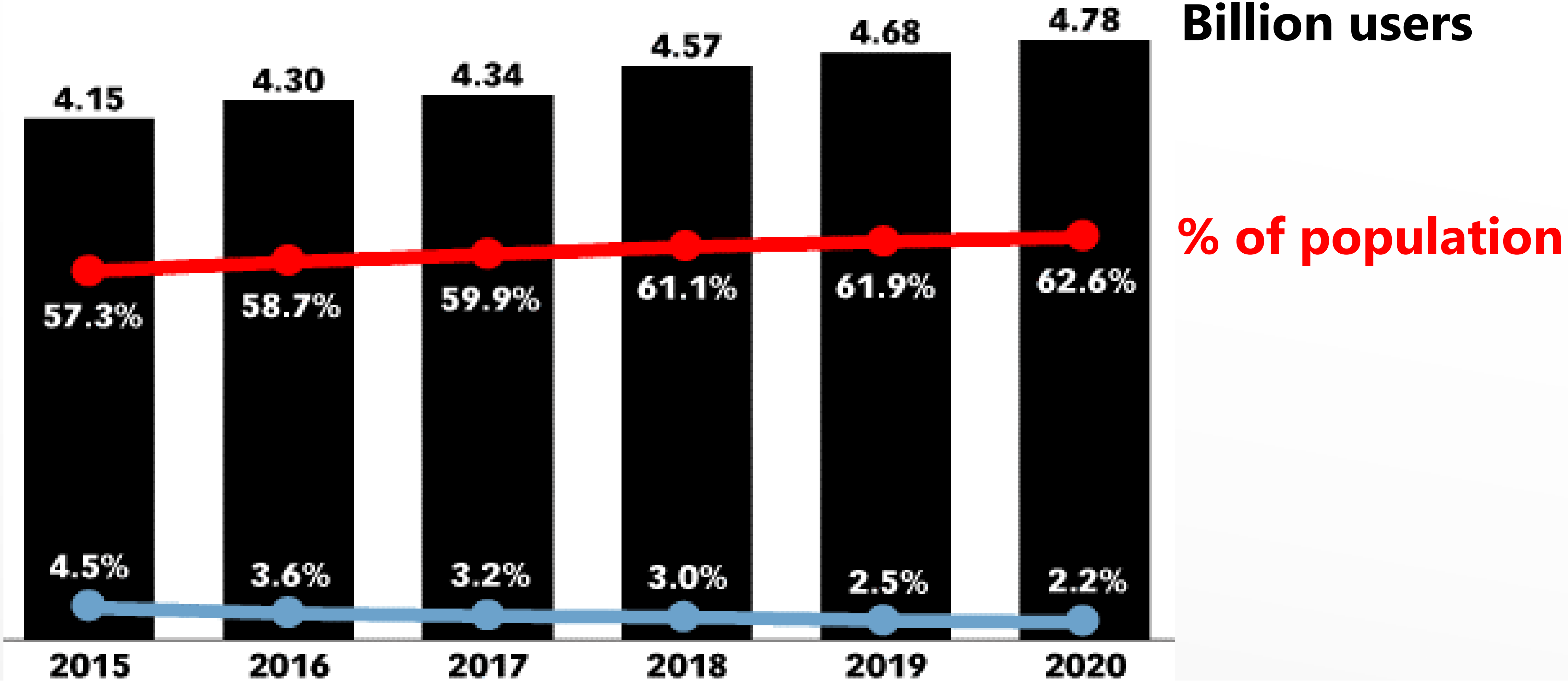
Physik im Smartphone

Bertram Batlogg
ETH Zurich

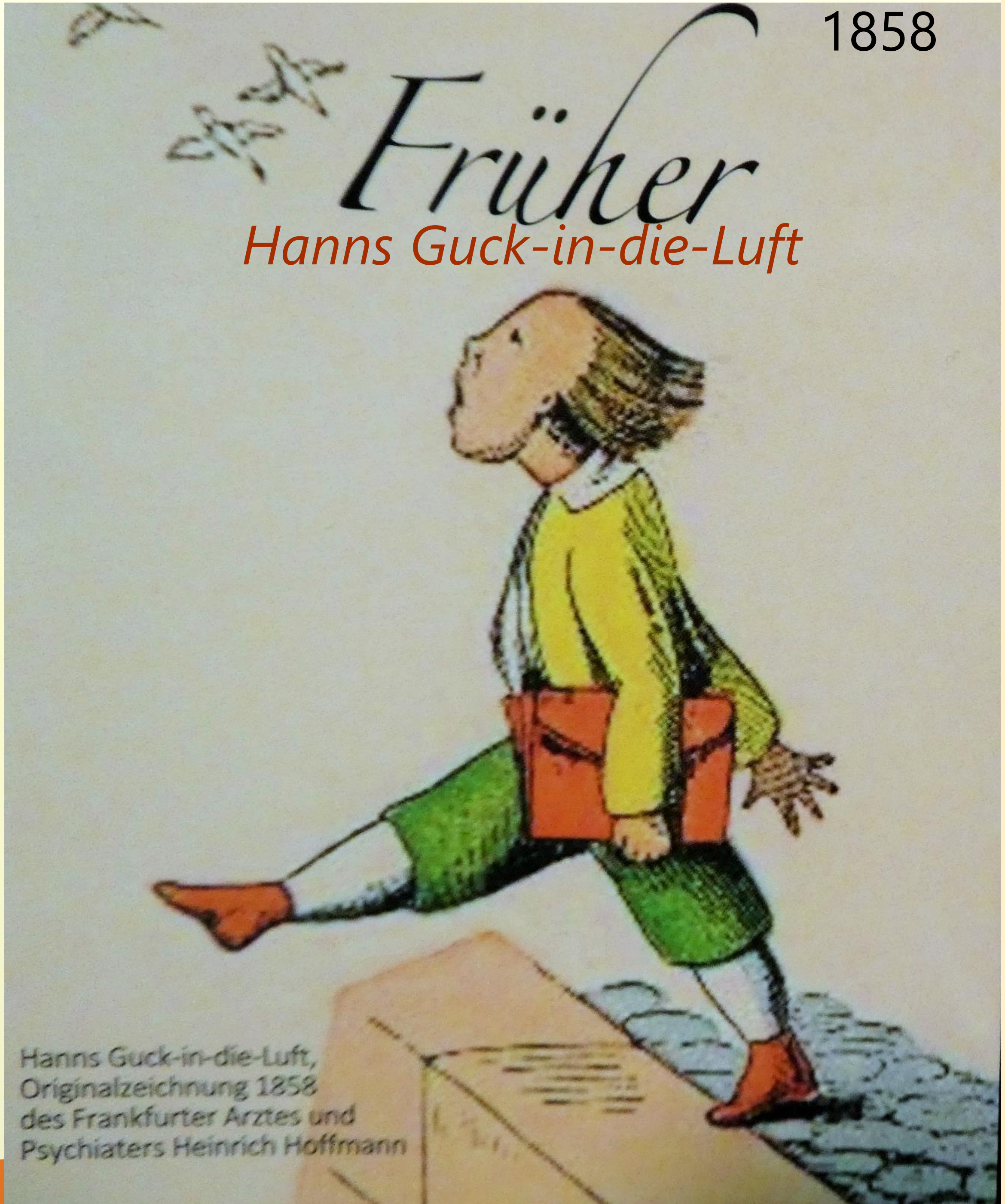
Photo : mit Dank an Claus Schwarzmann, Schoppernau ↓

Global smartphone shipment

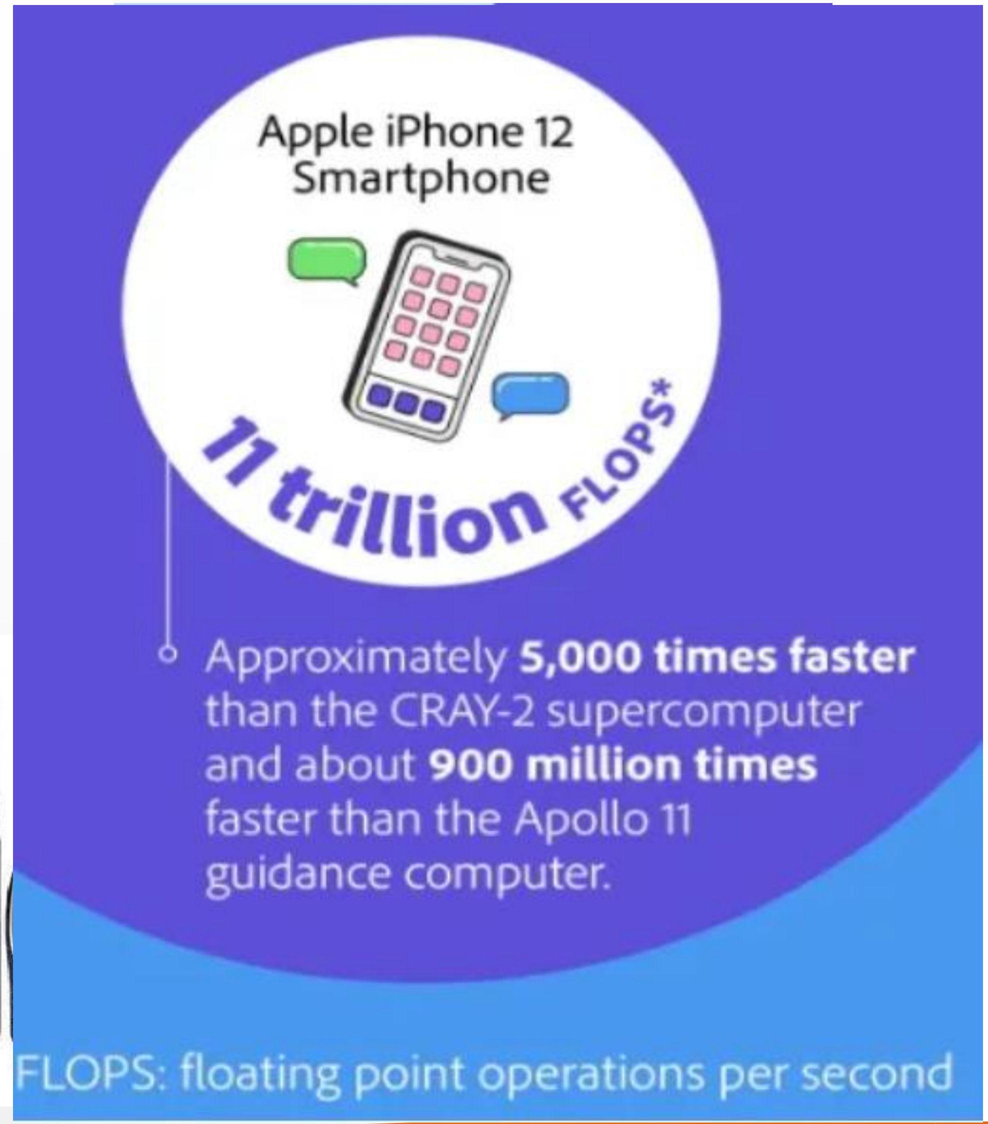
Mobile phone users and penetration worldwide 2015 -20

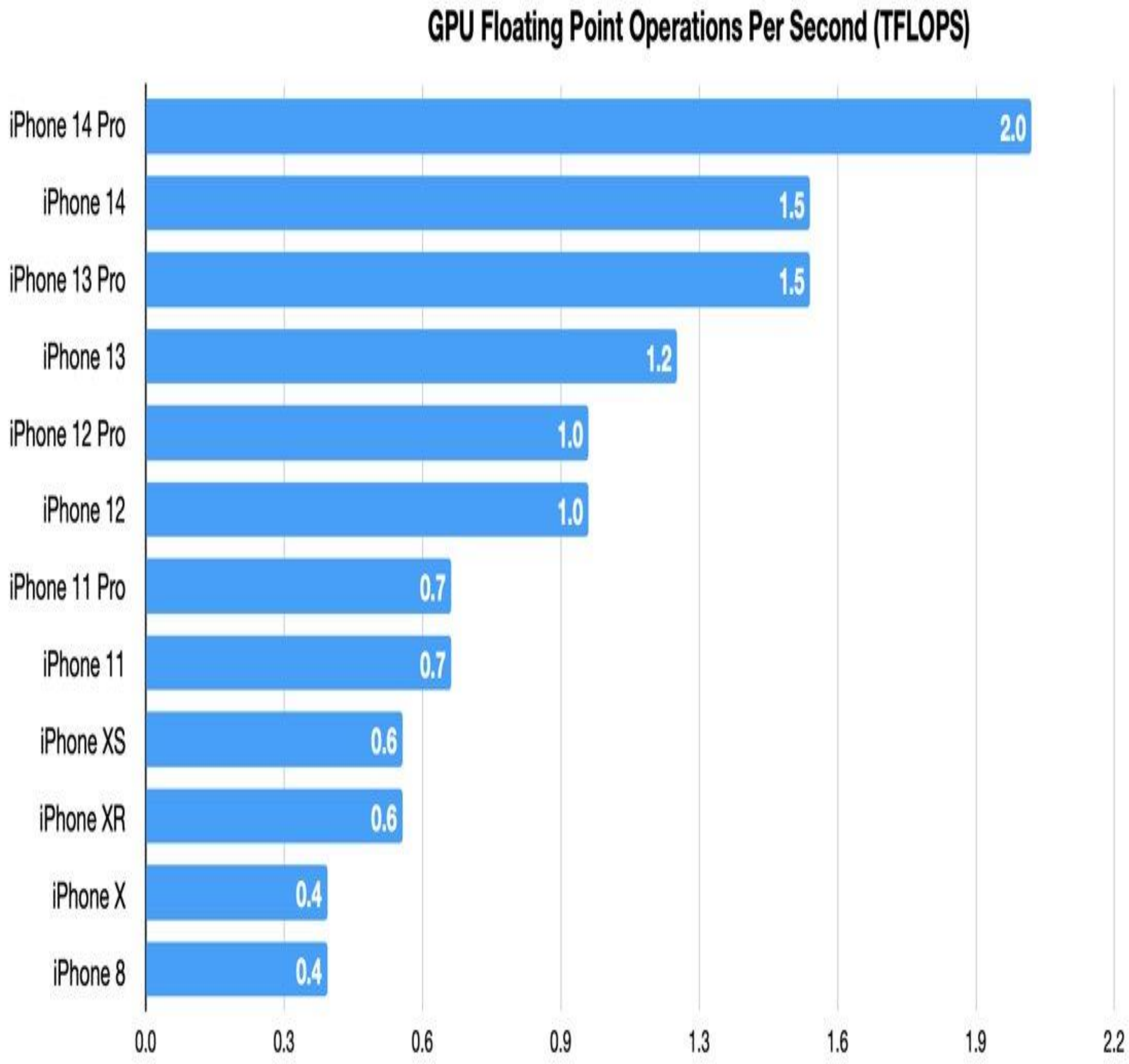


1858


Früher
Hanns Guck-in-die-Luft
Hanns Guck-in-die-Luft,
Originalzeichnung 1858
des Frankfurter Arztes und
Psychiaters Heinrich Hoffmann

Gigantische Rechenleistung





Selected physics topics

Topological constraint theory

Hall effect

Phase advance – group delay

General theory of relativity

$v_{ph} > c$

Piezoelectricity

Seismic waves

4 times brighter OLEDs – and spin-orbit coupling

Surface acoustic wave filters

Light field photography

Coriolis force gyroscope

MEMS accelerometer

Variable capacitance microphone

Metamaterials antenna

CCD and CMOS detectors

Atomic clocks

Li ion batteries

etc. etc. etc. ....

Selected physics topics *for today*

Topological constraint theory

General theory of relativity

Piezoelectricity

Surface acoustic wave filters

Coriolis force gyroscope

MEMS accelerometer

Variable capacitance microphone

Selected physics

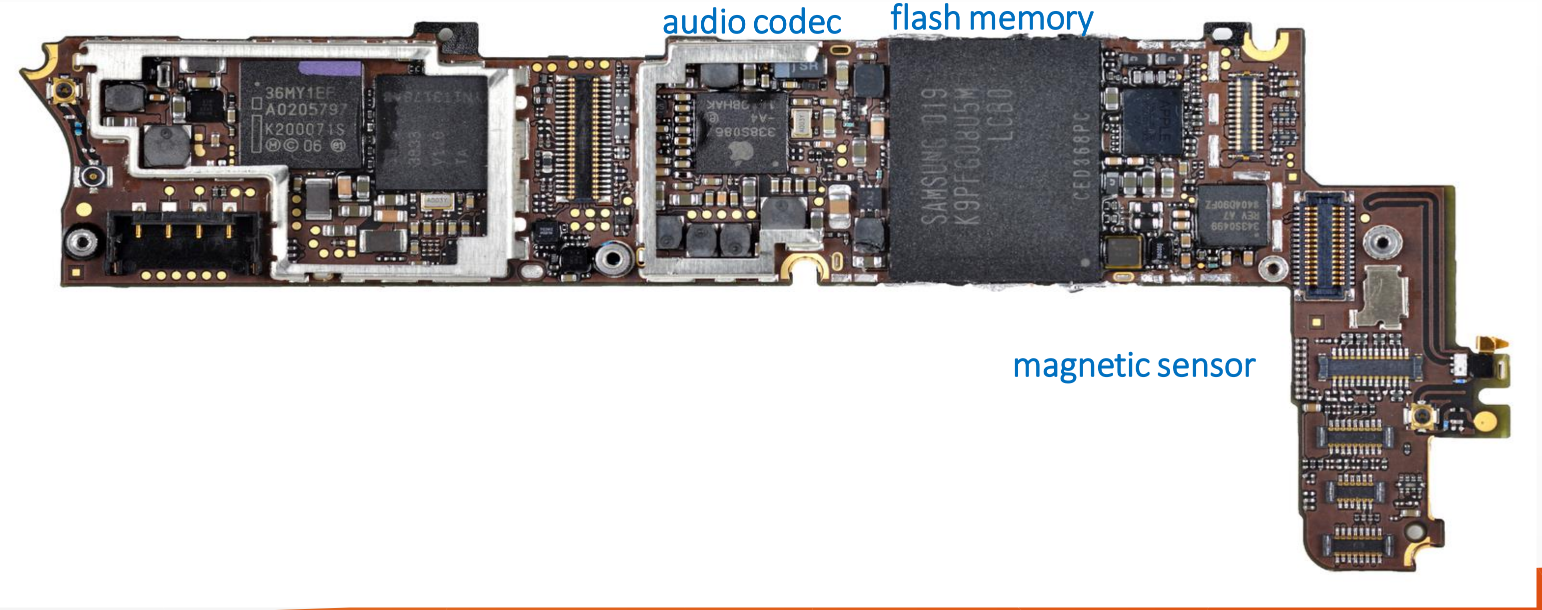
Topological constraint t

Piezoelectric

Surface acoustic

Coriolis force gyroscope

Variable capac



… “überall”

Quarz Kristall aus der zweiten Strassenröhre am Gotthard

brücke Lorüns, Vlbg.

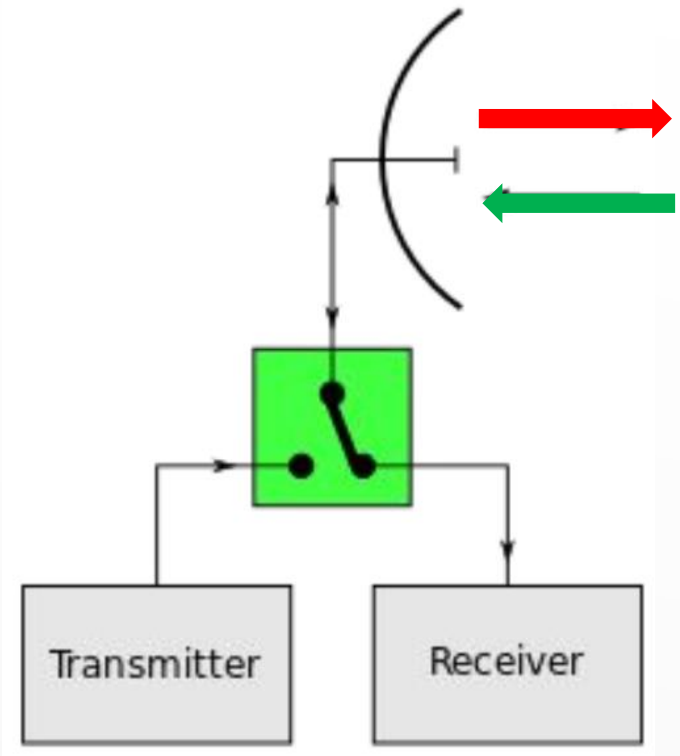
Train Cemetary Salar de Uyuni, Bolivia

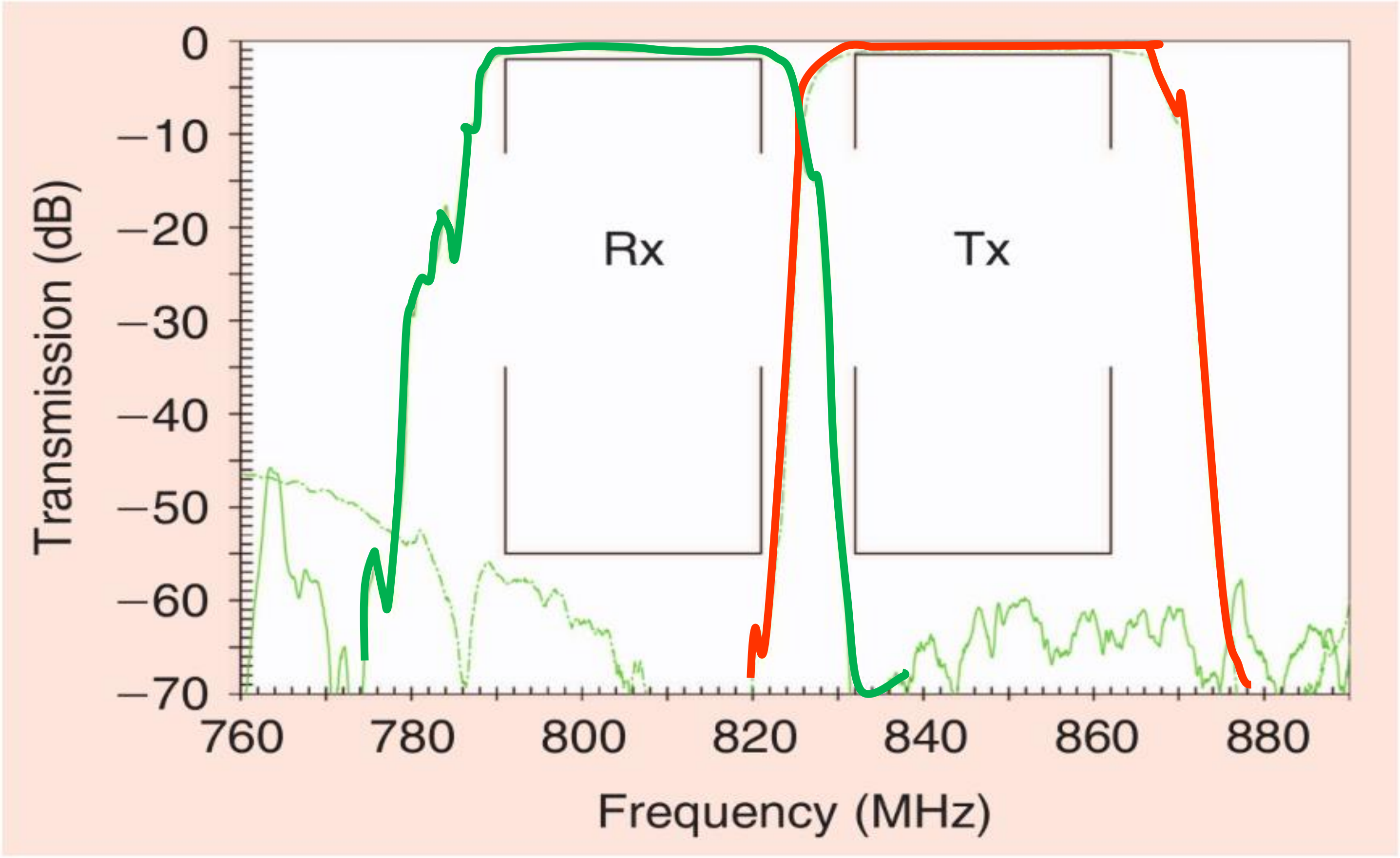
Wien Mariahilferstrasse

Mikrowellen Filter

Piezoelektrizität

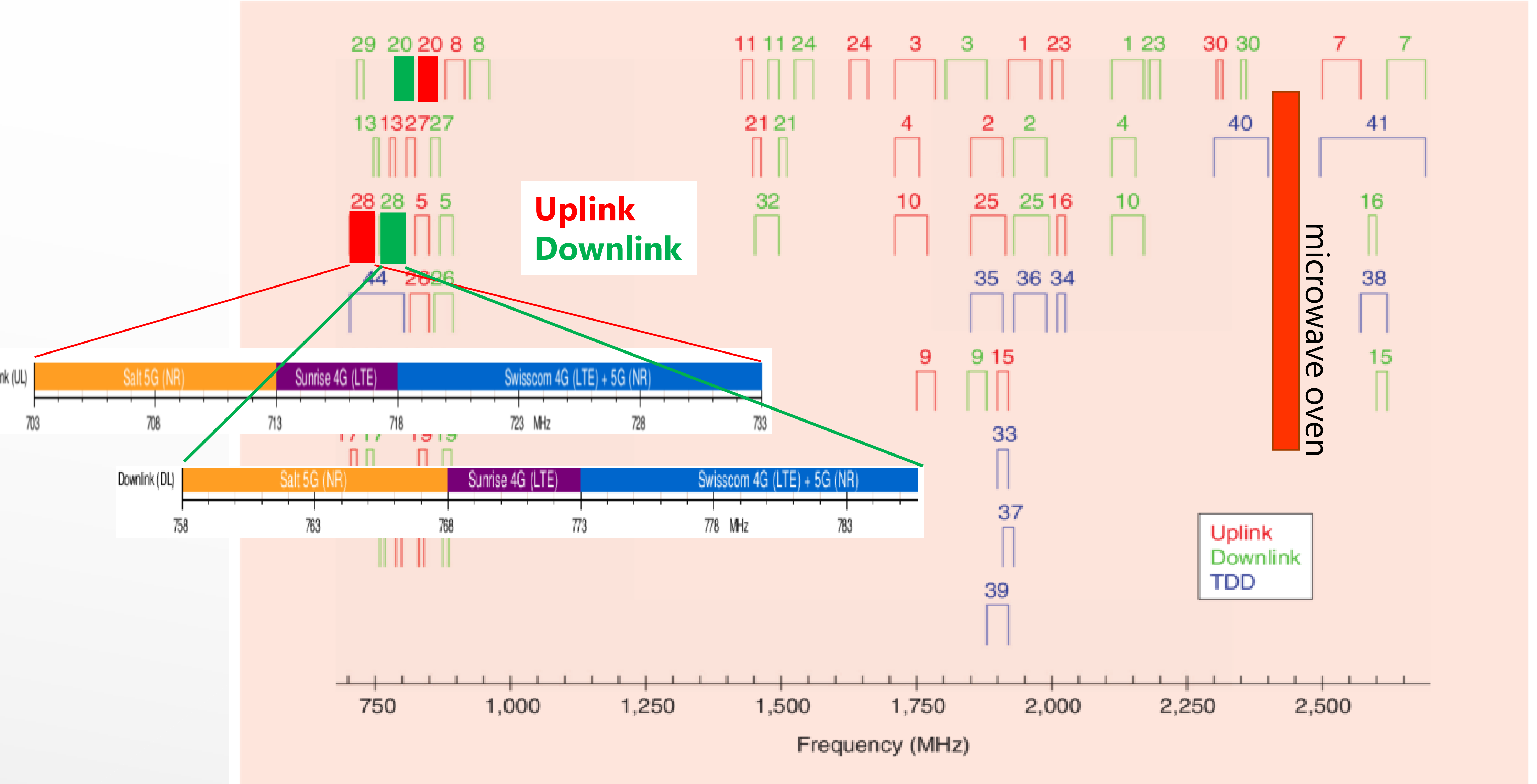
RF filters





Source: T. Bauer et al., A bright Outlook for Acoustic Filtering, IEEE Microwave Magazine (2015)

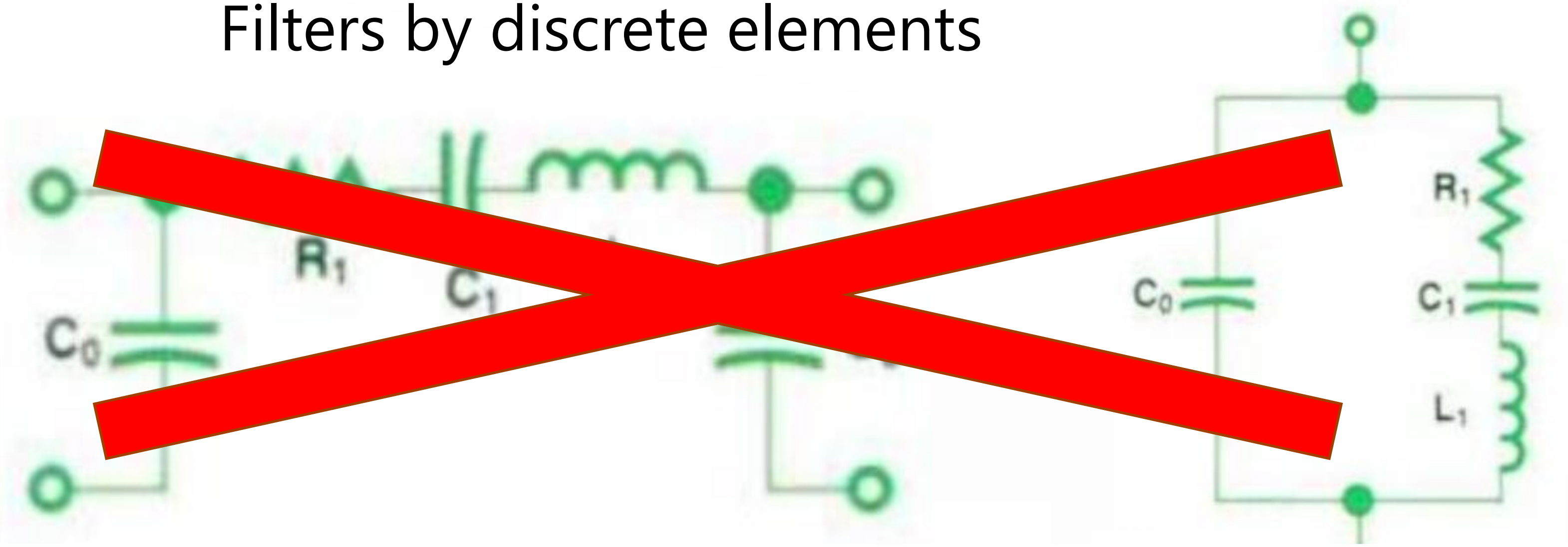
Uplink – downlink frequency bands



LTE bands up to 3 GHz.

