Electromagnetic Properties Sensors

1. Background (DC to low frequency)

→ Materials have electromagnetic properties

ε_r → relative permittivity

μ_r → relative permeability

σ → electrical conductivity

→ Electrical circuits can be built that interact with "nearby materials" that affect circuit performance

$\varepsilon_r \rightarrow C$

$\mu_r \rightarrow L$

$\sigma \rightarrow R$

→ can be used to detect the presence of or even the identity of an object

a. Electrical Conductivity Sensing

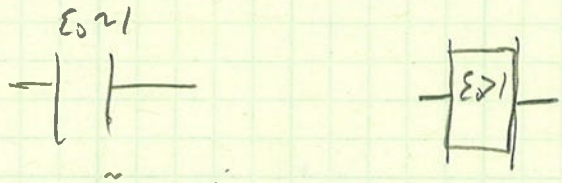
→ 2 bare electrodes

→ resistance is measured between them

→ can range from open to a short

b. Capacitive Sensing

① Parallel Plate electrodes



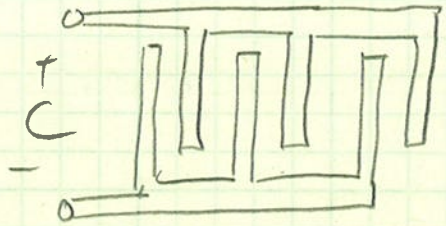
$A >> d^2$

$C_0 \cong \frac{\varepsilon_0 A}{d}$ $\qquad$ $C_t = \frac{\varepsilon_0 \varepsilon_r A}{d}$

$\frac{C_t}{C_0} \sim \varepsilon_r$ of object

② <u>Fringing Field Electrodes</u>

→ May use IDT structure

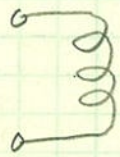


$A_{eq} \not\gg d^2$

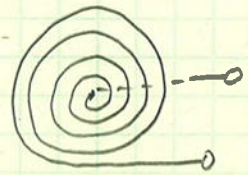
∴ much of the capacitance is due to the fringing fields outside of the plane of the electrodes

→ materials with $\varepsilon > 1$ interacting with the fringing fields will increase the measurable capacitance

③ <u>Inductive Coils</u>



or



planar coil

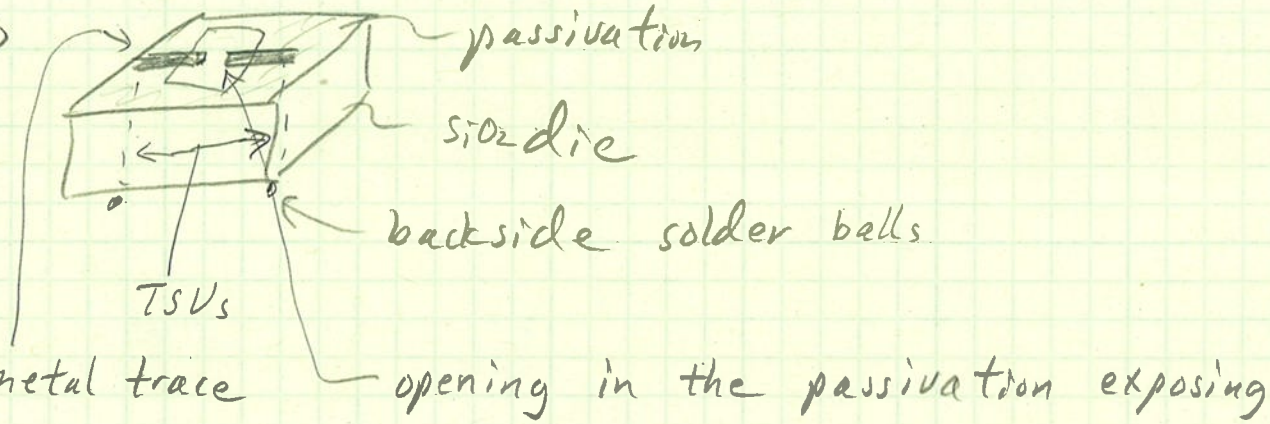
non-planar coil

→ materials with $\mu_R \neq 1$ interacting with the magnetic fields around the traces of the coils will affect the measurable inductance

