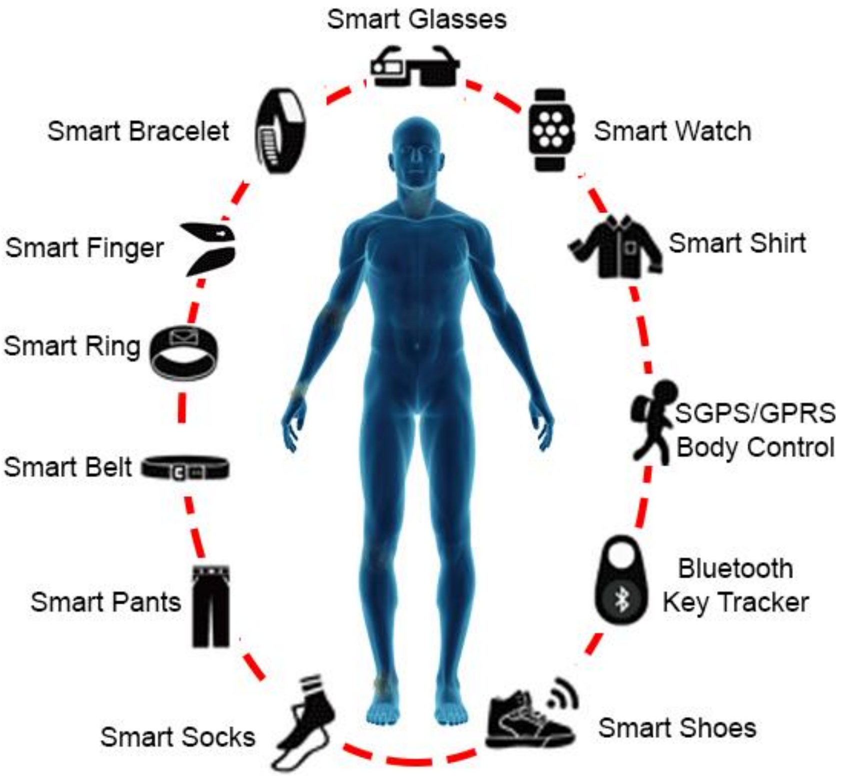
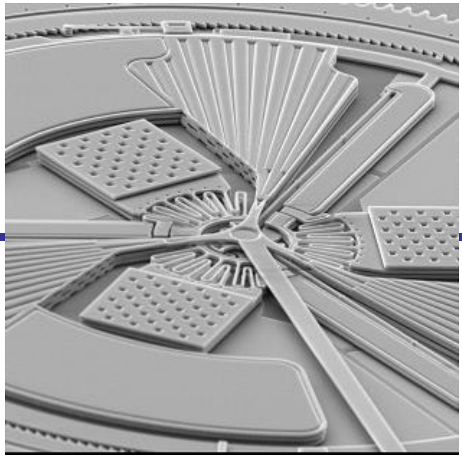
Wearable Devices
Introduction

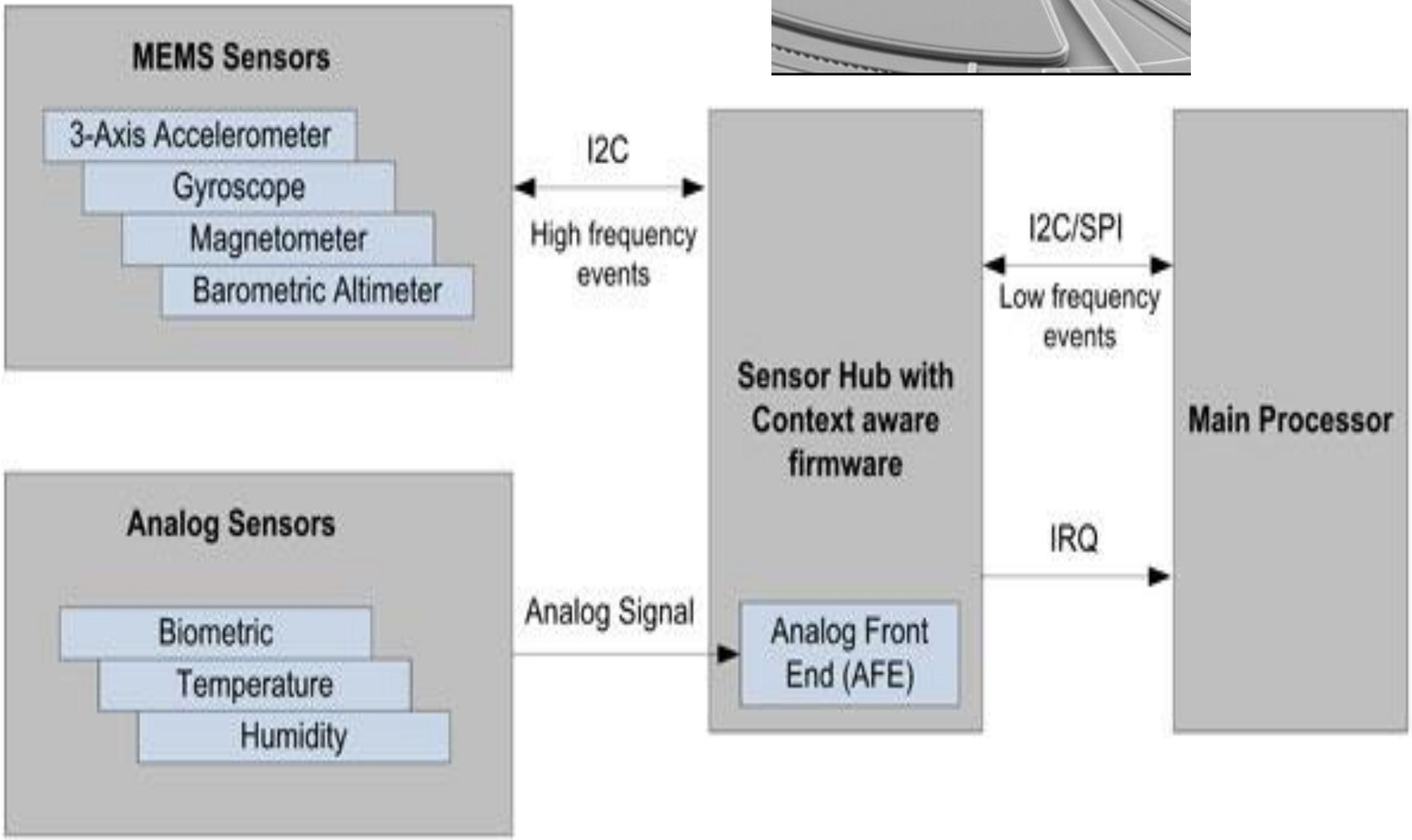
What's the wearable device

- Wearable close to and/or on the surface of the skin of users
- Electronic devices with
  - microcontroller
  - Sensors of different purposes
  - Wireless/wire interconnect
  - Software
  - Detect, analyze, and transmit information
  - Low power



Sensor Hub





- IRQ (Interrupt Request)

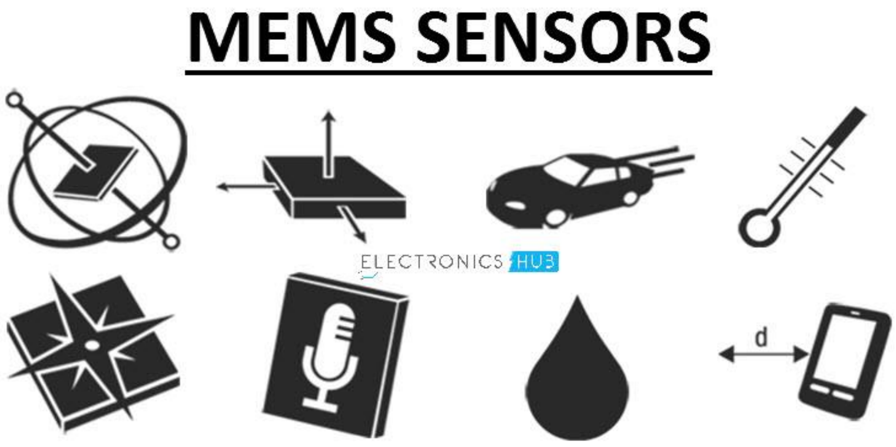
Sensor Types

- **Detecting activities**
- **Motion Sensor:** Micro-electro-mechanical system (MEMS)
  - Accelerometer
  - Gyroscope
  - Pressure sensor
- **Context Sensor**
  - Proximity Sensor
  - Thermometer
  - Hygrometer -measuring the amount of humidity and water vapor in the atmosphere, in soil, or in confined spaces
  - Barometer -measuring atmospheric pressure
- **Health related sensors**
  - Heart rate (HR)
  - Electrocardiogram (ECG),
  - Electroencephalogram (EEG)- detects electrical activity in your brain

What are MEMS?