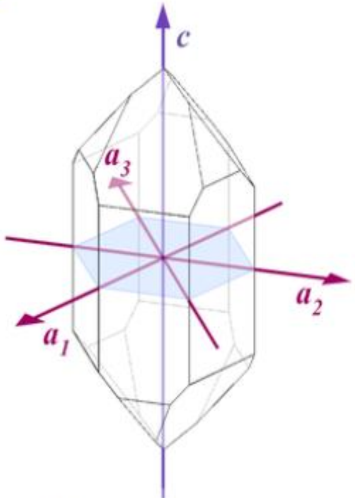
How to build the filters ?

Filters by discrete elements



Solution:
Piezoelectric effect – acoustic filters

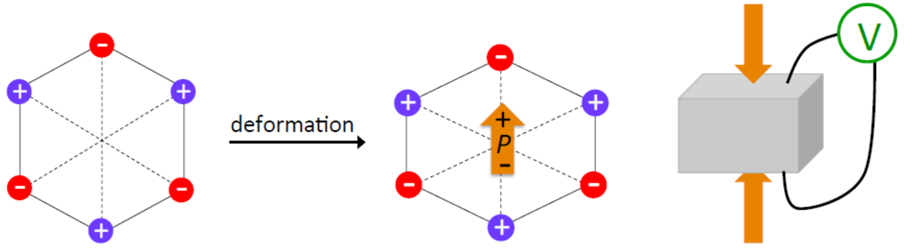
Piezoelectricity – SAW filters, quartz clocks …



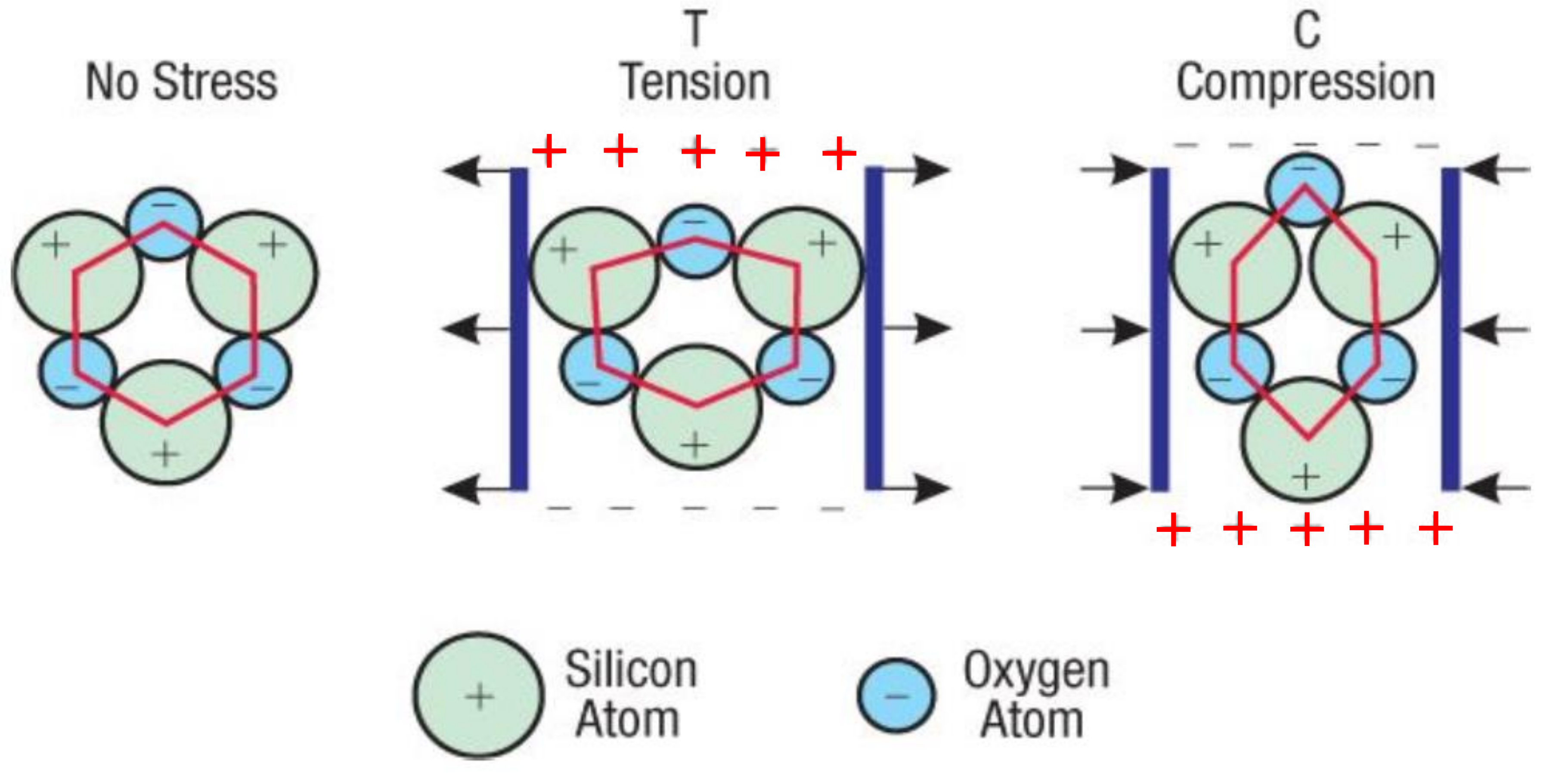
Jacques & Pierre Curie

1880 piezoelectric effect discovered in quartz and other materials

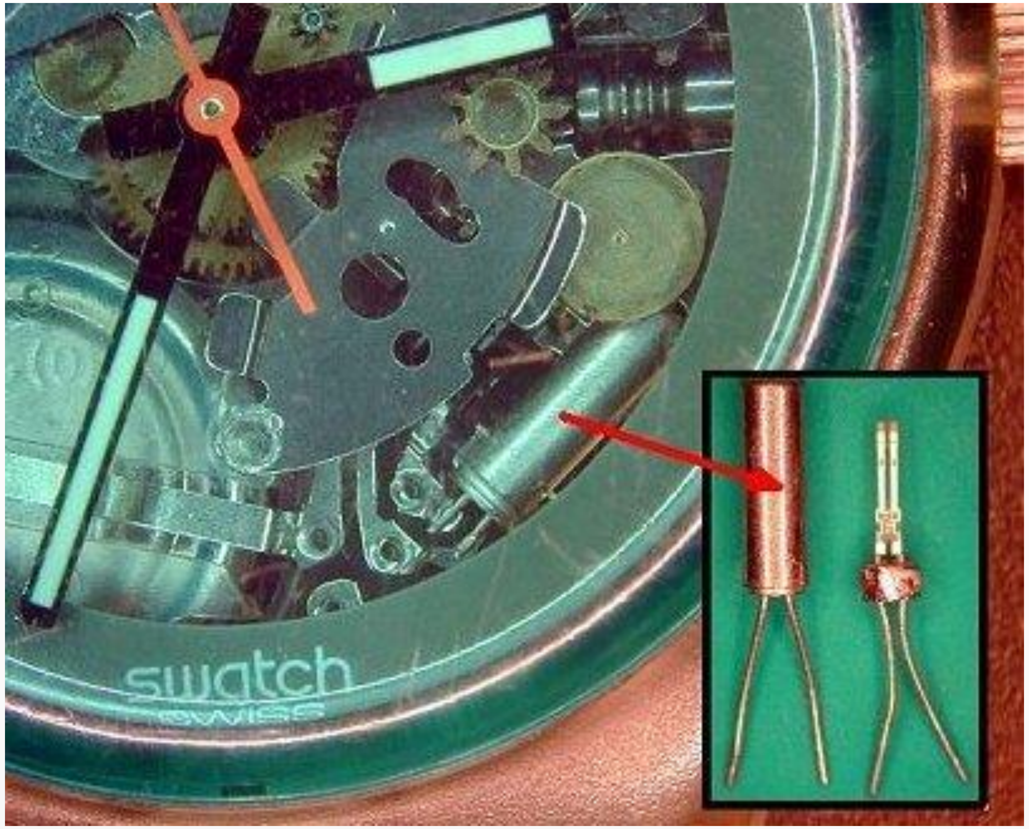
pressure → voltage

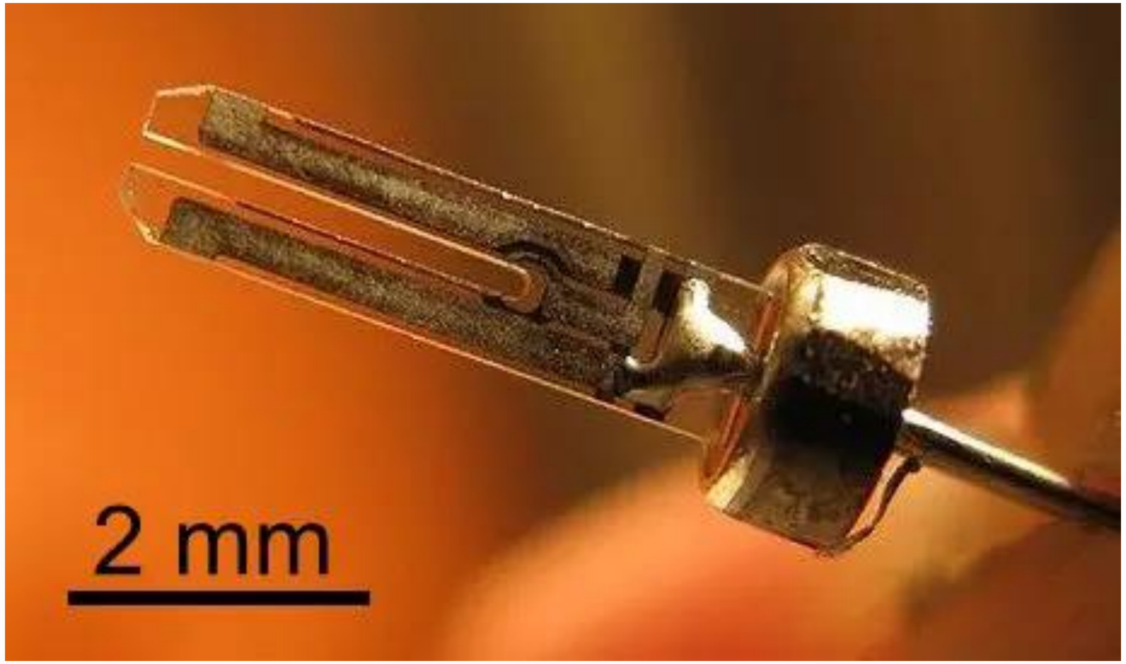


Piezoelectricity



Piezoelectricity : quartz tuning fork resonator



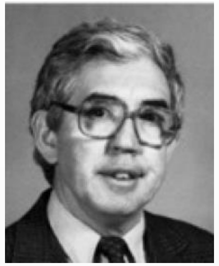


32 768 Hz = 2^{15} per second

Quartz clock 1927
Walter Marrison
Bell Labs

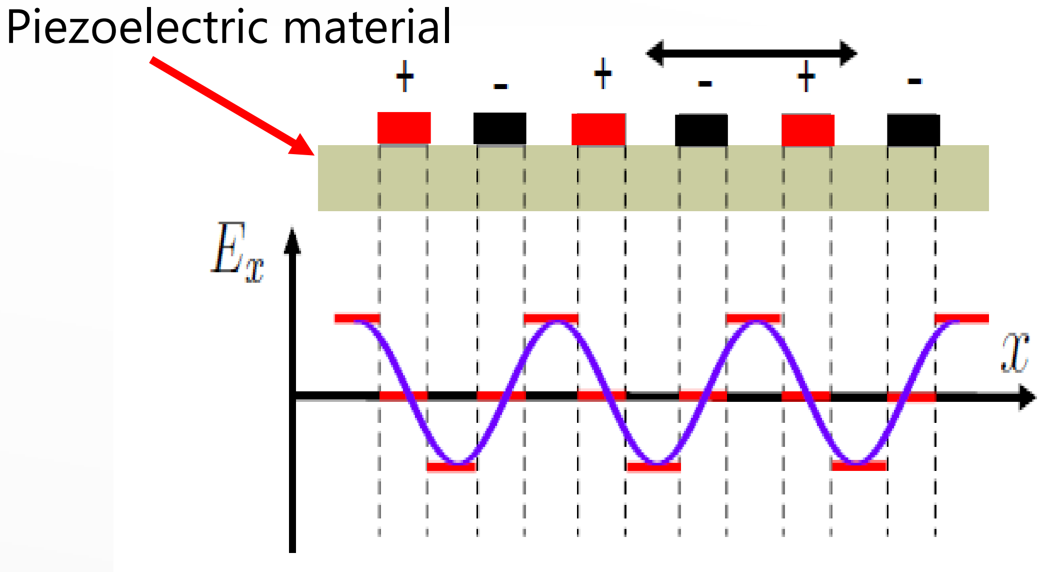
Industrial scale quartz crystal growth

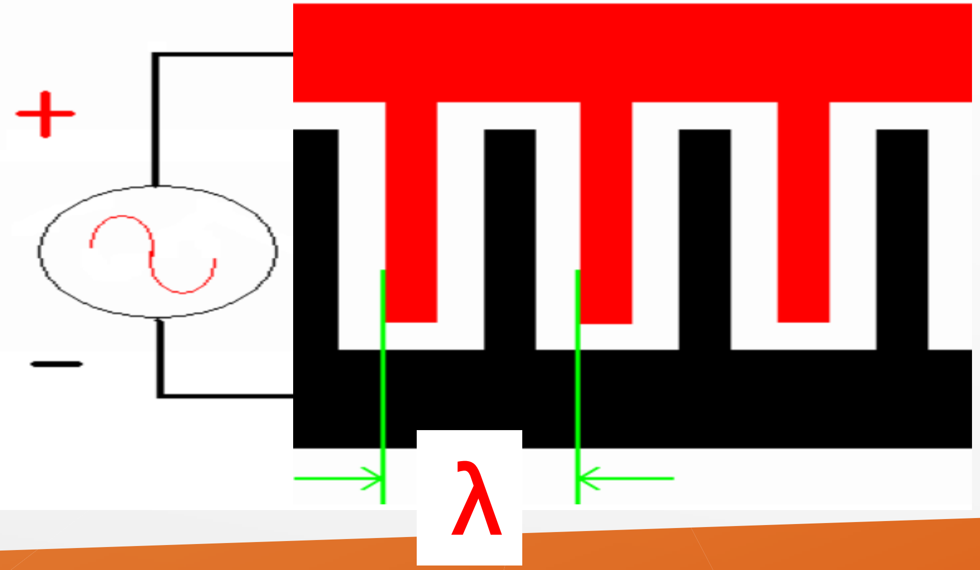
1950 A.C. Walker and Ernie Buehler
1959 Robert A. Laudise
(1930 – 1998)
AT&T Bell Labs

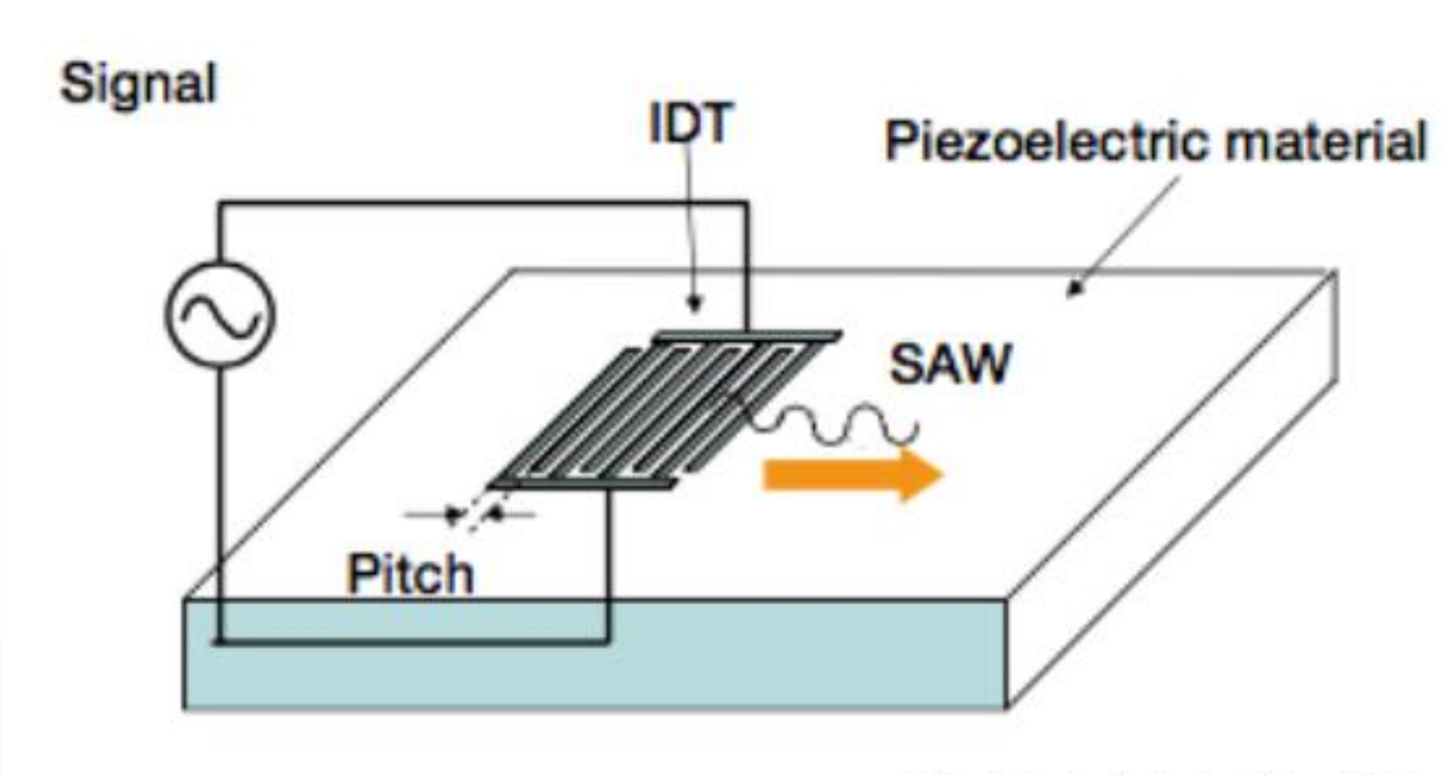


Hydrothermal growth
375 – 450 C
1000 – 1500 bar

Basic schematic of a Surface Acoustic Wave filter

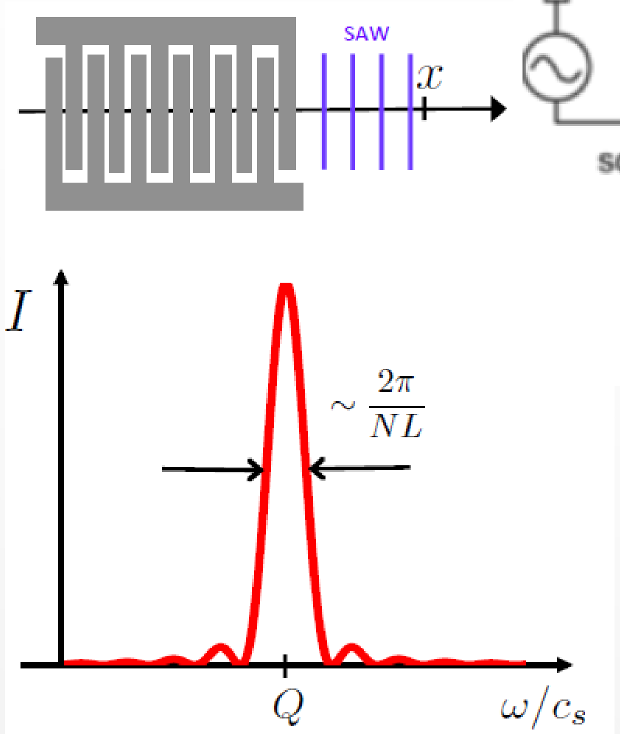


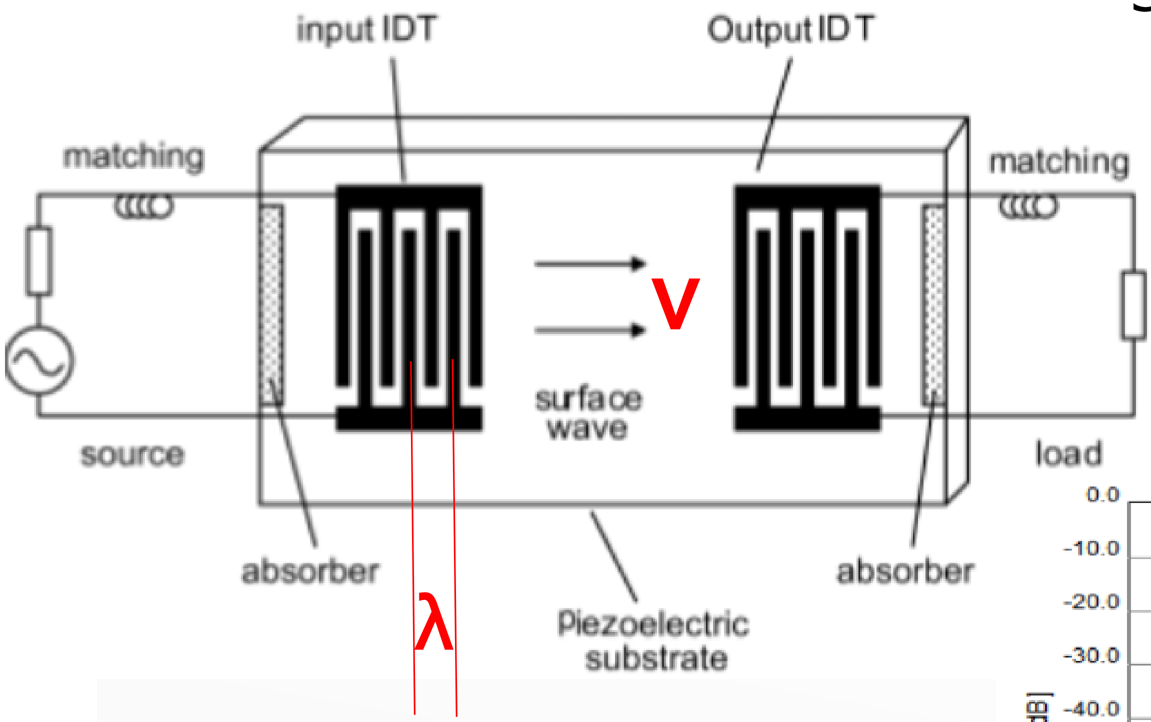




Taiyo Yuden Navigator, Fourth Issue (2010).

