MAS836 – Sensor Technologies for Interactive Environments

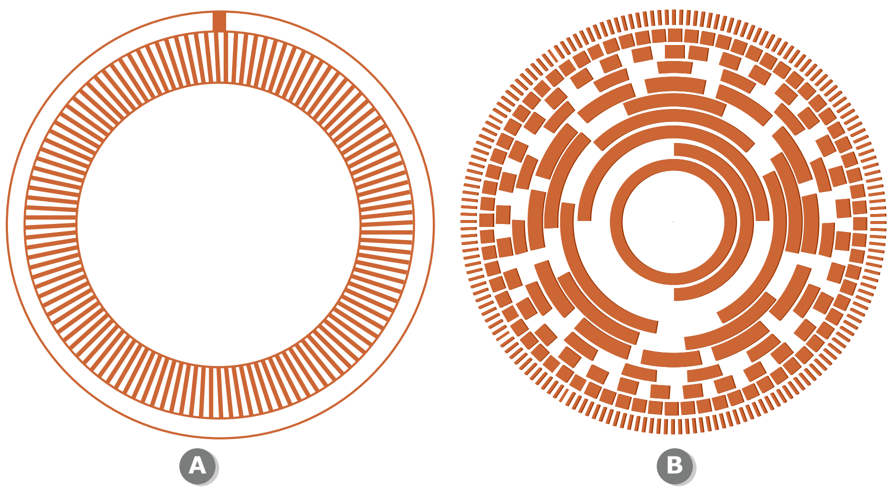
Lecture 4 – Pressure Sensors Pt. 1

Very Basic Digital Noise Reduction

- Remove outliers
- Average the signals
  - Summing N signals results in a resolution improvement of a factor $\sqrt{N}$
  - Provided that measurements are uncorrelated and exhibit Gaussian statistics
  - Must not be quantization limited
    - I.e., you *need* some noise to start with!
    - Note that this is *not* usually true for pickup, which is from a correlated source!
    - Pickup noise can add in phase
      - Linearly!!!
    - L3 BGO story...

Position Encoders

- Displacement
  - Rotary or Linear Potentiometer
  - Linear encoder
    - Optical
    - Magneto-Acoustic
  - Shaft encoders
    - Rotary into Linear w. screw



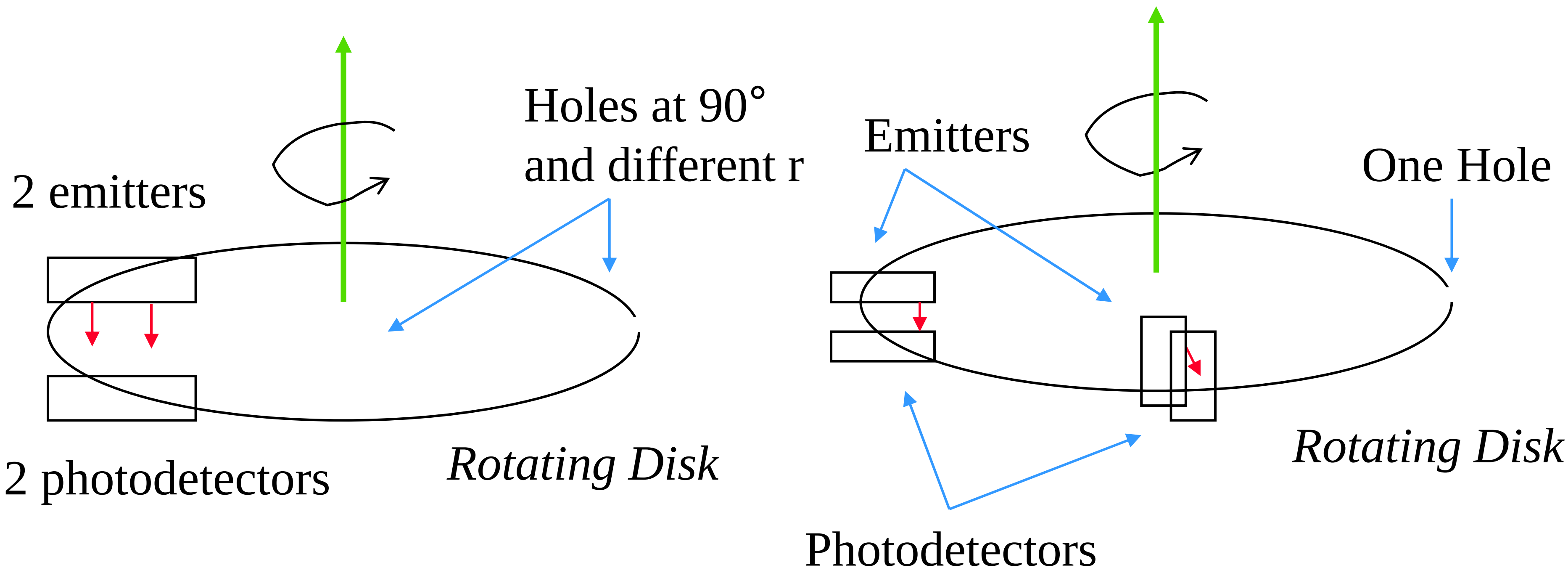
Incremental (A) and absolute (B) optical encoding disks.

Image by MIT OpenCourseWare.

(L) Incremental and (R) optical encoding disks.

Interface:	CANopen
Resolution/Revolution:	16 Bit = 65,536 steps
Revolutions:	up to 14 Bit = 16,384
Code	Binary
Housing Diameter:	58 mm
Shaft:	Full shaft 6 or 10 mm ø / hollow shaft 15 mm ø

Quadrature Encoders Determine Direction



2 Holes and 1 dual optical sensor

1 hole and 2 single optical sensors

One sensor measures “I” and the other measures “Q”
-> Direction determined by whether I leads Q in time or vice-versa

Can be spaced more closely, for rapid direction determination

Linear Encoders

Optical encoders

- Track micro marks
- 100 nm accuracy!
- Film encoders are in cheap printers

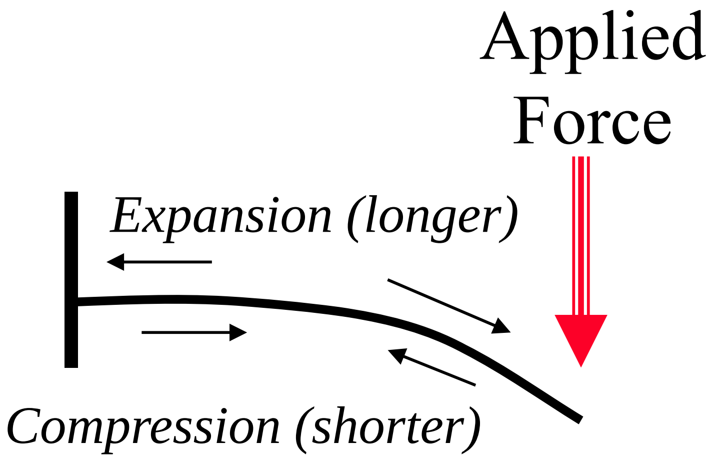
Screen shot of the webpage for Heidenhain Linear Encoders—sealed linear encoders and exposed linear encoders, removed due to copyright restrictions. See: Heidenhain.

