Working principle of a capacitive accelerometer

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Sensors

- Transducer: a device transforming a quantity from a form of energy to another.
- Sensor: transducer that transforms the quantity of interest into a form of energy for which it is possible to measure, to store, to process and to transmit the information.

Sensors

- Give to the system the possibility to gain information from the surrounding environment.

- Every complex system (artificial or living) has a sensorial part.

- Due to their importance a huge number of different sensors is available on the market.

Sensors


Accelerometer
Gyro
Pendulum Resistive Tilt Sensors
Piezo Bend Sensor
Metal Detector
Gas Sensor
Gieger-Muller Radiation Sensor
Digital Infrared Ranging
CDS Cell Resistive Light Sensor
Resistive Bend Sensors
UV Detector
Pyroelectric Detector
Limit Switch
Mechanical Tilt Sensors
Touch Switch
Pressure Switch
Miniature Polaroid Sensor
IR Pin Diode
Side view of Lens
IR Sensor w/lens
Thyristor
Magnetic Sensor
Hall Effect Magnetic Field Sensors
Polaroid Sensor Board
IR Reflection Sensor
IR Amplifier Sensor
IRDA Transceiver
Magnetic Reed Switch
Lite-On IR Remote Receiver
Radio Shack Remote Receiver
IR Modulator Receiver
Solar Cell
Compass
Compass
Piezo Ultrasonic Transducers

Mems

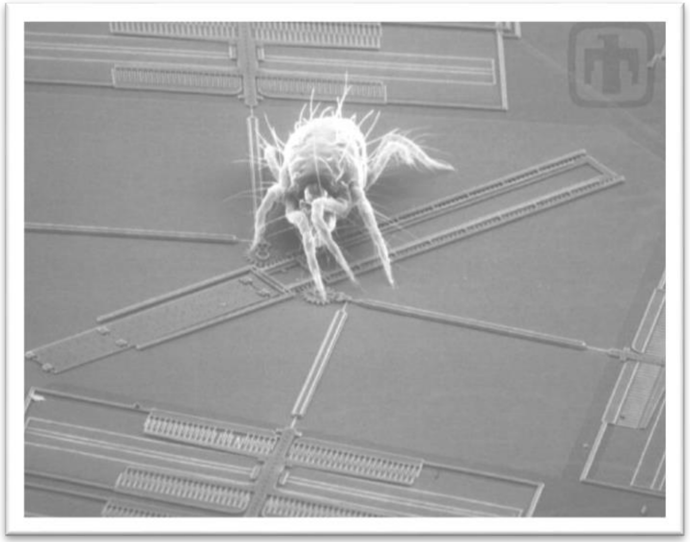
Micro-Electro-Mechanical Systems, or MEMS, is a technology that can be defined as miniaturized mechanical and electro-mechanical elements that are made using the techniques of microfabrication.

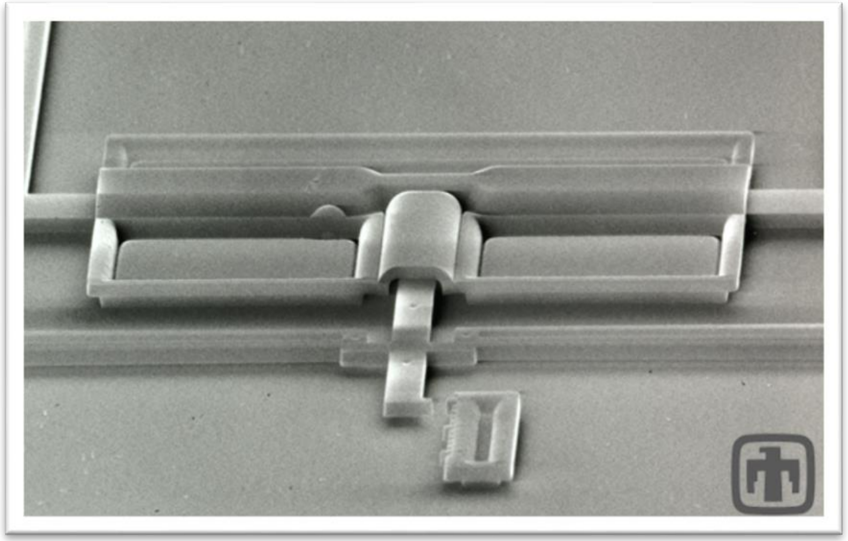
The dimension can vary from microns to millimeters.

- Low consumption
- Low costs
- High precision
- High integration
- Versatile technology

→ **SENSORS !**

Mems





Acceleration

In physics, acceleration is the rate at which the velocity of a body changes with time

In other words we have:

$$\vec{a} = \frac{\mathrm{d}\vec{v}}{\mathrm{d}t}$$

From Newton law also the following relation is true:

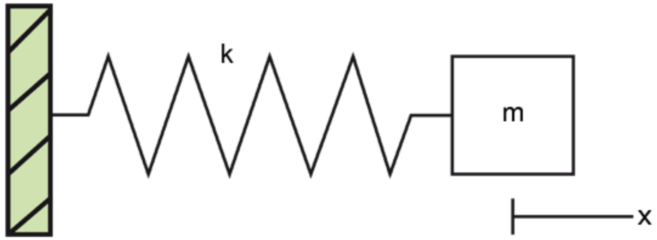
$$\vec{F} = m\vec{a}$$

How can we measure it?

Acceleration

Since $\frac{\vec{F}}{m} = \vec{a}$ we can try to evaluate in some way a force and then deduce the acceleration.

$$F = -kx = ma$$



Not very accurate!