SAW filter : highly frequency selective



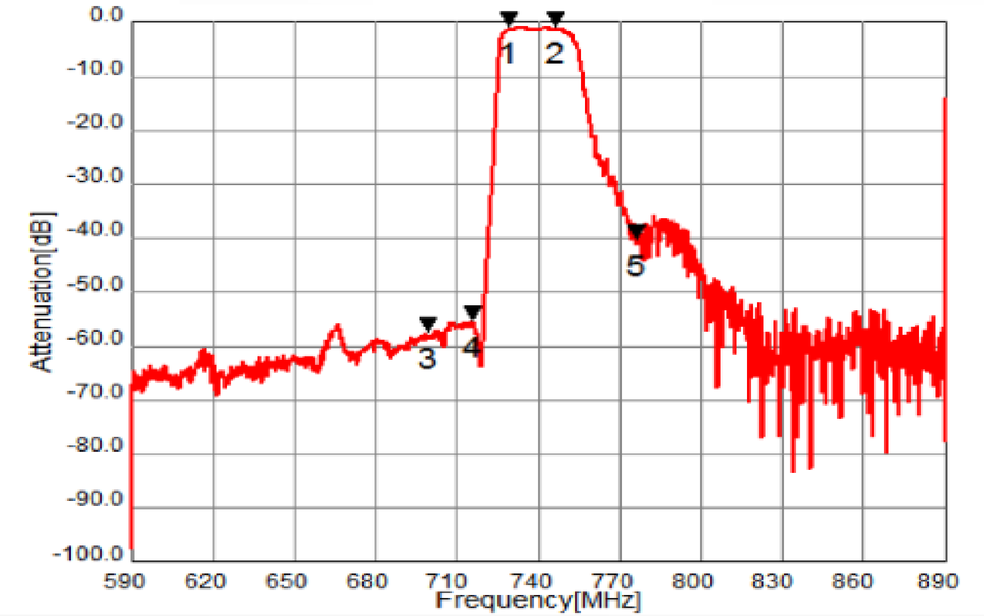


Surface wave velocity (~km/s)

$$10^9 = 10^3 / 10^{-6}$$

Electrode geometry (~μm)

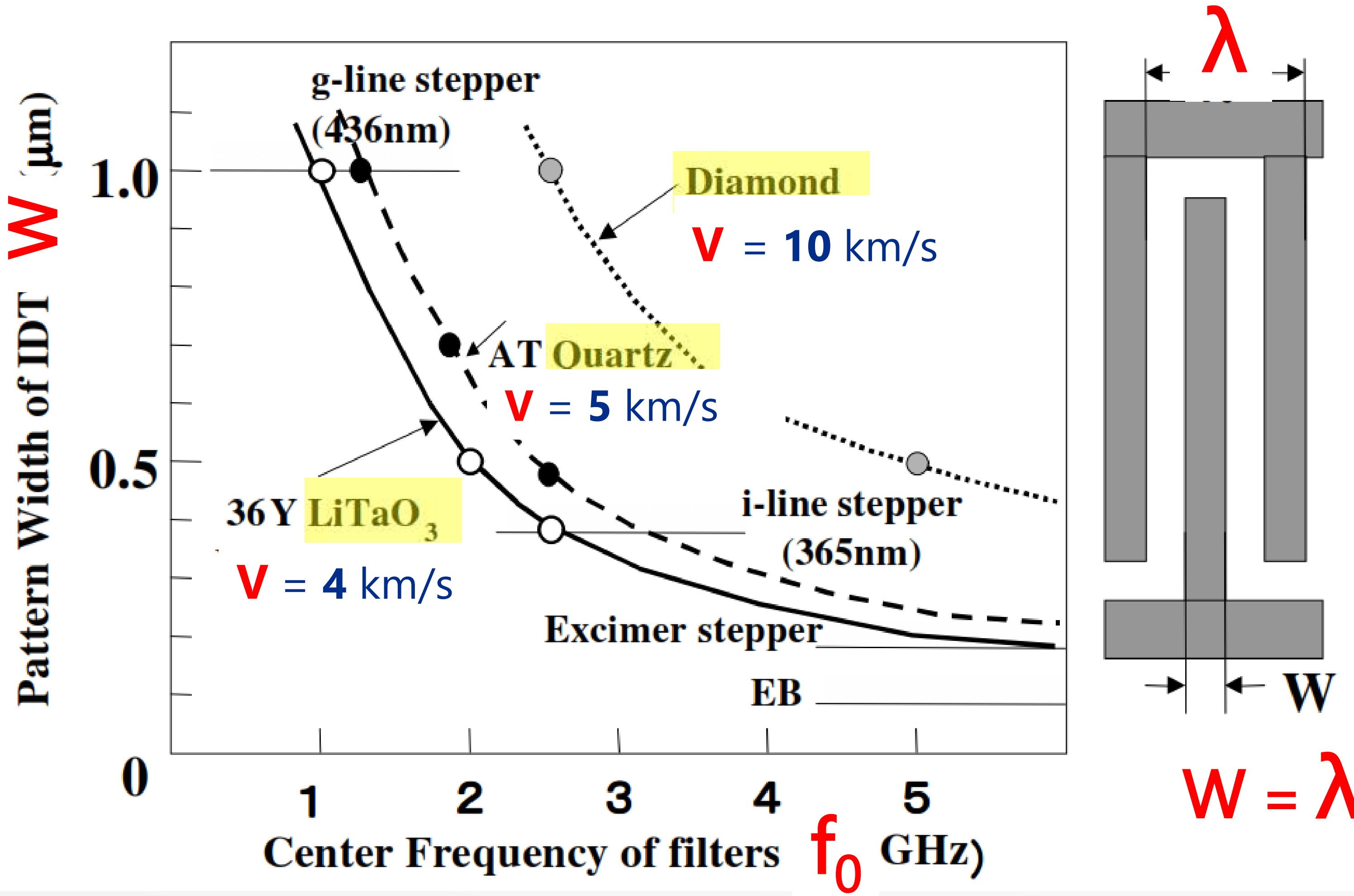
$$f_0 = v / \lambda$$



SAW filter for LTE Band 12
by Taiyo Yuden, Japan

Frequency - geometry

$f_0 = v / \lambda$

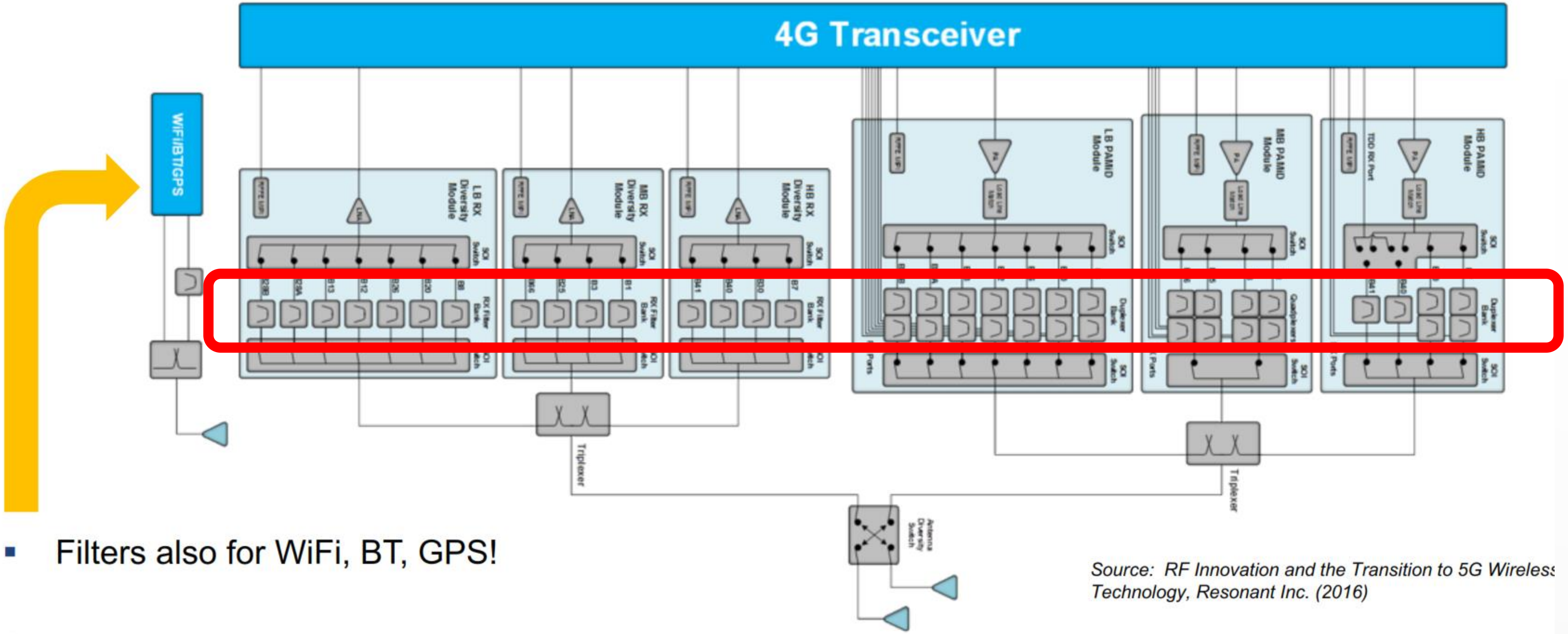


$\lambda = v / f_0$

$W = \lambda/4$

Complex filtering in modern transceivers

- Typical 4G RFFE design. Includes triplexers, quadplexers, filter banks

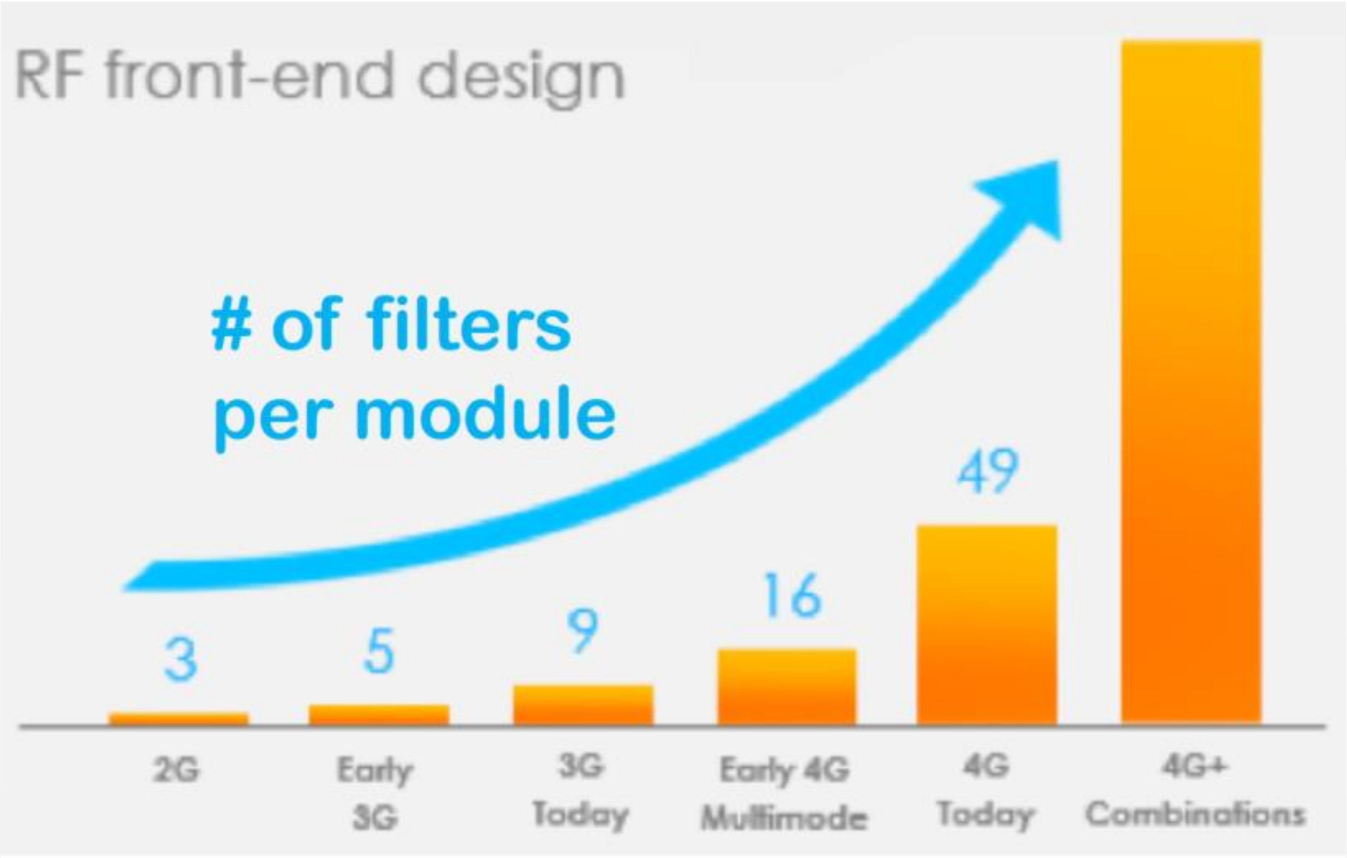


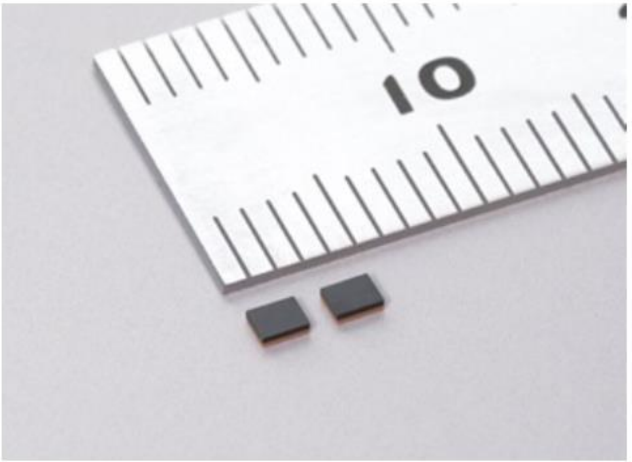
- Filters also for WiFi, BT, GPS!

Source: RF Innovation and the Transition to 5G Wireless Technology, Resonant Inc. (2016)

SAW filters are SMALL

ca. 1 x 1 x 0.5 mm^3



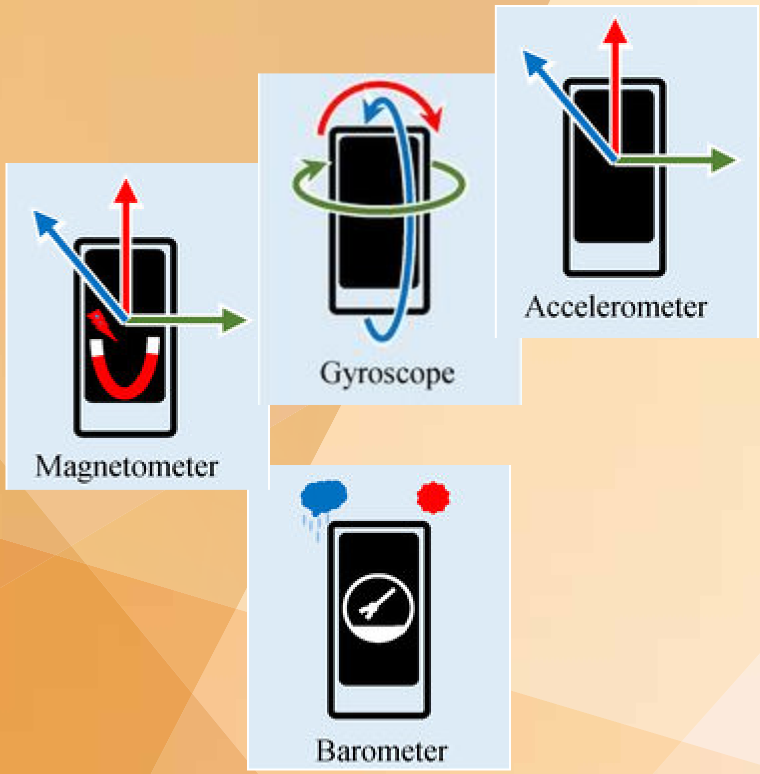


SAW Duplexers by Murata.
Source:
http://www.murata.com/about/newsroom/news/product/filter/2016/0920

How Many Sensors do You Think I Have?

Sensors

Accelerometer
Gyroscope
Magnetometer
Microphone
Ambient light sensor
Fingerprint sensor
Proximity
Barometer
Therometer
Air Humidity
Heart rate sensor
Pedometer
Blood oxygen sensor
UV sensor
. . .

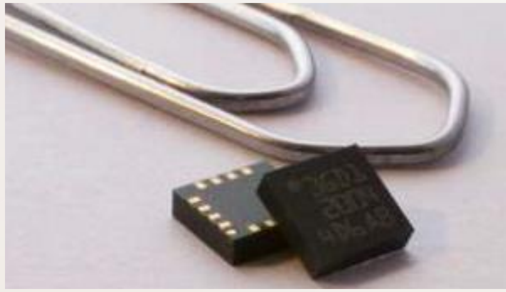


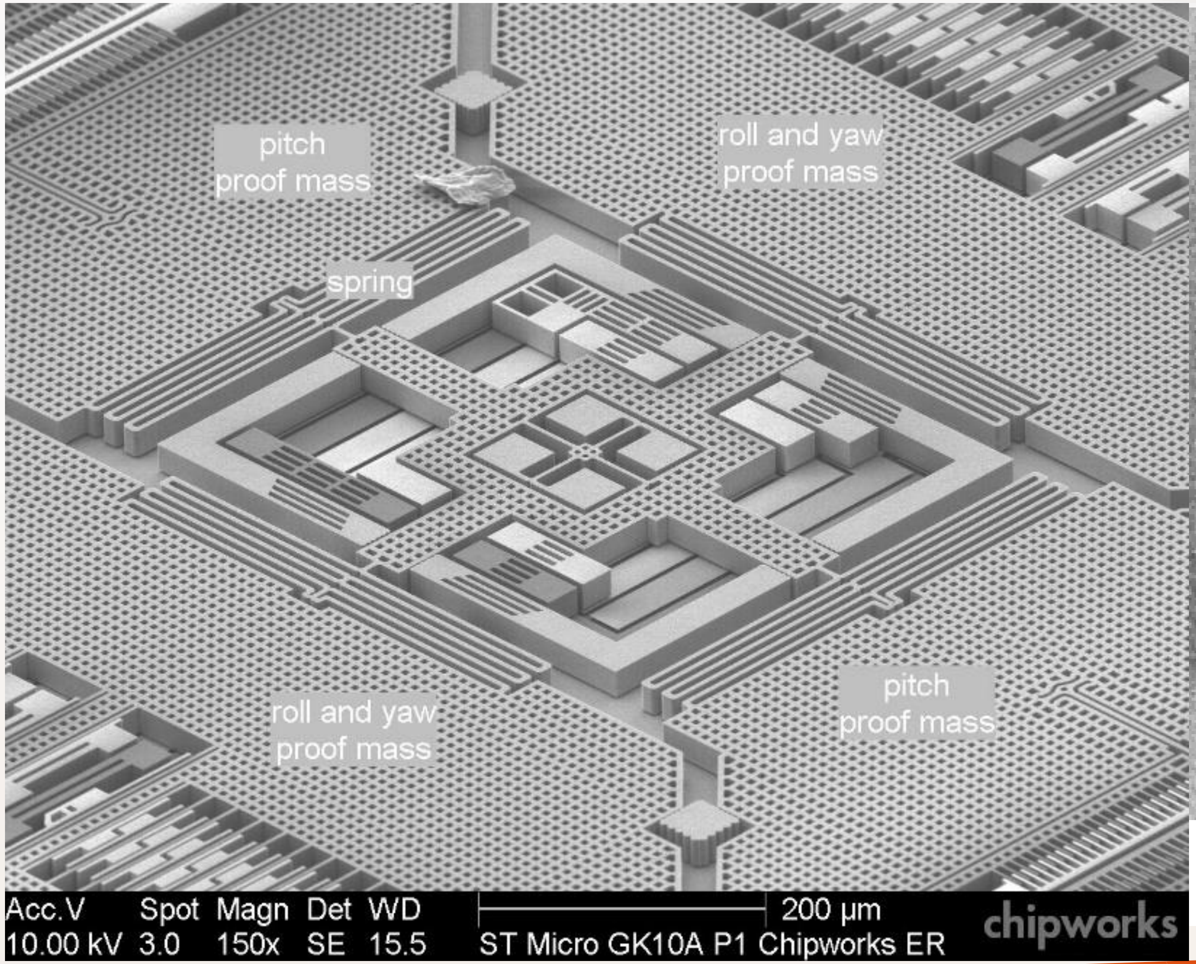
What are MEMS ?

- MEMS is an acronym for Micro Electro Mechanical Systems

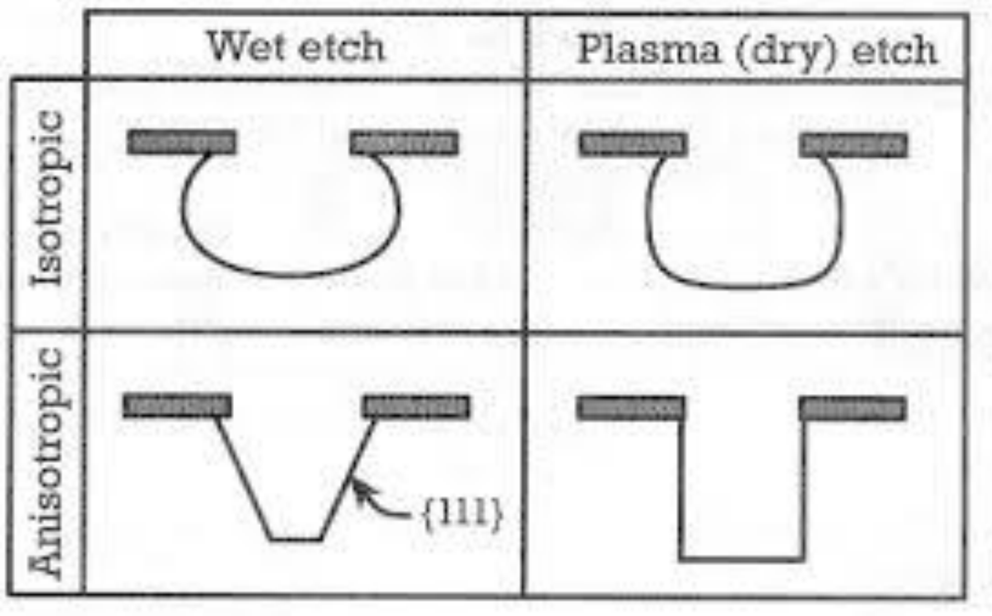
- They contain 3-dimensional structures realized through "Micro-Machining"

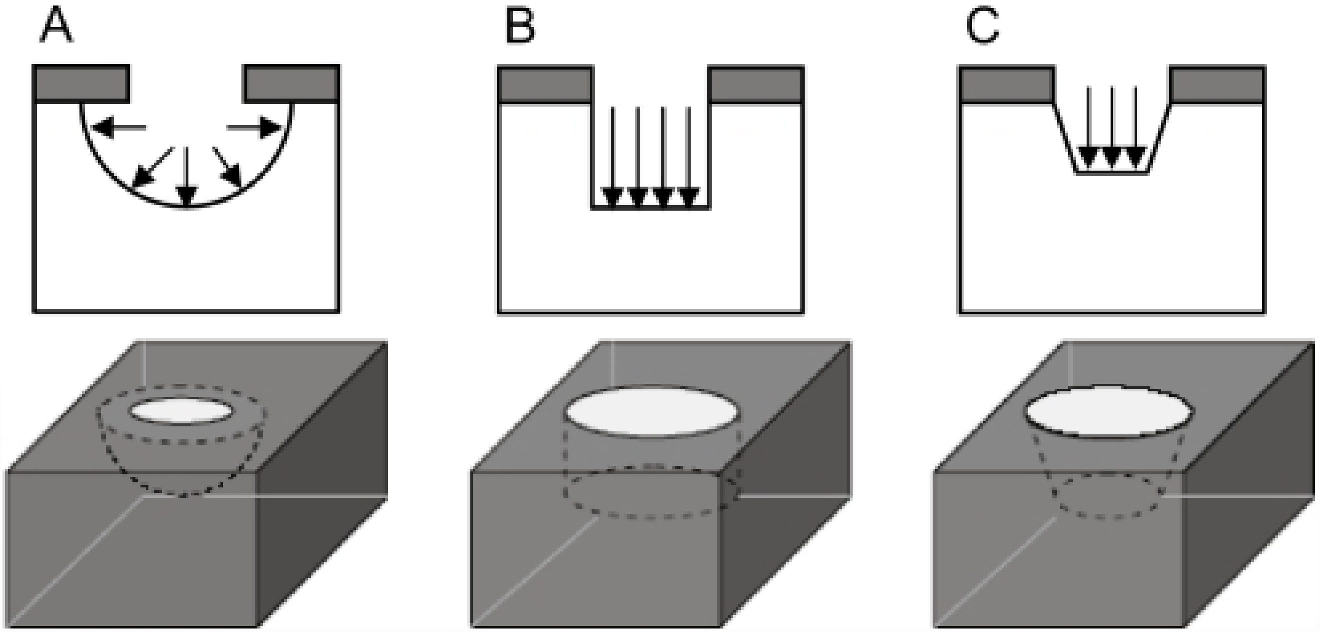
- These mechanical parts are micron-size devices that interact with external world for sensing and actuation



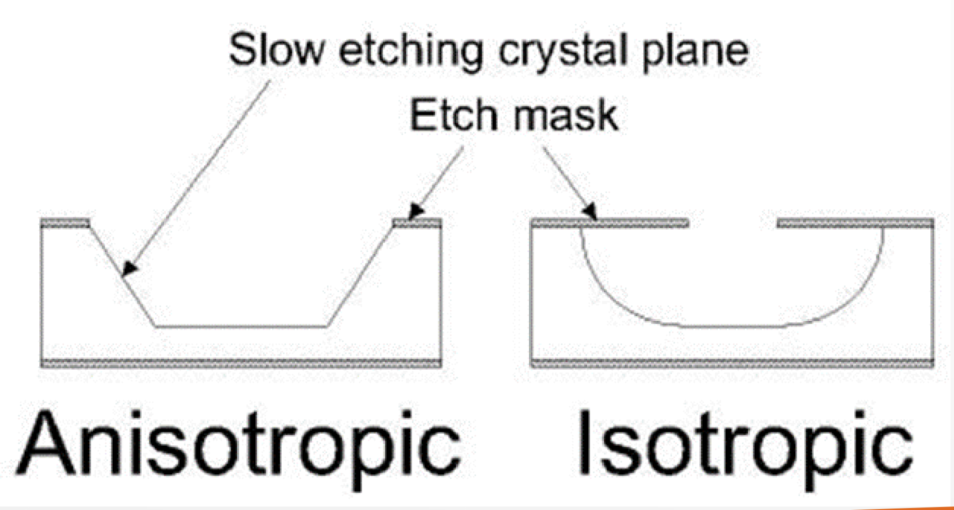


Etching : isotropic - anisotropic / wet - dry





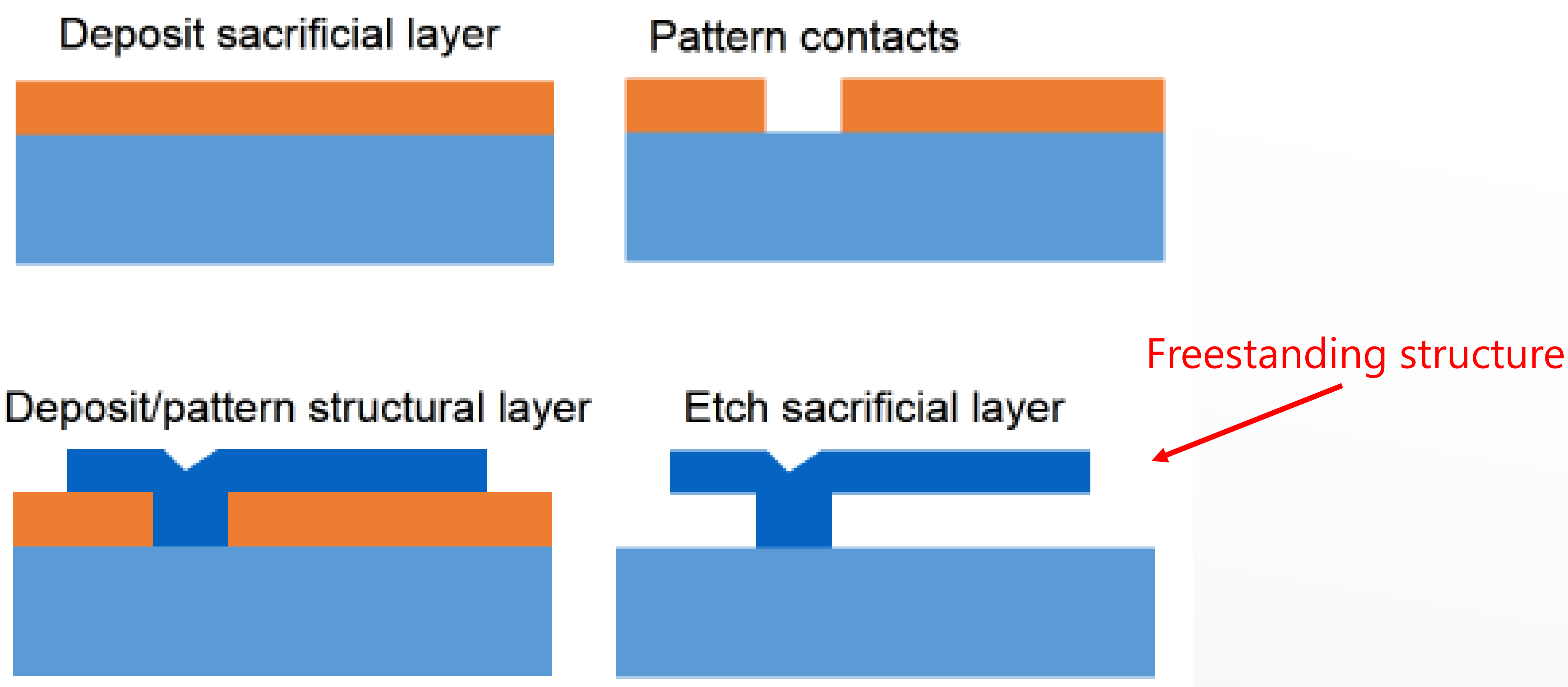
isotropic dry anisotropic wet anisotropic



