Macro Fiber Composite

as

low cost strain and vibration sensor

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G. Naumann **University of Applied Sciences**

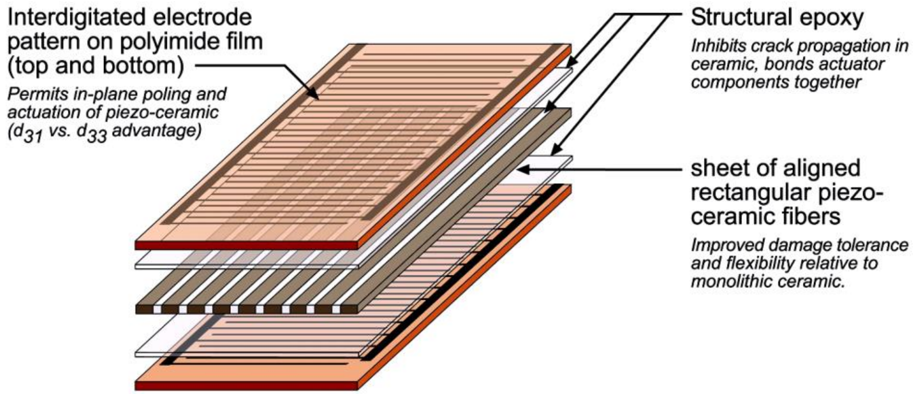
Overview

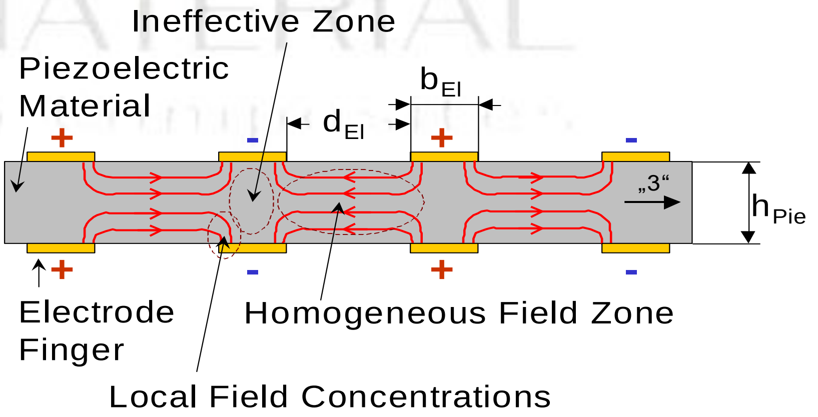
- **Strain Sensor Elements - Macro Fiber Composites**
  - Structural design
  - Types, Materials and Properties
- **Motivation**
- **Suitable electronics**
  - Voltage Amplifier vs. Charge Amplifier
  - Store&Hold Amplifier
- **Applications**
  - Static / low frequency
  - Vibration / Sound
  - ultrasound
- **Summary & Conclusions**

Strain Sensor Elements - Macro Fiber Composites (MFC)

Disadvantages of solid plate actuators

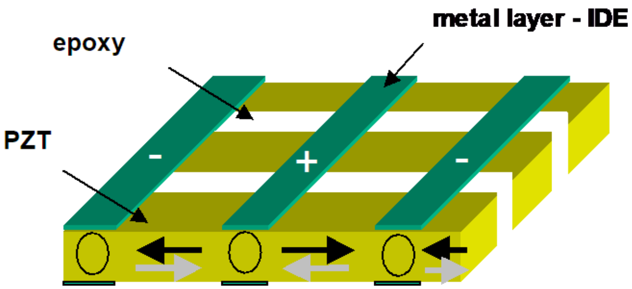
- nonelastic, no surface conformity
- only use of d31 in-plane
- Isotropic in-plane deflection

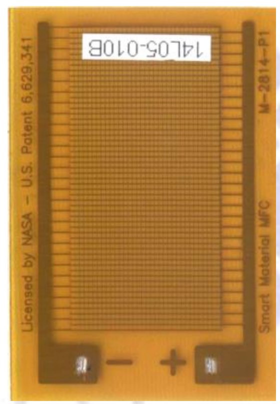




Strain Sensor Elements - available MFC Types

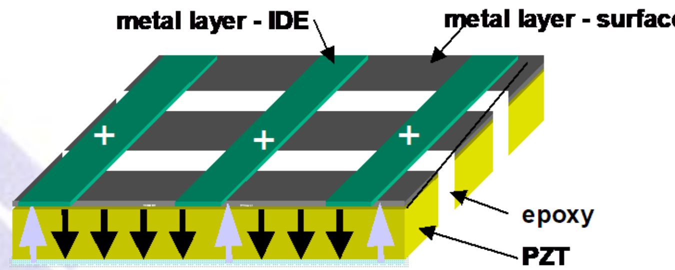
P1-Type MFC (d33)

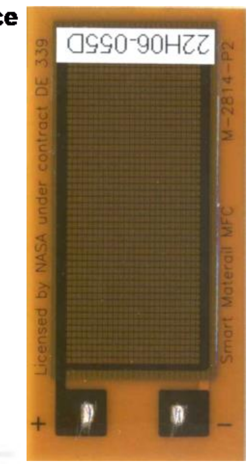




Elongator

P2-Type MFC (d31)