Magneto-Acoustic Linear Encoders

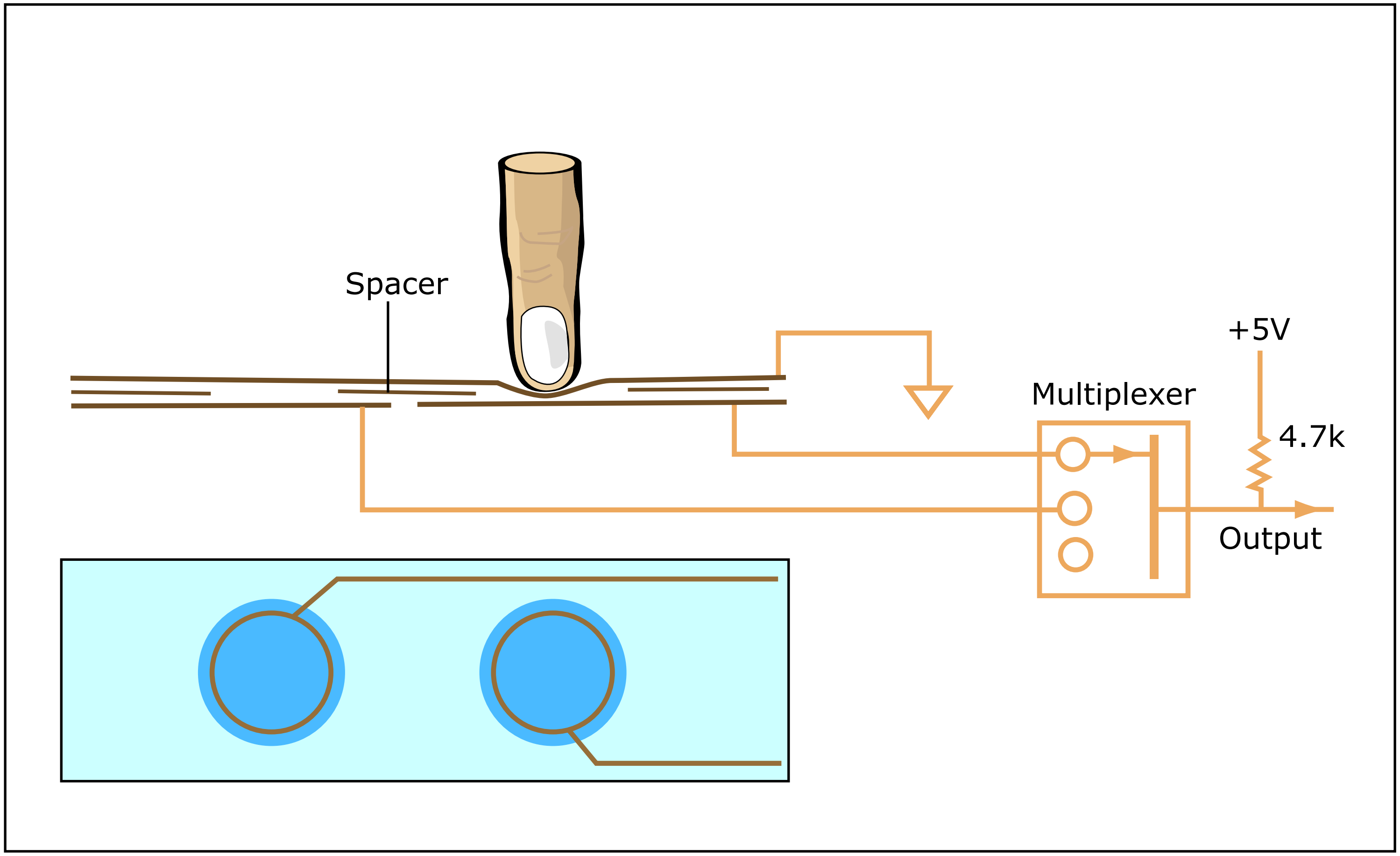
- 1 mil per sample, 9 kHz updates
- Must measure T too!
- MTS Sensors

Pressure

- Displacement into pressure
  - E.g., F = -kx, and P = F/A (force per area)
- Strain into Force
  - Strain is defined by s = ΔL/L
- Piezoresistivity



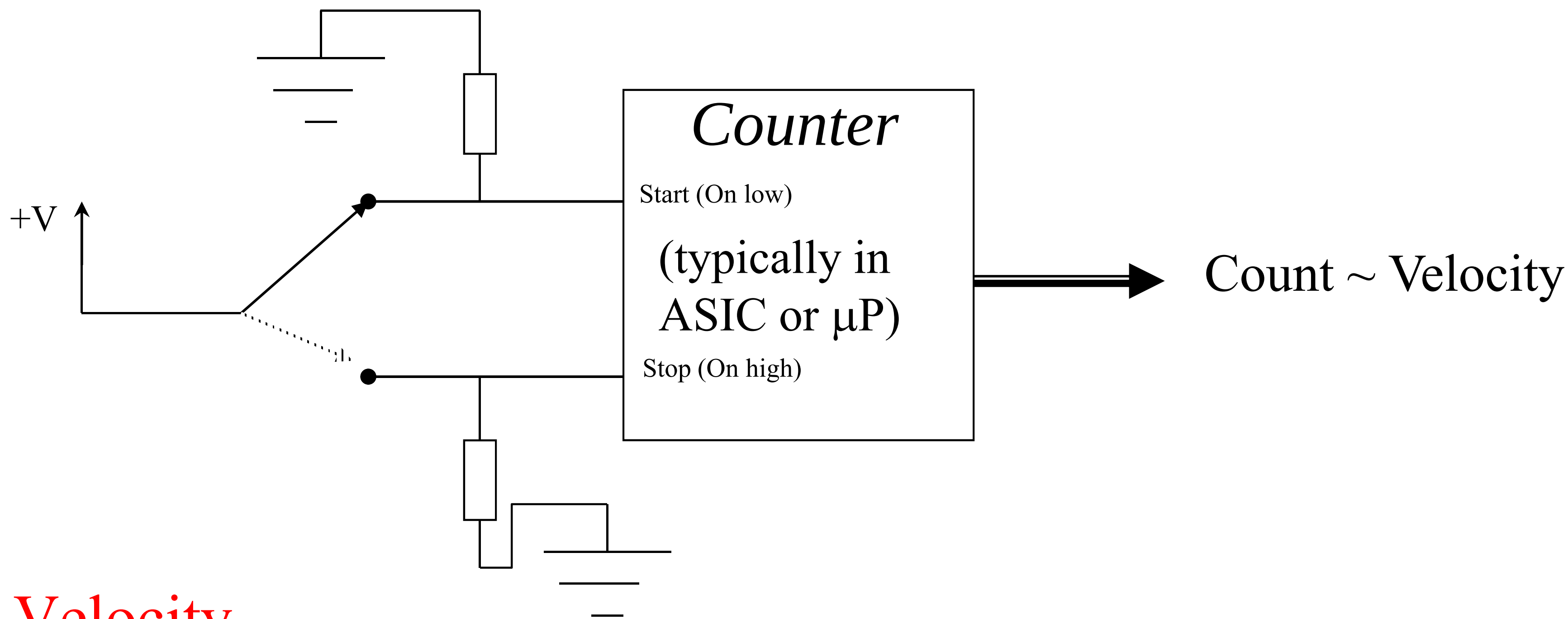
Membrane Switch



A membrane switch being used as a tactile sensor.

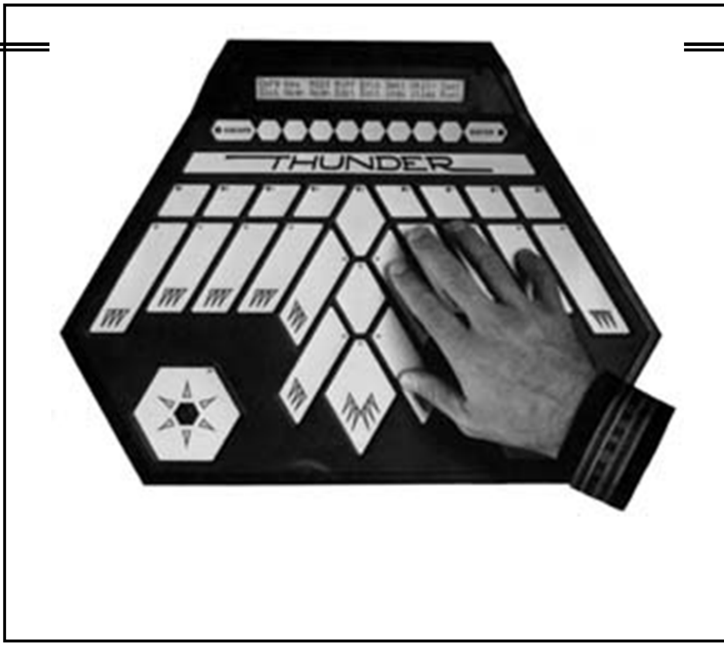
- Commercial – can be printed and snap-assembled
  - Made by ALPS among others (switch floor too)
  - Typically polled in row-column fashion (e.g., drive columns, read rows)

How a MIDI Keyboard Works



- Velocity
  - Measure time difference between key transitions
- Aftertouch
  - FSR underneath keys
    - FSRs were developed for this purpose (Interlink)
  - Poly aftertouch has FSR under each key
  - Mono aftertouch has FSR under key bank

The Buchla Thunder



Courtesy of Buchla. Used with permission.

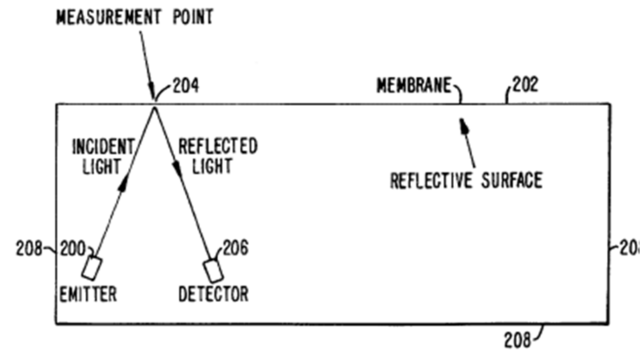
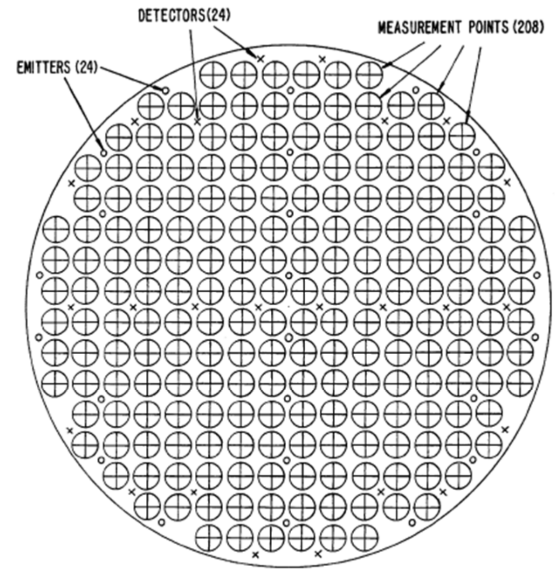


FIG. 2.