Etching profiles

openi.nlm.nih.gov

Surface Micromachining



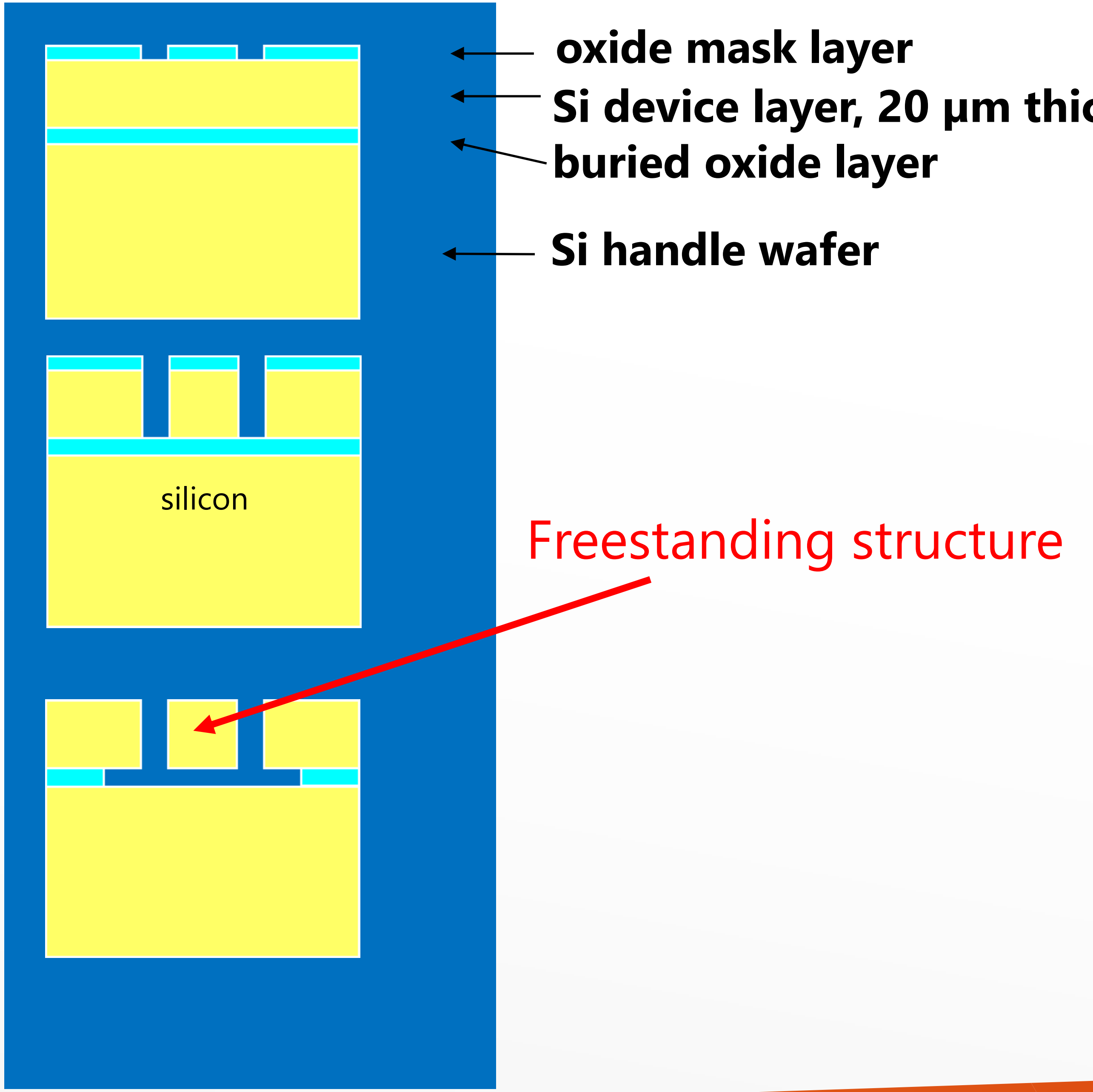
Surface Micromachining

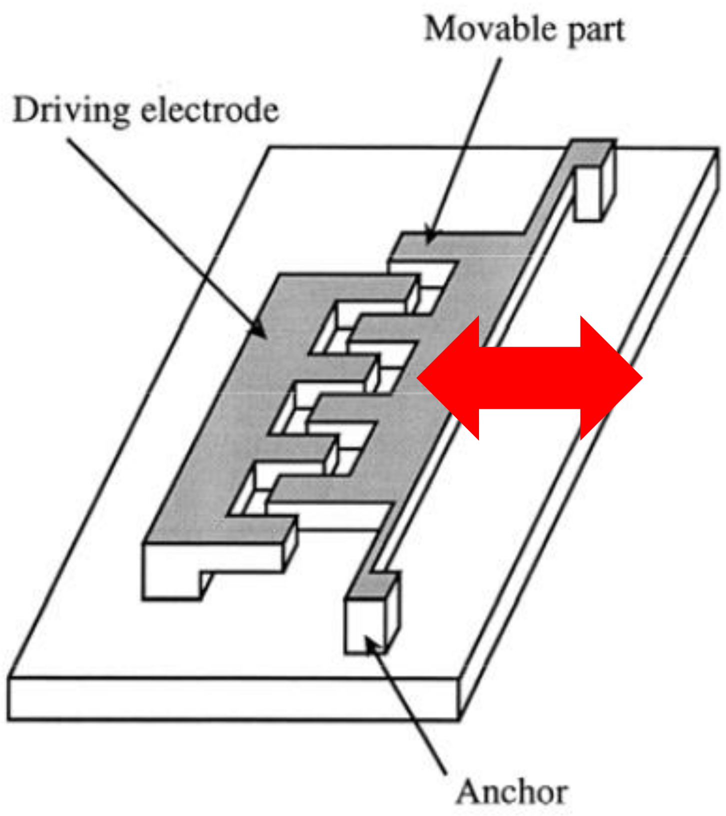
- Etching Solutions

  KOH, "TMAH", "EDP", N_2H_4, NaOH, CsOH, etc.
- Chemical reaction

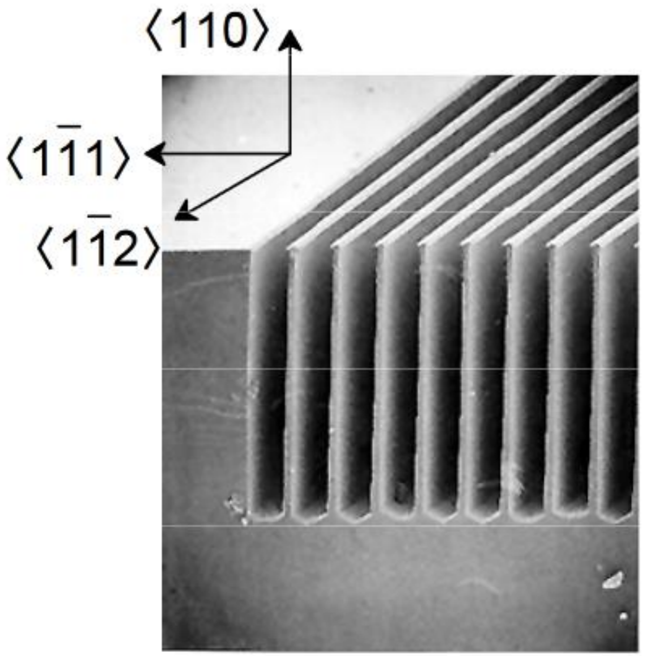
  $Si + 2OH^- + 2H_2O$

  $\rightarrow Si(OH)_4 + H_2 \rightarrow SiO_2(OH)_2^{2-} + 2H_2$

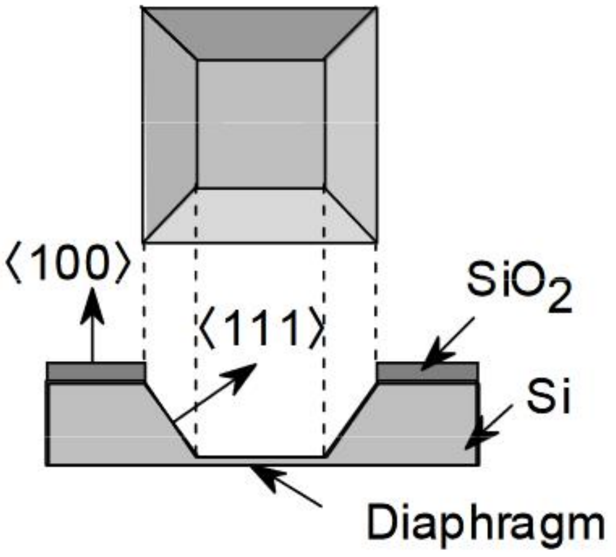




Comb drive type



Deep grooves on a (110) wafer

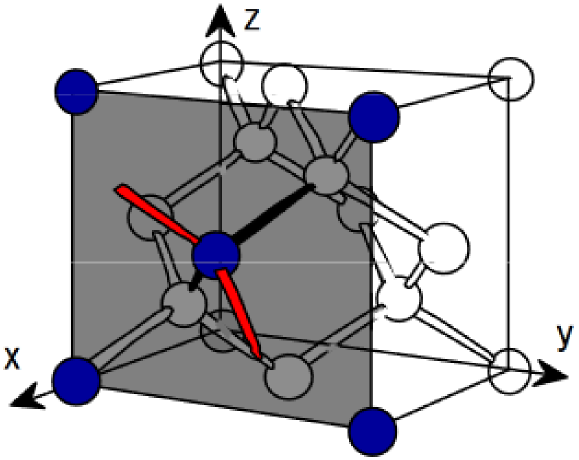


Diaphragm on a (100) wafer

Conventional “explanation” of etching anisotropy

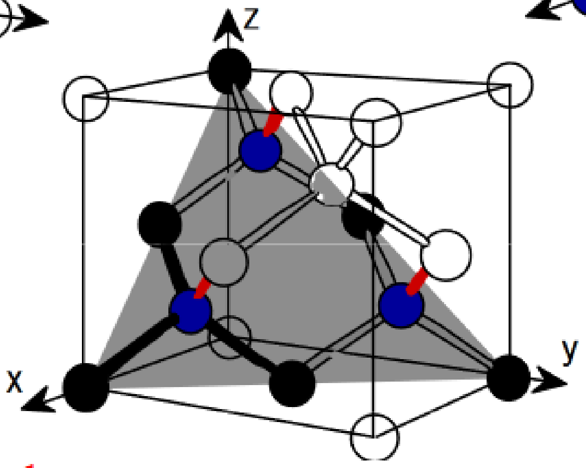
Hypothesis: Number of dangling bond appearing on the silicon surface determines the etching rate

fcc diamond structure



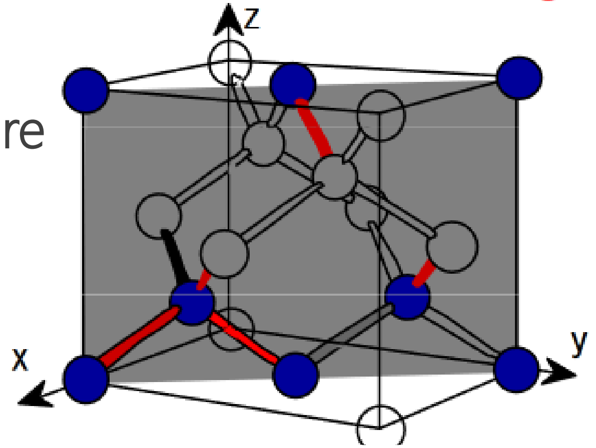
(100)

Dangling bond : **2**
Back bond : **2**



(111)

Dangling bond : **1**
Back bond : **3**



(110)

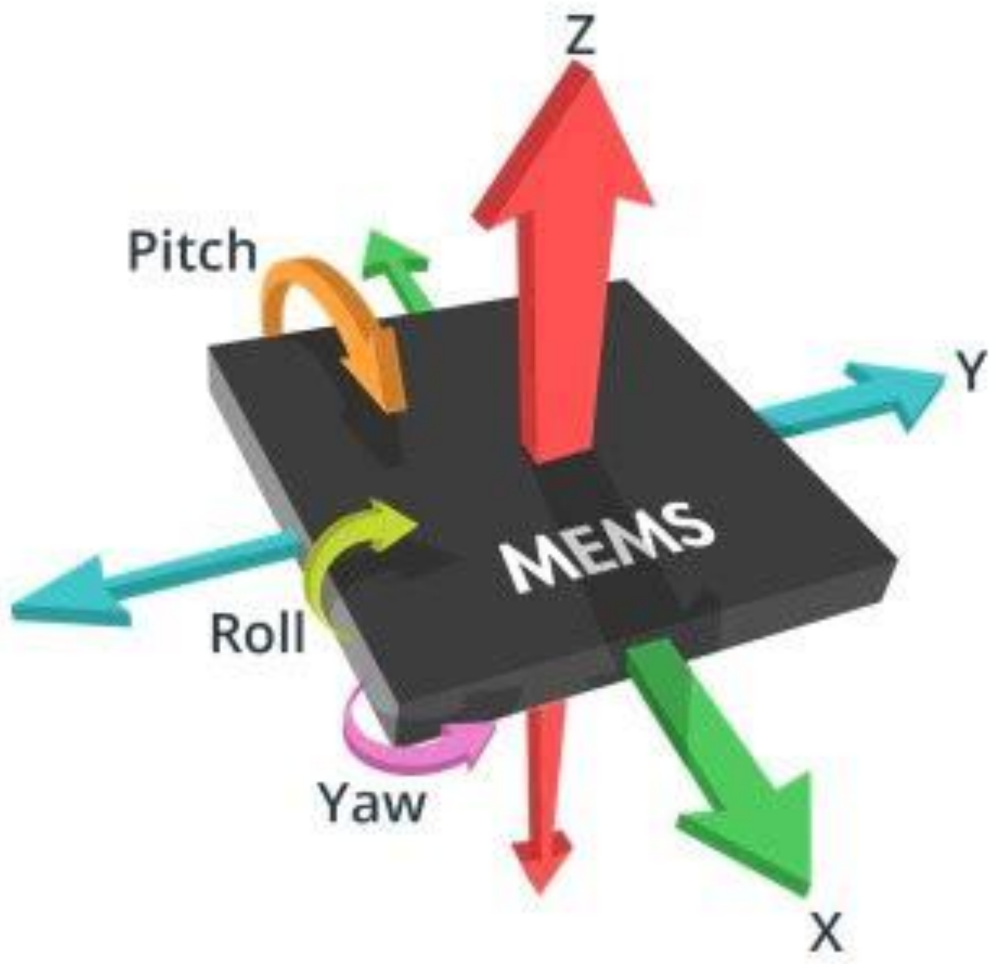
Dangling bond : **1 +(2)**
(Exposed back bond : **2**)
Back bond : **3**

Sensing Motion

portrait or landscape mode
step counter

Accelerometer

Sensing motion : rotation - acceleration



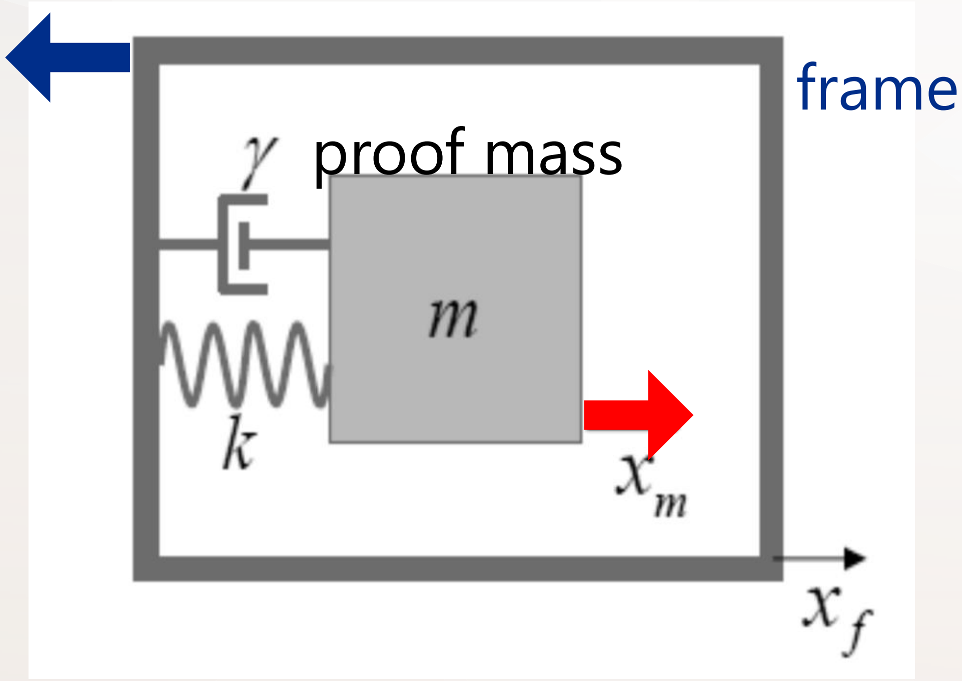
Gyroscope (in three dimensions, pitch, roll, and yaw): delta theta (radians), average rate (rad/s)

Accelerometer (accelerates in straight lines x, y, and z): delta velocity (m/s), average acceleration (m/s^2)

Accelerometer

Basic Operation Principle : *Newton's Laws*

Model : 2nd Order Spring-Damper



- F_e - Force applied on frame
- x_f - Reference frame displacement
- x_m - Proof mass displacement

Applying Newton's 1st and 2nd Laws:

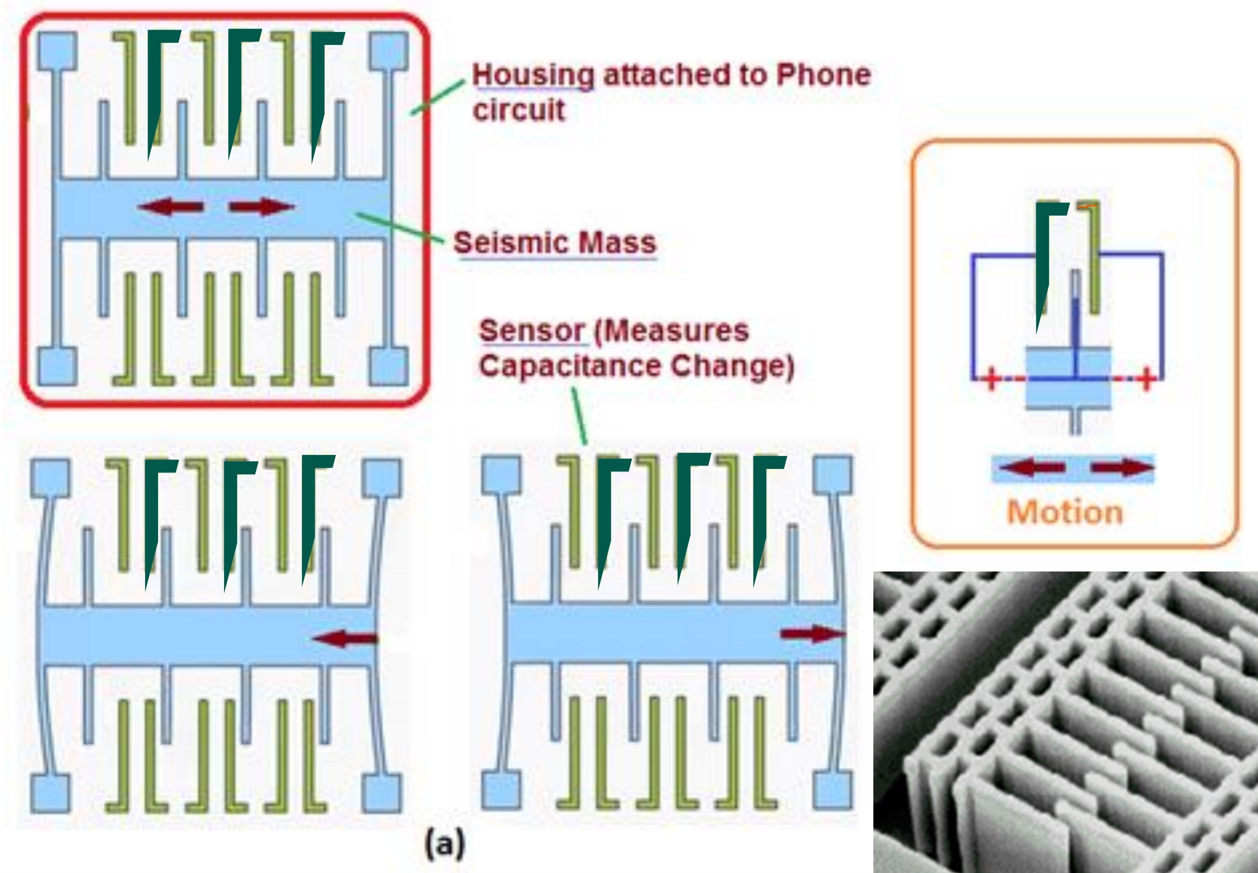
$$m\frac{\partial^2 x}{\partial t^2} + \gamma\frac{\partial x}{\partial t} + kx = F$$

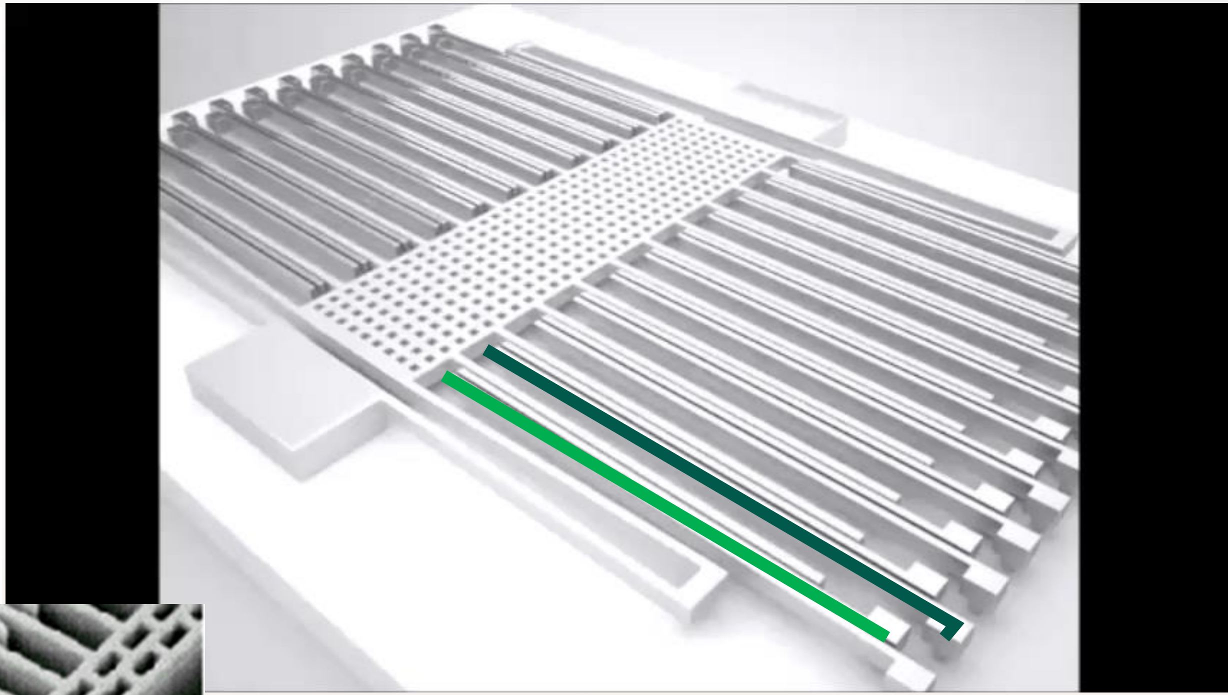
Or

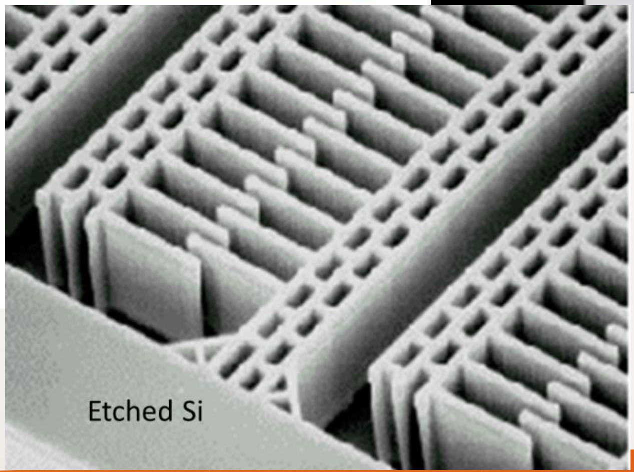
$$\boldsymbol{F = m\frac{\partial^2 x_f}{\partial t^2} - F_e}$$

Accelerometer

Final Product – MEMS Capacitive accelerometer



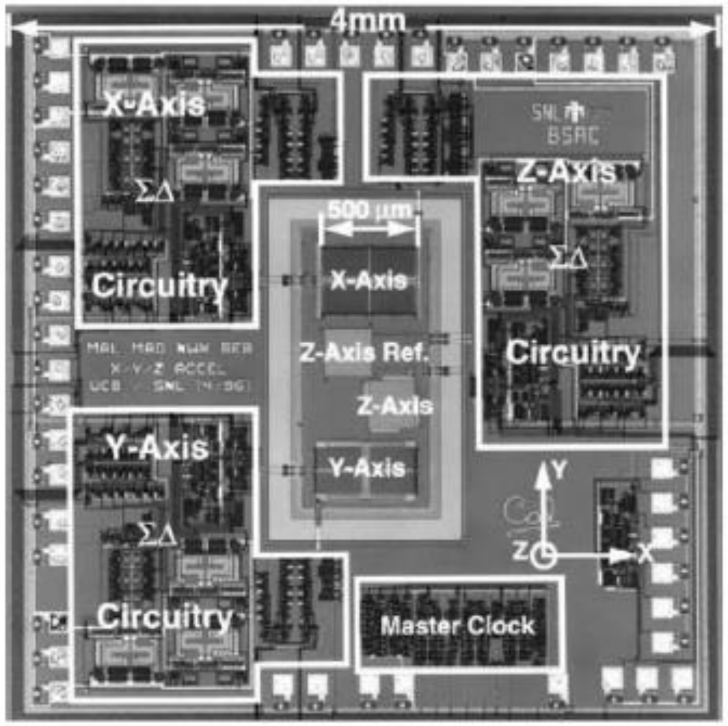


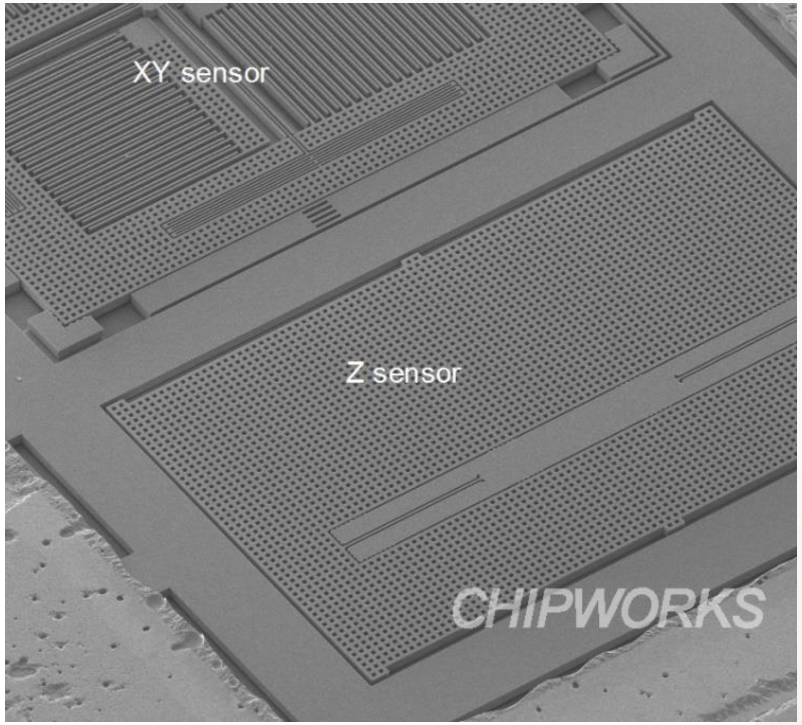


https://www.youtube.com/watch?v=p-gKaEkw9CU

Accelerometer

Final Product – MEMS 3D Capacitive accelerometer





b)

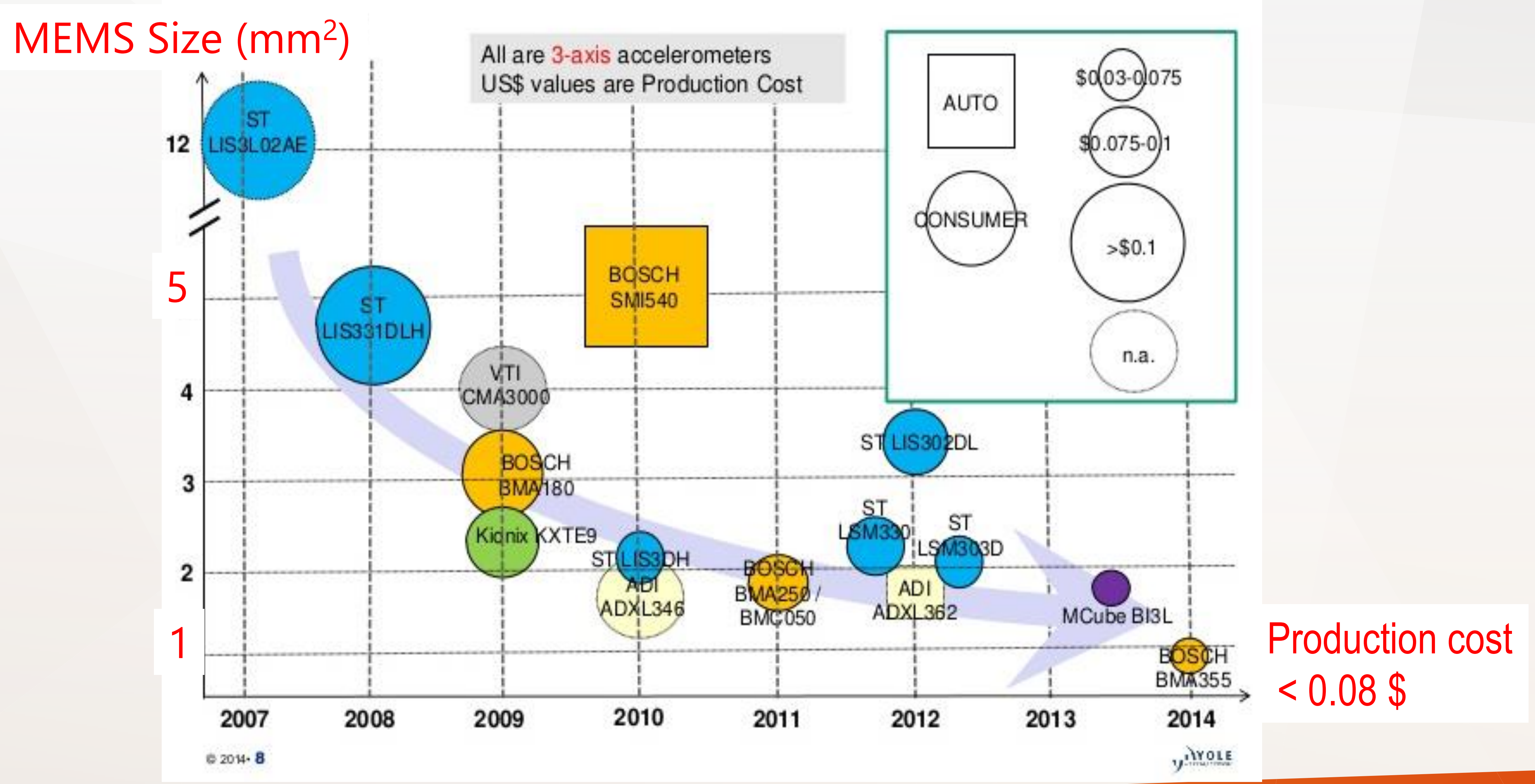
a) 3D accelerometer structure. It has three different sensors for x-/y-/z- axis acceleration and three different electronic circuitry for each axis [8]

b) 3D structure without electronics. NOTE: all three sensors are linked with the same proof mass [5]

Typical numbers

- Mass of proof mass: $0.1\mu\, g$
- Capacitance sensitivity: $20pF$
- Gaps between capacitor plates: $1.3\mu\, m$
- Frequency of signal V_0 : $1MHz$
- Pairs of plates: 46
- output signal is amplified and demodulated.