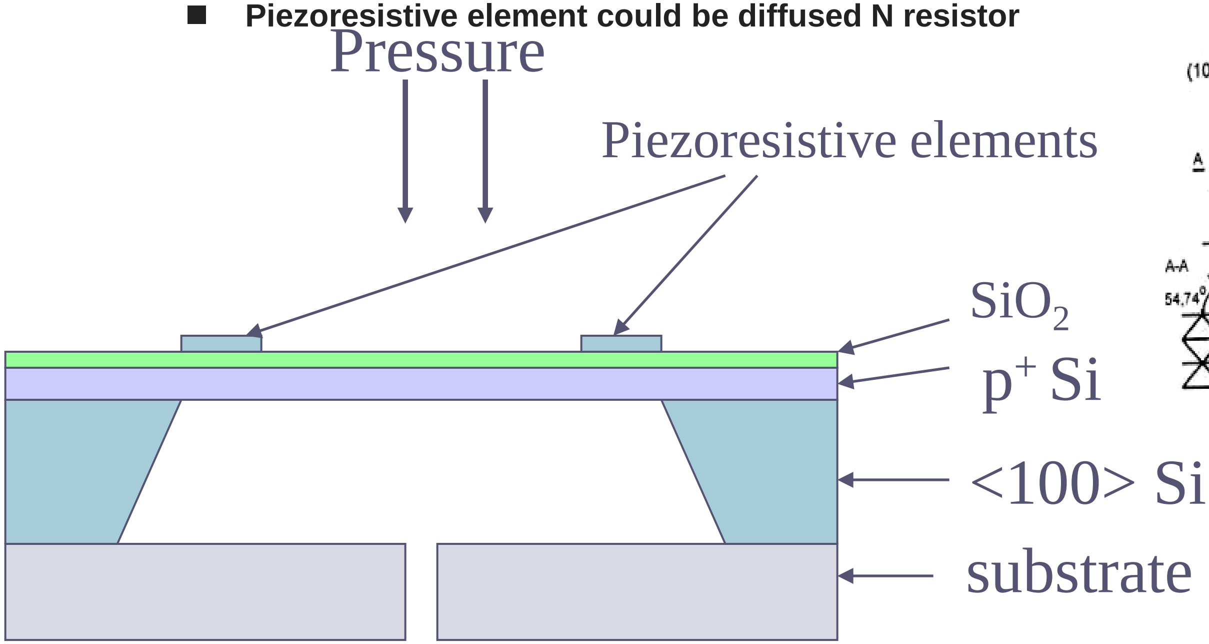
MEMS (Micro-electromechanical Systems)

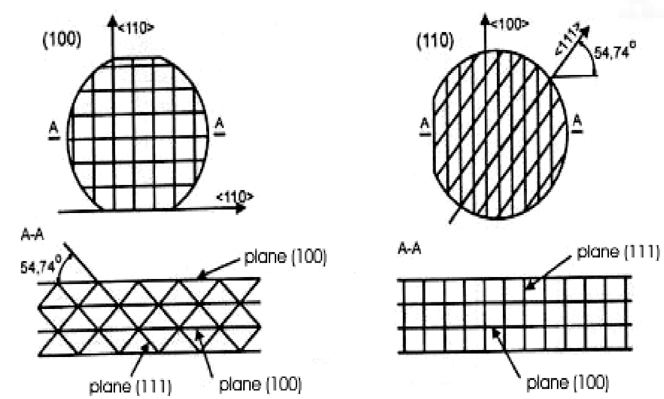
- **System combines mechanical and electrical components**
- **Fabricated using semiconductor technology**
- **Used for sensing**
- **Usually integrated with electronic circuitry for control and/or information processing**
- **Types**
  - Resistive
  - Capacitive



Piezoresistive Pressure Sensors

- Used to measure pressure or force ("**Piezo**", derived from the Greek piezein, which means to squeeze or press.)
- Structure
  - Create cavity by arranging crystal orientation
  - Thin and elastic membrane using polysilicon or SiN
  - Electrical resistivity
- MEMS Pressure Sensor operation
  - **Piezoresistive effect** is a change in the electrical resistivity of a semiconductor or metal when mechanical strain is applied.
  - **Piezoresistive element could be diffused N resistor**