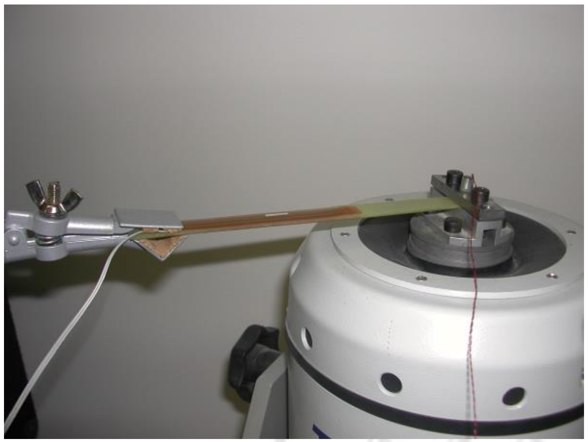




Contractor

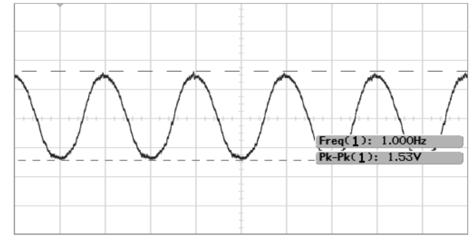
Device	Operation voltage		Capacity	Sensor characteristic		Actuator characteristic	Generator characteristic
	V_{op}^{+} [V]	V_{op}^{-} [V]	C_{pol} [nF/cm^2]	d_{33}^{eff} [pC/ N]	d_{31}^{eff} [pC/N]	Strain / Volt. [µstrain / V]	Charge/Strain [pC/ppm]
3-3 MFC	**1500**	**-500**	**0,42**	**460**	**-**	**0,7..0,9** [0 … 1500V]	**1670** [> 100V]
3-1 MFC	**360**	**-60**	**4,5**	**-**	**-370**	**- 2** [0 … 360 V]	**3250** [< 100 V]

Motivation

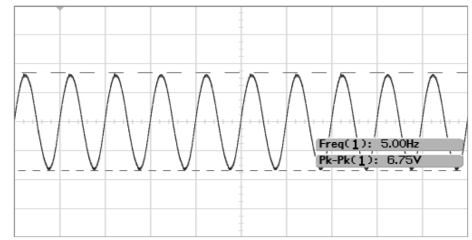


- cantilever beam set-up
- +/- 3 mm tip deflection (controlled)
- 1 Hz / 5 Hz / 10 Hz
- 1 MΩ input impedance (oscilloscope)

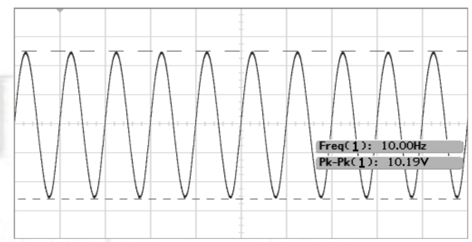
???



1,5 V p-p @ 1 Hz

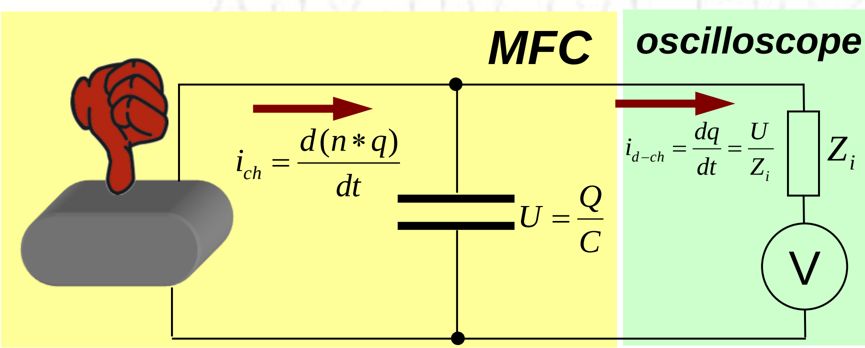


6,75 V p-p @ 5 Hz



10,2 V p-p @ 10 Hz

Piezo-equivalent model



Outer load leads to a continuous discharging of the sensor's capacitance

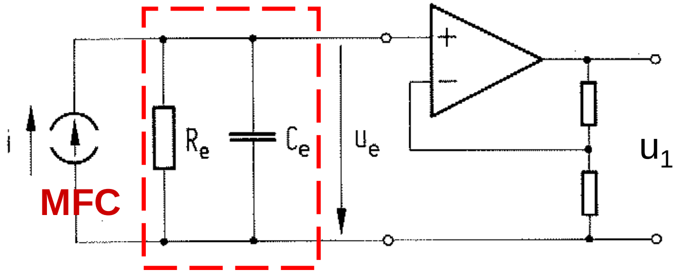
Special high impedance (load free) electronics are needed for quantitative measurements

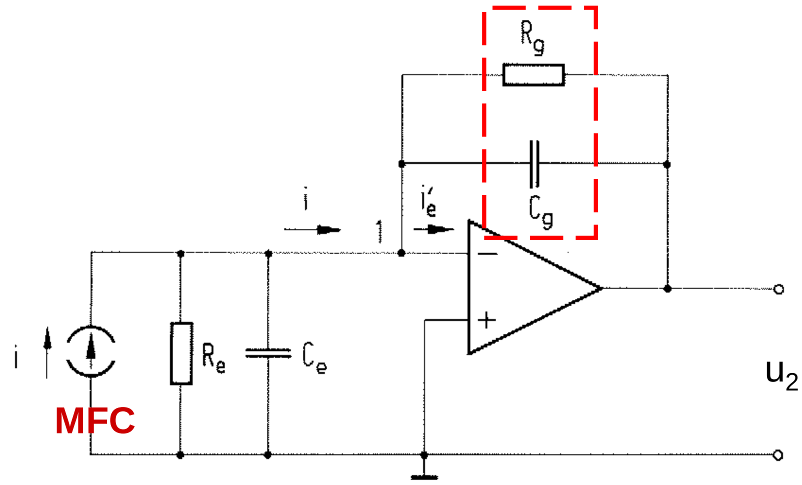
State of the Art - *Voltage amplifier* vs. *Charge amplifier*