Accelerometer

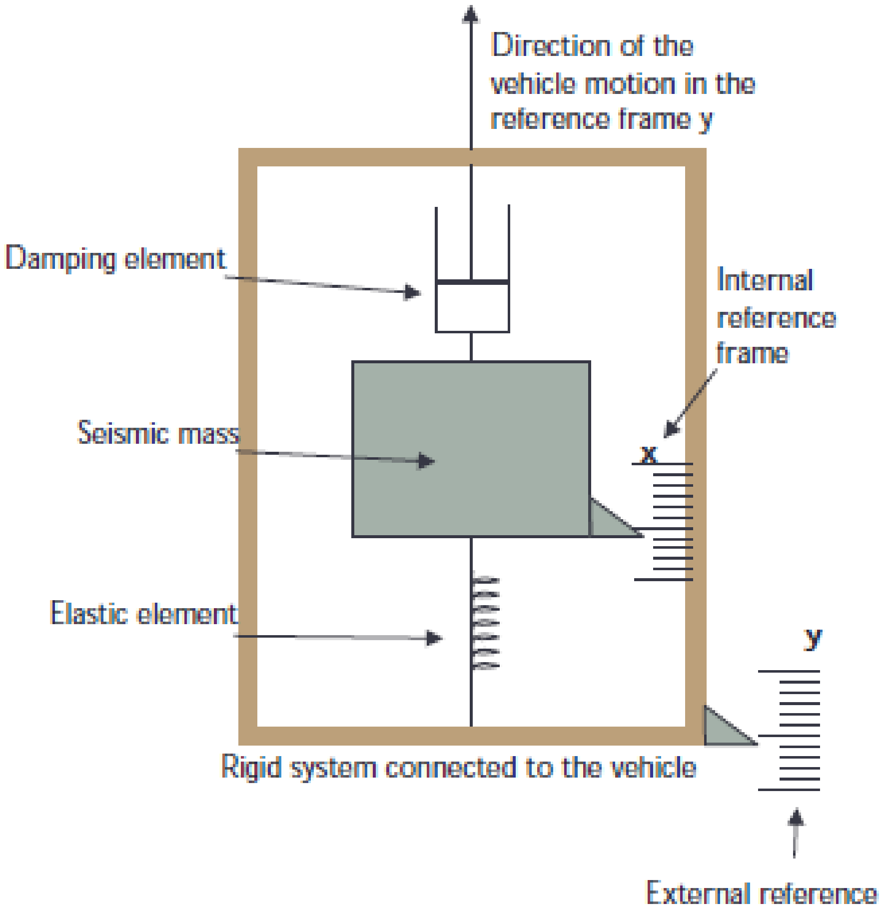
We add the damper due to damping forces

From dynamics we have:

$$k(z-y)+c(\dot{z}-\dot{y})+\mathrm{m}\ddot{z}=0$$

If we assume that we can measure the relative position between the mass and the frame, we define: $x=z-y$ and the dynamic equation become:

$$\ddot{x}+\frac{c}{m}\dot{x}+\frac{k}{m}x=-\ddot{y}=-a(t)$$



Accelerometer

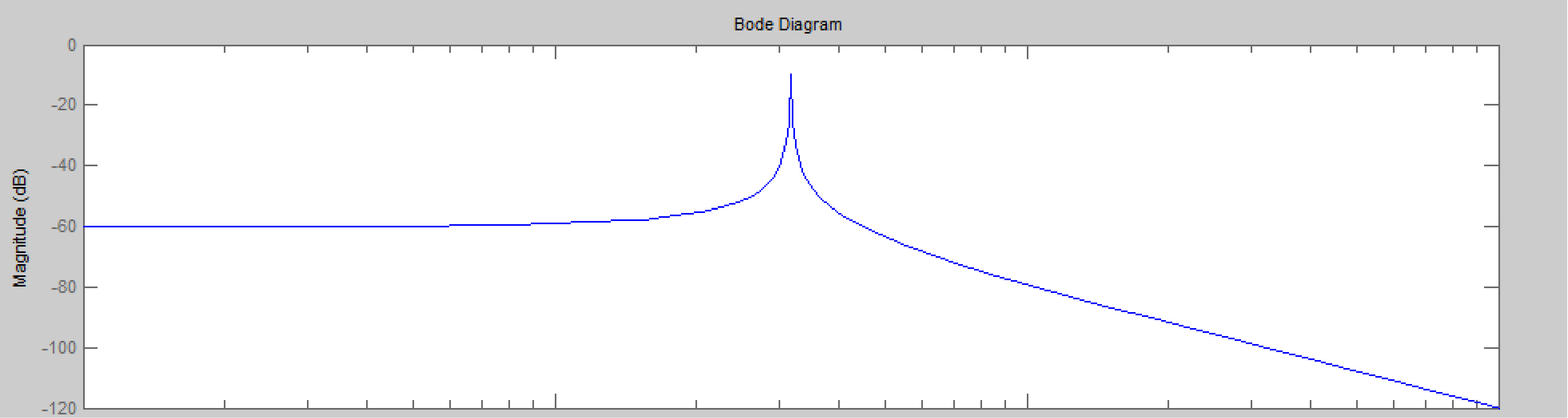
To calculate the transfer function of the system we apply Laplace transform and then evaluate $\frac{\mathcal{L}x(s)}{\mathcal{L}a(s)} = G(s)$

Obtaining :

$$G(s) = -\frac{1}{s^2 + \frac{c}{m}s + \frac{k}{m}}$$

Important information on the frequency behavior are obtained plotting Bode diagram.

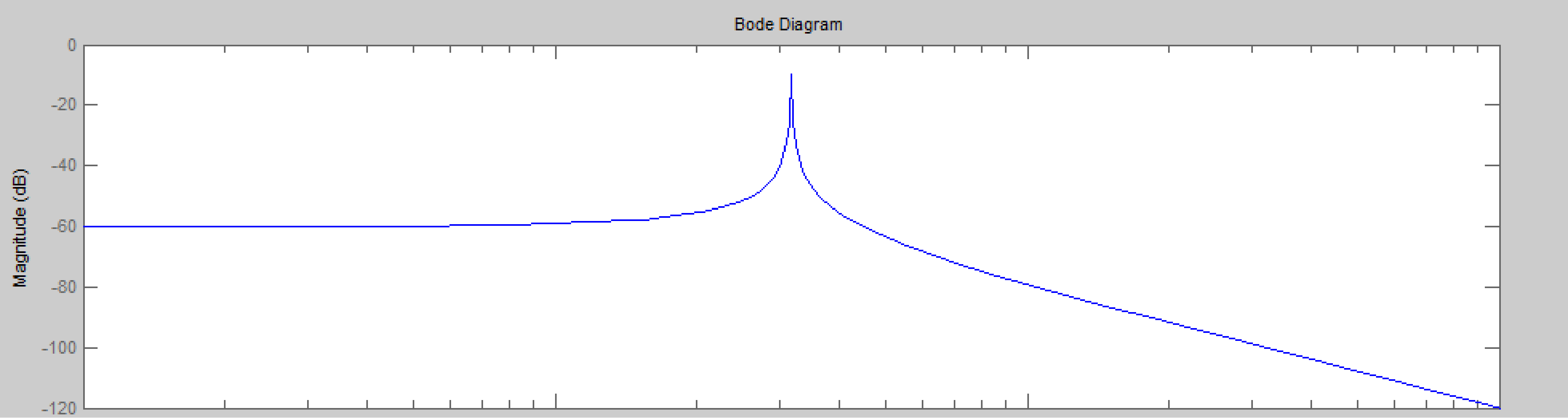
Accelerometer



Resonant low pass behavior ➔ if we want good measures we must stay in the flat part.