Piezoresistive Pressure Sensors

- Piezoresistive structure: Wheatstone Bridge configuration
  Diaphragm:橫隔膜

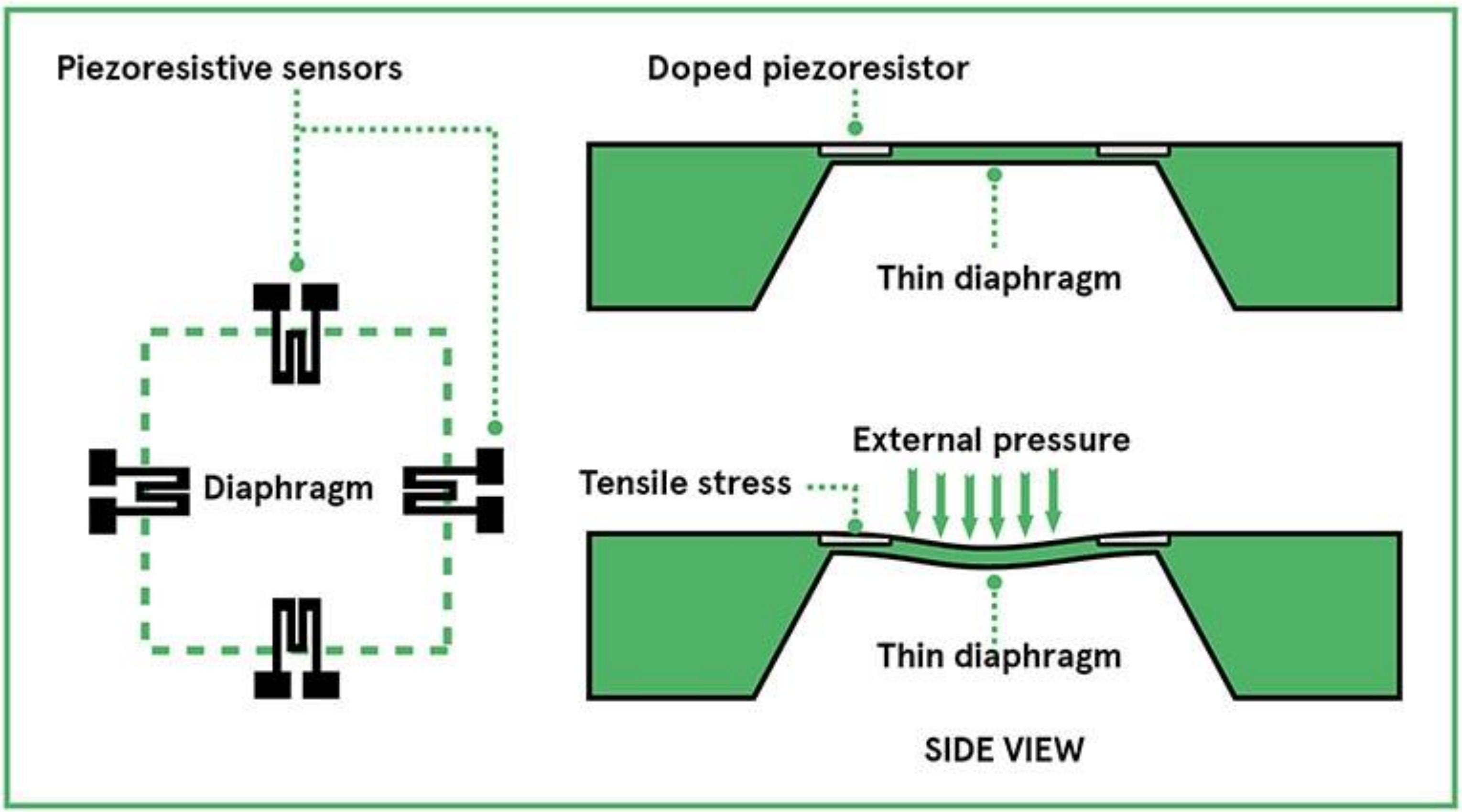


Illustration from "An Introduction to MEMS Engineering", N. Maluf

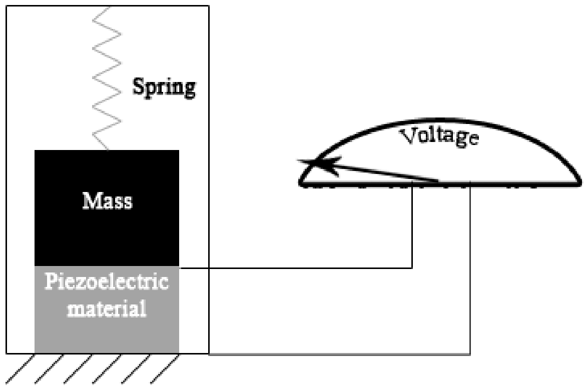
Accelerometers

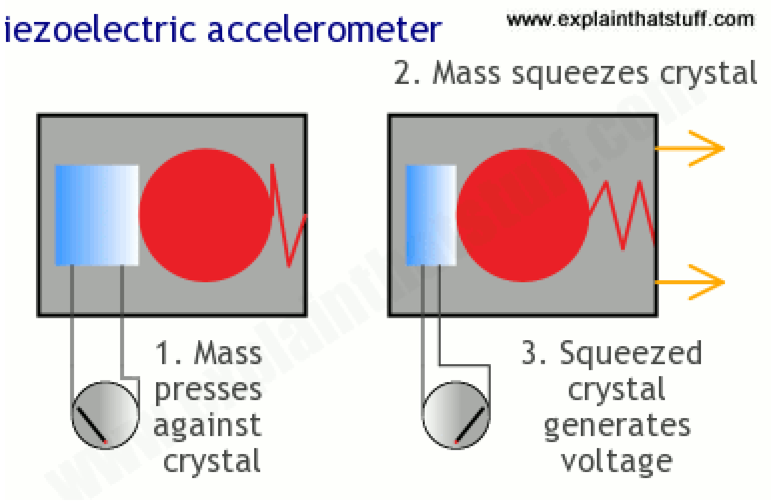
- MEMS Accelerometer: measure linear motion, either movement, shock or vibration but without a fixed reference.
- Accelerometer parameters
  - measure acceleration range (G) (1G=9.81 m/s^2)
  - sensitivity (V/G)
  - resolution (G)
  - bandwidth (Hz)
  - cross axis sensitivity
- MEMS Accelerometer Types
  - Piezoelectric accelerometer
  - Capacitive accelerometer

Application	Range	Bandwidth	Comment
Air Bag Deployment	± 50 G	~ 1 kHz	
Engine vibration	± 1 G	> 10 kHz	resolve small accelerations (< 1 micro G)
Cardiac Pacemaker control	± 2 G	< 50 Hz	multiaxis, ultra-low power consumption

Piezoelectric Accelerometers

- Piezoelectric material
- Mass
- Convert motion energy into voltage
- Voltage meter
- Provide an electrical signal in response to changes in acceleration



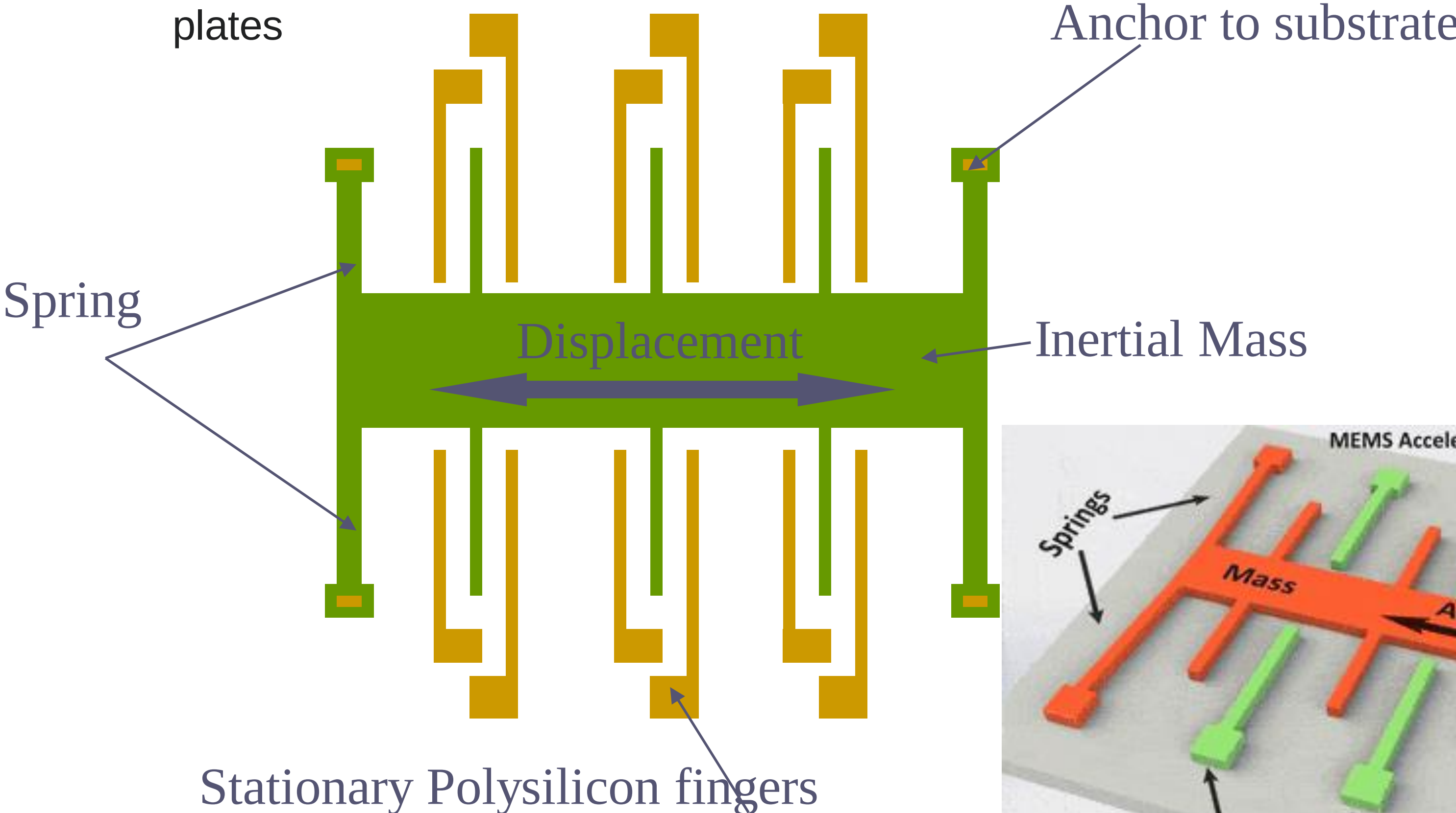


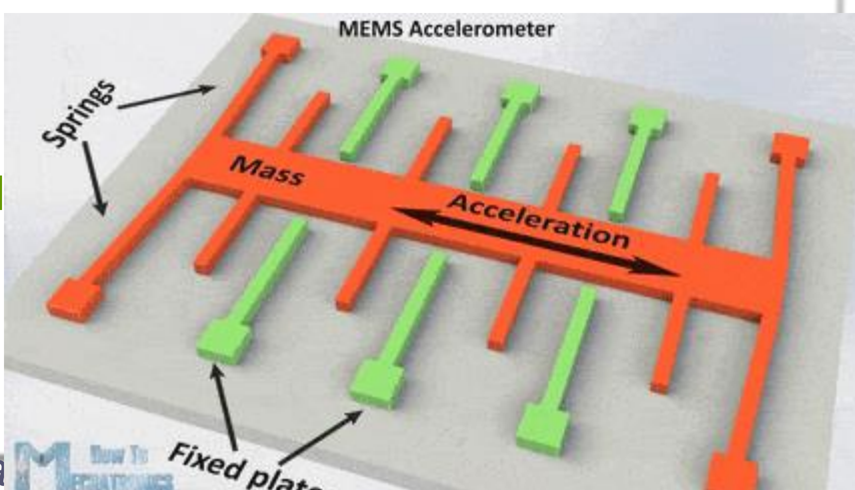
Capacitive Accelerometers

- **Inertial Measurement Unit** (IMU)
- Inertial mass
- Springs
- Fixed plates
- Movement causes the capacitance changes between springs and fixed plates

