MAS836 – Sensor Technologies for Interactive Environments

Lecture 7 – Capacitive Applications and Magnetic Sensing

Readings…

- See Baxter and Fraden
- Lots of readings posted on Stellar Refs and old ResEnv class site
  - https://resenv.media.mit.edu/classarchive/MAS836/
- These too:
  - https://www.eetimes.com/document.asp?doc_id=1279563#
  - http://multimedia.3m.com/mws/media/788463O/tech-brief-projected-capacitive-technology.pdf
  - Anthony Gray, 'Projected Capacitive Touch', Springer 2019

Capacitive Slider for Ceran Cooktop

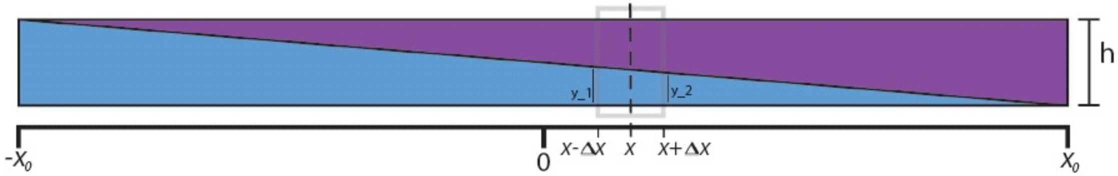
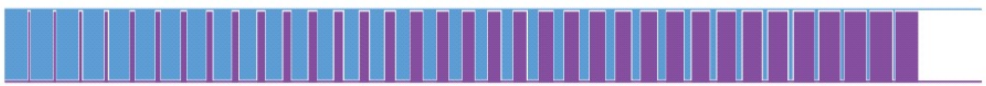


Figure 1: Idealized Geometry

Interdigitated Geometry



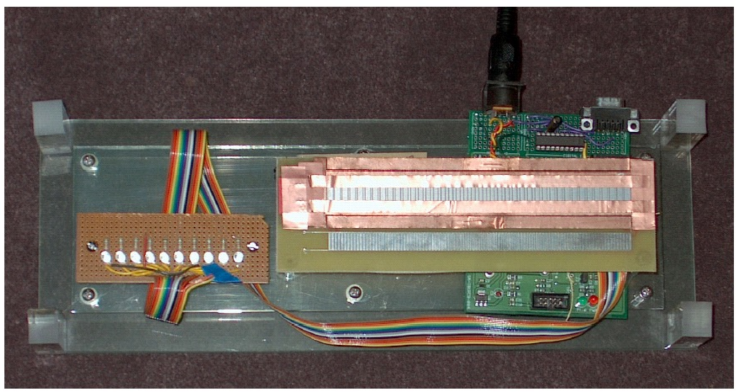
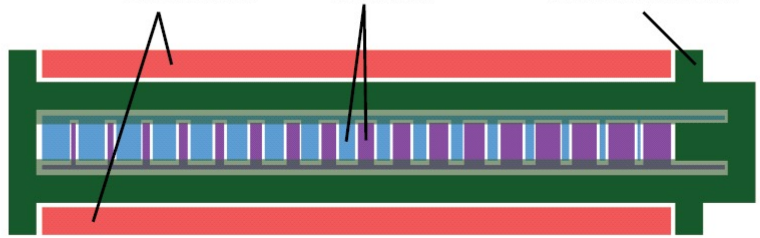
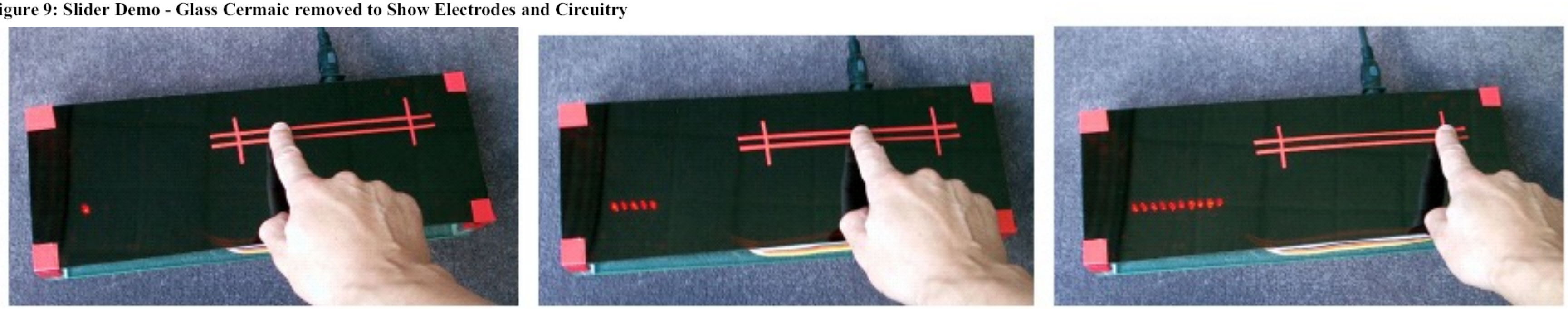


Figure 9: Slider Demo - Glass Cermaic removed to Show Electrodes and Circuitry



Shielded electrodes (compensate finger roll effects)

Lance Borque



https://resenv.media.mit.edu/#Projects#sensate-cooktops

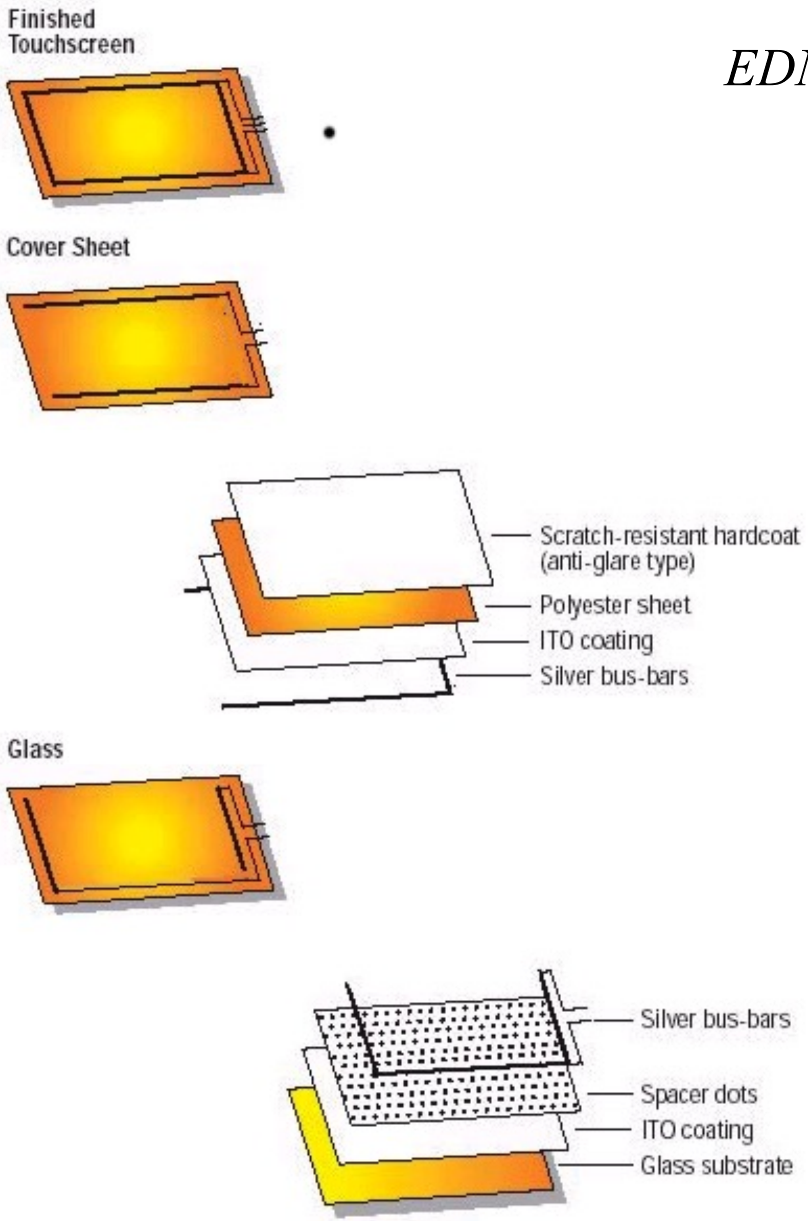
Touch Screen Types

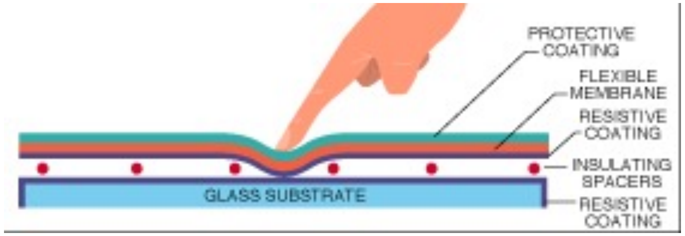
TABLE 1 -- TOUCHSCREEN COMPONENT SUPPLIERS

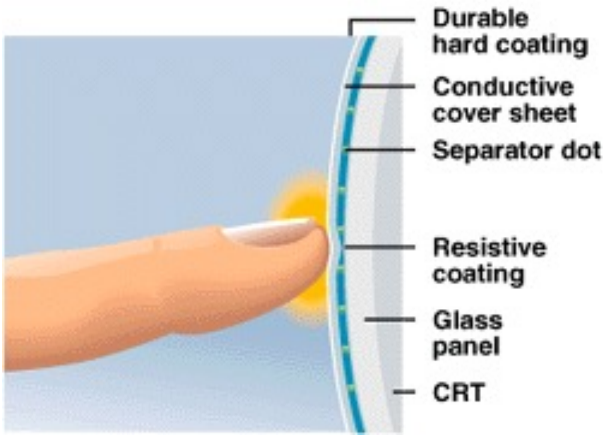
Company	*Resistive*		*Capacitive*		*Acoustic*		*IR*	*Platform*
	Four-wire	*Five-wire*	*Analog*	*Projected*	*SAW*	*GAW*		
Carrol Touch						X	X	
Computer Dynamics Inc.						X	X	
Dynapro Technology		X						
Elo Touchsystems		X			X			
MicroTouch Systems Inc.		X	X (with pen)	X				X
Philips Semiconductor			X (with pen)					
Symbios Logic			X (with pen)					

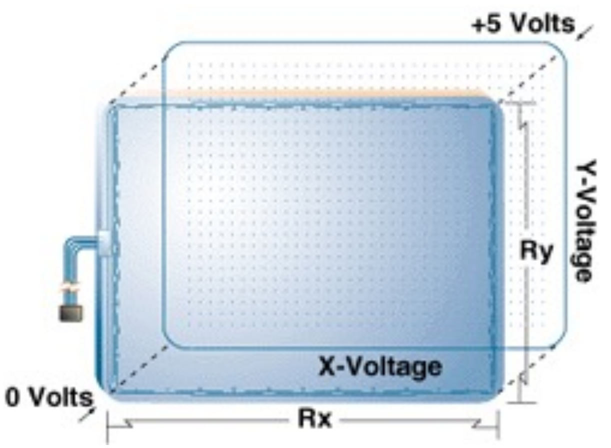
Resistive Touch Screens

EDN

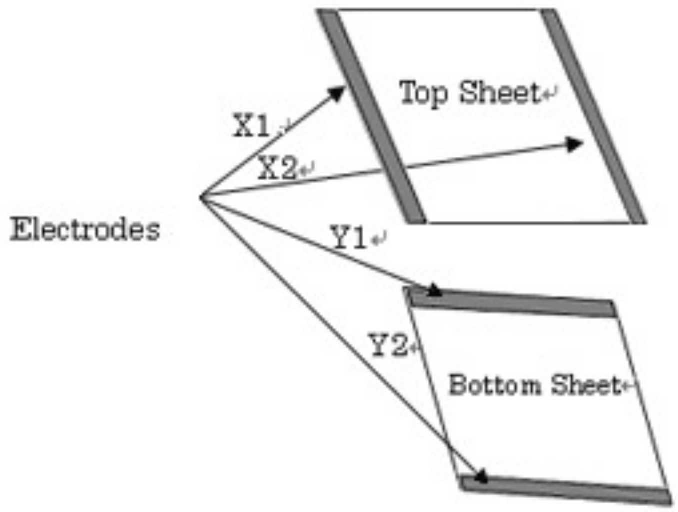




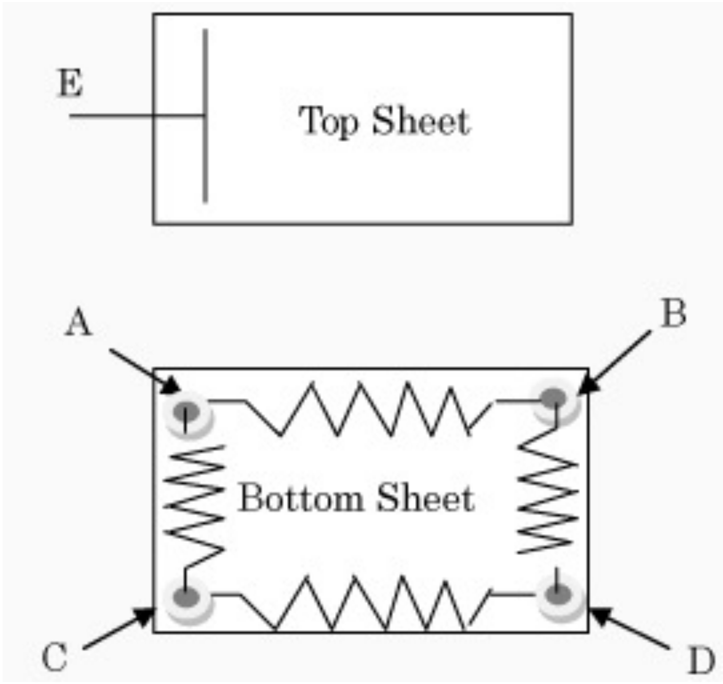




4-vs-5-wire resistive touch screens



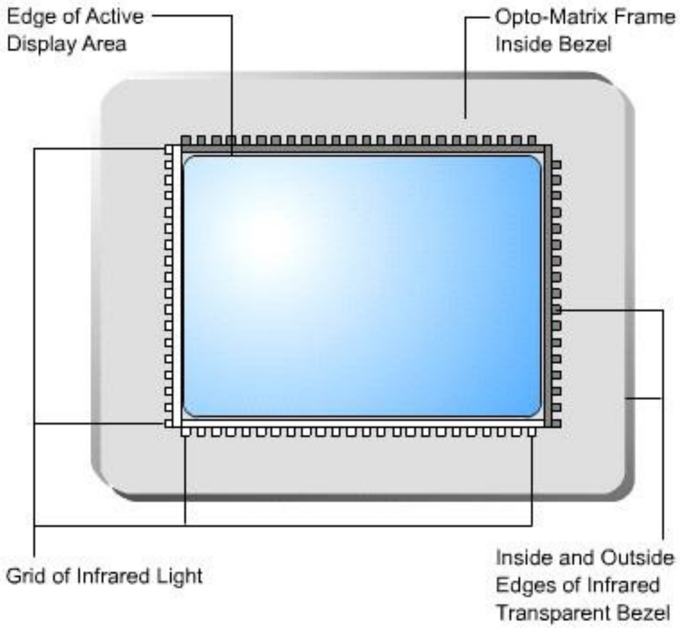
4-wire

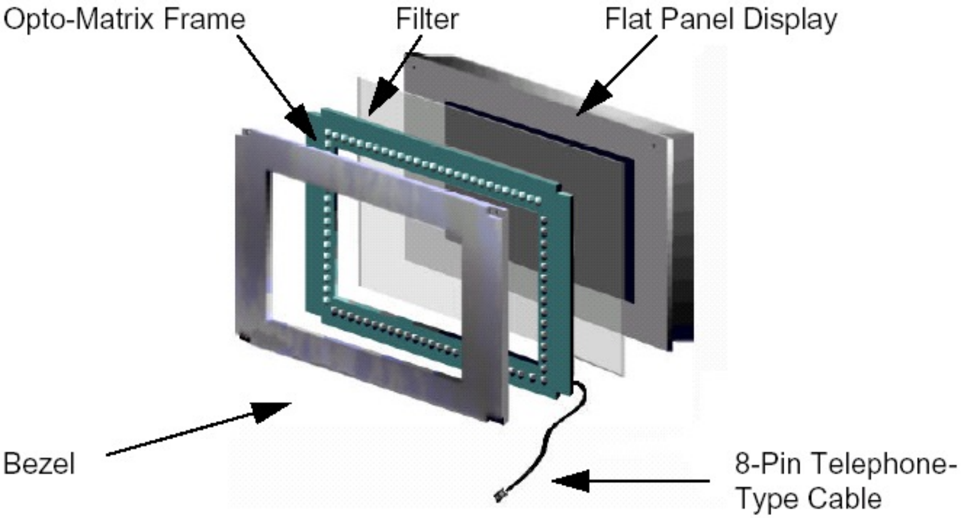


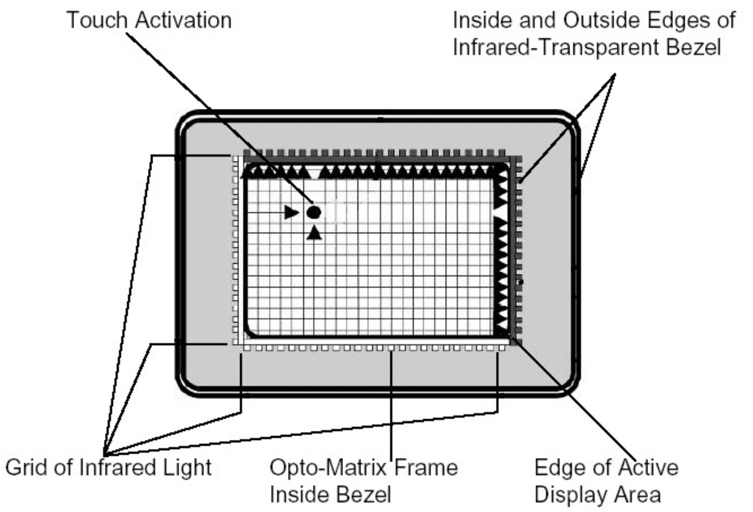
5-wire

https://www.dmccoltd.com/en/museum/touchscreens/technologies/

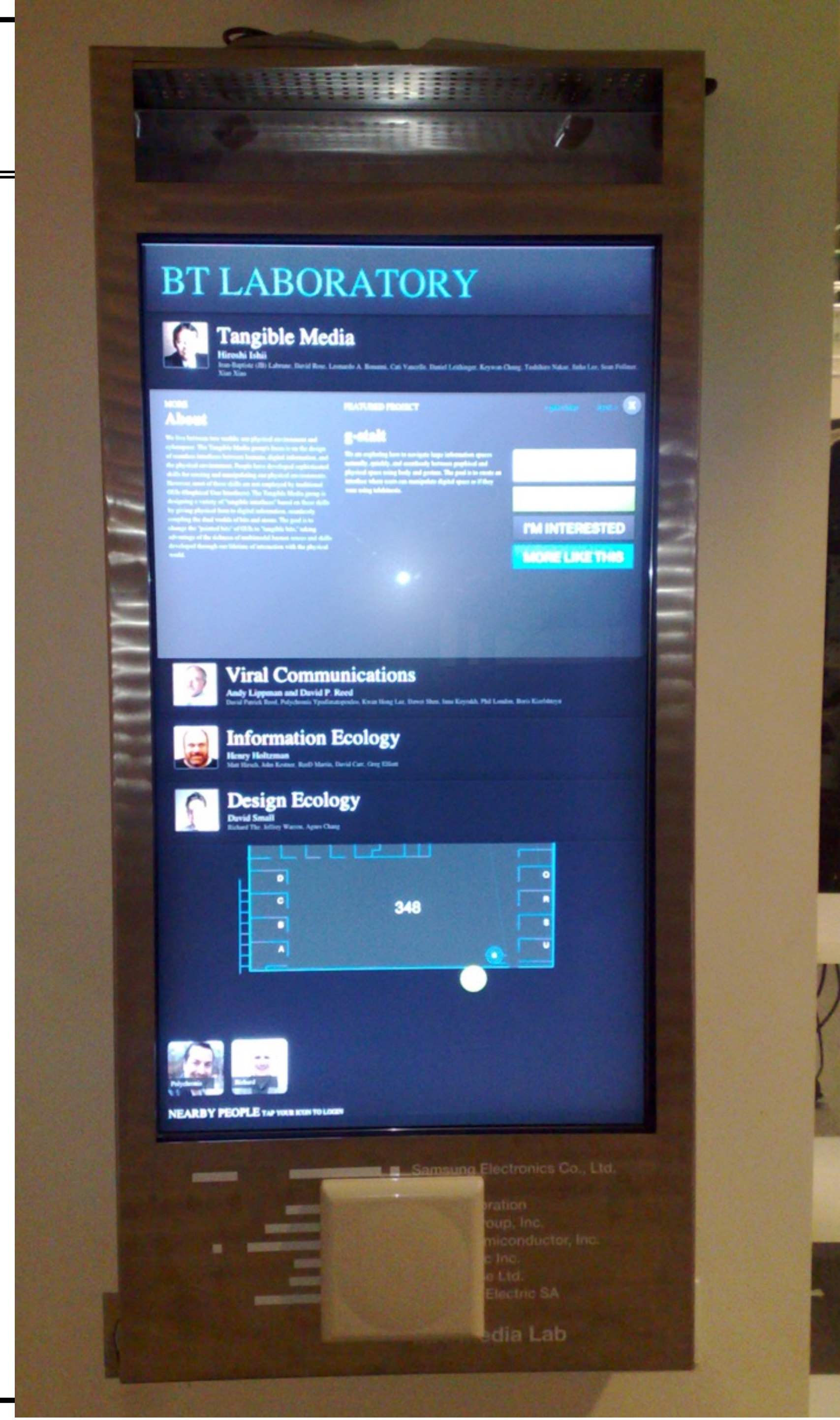
IR Touch Screens



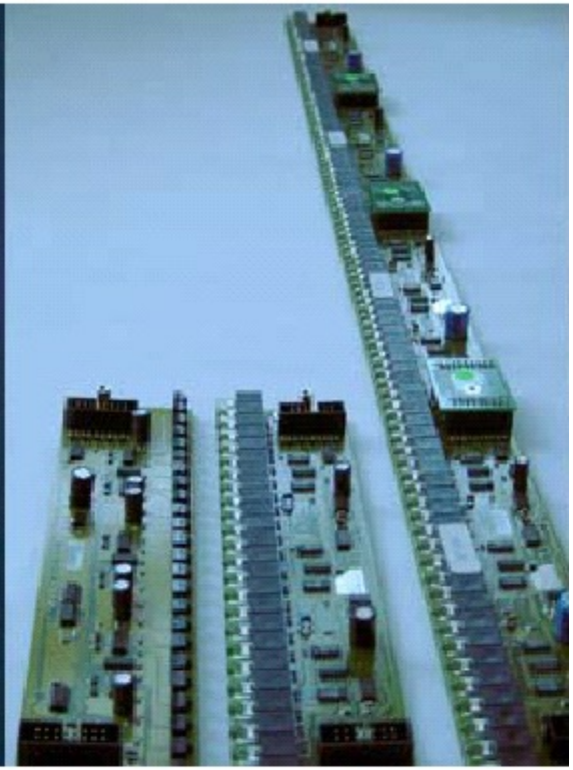




- These work that way



Larger version for the I-Tube



- Oliver Irschitz & Peyote Systems, Vienna

Musical Interactive Surfaces

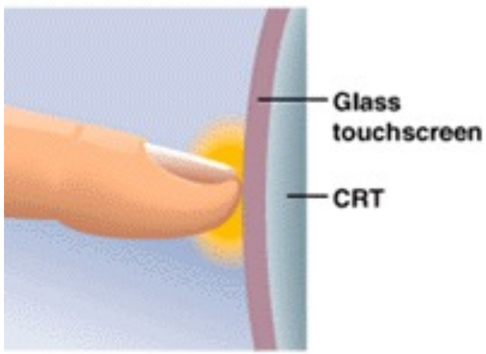
Bernard Szajner
LaserHarp
Light Curtain

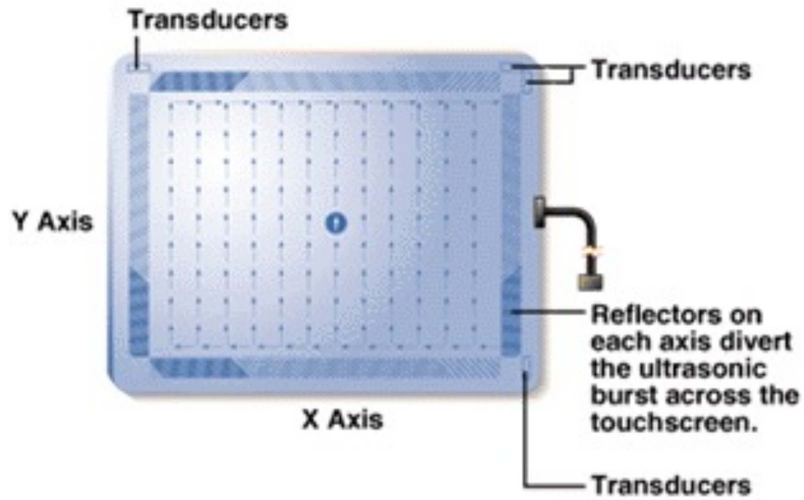
Rubine & McAvinney (CMU)
VideoHarp
Shadows on photodiode array

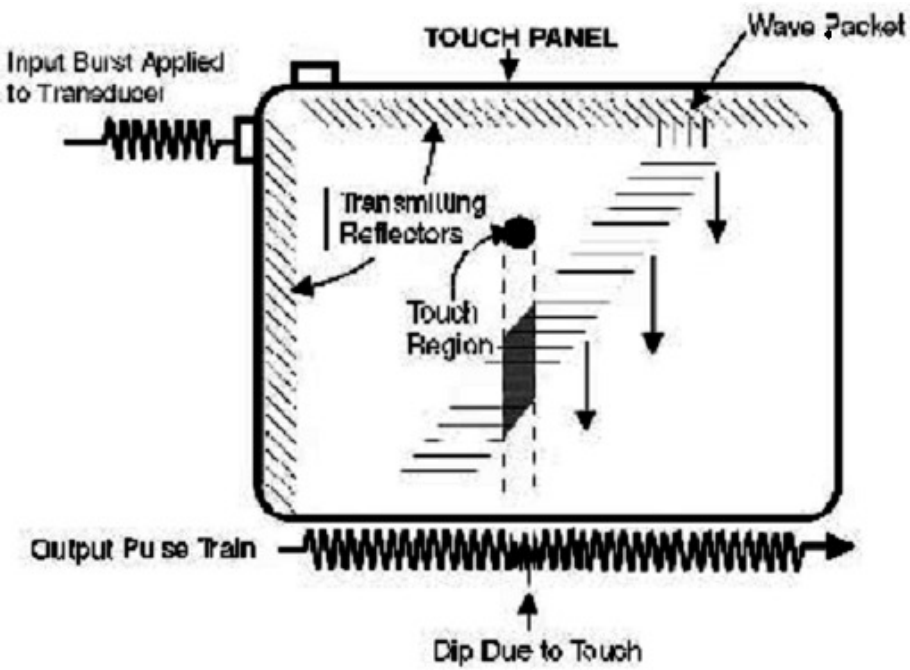
Jean-Michael Jarre's LaserHarp

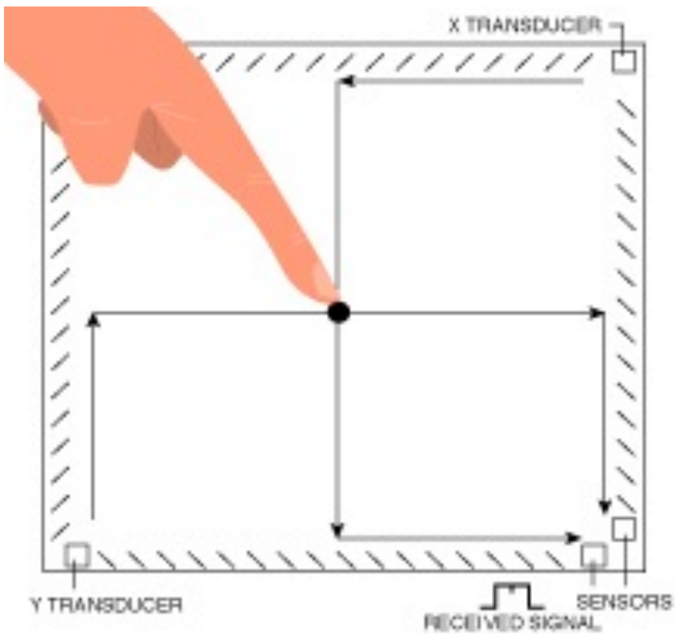
Asbestos Gloves?

Surface Acoustic Touch Screens

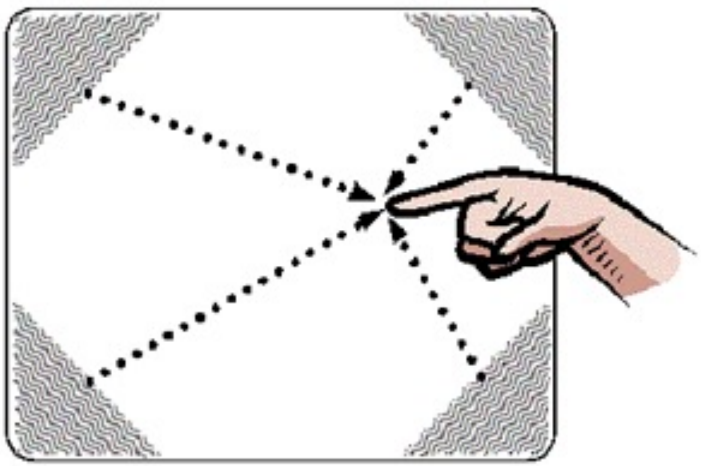






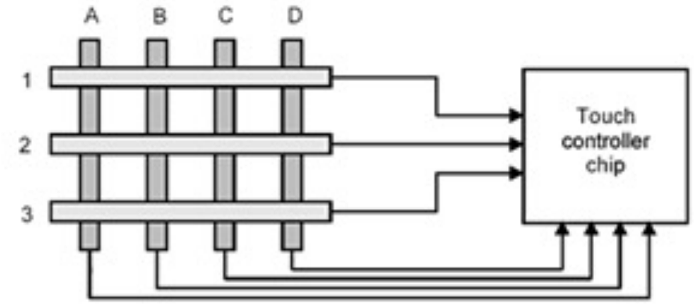


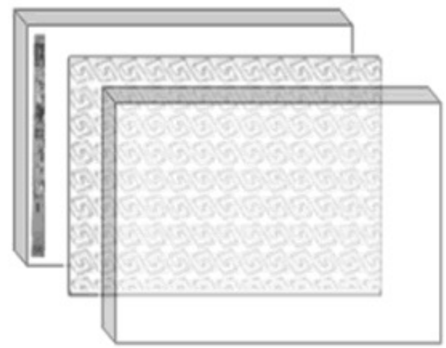
Capacitive Touch Screens

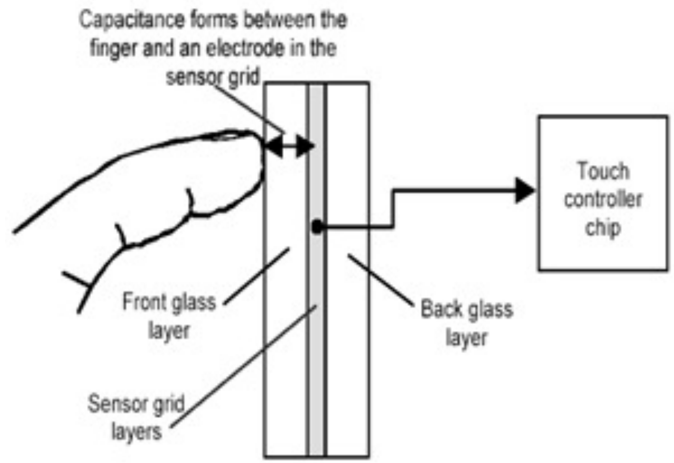


Surface Capacitance

Transmit from 4 corners
Receive around screen.
Or vice-versa…,

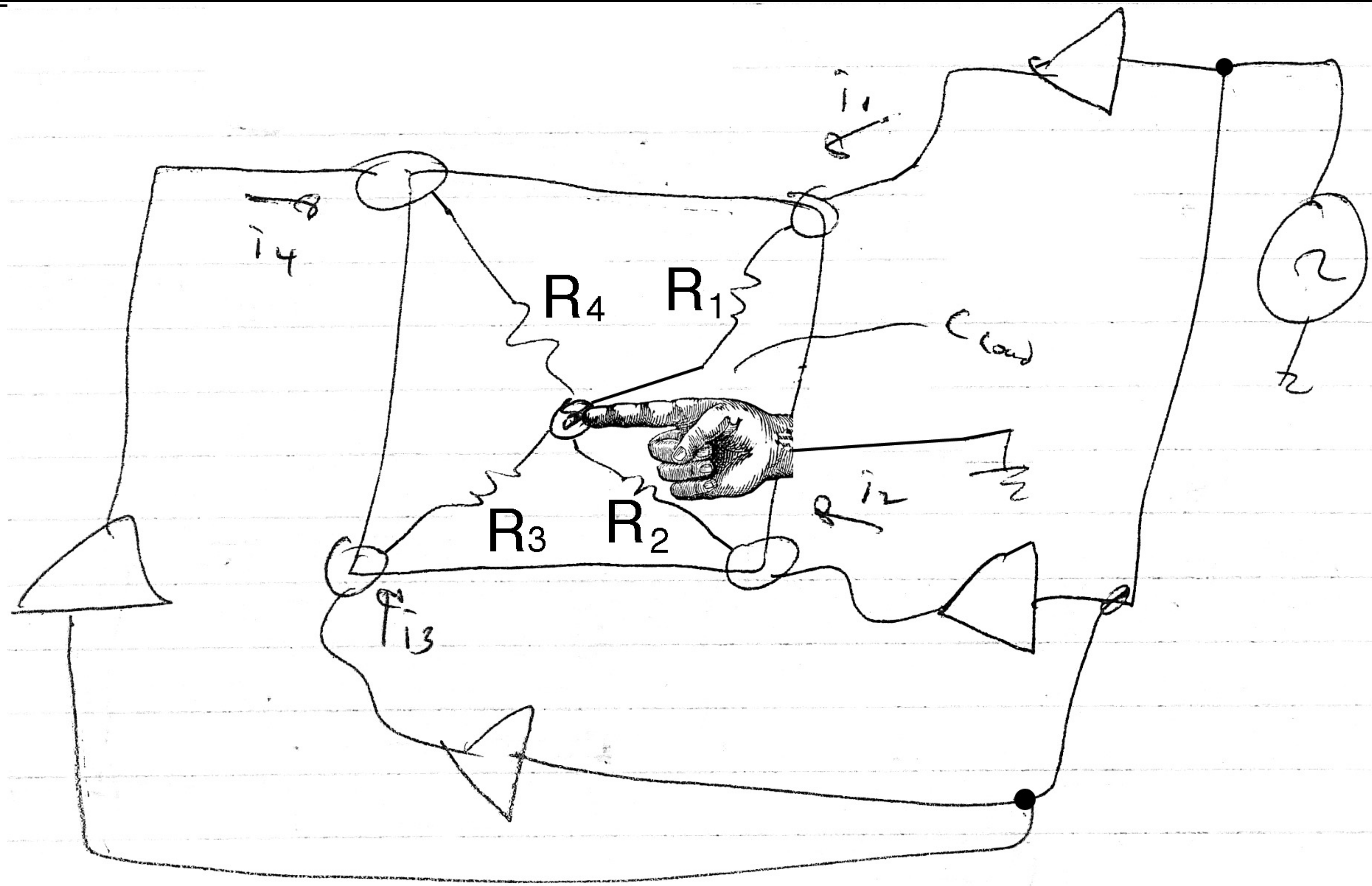






Pixellated or grid capacitance

Analog Loading-Mode Touch Screen



- Current splits - Measure Capacitive loading as sourced @ 4 corners
  - Sum/Difference across x,y can locate touch in plane
- Can receive outside screen too w. different signals xmit at 4 corners
- Neil's complex impedance planar resistive sensor sheet