For $\omega \ll \omega_n$ the magnitude does not depend on frequency so we can assume that $G(s) \approx G(0)$ in this region.

Accelerometer



According to this assumption we have that:

$$G(s) = -\frac{m}{k}$$

From which we can finally deduce the measured value for acceleration ➔ $a(t) = -\frac{k}{m}x(t)$

Accelerometer

We found that:

$$a(t) = -\frac{k}{m}x(t)$$

Which is called the fundamental equation of accelerometers.

This equation gives us the measured value of the acceleration in terms of $x(t)$.

Note that we assumed to know in some way x(t).

How can we obtain a method to measure x(t)?

Measuring position (1)

Equation for plates capacitor:

$$C = \varepsilon\frac{A}{x}$$

$$C_1 = \varepsilon\frac{S}{x_0 + x} = \varepsilon\frac{S}{x_0\left(1+\frac{x}{x_0}\right)} = \frac{C_0}{1+\delta}$$

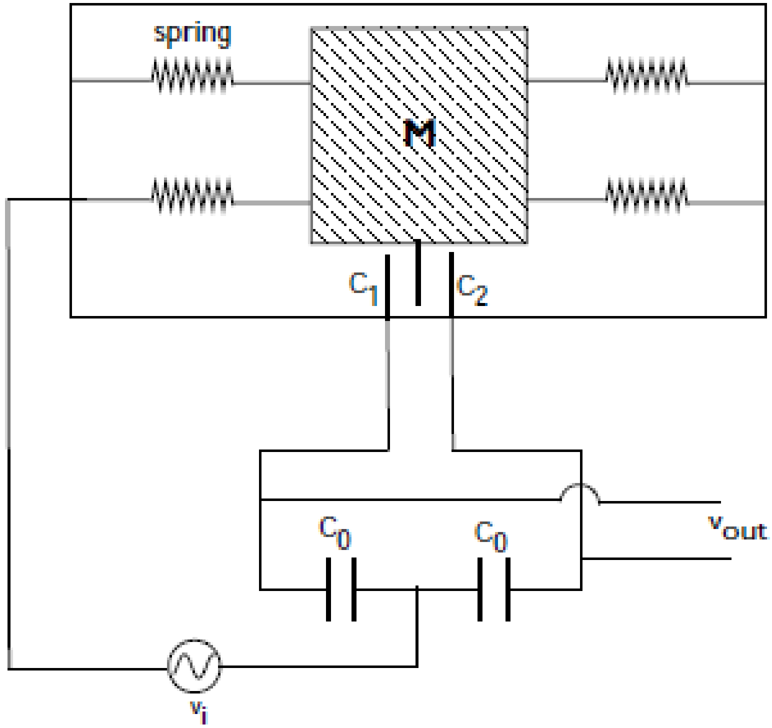
$$C_2 = \varepsilon\frac{S}{x_0 - x} = \varepsilon\frac{S}{x_0\left(1-\frac{x}{x_0}\right)} = \frac{C_0}{1-\delta}$$

$$where\ \delta = \frac{x}{x_0}$$

in a Wheatstone bridge: $if\ \delta \ll 1 \quad v_{out} = \frac{v_{in}}{2}\cdot\delta$

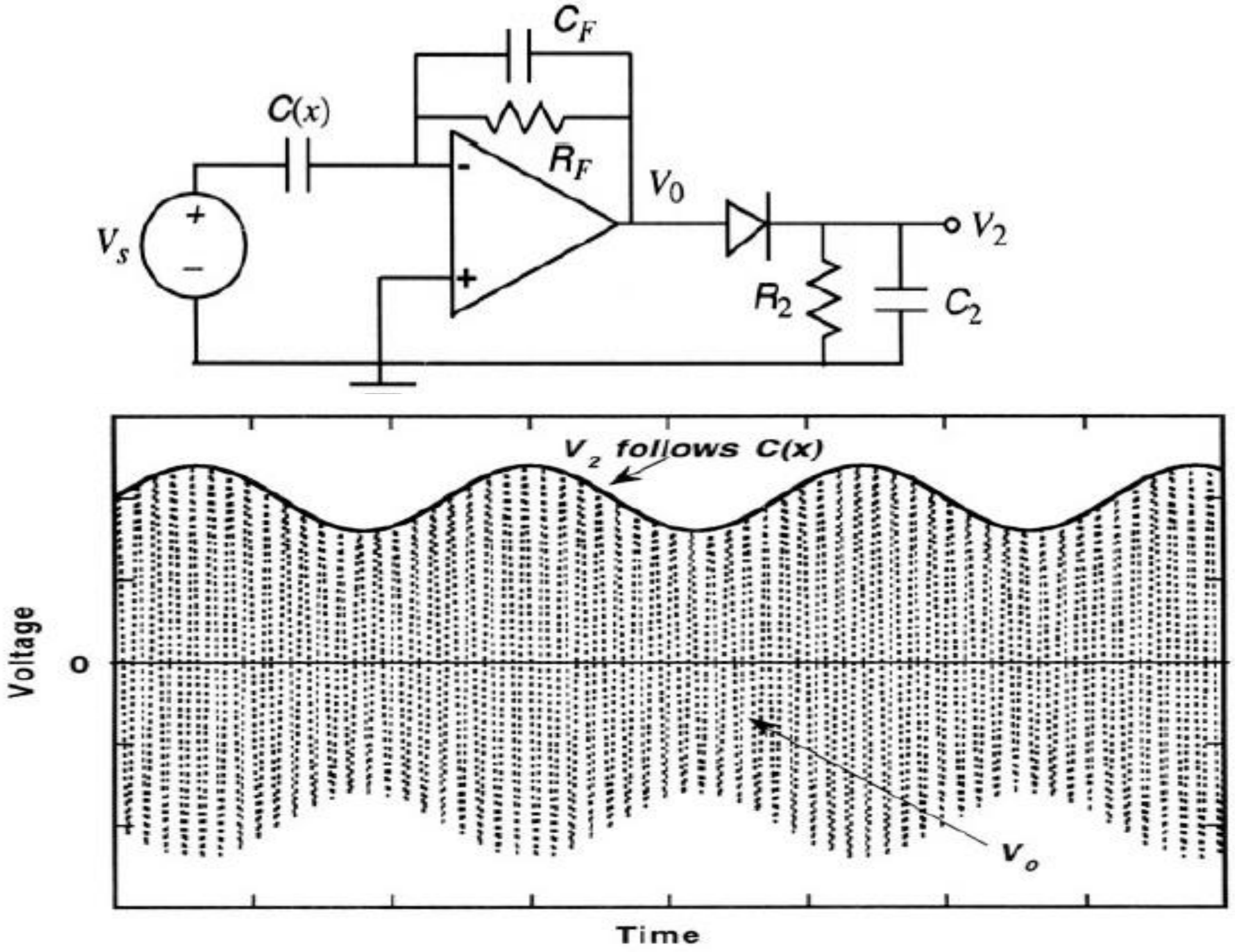
at low frequency regime:

$$a = \frac{K}{M}\cdot x = \frac{K}{M}\cdot x_0\cdot\delta = \frac{K}{M}\cdot \underline{x_0\cdot 2\cdot\frac{v_{out}}{v_{in}}} \rightarrow X(v)$$



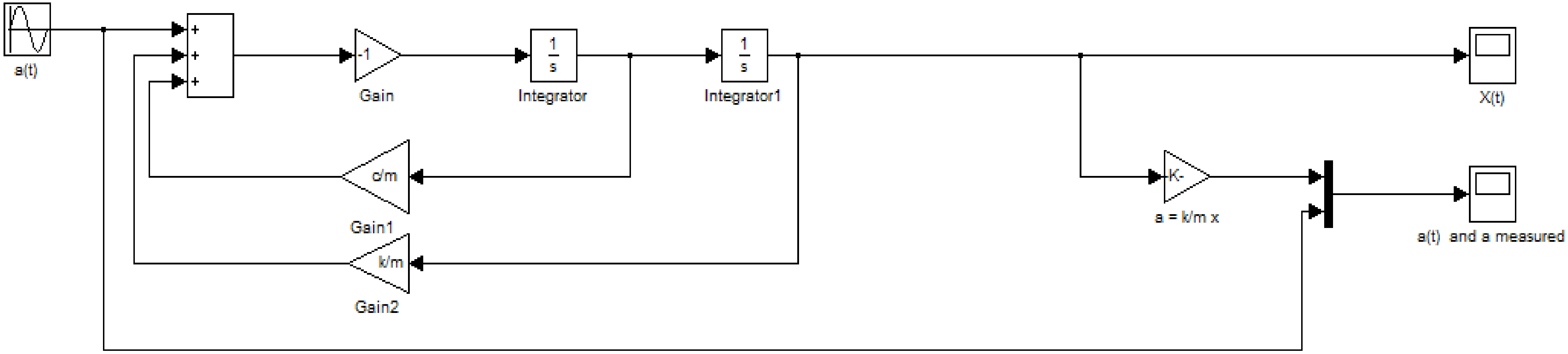
The common plate is connected to the voltage supply through the mass and the spring.

Measuring position (2)



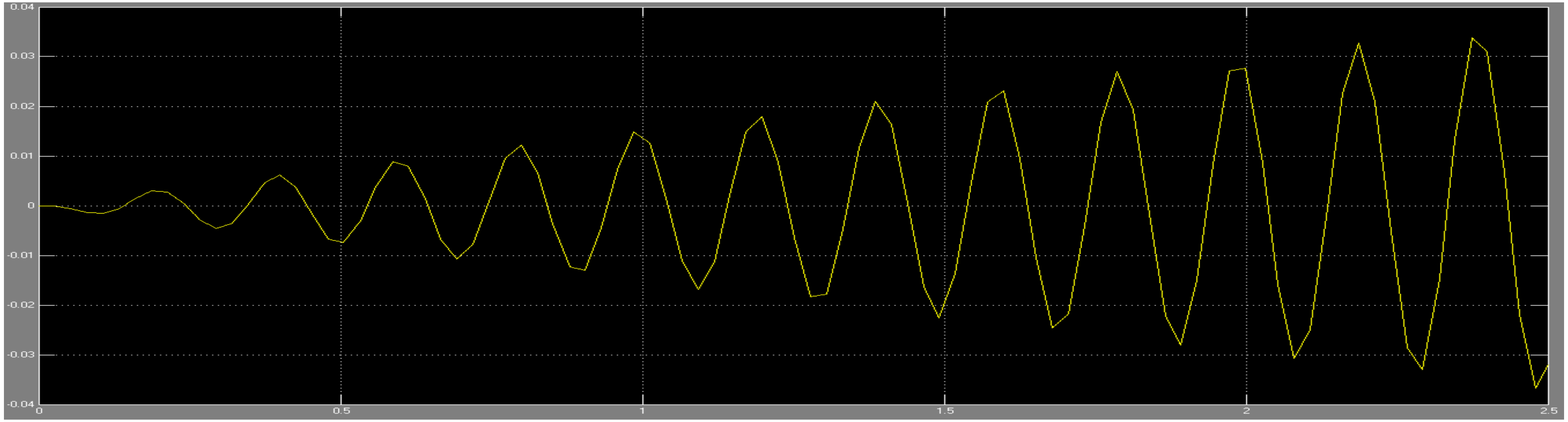
Simulation

Now that we can have everything we need, we can proceed building a model for our accelerometer.