R_e, C_e … MFC- and wire-specific parameters

R_g, C_g … Parameters in the feedback circuit

$Q_0 = d\ F_0$ … Charge at $t = t_0$





$$u_1 \sim \frac{Q_0}{C_e} e^{-\frac{t}{R_e\ C_e}}$$

$$u_2 = \frac{Q_0}{C_g} e^{-\frac{t}{R_g\ C_g}}$$

u_1 = f (MFC material and wiring cables**)**

u_2 = f (R_g and C_g in the feedback circuit**)**

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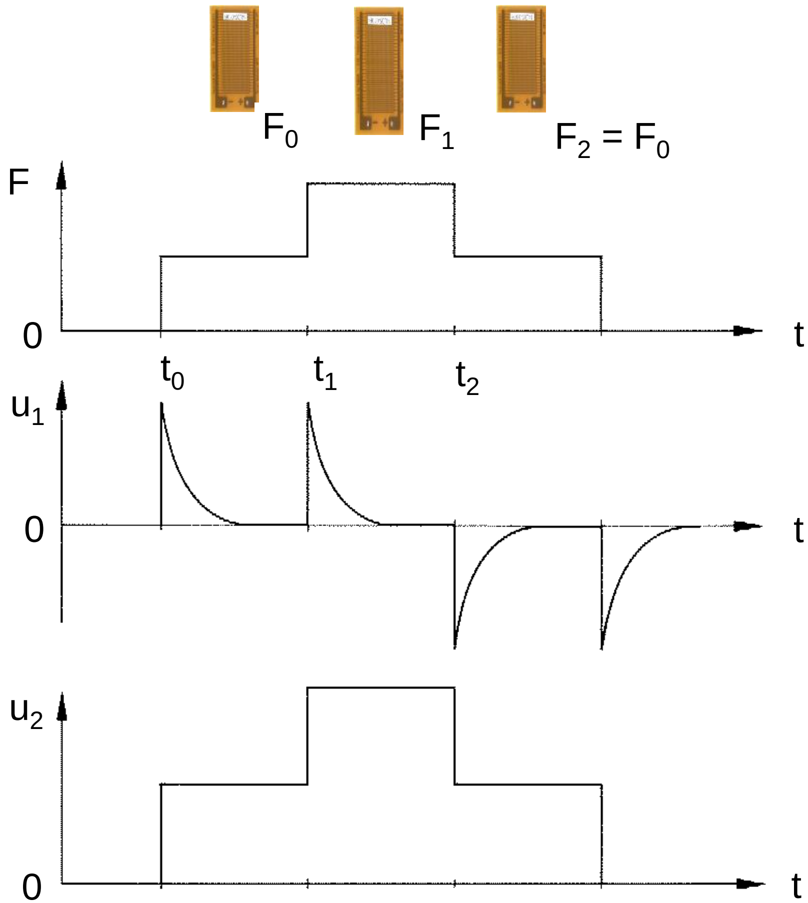
State of the Art - *Voltage amplifier* vs. *Charge amplifier*



Force at MFC:

$t = t_0$, $F = F_0$
$t = t_1$, $F = F_1$ …

Output at voltage amplifier:

time-variant (R_e, C_e)
for dynamic measurements

Not applicable for static measurements

Output at charge amplifier:

time-invariant ($R_g \rightarrow \infty$)
for static measurements

Drift (noise integration) is critical

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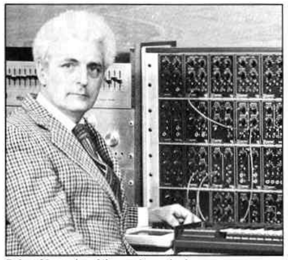
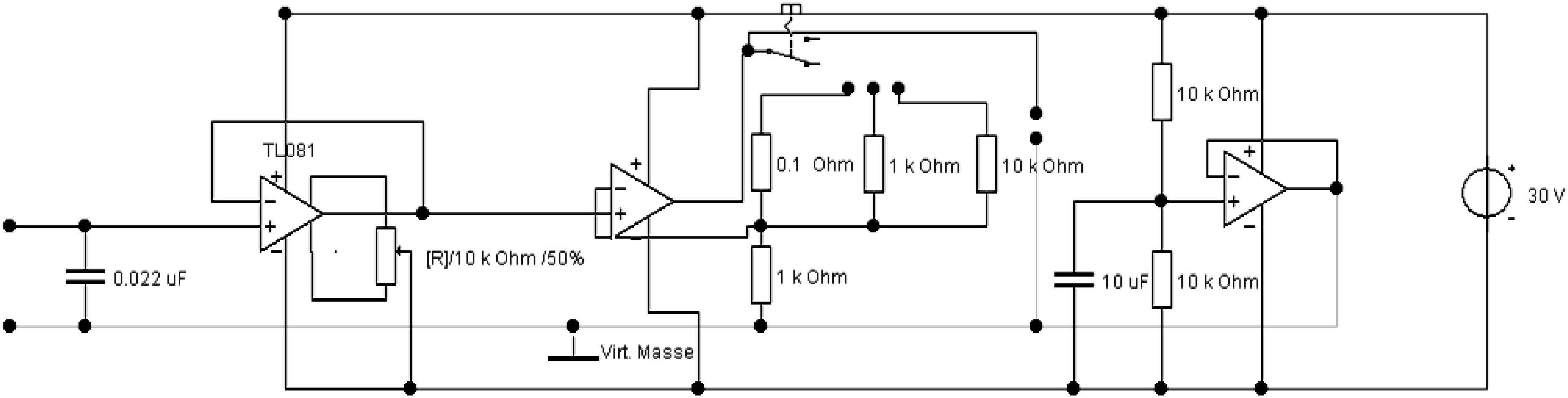
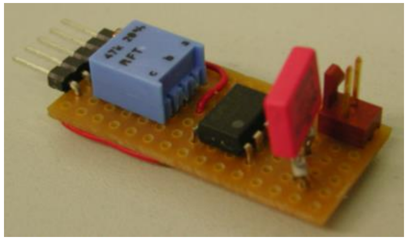
"New" approach – Store&Hold Amplifier


Robert Moog, sire of the music synthesizer.