$$C = \frac{\epsilon A}{d}$$

$$\epsilon = \epsilon_r \epsilon_0$$

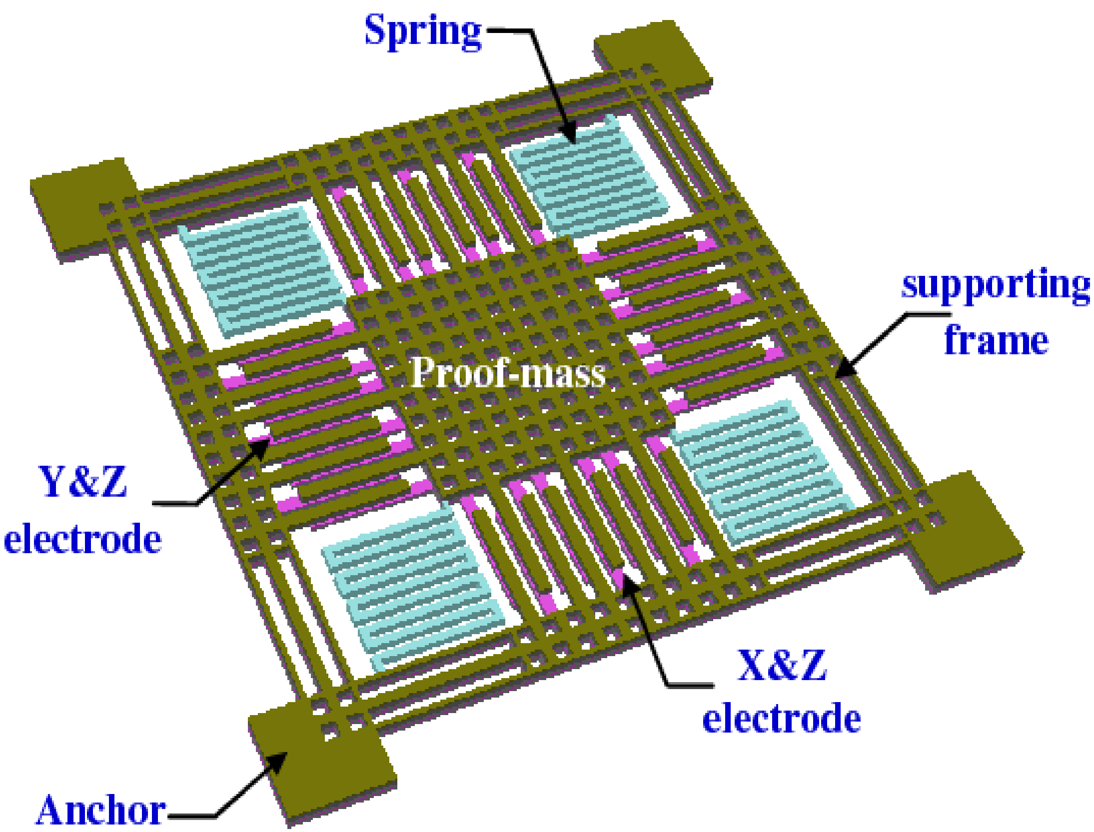


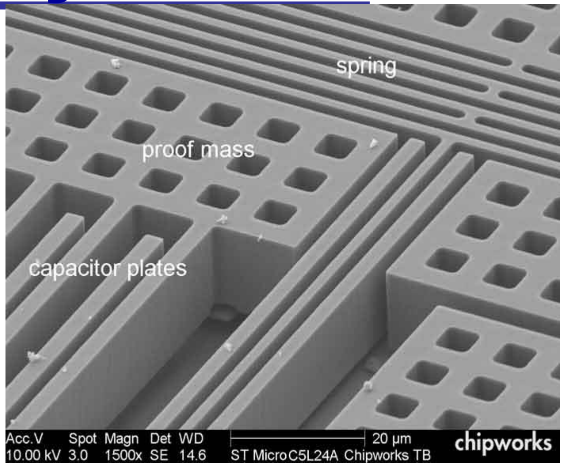


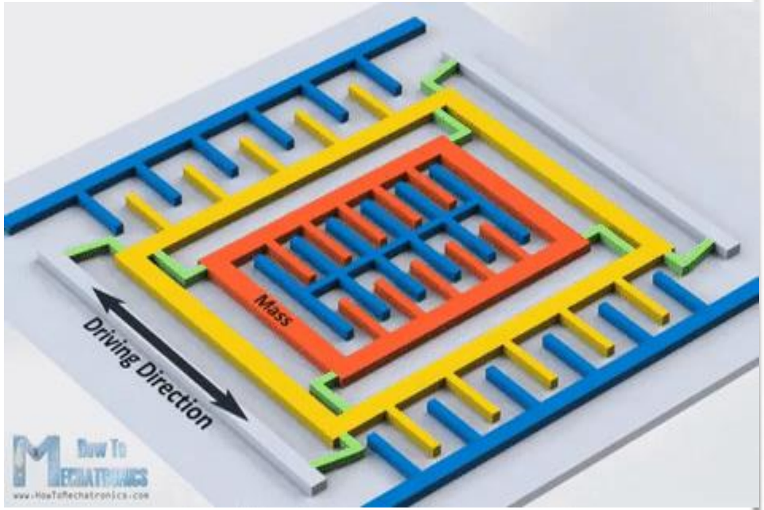
Based on ADXL accelerometers, Ana

Capacitive 3axis Accelerometers measure 3 direction Gravity

- Extended to X&Z and Y&Z directions

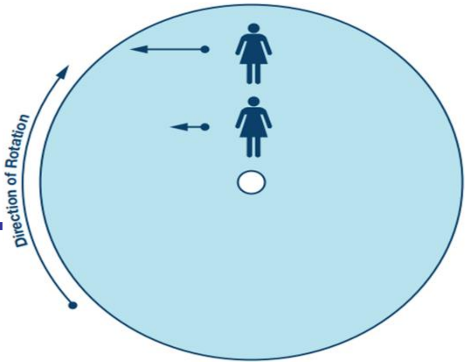






Based on ADXL accelerometers, Analog Devices, Inc.

MEMS Gyro



- **Principle:**
  - measure angular rate by means of Coriolis acceleration
  - Coriolis acceleration: The rate of increase of tangential speed caused by radial velocity
  - Rotation Platform: closer to center, lower the Coriolis acceleration
- **Coriolis Acceleration**
  - If Ω is the angular rate and *r* is the radius, the tangential velocity is Ωr
  - If r changes at speed v there will be a tangential acceleration Ωv
  - If you have a mass (M), the platform must apply a force—$2M\Omega v$—to cause that acceleration
  - The mass experiences a corresponding reaction force
- **MEMS Gyro**
  - Mass is micromachined from polysilicon
  - Tie to silicon frame
  - Resonate in only one direction
  - Figure 2 shows that when the resonating mass moves toward the outer edge of the rotation, it is accelerated to the right and exerts on the frame a reaction force to the left. When it moves toward the center of the rotation it exerts a force to the right, as indicated by the green arrows.

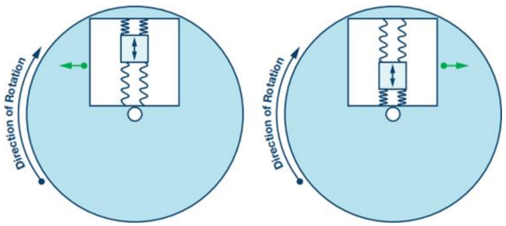
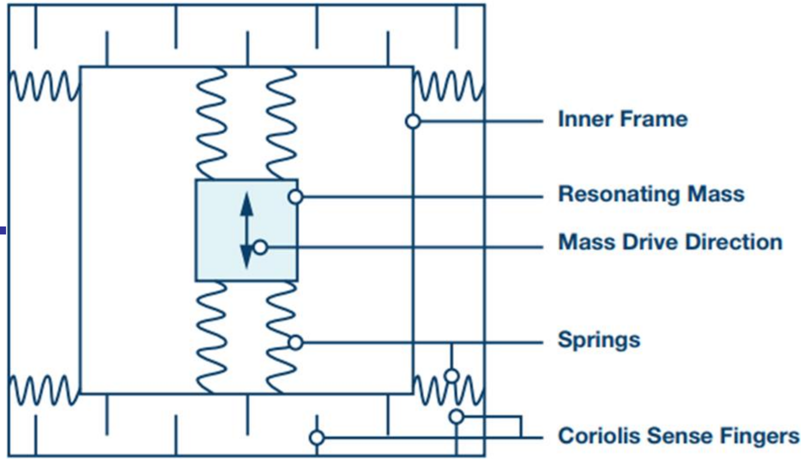


Figure 2

MEMS Gyro



- **Structure:**
  - Resonating Mass
  - Inner frame/outer frame
  - Two sets of springs 90° relative to the other
  - Coriolis sense fingers: sense the capacitance changes due to force
- **Coriolis Effect**
  - Resonating mass and frame displaces laterally
  - Higher the rotational speed,
  - higher the mass/frame displacement