Touch Screen Tradeoffs

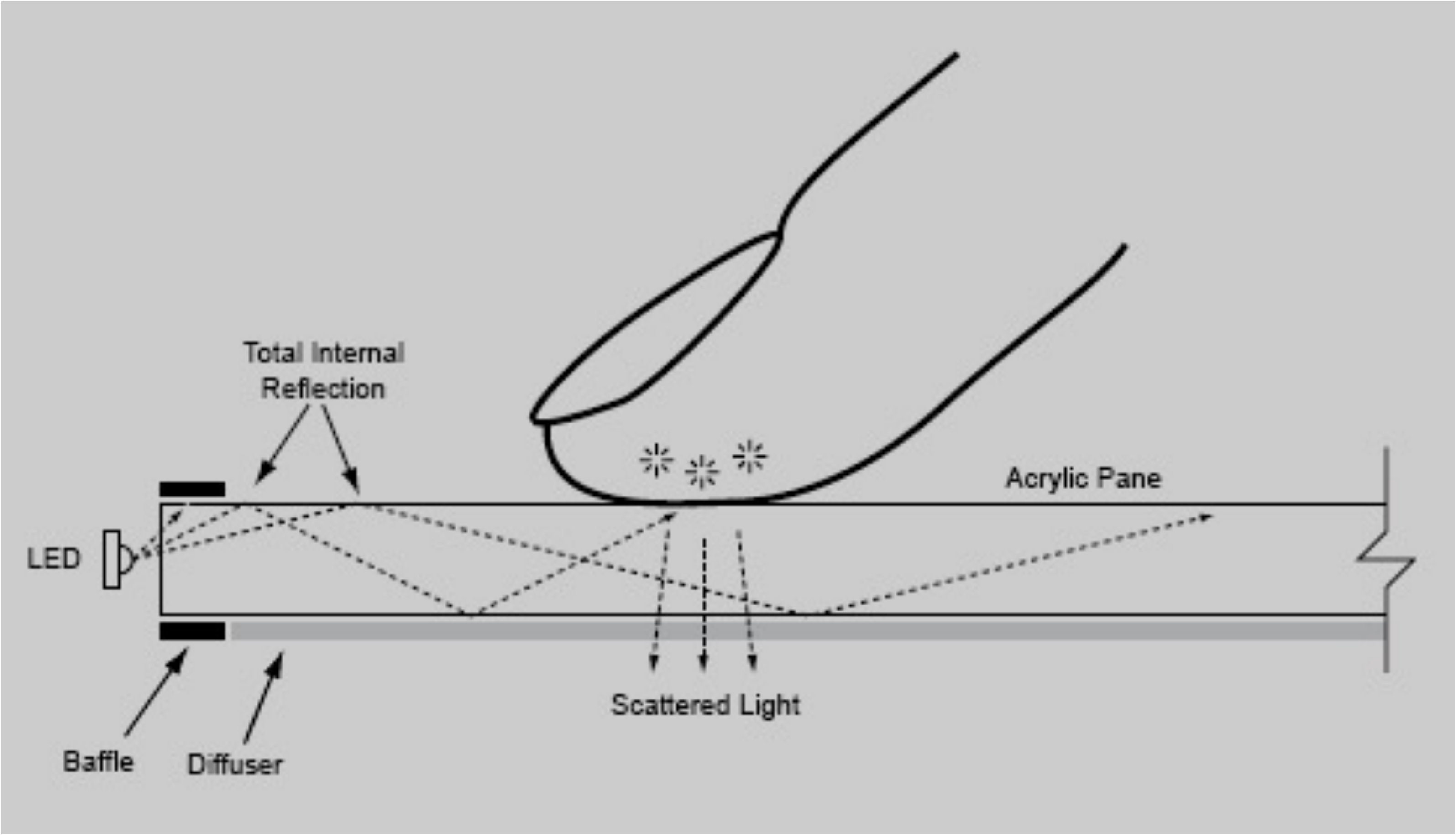
TABLE 2 -- TOUCHSCREEN TECHNOLOGY TRADE-OFFS

Technology		*Touch type (note 1)*	*Resolution (points)*	*Z-axis measure*	*Touches/ point (millions)*	*Resistance to*		*Drift*	*Trans-parency (%)*	*Cost*
						surface damage	*surface contamin-ation*			
Resistive	*Four-Wire*	F,G,S	2048X2048	N	1M	Low	High	Y	55 to 85	$199
	Five-Wire	F,G,S	2048x2048	N	35M	Moderate	High	Y	55 to 85	$595
Capacitive	*Analog*	F,CS	1024x1024	N	>50M	High	High	Y	80 to 85	$495
	Projective	F,G,CS	0.25-in. pads	N	>50M	Immune	Immune	N	80 to 85	$495
Acoustic	*GAW*	F,G,AS	900/in.	Y	>50M	Moderate	Moderate	N	90 to 95	$685
	SAW	F,G,AS	900/in.	Y	>50M	High	High	N	90 to 95	$685
IR		F,G,S	150/in.	N	>50M	Immune	Moderate	N	100	
Platform		F,G,S	40/in.	Y	>50M	Immune	Immune	Note	100	$525

Notes:
1. F=bare finger, G=gloved finger, S=stylus, CS=conductive stylus only, and AS=absorbing stylus only
2. Surface contamination only affects IR if it is thick enough to intrude into the optical grid.

GAW = “Guided Acoustic Wave” - travels through panel, not on surface

FTIR Touch Screens

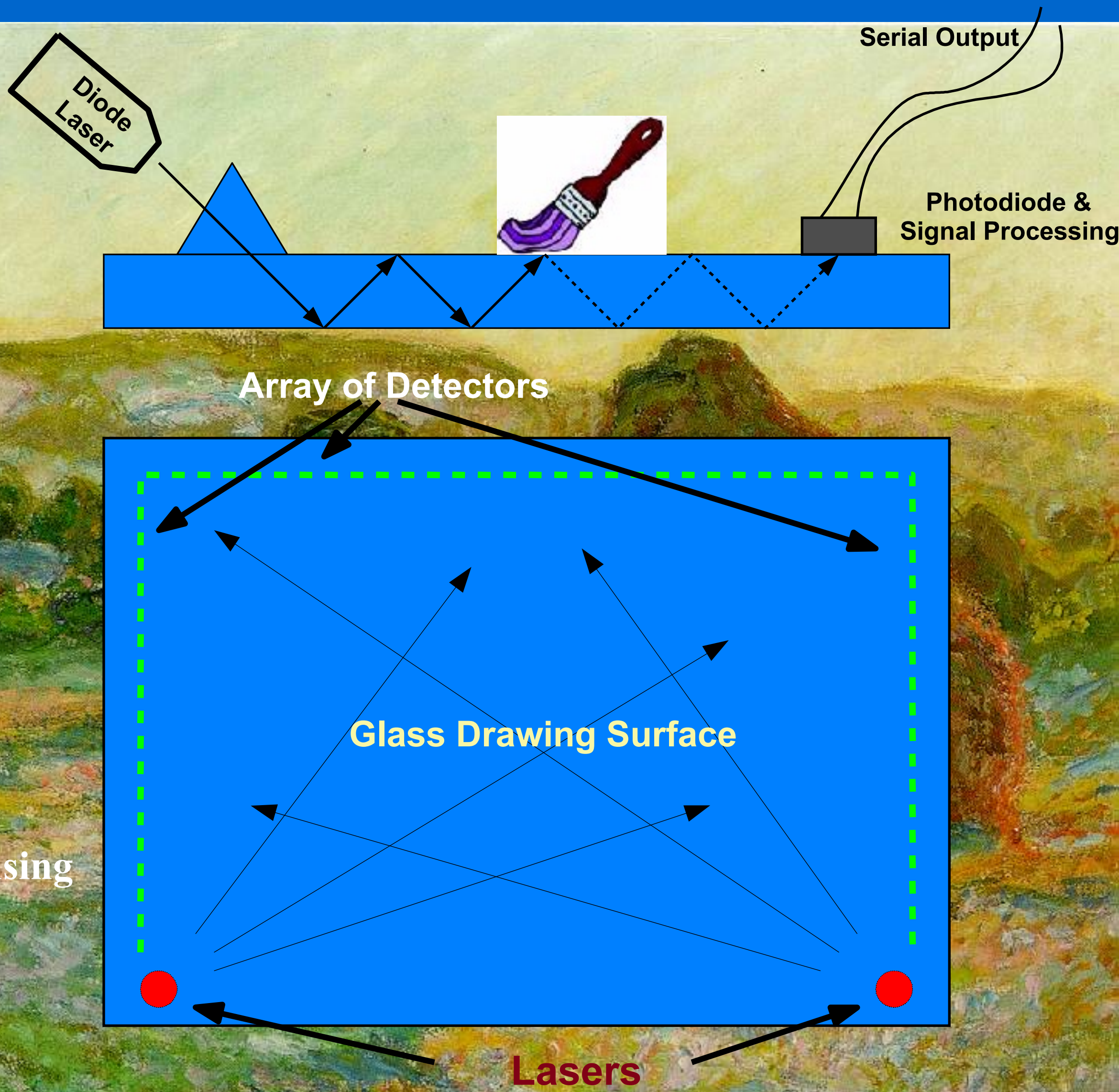


- IR Camera in Back
  - https://www.youtube.com/watch?v=qAg7eUF_dzA

Jeff Han, Perceptive Pixel

Tracking fingers and objects via frustrated total internal reflection (FTIR)

- All touch screen technologies are essentially single point.



Couple laser into a pane of glass

Sense brush strokes and finger contact using Frustrated Total Internal Reflection

No modification of the glass is necessary

All components on rear of glass

Hong Ma and Debra Horgan

The Mathews/Bowie Radio Baton

- Electronics developed by Bob Bowie in 1987
  - Inspired by electronics on cathode strip drift chambers (BNL)
- Independently tracks positions of batons in x,y,z over table
  - Initially designed by Max for conductor programs
  - Descendent of Mechanical Drum and Daton projects

Radio Baton Capacitive Sensing

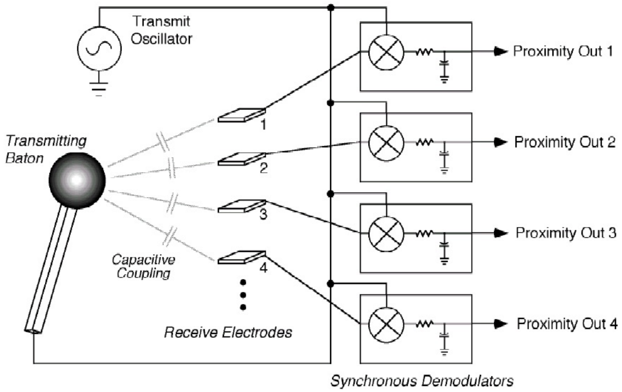
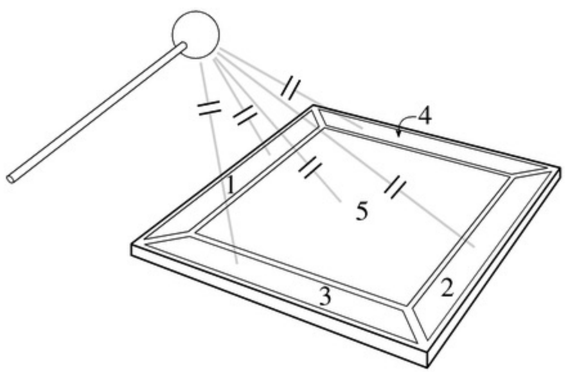


Figure 2: Proximity sensing in the Mathews/Boie Radio Drum



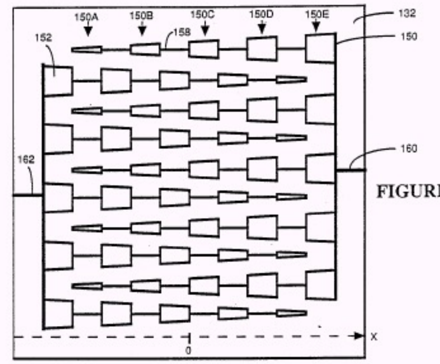


FIGURE 2

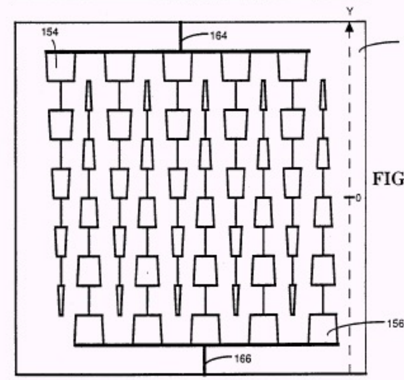
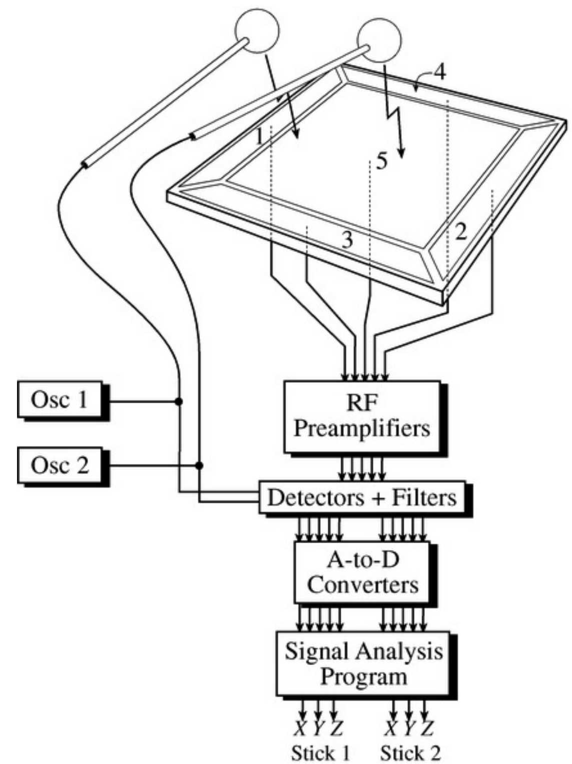
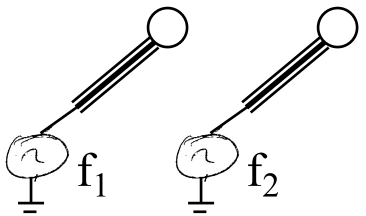


FIGURE 3



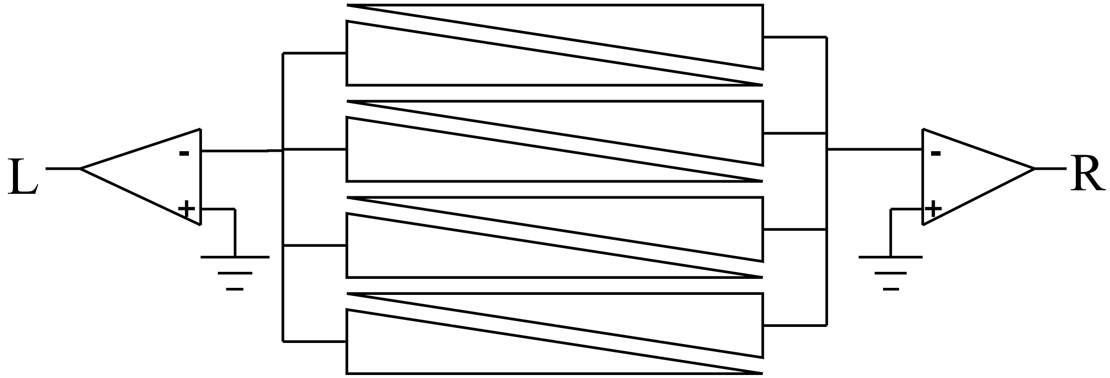
- Transmit mode
  - Baton connected to transmitter that capacitively couples into receive antenna plane
  - Each baton transmits (and is detected) at a different frequency
  - A variety of different tapered electrode geometries possible
  - Inspired violin/cello/Fish electronics at Media Lab

Other electrode geometries...

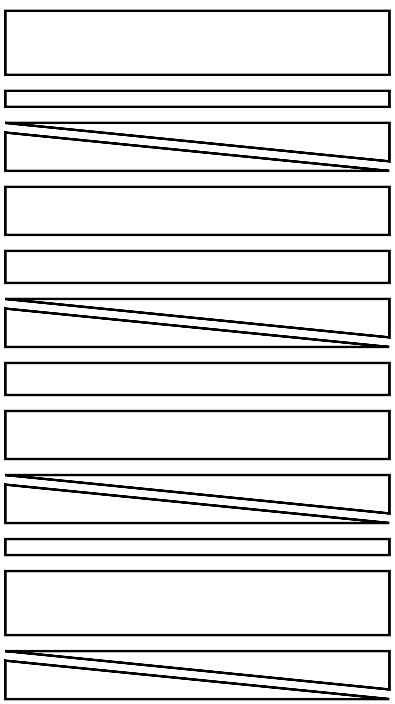


Demodulate received signals using f_1 or f_2
(can switch as well)

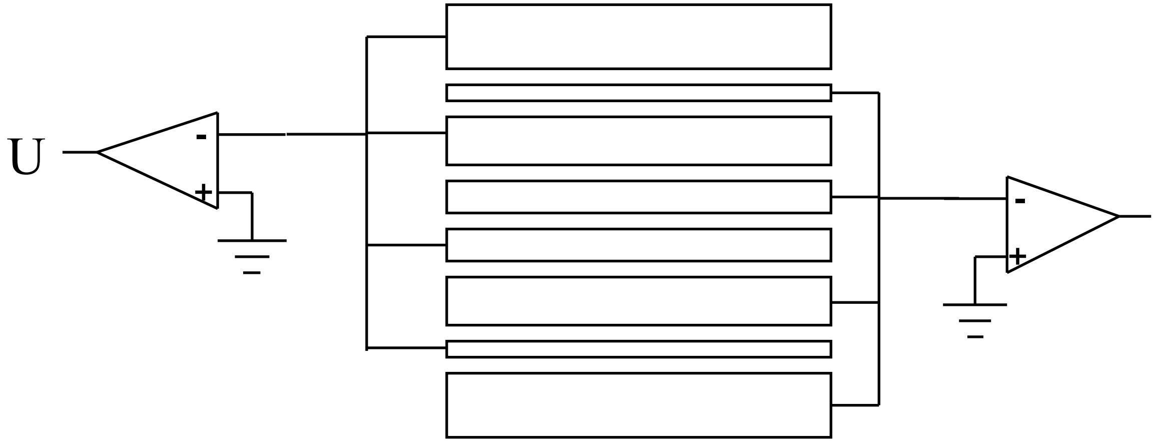
Left-Right



Alternating Hybrid

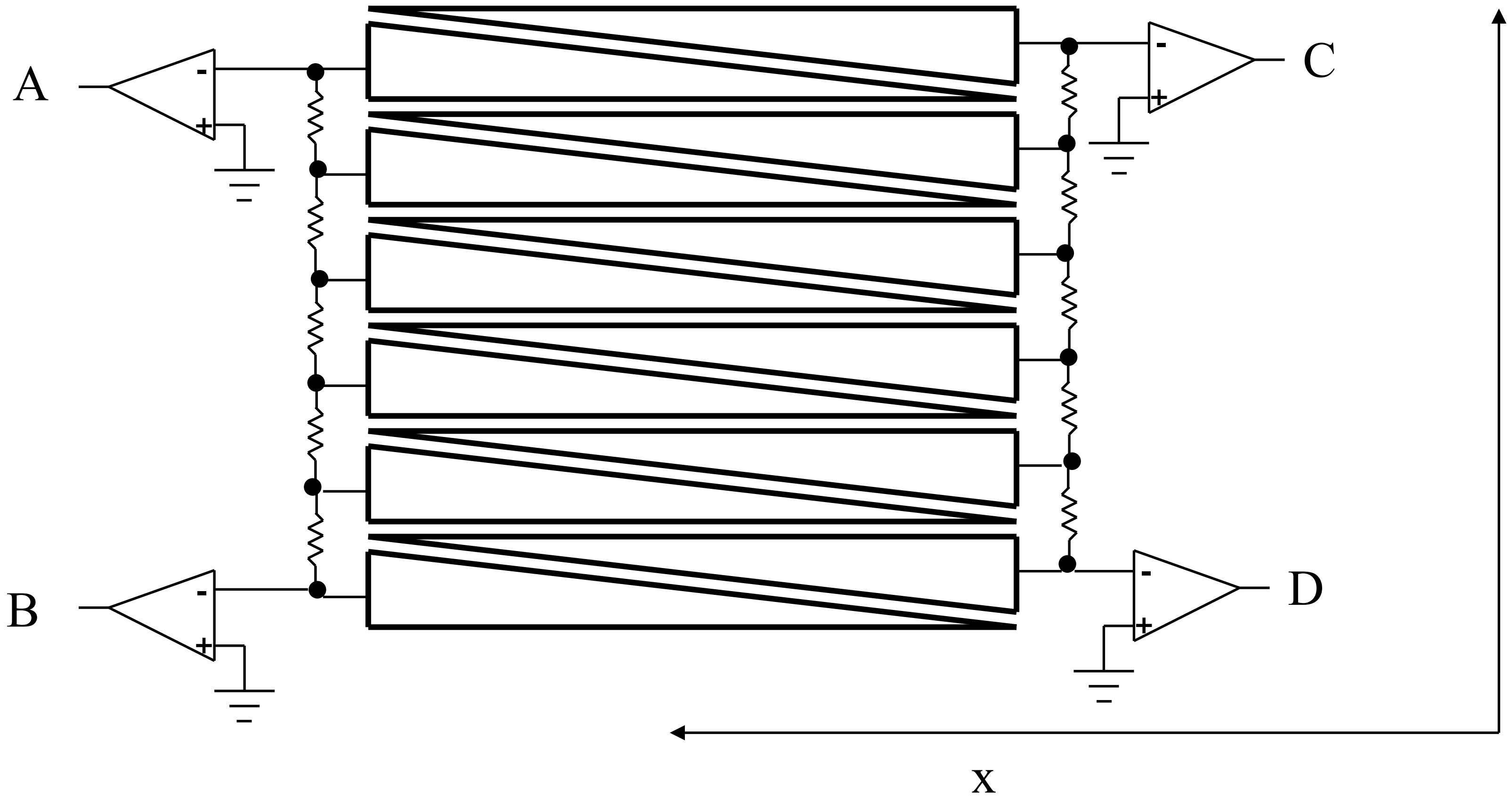


Up-Down



Actual implementation is at finer scale

Charge Division Receive Electrodes

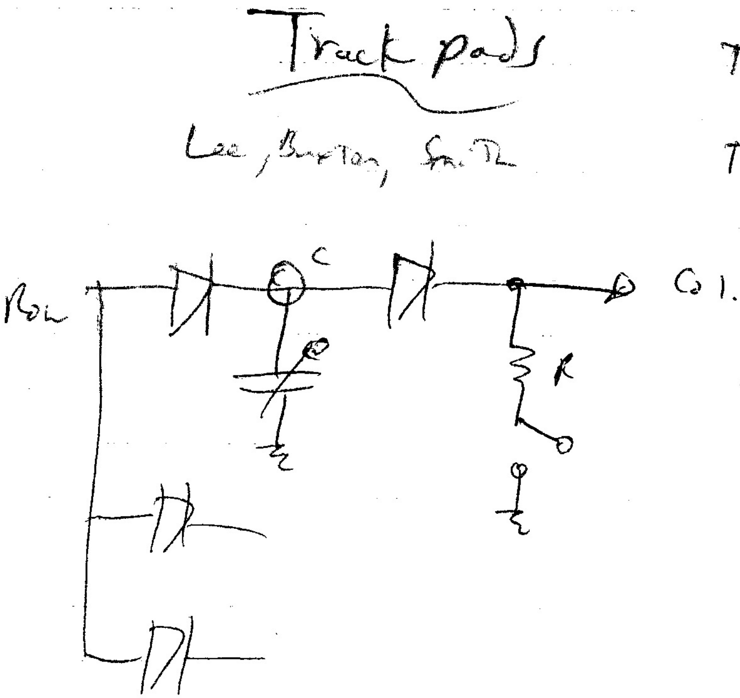


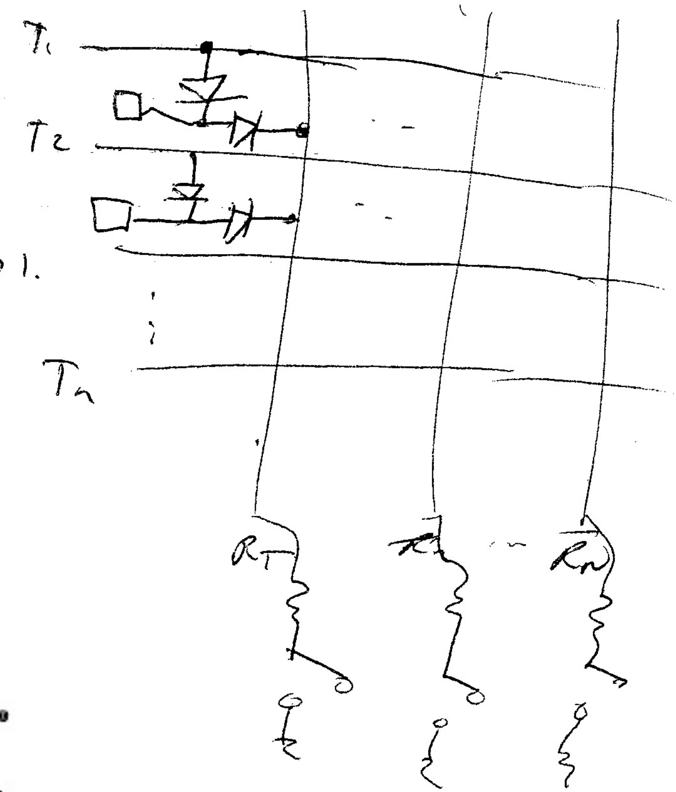
X = ((A + B) – (C + D)) / (A + B + C + D)

Y = ((A + C) – (B + D)) / (A + B + C + D)

A multi-touch three dimensional touch-sensitive tablet - Lee, Buxton, Smith - 1985

Scanning by Recursive Subdivision





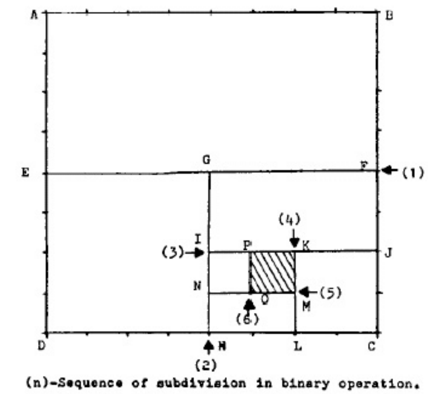


Fig. 2 Recursive subdivision operation for 8 by 8 tablet.

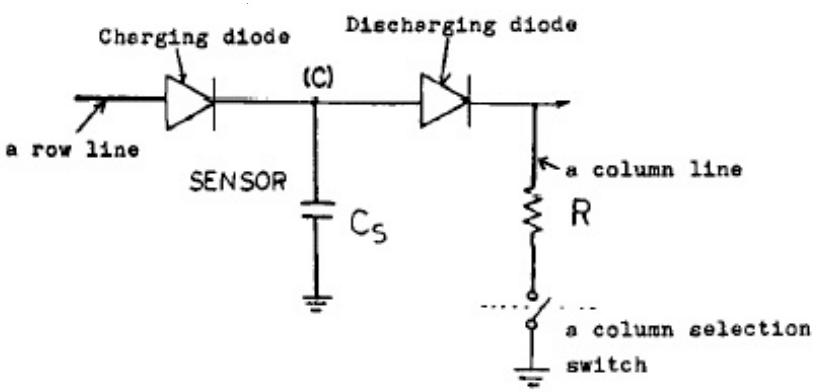
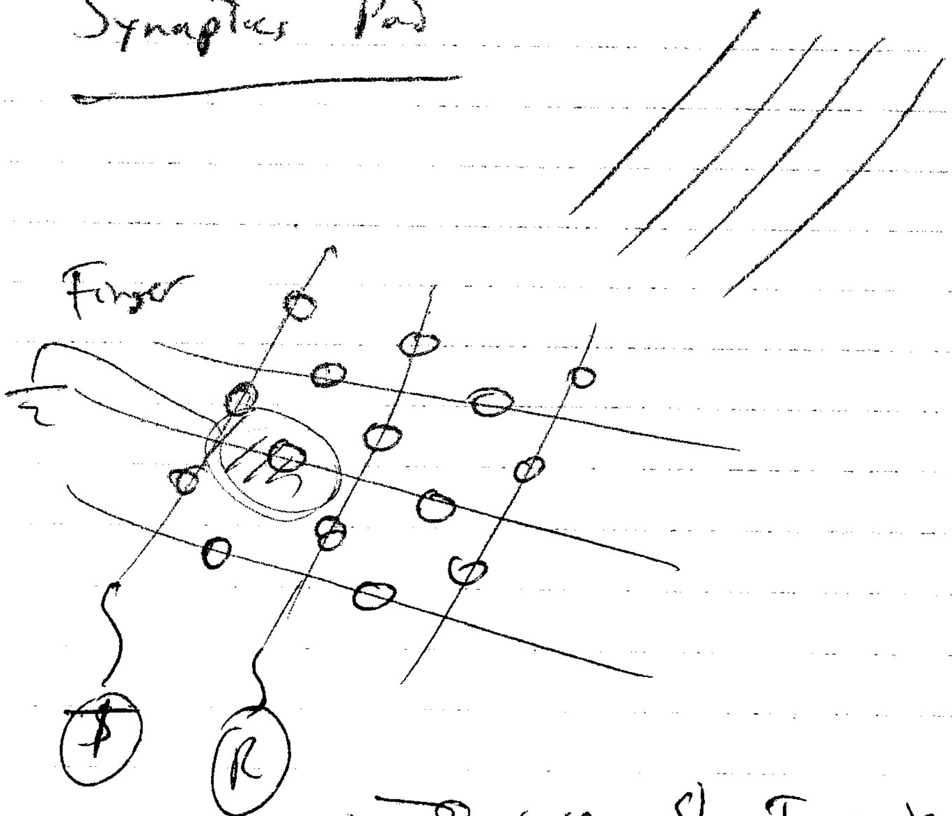


Fig. 1 A model of a selected sensor in the sensor matrix.

In order to select a sensor by row and column access, two diodes are used with each sensor. One diode, connected to the row line, is used to charge up the sensors in the row. It is referred to as the Charging Diode (CD) as shown in Figure 1. The CD also serves to block the charge flowing back to the row line when the row line voltage is dropped to zero. The other diode called the Discharging Diode(DD), connected to the column line, enables discharging of the selected row sensors to a virtual ground. Also the DD blocks charge flow from the sensors in the selected row to the sensors in the unselected rows during the discharging period. The selection of rows, by the row selection procedure, causes the sensors to be charged. The sensors in the column are then discharged through associated timing resistors connected to the column selection switches.