Principle often used in analog synthesizer keyboard units based on the earlier developments by Robert Arthur Moog in 1950



generated charge is stored in a nearly leakage free capacitor and hold there for a longer time by measuring the voltage load free with a high impedance voltage follower



Fields of Applications

strain based applications

- **static / low frequency**
  - deformation
  - pressure
- **vibrations / sound**
  - mechanical vibrations
  - body sound propagation
- **ultrasound**
  - acoustic emission
  - guided wave ultrasound

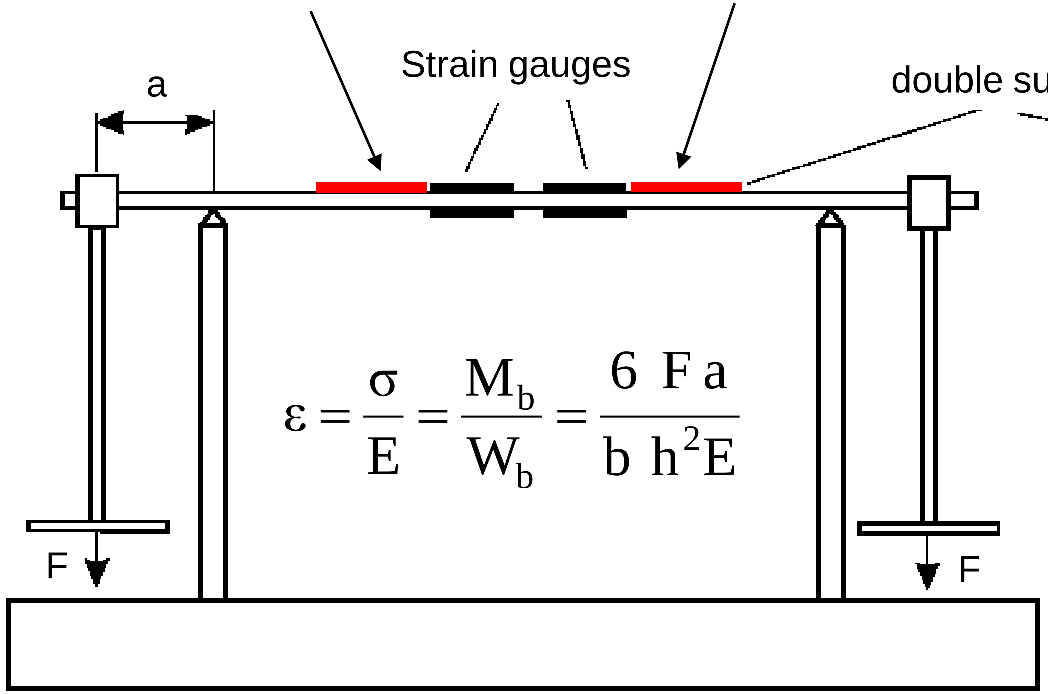
store&hold amplifier

voltage amplifier

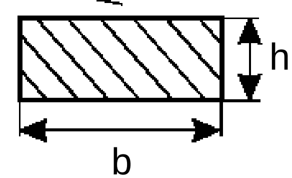
store&hold amplifier

voltage amplifier

