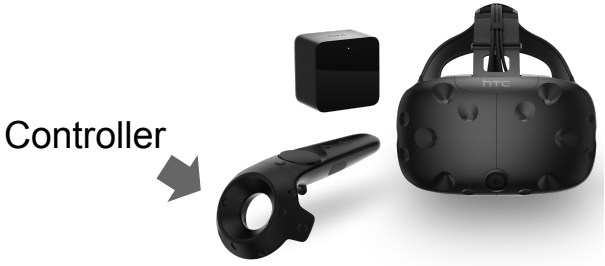
- DIY balancing robot
- Mi Mitu toy robot
- Mi Ninebot Mini

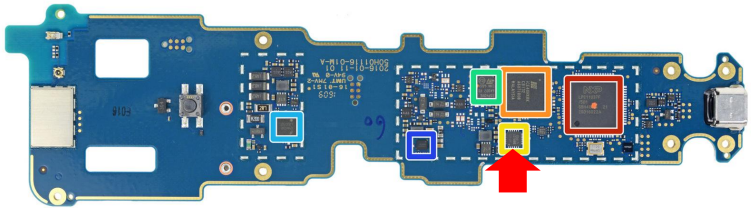
HTC Vive

- HTC Vive Headset



HTC Vive Controller





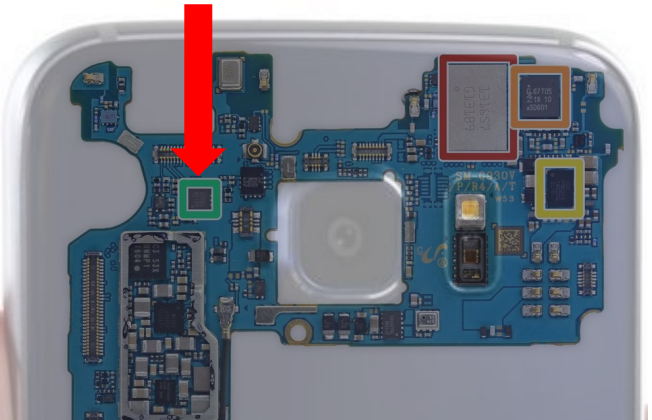
MEMS Chip

HoloLens

Video Demo: Samsung S7

STMicroelectronics LSM6DS3

MEMS Chip



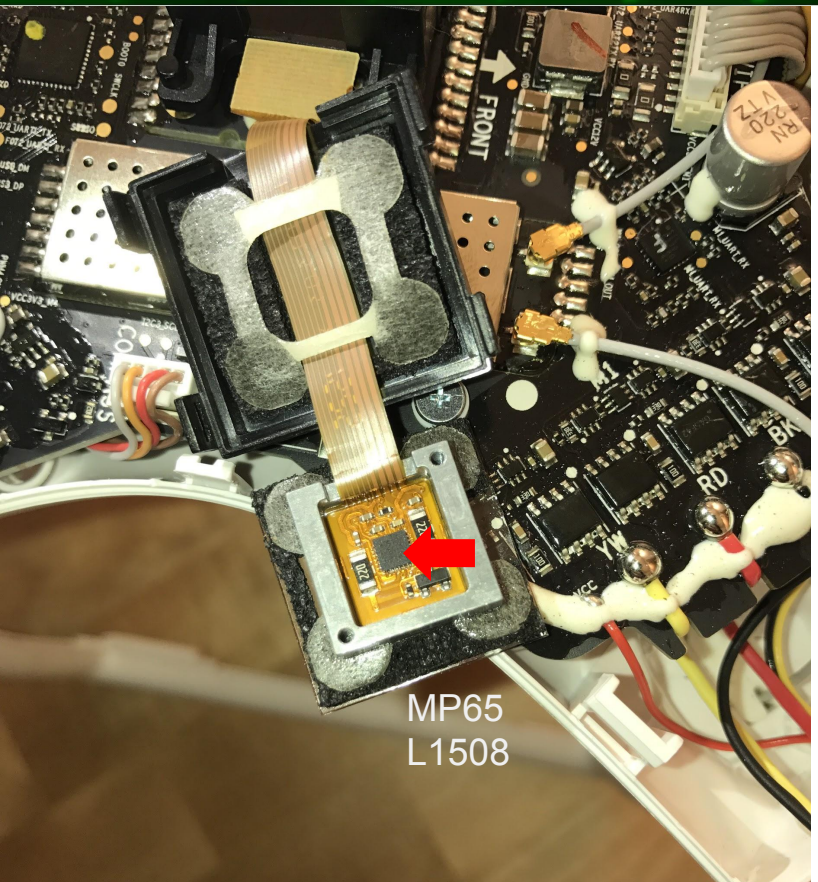
Video Demo: iPhone 7

InvenSense 773C

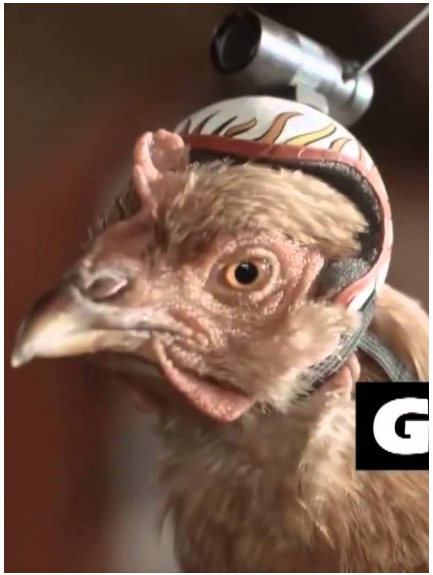
Video Demo: iPhone 7

with Doppler Frequency Shift

DJI Phantom 3 Standard

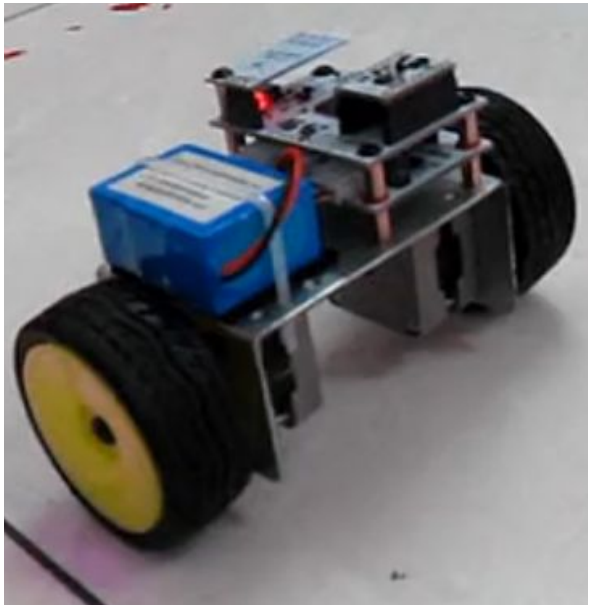


DJI Phantom 3 Standard - Camera



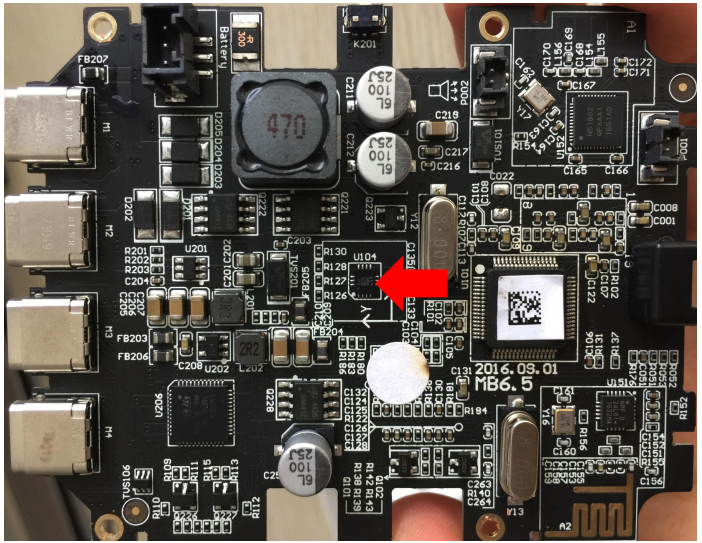
DIY Self-balancing Robot

MPU6050 module

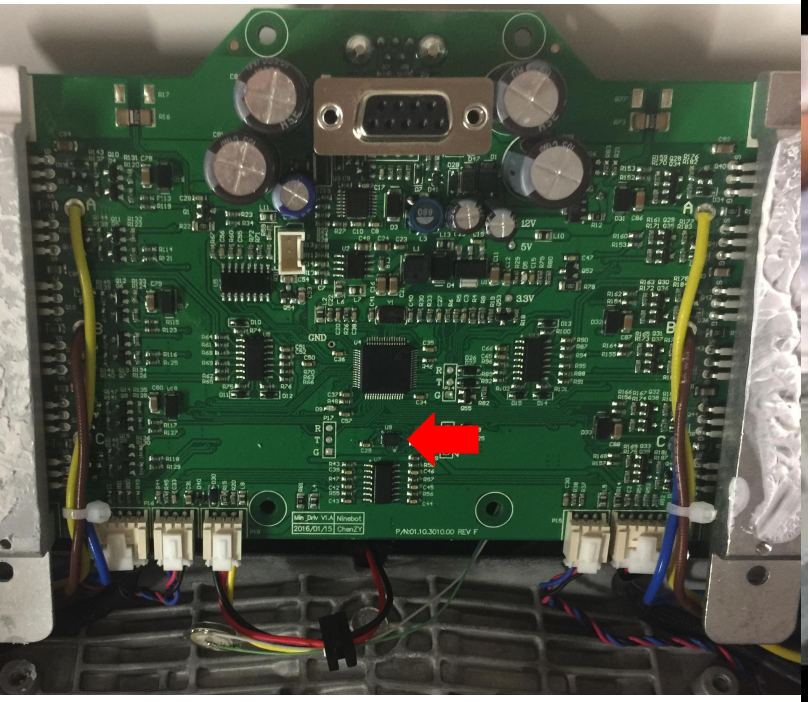


Acknowledgement: Resonating frequency first found by T. Trippel, et al. EuroS&P, 2017.

MiTu Self-balancing Robot



Commerical Scooter

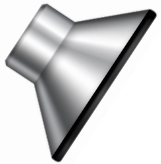


Commerical Scooter

Without Power Amplifier

With Power Amplifier

What about real car?



?

MEMS and Security: An inexhaustive list

	Gyroscope	Accelerometer	Other MEMS*
DoS	Son, et al.	Trippel, et al.	TODO
Manipulation	This work!	Trippel, et al.	TODO