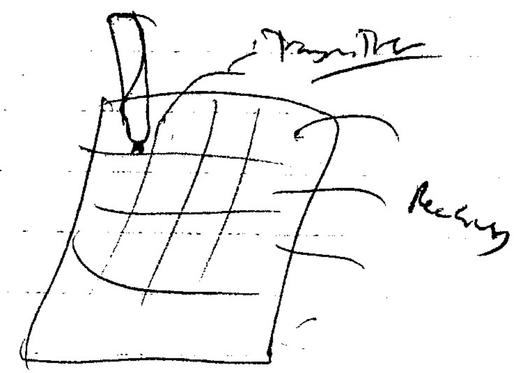
Touch and Track Pads

Synaptics Pad



Picture

IBM Cross Pad



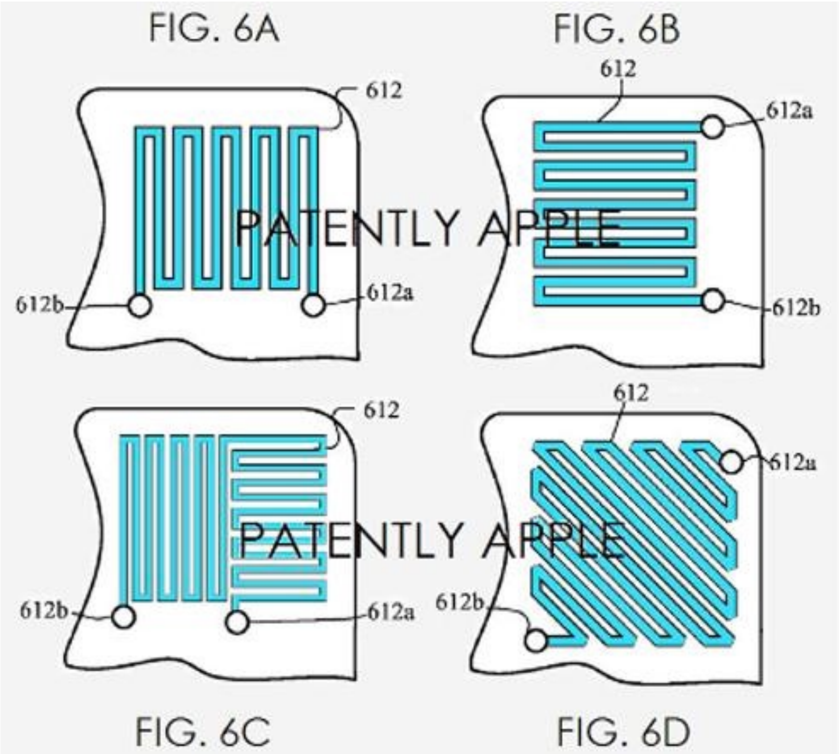
T/R Mode

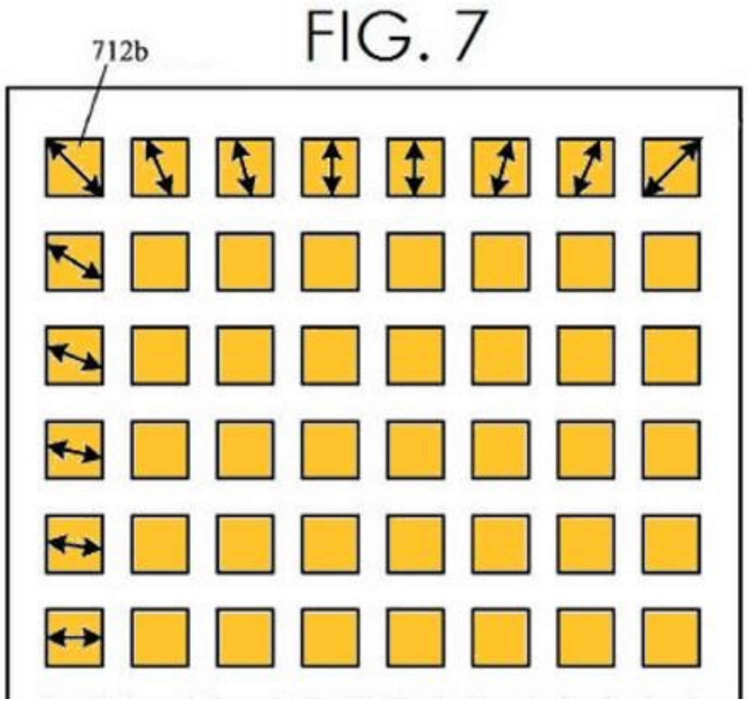
→ use Shunt mode
→ finger interferes on coupling
→ Digital Readout quickly find coarse location
→ Analog interpolation goes finer.

Signal goes down!

Projected Capacitive Touch
Mutual Capacitance Touch Sensing

iPhone Pressure Sensitive Touch Screens

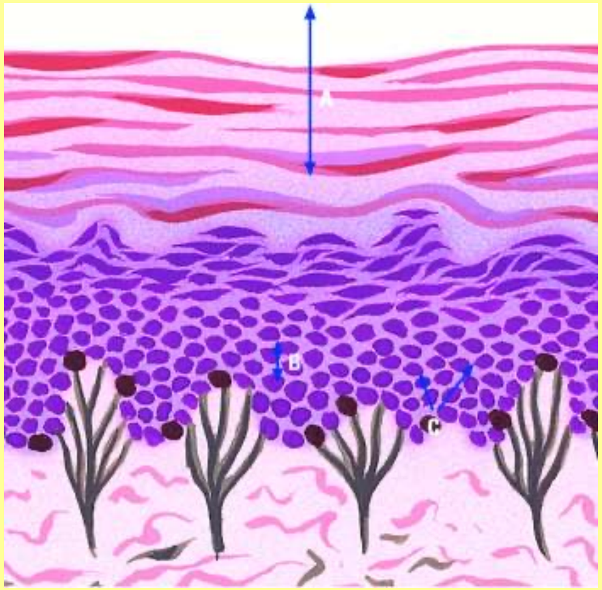




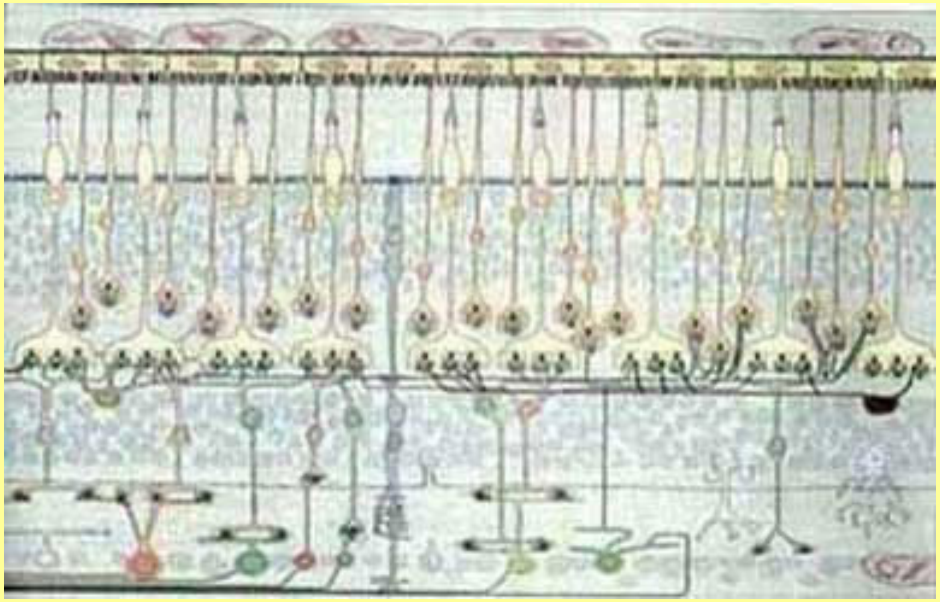
https://www.forbes.com/sites/jvchamary/2015/09/12/3d-touch-iphone-6s/#354c53bb4cee

- Strain Gauge array near edge of the display

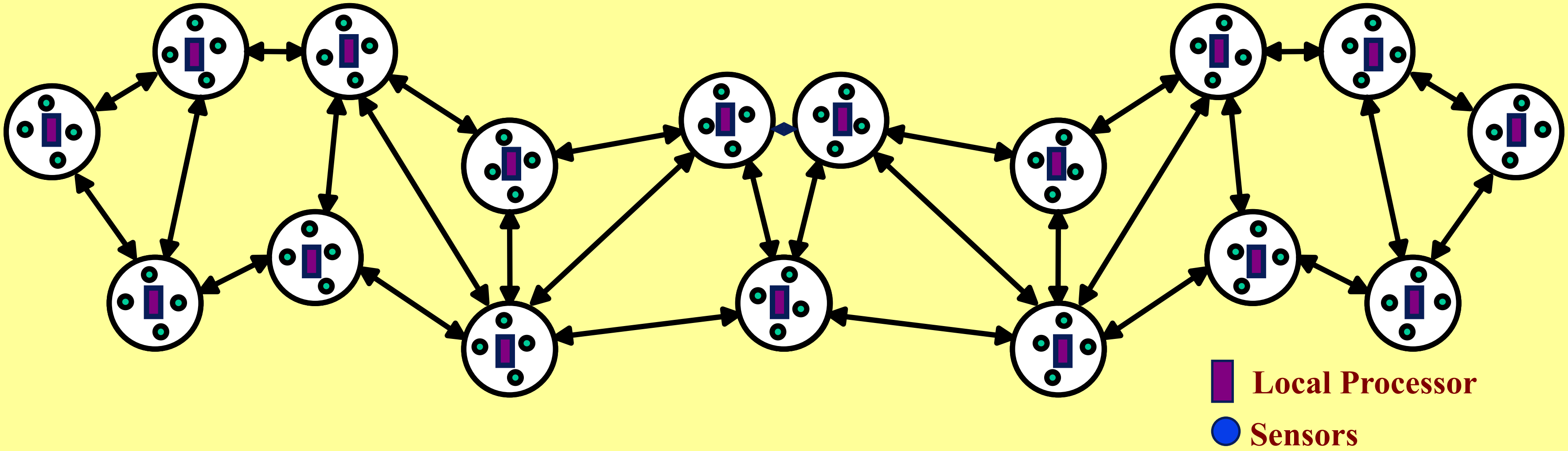
Sensate Media



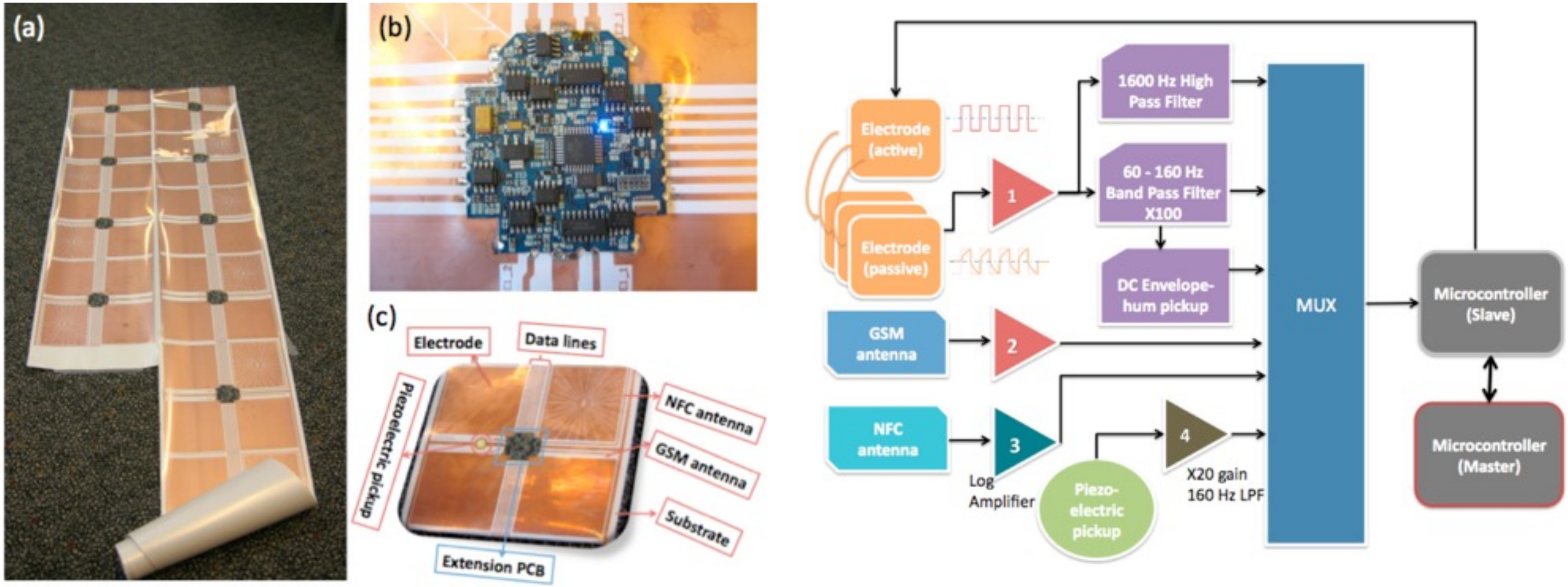
Skin



Retina



Scalable E&M Sensate Surface



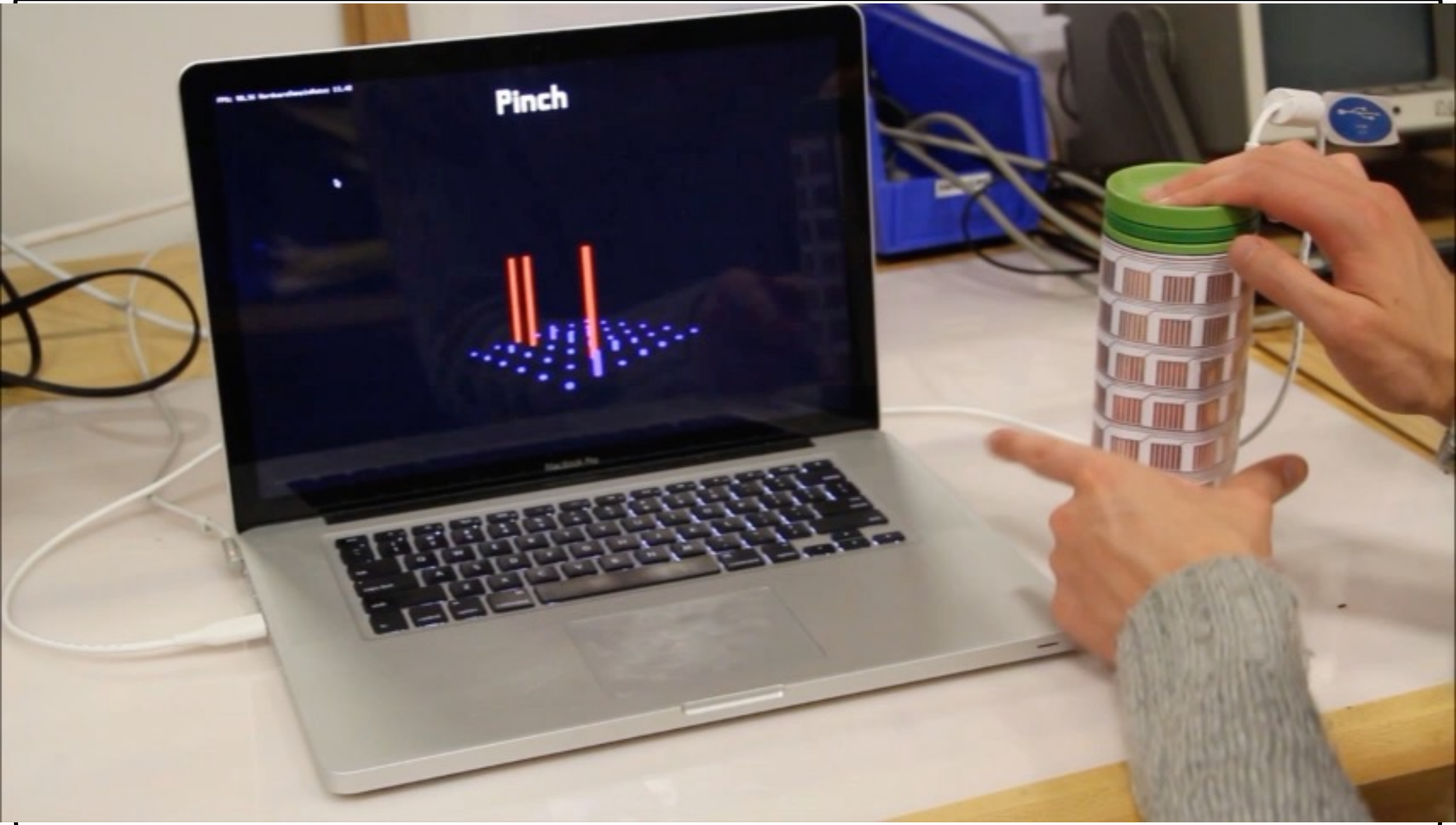
Passive and active capacitive sensing, vibration sensing, GSM, NFC sensing

4 x 4 "cells" on common network

Guest researchers @ MSR UK, summer 2010

Leveraging Conductive Inkjet Technology to Build a Scalable and Versatile Surface for Ubiquitous Sensing, Nan-Wei Gong, Steve Hodges, Joe Paradiso, in Ubicomp 2011

NanWei Gong's PrintSense

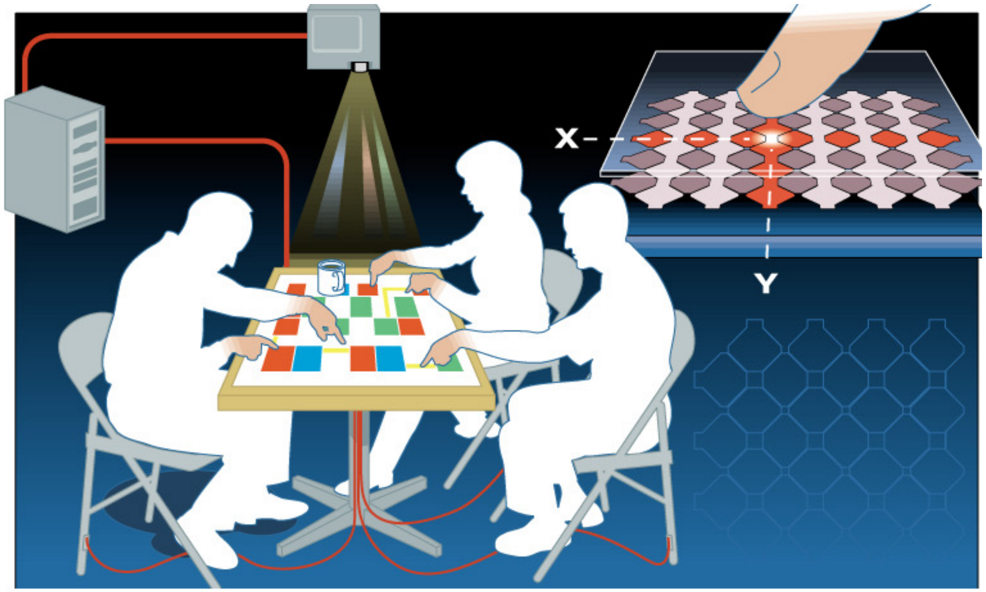


The DiamondTouch Solution

Darren Leigh, *leigh@merl.com*

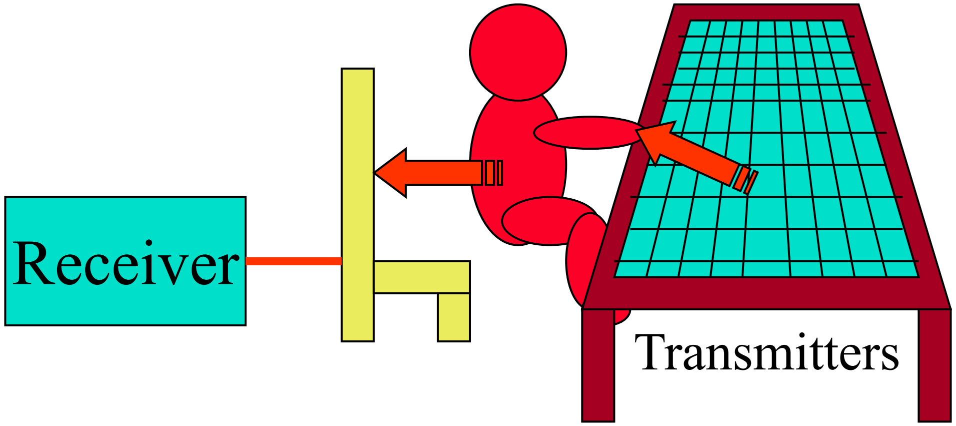
Paul Dietz, *dietz@merl.com*

- A true multi-user touch interface
  - Simultaneous multiple users
  - Identifies user touching each point



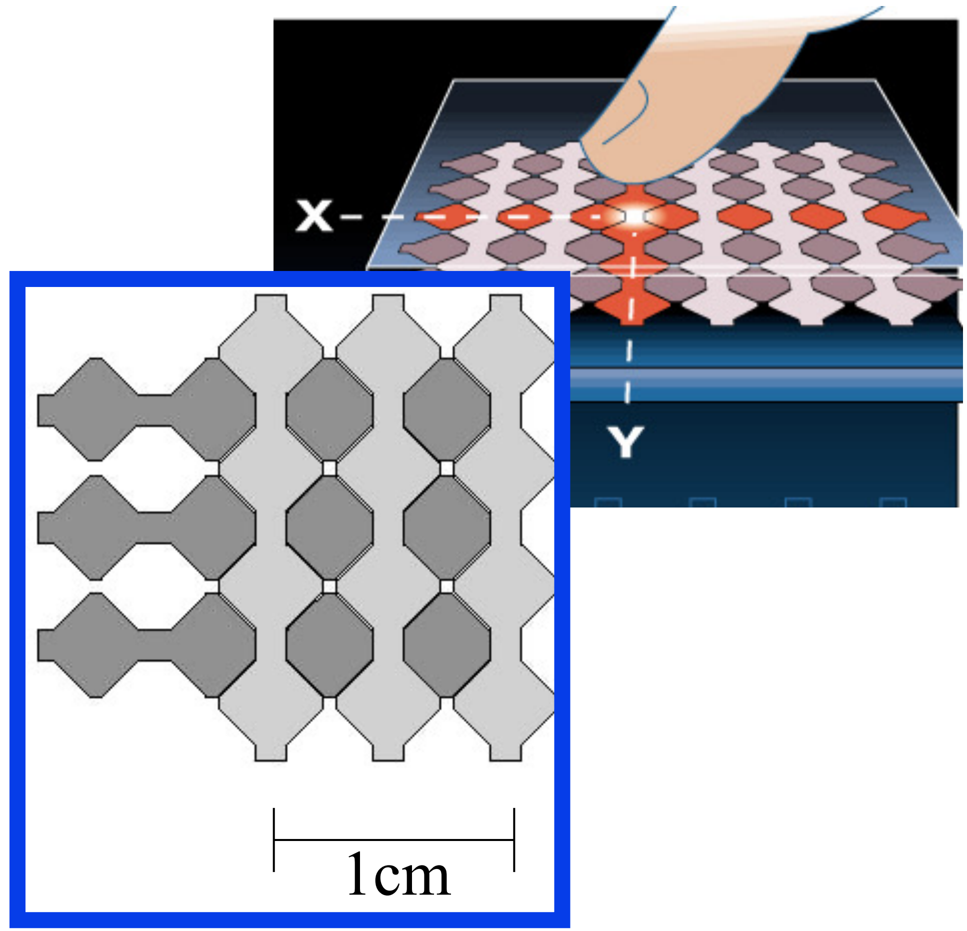
How DiamondTouch Works

- Touch surface is a transmitter array
- Chairs or floor areas are receivers
- User capacitively couples signal from touch point to his/her receiver



Row/Column Pattern

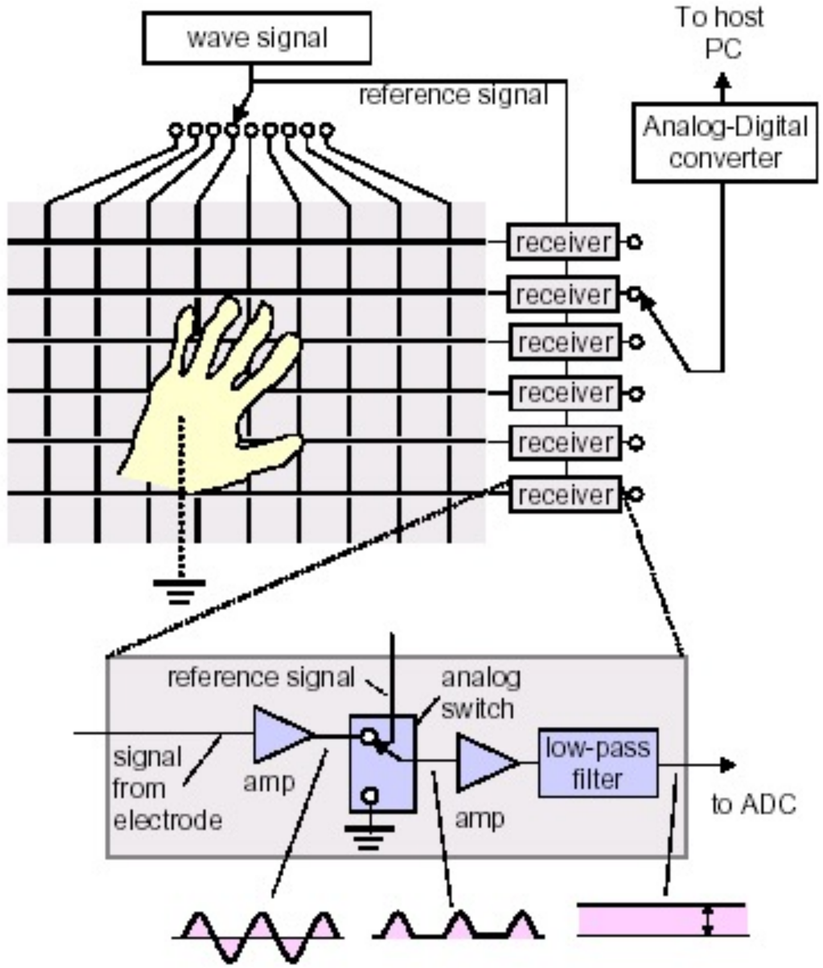
- Need lots of coupling surface area
  - Problem: The top layer shields the bottom
- Resolution
  - Finger must couple multiple rows/columns for interpolation
  - 0.5cm grid

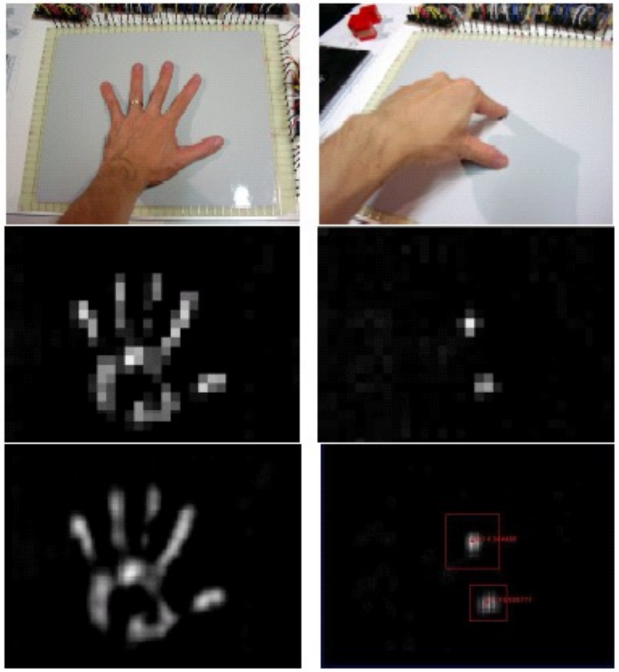


Features of DiamondTouch

- Multi-point
  - Detects multiple, simultaneous touches
- Identifying
  - Detects which user is touching each point
- Debris Tolerant
  - Coffee cups, etc. do not interfere with operation
- Durable
  - Heavy use without repair/recalibration
- Unencumbering
  - Finger use! No special stylus to lose
- Inexpensive
  - Compares favorably with less capable technologies

Jun Rekimoto's Smart Skin



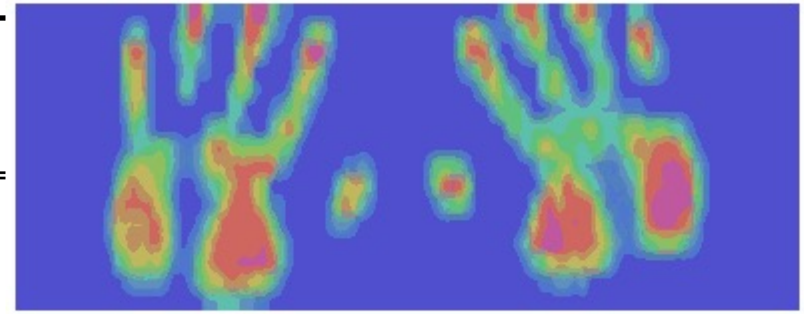


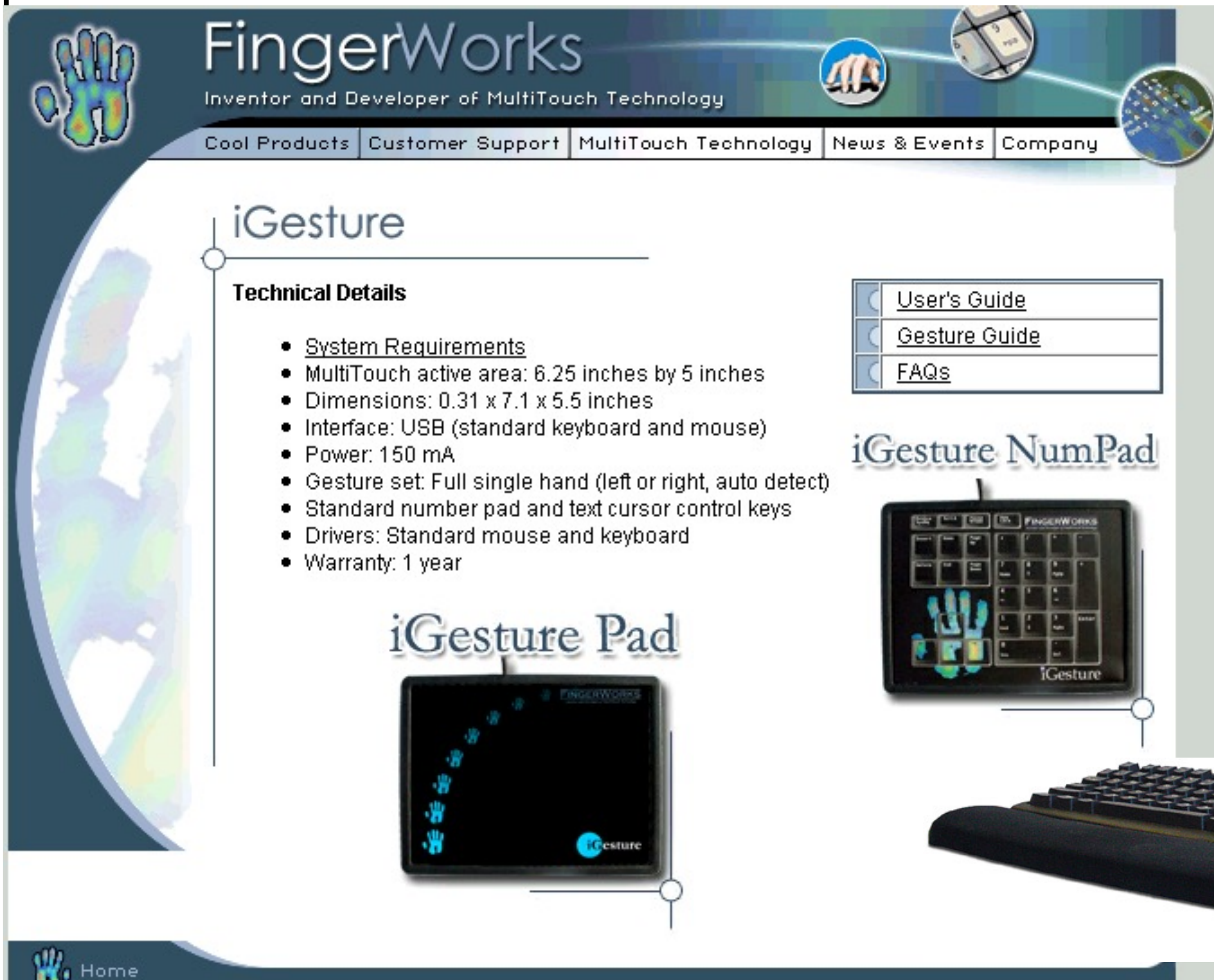
Much like an ALPS trackpad…

Fingerboard

University of Delaware EECS spinof

Bought by Apple!!