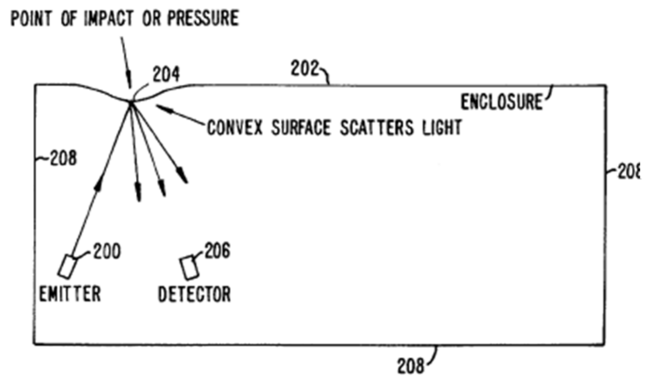
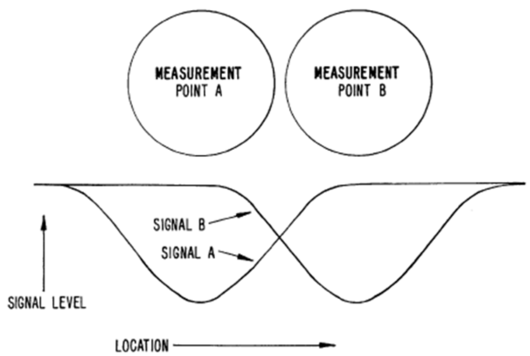
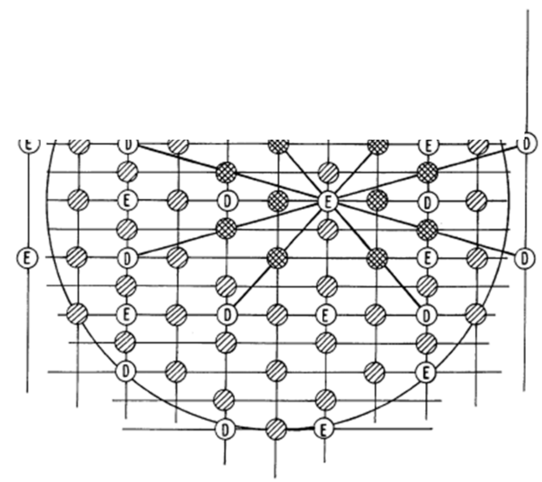


FIG. 3.



US Patent 5,913,260 - June 15, 1999 Donald F. Buchla

System and method for detecting deformation of a membrane



- Thunder 2 Tracks multipoint finger position optically using reflective back of mylar drumhead.
- Thunder 1 used capacitance

Optical Pressure Sensors

Figure 3: Camera view of membrane: (a) undeformed (b) in contact with an object.

- Pressure Profile of deformable dot-matrix fingertip (Hristu, Ferrier & Brockett)

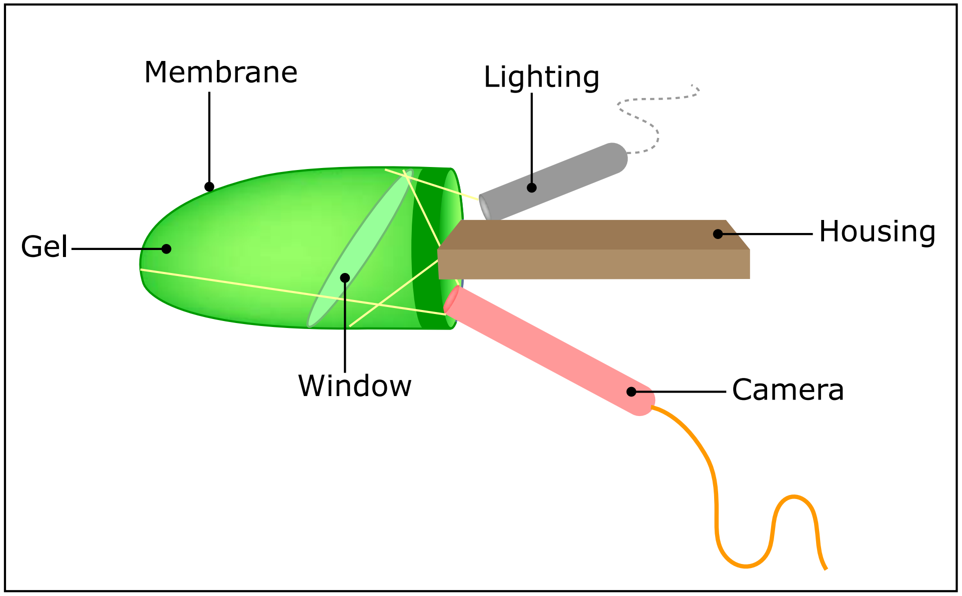
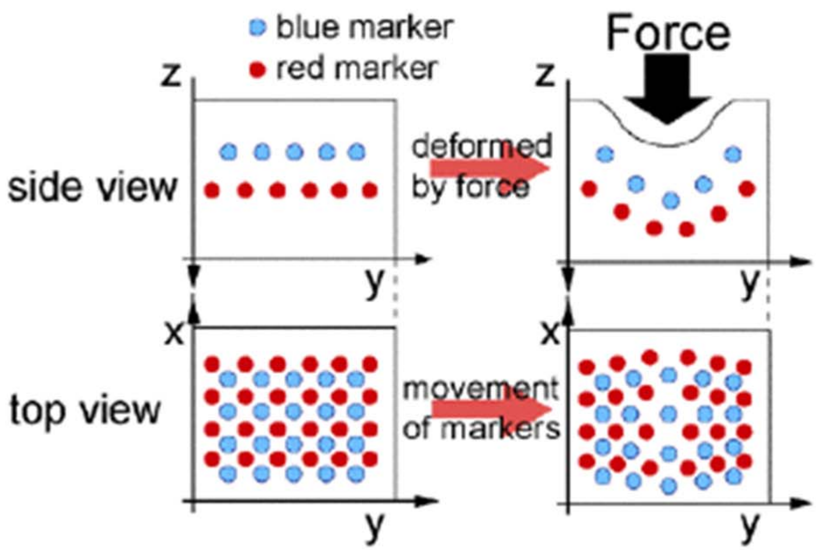
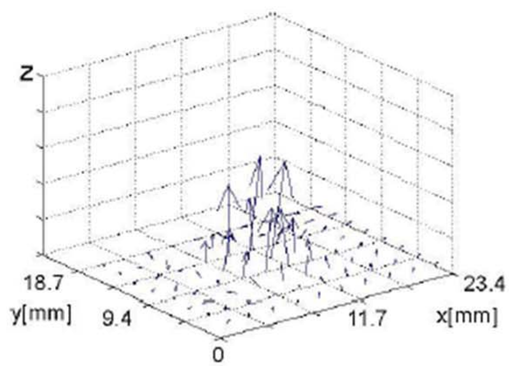
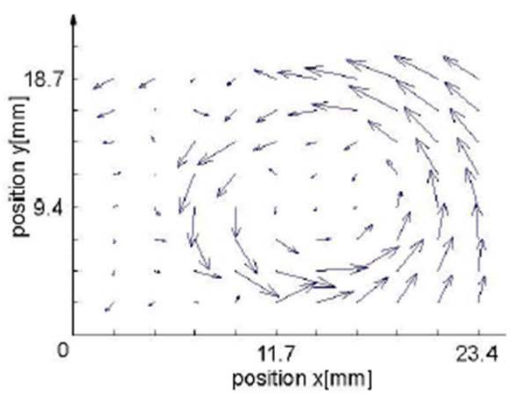


Image by MIT OpenCourseWare.