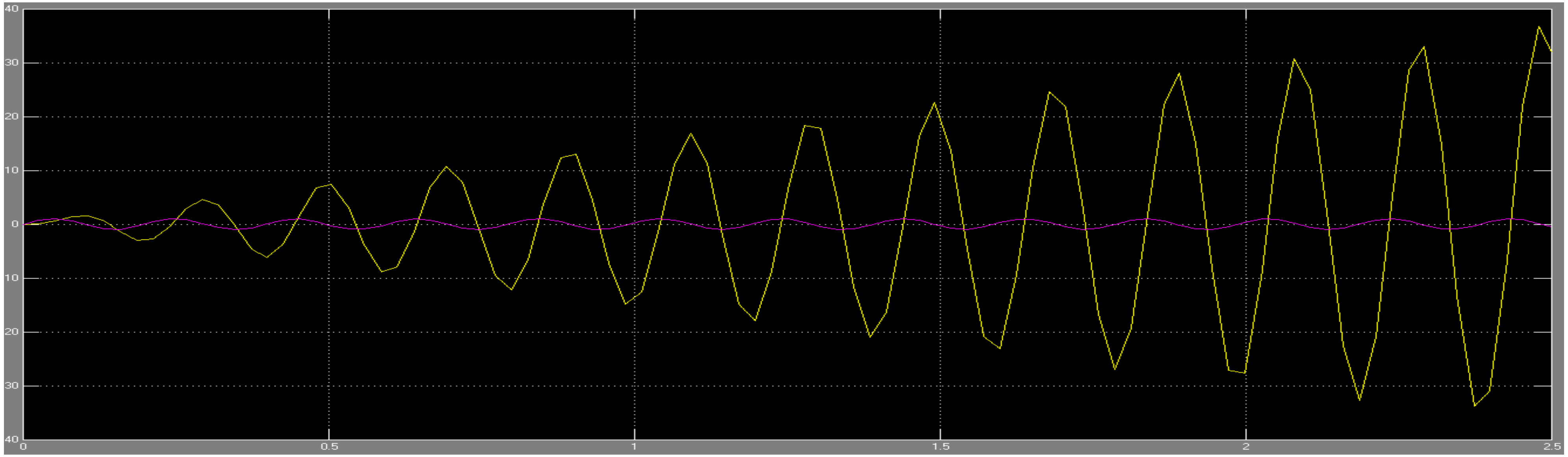
Simulation $(\omega = \omega_n)$

x(t)



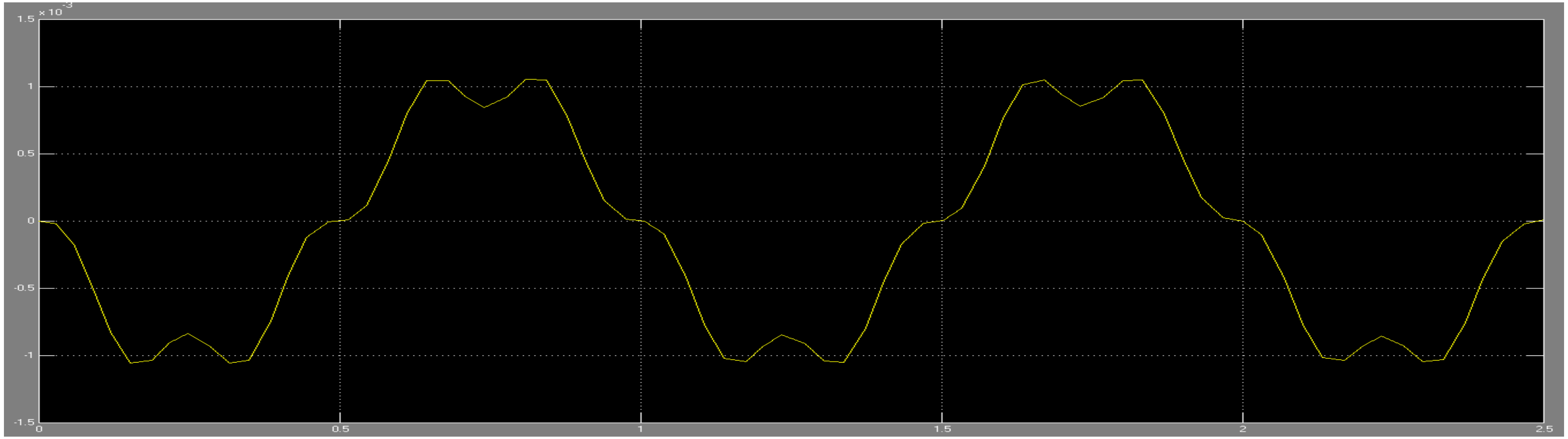
a*(t)

a(t)



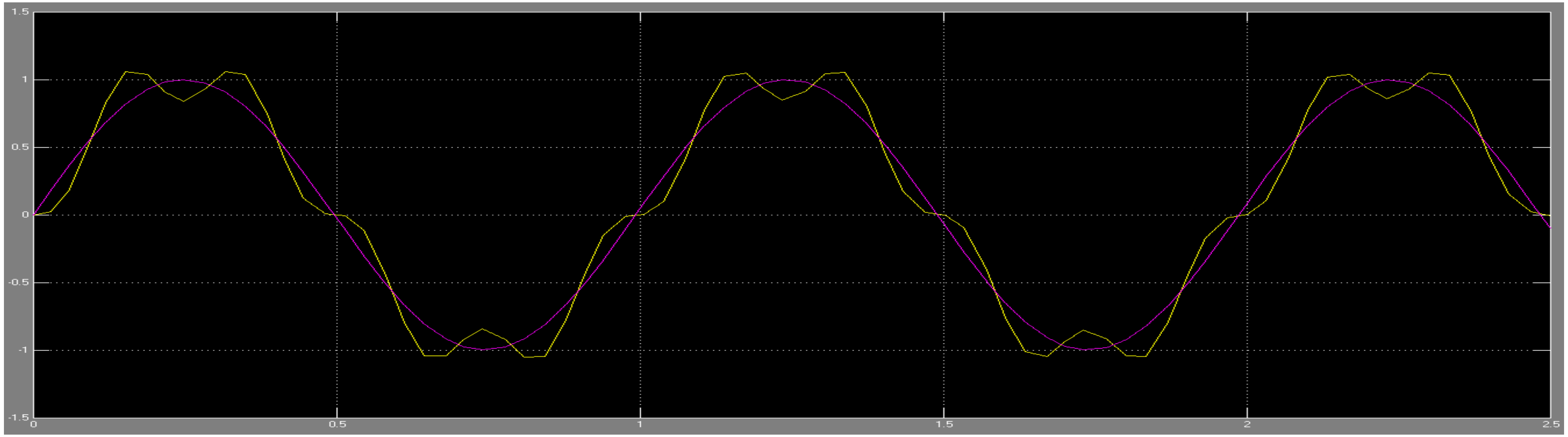
Simulation $(\omega < \omega_n)$

x(t)