- -Capacitive matrix
  - -Big fingerprint device?
  - - Multitouch; takes "picture"
- -Updates 50-200 Hz
- -Seem to be marketing standard UI?
  - -Not Music…

GEM Detector Alignment

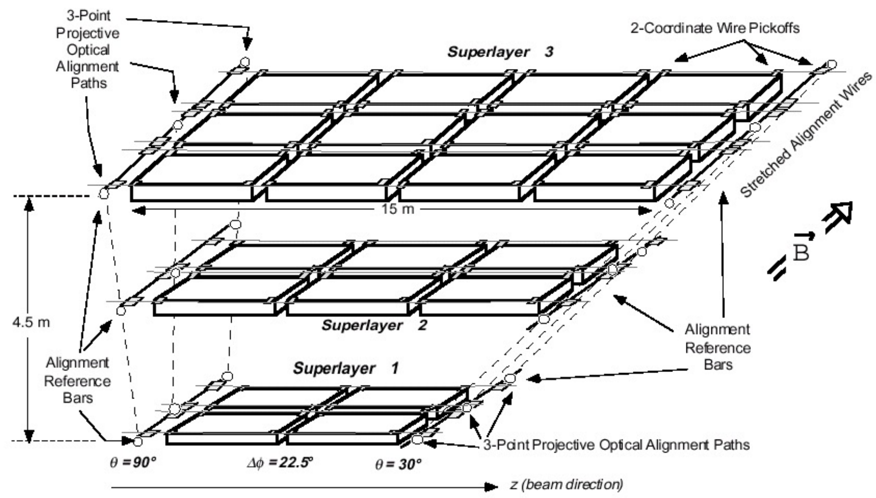
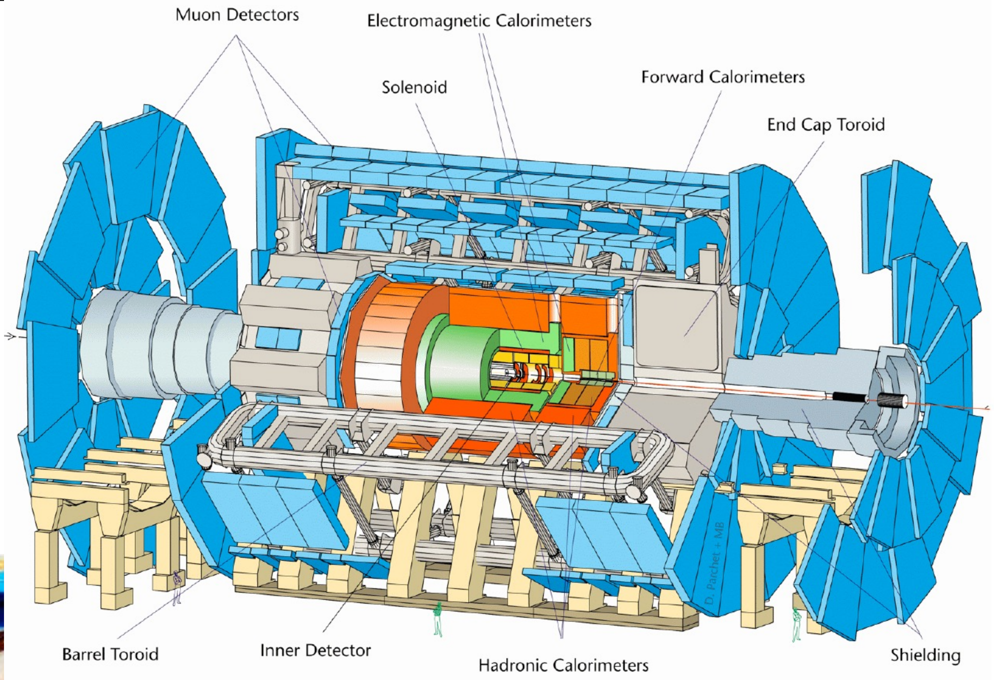
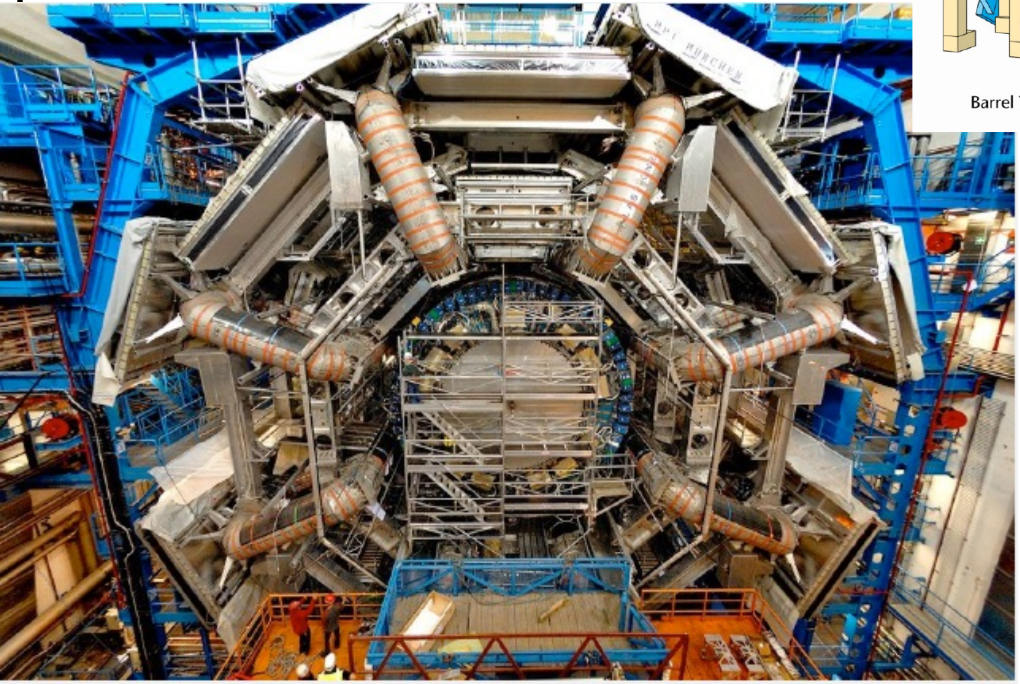


Figure 1: Axial/Projective alignment in the GEM barrel module

30 microns across 6 meters

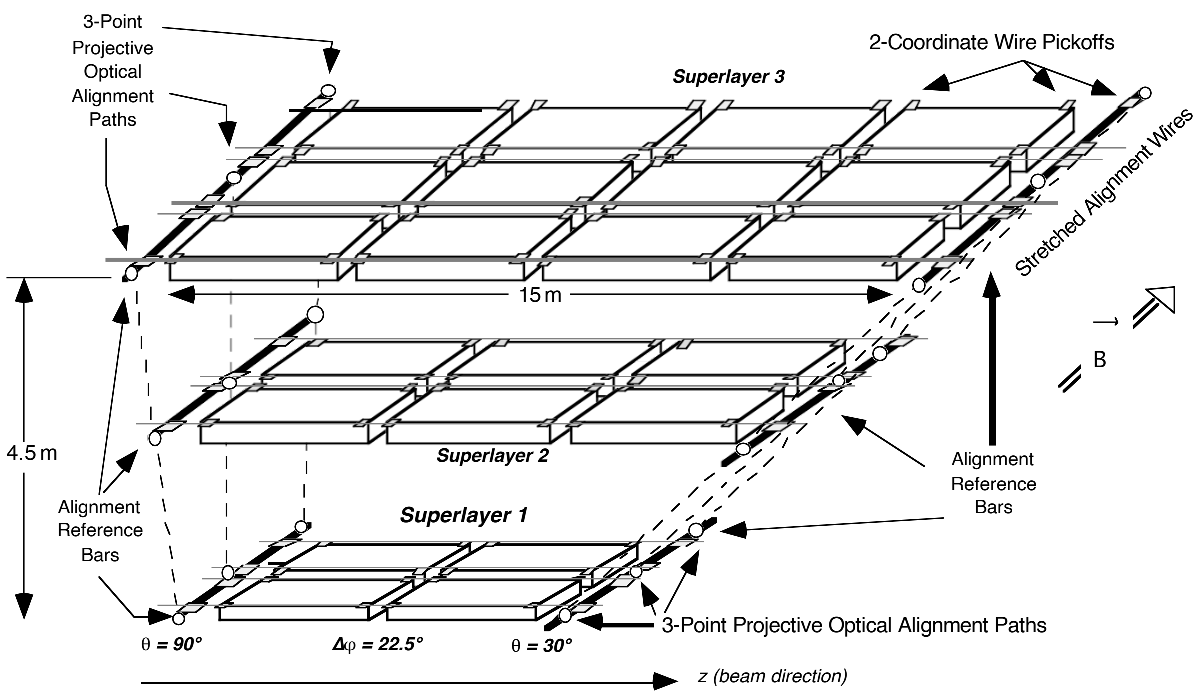
GEM wasn't built, but ATLAS exists…





De ATLAS detector onder constructie

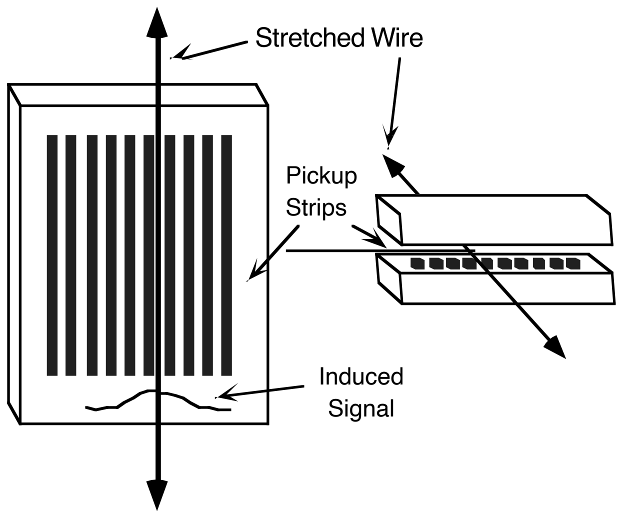
GEM Muon Alignment Frame

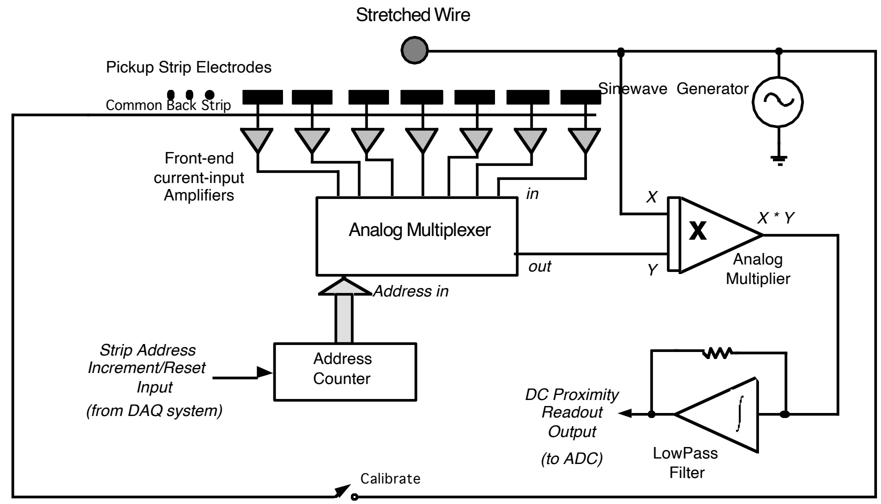


Barrel sector shown (1/16 of 2π)

- **Precision multipoint scheme (i.e. stretched wire) measures axial coordinate.**
- **3-Point optical system measures interlayer sagitta error at axial endpoints.**

Mini-Strip Wire Readout

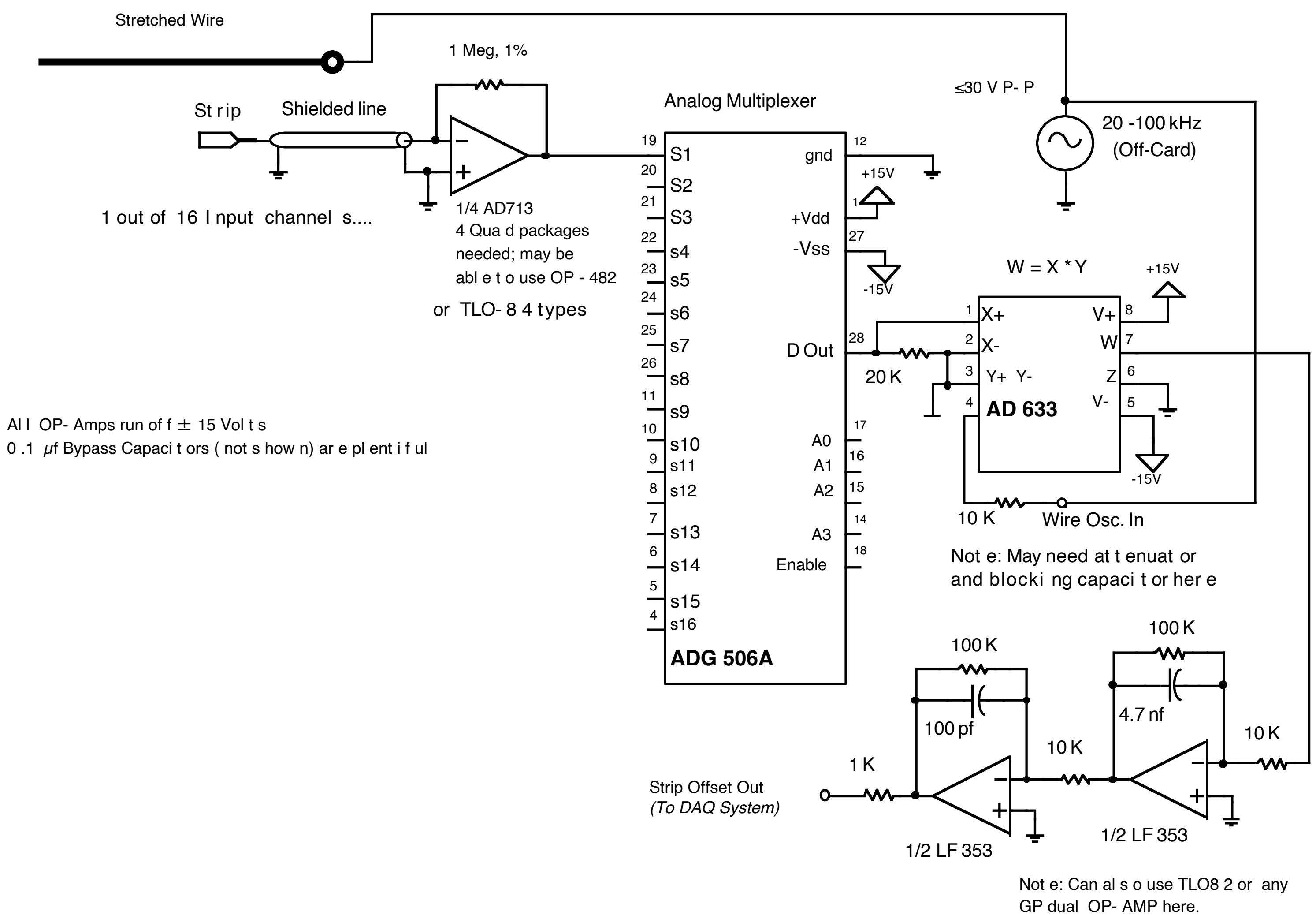




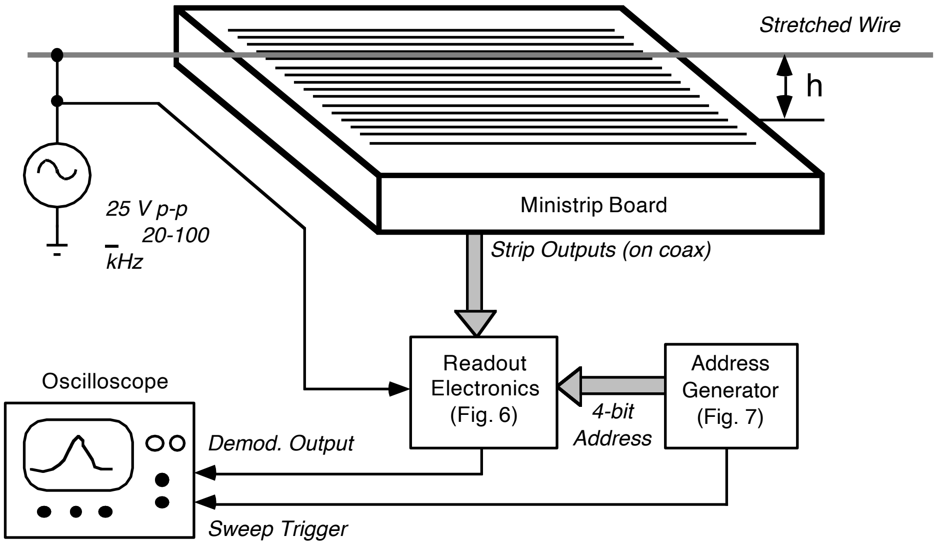
- **Break pickup electrode into array of strips parallel to wire**
  - **Current amplifiers; strips at virtual ground; field configuration known**
  - **Centroid of induced signal precisely locates wire across strips**
  - **Multiple pickups; calibration requirements reduced (easily calibrated by driving common backing strip)**
  - **Width of centroid strongly dependent on wire height**
  - **Analogy to cathode strip chambers; A. Korytov, MIT**
- **Synchronously detect signal broadcast over wire**
  - **Low Pass cutoff circa 300 Hz, xmit ranges 20 - 100 Khz**

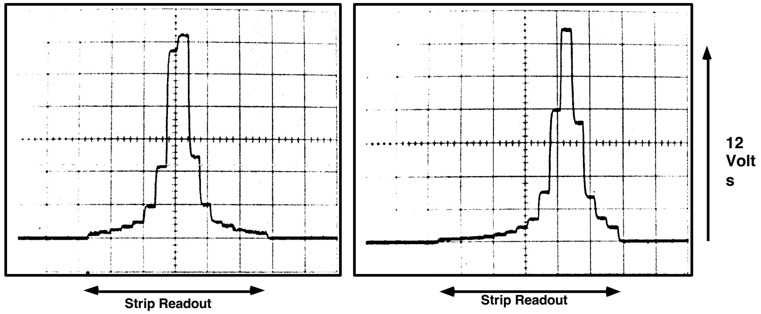
- Very low noise sensitivity

Wire Test Electronics



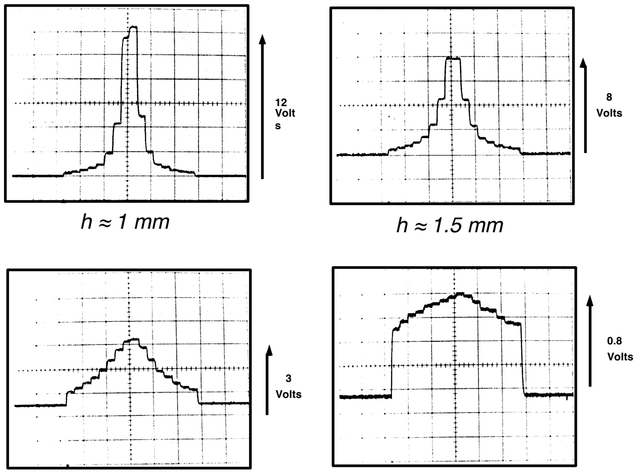
Mini-Strip Operation





Wire at center of strip board

Wire displaced to strip board edge



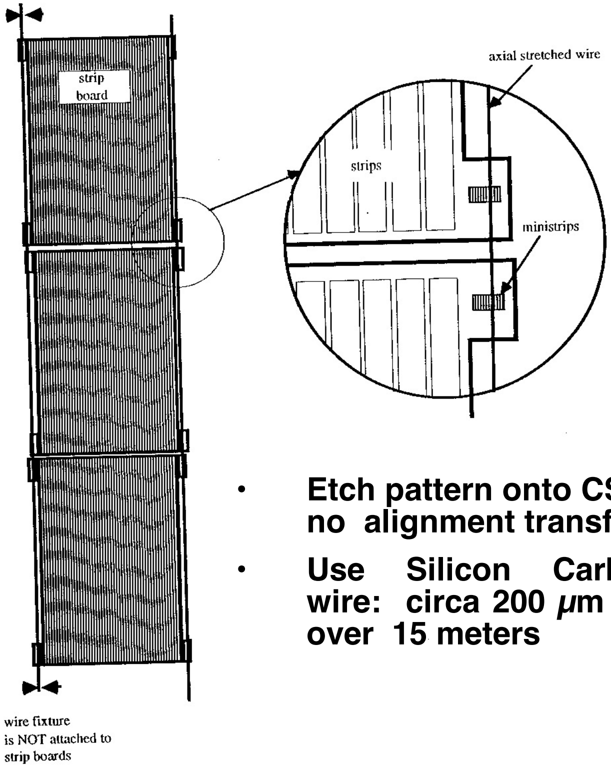
$h \approx 1$ mm

$h \approx 1.5$ mm

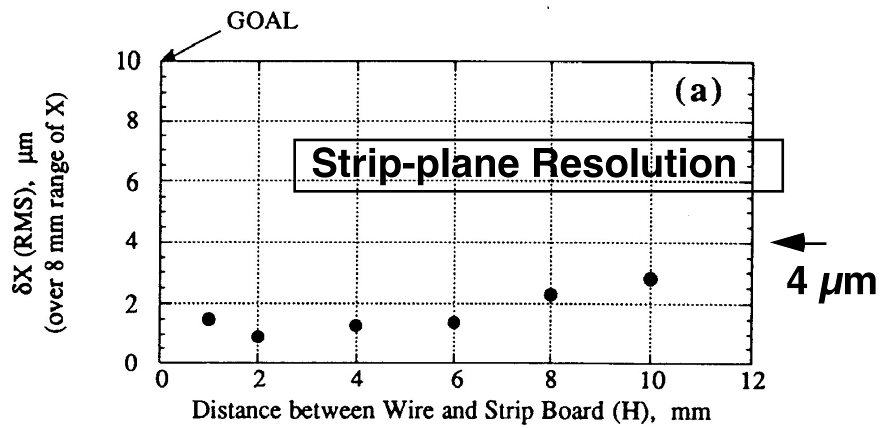
$h \approx 3$ mm

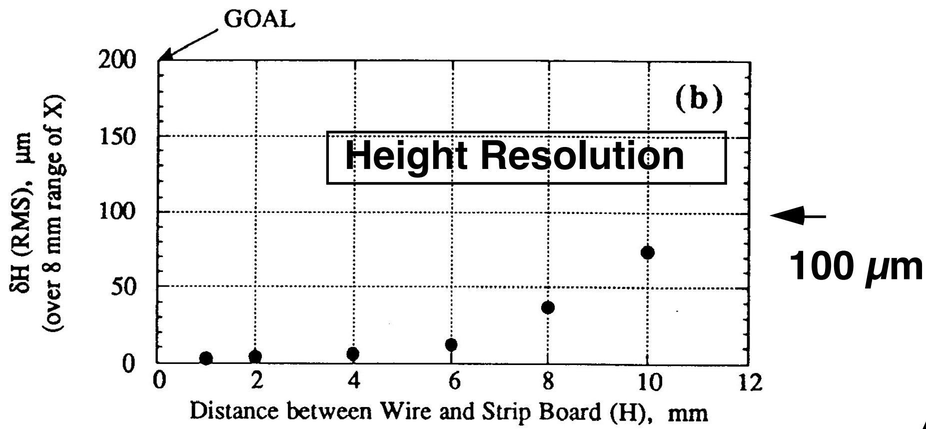
$h \approx 10$ mm

MiniStrip Resolution & Application



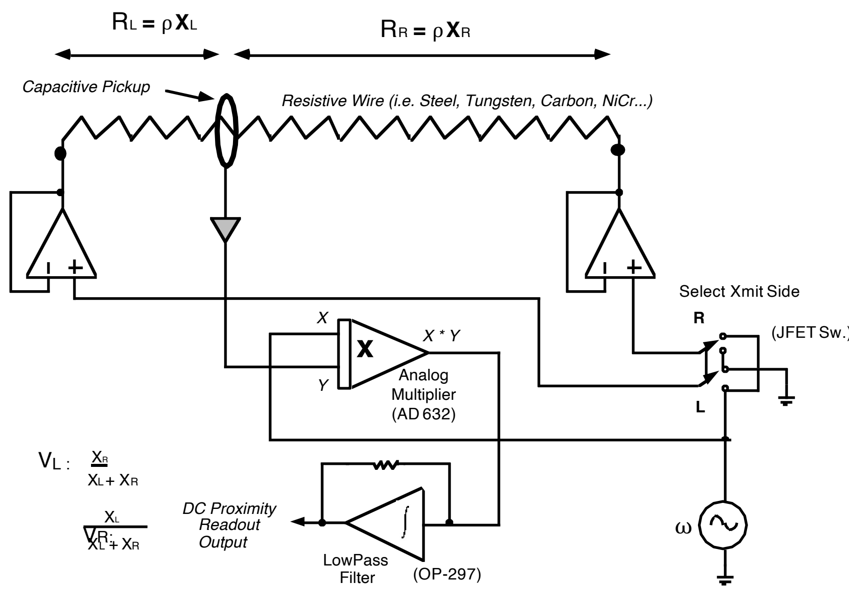
- Etch pattern onto CSC: no alignment transfer
- Use Silicon Carbide wire: circa 200 μm sag over 15 meters





- CAMAC readout @ Princeton
- Multipoint, long wire tests...

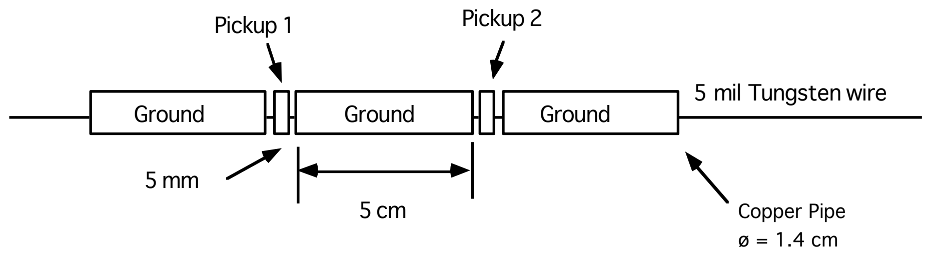
Axial Wire Position Measurement

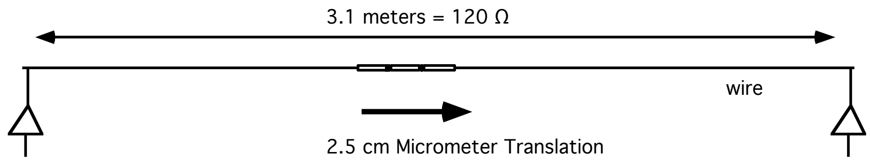


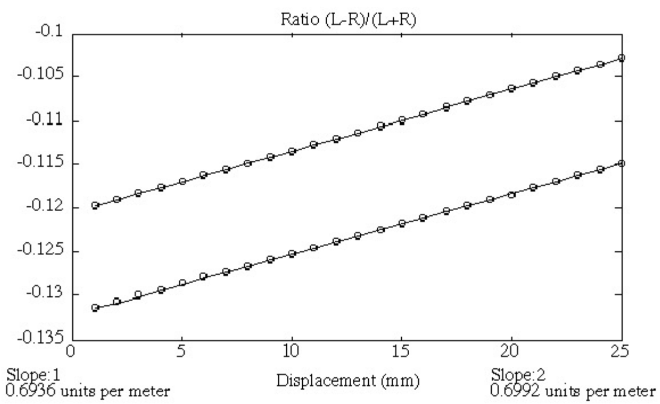
$$\frac{V_L - V_R}{V_L + V_R} = 2\,\frac{X_R - X_L}{X_{tot}}$$

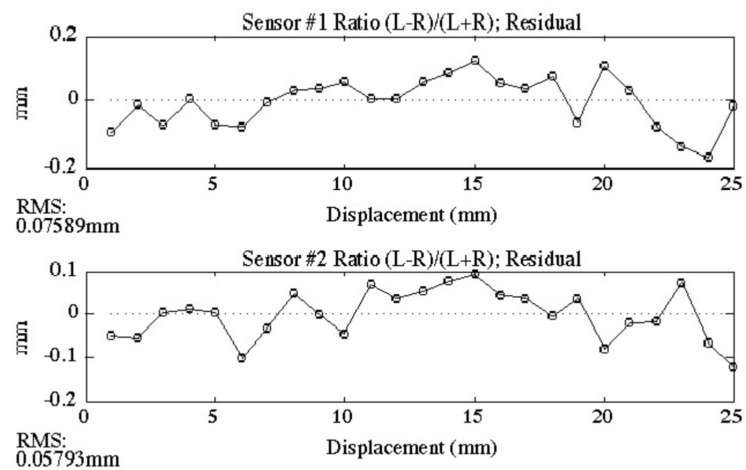
- In GEM, an axial wire resolution of 2-3 mm would help installation, survey, etc.
- Possible by charge division?
  - Use resistive wire (i.e. 200-10KΩ)
  - Transmit from one end, ground other (and vice-versa)
  - Capacitive pickoff is like potentiometer wiper...
- Resolution of 2-3 mm seems coarse, but over up to 15 meters...
  - Daunting

Short-Range Axial Tests

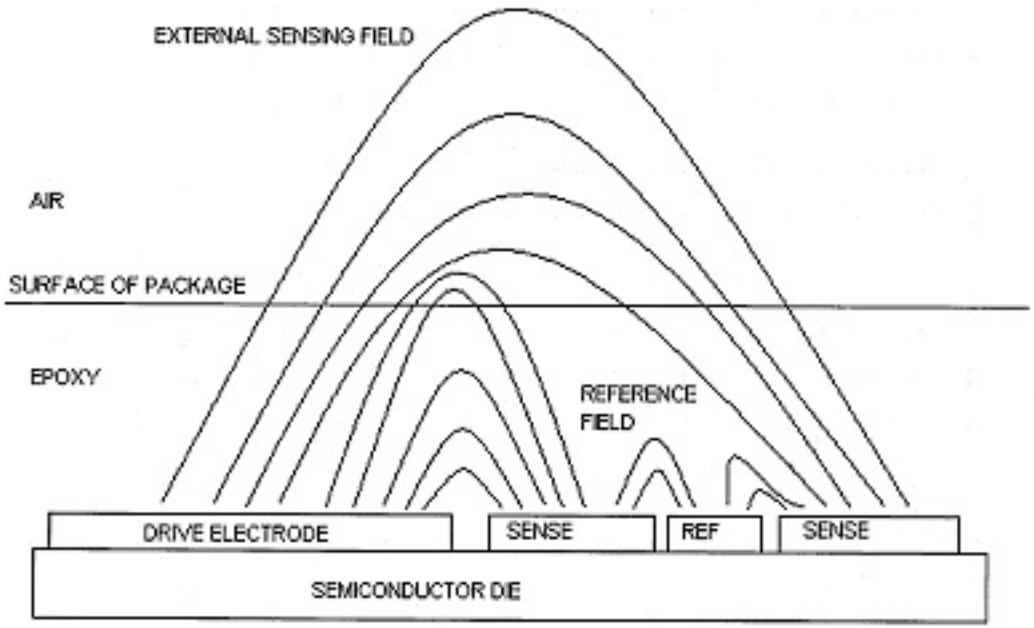


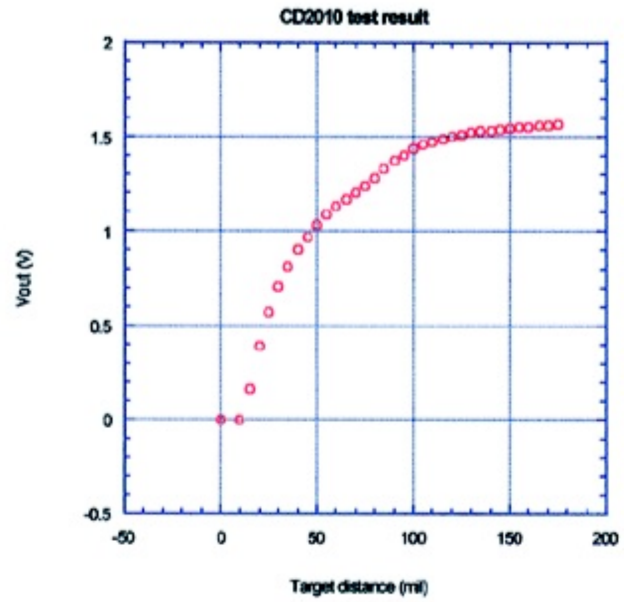






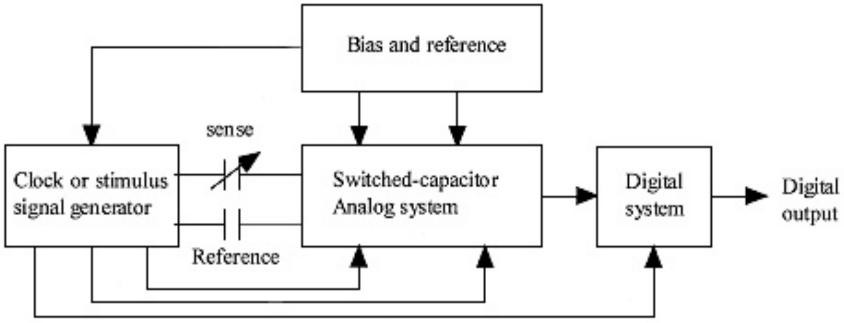
Capacitive Chip from Cherry Electrical Products



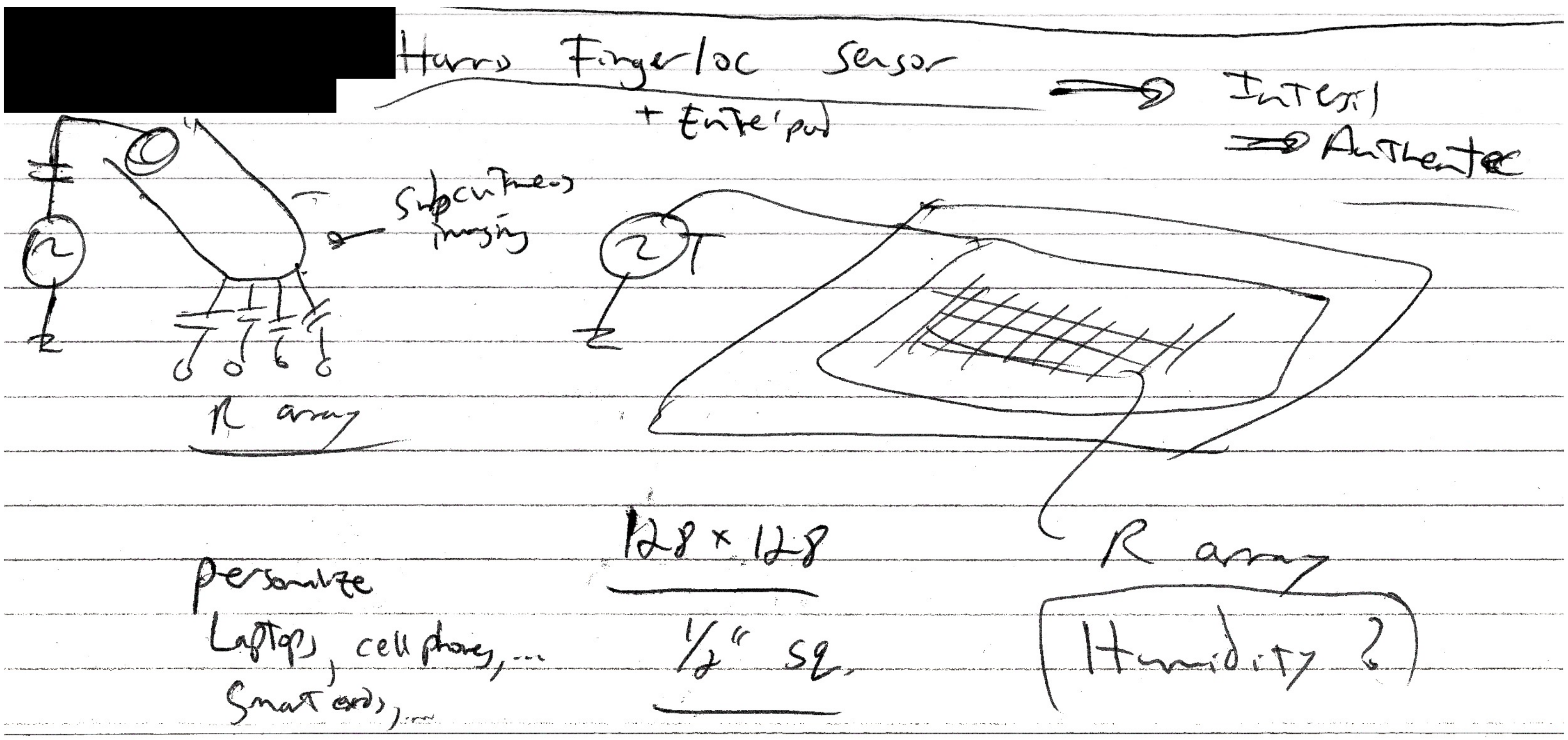


An idealized side view of the sensor shows the electrostatic field map. The fringe field set up between the drive and sense electrodes extends beyond the package surface, where a target will interrupt it and cause a measurable change in capacitance. The small fringe field between the reference and sense electrodes remains inside the package, insensitive to the presence of a target. The measurement circuitry must detect the difference between these two capacitance values.

- Self calibrating with reference drive
- Range is under a quarter-inch!
- Somewhat precise...