Applications – *quasi-static strain measurements*



$$\varepsilon = \frac{\sigma}{E} = \frac{M_b}{W_b} = \frac{6\ F\,a}{b\ h^2 E}$$



E-Modul: 210.000 N mm^{-2}

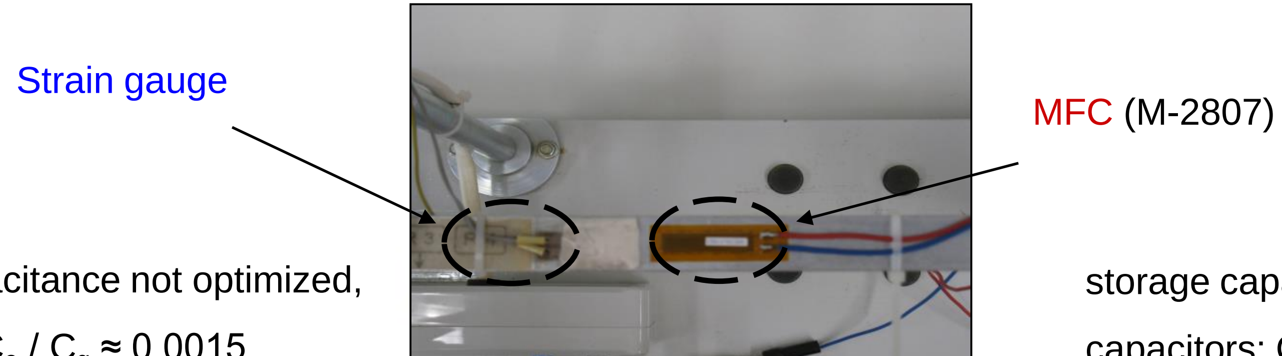
length a: 121 mm

bar hight h: 6 mm

bar width b: 20 mm

force F: 15 N

Applications – *quasi-static strain measurements*

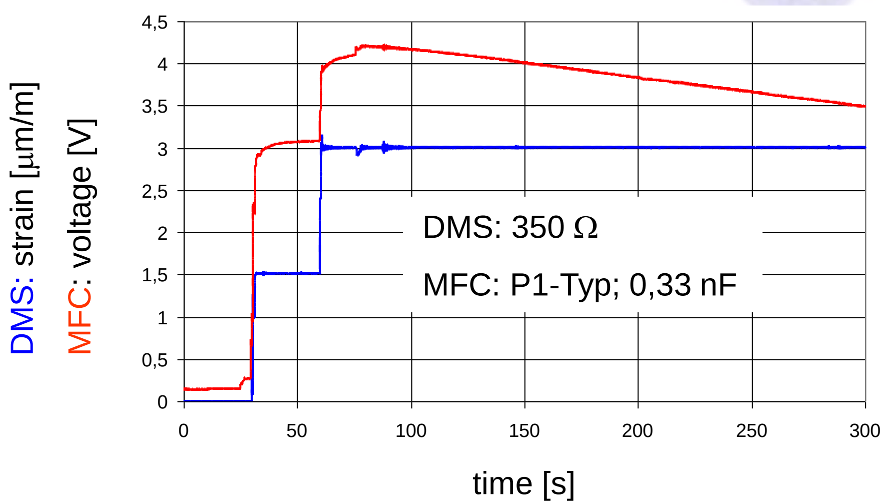


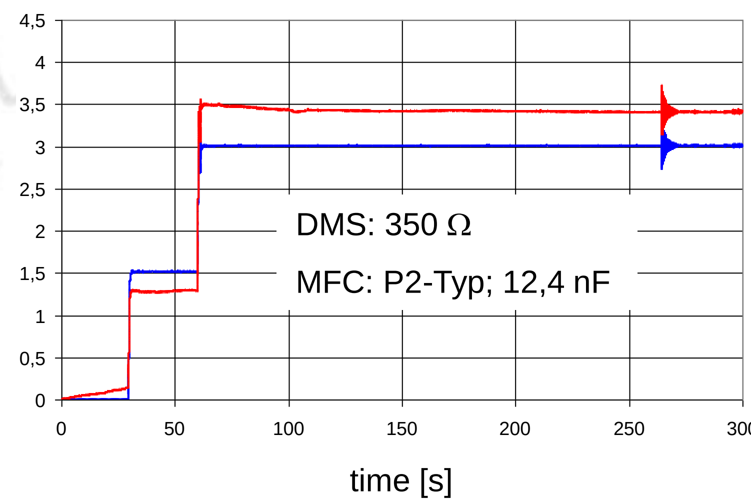
storage capacitance not optimized,

capacitors: C_e / C_g ≈ 0.0015

storage capacitance optimized,

capacitors: C_e / C_g ≈ 0.56





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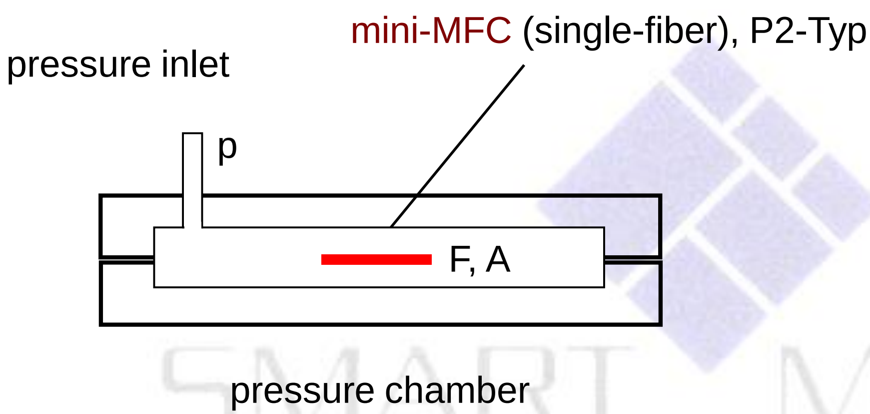
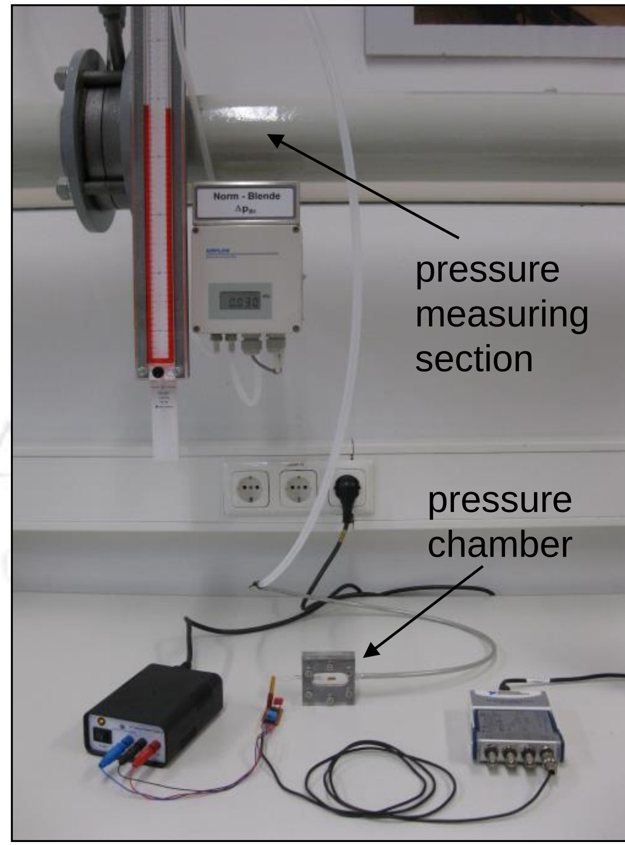
Advanced Piezo Composites