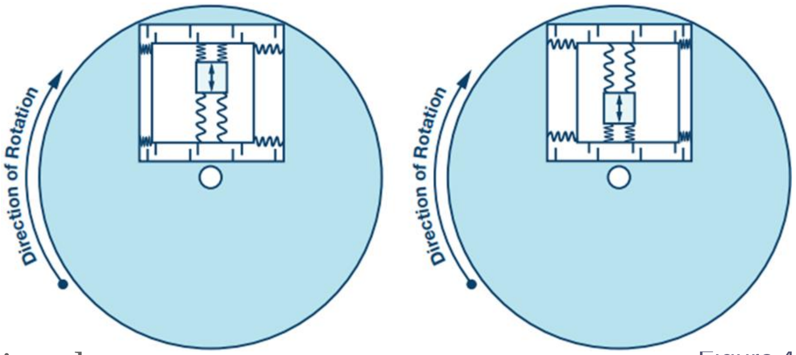


Figure 4

- **Capacitive Sensing**
  - Coriolis acceleration is an extremely small signal
  - Causing fractions of Angstroms of beam deflection
  - Corresponding capacitance changes on the order of zeptofarads (1.0×10^{-21} farad)
  - Important to minimize cross sensitivity to parasitic sources such as temperature, package stress, external acceleration, and electrical noise
  - Partially by amplifiers and filters

MEMS Gyro

Vibration Rejection

- Only sensitive to rotation rate and nothing else
- In fact, sense to acceleration due to
  - asymmetry of mechanical designs
  - micromachining inaccuracies
- Types of acceleration sensitivity
  - Linear acceleration (ie. g sensitivity)
  - Vibration rectification (ie. g^2 sensitivity)

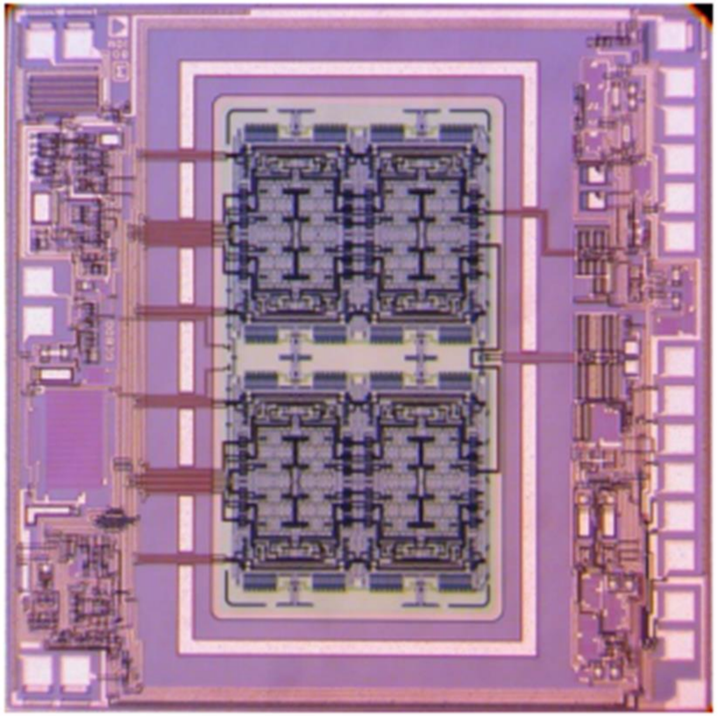


Figure 5

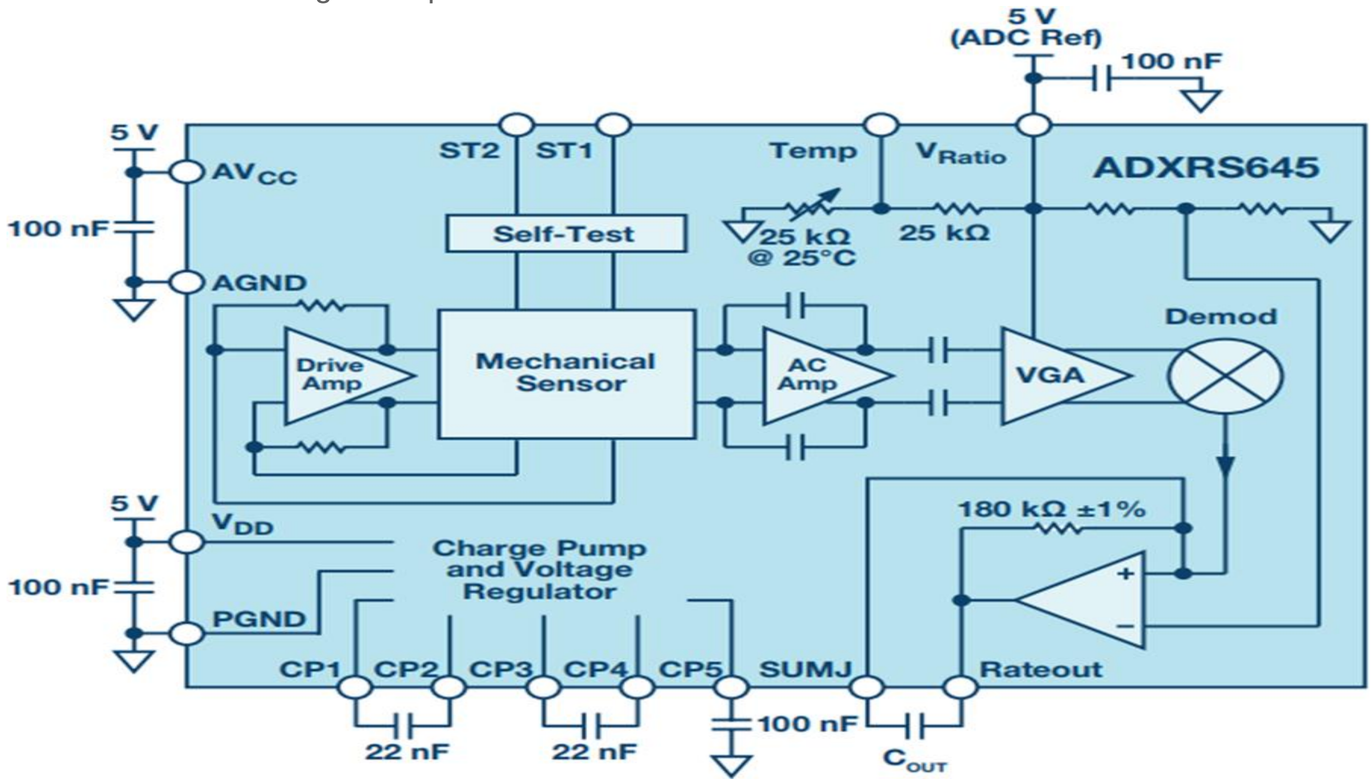
Differential Pairs

- differentially sense signals
- resonator pairs are mechanically independent and they operate antiphase.
- They measure the same magnitude of rotation but give outputs in opposite directions
- The difference between the sensor signals is used to measure angular rate.
- Cancels nonrotational signals that affect both sensors
- reject common-mode external accelerations that are unrelated to angular motion.

MEMS Gyro

Integrated Circuit

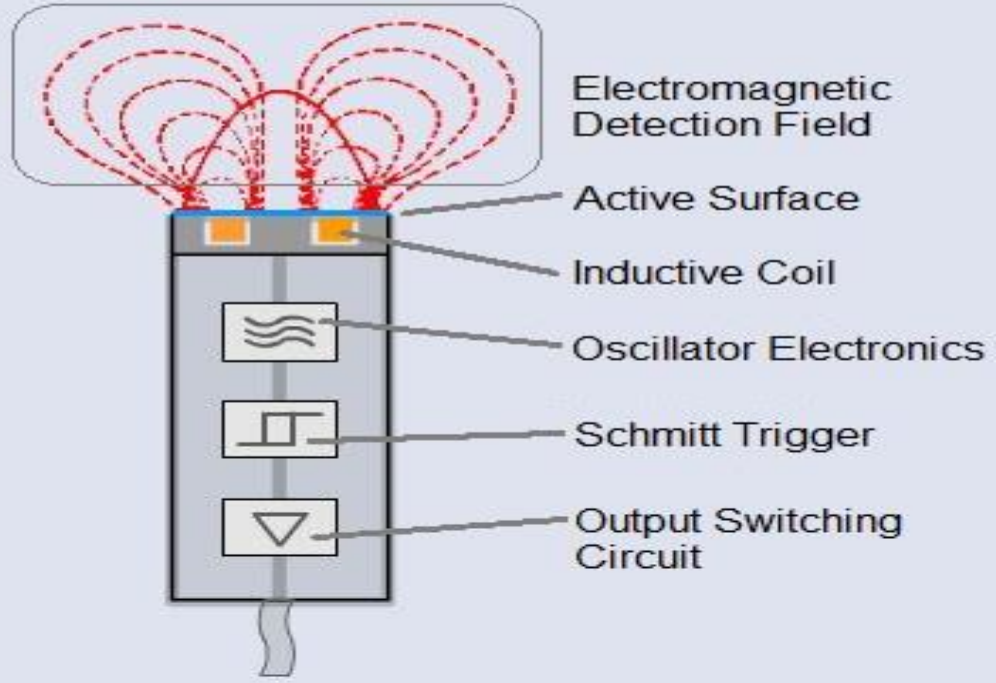
- Resonator circuit senses the velocity of the resonating mass, amplifies
- Drives the resonator while maintaining a well controlled phase (or delay) to the Coriolis signal path.
- The Coriolis circuitry is used to detect the movement of the accelerometer frame
- Extract the magnitude of the Coriolis acceleration
- VGA : variable gain amplifier