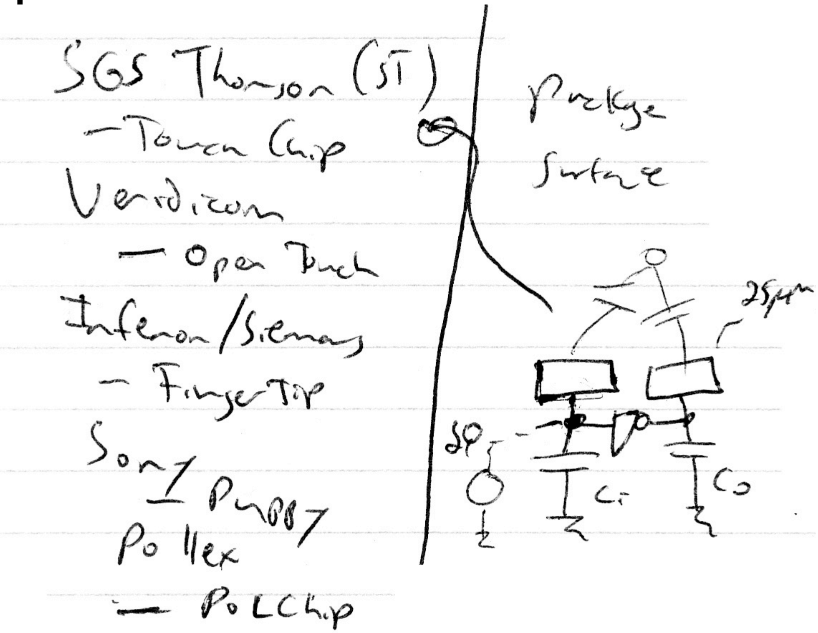
Capacitive Fingerprint Chips

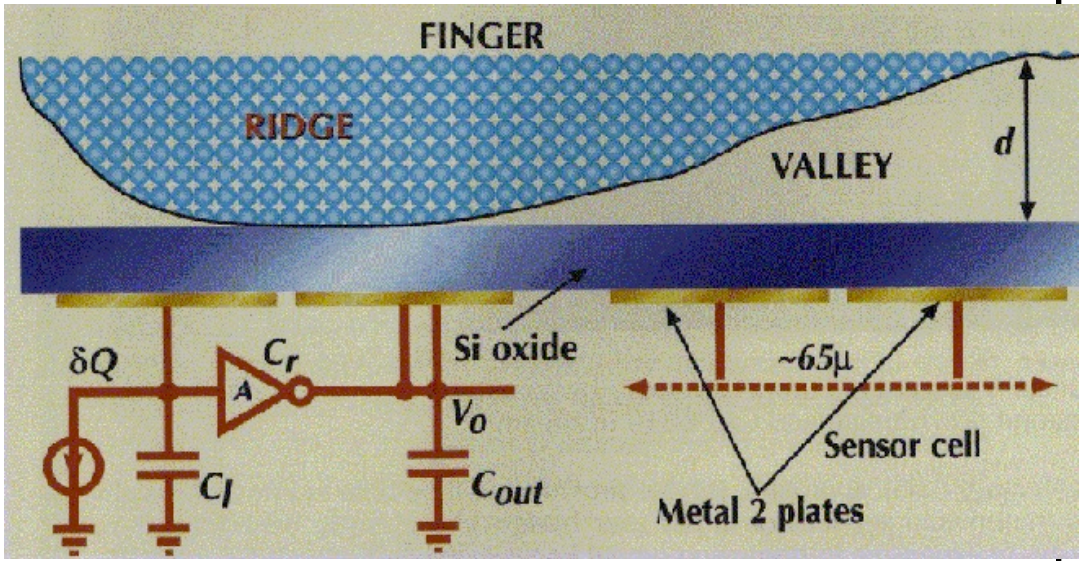


Authentic & Entrepad

Variety of devices produced, from 128 x 128 pixels down to 96 x 96 to 192 x 16

More capacitive fingerprint chips...





The cell works in two phases: first, the charge amplifier is reset, shorting input and output of the inverter. During this phase, output of the inverter settles to its logical threshold. During the second phase, a fixed amount of charge is sinked from the input, causing an output voltage swing inversely proportional to feedback capacitance value. Since feedback capacitance in inversely proportional to the distance of the skin, a linear dependence of output voltage on skin distance is expected. For a fixed amount of sinked charge, the output voltage of the inverter will range between two extremes depending on feedback capacitance value: 1) the upper saturation level if no feedback capacitance is present; 2) a value close to the logical threshold when the feedback capacitance is large.

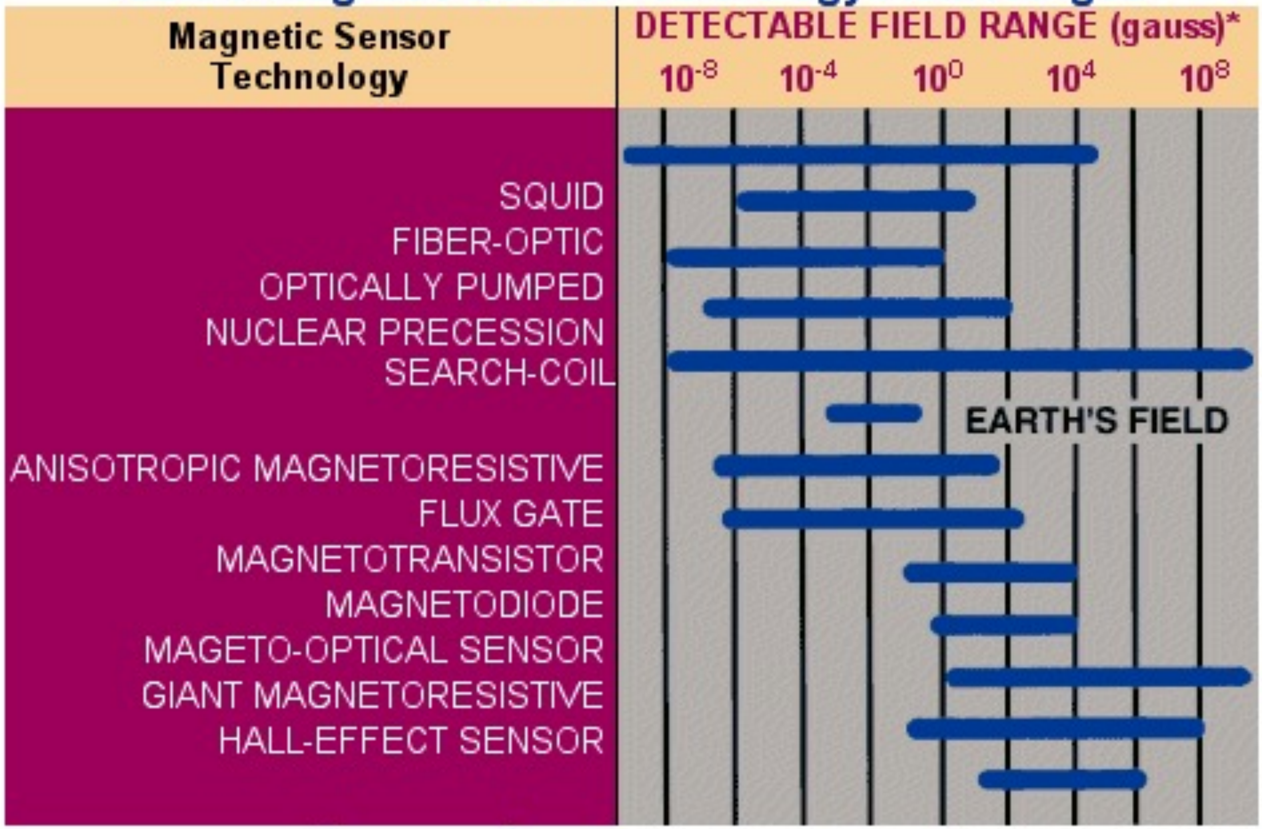
The current prototype is able to capture a fingerprint image at 390 dpi, enough to provide high-reliability fingerprint matching based on image processing algorithms. Future prototypes are expected to increase resolution to as much as 512 dpi.

THE UniBO FINGERPRINT CAPACITIVE SENSOR

U. Bolonga and SGS-Thompson

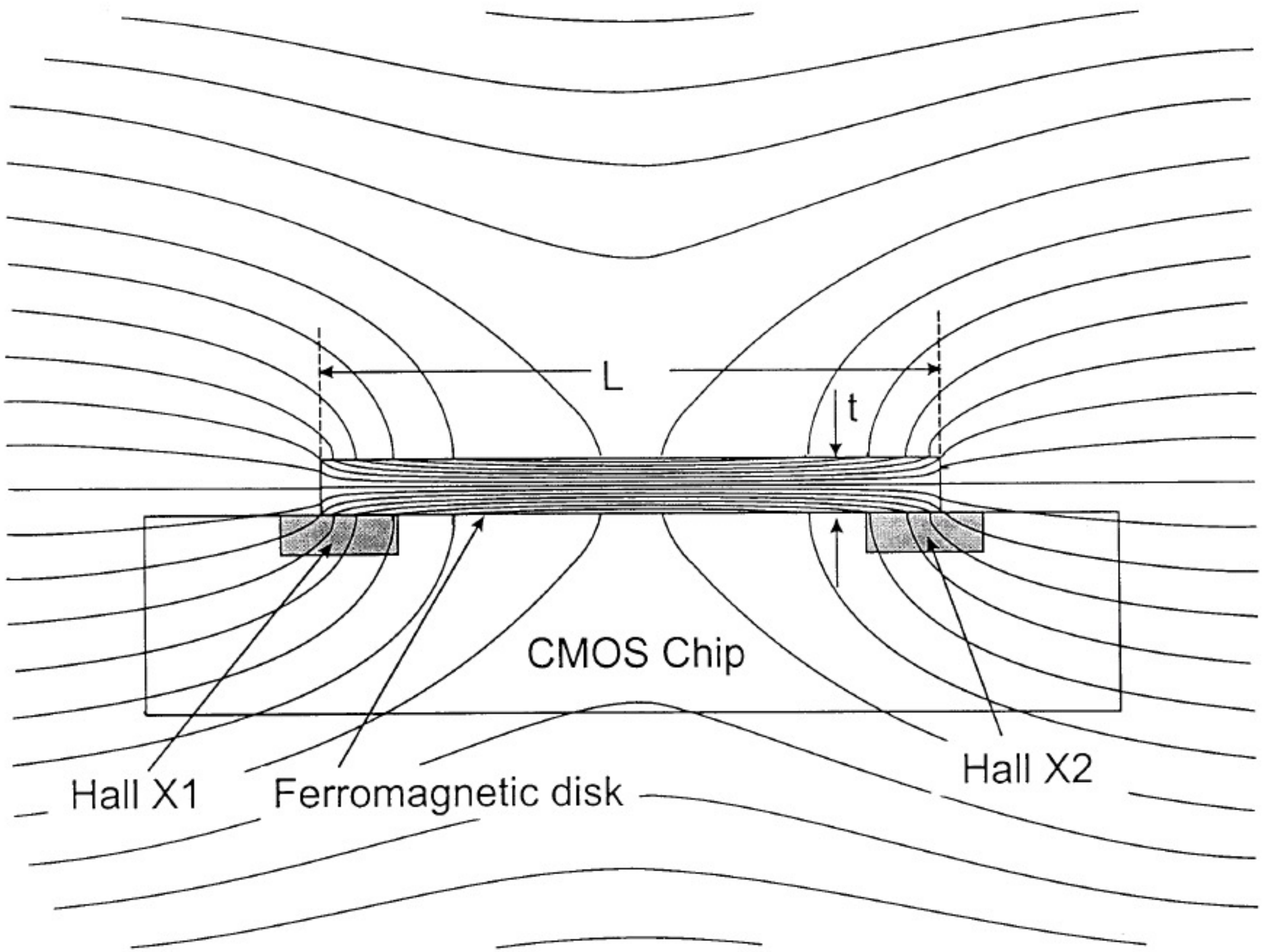
Magnetic Field Sensors

Table 1. Magnetic Sensor Technology Field Ranges



*Note: 1 gauss = 10^{-4} tesla = 10^{5} gamma

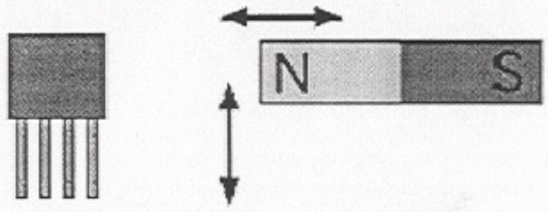
Flux Concentrators



Magnetic permiable material can attract flux lines and increase local magnetic field (hence sensitivity of small detectors – like a lens

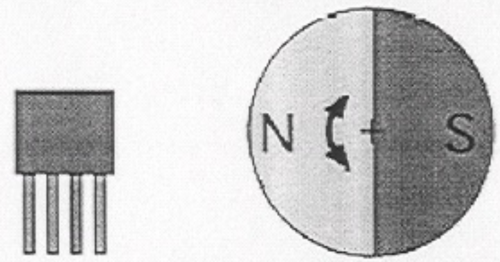
Some typical applications of magnetic field sensors

Translation Displacement



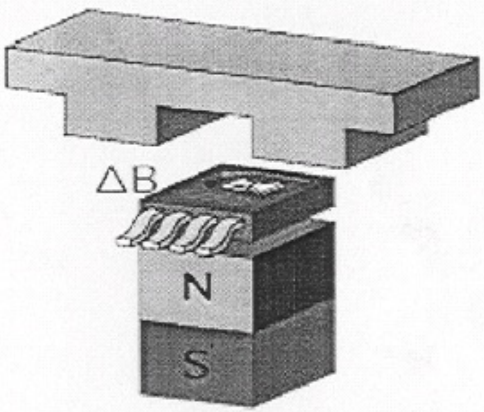
Long distance between the magnet and the sensor: Up to 15 cm.

Rotary Displacement



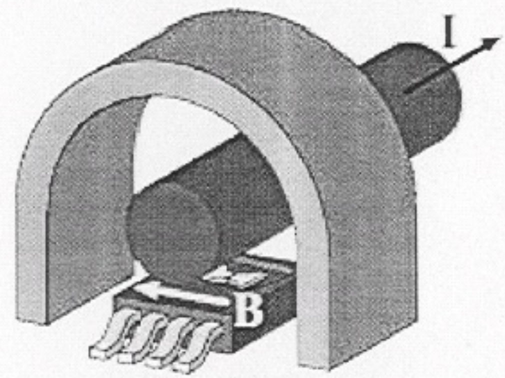
Long distance between the magnet and the sensor.

Lateral field Measurement



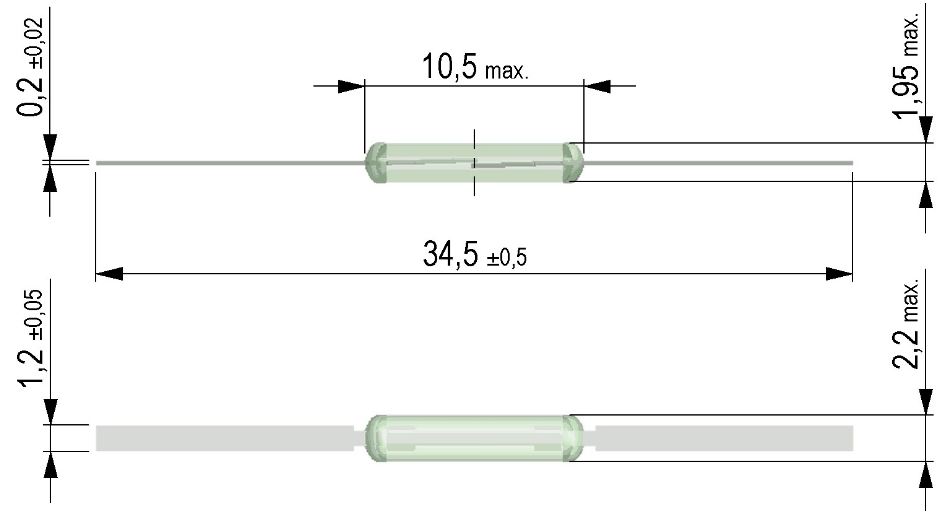
Our sensor is sensitive to a field parallel to the top surface of the package.

Current Measurement



Low current measurements. Simplification of the magnetic circuit geometry.

Magnetic Reed Switches



- Simplest magnetic sensor
- Passive operation
- Not extremely sensitive or high BW, but reliable
- Often used as door-close sensor, for example

Hall Sensors

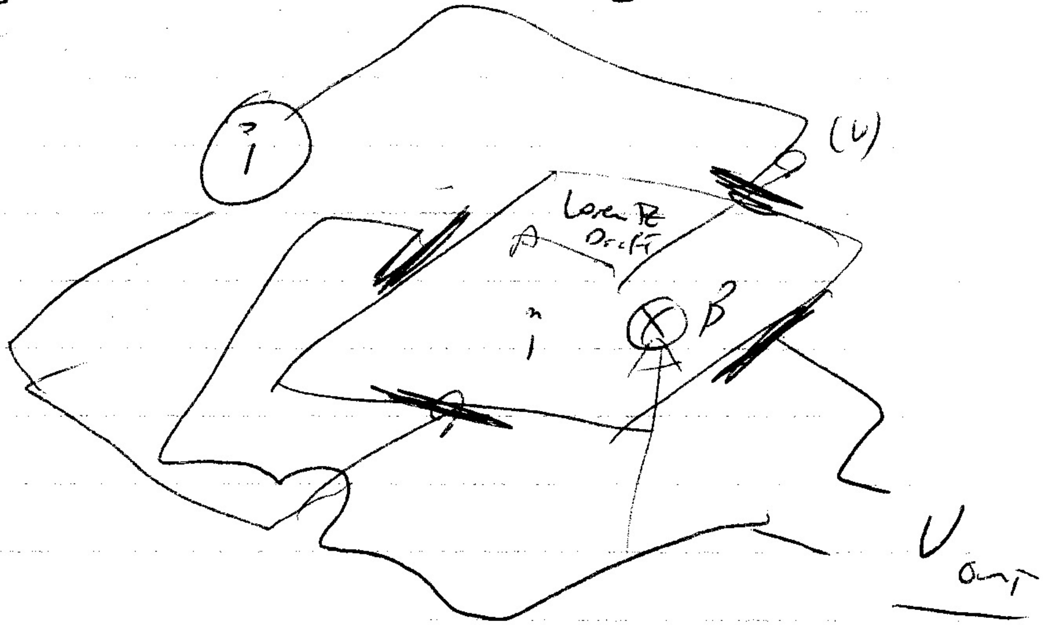
$$\vec{F}_L = -e\vec{V} \times \vec{B}$$

Magnetic Field Sensors

DC Field

— Hall Sensors

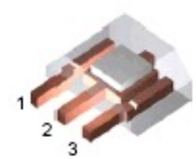
Work for Strong magnets out to several cm.

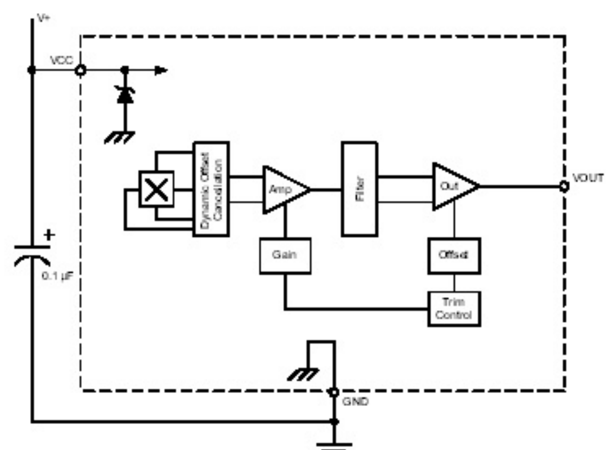


→ Allegro — www.allegromicro.com

Package UA, 3-pin SIP

1. VCC
2. GND
3. VOUT





Many Varieties...

Hall-Effect Sensor Selection Guides

* **Current Sensor Modules** (ACS750SCA-050, ACS750LCA-050, ACS750SCA-075, ACS750LCA-075, ACS750SCA-100, ACS750ECA-100)
The ACS750 is the latest in innovative, integrated solutions from Allegro MicroSystems and the first step in a new revolutionary line of fully-integrated in-circuit current sensors. This unique current-sensing assembly includes a high-current conductor, magnetic concentrator, and an optimized monolithic Hall IC in a convenient and compact package.
* **Unipolar Hall-Effect Digital Switches** (3121, 3122, 3123, 3141, 3142, 3143, 3144, 3240)
The unipolar Hall-effect switch is characterized by the magnetic operate threshold (Bop). If the Hall cell is exposed to a magnetic field from the south pole greater than the operate threshold, the output transistor is switched on; by dropping below the threshold (Brp), the transistor is switched off.
* **Micropower Omnipolar Hall-Effect Digital Switches** (3212, 3213, 3214)
Unlike other Hall-effect switches these devices switch on with the presence of either a north or south magnetic field that has sufficient strength; in the absence of a magnetic field the output is off. These switches have a lower supply voltage range as well (2.5 V to 3.5 V) and a sample period generated by a unique clocking scheme to reduce power requirements.
* **Bipolar Hall-Effect Digital Switches** (3132, 3133, 3134, 3425)
The bipolar Hall-effect switches generally switch on with a south pole of sufficient strength and switch off with a north pole of sufficient strength however the output state is not defined if the magnetic field is removed. To ensure the device switches an opposing magnetic field of sufficient strength should be used.
* **Hall-Effect Switches for Two Wire Applications** (1140, 1142, 1143, 1145, 1180, 1181, 1182, 1183, 1184, 3161, 3163, 3260, 3361, 3362)
The output signal for Hall-effect switches for two wire applications is based on their current consumption.
* **Programmable Hall-Effect Switches** (3250, 3251)
The programmable Hall-effect switch sensor can be programmed to the desired magnetic operate switch point.
* **Latching Hall-Effect Digital Switches** (3175, 3177, 3185, 3187, 3188, 3189, 3275, 3280, 3281, 3283)
The latching Hall-effect switches will always switch on with a south magnetic of sufficient strength and switch off with a north magnetic field of sufficient strength. The output will not change if the magnetic field is removed.
* **Linear Hall-Effect Sensors** (1321, 1322, 1323, 3503, 3515, 3516, 3517, 3518)
The linear Hall-effect sensors voltage output accurately tracks the changes in magnetic flux density.
* **Dual-Output Hall-Effect Digital Switches** (3275)
The dual-output Hall-effect device features two outputs which are independently activated by magnetic fields of opposite polarity.
* **Direction-Detecting Hall-Effect Digital Switches** (3422, 3425)
The direction-detection Hall-effect sensor is a new generation of special function integrated sensors that are capable of sensing the direction of rotation of a ring magnet.
* **Gear-Tooth/Ring-Magnet (Dual Element) Hall-Effect Sensors** (3059, 3060, 3064)
The gear-tooth/ring-magnet Hall-effect sensors are monolithic integrated circuits that are designed switch in response to differential magnetic fields created by ferrous targets.
* **Adaptive Threshold Sensor Modules** (ATS610LSA, ATS611LSB, ATS612LSB, ATS612LSG, ATS622LSB, ATS625LSG, ATS643LSH, ATS645LSH-I1, ATS645LSH-I2, ATS660LSB, ATS665LSG, ATS671LSE, ATS672LSB-LN)
The adaptive threshold sensors are smart sensors that learn about their targets to optimize the magnetic circuit detection. Each module combines in a compact high-temperature plastic package, a samarium-cobalt magnet, a pole piece, and a Hall-effect IC that has learning capability. These sensors can be easily used in conjunction with a wide variety of gear or target shapes and sizes.

Mark Feldmeier Likes This One These Days

A1321, A1322, and A1323
Ratiometric Linear Hall Effect Sensor ICs for High-Temperature Operation

The A1321 and A1323 devices are intended to replace the A3515/7 and A3516/8 devices respectively. It is recommended that these new devices be used for all new designs.

Features and Benefits

- Temperature-stable quiescent output voltage
- Precise recoverability after temperature cycling
- Output voltage proportional to magnetic flux density
- Ratiometric rail-to-rail output
- Improved sensitivity
- 4.5 to 5.5 V operation
- Immune to mechanical stress
- Solid-state reliability
- Robust EMC protection

Packages: 3 pin SOT23W (suffix LH), and 3 pin SIP (suffix UA)

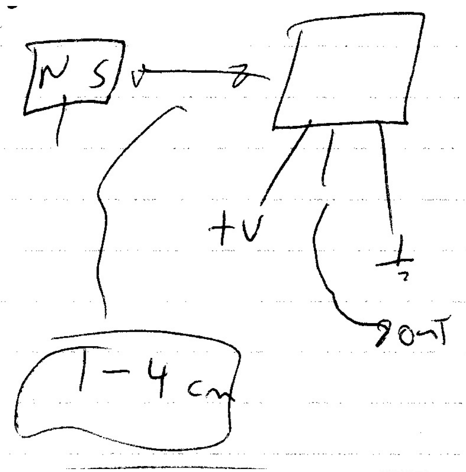
Not to scale

5 mA

Allegro

Packages and integrated sensors

— Gloves
— Encoders
— etc.
Analog Pens



ANALOG DEVICES

Hall sensor package

Linear Output Magnetic Field Sensor

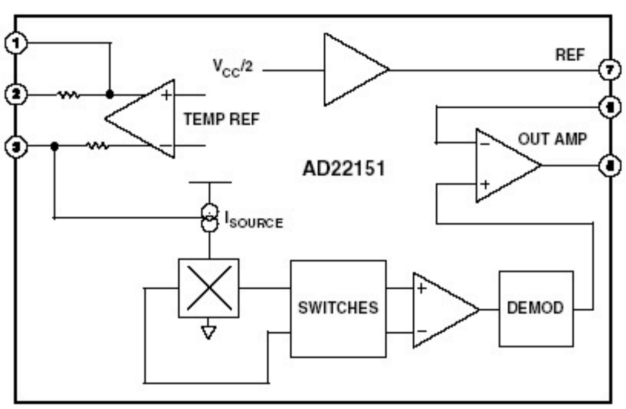
AD22151

FEATURES
Adjustable Offset to Unipolar or Bipolar Operation
Low Offset Drift over Temperature Range
Gain Adjustable over Wide Range
Low Gain Drift over Temperature Range
Adjustable First Order Temperature Compensation
Ratiometric to V_{CC}

APPLICATIONS
Automotive
- Throttle Position Sensing
- Pedal Position Sensing
- Suspension Position Sensing
- Valve Position Sensing

Industrial
- Absolute Position Sensing
- Proximity Sensing

FUNCTIONAL BLOCK DIAGRAM



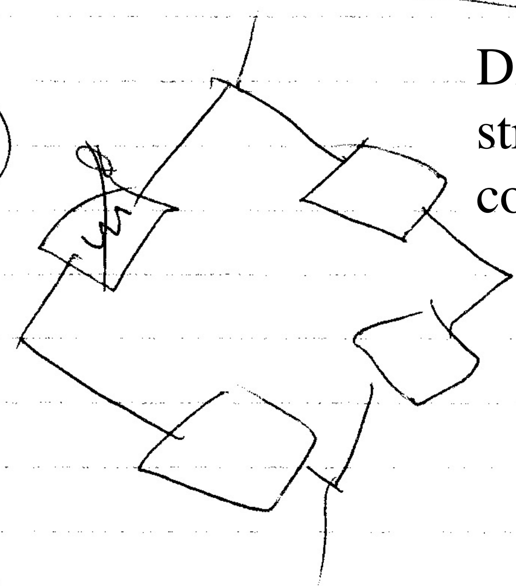
Permalloy

Permalloy Sensors [Ni - Fe]

→ magnetically sensitive resistance

2-3% change

1-5 MHz



Differential strapping for compasses

- Phillips KMZ series
- Honeywell (HMC)

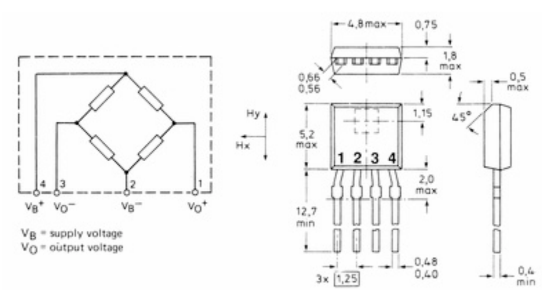
→ Very sensitive [Compass !!]

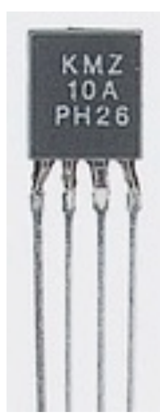
→ Low R bridge (200Ω) — High current

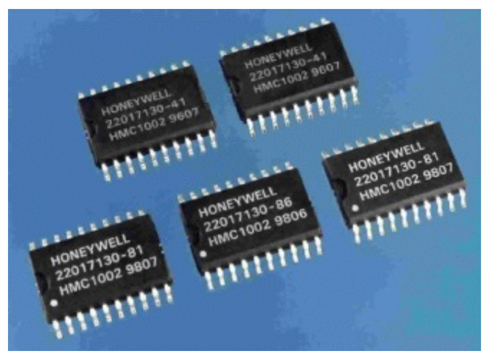
→ Permalloy can demagnetize → Strap!

→ GMR

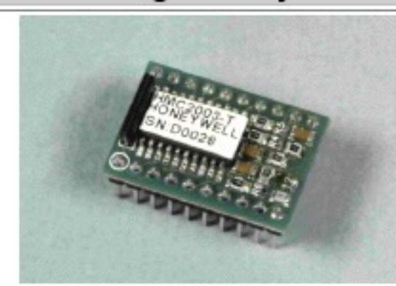
Sandwich 70% R change







HMC2003 Magnetic Hybrid

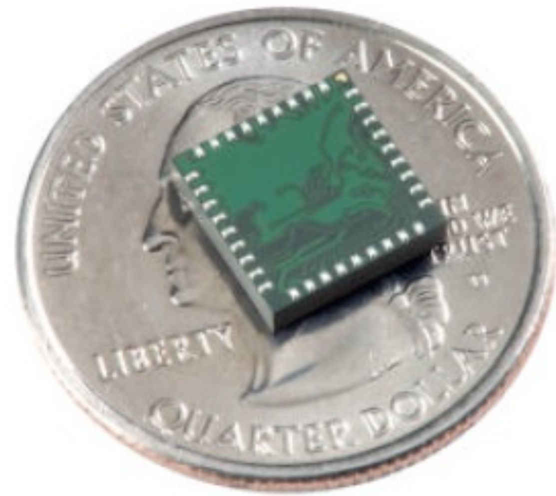


+/- 2 Gauss max range

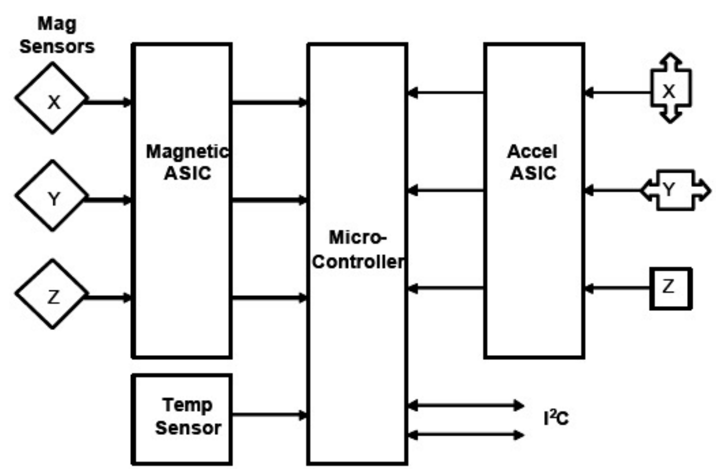
Digital 3-axis tilt-compensated compass

3-Axis Compass with Algorithms HMC6343

The Honeywell HMC6343 is a fully integrated compass module that includes firmware for heading computation and calibration for magnetic distortions. The module combines 3-axis magneto-resistive sensors and 3-axis MEMS accelerometers, analog and digital support circuits, microprocessor and algorithms required for heading computation. By combining the sensor elements, processing electronics, and firmware into a 9.0mm by 9.0mm by 1.9mm LCC package, Honeywell offers a complete, ready to use tilt-compensated electronic compass. This provides design engineers with the simplest solution to integrate high volume, cost effective compasses into binoculars, cameras, night vision optics, laser ranger finders, antenna positioning, and other industrial compassing applications.



FEATURES	BENEFITS
Compass with Heading/Tilt Outputs	A complete compass solution including compass firmware
3-axis MR Sensors, Accelerometers and a Microprocessor in a Single Package	A digital compass solution with heading and tilt angle outputs in a chip-scale package
Compass Algorithms	For computation of heading, and magnetic calibration for hard-iron
9 x 9 x 1.9mm LCC Surface Mount Package	Small size, easy to assemble and compatible with high speed surface mount technology assembly
Low Voltage Operations	Compatible with battery powered applications
EEPROM Memory	To store compass data for processor routines
Digital Serial Data Interface	I²C Interface, easy to use 2-wire communication for heading output
Moderate Precision Outputs	Typical 2° Heading Accuracy with 1° Pitch and Roll Accuracy
Lead Free Package Construction	Complies with RoHS environmental standards
Flexible Mounting	Can be mounted on horizontal or vertical circuit boards



Now commonly integrated into IMUs

AMR vs. GMR magnetic field sensors

CHARACTERISTICS OF SOME AMR AND GMR SINGLE-AXIS MAGNETIC SENSORS

T-4/32

CHARACTERISTICS (*1)	AMR HMC1021	AMR KMZ10A	GMR AA005-02	UNIT
a) Full Scale Field Range (FS)	0.6 (*2)	0.6 (*2)	7 (*3)	mT
b) Sensitivity (typical)	50	64	27.5	mV/mT
c) Bandwidth (BW)	5	1	1	MHz
d) Linearity Error within FS	1.6	4	2	%FS
e) Hysteresis Error within FS	0.3	0.5	3	%FS
f) Equivalent Offset at 300K	30	19	10	%FS
g) Offset TemCoef. Error (*4)	0.1	0.47	0.22	μT/K
h) 1/f Noise Density at 1 Hz	1	n.a.	16 (*5)	nT/√Hz
i) White Noise Density (*6)	0.1	0.1	0.2	nT/√Hz
Resolution:				
j) For a quasi-DC field (*7)	3	30	210	μT
k) For low freq. fields (*8)	8.5	n.a.	140	nT
l) For high freq. fields (*9)	0.1	0.1	0.2	nT

Notes (*):
(1) At the supply voltage of 5V.
(2) If exposed to a field higher than 2 mT, the sensor has to be reset.
(3) Maximum rating: 30 mT.
(4) Without Set/Reset offset reduction.
(5) Our own measurement.
(6) Equivalent noise field at a sufficiently high frequency, beyond the 1/f region.
(7) After zeroing the initial offset, without Set/Reset offset reduction, within $\Delta T = 10K$: (j) = 0.01 (e) FS + (g) ΔT + (k).
(8) (k) = Peak to peak equivalent noise field: 7 x (rms noise field, $0.1 < f < 10Hz$).
(9) For BW << 1Hz, we take (l) ≈ (i) √1Hz. Otherwise, (l) is proportional to √BW.

Compasses...