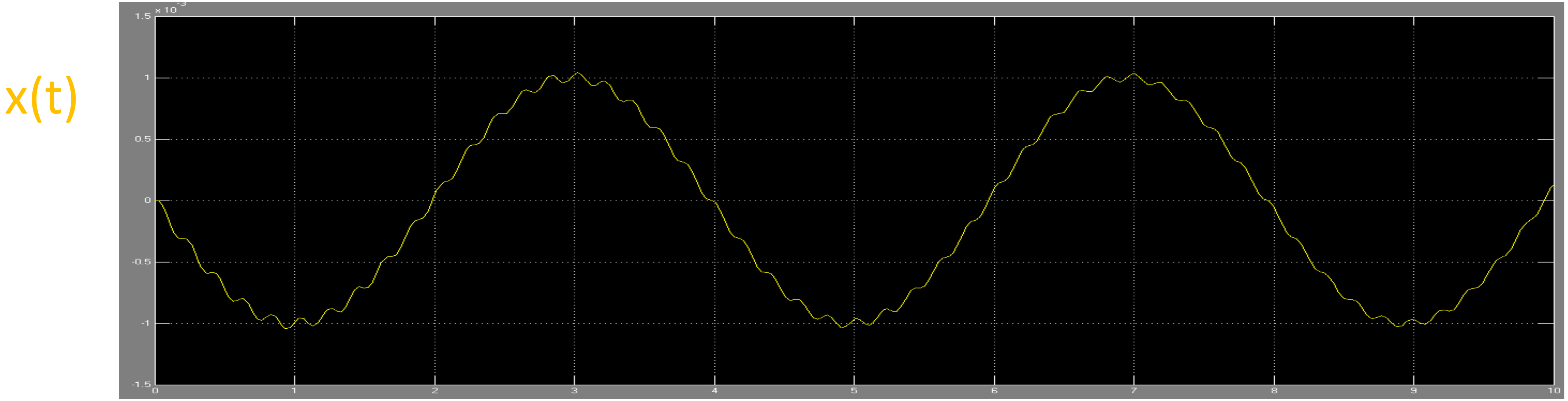


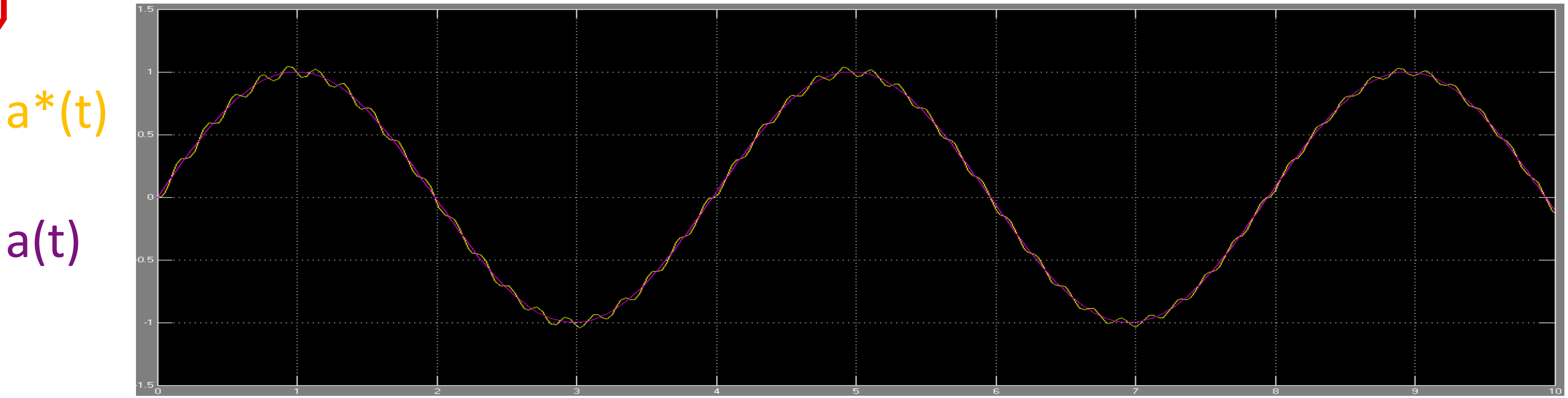
a*(t)

a(t)