GelForce (U. Tokyo – Kamiyama et al)







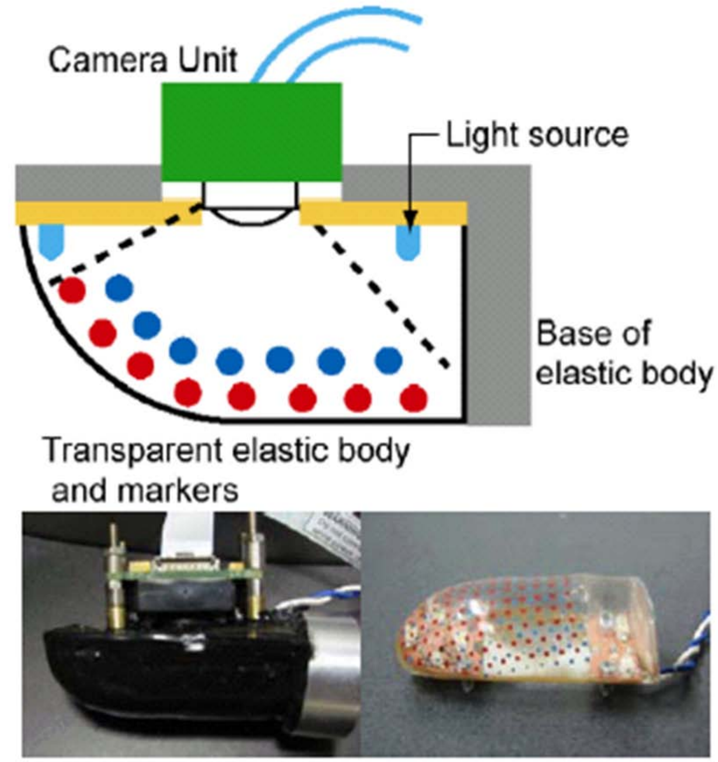


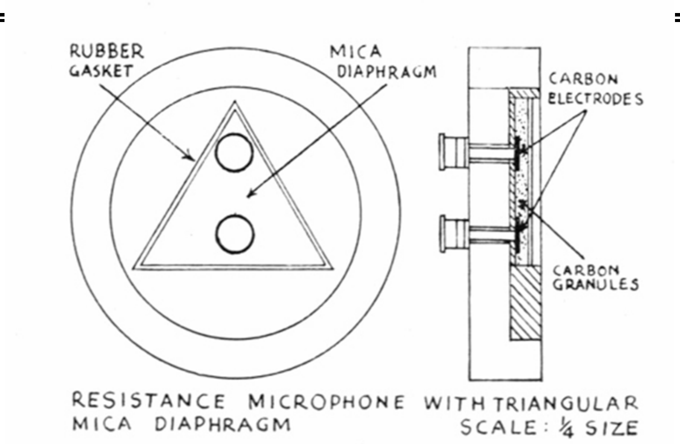
Figure 10: Endowing an robotic finger with the sense of touch

See: YouTube

Dual layers resolve both normal and shear forces – *Derive pressure vector*

The Carbon Microphone – Sonic FSR

1878



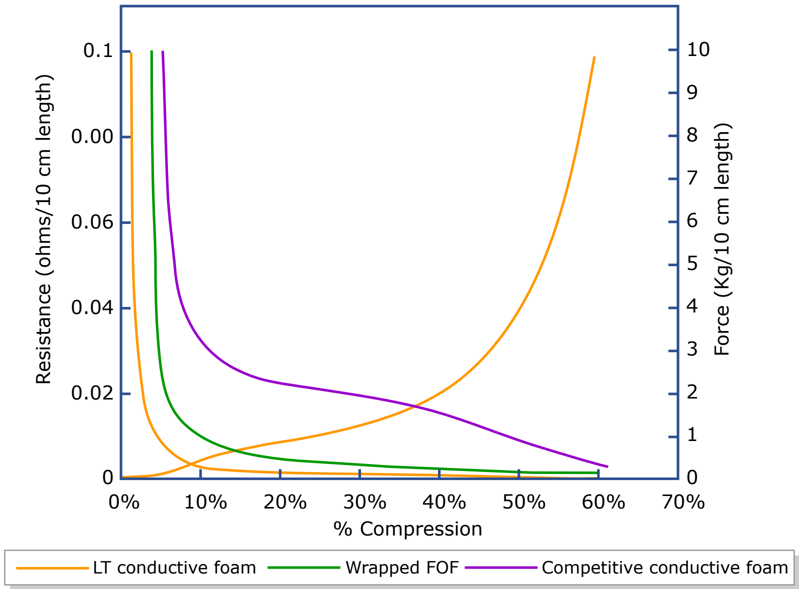
1929

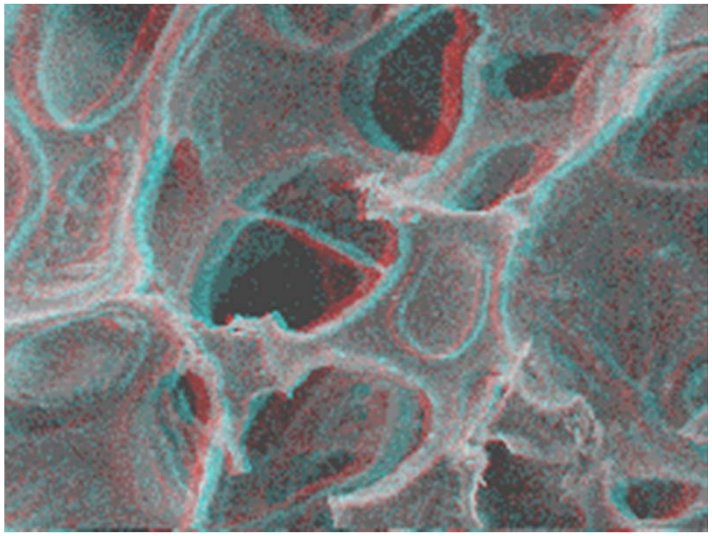
1628 N-1 Type Carbon Microphone

Microphone Characteristics

A. Minimum Sensitivity @ 1 kHz with 85 mA(DC) Applied Current: 38 dBmV
B. Impedance Range: 15-60 ohms

Conductive Foam





Standard (3D!)

Metalized

Resistive (conductive) Elastomers

Image of a freshly made polymer sensor removed due to copyright restrictions.
See 'ForSE FIElds' - Force Sensors For Interactive Environments.

Early Z-Tiles from the University of Limerick

McElligott, L., et al, 'ForSe FIElds' - Force Sensors for Interactive Environments," in UbiComp 2002

- Carbon or silver-loaded silicone rubber
- Dynamic range limits, hysteresis, longevity…
- Commercial conductive rubber from:
  - "Zoflex" from Xilor, inc. (rfmicrolink.com)

See: Koehly et al, "Paper FSRs and Latex/Fabric Traction Sensors: Methods for the Development of Home-Made Touch Sensors," Proc. Of NIME 06