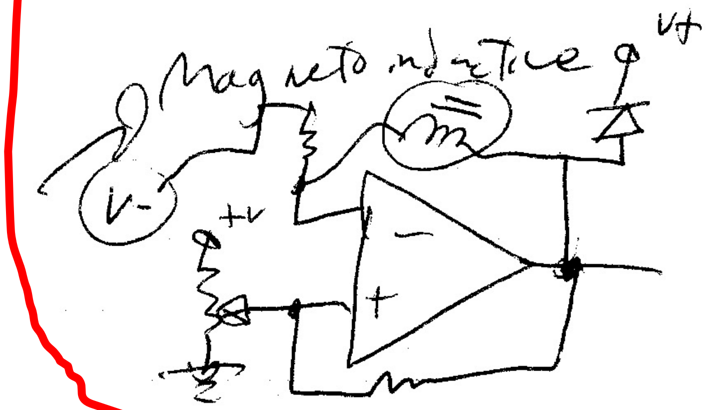
Head Trackers

→ Vector 2X Types (Precision Navigation)

→ KVH Fluxgate

→ Dinsmore

→ Compasses often Packaged with TILT Sensors

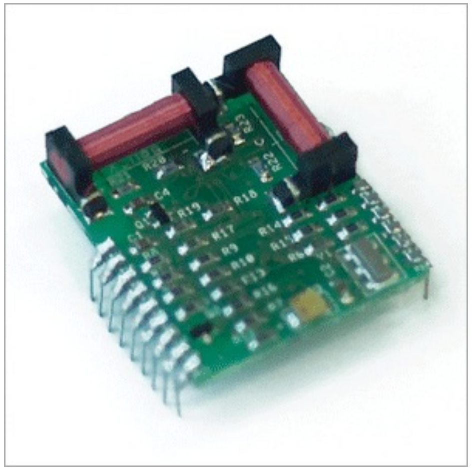


Coil is inductive in L/R relaxation oscillator

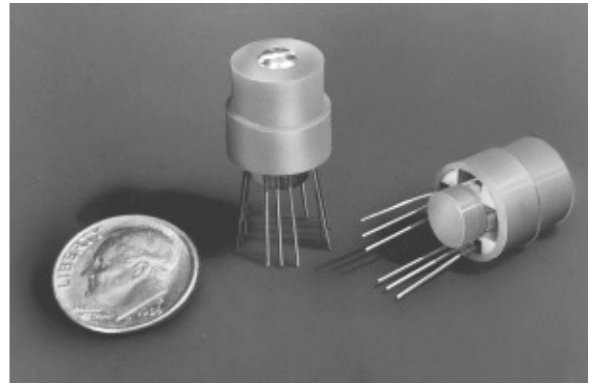
$f \propto L \propto B$

Core permeability changes in B, hence L changes

Compasses...



Vector 2X



Dinsmore

Compass needle
Angle sensed
with Hall sensors

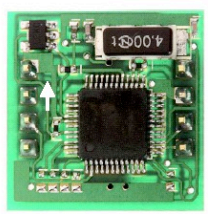
HMR3100

Honeywell
SENSOR PRODUCTS

DIGITAL COMPASS SOLUTION

Features

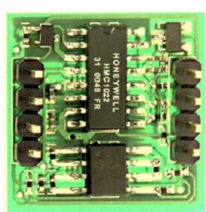
- 5° Heading Accuracy, 0.5° Resolution
- 2-axis Capability
- Small Size (19mm x 19mm x 4.5mm), Light Weight
- Advanced Hard Iron Calibration Routine for Stray Fields and Ferrous Objects
- 0° to 70°C Operating Temperature Range
- 2.6 to 5 volt DC Single Supply Operation



Top Side

General Description

The Honeywell HMR3100 is a low cost, two-axis electronic compassing solution used to derive heading output. Honeywell's magnetoresistive sensors are utilized to provide the reliability and accuracy of these small, solid state compass designs. The HMR3100 communicates through binary data and ASCII characters at four selectable baud rates of 2400, 4800, 9600, or 19200. This compass solution is easily integrated into systems using a simple USART interface.



Bottom Side

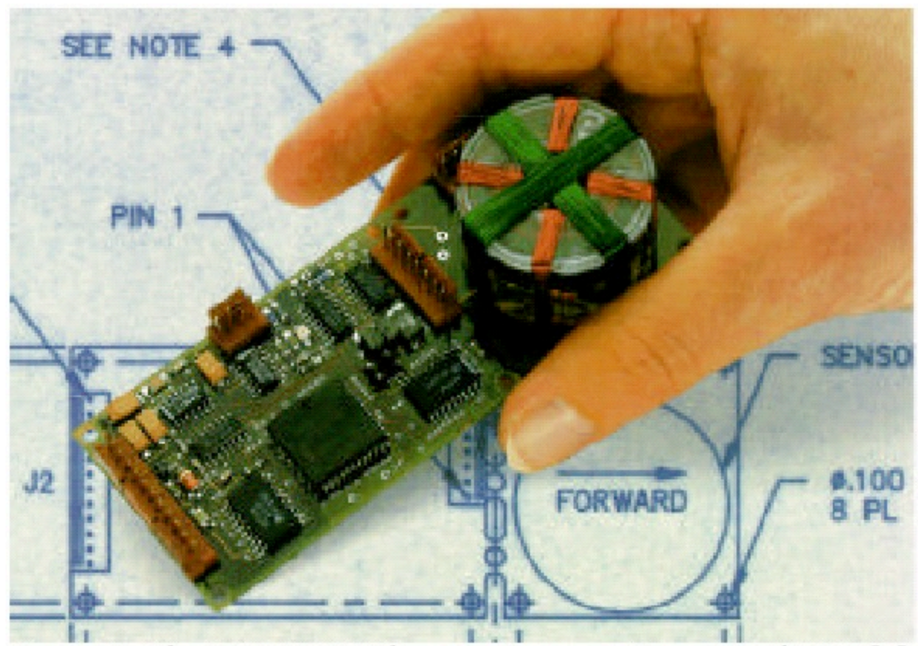
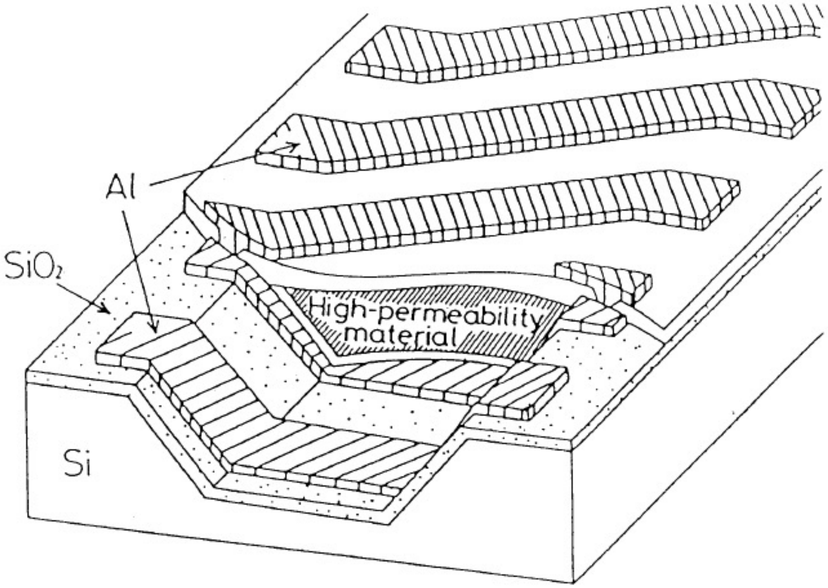
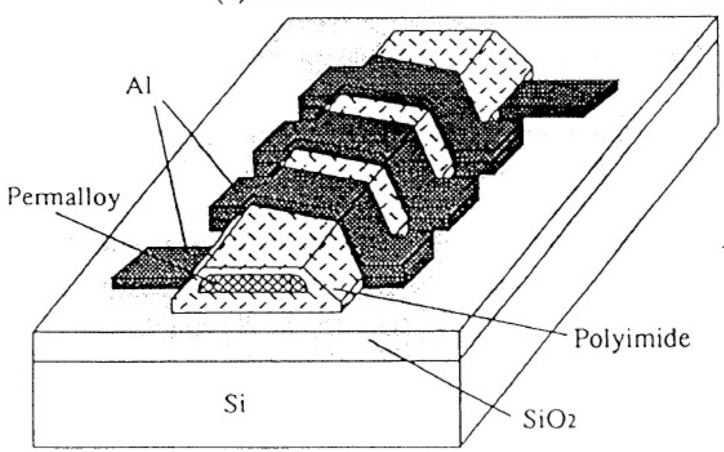


Figure 5: The KVH C-100 Fluxgate Compass. Courtesy of KVH [2].

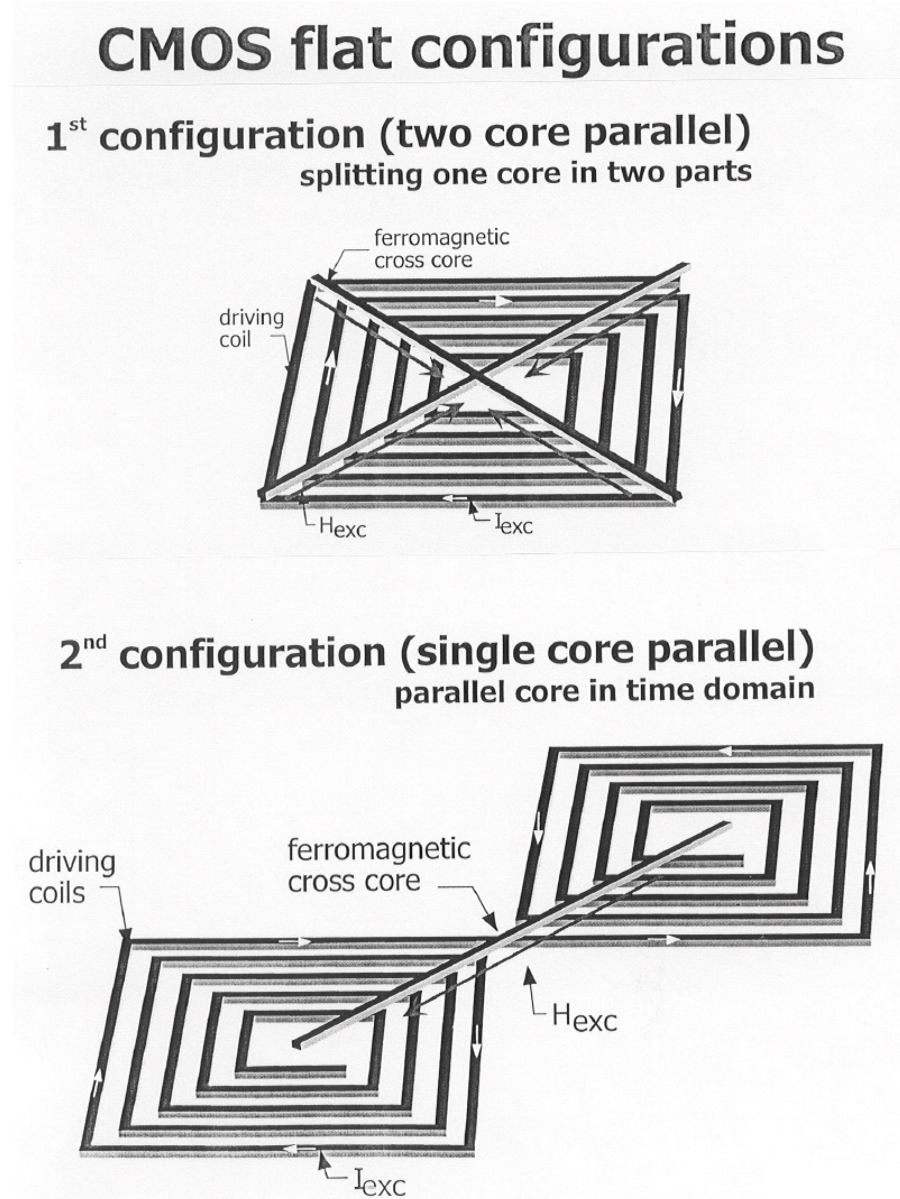
IC incarnations of FluxGate Sensors



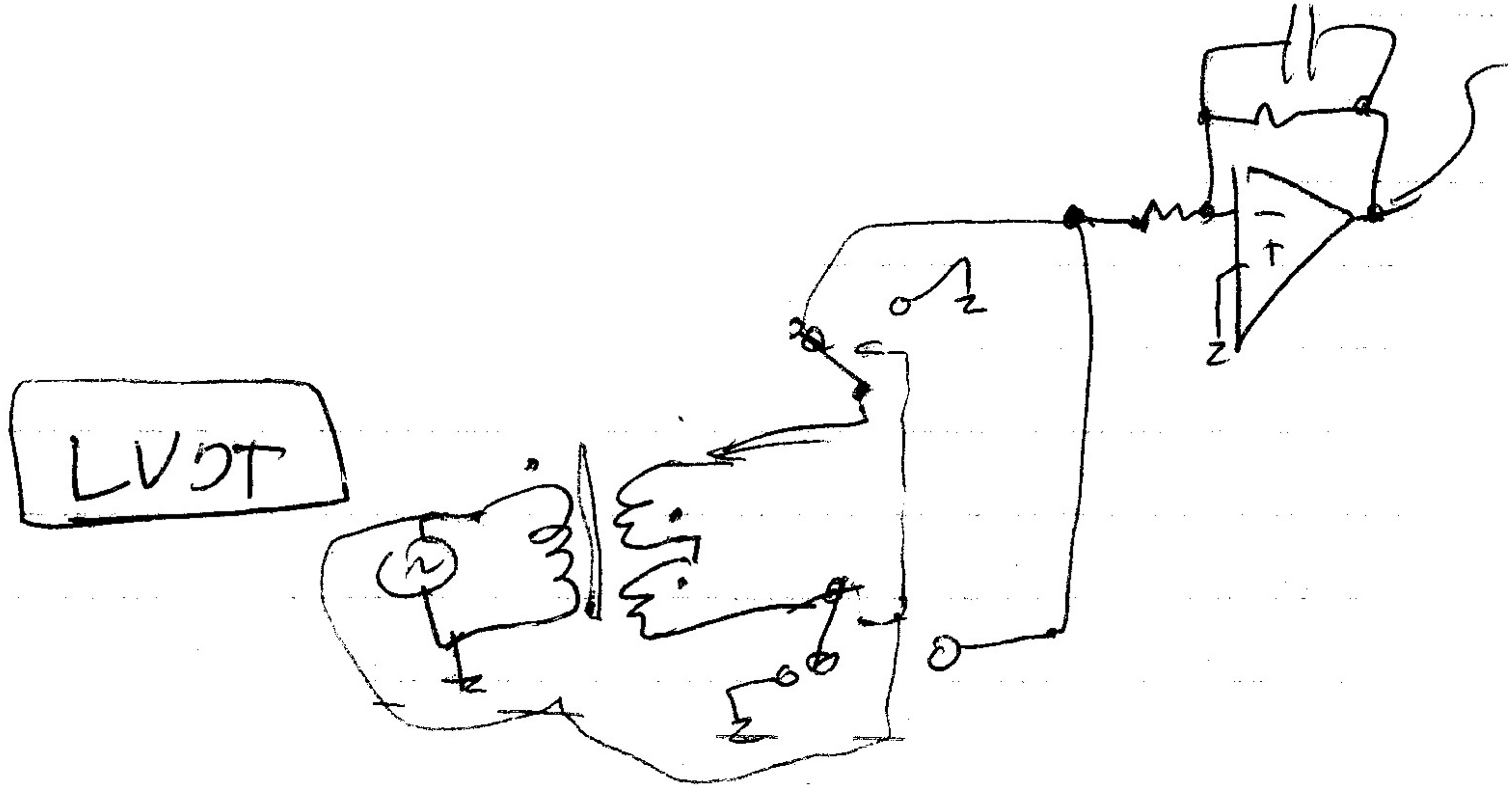
(a) Rod core sensor



(b) Thin-film core sensor

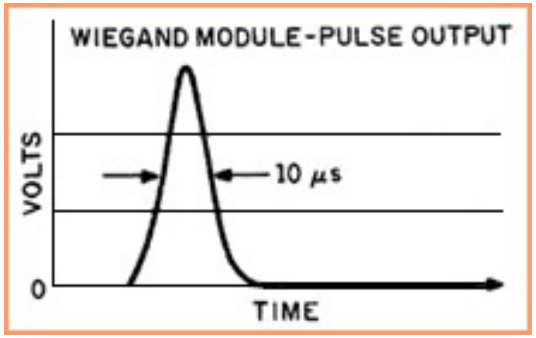


The LVDT

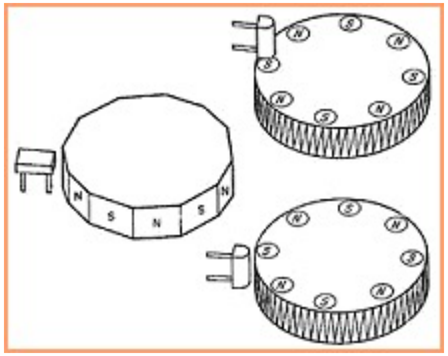


Very precise displacement sensing of core as receive coil asymmetry increases with core displacement

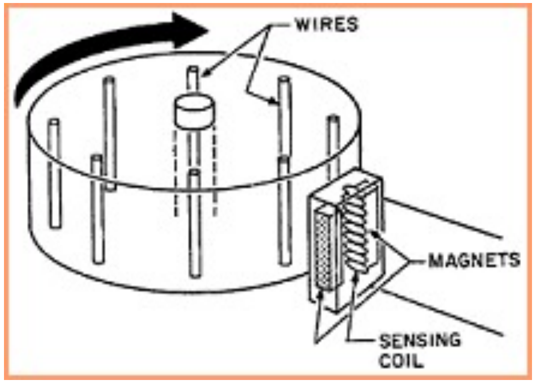
The Wiegand Effect



Weigand pulses tend to be short (HF components!)



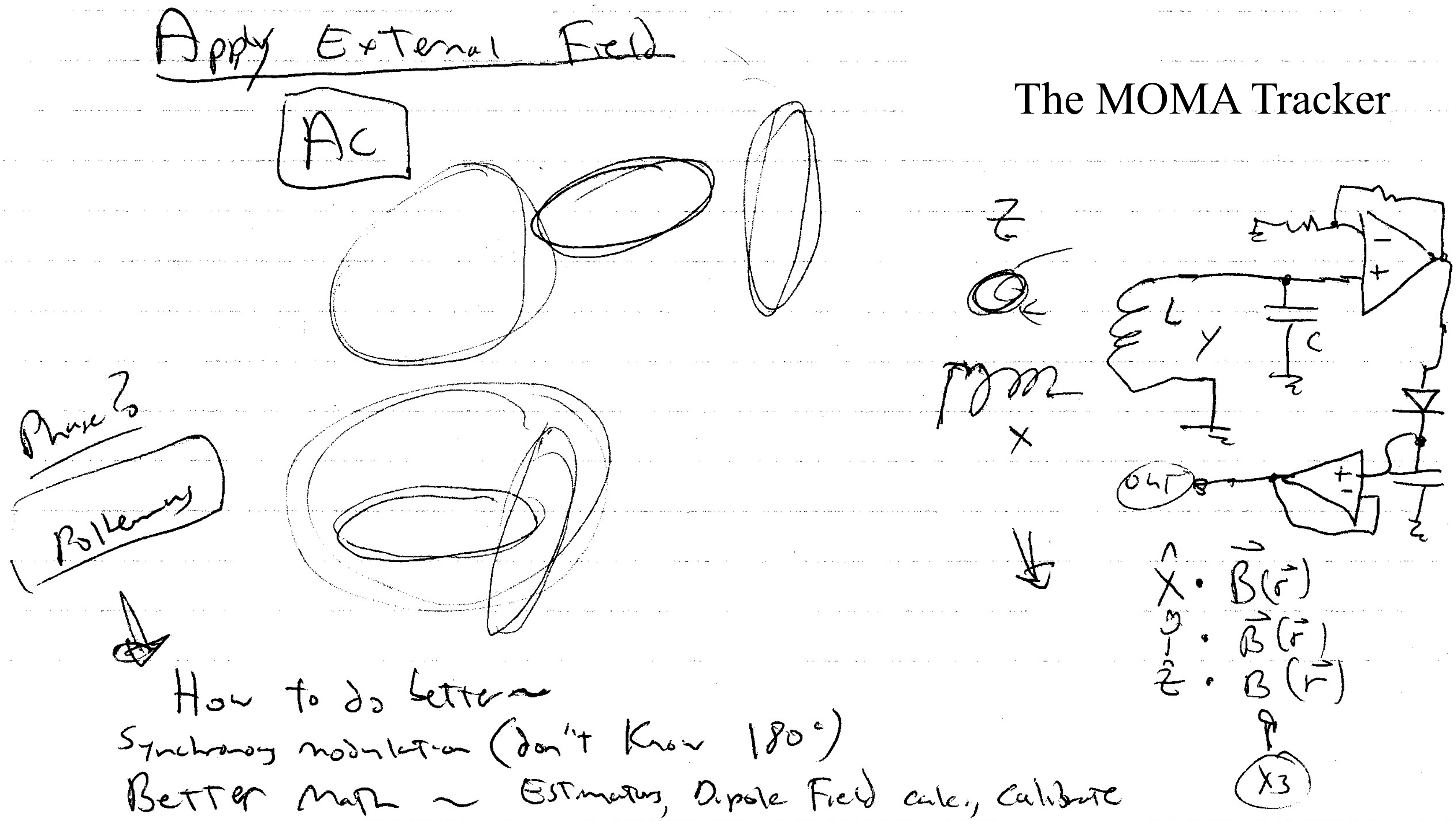
Shaft encoder w. alternating poles on disk



Shaft encoder w. distributed Weigand wires

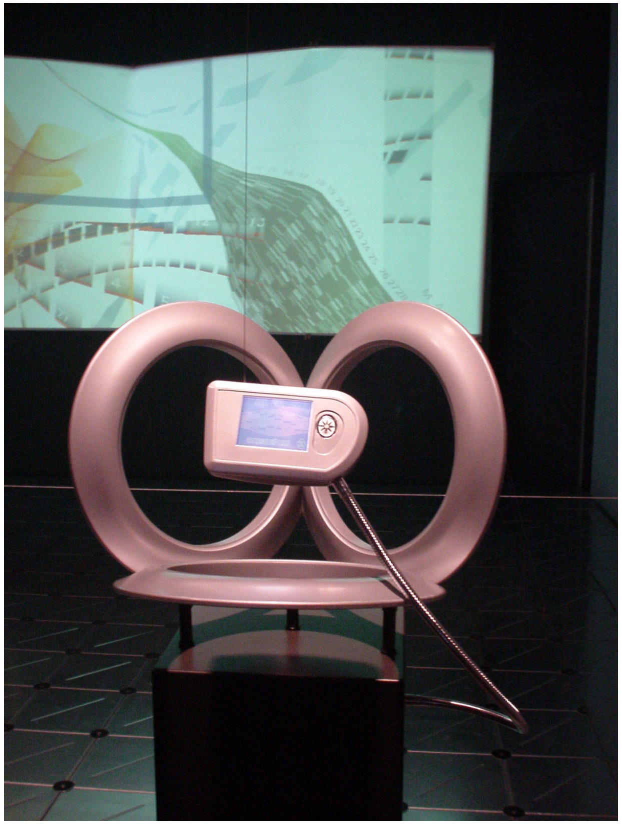
- Metal wire made with large Magnitization hysteresis
  - At a certain magnetic field strength, all domains reverse together
  - Produces a voltage pulse (e.g., 2-6 V into 24K Ohms) when domains switch.
    - Also produces a magnetic field pulse (J-Wires for library-book antitheft systems)
  - Pulse can be readout for magnetic field switch
  - Products exist…

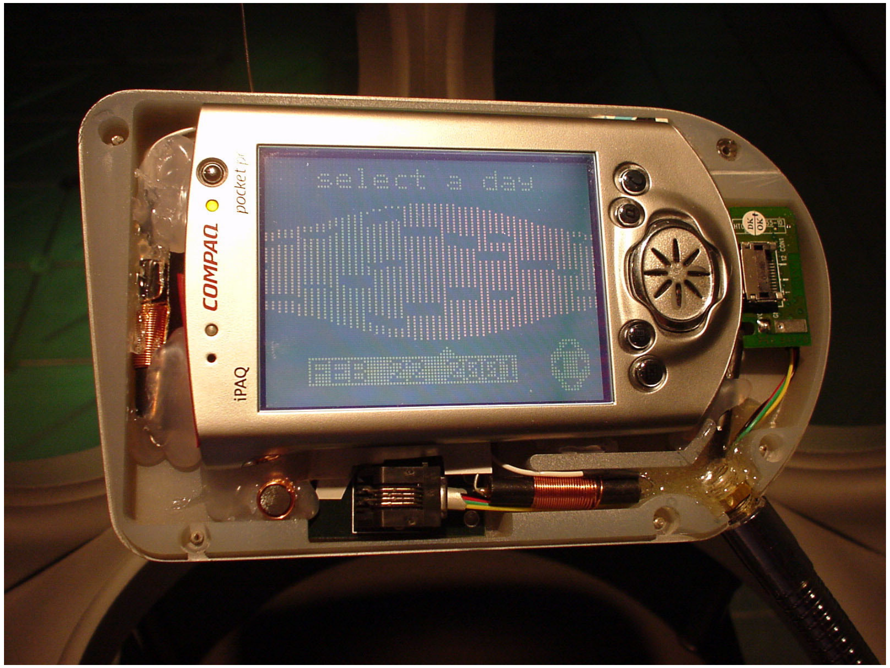
Magnetic Field Trackers



Polemis actively points magnetic field at pickup (dithers for control)

Active Magnetic Tracking

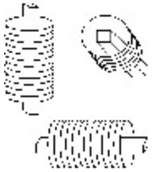




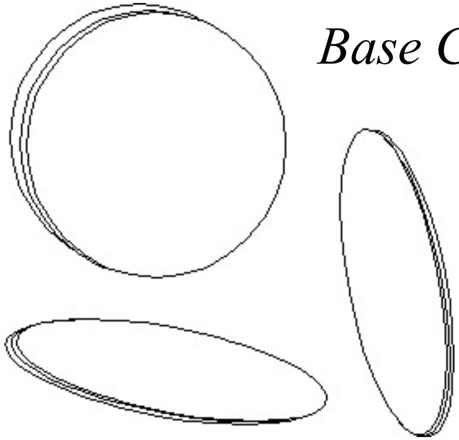
MOMA Installation, 1/01

Workspheres

Collaboration with Maeda group

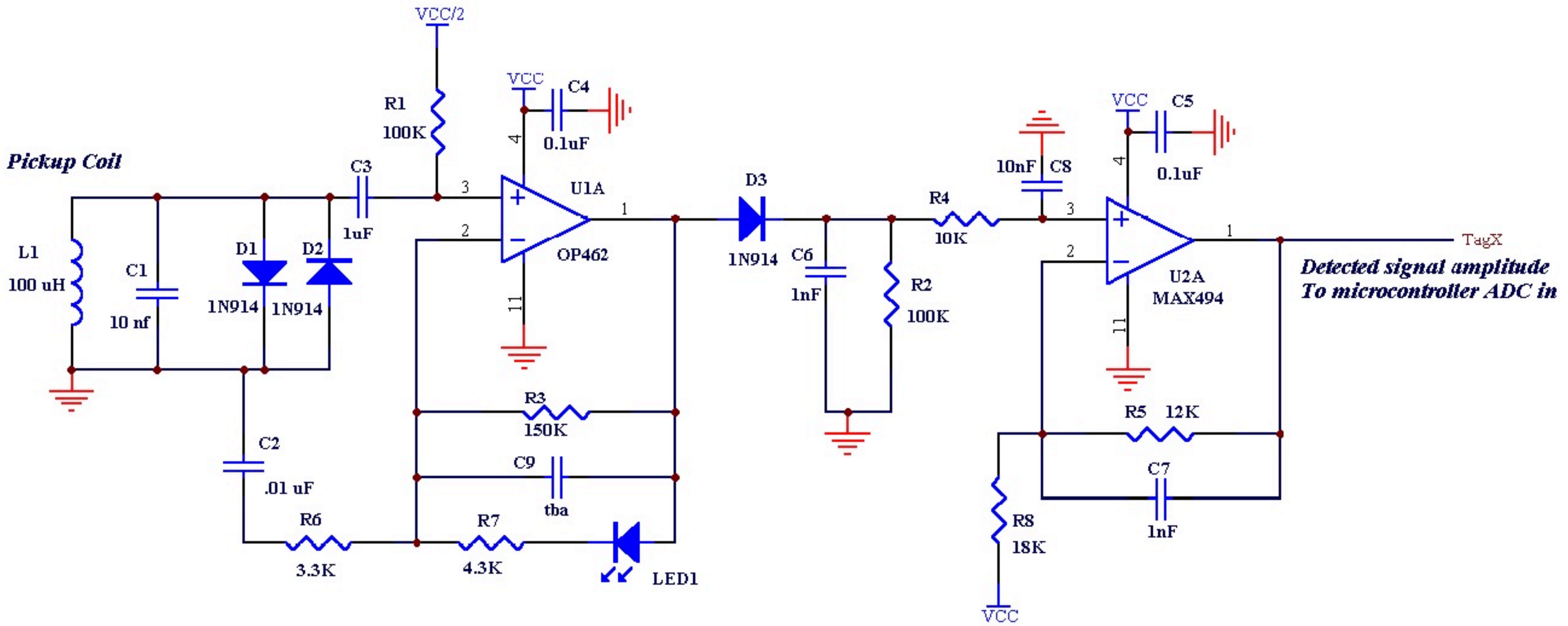


PDA Coils



Base Coils

The MOMA Electronics

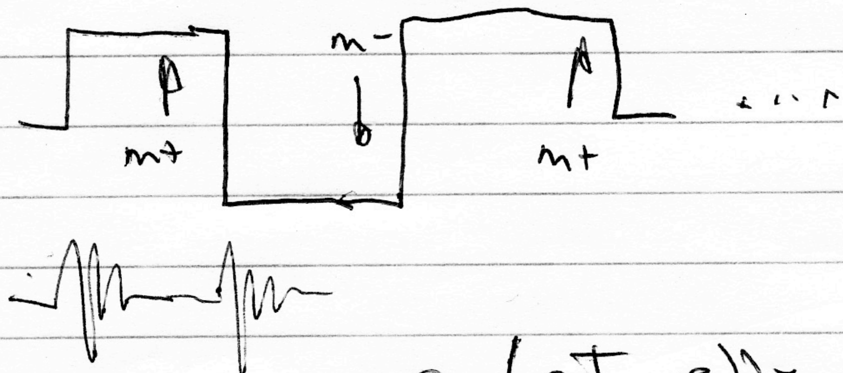


Flock of Birds Technique

Flock of Birds or Ascension

Although $\vec{B}$ sees through skin,
Eddy current cause distortion, shielding.

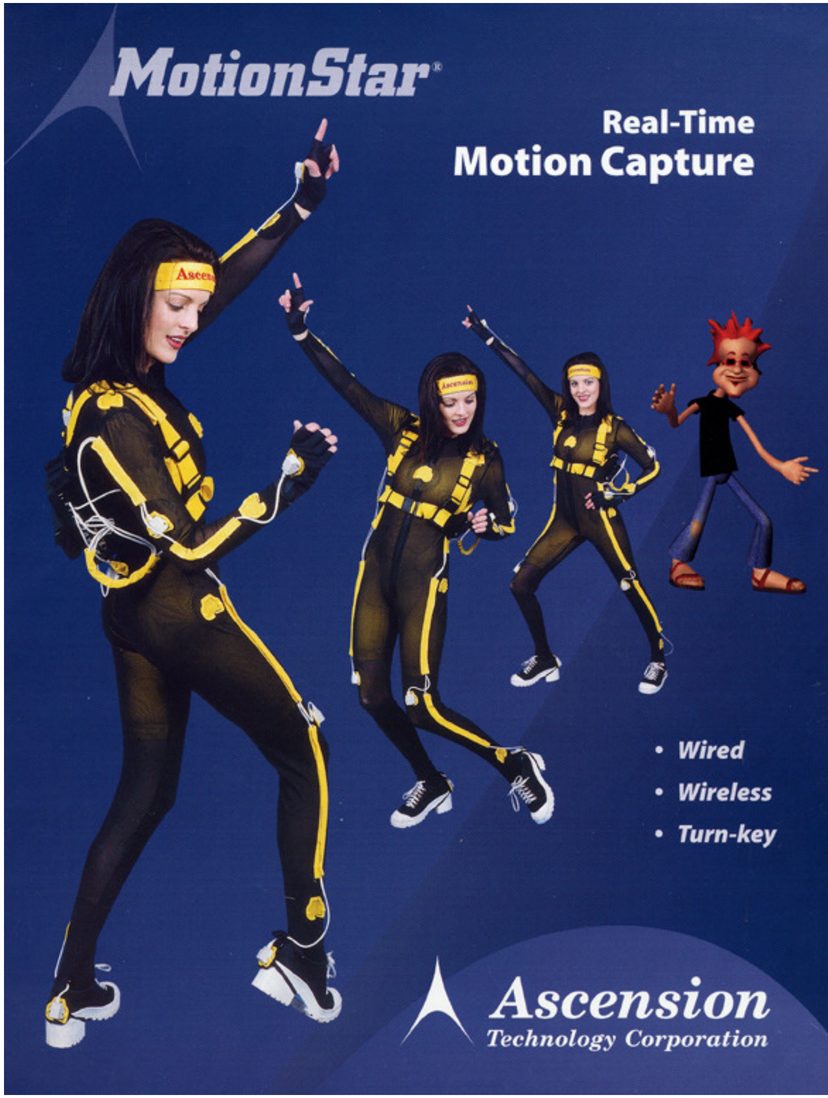
Use quasi-DC mode:



$$\Sigma (m^+ - m^-)$$

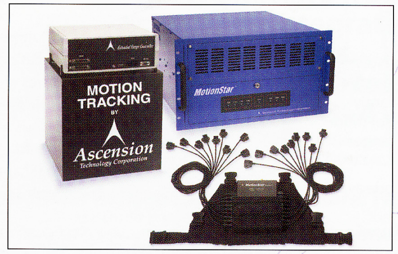
→ Let eddy current die away before measurements.