Proximity Sensor

Proximity Sensor

- Detect nearby object without physical touch
- Emits an electromagnetic field or a beam of electromagnetic radiation, and looks for changes in the field or return signal.



Internal Elements of an Inductive Proximity Sensor

Principle of Green Light PPG

- **Photoplethysmography:**
  - Describe the use of non-invasive optical techniques to measure blood vessel volume changes
- Blood absorb greenlight and reflect red lights
- Blood vessel pushes the skin
- Changes the density of blood vessel and the reflected intensity of green light
- The reflected light through the tissue decreases during systole and increases during diastole.

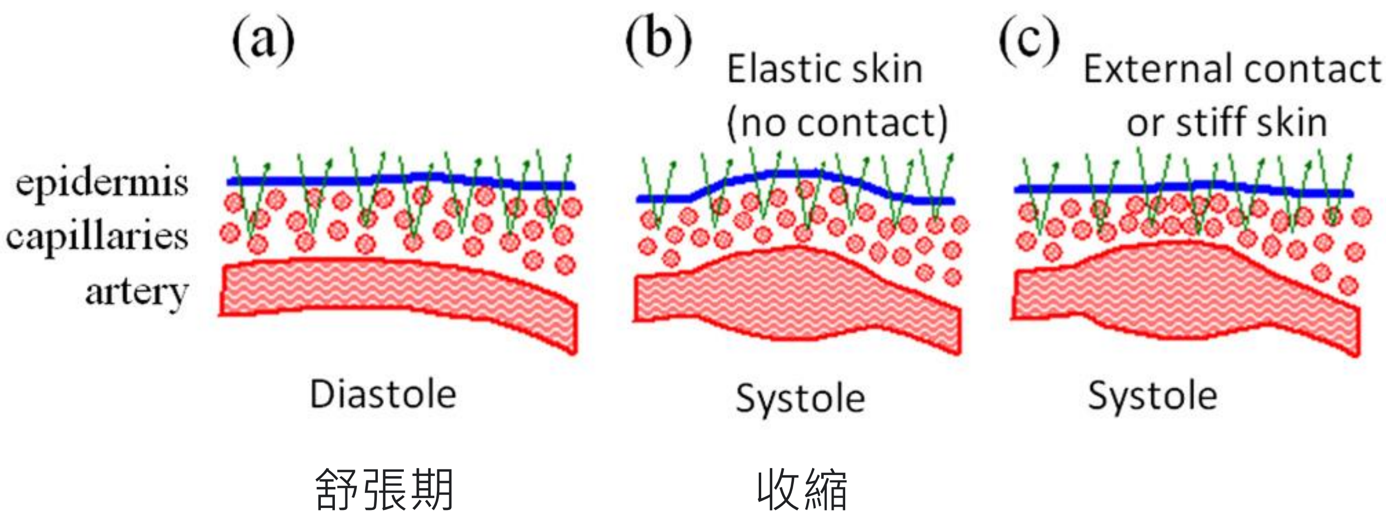
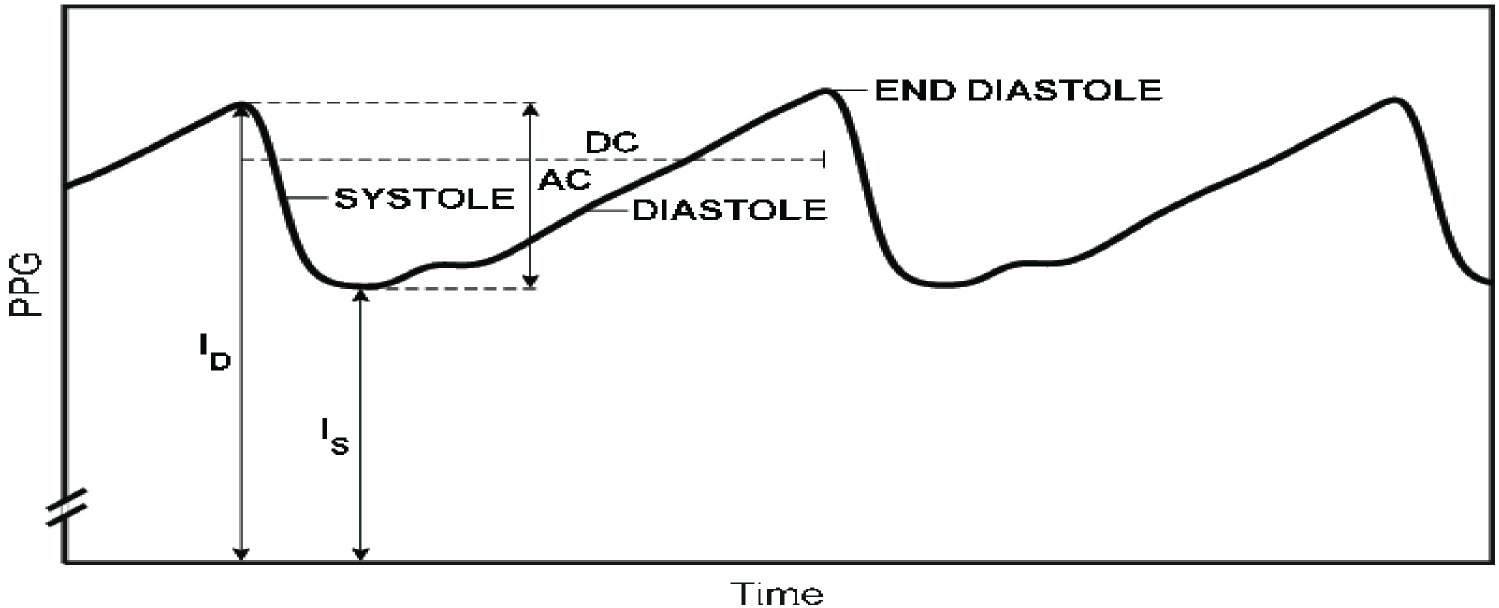


figure source: Kamshilin, A. A., & Margaryants, N. B. (2017). Origin of photoplethysmographic waveform at green light. Physics Procedia, 86, 72-80.

Principle of Photoplethysmography

- Inject light from skin surface
- Absorption or reflection of light changes depending on the blood vessel shrink or expand
- Light sensor measure the intensity of reflected light
- AC is the difference between the maximal (I_D) and minimal (I_S) light transmission through the tissue; DC is the mean light transmission through the pulse.
- Calculate the period
- AC/DC ratio of green light is larger than red light



Block Diagram of a PPG System

- LED: green light source
- Photo detector:
- TIA (Transimpedance Amplifier): amplify and filtering
- PGA: programmable gain amplifier