Force Sensitive Resistors

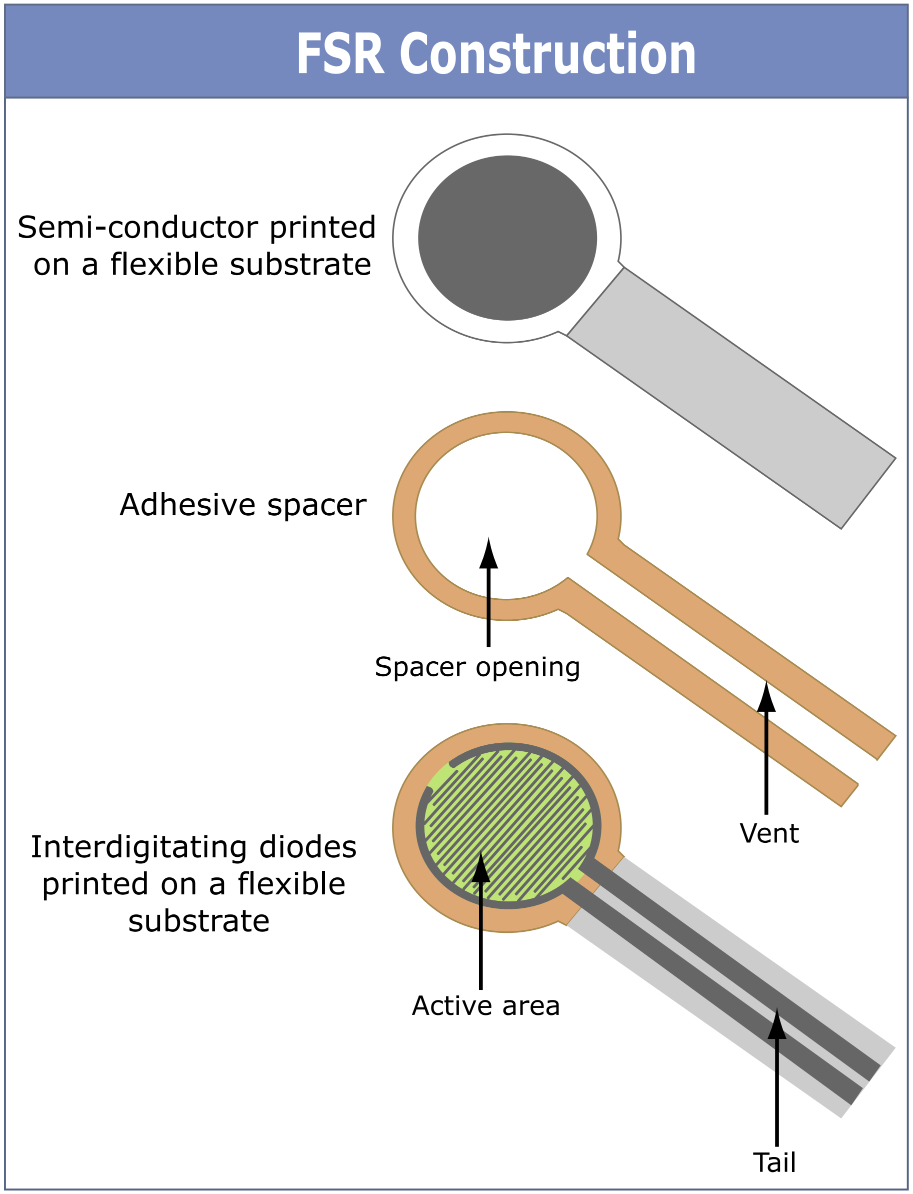
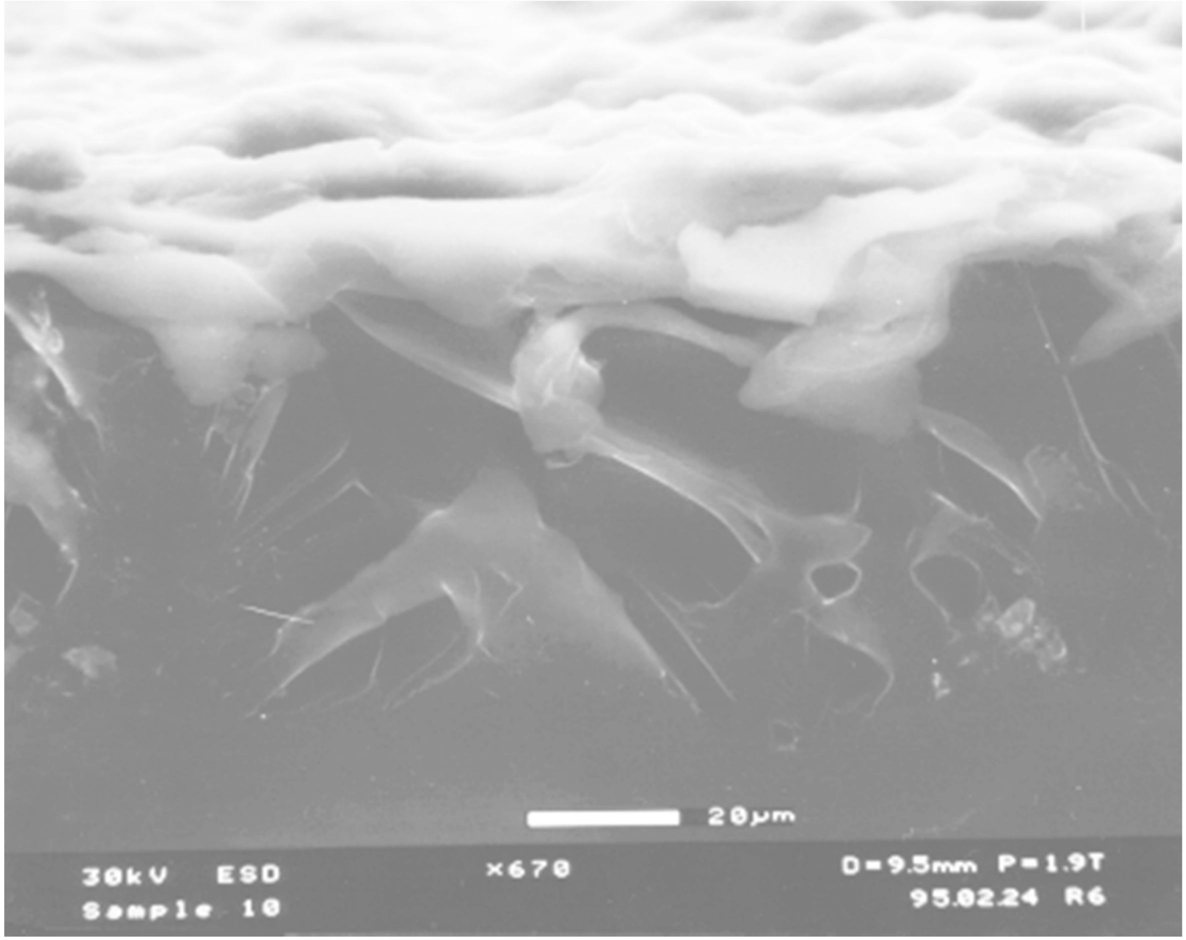


Image by MIT OpenCourseWare.

- Composite structure
  - Top, ink, electrodes
    - Flat, but can be fragile to shear force (delamination) and sensitive to bend

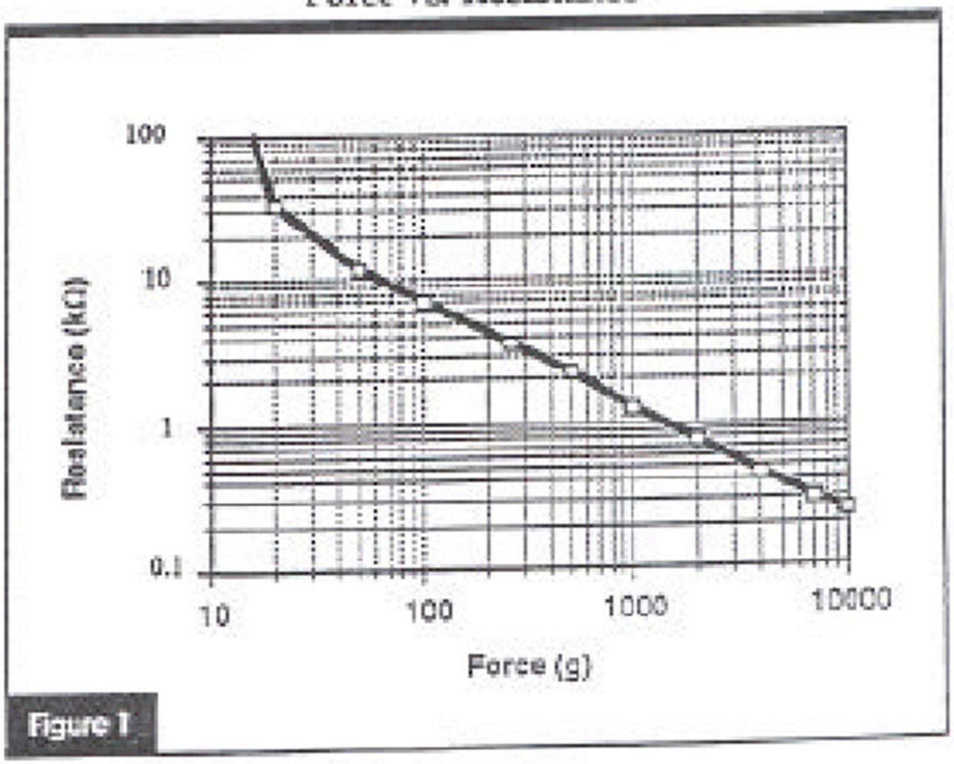
Conductive Polymers and FSR's



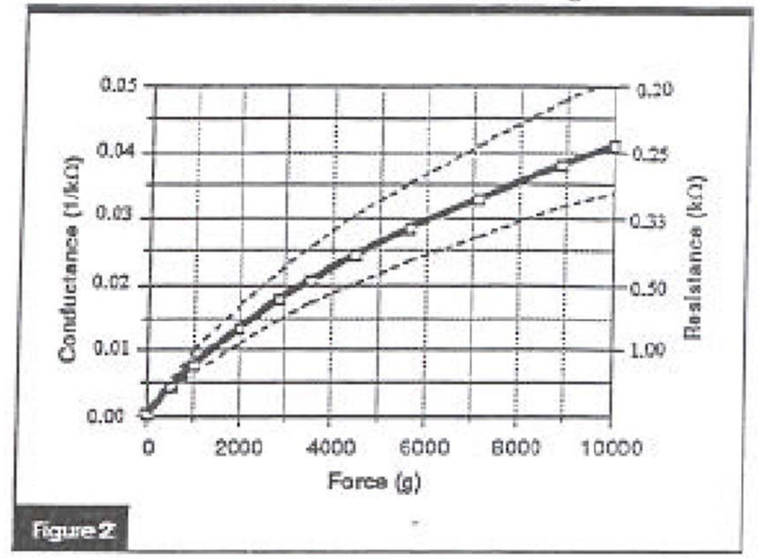
- Microphotograph, showing conductive ink and metalization from Interlink FSR

FSR Characteristics

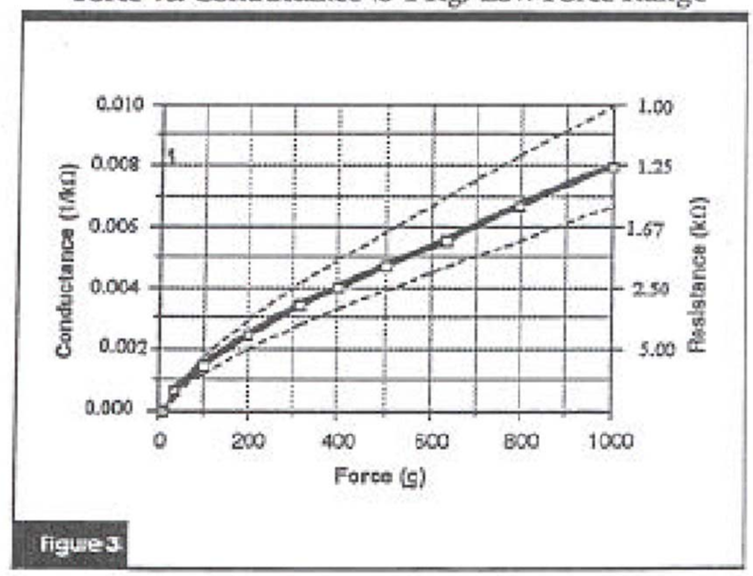
Force vs. Resistance



Force vs. Conductance (0-10 Kg)