MEMS Accelerometers are getting smaller

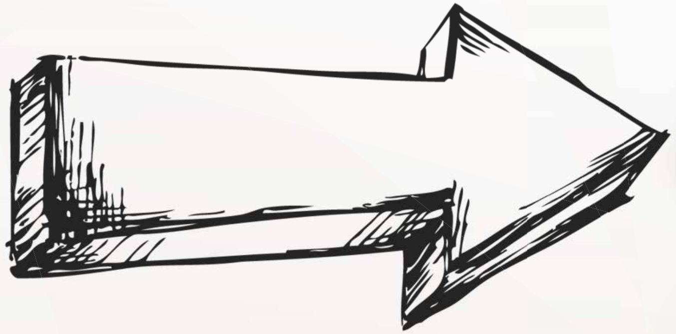


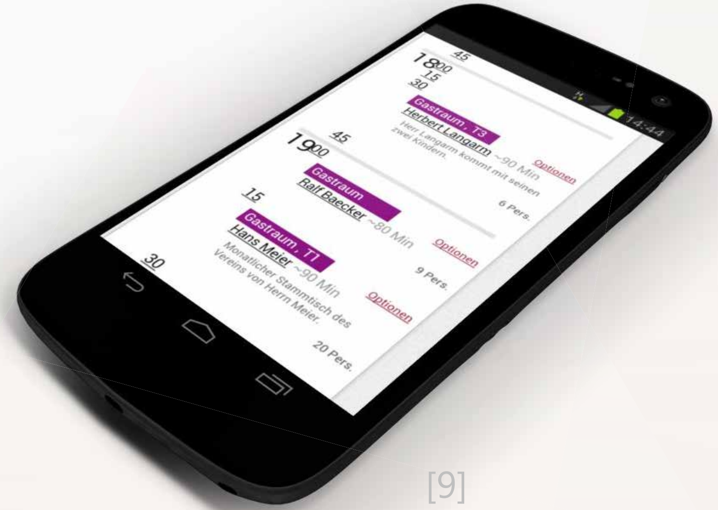
Sensing Rotation

Gyroscope

Gyroscope

getting a gyroscope into a smartphone

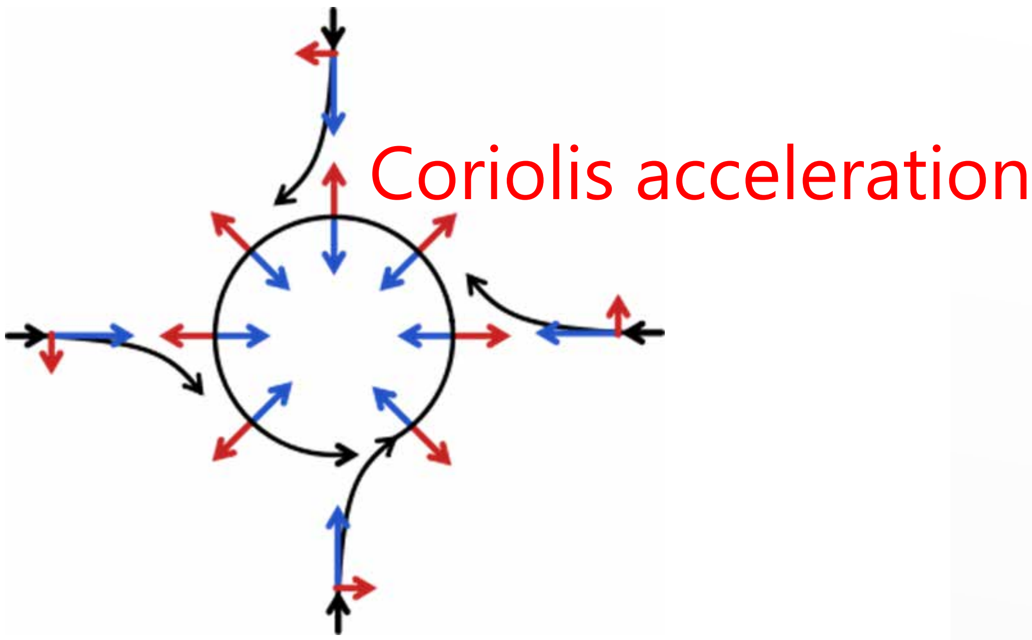




[9]

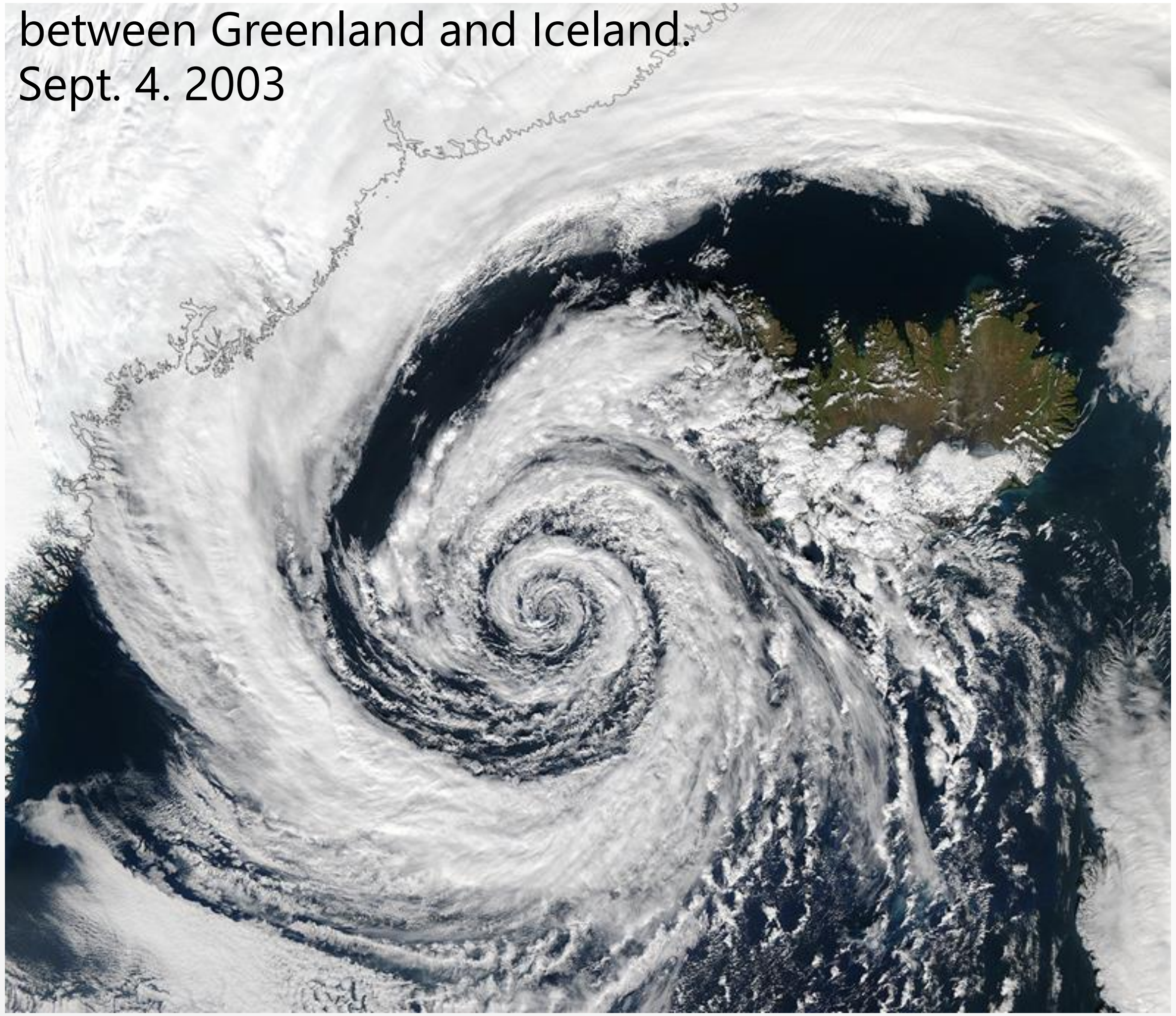
… Coriolis effect

flow around a **low**-pressure area in the Northern Hemisphere



… Coriolis effect

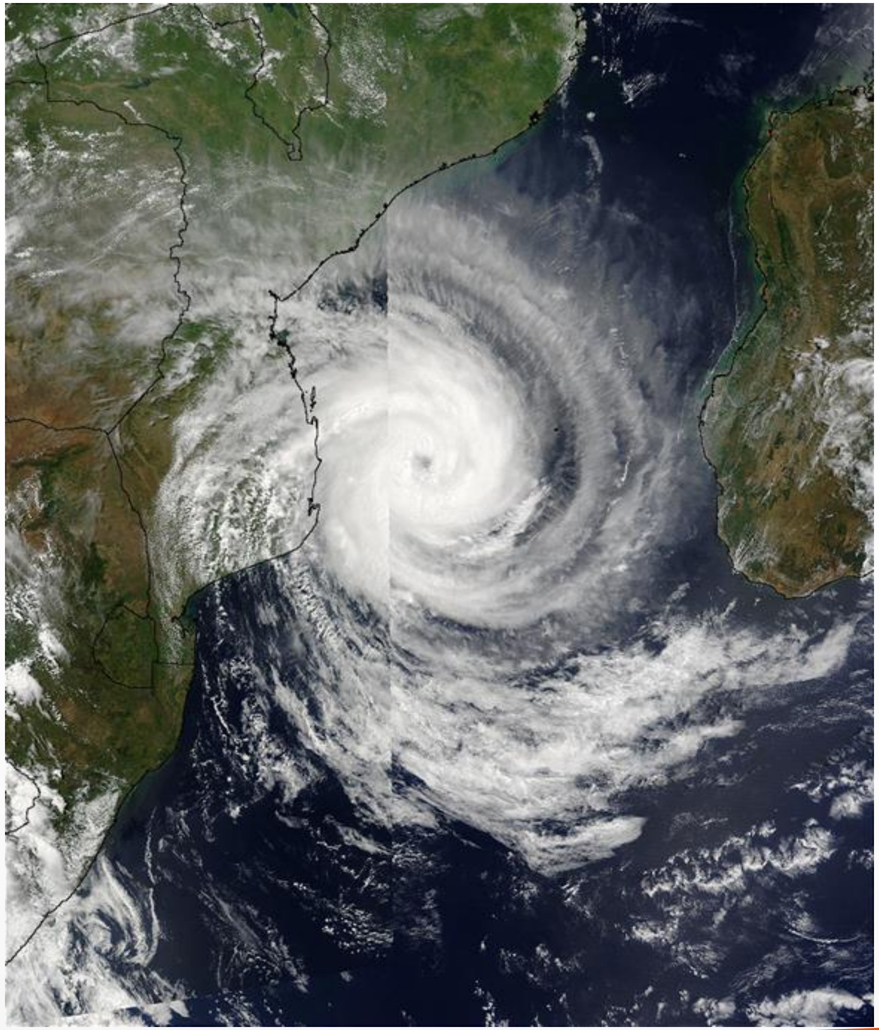
N -hemisphere



between Greenland and Iceland.
Sept. 4. 2003

S -hemisphere

between Mozambique, on the left, and Madagascar on February 26, 2003.



Gyroscope

Fundamentals – Coriolis Force

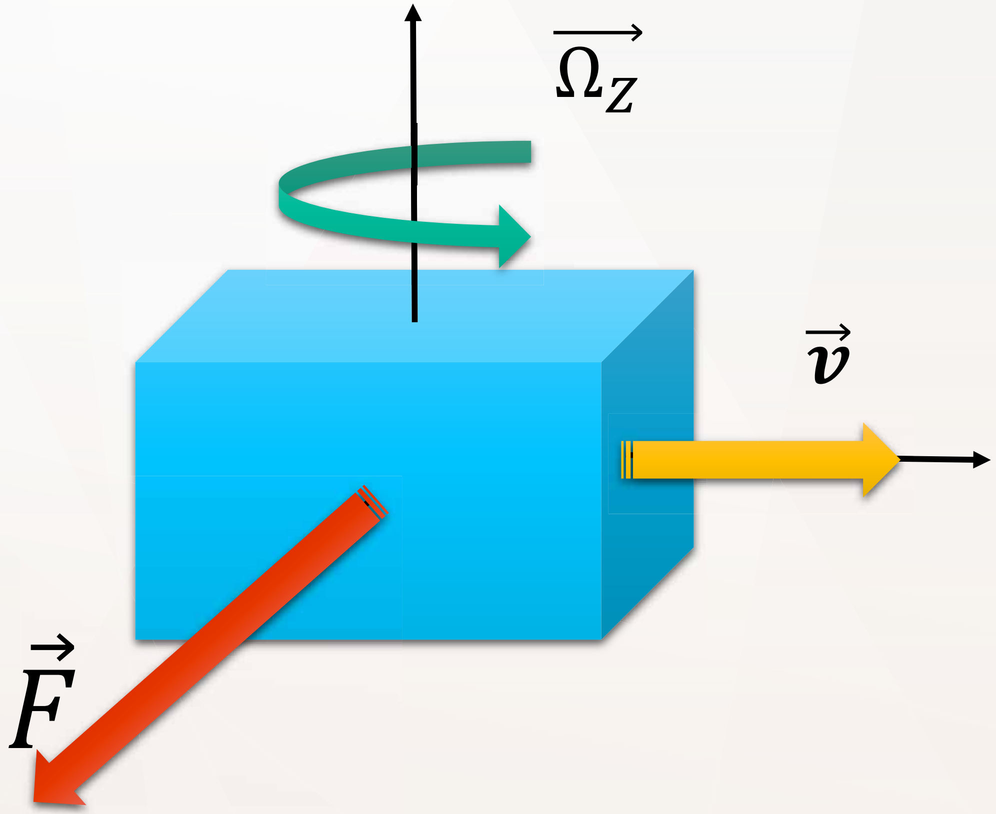
$$\boldsymbol{F}_{Coriolis} = -2m\boldsymbol{\Omega} \times \boldsymbol{v}$$

MEMS gyroscopes use the Coriolis effect

Consider a mass moving in direction **v**.

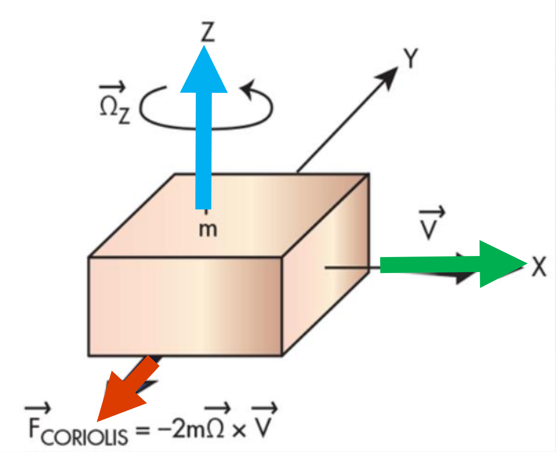
When an angular movement is applied (**green arrow**), the mass experiences a force in the direction of the **RED arrow** as a result of the Coriolis effect

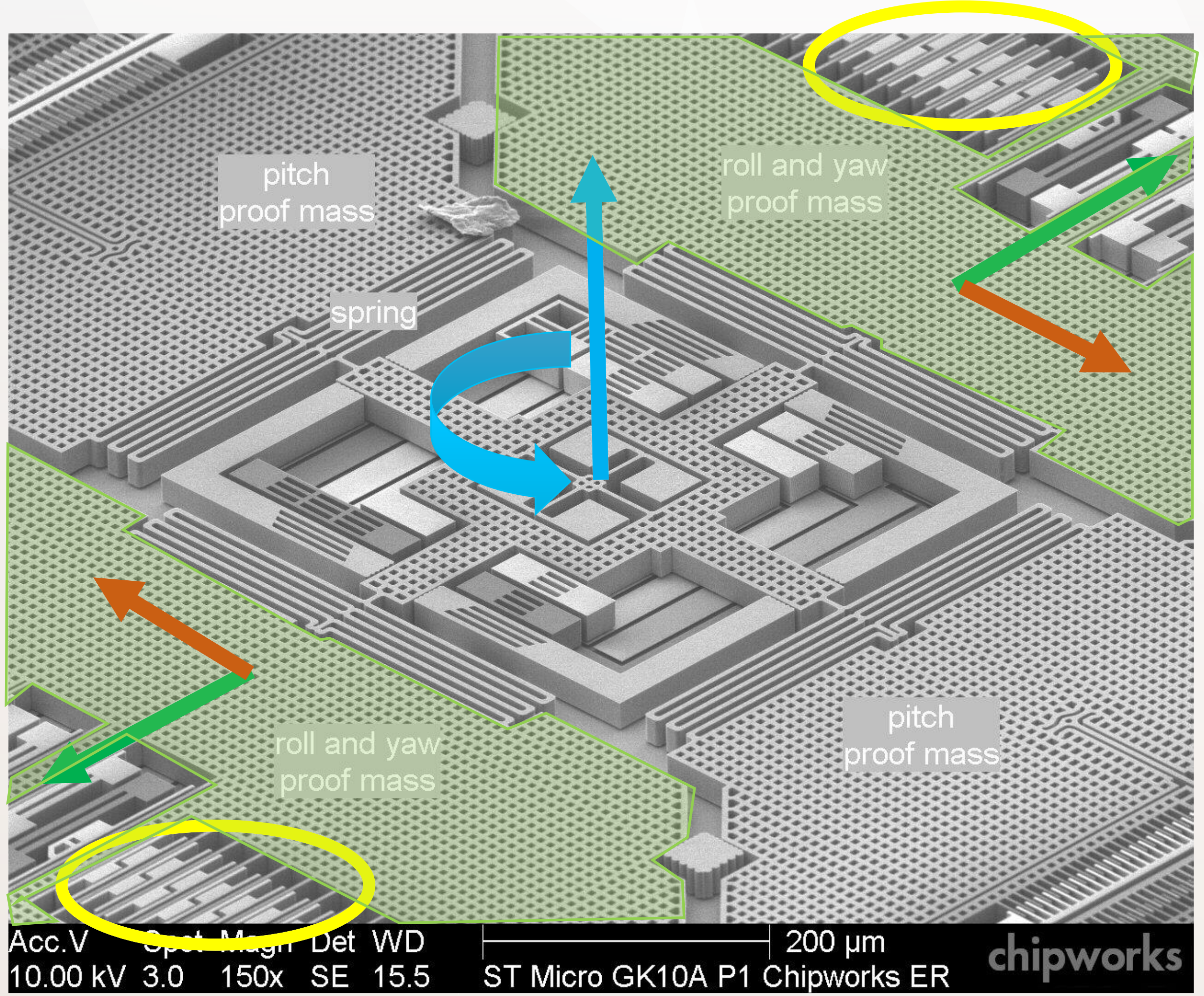
In a MEMS gyroscope, the resulting physical **displacement** is then read using a capacitive sensing interface.



Gyroscope

3 Axis Gyroscope (iPhone)





[11]

Yaw:

The two yaw proof masses **oscillate** in opposed directions **v1,v2** (same as for roll)

If yaw is applied (**omega**), the **Coriolis force** acts on both masses.

The masses are forced parallel to the plane.

This time the Capacitance is measured by a comb structure (**yellow circles**)

Thus the these two proof masses are influenced by both roll and yaw.