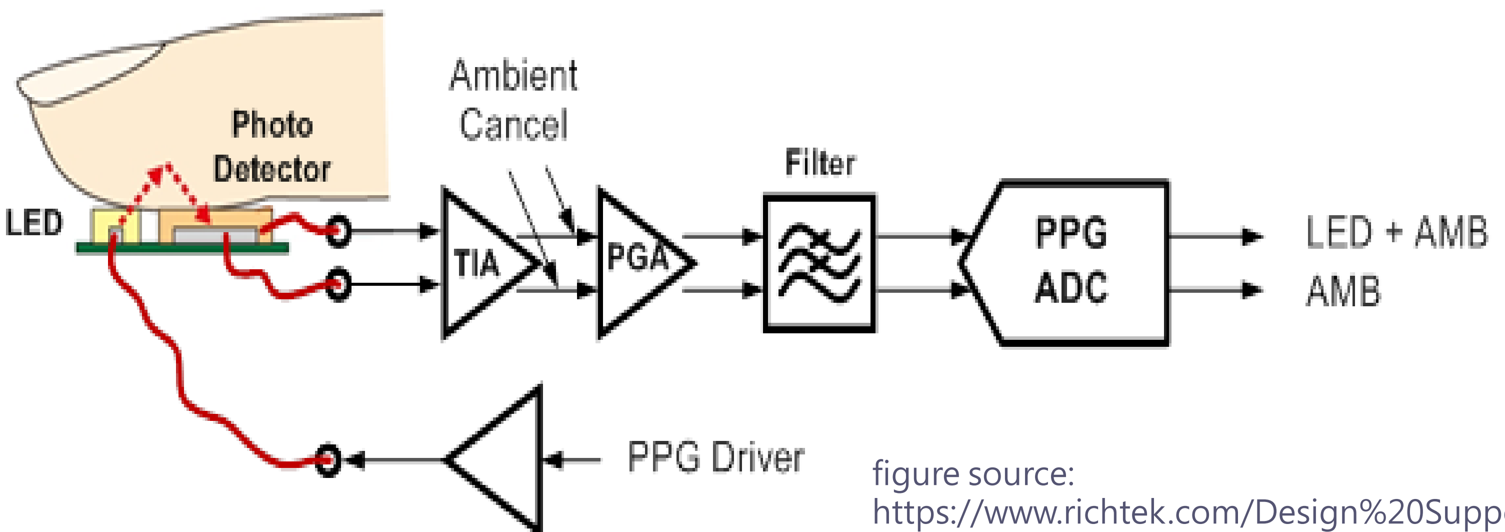
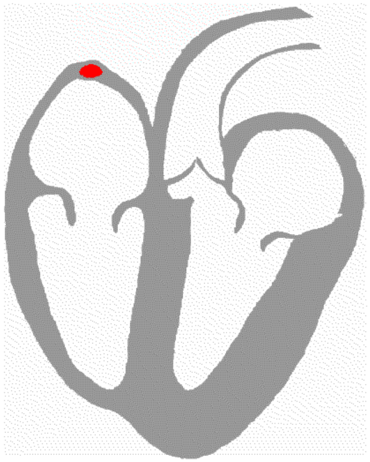


figure source: https://www.richtek.com/Design%20Support/Technical%20Document/AN057?sc_lang=zh-TW

Principle of Electrocardiography (ECG)

1. The shrink and expand of heart cell changes the voltage and transmits to skin
2. Put at least two electrodes on human body to record voltage difference to get ECG waveform
3. Pan–Tompkins Algorithm to find position of R wave
4. Find the period of R wave

   Heart Rate (bpm) = 60 / RR (s)



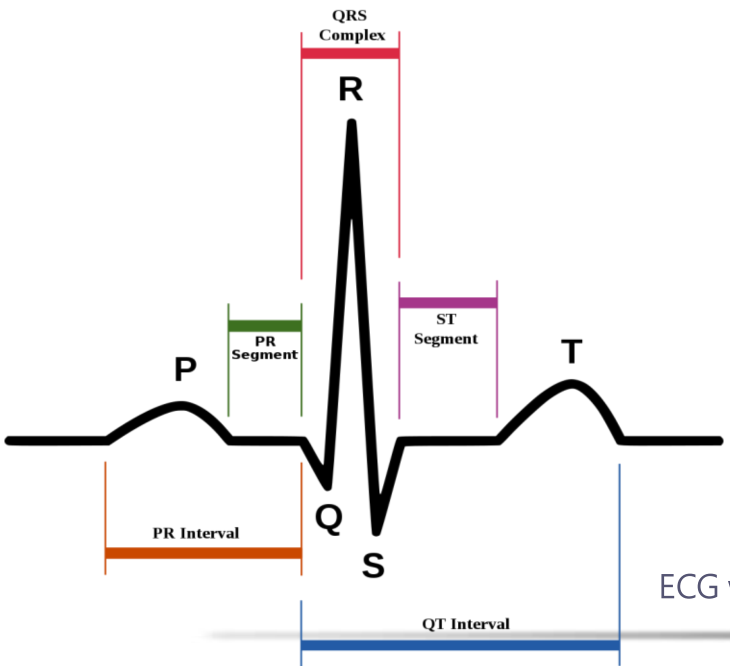


figure source: https://commons.wikimedia.org/wiki/File:ECG_principle_slow.gif#/media/File:ECG_principle_slow.gif

ECG waveform-P/Q/R/S/T

Block Diagram of an ECG System

- IA (Instrumentation Amplifier): suppress common mode signals （interference from 50Hz/60Hz）
- PGA (Programmable-Gain Amplifier):
- LPFilter: suppress high frequency interference and avoid overlap of ADC signals
- VRLD (Right Leg Drive): drive opposite phase common mode signals back to human body

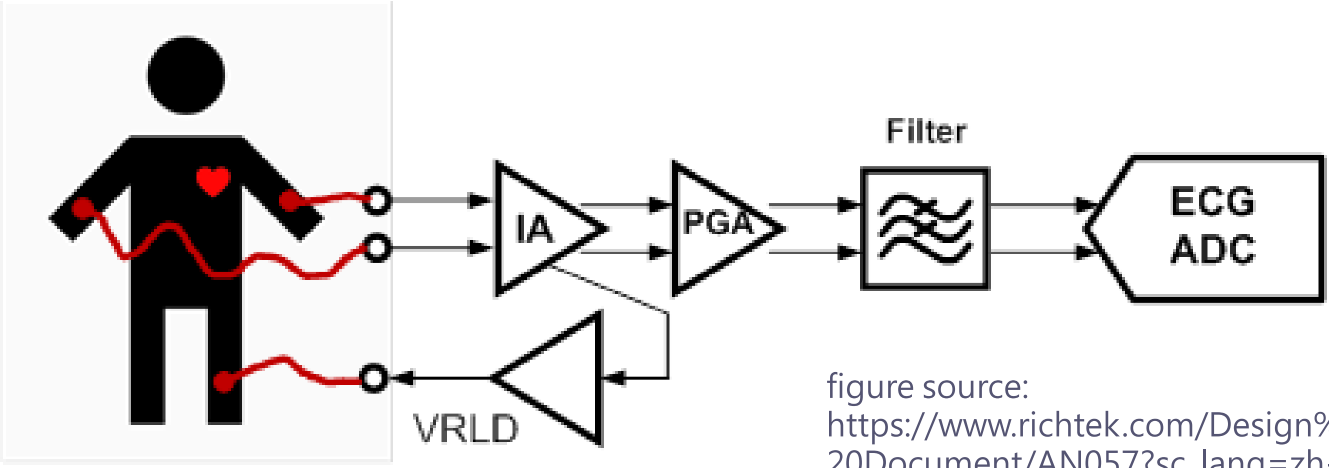


figure source: https://www.richtek.com/Design%20Support/Technical%20Document/AN057?sc_lang=zh-TW