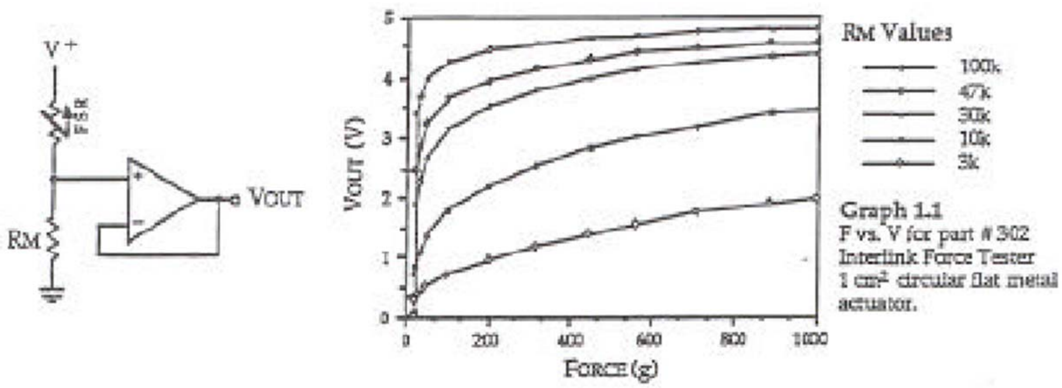


Force vs. Conductance (0-1 Kg) Low Force Range

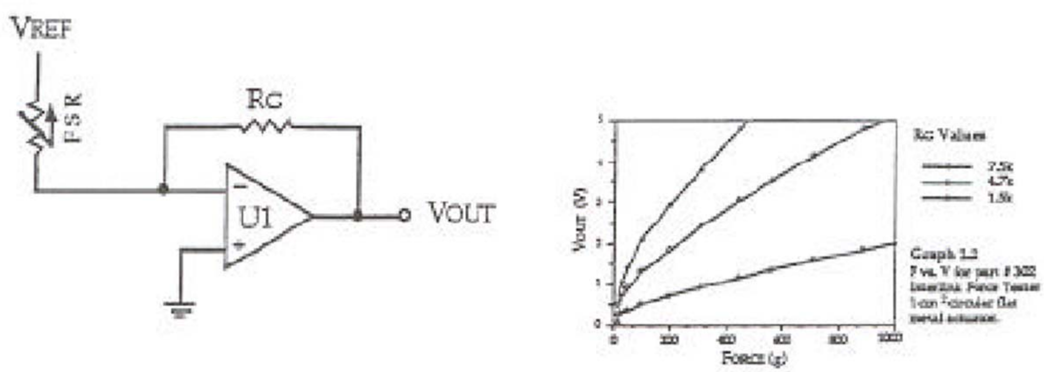


- 3-4 decades of sensitivity, 0.01 - 100 PSI, hundreds of Ω to 10 Meg Ω
  - Depending on device & Manufacturer
  - "---" is part-part repeatability bound
    - Typically ±15% - ±25% for Interlink
  - Sensitive to temperature, humidity…

FSR Interface Circuits



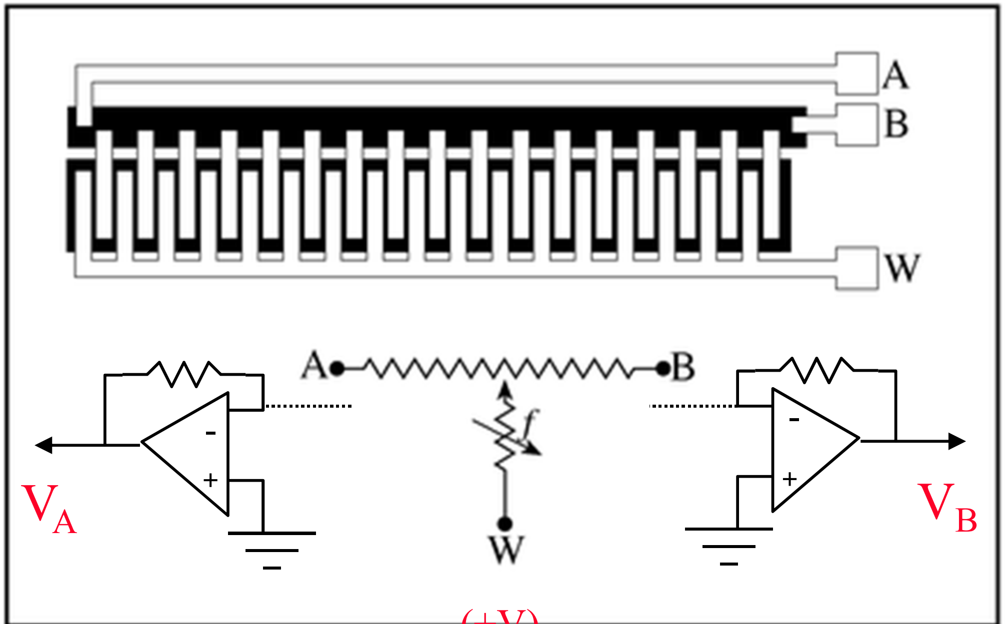
Voltage Divider

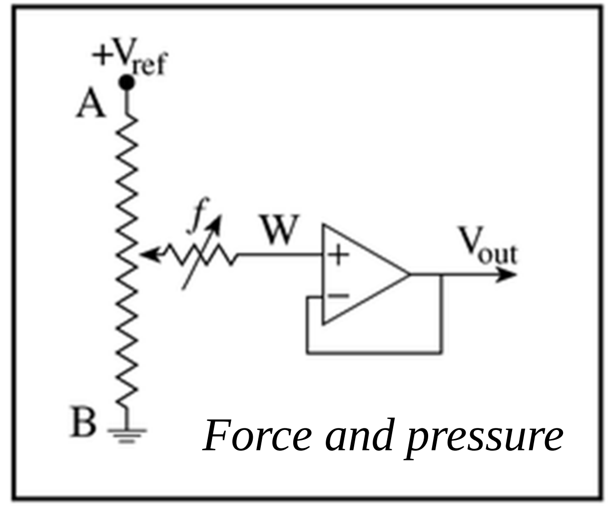


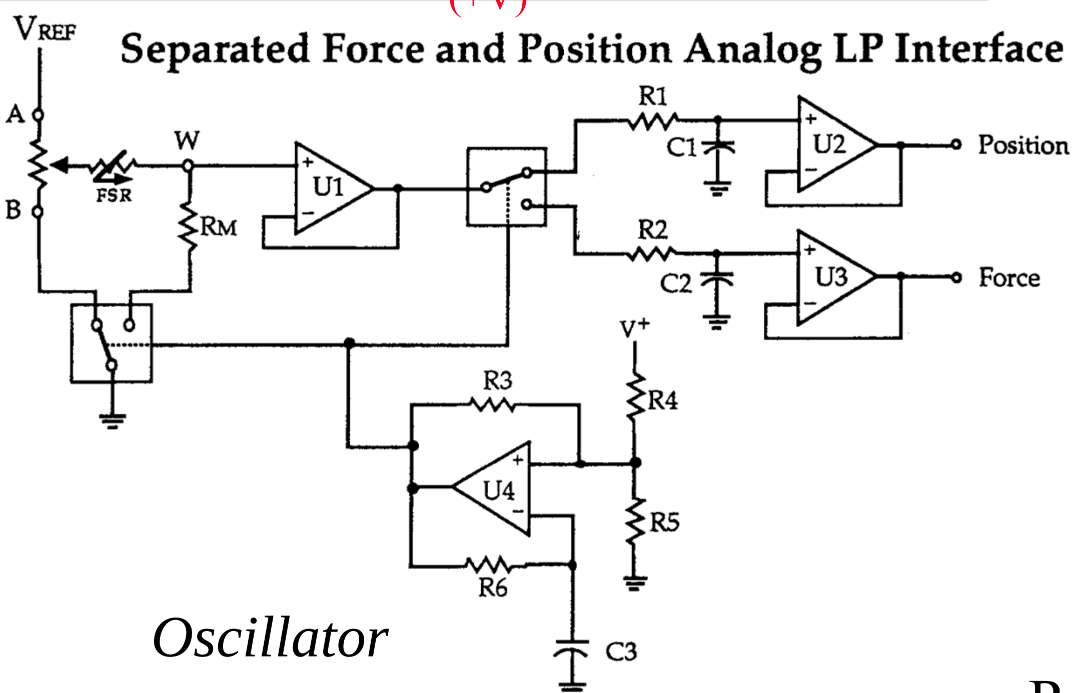
Current-to-Voltage

- Voltage Divider
  - Very nonlinear; switch characteristic
  - Only buffer needed
- Current Mode
  - Smoother range but (Less headroom)
  - Transimpedance amp