Commercial magnetic trackers



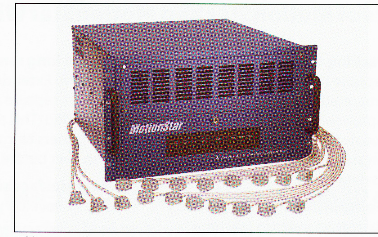
www.ascension-tech.com

MotionStar Wireless



TECHNICAL	
Degrees of freedom:	6: (position and orientation)
Max. number of sensors:	80 (20 per performer) plus 2 serial interface inputs for user devices
Translation range:	±10 ft in any direction, 2 transmitters max.
Angular range:	All-attitude: ±180° Azimuth & Roll, ±90° Elevation
Static Accuracy position:	0.3 inch RMS at 5 ft range, 0.6 inch RMS at 10 ft range
Static Accuracy orientation:	0.5° RMS at 5 ft range 1.0° RMS at 10 ft range
Static Resolution position:	0.03 inch at 5 ft range 0.10 inch at 10 ft range
Static Resolution orientation:	0.1° at 5 ft range 0.2° at 10 ft range
Update rate:	Up to 100 measurements/second
Outputs:	X,Y,Z position and orientation angles, rotation matrix, or quaternions
Interface:	Ethernet, RS232C
Line of sight restrictions:	None
Metallic Distortion:	Minimal; keep transmitter & sensors away from floor, walls and ceiling
PHYSICAL	
Performer Mounted Components—	
Sensors:	1.0" x 1.0" x 0.8" (L x W x H) (attached via wires to electronics unit in backpack) *Weight:* 0.6 oz. per sensor without cable
Backpack:	6.9" x 5.5" x 2.0" (L x W x H), Weight: 35 oz.
Battery (L x W x H):	5.9" x 2.6" x 0.9", Weight: 19 oz.
Operating time:	Up to 2 hrs. continuous
Base Station Components—	
MotionStar Chassis:	18" x 19" x 10" (L x W x H), Weight: 45 lbs.
Remote Sensor Unit:	6.5" x 4.2" x 2.5" (L x W x H), Weight: 0.7 lbs.
Extended Range Controller:	9.5" x 11.5" x 4.8" (L x W x H), Weight: 6.5 lbs.
Extended Range Transmitter	12" x 12" x 12" (L x W x H), Weight: 45 lbs.
Environment:	Metal objects and stray magnetic fields in the operation volume will degrade performance

MotionStar



This system also includes the Extended Range Transmitter & Controller.

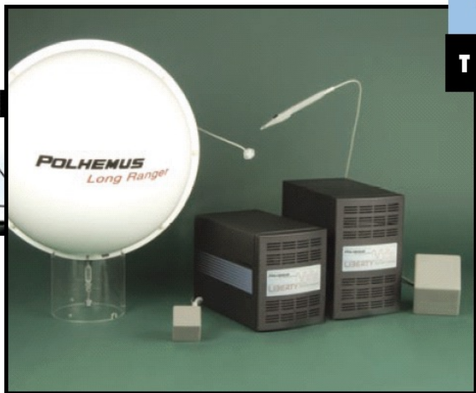
TECHNICAL	
Degrees of freedom:	6: (position and orientation)
Max. number of sensors:	108 (18 per performer)
Translation range:	±10 ft in any direction, 2 transmitters max.
Angular range:	All-attitude: ±180° Azimuth & Roll; ± 90° Elevation
Static Accuracy position:	0.3 inch RMS at 5 ft range 0.6 inch RMS at 10 ft range
Static Accuracy orientation:	0.5° RMS at 5 ft range 1.0° RMS at 10 ft range
Static Resolution position:	0.03 inch at 5 ft range 0.10 inch at 10 ft range
Static Resolution orientation:	0.1° at 5 ft range 0.2° at 10 ft range
Update rate:	Up to 120 measurements/second
Outputs:	X,Y,Z position and orientation angles, rotation matrix, or quaternions
Interface:	Ethernet, RS232C
Line of sight restrictions:	None
Metallic Distortion:	Minimal; keep transmitter & sensors away from floor, walls and ceiling
PHYSICAL	
Transmitter:	12" x 12" x 12" (L x W x H), Weight: 45 lbs.
Sensor:	1.0" x 1.0" x 0.8" cube with 35' cables
Enclosure:	Each rack-mounted chassis houses up to 18 sensor cards with integrated power supply and interface
Environment:	Metal objects and stray magnetic fields in the operation volume will degrade performance

Ascension
Technology Corporation

Commercial magnetic motion capture trackers

LIBERTY

TECHNICAL SUMMARY



COMPONENTS

LIBERTY includes a System Electronics Unit (SEU), one sensor and one source.

Optional accessories include a longer range source, stylus and a variety of cable lengths for each sensor, stylus or source.

System Electronics Unit
Contains the hardware and software necessary to generate and sense the magnetic fields, compute position and orientation, and interface with the host computer via RS-232 or USB.

Source
The source contains electromagnetic coils enclosed in a molded plastic shell that emit magnetic fields. The source is the system's reference frame for sensor measurements.

Sensor
The sensor contains electromagnetic coils enclosed in a molded plastic shell that detect the magnetic fields emitted by the source. A lightweight, small cube, the sensor's position and orientation is precisely measured as it is moved. The sensor is a completely passive device, having no active voltage applied to it.

SPECIFICATIONS

Update Rate
240 Hz per sensor, simultaneous samples

Latency
3.5 milliseconds

Number of Sensors
240/8 has 1 to 8 sensors, 240/16 has 1 to 16

I/O Ports
USB; RS232 to 115,200 Baud rate, both standard

Static Accuracy
0.03 in. RMS for X, Y or Z position; 0.15° RMS for sensor orientation

Resolution
0.00015 in. (0.038 mm) at 12 in. (30 cm) range; 0.0012° orientation

Range
36 in. (90 cm) at above specifications; useful operation in excess of 72 in. (180 cm)

Multiple Systems
Provision available to operate two separate systems in same environment

Angular Coverage
All-attitude

Data format
Operator selectable ASCII or IEEE 754 binary; English/Metric Units

External Event Marker
User input flag and output marker

Output Sync Pulse
TTL frame sync output

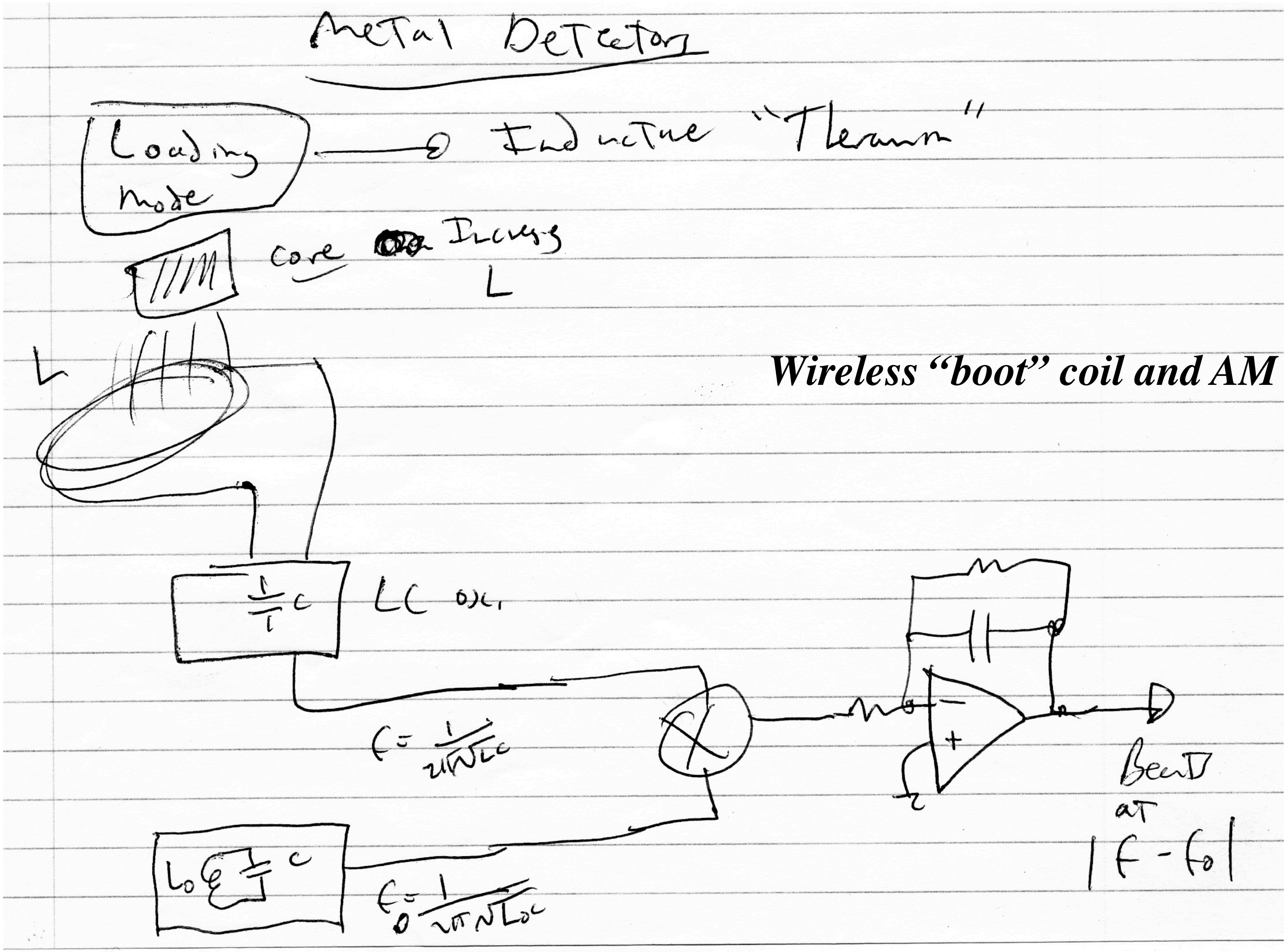
Physical Characteristics
SEU w/power supply:
12.2 in. (31 cm) L x 7 in. (17.8 cm) W x 8.5 in. (21.6 cm) H; weight 9 lbs. (4.1 kg)
240/12 and 240/16:
12.2 in. (31 cm) L x 7 in. (17.8 cm) W x 11 in. (27.94 cm) H; weight 11 lbs. (5 kg)

Field Source:
Standard TX2:
2.3 in. (5.8 cm) L x 2.2 in. (5.6 cm) W x 2.2 in. (5.6 cm) H; weight 8.8 oz. (250 gm)
TX4: 4.07 in. (10.4cm) L x 4.07 in. (10.4cm) W x 4.04 in. (10.3cm) H 1.60 lbs. (726gm)
Long Ranger: Source is 18 inches in diameter

Sensor:
0.9 in. (22.9 mm) L x 1.1 in. (27.9 mm) W x 0.6 in. (15.2 mm) H;
weight 0.8 oz. (23 gm)

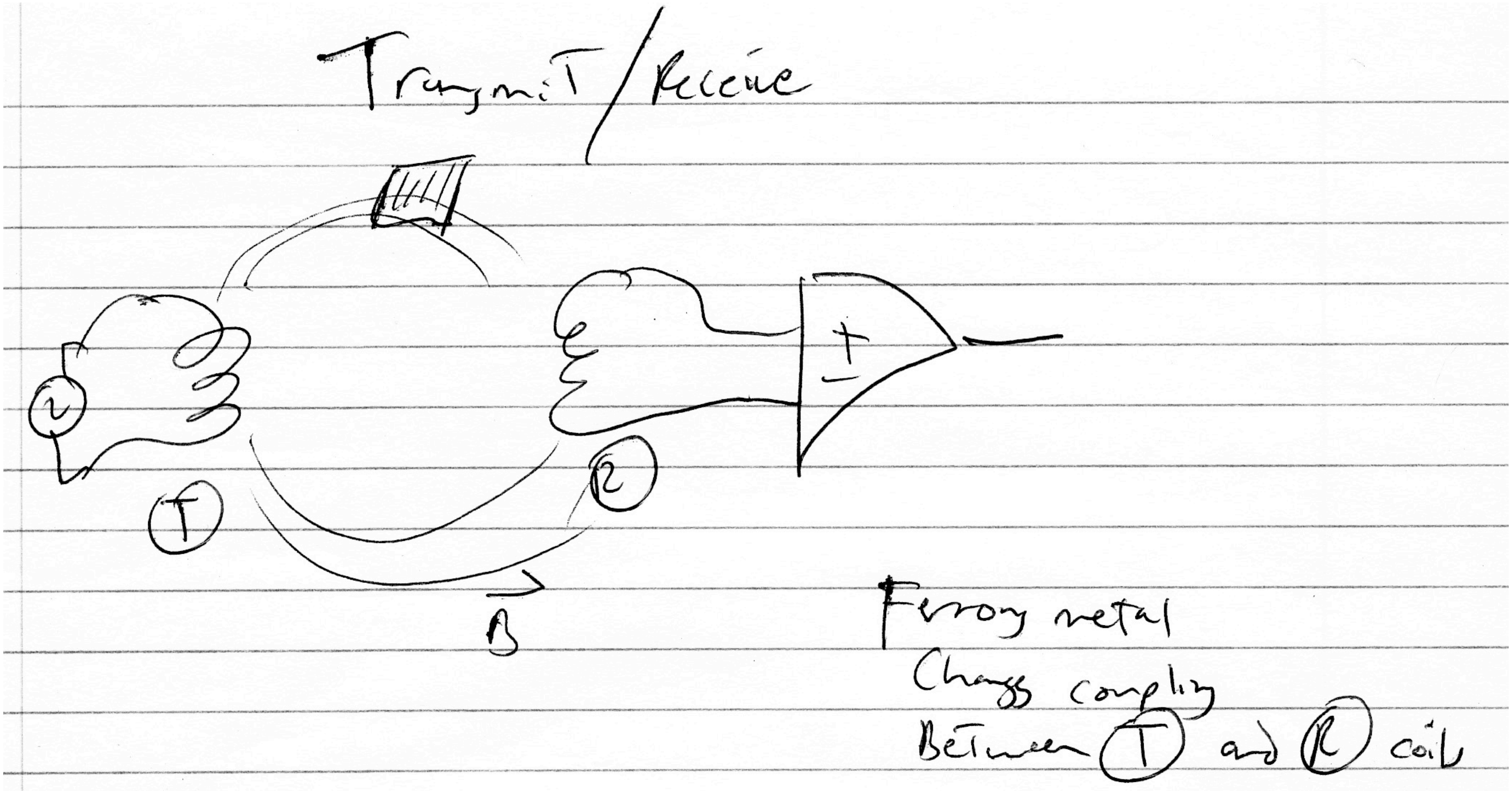
http://www.polhemus.com

Beat frequency metal detector

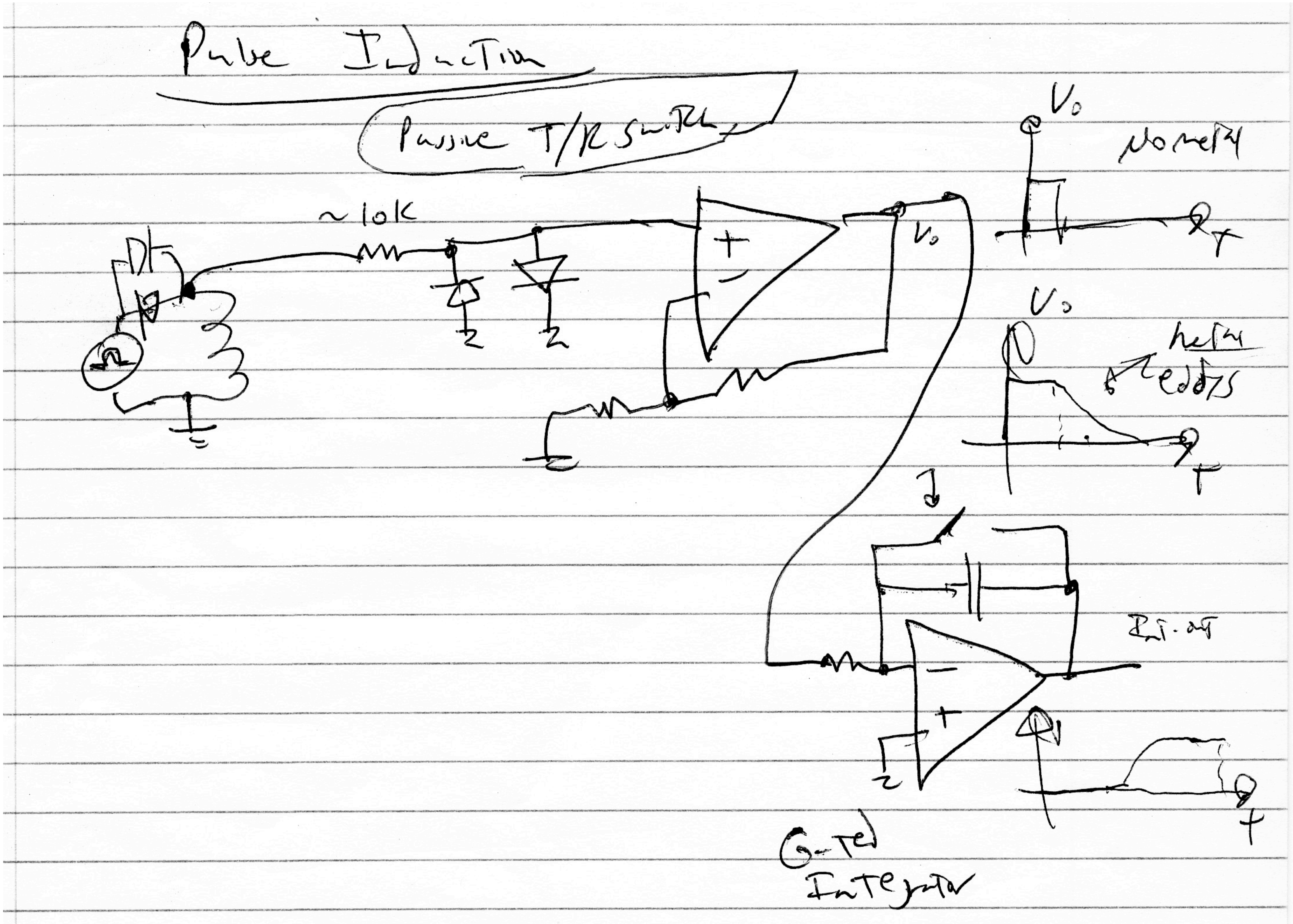


Wireless "boot" coil and AM radio

Flux Transmission Metal Detector



Pulse Induction Metal Detector



Swept-Frequency Resonant Tags for Realtime, Continuous Control of Tangible Interfaces

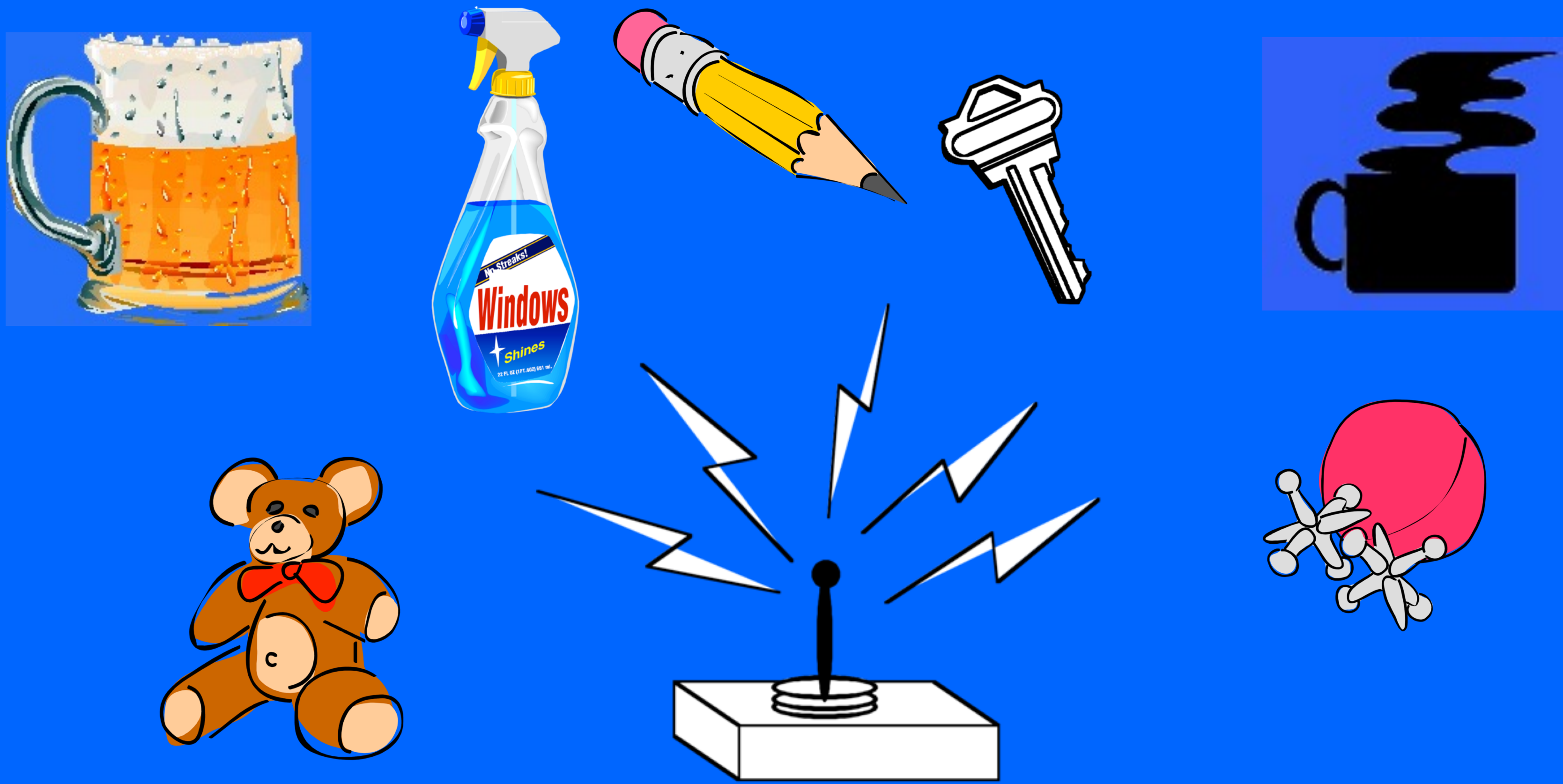
Joe Paradiso, Kai-Yuh Hsiao

Responsive Environments Group

MIT Media Laboratory

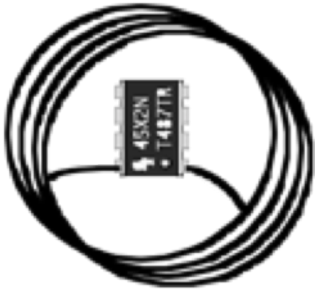
-- CHI99, 5/99

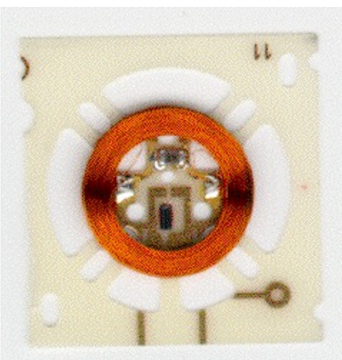
Smart, Passive Objects



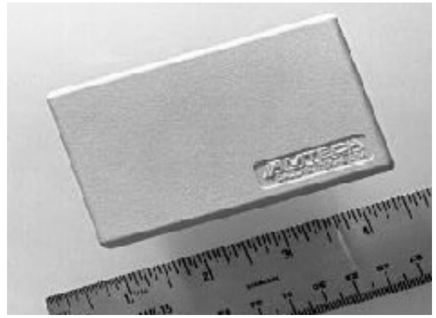
- *ID, sensors in passive objects remotely interrogated*
  - Tangible bits with no batteries, wires, line-of-sight!

Noncontact ID and Sensing - RF Tags



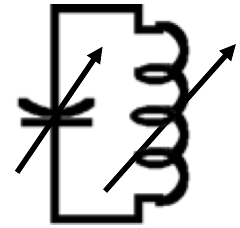


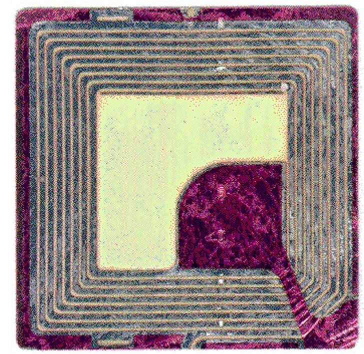
Inductively coupled



RF Coupled (Amgen)

Electrostatically Coupled (Motorola Bistatix)





LC Tag

Magnetostrictor

Chip Tags

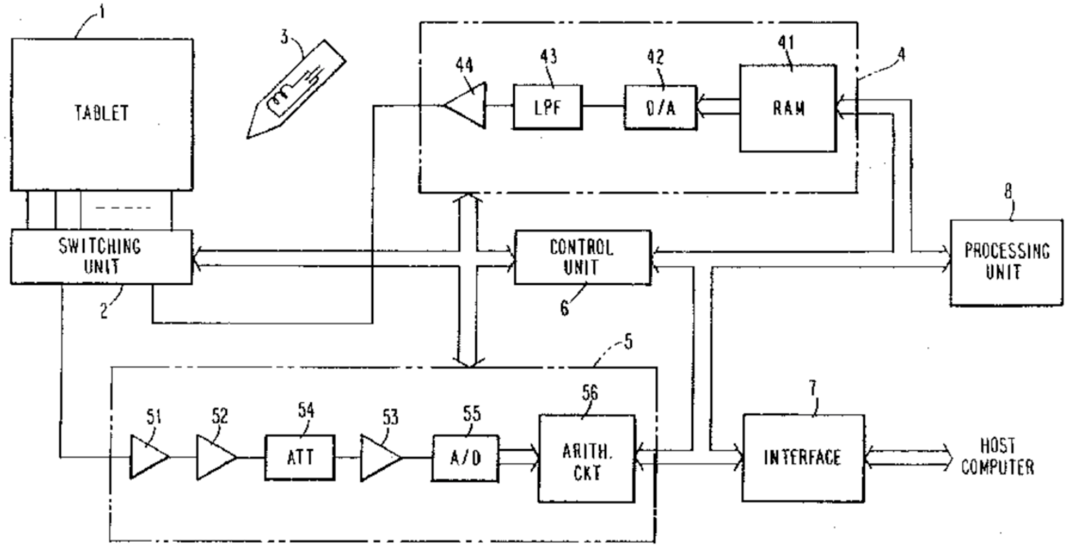
Printed Electronics!

Shoplifting Tags

Resonance = f(T,P,F,a,...)

Close Proximity - Limited bandwidth

Tagged Objects as Passive Trackers



Wacom Tablet

• LC tags in pens ID'ed & tracked across multiple coils in tablet

Zowie Game

LC tags in toys ID'ed and tracked across multiple coils in board

Used in SenseTable

Both close-range interactions

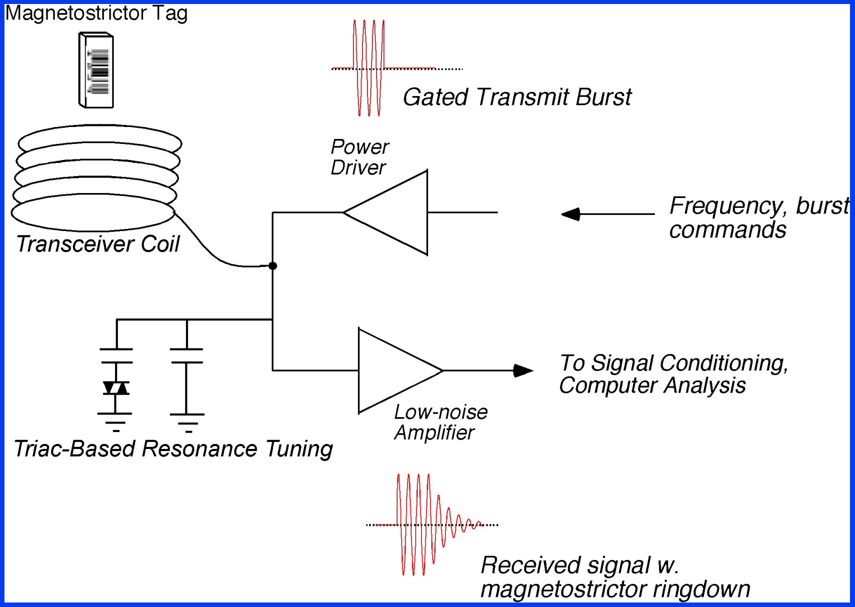
Tagged Objects as a Musical Controller

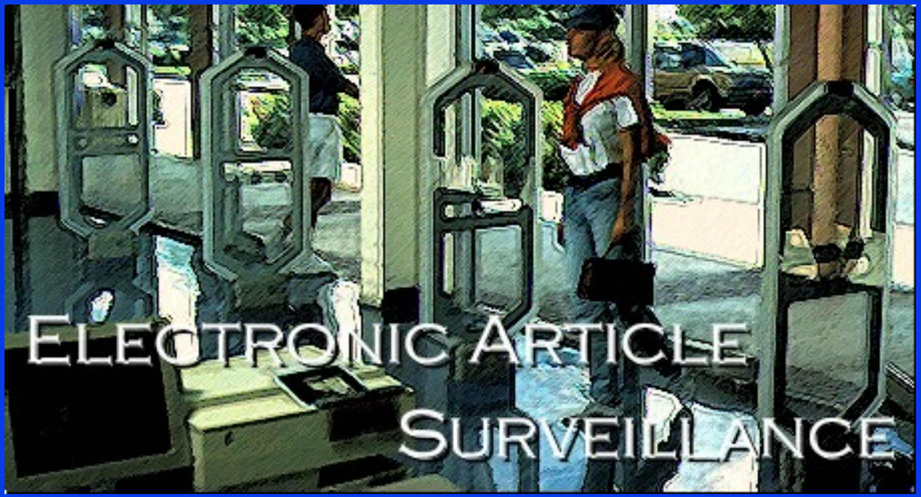
Don Buchla's Marimba Lumina

LC tags in mallets detected and tracked by multiple coils below pads

Close-range interaction (trigger with close z, track in x,y)

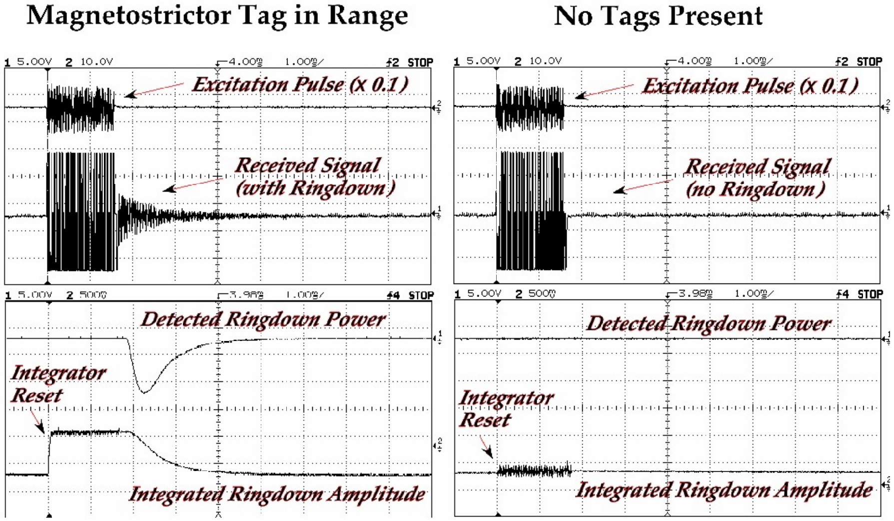
Ringdown Tag Readers





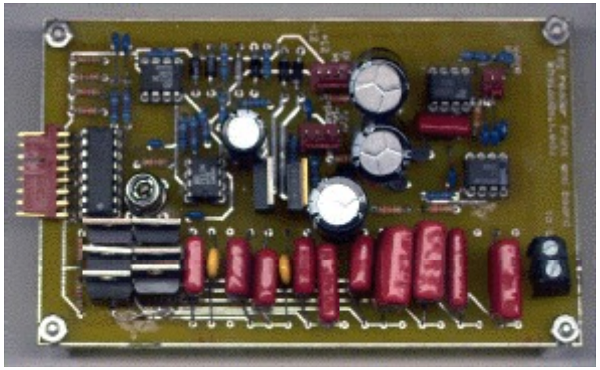
- Very simple, inexpensive prototype tag reader detects Magnetostrictor (Sensormatic) shoplifting tags
  - In-store sysems can reach circa 12 feet in range
  - High-Q mechanical structures (not so good with LC)
  - By cutting tag to different lengths, we get several (4-6) bits of very cheap ID
- Slow
  - Must sit at frequencies of interest and interrogate

Media Lab Ringdown Prototypes



Paradiso & Hsiao

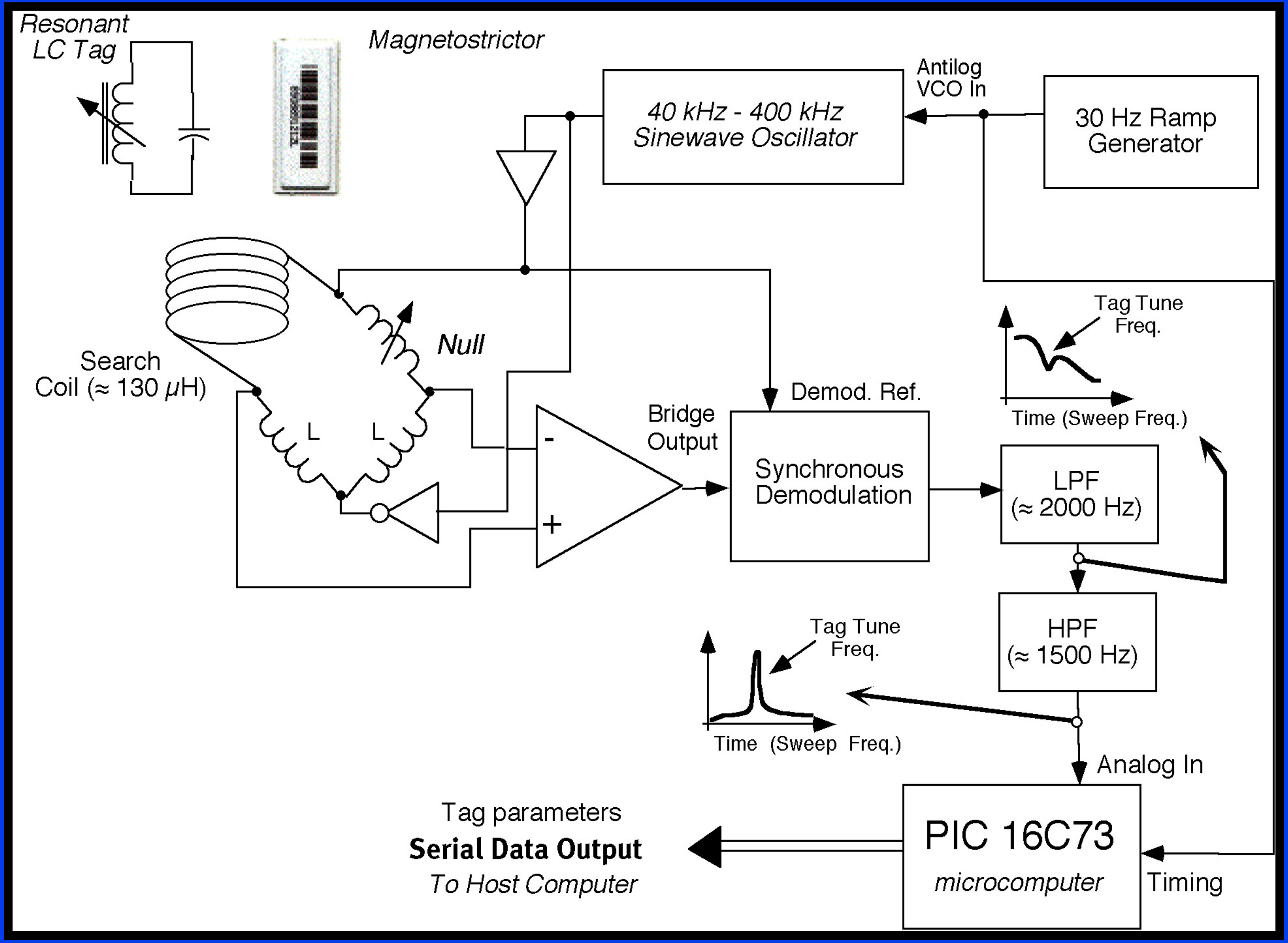
1997 Prototype, running 30-150 kHz



Triac-switched capacitor ladder for tuning search coil on transmit, Comp. MOSFET drivers