MAGNETIC SENSOR

Magnetic north / Compass
diplay on/off

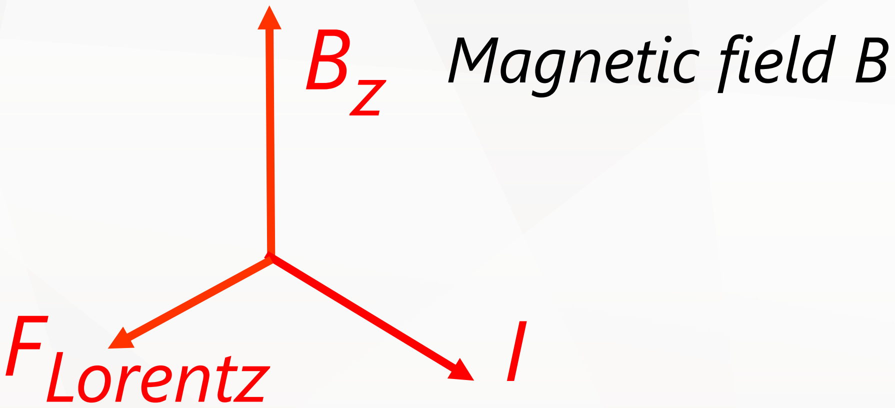
…

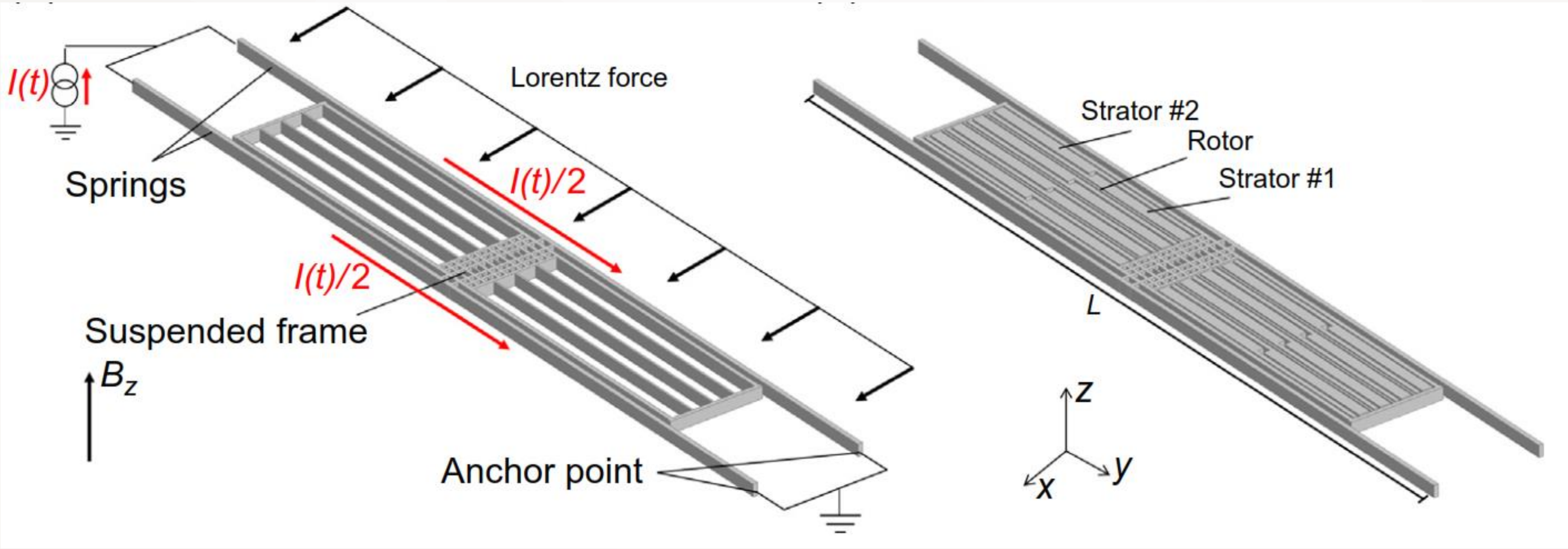
MEMS magnetometer

Hall effect sensor

MEMS magnetometer

Lorentz force





Microphones

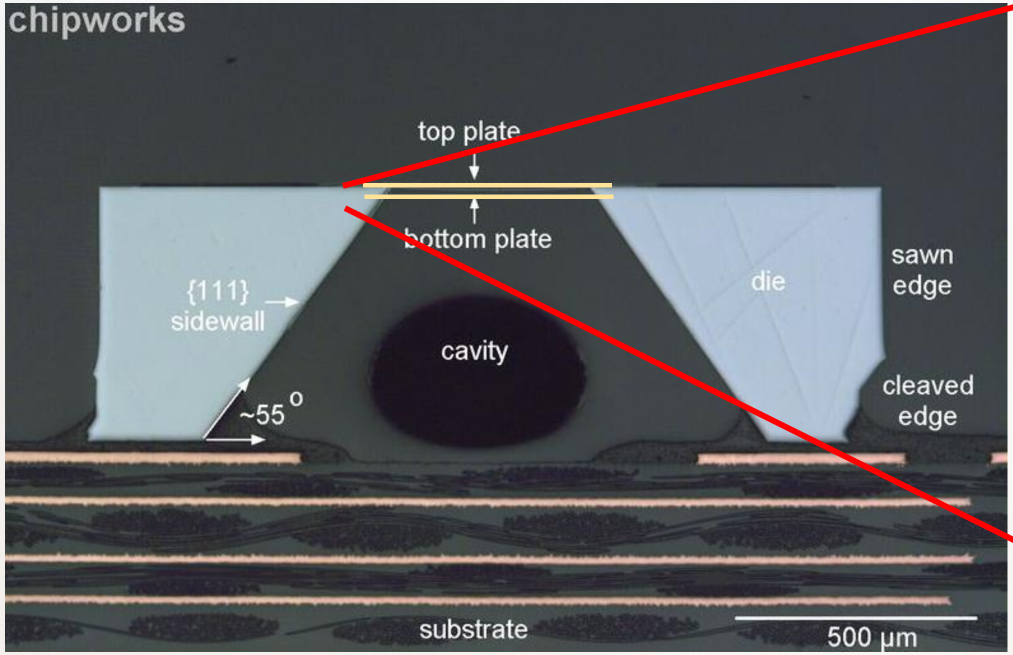
MEMS capacitive microphones

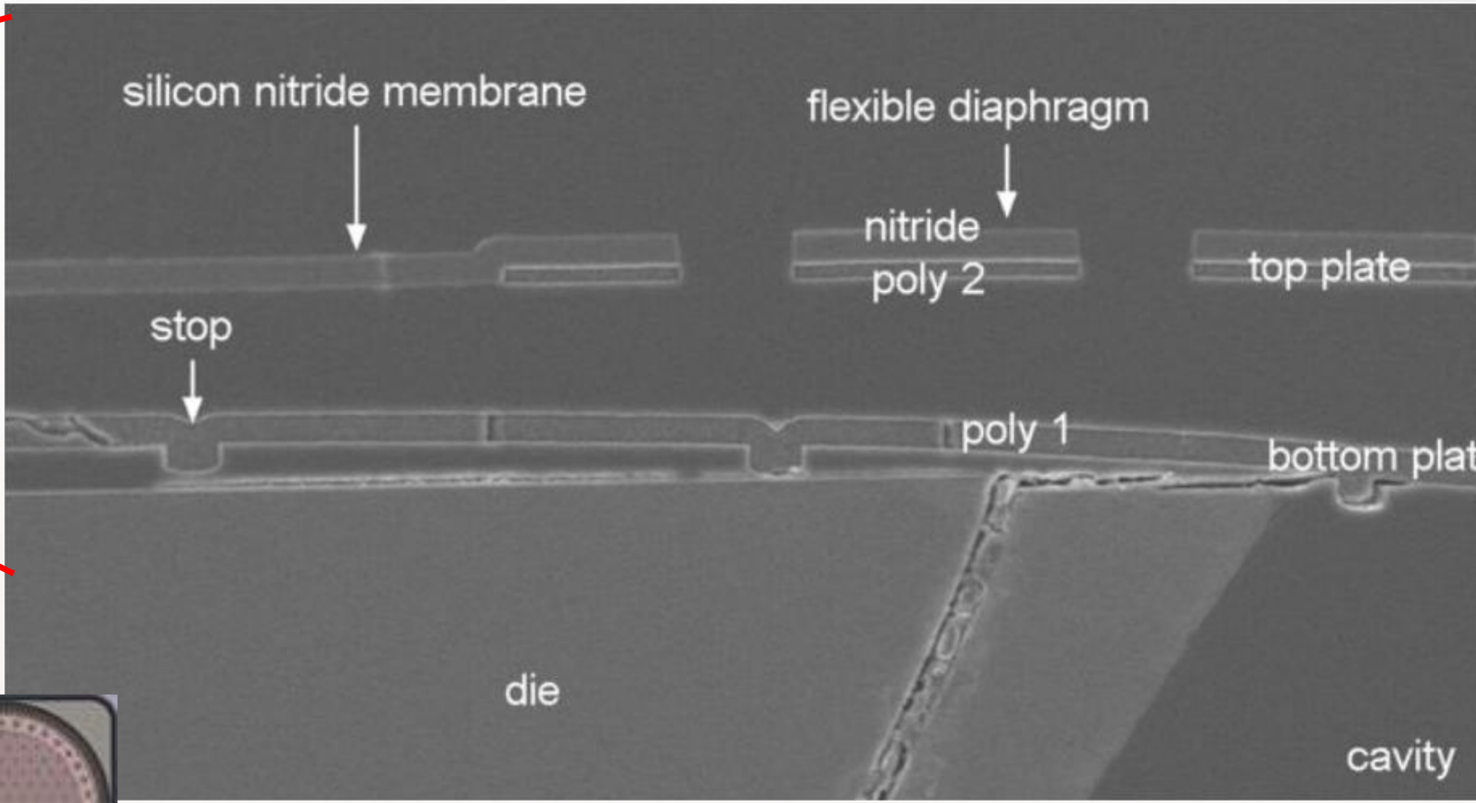
Electret microphones

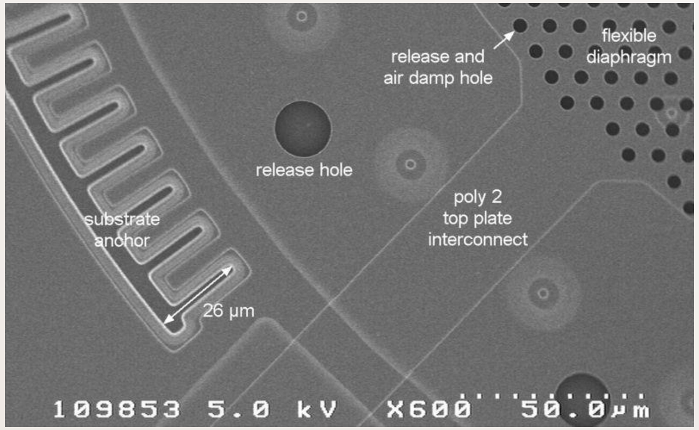
Piezoelectric microphones

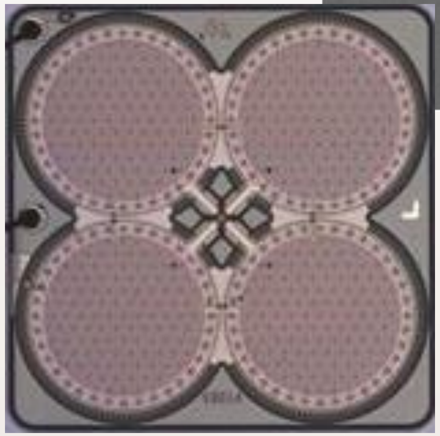
MEMS microphones

Variable capacitor microphones







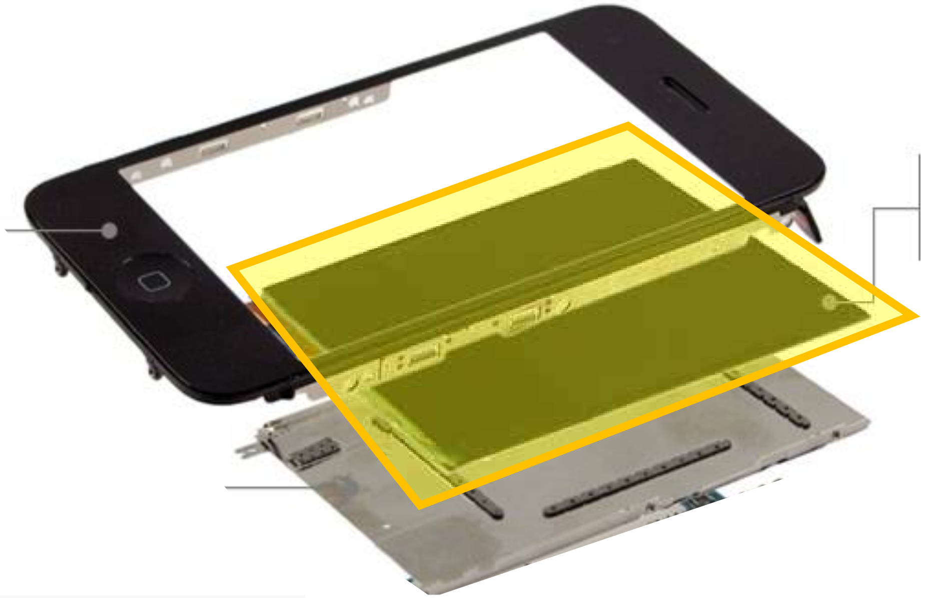


http://www.memsjournal.com/2011/03/overview-of-mems-microphone-technologies-for-consumer-applications.html

Display Glass

Topological network theory

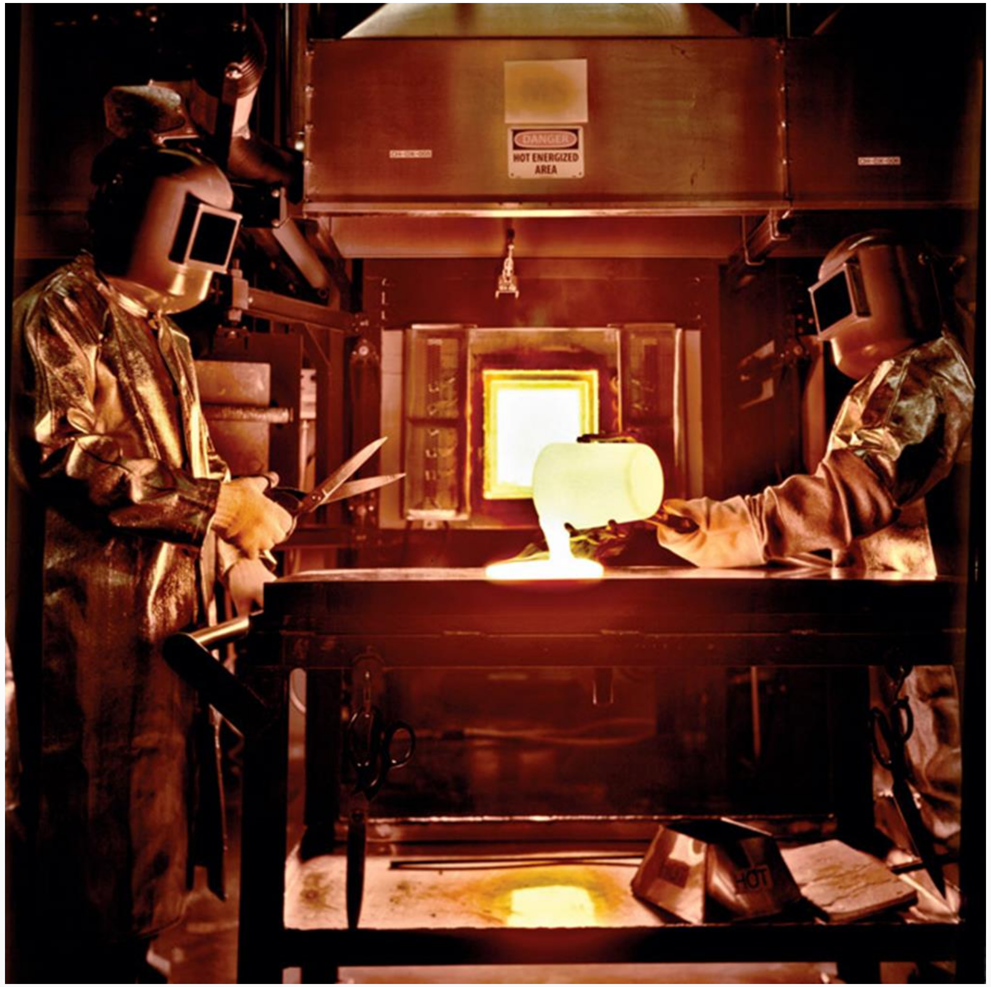
Display module glass (Gorilla Glass)



Display module glass

Glass , the amazing old yet high-tech material

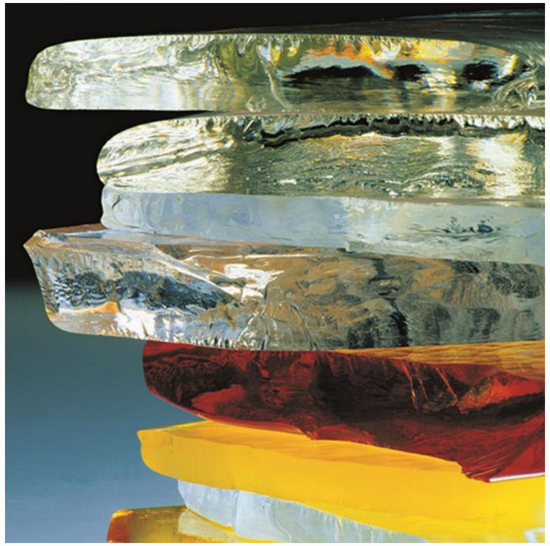
Glass starts out as a mixture of very fine powders like limestone, sand, and sodium borate.

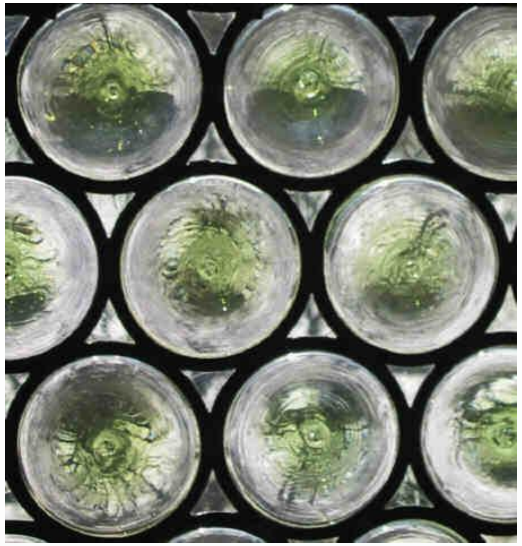


Molten glass cools to become so gummy it can be cut with scissors.

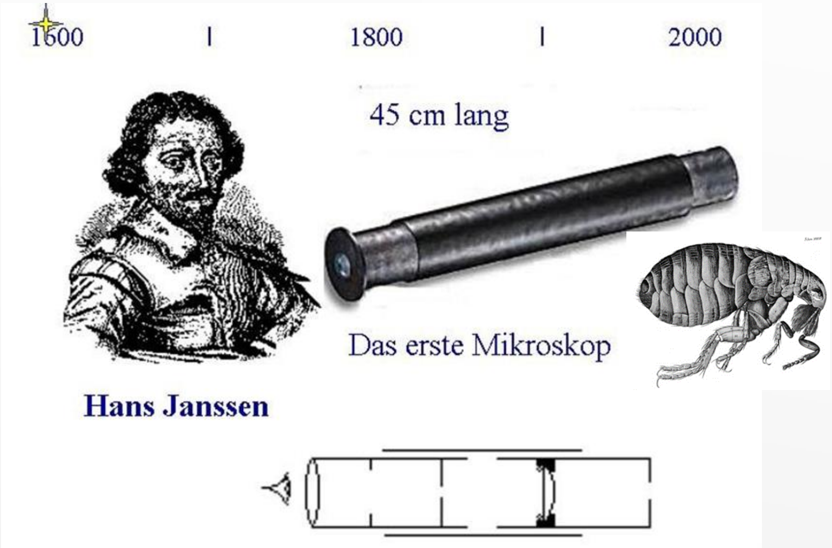
http://www.wired.com/2012/09/ff-corning-gorilla-glass/

Glass , the amazing old yet high-tech material



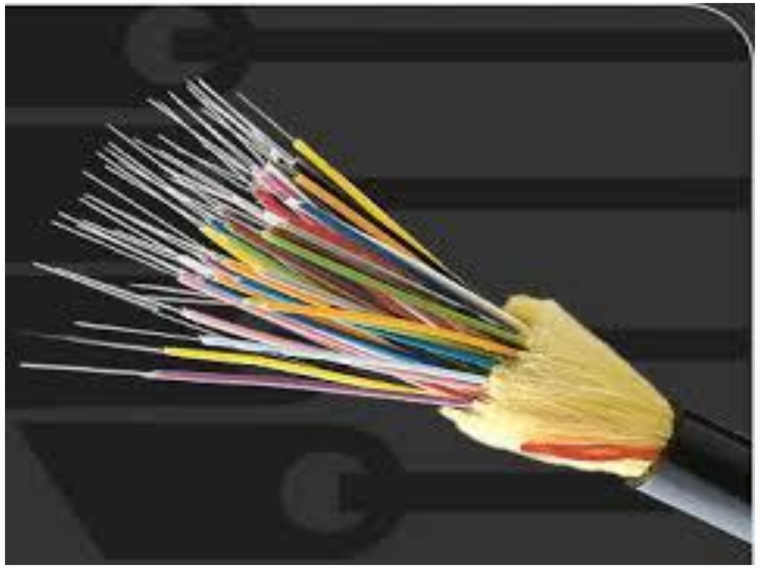


12. Jh. Salvino D'Armate fabricates the first reading glasses

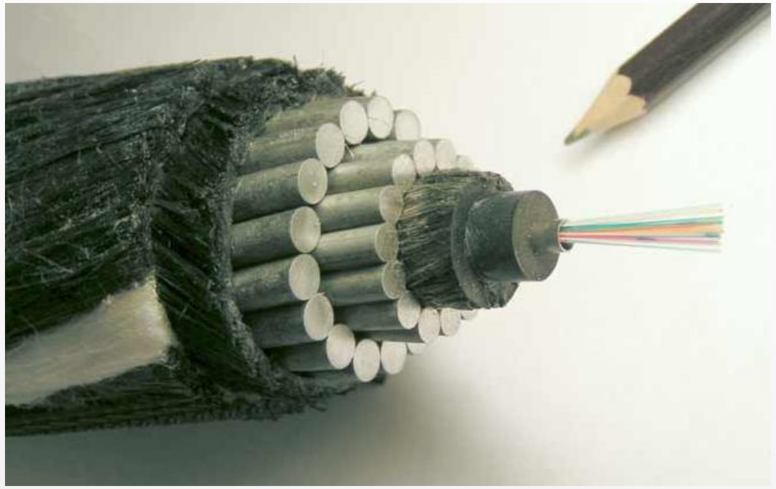


Teleskop: Hans Lippershey, Zacharias Jansen und Jacob Metius, ca. 1608

Glass : essential to modern communication

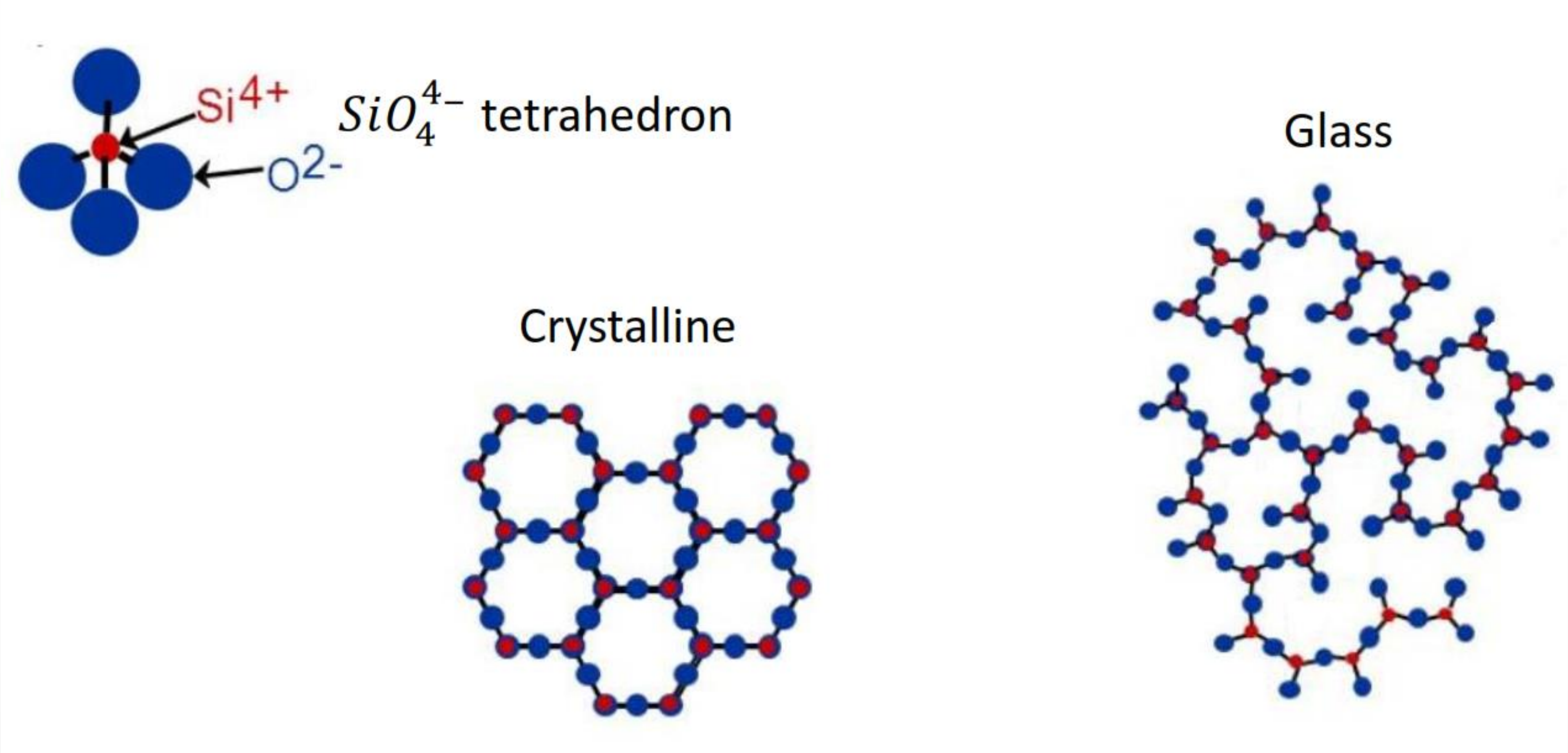


Glass fiber for data transmission
only **0.2 dB** attenuation **per km** (!!) in near-IR



Corning develops flexible glass foils

Glass as an atomic network



Glass "ingredients"

- ✓ Glass former: high valence state, covalent bonding with O
- ✓ Modifier: low valence state, ionic bonding with O

1 H Hydrogen 1.00794																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

Network modifiers | Glass formers | Intermediates

J.C. Philips, 1979

Modern theory of glasses

Topological constraint theory

Gorilla Glass (Corning)

"First glass designed on computer" (Mauro)

	mass fraction
SiO_2	61.91
Al_2O_3	17.43
Na_2O	12.58
K_2O	3.45
MgO	3.26
CaO	0.15
TiO_2	0.63
ZrO_2	0.02

all fractions are in %.

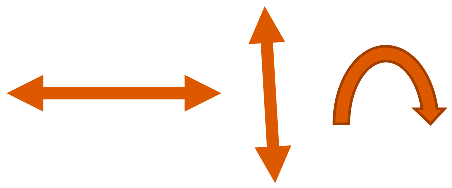
Optimal stability of network ?

Maxwell's Rule : number of constraints = number of degrees of freedom

$$N_c = N_{DoF}$$

Counting degrees of freedom (in 2 dim)

n objects : **n** x 2 =2**n**, minus 3 collective DoF = 2**n** - 3

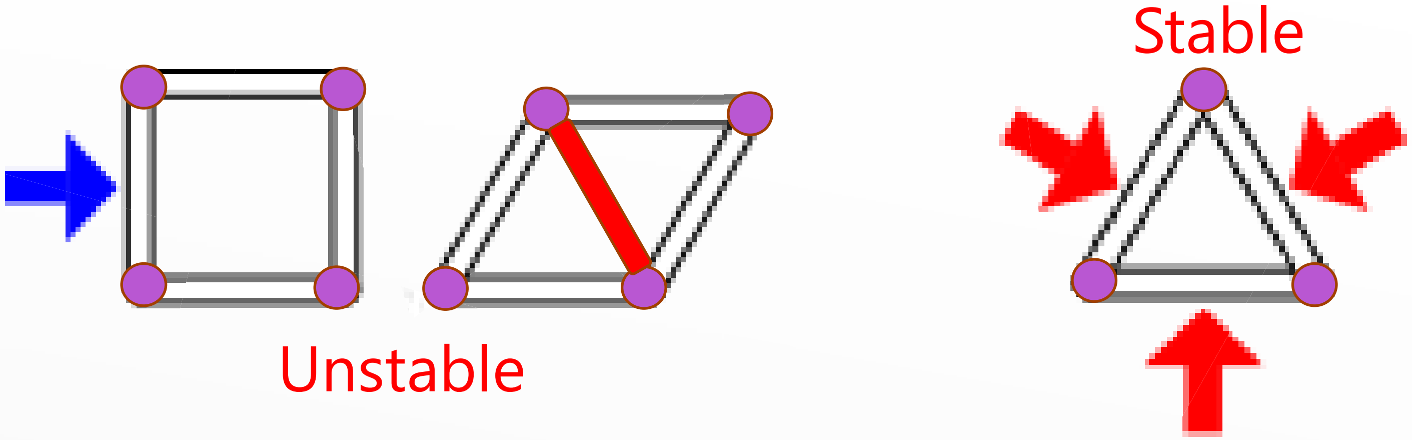


Phillips, J. C. (1979)

Optimal stability of network ?

Maxwell's Rule : number of constraints = number of degrees of freedom

$$N_c = N_{DoF}$$

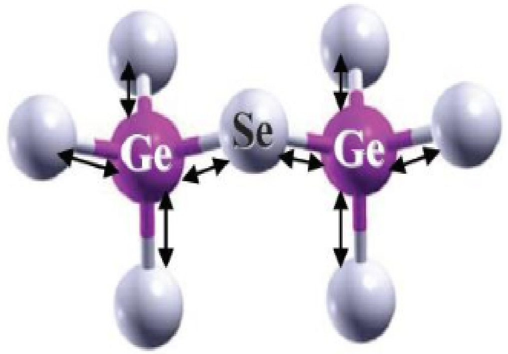


Phillips, J. C. (1979)

J.C. Philips, 1979

Counting constraints

Constraints originate in bonding (“ball-and-stick” model)
Number of constrains depends on atom coordination *"r"*

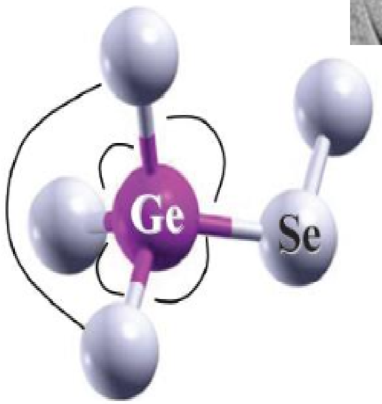


Two-body length constraints

$$N_c = N_{bond} + N_{angl}$$

rigid bond lengths constraints

rigid angular constraints



Three-body angular constraints

$$N_{bond} = \frac{\langle r \rangle}{2} \qquad N_{angl} = (2\langle r \rangle - 3)$$

$$N_c = \frac{\langle r \rangle}{2} + (2\langle r \rangle - 3)$$

J.C. Philips, 1979

Chemical composition and network stability

Define average number of constrains per atom

(mean field approach)

chemical composition x_i = *molar fraction of atom type **i***

$$\langle r \rangle = \sum_i x_i r_i \qquad N_c = \frac{\langle r \rangle}{2} + (2\langle r \rangle - 3)$$

Condition for an isostatic network

$$N_c = N_D = 3 \quad \Rightarrow \quad \langle r \rangle = 2.4$$

Optimal **composition** results in optimal **network stability**

Modern theory of glasses

J.C. Philips, 1979

Gorilla Glass (Corning)

"First glass designed on computer" (Mauro)

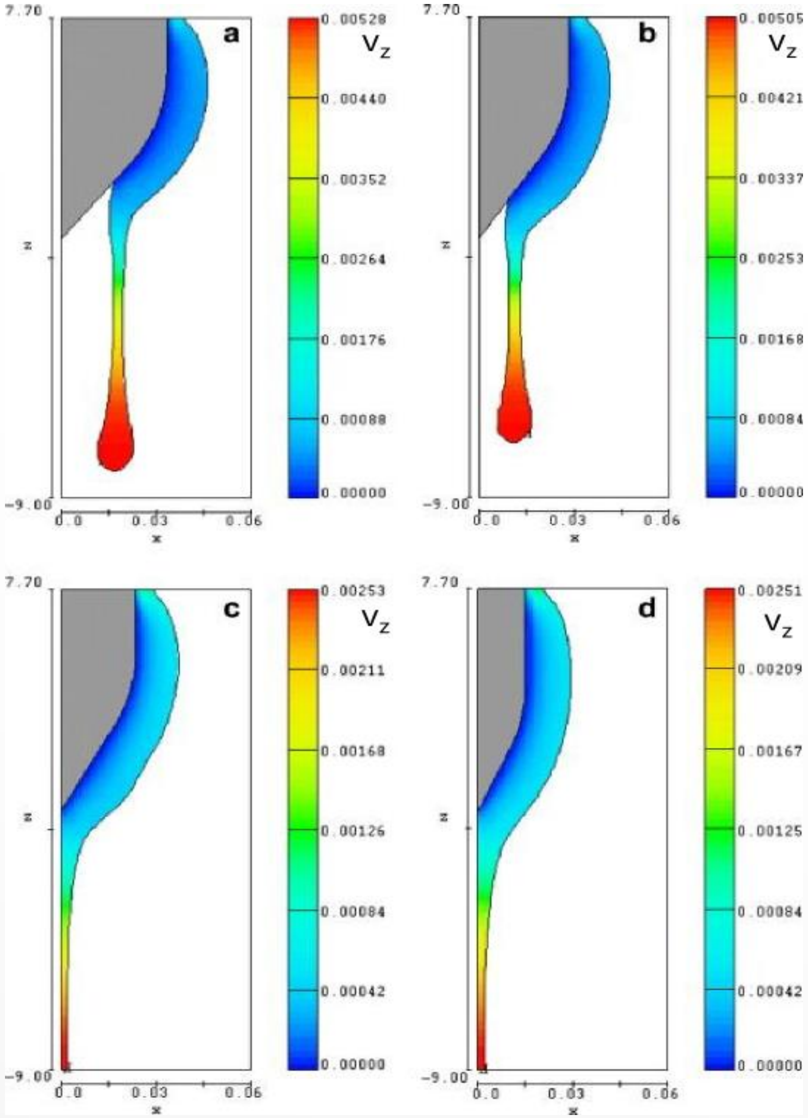
	mass fraction
SiO_2	61.91
Al_2O_3	17.43
Na_2O	12.58
K_2O	3.45
MgO	3.26
CaO	0.15
TiO_2	0.63
ZrO_2	0.02

all fractions are in %.