Long Range	TODO	TODO	TODO

* Other MEMS chips include MEMS microphones, barometers, digital micromirror display and so on.

Countermeasures

1. Shell
   - prevent sonic energy from intruding.
   - reflective material with multilayer may be considered.

2. Software
   - actively detect the resonating sound with microphone.
   - warn or perform noise cancelling.

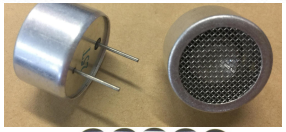
3. Chip
   - new design of MEMS chips that can resist sonic attacks*.

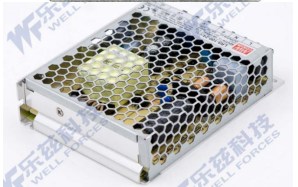
4. Multi Sensors

*Serrano D E, et al. PLANS, 2016.

BOM

Device	Model	Price
Signal Genenerator	SP F20A Max Freq: 20MHz (>> 30kHz) Max Ampl: 20Vpp	$320
Ultrasound Emitter	2425	$0.4
Amplifier	TDA8932	$2
DC Power	LRS-100-24	$10
Signal Generator (Cheaper one)	UTG9002C Max Freq: 2MHz Max Ampl: 25Vpp	$16





References

1. Man, Kin F. "MEMS reliability for space applications by elimination of potential failure modes through testing and analysis." MEMS Reliability for Critical and Space Applications. Vol. 3880. 1999.