Richtech(立錡科技) RT1025

介紹影片

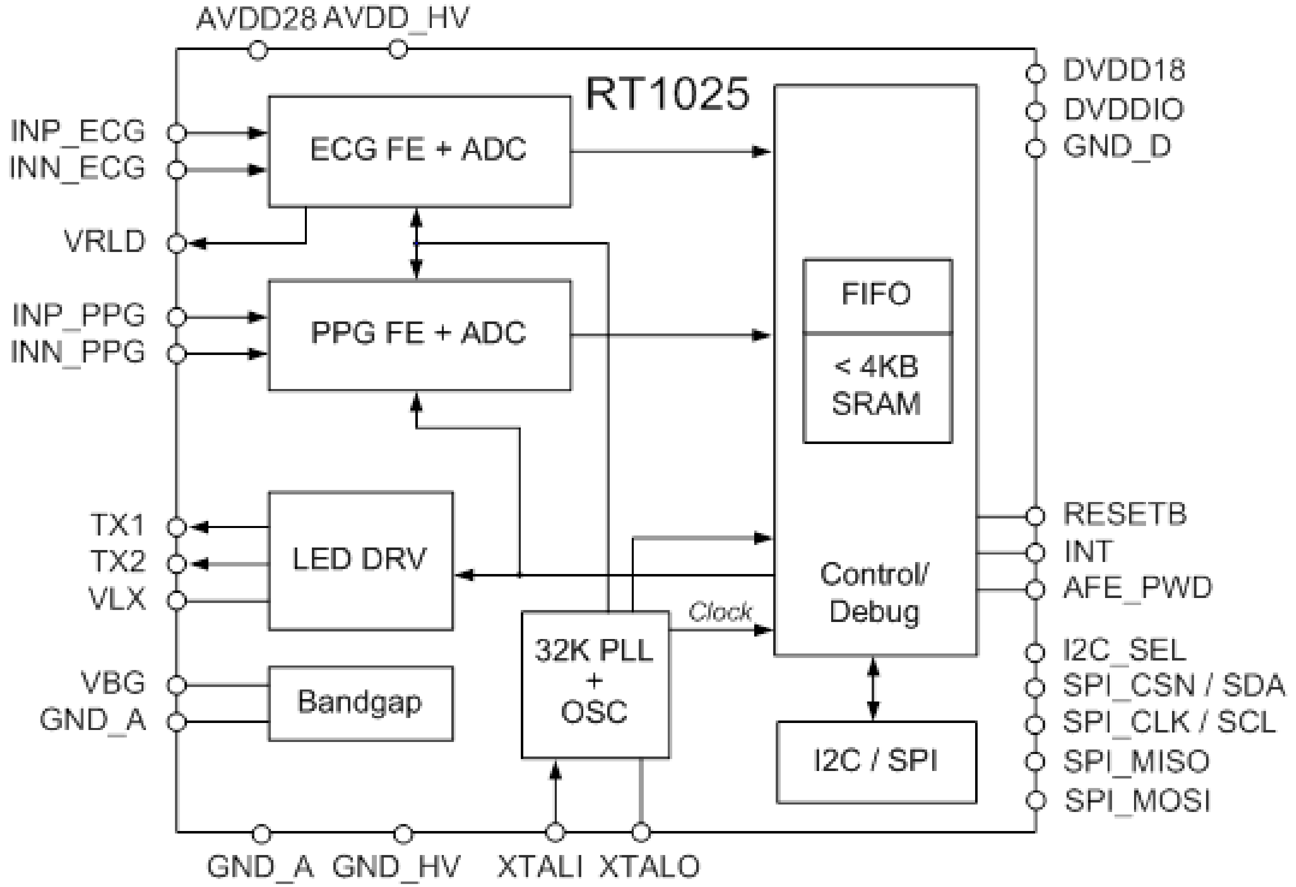
- Integrate ECG及PPG

接ECG電極(1-lead)

接photodiode

接LED

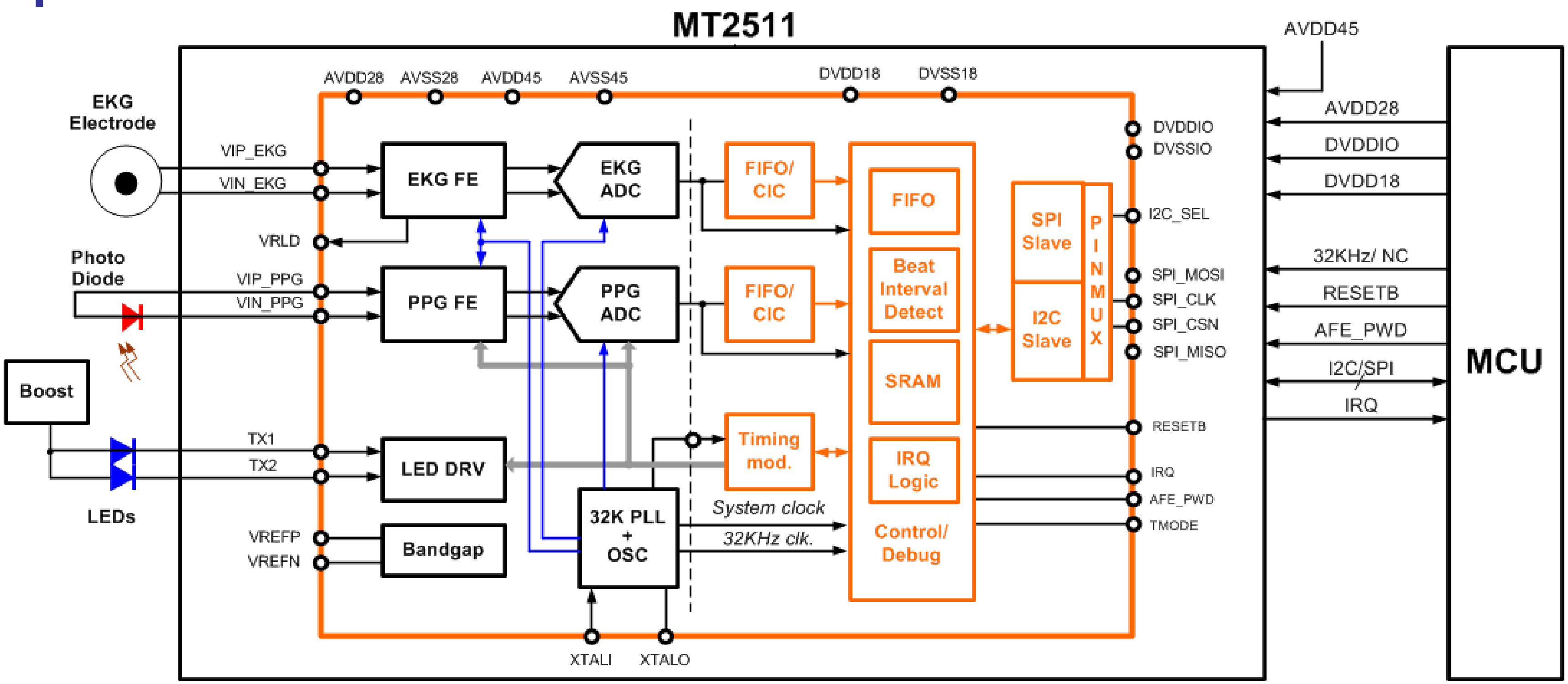
接MCU



datasheet: https://www.richtek.com/assets/product_file/RT1025/DS1025-00.pdf

MTK(聯發科) MT2511

figure source: https://labs.mediatek.com/zh-tw/chipset/MT2511



- 2015 MTK acquires Richtech
- 2017 MT2511 datasheet release
- 2018 RT1025 datasheet release

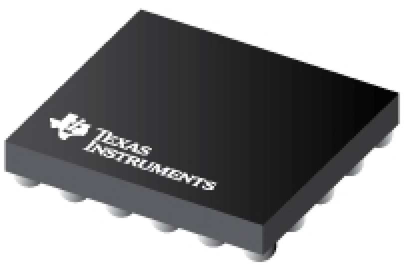
Chip Vendors

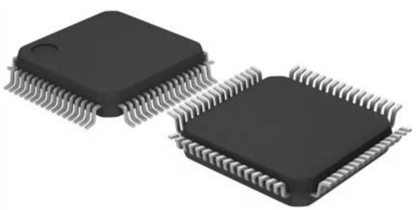
- ECG + PPG Systems

RICHTEK

Texas Instruments

ANALOG DEVICES





RT1025

AFE4900

ADAS1000

MEMS Resources

Reference Books

- Nadim Maluf, An Introduction to Microelectromechanical Engineering (Artech House, Boston,2000)
- M. Elewenspoek and R. Wiegerink, Mechanical Microsensors (Springer-Verlag, 2001)
- Héctor J. De Los Santos, Introduction to Microelectromechanical (MEM) Microwave Systems (Artech House, Boston, 1999)

Websites

- Sandia National Lab: http://mems.sandia.gov
- Berkeley Sensors and Actuators Center: http://www-bsac.eecs.berkeley.edu
- MEMS Clearinghouse: http://www.memsnet.org/

Some companies with MEMS products

- Accelerometers – Analog Devices: http://www.analog.com/technology/mems/index.html
- Digital Light Processing Projector- Texas Instruments: http://www.dlp.com
- Micro-electrophoresis chip – Caliper Technologies: http://www.calipertech.com

Reference

- 看看穿戴式行動裝置 - http://goo.gl/6WbMpe
- 穿戴式產品演化趨勢與開發策略思維分析 - http://goo.gl/b5nPBz
- [閒聊] 世上最早的穿戴式電腦？三百年前的清朝算盤戒指！ - http://goo.gl/Wpj0d5
- A brief history of wearable tech - http://goo.gl/KWSIxP
- Pulsar Calculator Watch - http://goo.gl/uwLN3D
- 未來服飾-智慧衣 - http://goo.gl/dxrA42
- 微軟 HoloLens 技術解謎（上）：如何還原三維場景 - http://goo.gl/j9GeBY
- IoT產業分析 - https://goo.gl/vBS0CW

Thank you