Thin sheet production with fusion draw process

ca. 15 Mio m^2 / y

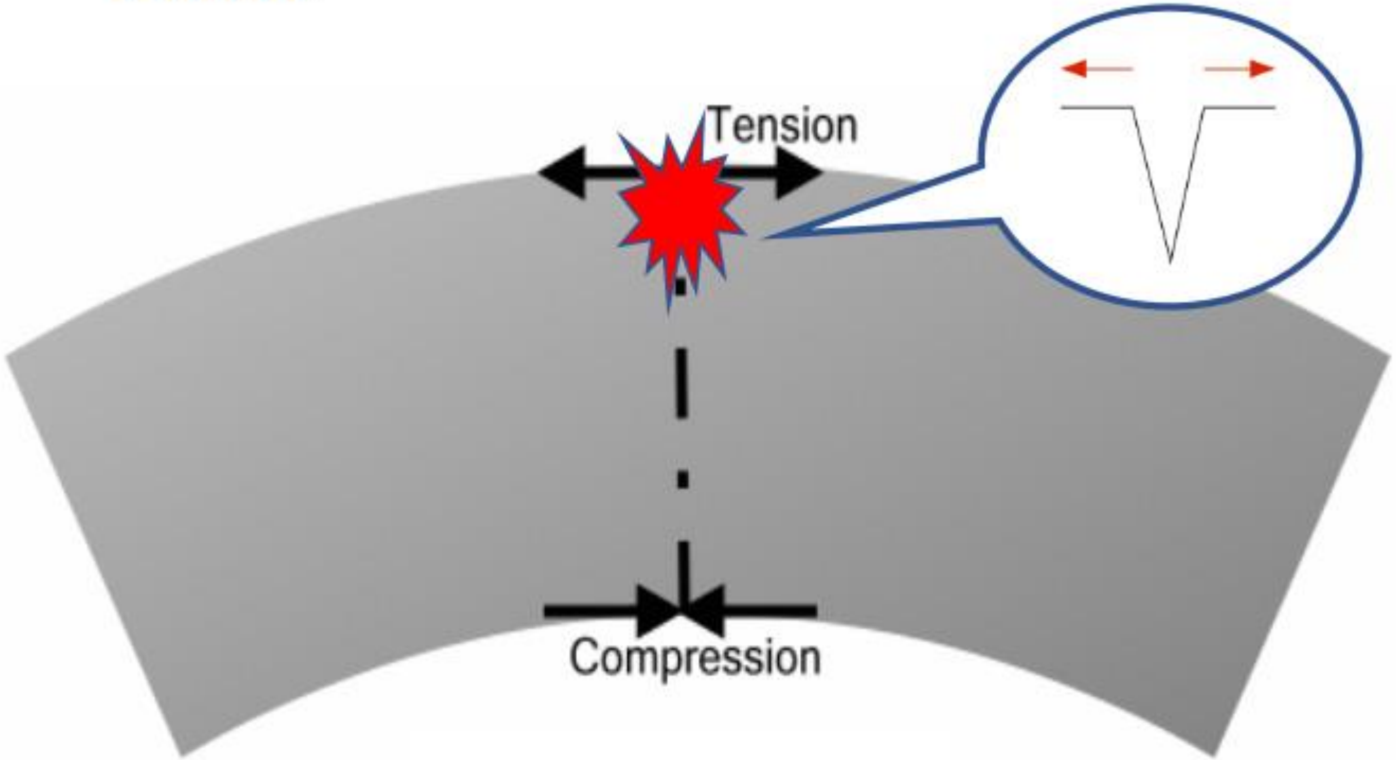
ca. 2000 soccer fields / y



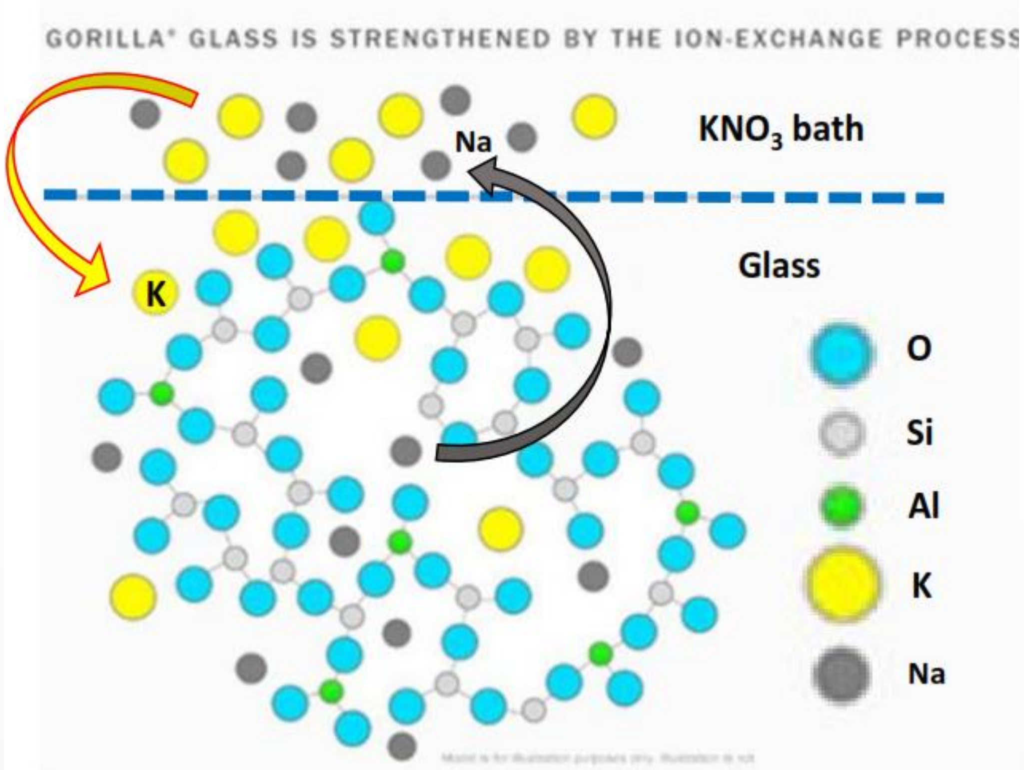
Making glass tough and scratch resistant

Problem: Glass is resistant to compressive stresses, but not to tensile stresses.

Idea: Modify the surface of glass to be in a permanently compressed state. This can cancel tension.



Toughening by ion exchange (K – Na)

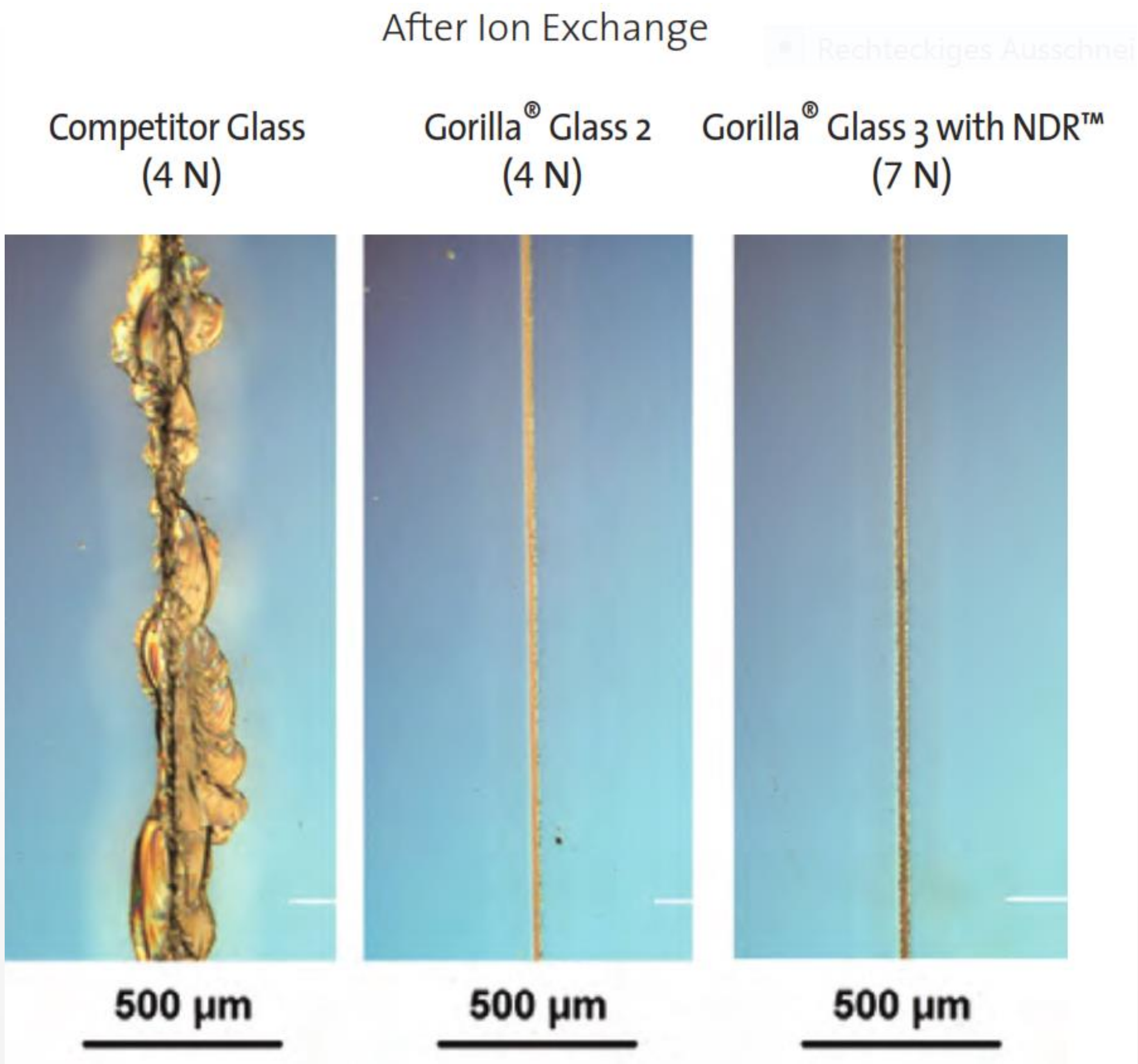


Source: Corning; Secret of Tough Glass: Ion Exchange

Method: Replace Na atoms by larger K atoms (just below Na) by putting the glass in a KNO_3 bath. This creates a gradient of compression on the surface to compensate for tensile stresses.

K insertion (for Na) produces **compressive stress** near surface

Scratch resistance after ion exchange toughening



Composite car windshield : conventional + Gorilla Glas

ASLG - Annea

Navigation GPS

Navigation with the smartphone : Global Positioning System

Where are we on the Lake of Constance (Bodensee) ?

Navigation with the smartphone : Global Positioning System

Um genau 12:00:**00** h blasen die Nebelhörner in Bregenz und in Lindau
Hören auf dem Boot die Signale später :
Laufzeit = Ankunftszeit - Sendezeit

Von Lindau um
12:00:**10**
10 sec x 1/3 km/sec
= **3.3** km Entfernung

Von Bregenz um
12:00:**14**
14 sec x 1/3 km/sec
= **4.7** km Entfernung

Was braucht's zur genauen Ortsbestimmung?
Synchronisation der Uhren *(12:00:00 ist für alle Uhren gleich, gleich schneller Gang)*
Genügend feine **Zeitauflösung** *(1/330 sec für 1m Ortsgenauigkeit)*
Genau Position der Sender
Genauer **Wert der Schallgeschwindigkeit**

Introduction to GPS

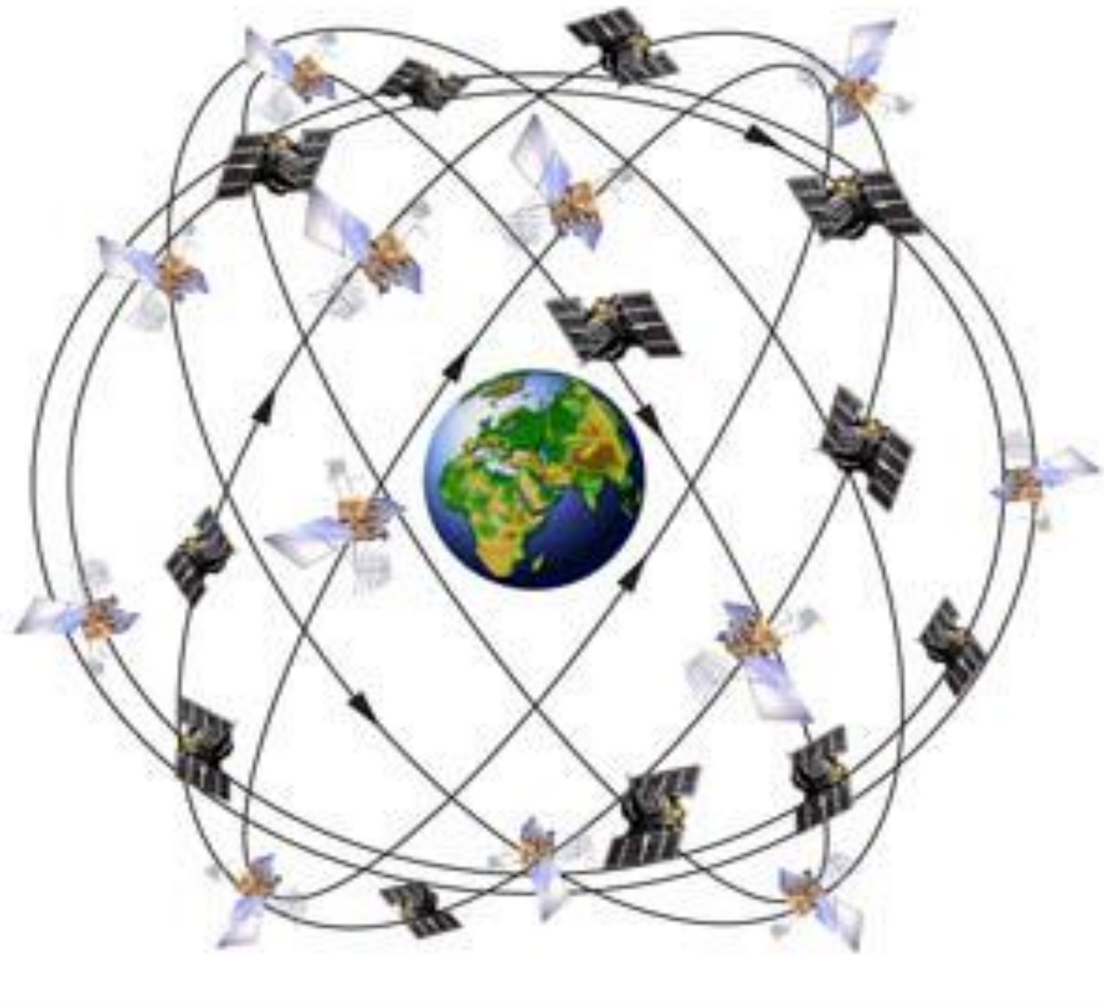
24 (31) satellites

20 000 km above sea le

Orbital period 12 hrs

Velocity 13800 km/h

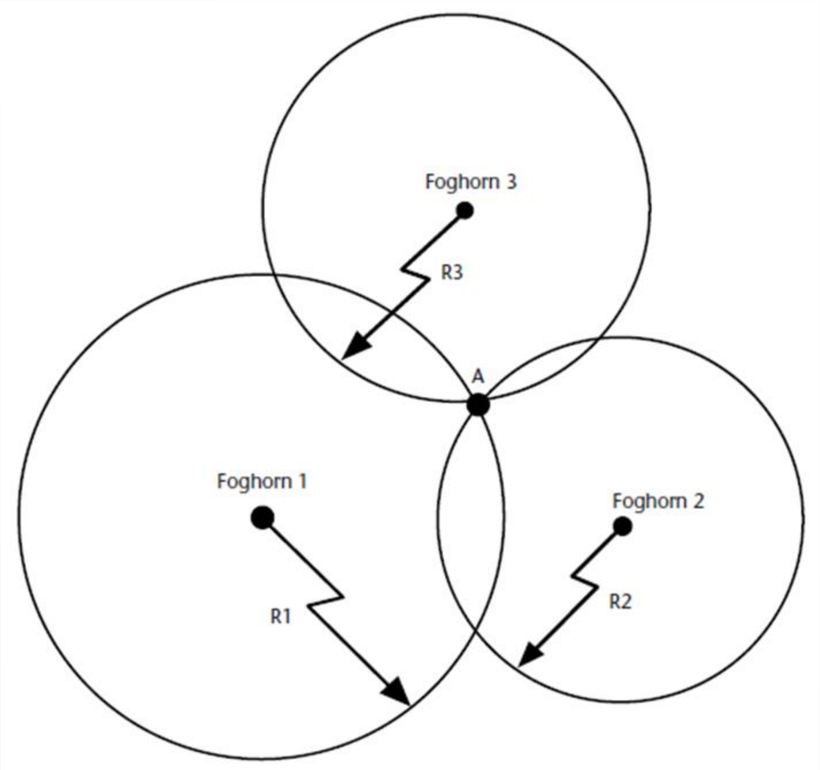
3800 m/s



Trilateration in 3+1 dimensions : 3 space- und 1 time-coordinate -> min. 4 satellites

Each satellite broadcasts location and time at transmission

Distance = speed of light × travel time



Foghorn - GPS location

"foghorn " : sound

GPS : microwaves ("light")

10^6

Signal propagation speed

Speed of sound 334 m/s

speed of light 299 792 458 m/s

time for signal to propagate 1 m

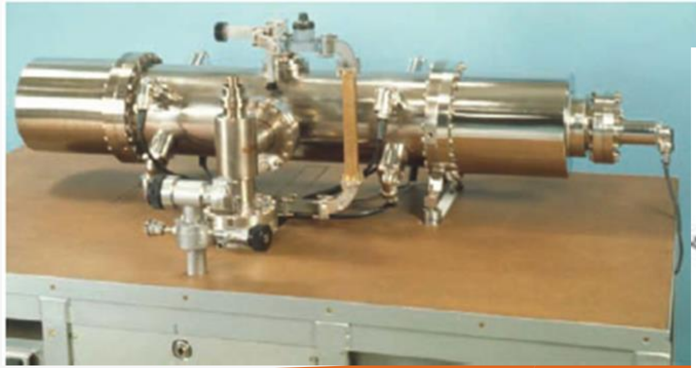
1m in 0.003 sec

0.000 000 003 3 s = 3.3 nanosec

"stopwatch"

Atomic clock 1ns/ month

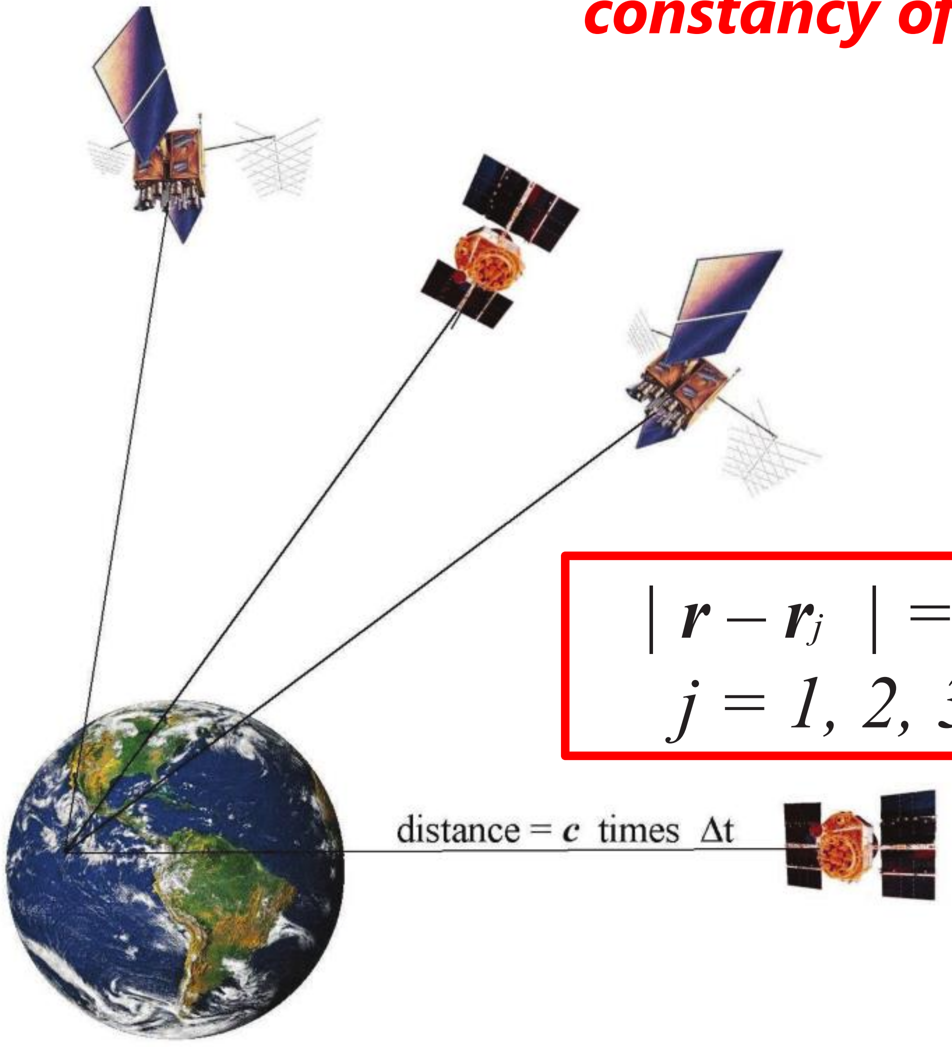
Rubidium and Caesium atomic clocks



GPS principle

Navigation in the GPS is based on

constancy of the speed of electromagnetic signals c



min. 4 satellites transmit location and time stamp

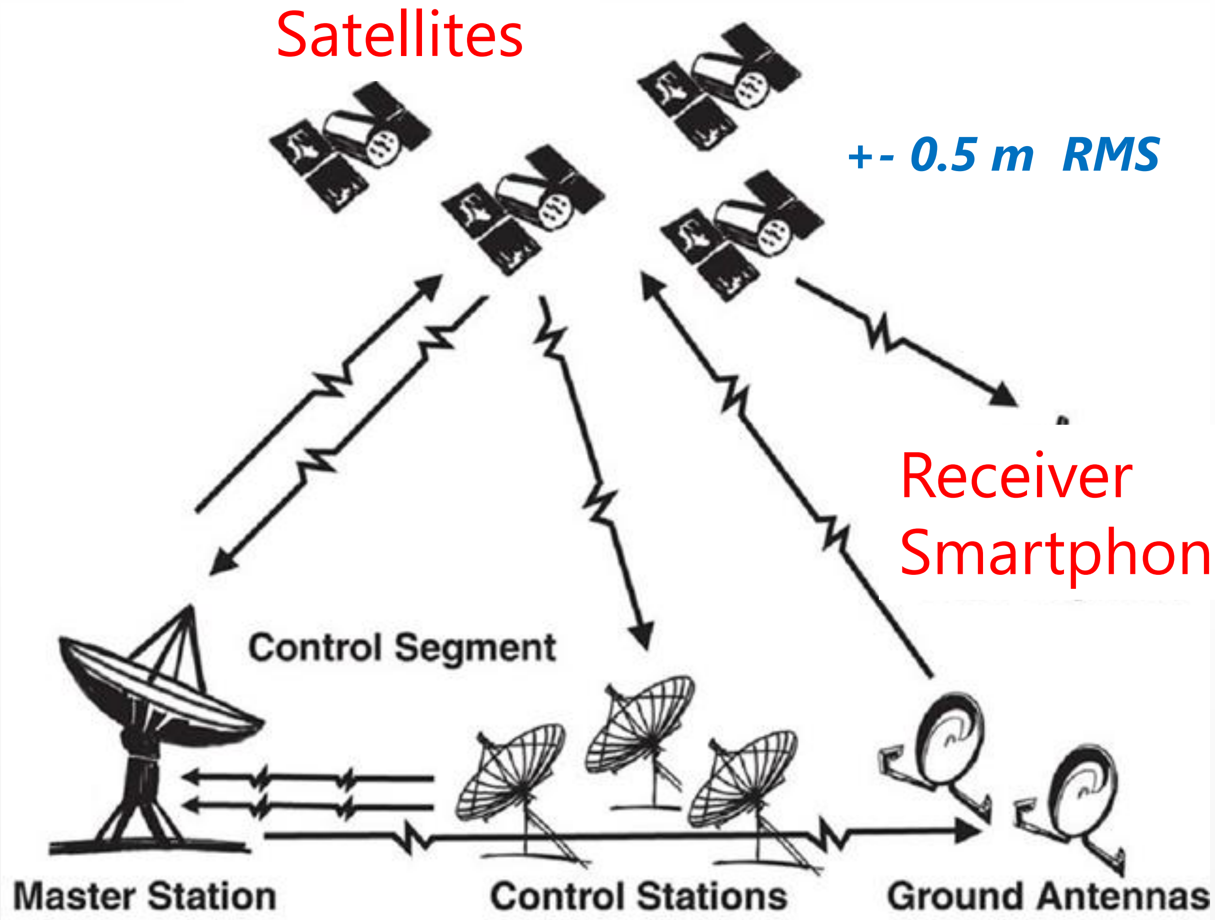
$\{t_j, r_j\}, \quad j = 1, 2, 3, 4.$

distance = "pseudorange"

$$|\boldsymbol{r} - \boldsymbol{r}_j| = c\,(t - t_j)$$
$$j = 1, 2, 3, 4.$$

GPS = rich physics + fascinating engineering

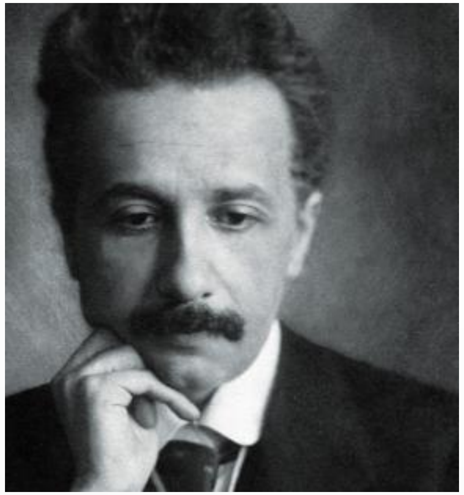
Earth and satellites are moving
Satellites orbit approx. 20 000 km above earth



Ground control : measure satellite orbits and synchronize clocks

Relativistic effects in GPS

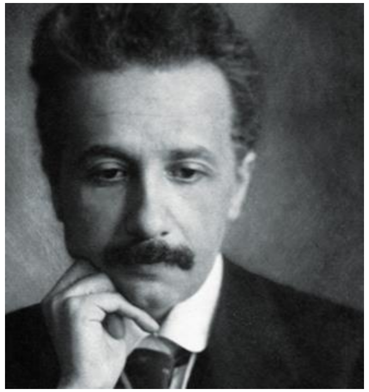
***R**ust **i**n **p**eace : train graveyard at the edge of Salar de Uyuni , Bolivia*



1 - Moving clocks beat more slowly

"constancy of the speed of light"

A clock ***moving*** relative to a system of synchronized clocks in an inertial frame (ECI) **beats more slowly**.



r_s radius of the satellite´s orbit (ca 26 562 km),
$v_s \approx$ 3863 m/sec

$$t' = \sqrt{1 - \frac{v^2}{c^2}}t$$

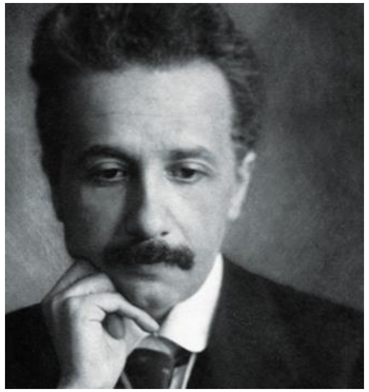
$$-\frac{1}{2}\frac{v^2}{c^2} \approx -8.35 \times 10^{-11}$$

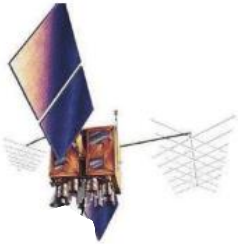
Clock at earth's equator (radius a_1 =6378 km) ,
speed $\omega_E . a_1$ 464 m/s

$$\frac{\Delta f}{f} = -\frac{1}{2}\frac{v^2}{c^2} - (-\frac{1}{2}\frac{(\omega a_1)^2}{c^2}) = -8.228 \times 10^{-11}$$