The FSR Potentiometer







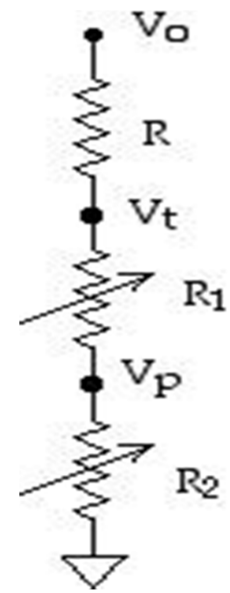
Can also inject voltage into W and have transimpedance amplifiers at A and B

Position is:

$(V_A - V_B)/(V_A + V_B)$

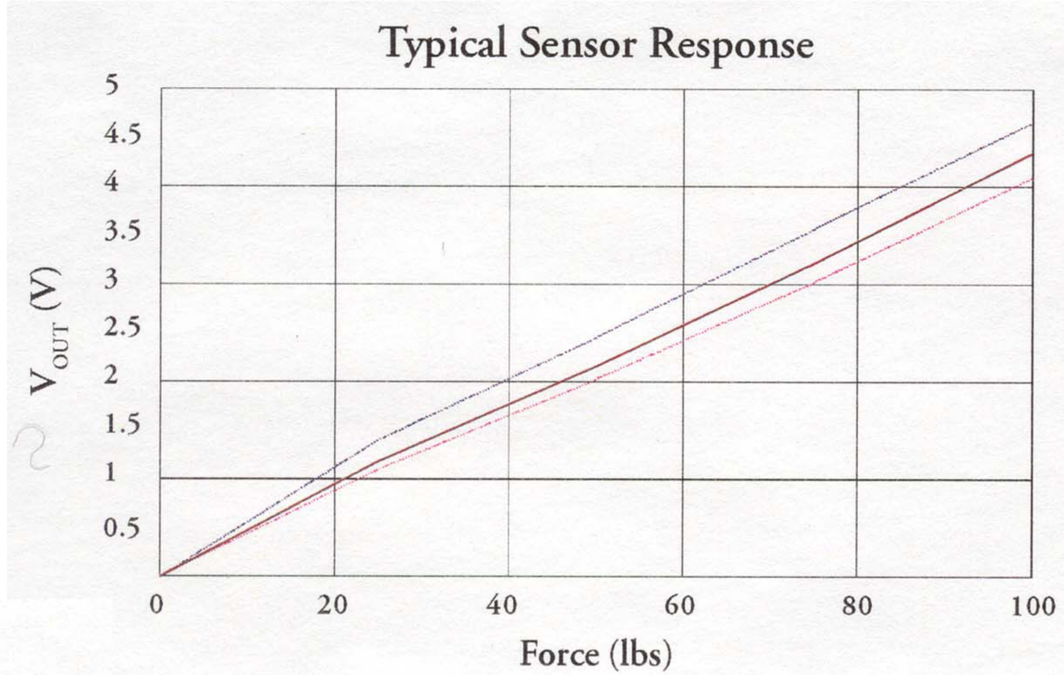
and Force becomes:

$V_A + V_B$



Ratiometric? From Rob Poor?

The FlexiForce (from TekScan)



Performance

Linearity (Error)	< ±5%
Repeatability	< ±2.5% F.S.
Hysteresis	< 4.5 % F.S.
Drift	< 3%/ Logarithmic Time
Rise Time	< 20 μsec

Typical Response

Force Ranges	1 lb. (4.4 N)
	25 lb. (110 N)
	100 lb. (440 N)
	500 lb. (2200 N)
	1000 lb. (4400 N)

Tekscan Specs

Table 1. Specifications of Representative Tactile Sensors

	Human Skin [i]	Fingerprint Imaging Sensor [vii]	Smart Skin
Resolution (mm)	2	0.1	0.1-10
Sensor Area (mm^2)	25x25	13x20	10^2–10^7
Number of Sensels	10^2	~10^4	10^2–10^6
Sensel Force Range (N)	0.4-10	switch	0.05-100
Linearity	Moderate	-	High
Hysteresis	Low	-	Very Low
Compliance	Yes	No	Yes
Bandwidth (Hz)	100	~10	100
Operating Temperature (°C)	-20 to 60	-10 to 45	-40 to 100

Robustness?

Force Imaging

Pressure images by Ken Perlin have been removed due to copyright restrictions.

Car driving over force imaging plate

Hong Tan, Purdue

They do chair seats and beds too...

Ken Perlin/NYU make transparent "interpolating" FSRs

QTC Pressure Sensors

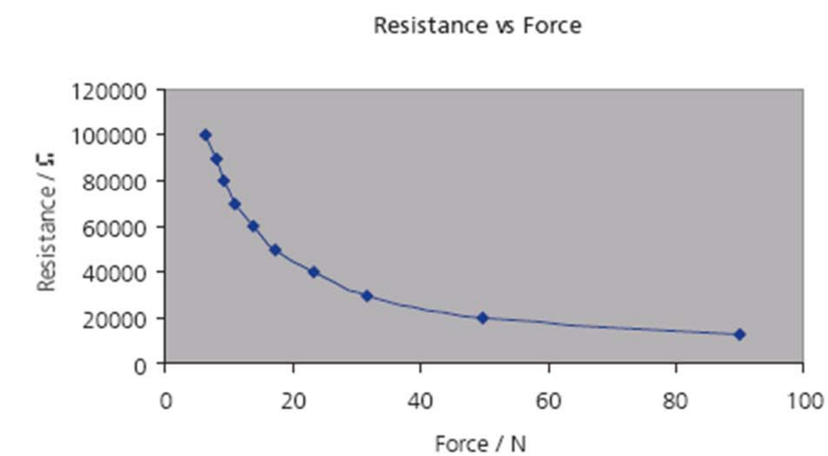
- Made by Peratech in the UK
- Quantum Tunneling Composites
- Metal-filled polymers, no direct conductive path
  - Current flows via quantum tunneling (AC readout w. capacitance?)
  - More tunneling (hence current) with more pressure
  - No zero-point deadband, smoother response, more durability (maybe)

SPECIFICATIONS

	QSRC025050	QSRC025130	QSSC025400
Dimensions			
Form Factor	Circular	Circular	Square
Active Area	5mm	13mm	40mm
Lead Length	35mm	35mm	35mm
Thickness	1mm	1mm	1mm
Electrical			
Stand-off resistance[1]	10^8 ohms	10^8 ohms	10^8 ohms
Force sensitivity range[2]	0 N - 100 N	0 N - 100 N	0 N - 100 N
Part-to-part force repeatability[3]	±10%	±10%	±10%
Single part force repeatability[3]	±2%	±2%	±2%
Force resolution	0.5%	0.5%	0.5%
Max current	100μA/cm²	100μA/cm²	100μA/cm²
Environmental			
Temperature Range	-30°C to 100°C	-30°C to 100°C	-30°C to 100°C
Humidity	0% - 100%	0% - 100%	0% - 100%
Lifetime	> 1M cycles at 10N	> 1M cycles at 10N	> 1M cycles at 10N

1. Unloaded, unbent
2. Dependent on mechanics
3. With repeatable actuation system

SENSING PERFORMANCE



FSR Bendy Sensors

The Flex Sensor is a unique component that changes resistence when bent. An unflexed sensor has a nominal resistance of 10,000 ohms (10 K). As the flex sensor is bent the resistance gradually increases. When the sensor is bent at 90 degress its resistance will range between 30-40 K ohms.

The sensor measures 1/4 inch wide, 4 1/2 inches long and only .019 inches thick!

Available from the Images Co. (for PowerGlove - made by "Abrams-Gentile)

High-end versions made by Immersion for their CyberGlove
- 0.5° resolution, 1° repeatability, 0.6% max nonlinearity, 2-cm min bend radius

These only measure bend in one dimension (expanding the FSR's on surface)
- Conduction saturates quickly when contracted
- Can measure bidirectional bend with 2 FSR's back-to-back (and diff amp)