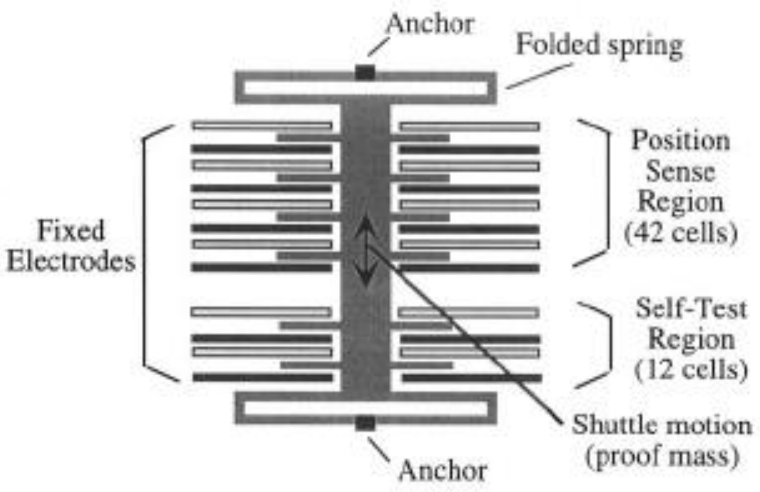


Simulation $(\omega \ll \omega_n)$

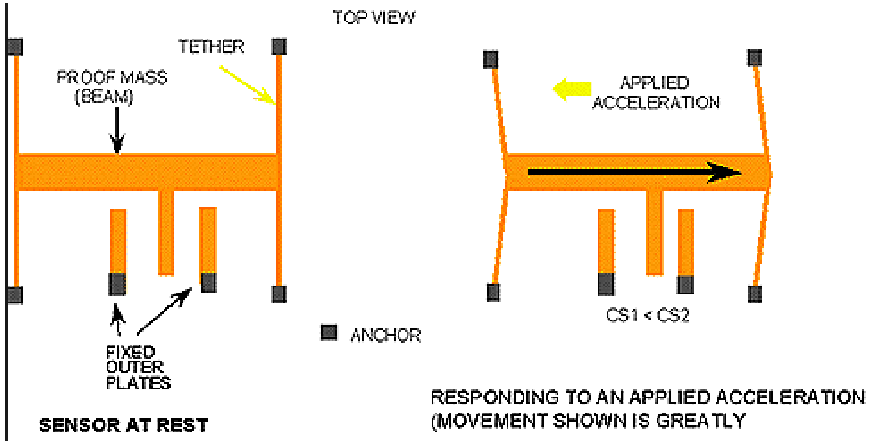




ADXL 150



$$V_{out} = \frac{V_s}{2} \pm \alpha + \beta a V_s$$



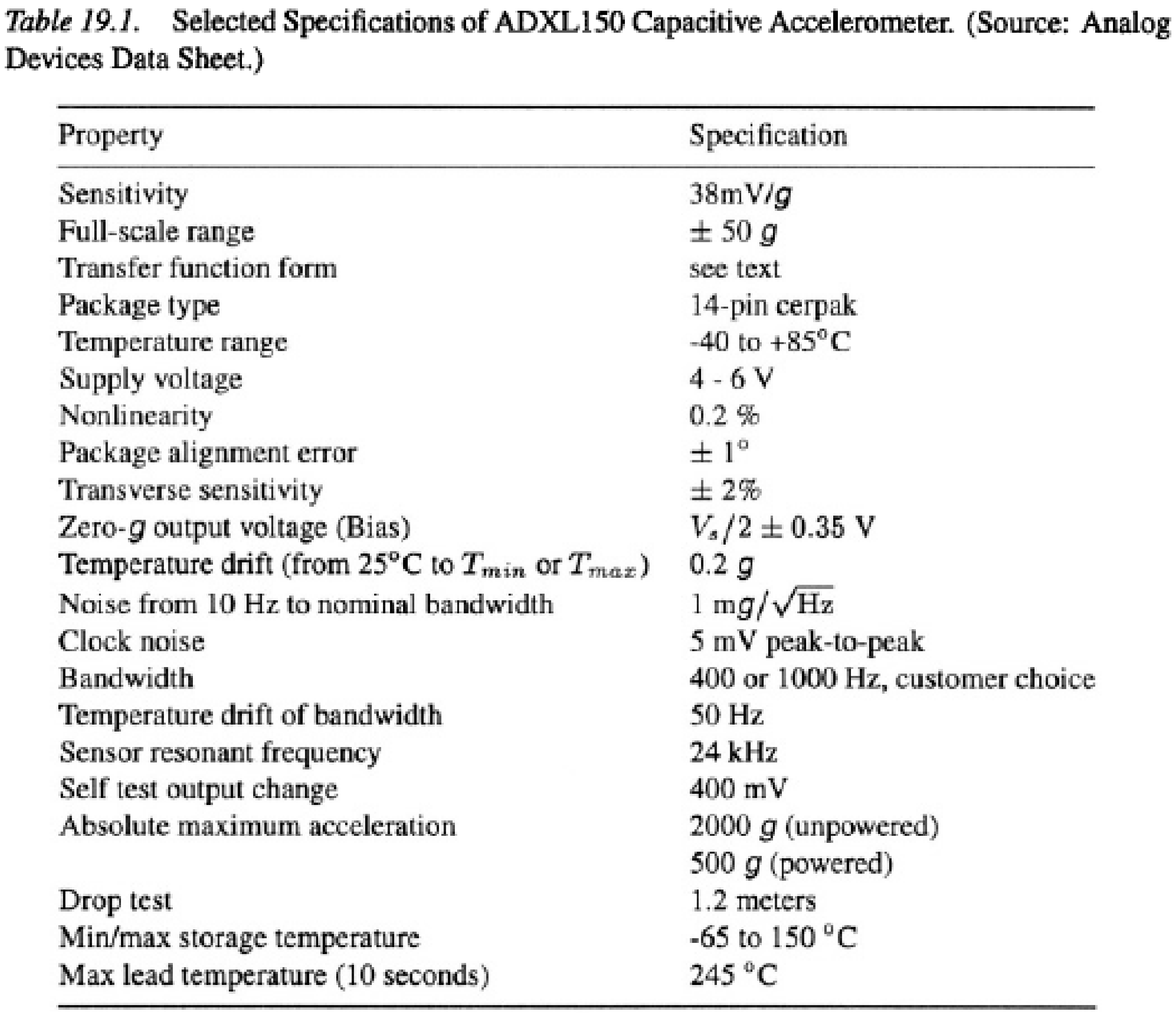
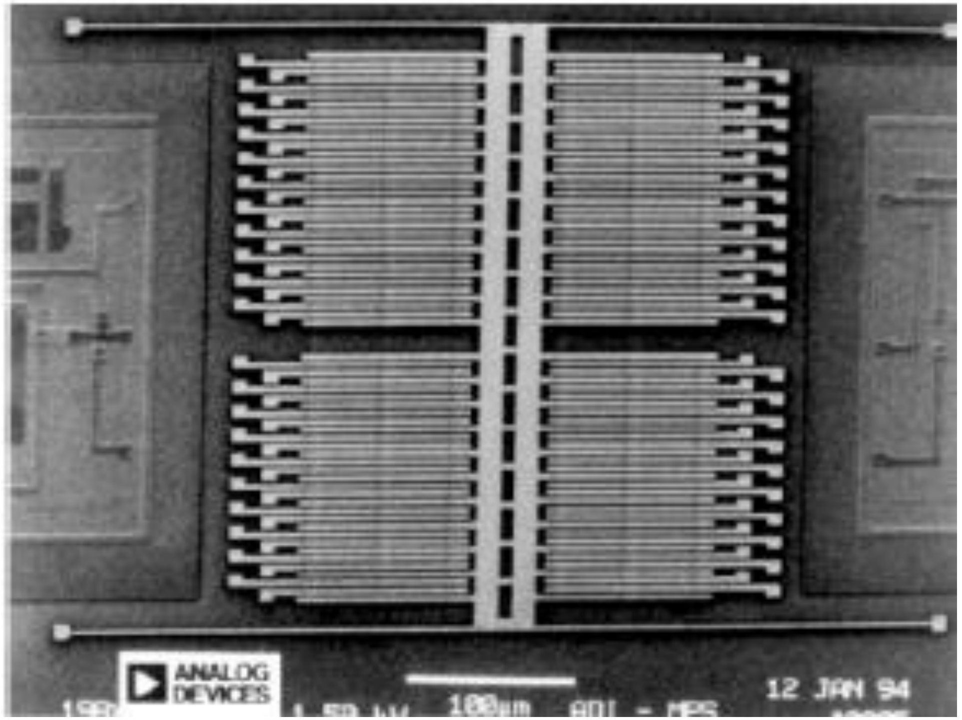
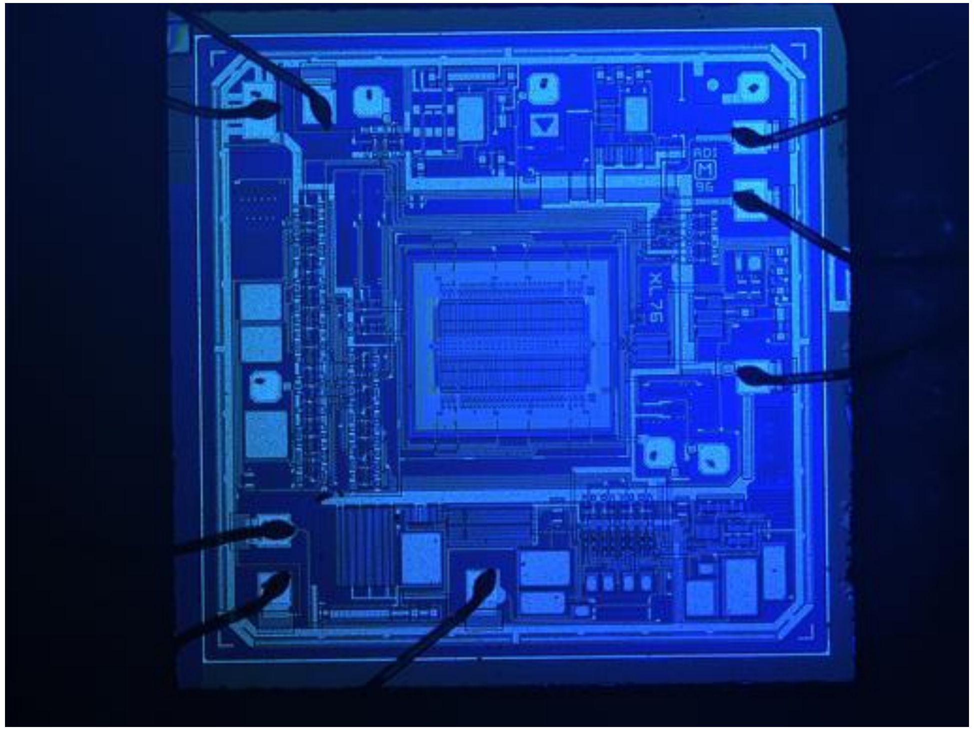