Applications – *low frequency pressure sensor*

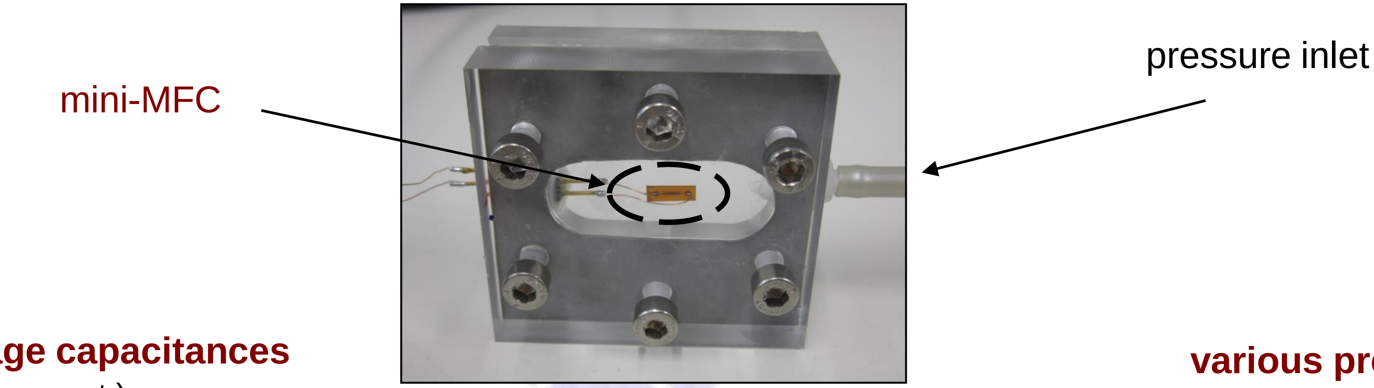




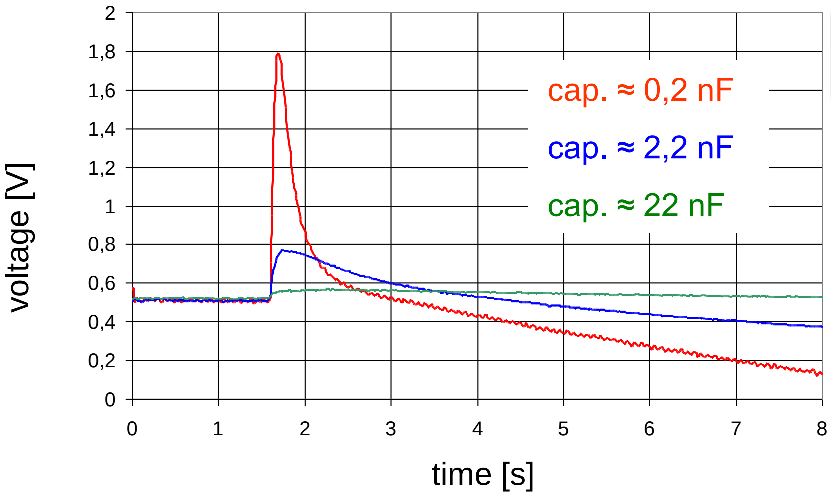
$$p = \frac{F_0}{A} = \frac{Q_0}{d_{33}A} \rightarrow Q_0 = p * d_{33} * A$$

d … piezoelectric charge coefficient

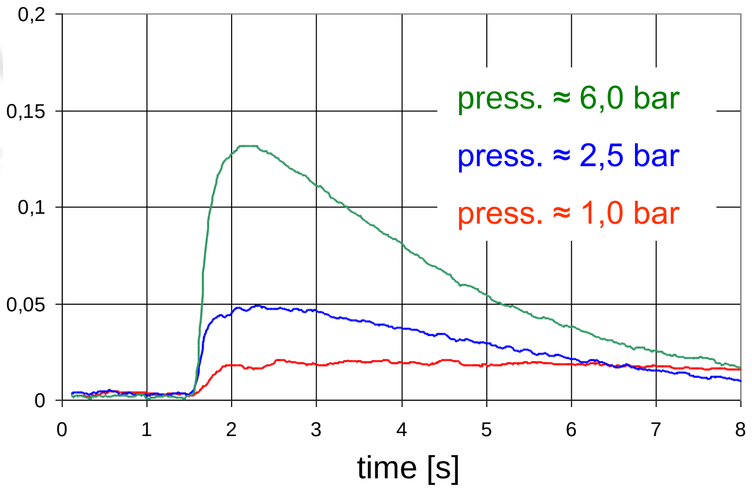
Applications – *low frequency pressure sensor*



various storage capacitances
(pressure 2,5 bar=const.)

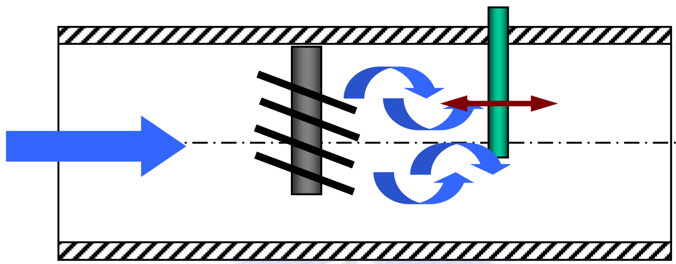


various pressure levels
(capacitance 22nF=const.)



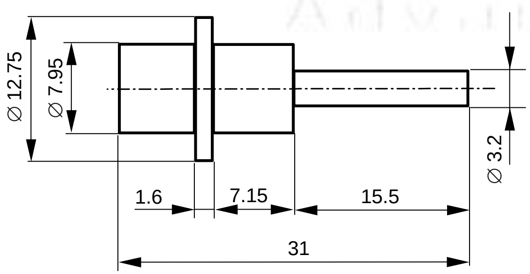
Applications – *vibration sensor for flow meters*

Principle of work

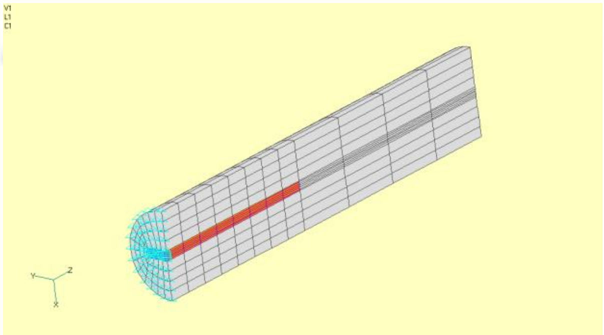


Most of the monolithic ceramic sensors break after a short life time

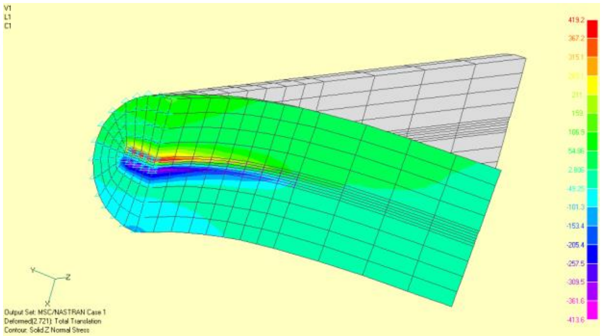
Stress analysis shows high values for stresses and their gradients



Sensor Pin



FEA model



FEA results (σ_{max}=400 N/mm²)