Error if uncorrected : 2.13 km/day

2 - Gravitational time dilation





Clock in satellite at potential $\boldsymbol{\Phi} + \Delta\boldsymbol{\Phi}$

$$\Phi = -\frac{GM}{r}$$

$$\frac{\Delta f}{f} = \frac{\Delta\Phi}{c^2}$$

$GM = 3.986004415 \times 10^{14}\ m^3/s^2$

Clock in satellite **runs faster**

Clock at earth surface at potential $\boldsymbol{\Phi}$

$$\Phi_{\text{reference}} \cong -\frac{GM}{a_1}$$

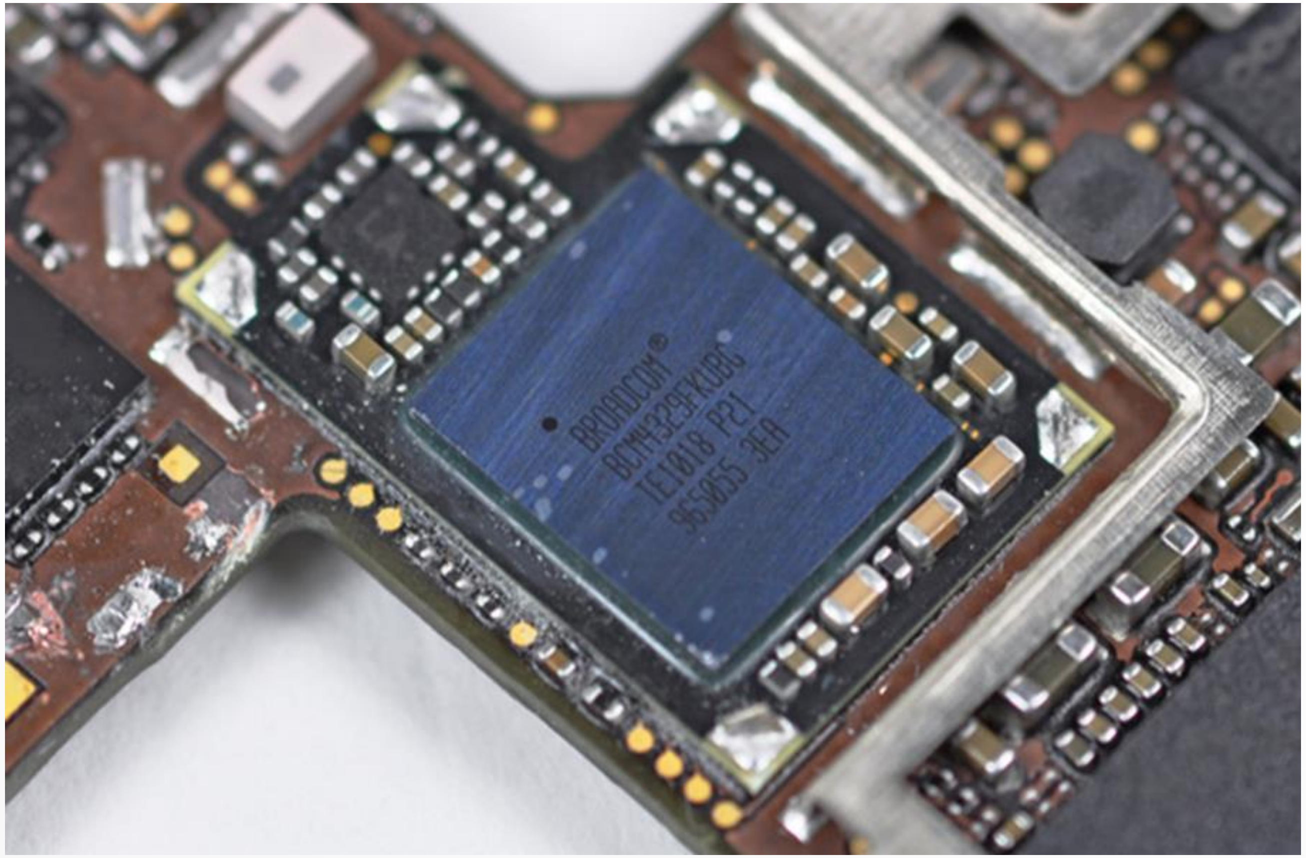
$$\frac{\Delta f}{f} = \frac{\Phi - \Phi_{\text{reference}}}{c^2} = -\frac{GM}{c^2 r} - \left(-\frac{GM}{a_1 c^2}\right) \approx 5.288 \times 10^{-10}$$

Error if uncorrected ≈ 13.7 km/day

No GPS without Relativistic effects

Gravitation :
clocks in satellite run **faster** (w.r.t. earth surface)

Atomic clocks
Quartz oscillator clocks



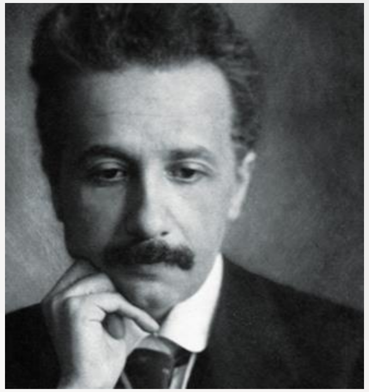
Relative motion of clocks
clocks in satellite run **more slowly**

Solution:
Slow down satellite clocks
BEFORE launch by 4.47 10 $^{-10}$
by 0.00457 Hz
to 10 229 999. 99543 Hz

GPS Reference frequency =
10 230 000 Hz (10.23 MHz)

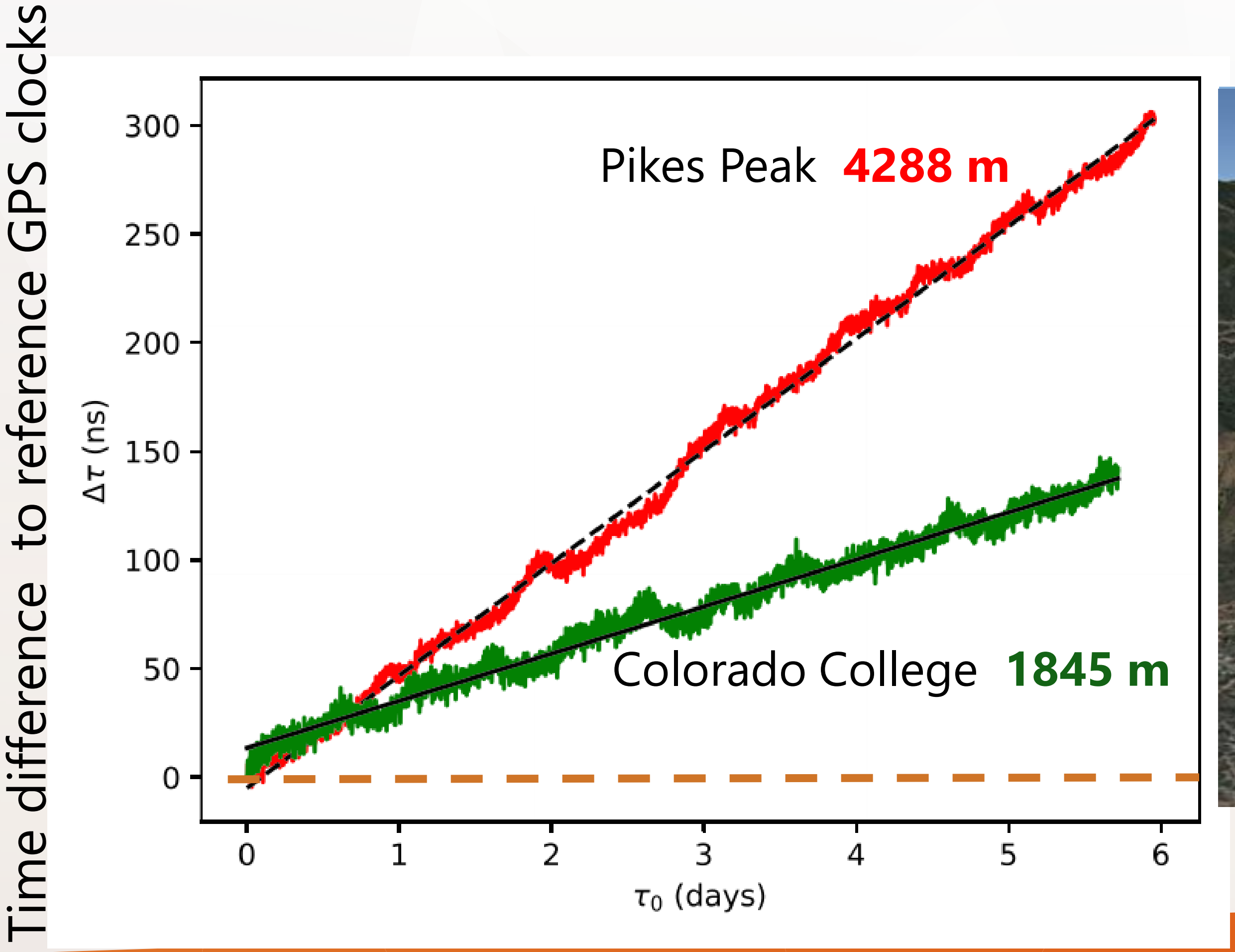
Neil Ashby, Physics Today (2002), Neil Ashby and Robert A. Nelson (2009)

Gravitational time dilation

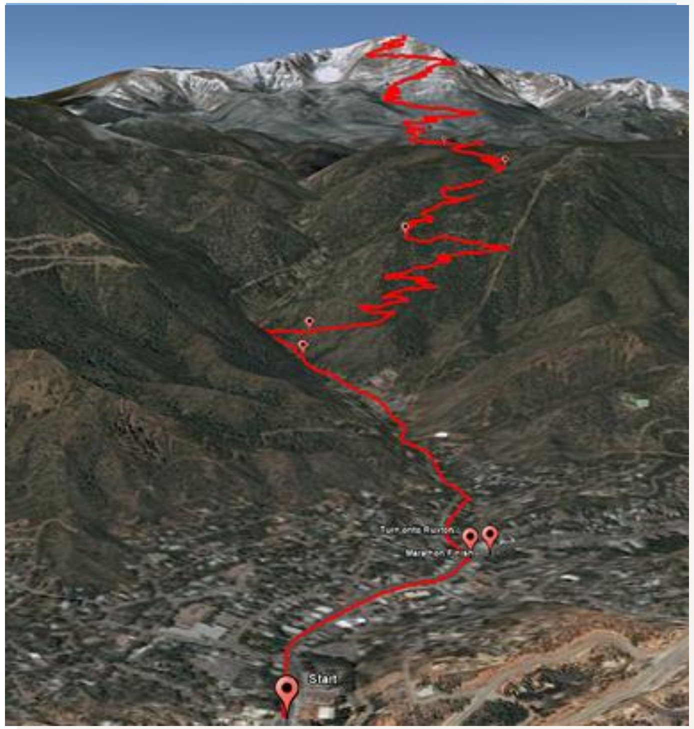


General relativity predicts that clocks run more slowly near massive objects. (9.4194 ns /day km)

Students' experiment in Colorado.



Pikes Peak Marathon 1985



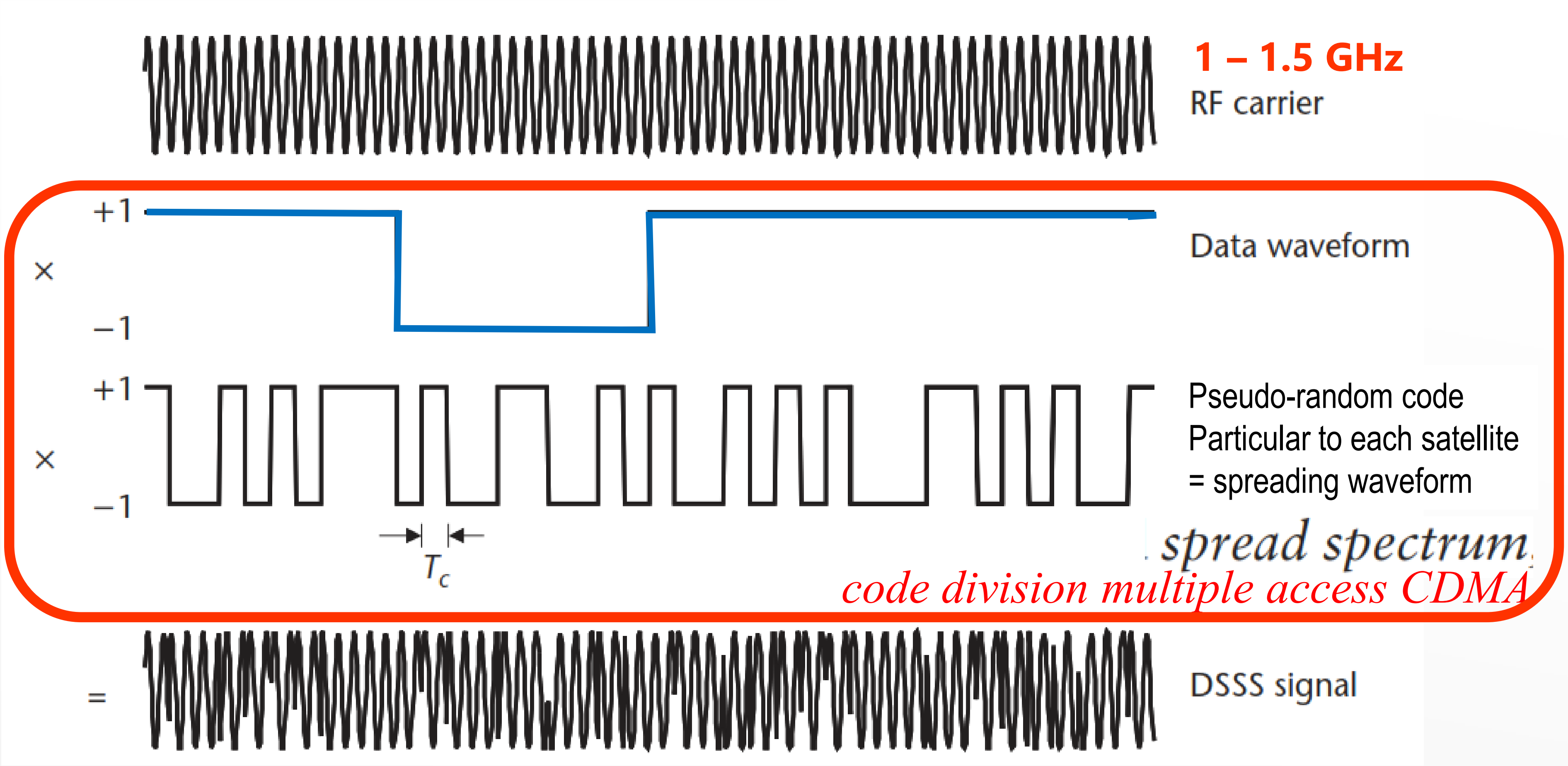
M. Shane Burns et al.; *American Journal of Physics* **2017,** 85, 757-762. DOI: 10.1119/1.5000802

Data transmission - coding

GPS

Smartphone network

GPS signal coding (simplified)



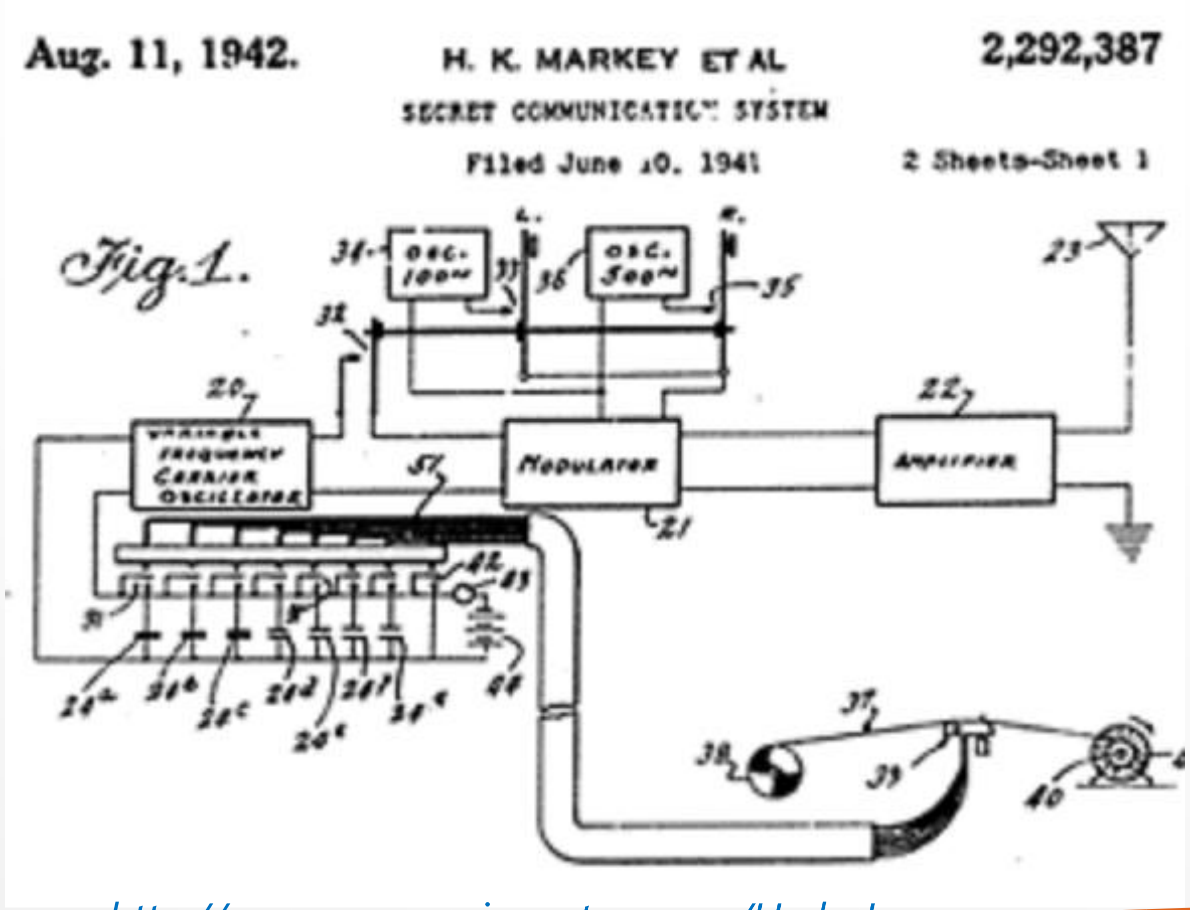
Group velocity ≠ phase velocity

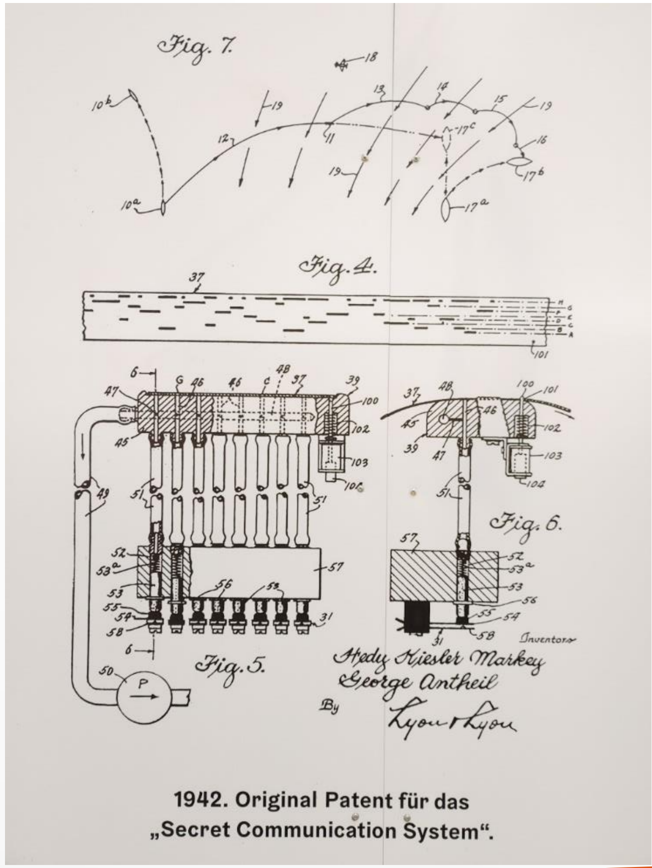
Spread spectrum / CDMA invention

"Secret Communications System."

Inventors : **Hedy Keisler Markey** and **George Antheil**

actress "The Most Beautiful Girl in The World" composer "the bad boy of music"





http://www.women-inventors.com/Hedy-Lammar.asp
http://inventionconvention.com/americasinventor/dec97issue/section2.html


Hedy Lamarr
(1914 – 2000)
An Austrian-American actress, she developed the frequency-hopping spread-spectrum technology as part of the Allied war effort with composer George Antheil.
The core concepts of their work were later incorporated into modern technologies such as Wi-Fi, CDMA, Bluetooth, etc.
She acted in over 30 movies, including leading roles opposite screen legends such as Clark Gable and James Stewart.
© CURIOUS ROBOT

Hedwig Eva Maria Kiesler

Unofficial Newspaper U.S. Forces

WESTERN EUROPE EDITION

THE STARS AND STRIPES

Unofficial Newspaper of U.S. Forces in the European Theater

Vol. 2—No. 128 1 Fr. Monday, Nov. 19, 1945

Hedy Adds New Twist to War

Hedy Lamarr

Actress Invents Control Device While Toying With Torpedo Idea, Has Patent to Prove It

HOLLYWOOD, Nov. 18 (AP).—It could not have been a press agent's stunt, because the timing was too perfect, but the report from London that film actress Hedy Lamarr had patented a radio steering device for torpedoes at least had a patent to back it up.

In an interview, Hedy modestly admitted she did only "creative work on the invention," while the composer and author, George Antheil, "did the really important chemical part."

Hedy was not too clear about how the device worked, but she remembered that she and Antheil sat down on her living room rug and were using a silver match box with the matches simulating the wiring of the invented "thing".

She said that at the start of the war "British fliers were over hostile territory as soon as they crossed the channel, but German aviators were over friendly territory most of the way to England... I got the idea for my invention when I tried to think of some way to even the balance for the British. A radio controlled torpedo, I thought would do it."

Hedy asserted that the "control" device works on aerial as well as submarine torpedoes.

She said it works on anything and added that it was "lots of fun planning the invention and watching them pick, sort and put together all the little thingamabobs that went into the device." She said it was lots more fun being scientific than going to the movies.

She coyly dodged a query as to whether any company was interested in producing the device but did admit that as far as she knew nobody has ever used it yet for any practical purpose.

1940's Film Goddess Hedy Lamarr Responsible For Pioneering Spread Spectrum

Have you ever heard of "Spread Spectrum"? Well, it shouldn't surprise you that most people haven't. Afterall, it's the technical basis that makes wireless communications work in cellular phones, faxes, and other wireless communications systems. It's currently utilized in "wireless" LANS, integrated bar code scanner, palmtop computer, radio modem devices for warehousing, digital dispatch, digital cellular telephone communications, city/state or country networks for passing faxes, computer data, e-mail

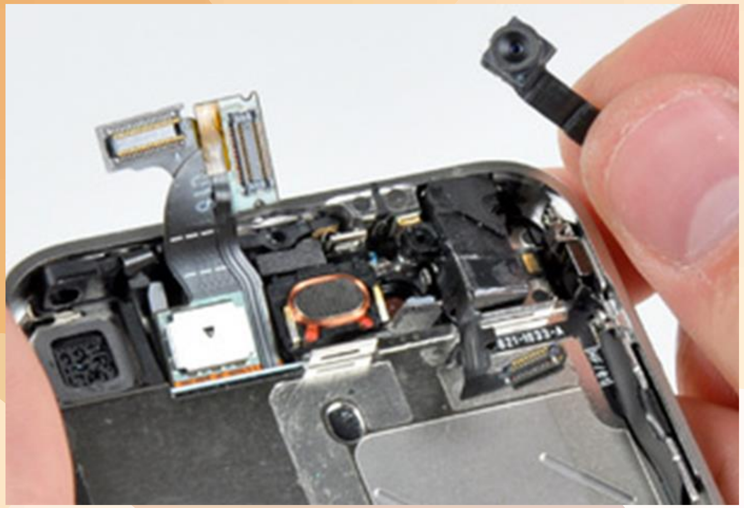
However, what's IS surprising is that the inventor behind this amazing process is an incredibly beautiful and talented actress of the 1940's! Her name is Hedy Lamarr, known as "The Most Beautiful Girl in The World", who first became famous for her scandalous skinny dipping scene in the 1933 Austrian art film "Ecstacy" (which at the time was banned by the U.S. Customs Department). Often quoted as saying "Any girl can be glamorous. All she has to do is stand still and look stupid." Lamarr starred with Clark Gable, Spencer Tracy, Judy Garland, appearing in approximately 25 films during her film career.

Camera : sensing photons

- CCD CMOS light sensors

- speculation on future trends

Physics : Photon-detection in semiconductors

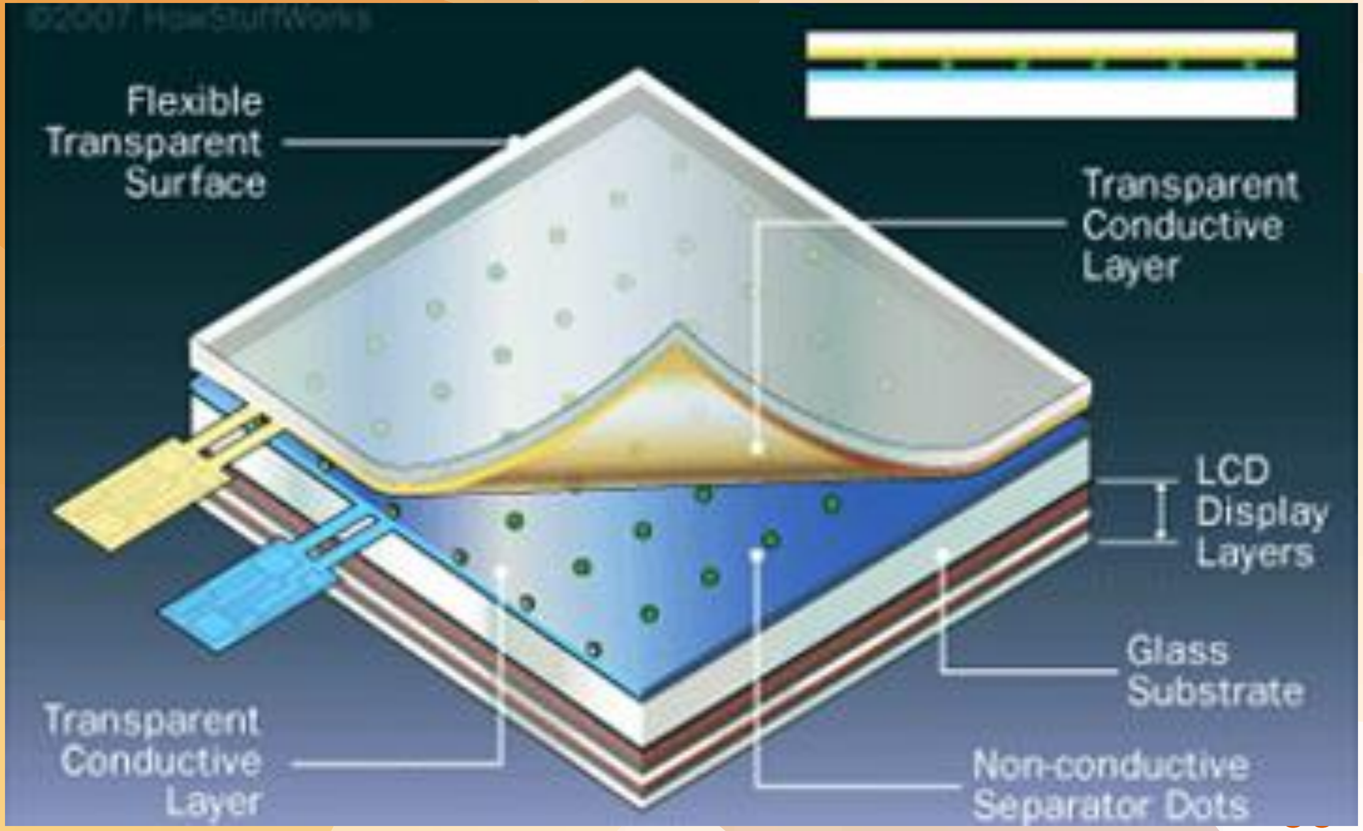


TOUCH SENSOR

Touch screen

Fingerprint sensor

…



Physik im Smartphone

Eine Fundgrube voller Physik

Ein Wunderwerk der Technik