Table 19.1. Selected Specifications of ADXL150 Capacitive Accelerometer. (Source: Analog Devices Data Sheet.)

Property	Specification
Sensitivity	38mV/g
Full-scale range	$\pm$ 50 g
Transfer function form	see text
Package type	14-pin cerpak
Temperature range	-40 to +85°C
Supply voltage	4 - 6 V
Nonlinearity	0.2 %
Package alignment error	$\pm 1^\circ$
Transverse sensitivity	$\pm$ 2%
Zero-g output voltage (Bias)	$V_s/2 \pm 0.35$ V
Temperature drift (from 25°C to T_{min} or T_{max})	0.2 g
Noise from 10 Hz to nominal bandwidth	1 m$g/\sqrt{\text{Hz}}$
Clock noise	5 mV peak-to-peak
Bandwidth	400 or 1000 Hz, customer choice
Temperature drift of bandwidth	50 Hz
Sensor resonant frequency	24 kHz
Self test output change	400 mV
Absolute maximum acceleration	2000 g (unpowered) 500 g (powered)
Drop test	1.2 meters
Min/max storage temperature	-65 to 150 °C
Max lead temperature (10 seconds)	245 °C

ADXL 150



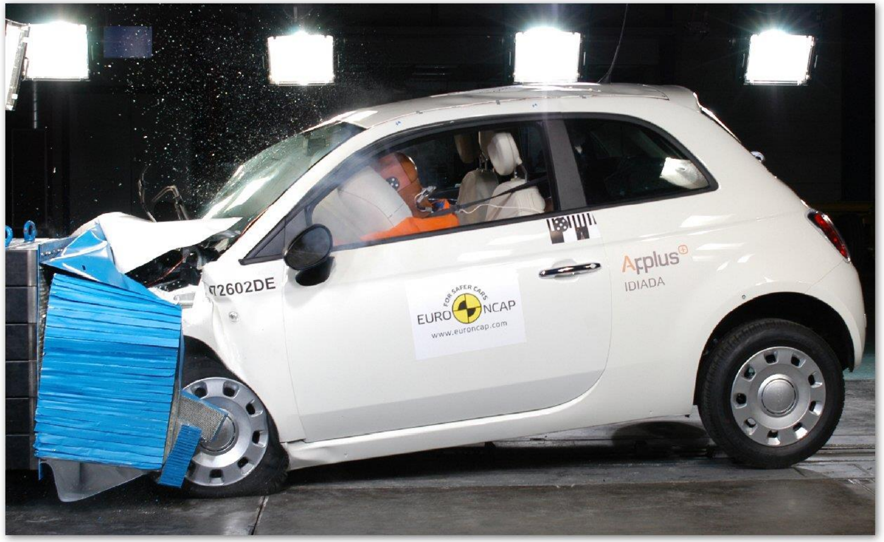


Conclusion

- Because of their high sensitivity, small size and low cost, surface micromachined accelerometers have made numerous new applications possible.

- The imagination of designers now seems to be the limiting factor in the scope of potential applications.

Conclusion (applications)



Ignition of airbag explosive (AUTOMOTIVE)

Feel vibrations of rotating machines (INDUSTRY)

Monitoring the acceleration for crew health / Firing next stage in some rockets (SPACE-AERONAUTICS)

Measuring the movement of Wii joystick / orientation and movement of smartphones (COMMERCIAL)

THANK YOU

Bibliography:

- Microsystems design, *Stephen D. Senturia*
- *Mechanical Vibrations, S. Rao*