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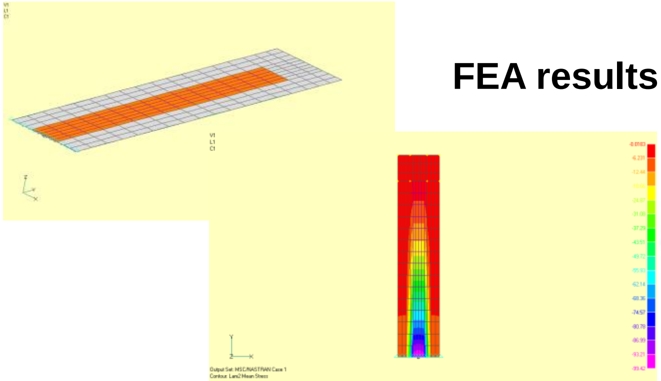
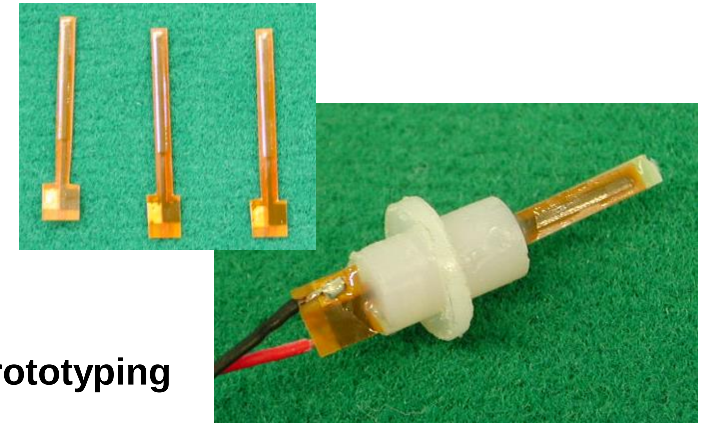
Applications – *vibration sensor for flow meters*

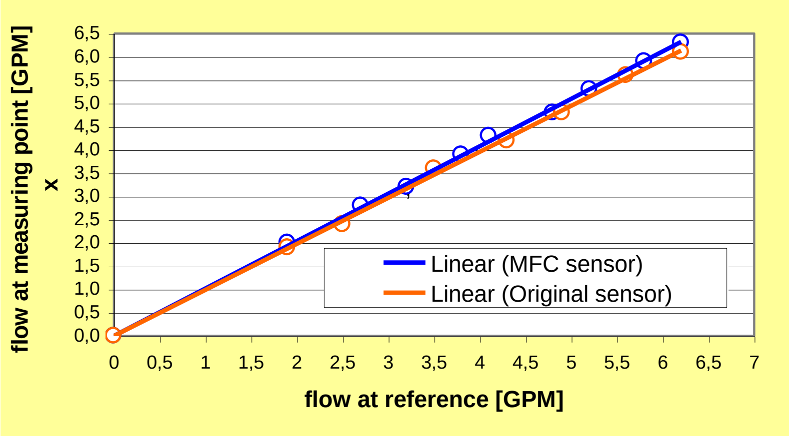
<u>MFC based sensor development</u>



FEA results (σ_{max}=-100 N/mm²)



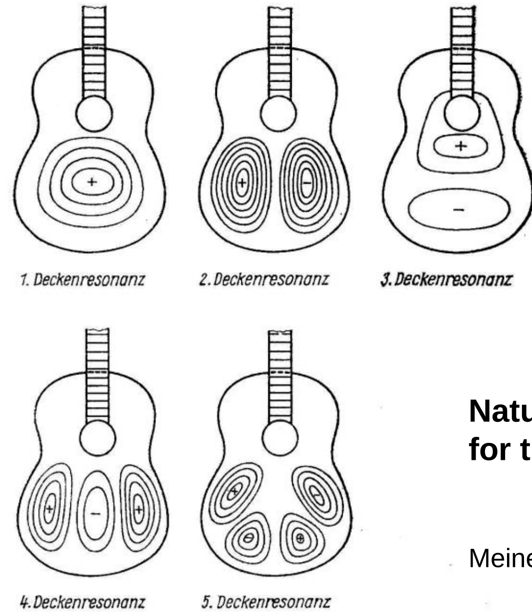
Prototyping



Results:

- Max stresses could be reduced down to a fourth and are compressive only
- Sensitivity of the novel sensor element is closely comparable to the original sensor element

Applications – *sound pick-up system for acoustic instruments*



Natural frequency modes for the table

Meinel: Elektrogitarren, 1987

The *ideal sound* is religion for the most of musicians.

Therefore position and frequency response of the pick-up are a question of individual taste.

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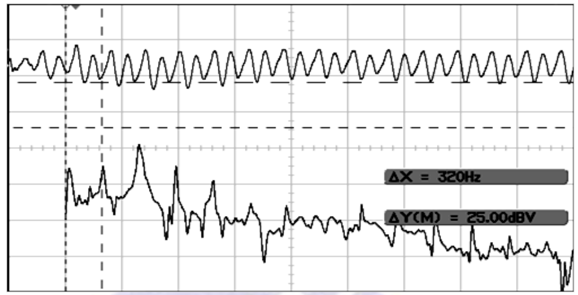
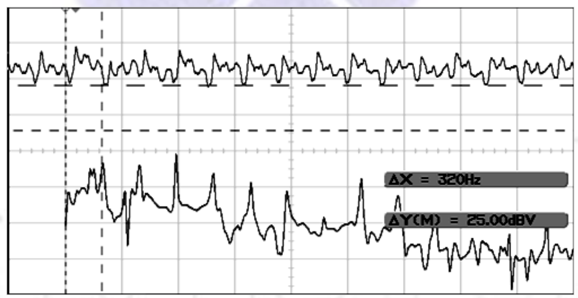
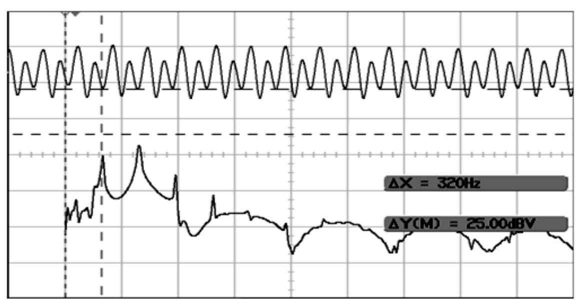
Applications – *sound pick-up system for acoustic instruments*