2. Dean, Robert N., et al. "On the degradation of MEMS gyroscope performance in the presence of high power acoustic noise." Industrial Electronics, 2007. ISIE 2007. IEEE International Symposium on. IEEE, 2007.
3. Castro, Simon, et al. "Influence of acoustic noise on the dynamic performance of MEMS gyroscopes." ASME 2007 International Mechanical Engineering Congress and Exposition. American Society of Mechanical Engineers, 2007.
4. Son, Yunmok, et al. "Rocking Drones with Intentional Sound Noise on Gyroscopic Sensors." USENIX Security. 2015.
5. Trippel, Timothy, et al. "WALNUT: Waging doubt on the integrity of mems accelerometers with acoustic injection attacks." IEEE European Symposium on Security and Privacy, 2017.
6. Mikko Saukoski. System and circuit design for a capacitive mems gyroscope, Doctoral Dissertation, 2008.
7. Serrano D E, et al. Environmentally-robust high-performance tri-axial bulk acoustic wave gyroscopes. Position, Location and Navigation Symposium (PLANS), 2016.
8. Farshteindiker, Benyamin, et al. "How to Phone Home with Someone Else's Phone: Information Exfiltration Using Intentional Sound Noise on Gyroscopic Sensors." WOOT. 2016.

Acknowledgement

Dr. Sun, Yinan - Tsinghua University

Dr. Li, Ke

Q&A

Thank you.