Potentially good range, but slow Response (e.g., 10 ms/tag)

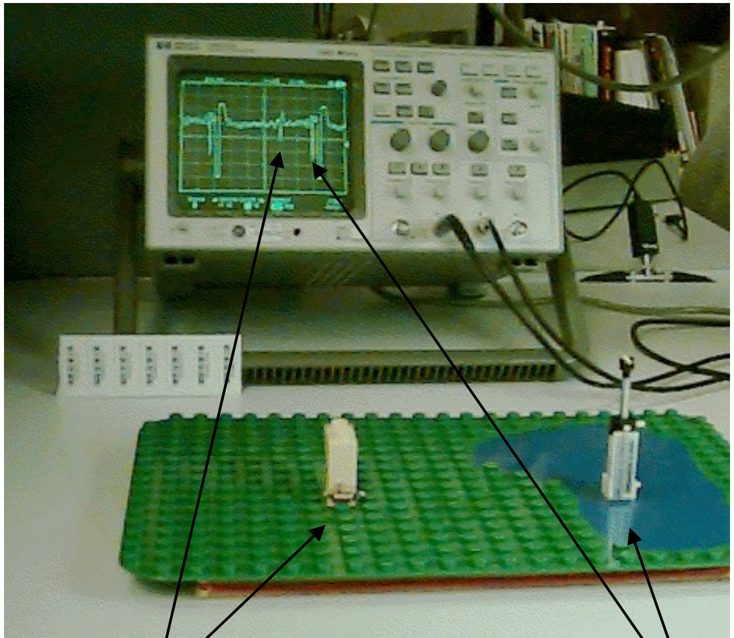
Swept-Frequency Tag Reader



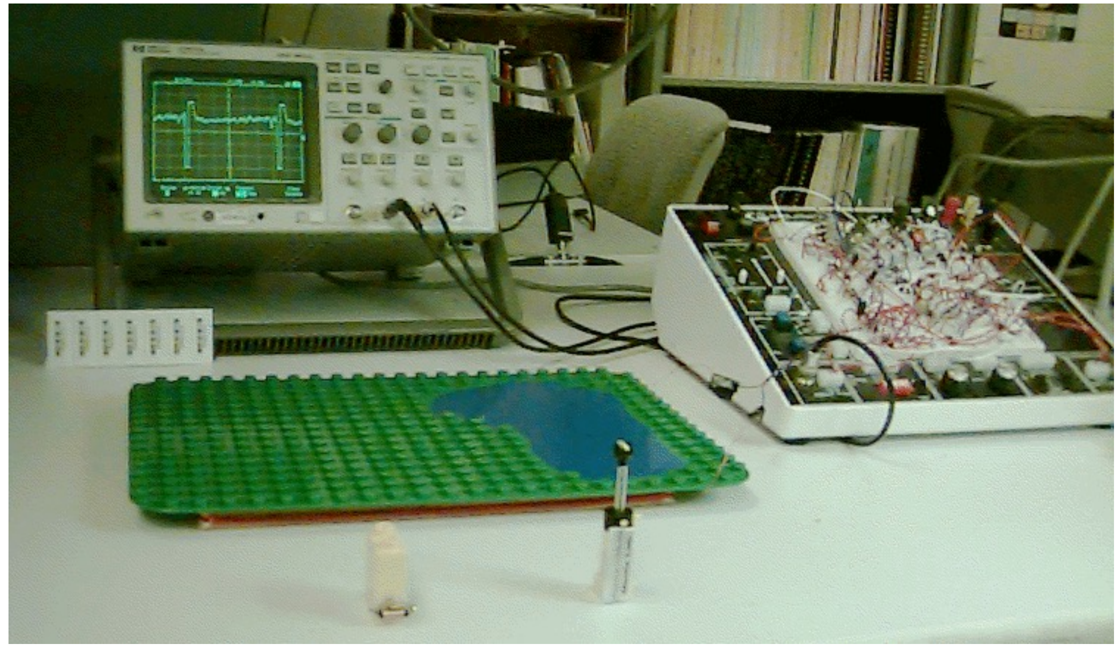
- Looks for magnetically-coupled resonant loads from 50-300 KHz
- Early EAS systems, “Grid-Dip Meter”
- Simple, cheap, fast, but limited range

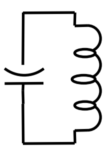
Early (1995) ML Lego Demo

Tags Present



Tags Absent





LC
(200 kHz)

Magnetostrictive
Resonator (60 kHz)

orient.mpg

- **Pickup coil under LEGO platform**
  - **Drive frequency swept 40 - 300 kHz**
  - **Resonant loading detected => tag identified**

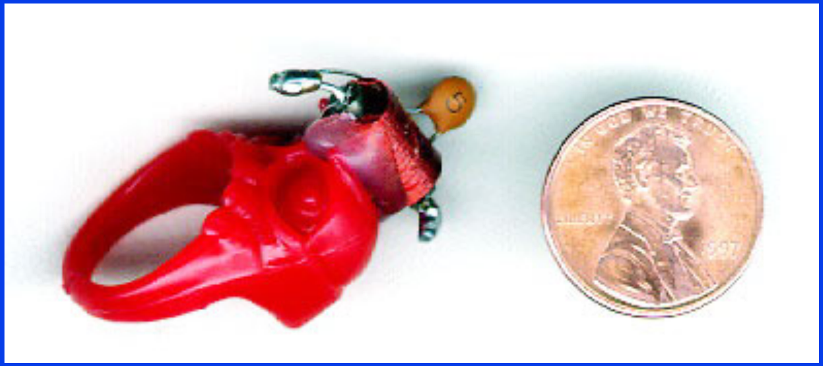
Multiple modes of control

Increase read range and # objects

Now 20 tags in system and 16 objects

- Wearable Ring tags
  - Continuous control on each finger (no glove)
- Tags that sit in reader area
  - Set background, context…
- 3-axis tags (respond to orientation and range)
  - Can be rolled around or manipulated
- Local sensor tags
  - Respond to pressure (or pull, etc.) and displacement

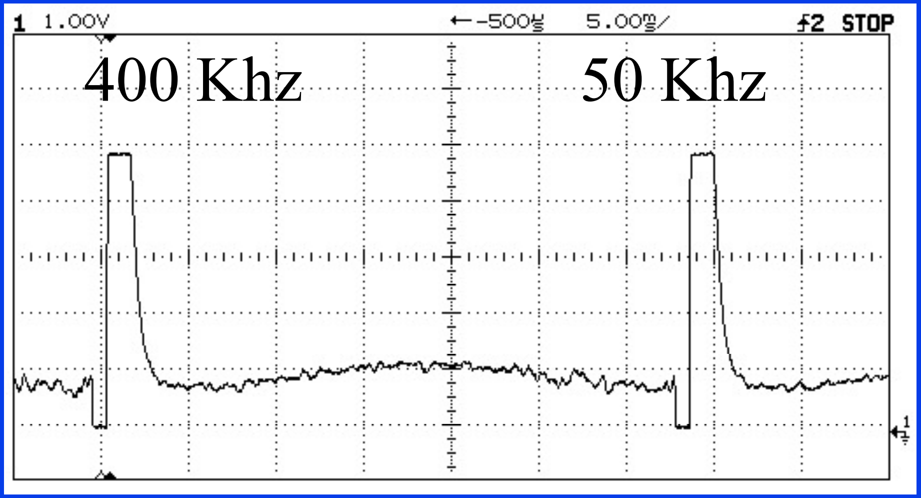
Many degrees of control…



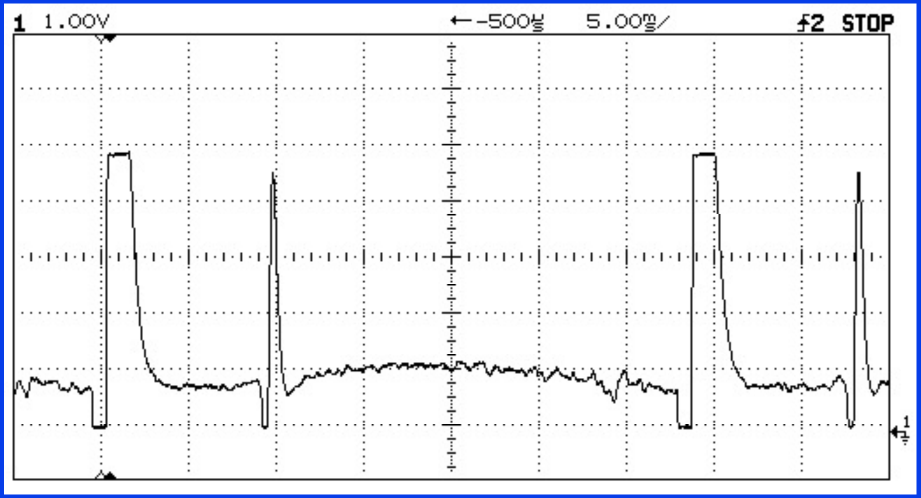
Tagged Objects

Resonant Frequency is "ID"
Pick L,C or cut resonant strip

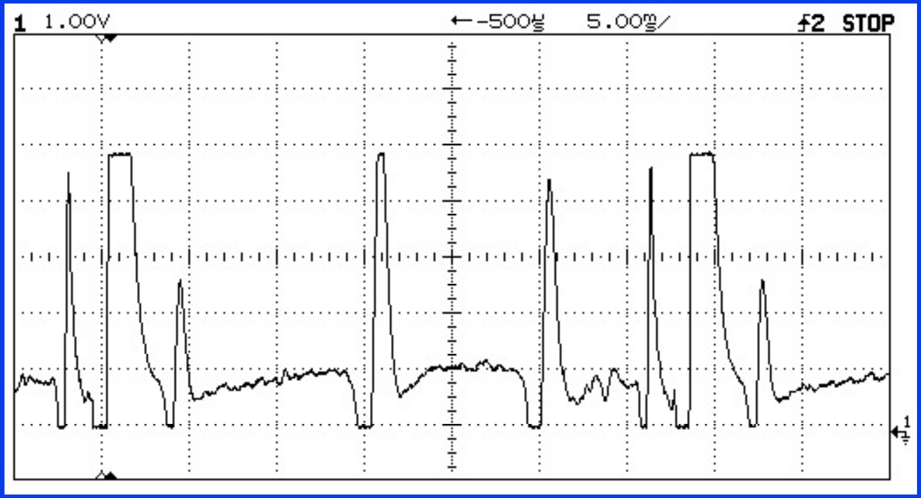
Actual Baseline - Antilog Sweep



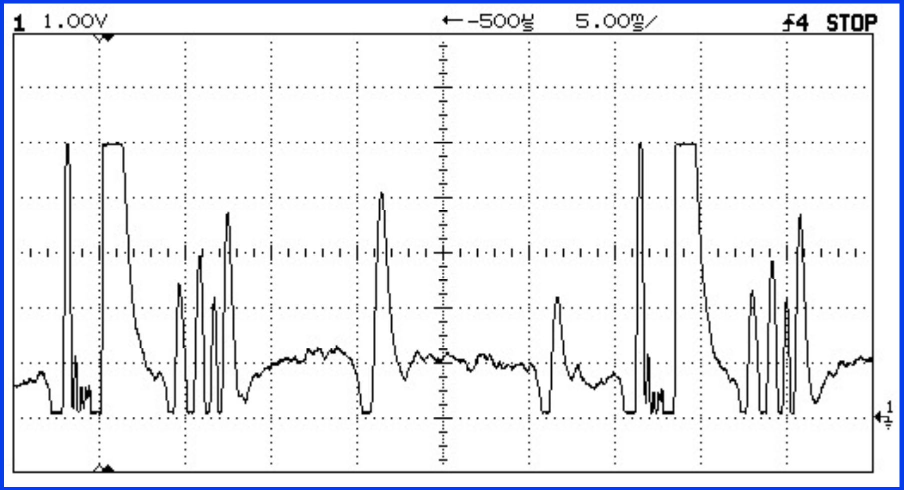
No Tags



Pumpkin Only

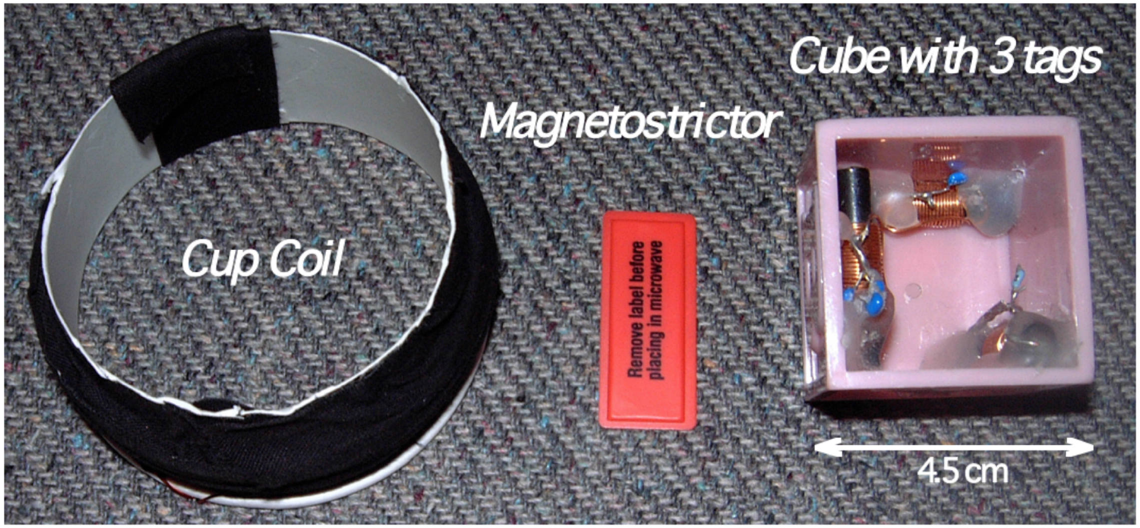


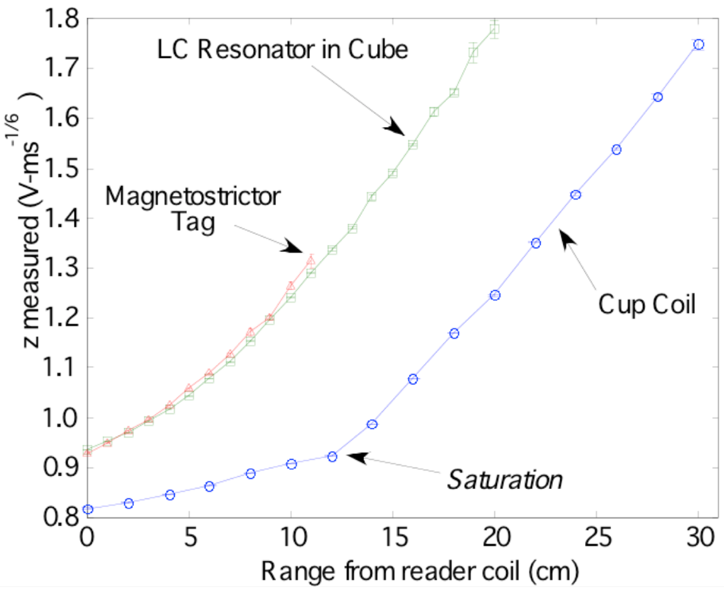
Red Ring, Block Face, Dinosaur



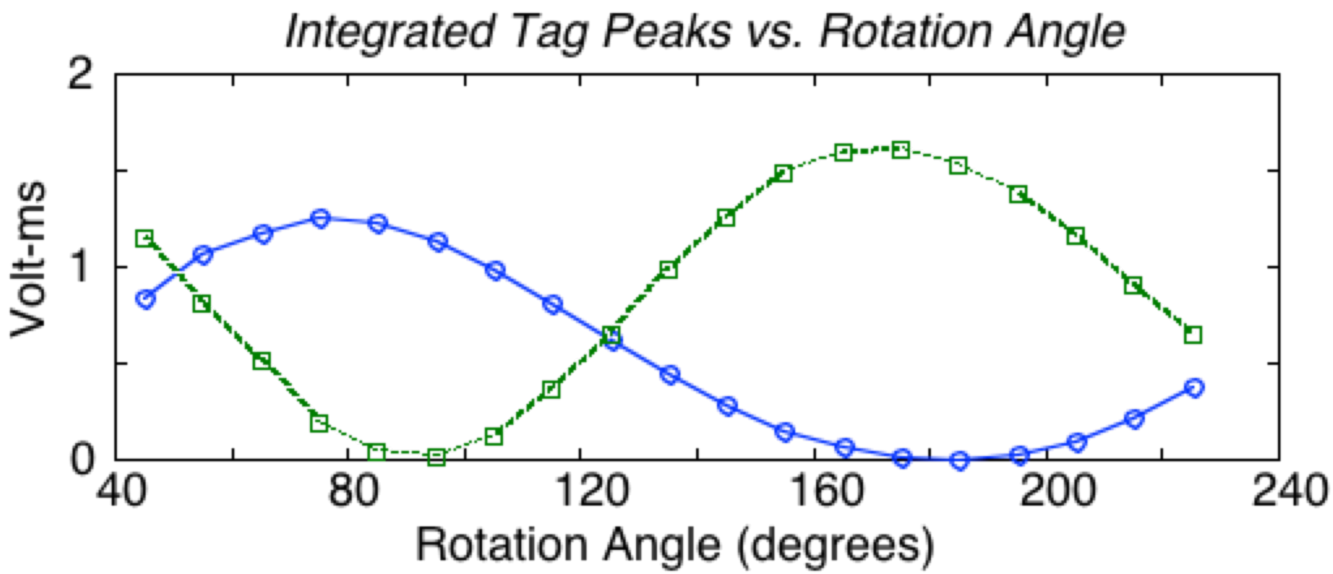
All Rings, Goblin, Corn, Dinosaur

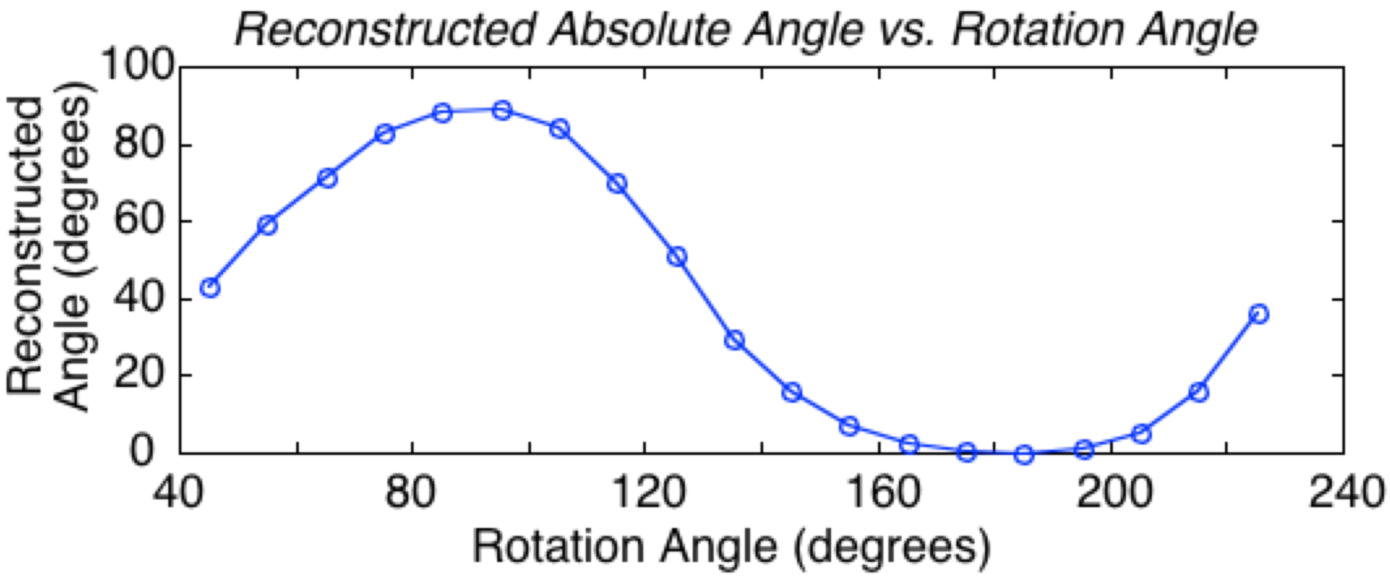
Tag Proximity Sensing





Tag Angle Sensing



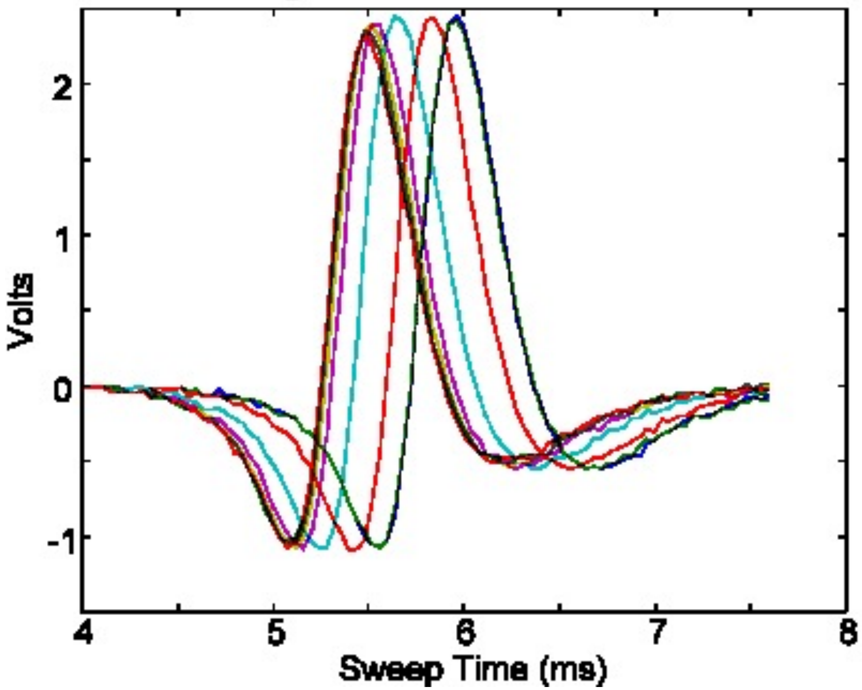


Tag Pressure Sensing

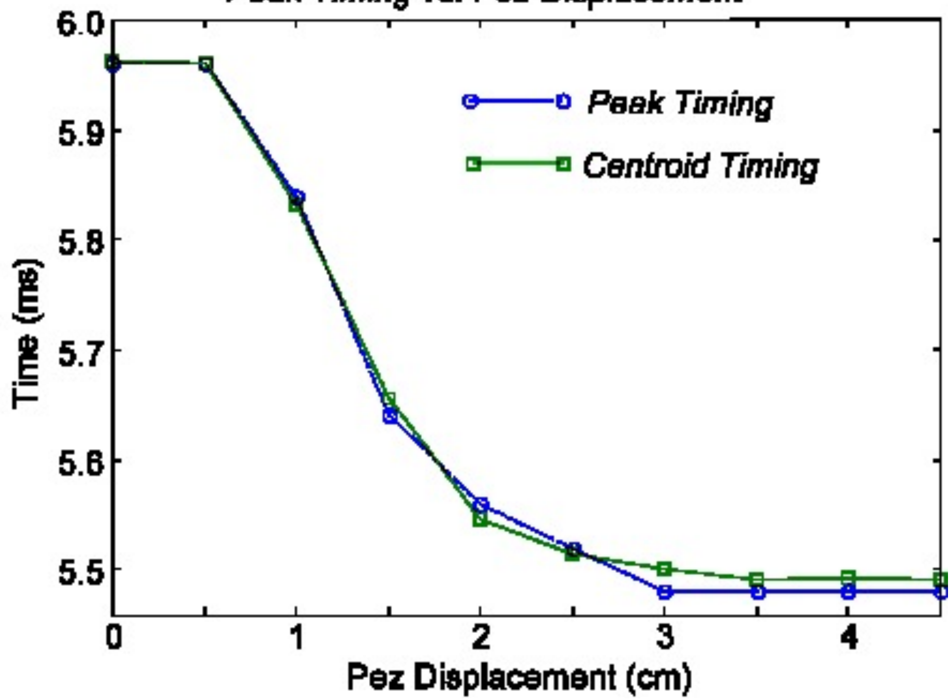
Pez Controller Extended

Pez Controller Contracted

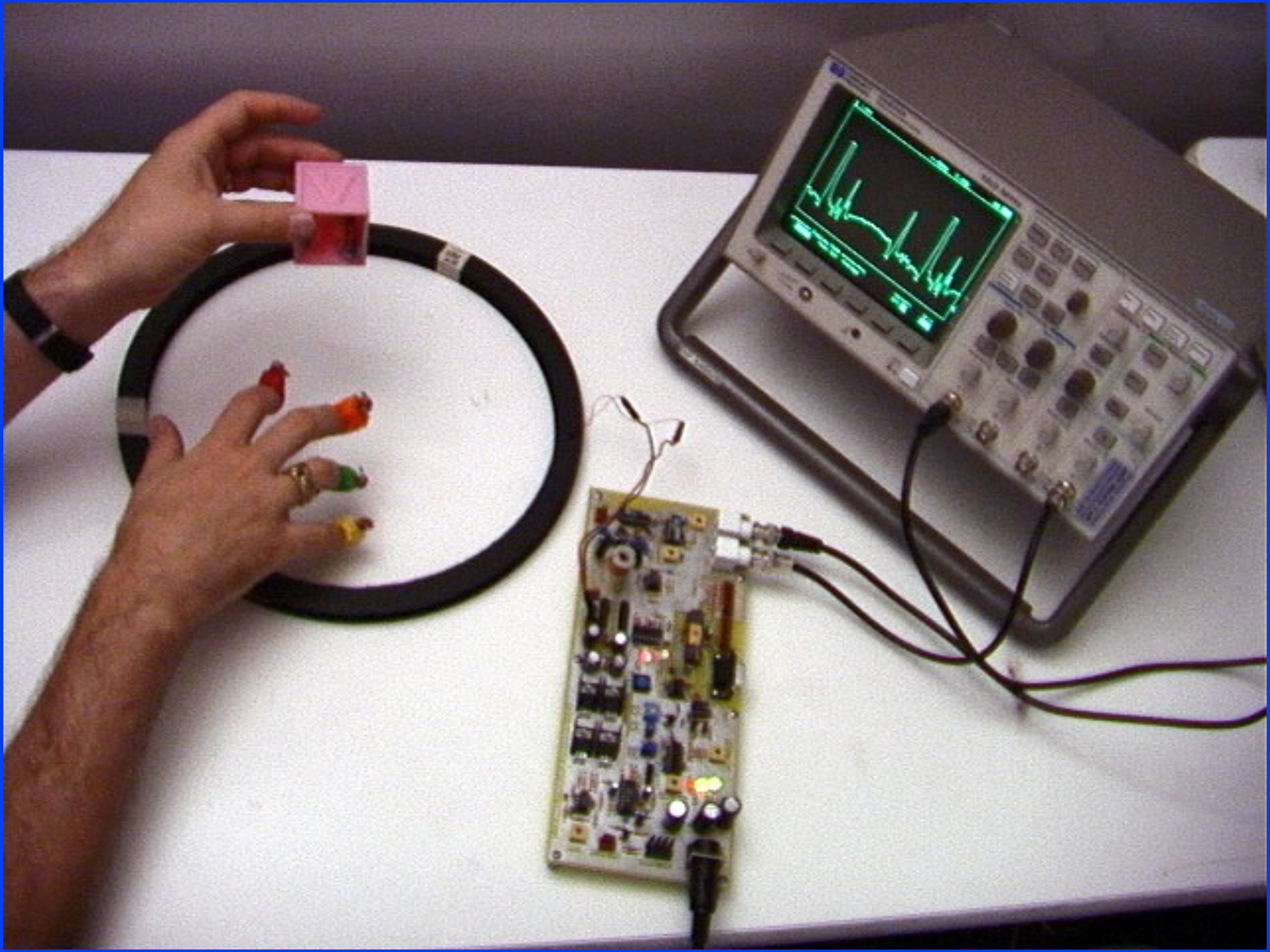
Tag Peaks as Pez is Pulled



Peak Timing vs. Pez Displacement



Swept Tags as a Musical Controller

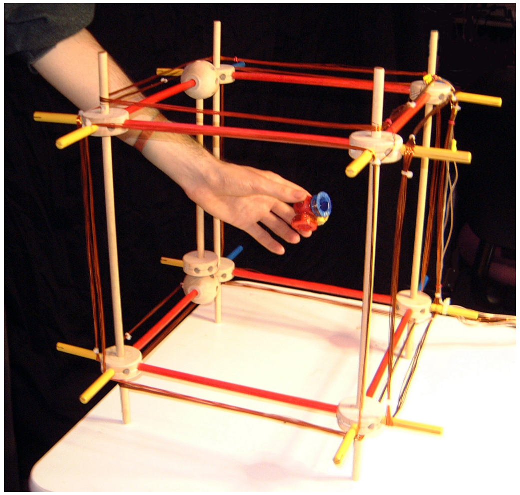


Inspired by John Zorn's early Performances

Tag tracking and sensing

SMAU Convention, Milan, October 2000

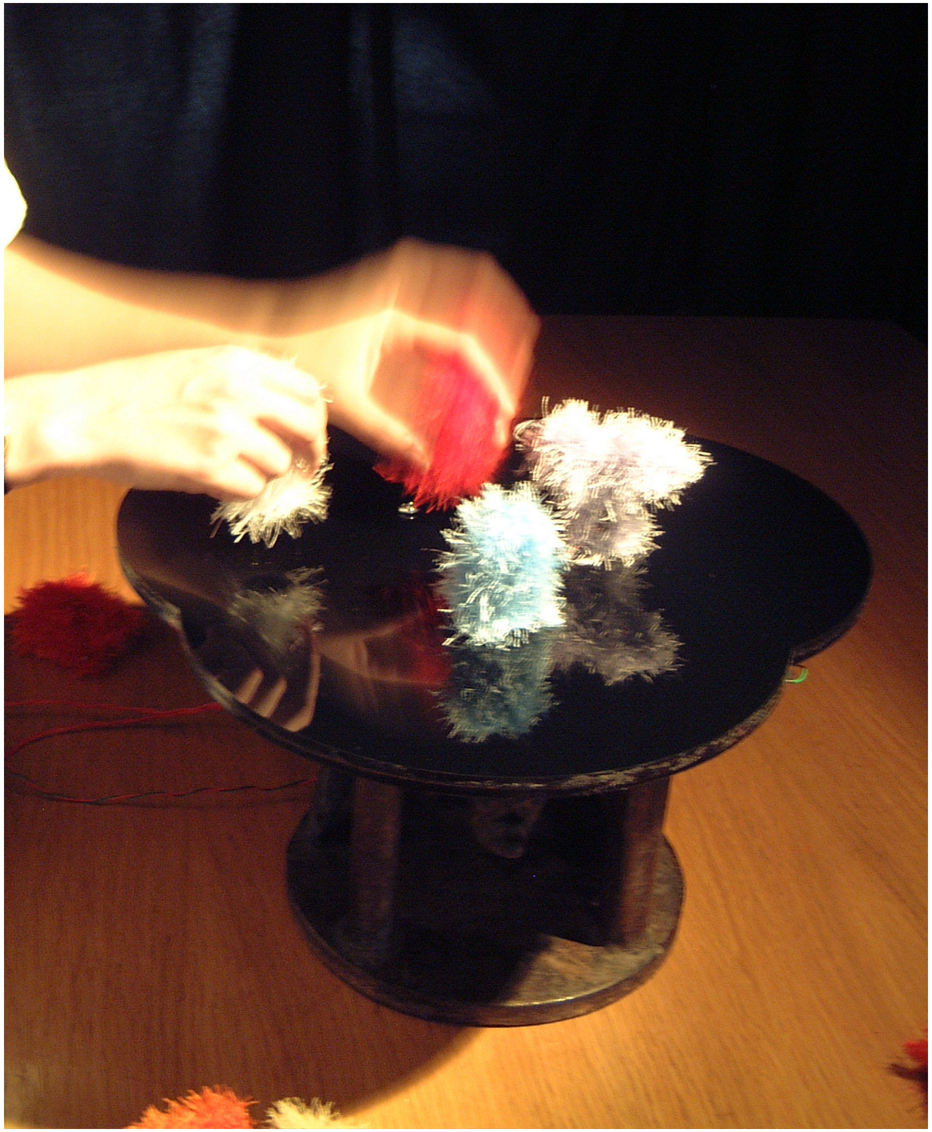
EMP Seattle, April 2001



Volumetric Tag Tracking

Advanced Musical Mappings – Demo!

Musical Navigatrix



Laurel (Pardue) Smith's Meng, 2001

- Multicoil tracking (Olympics)
  - X,Y,Z sensitivity
  - Can lock tag response w. switch
- Control musical parameters at high level (sequences, timbres)
- Can record, overdub actions