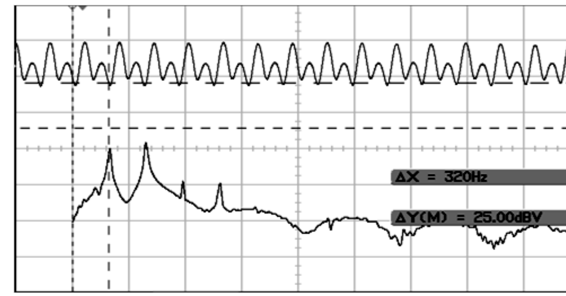
MFC Sensor 2807-P1



MFC Sensor 2503-P1



MFC Sensor 2814-P2



Acceleration sensor

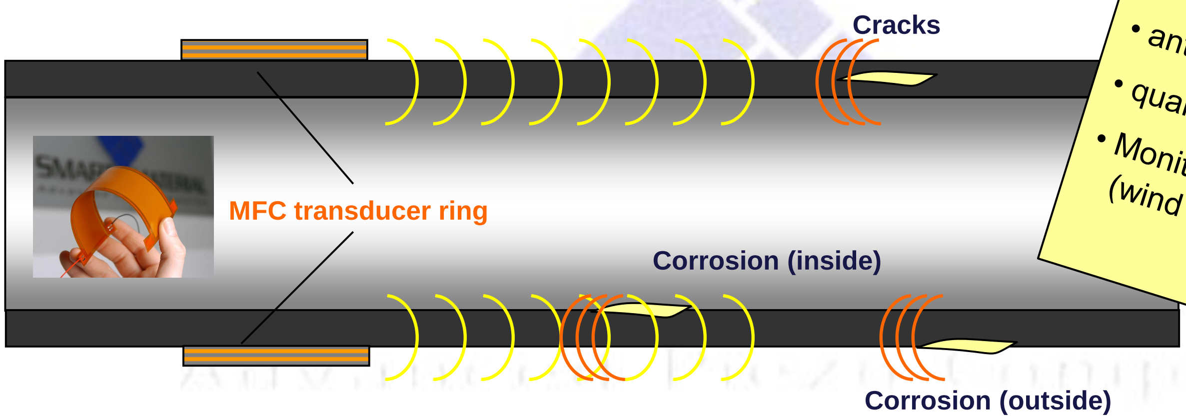
Results:

- neck and bridge position give an equalized response
- P1 type MFCs have a better high frequency transparency
- An-isotropic behavior gives a higher DOF for positioning
- MFCs measure strain proportional
- Acceleration sensors measure acceleration proportional

Applications – *ultrasound structural health monitoring*

Currently up-growing research activities on the field of ultrasound guided wave inspection systems.

Principle:



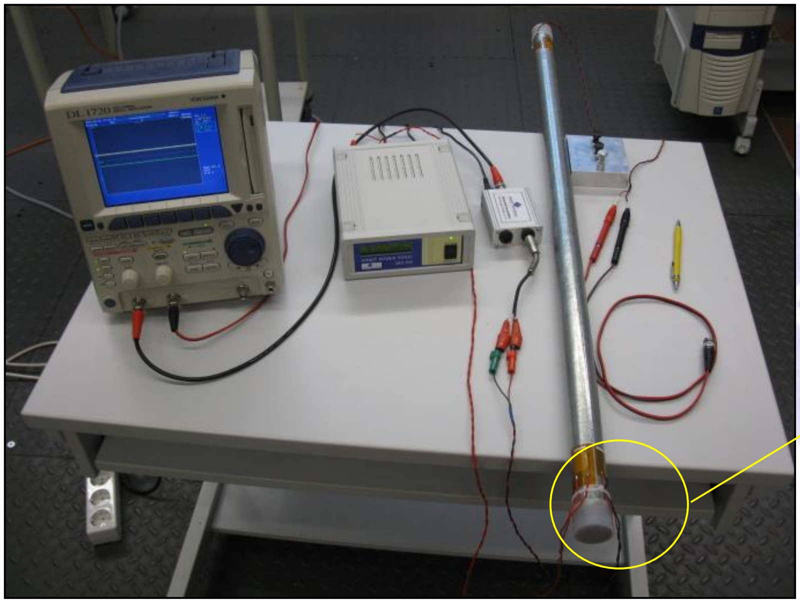
Fields of application

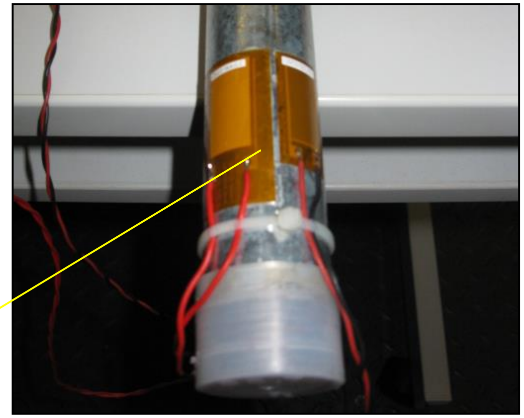
- pipeline inspection
- antenna or wind mill masts
- quality control for metal coils and ropes
- Monitoring of thin and straight structures (wind turbine blades)

Advantages using MFC's :

- **Flexible design allows wrap around**
- **d_{33} effect offers excellent acoustic performance and sensitivity**
- **Basics of MFC technology open a wide range for cost effective layouts along specific acoustic requirements**

Applications – *ultrasound structural health monitoring*





Reverberations from both ends

Smart PowerSonic™

+/-280V up to 100 kHz

10 cycle 30 kHz burst

Summary & Conclusions

- **Based on their unique design the MFC elements combine most of the basic requirements for strain sensors like high sensitivity, robustness, reliability and an an-isotropic behavior.**
- **Voltage and charge amplifiers as commercially available equipment match the specific electric behavior of piezo sensors well, but they are also showing some essential drawbacks like signal stability and drift.**
- **With the Store&Hold amplifier a novel electronic unit was developed and evaluated to overcome the disadvantages of current systems.**
- **Based on several applications it was shown that MFC sensors combined with modified electronics offer an incredible variety of new and interesting applications.**
- **Those results motivated us to force the future the work on both the MFC sensor and the pre-amplifier as well. We plan to comerialize that system next time under the name *SmartCharge™.***

Thank you for your attention

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