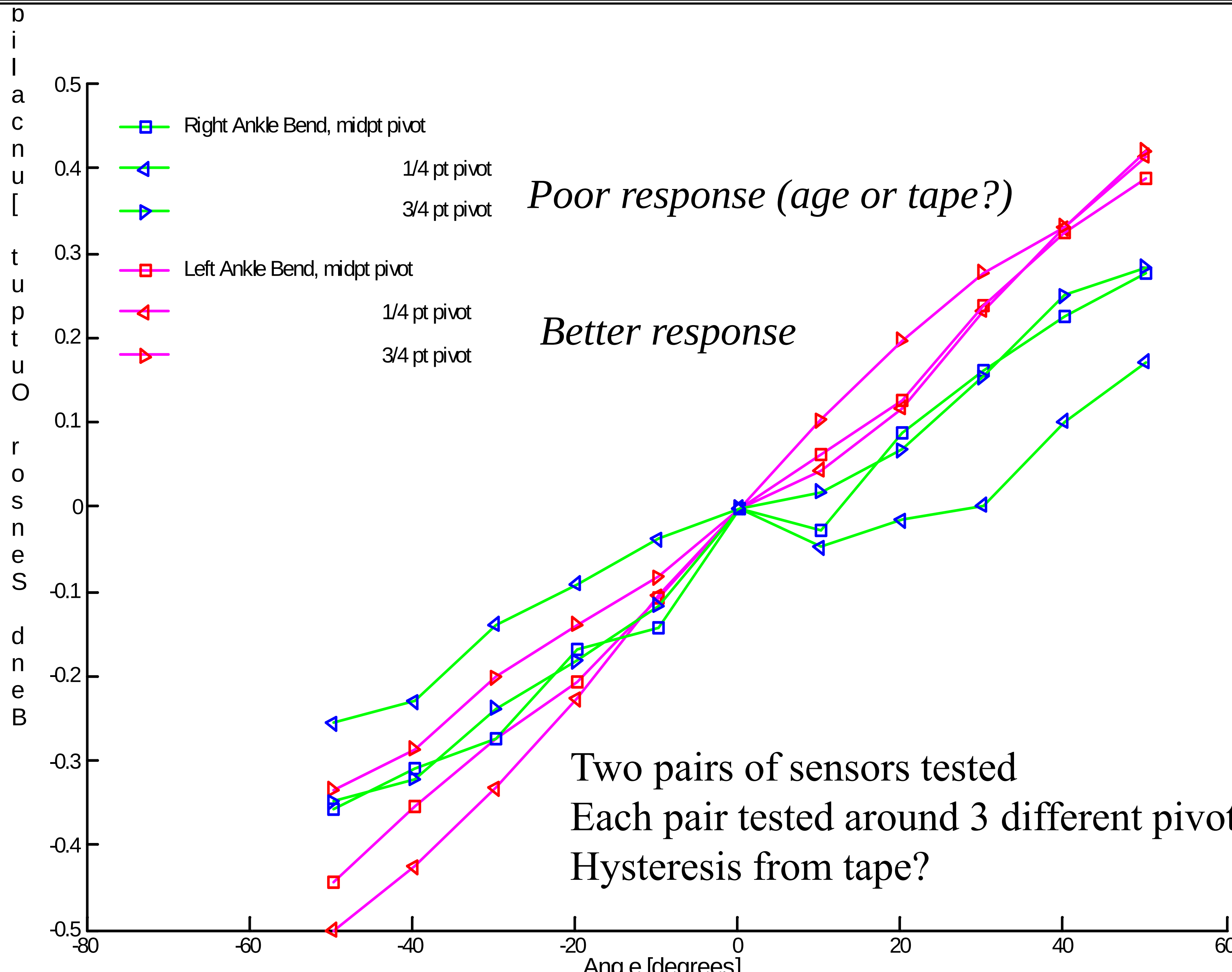
Resolution and Calibration Tests (from Stacy Morris '04)

Bend Sensor calibration
Pin Bendy Sensor with Batteries and bend according to printed protractor

Images removed due to copyright restrictions.

FSR calibration
Apply known pressure via rubber bumper with materials tester

Abrams-Gentile (used) Bend Sensor Pairs into differential amp for bidirectional bend sensing



Stretchy FSR "strain sensors"

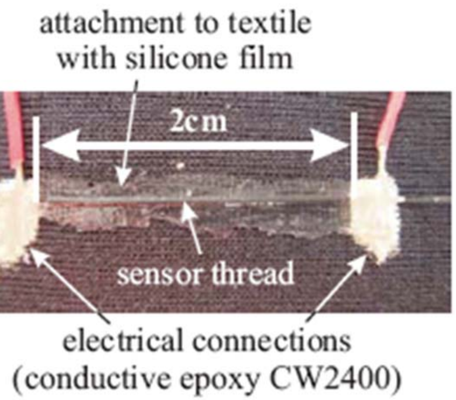


Figure 2. Sensor thread attached to the textile with a silicone film.

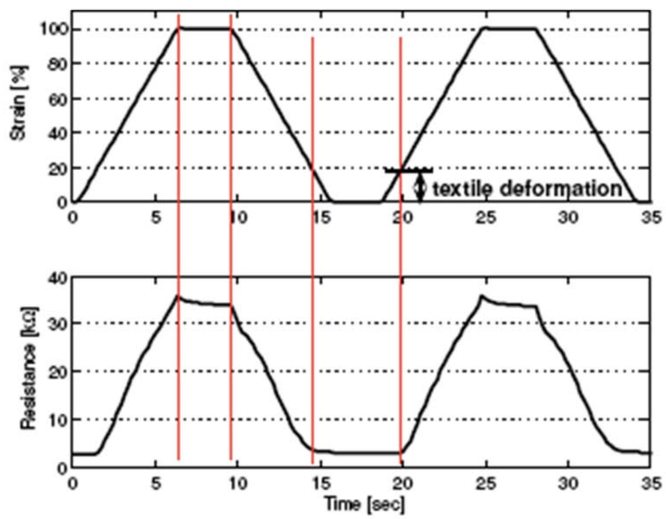
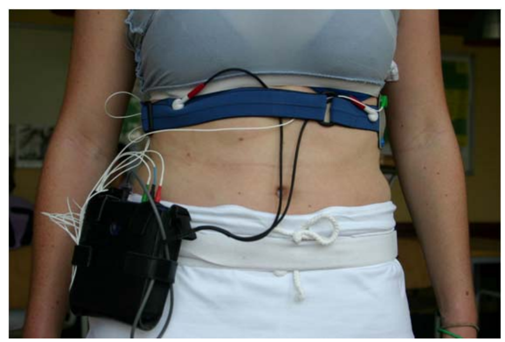
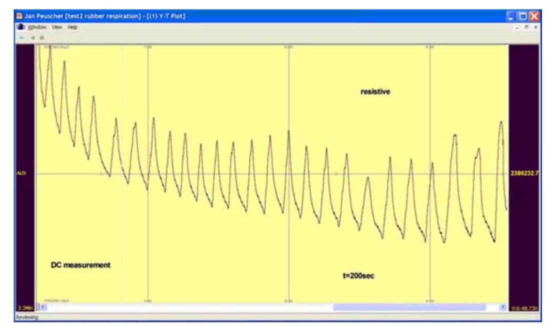


Figure 3. Typical response of sensor to a given strain (sensor length 2cm).

Recognizing Upper Body Postures using Textile Strain Sensors
Corinne Mattmann, Oliver Amft, Holger Harms, Gerhard Tröster, and Frank Clemens (ETH Zurich) - Proc. Of ISWC 2007

"A novel strain sensor was used which was developed by EMPA, Switzerland [12]. The sensor thread consists of a commercial thermoplastic elastomer (TPE) filled with 50wt-% carbon black powder and changes resistivity with length. It is fiber-shaped with a diameter of 0.3mm and has, therefore, the potential to be fully integrated into textile. In this prototype setup, the sensor was attached with a silicone film (see Fig. 2) which enables a measurement range of 100% strain. The length of the sensor was chosen to be 2cm."





TMS International - breathing belts (resistive)

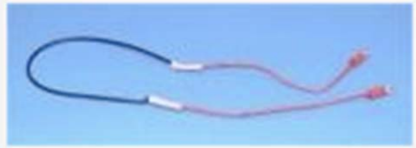
http://www.tmsi.com

More on fabric-compatible sensors in Bio Lecture…

Merlin Stretch Sensors…

Merlin Stretch Sensor

The Merlin Stretch Sensor uses the latest 'Smart' material technology to give a uniquely flexible sensor, that can literally take measurements bent around corners or be woven into fabric.



enlarge

- Flexible sensor, bends around corners!
- Small form factor - 2mm Cord
- Economical

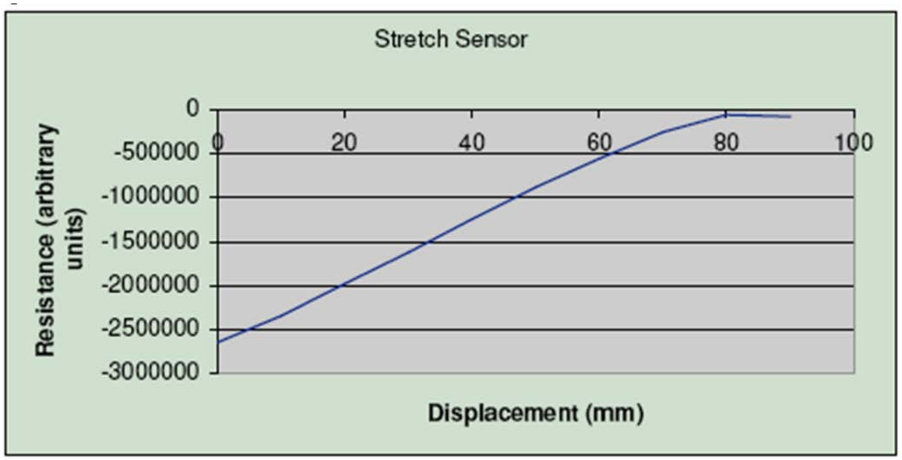
What is it?

The Stretch Sensor is a flexible cylindrical cord with spade electrical fixings at each end. The sensor behaves like a variable resistor, the more you stretch it the higher the resistance.

How does it work?

As the length of the Stretch Sensor alters so does it's resistance. For each centimeter of length change there is a resistance change of approximatly 400 Ohms/cm.

Comercial stretchy resistive sensor



http://www.merlinrobotics.co.uk