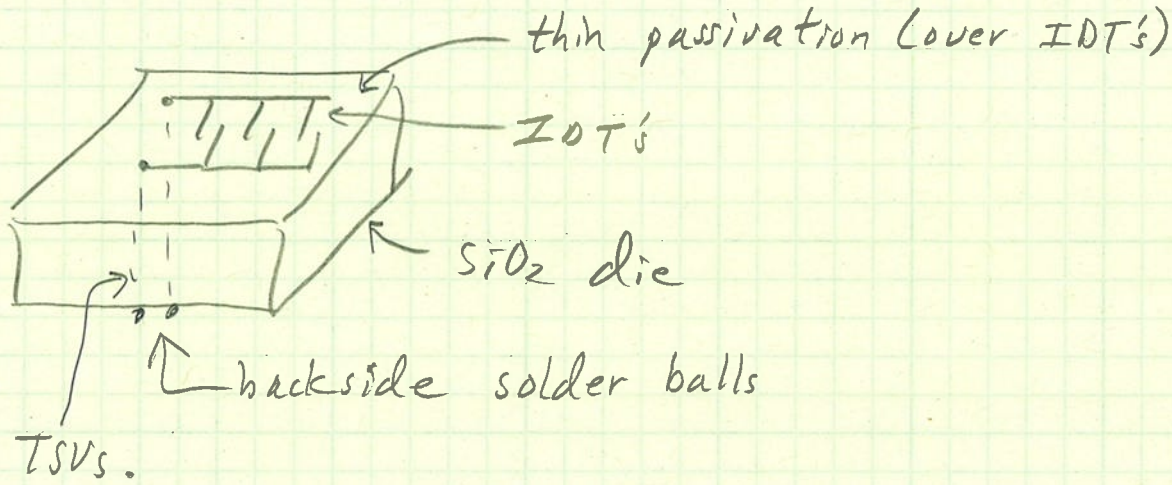
2. Implementation

a. Traditional MEMS

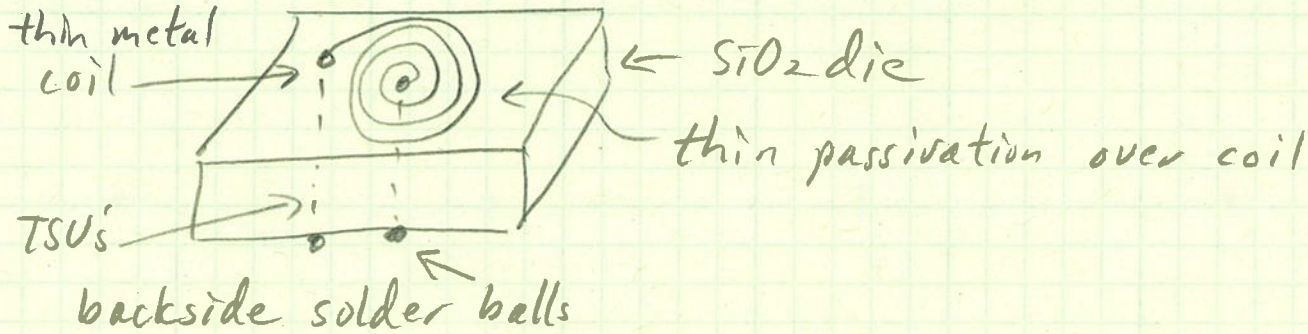
→ bare electrodes, IDT structures, even coils can be made on a MEMS chip

① 

② Capacitive Sensor

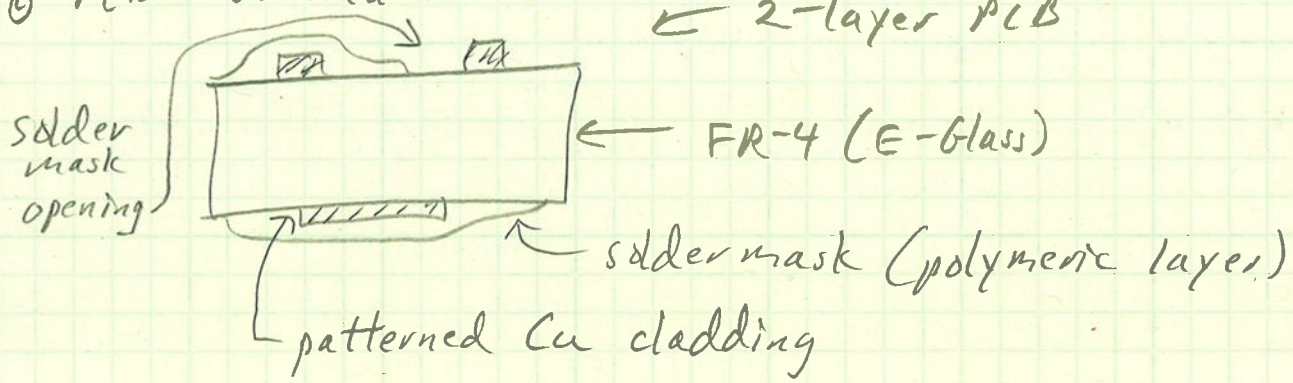


③ Inductive Sensor



b. Printed Circuit Board Technology

① PCB structure

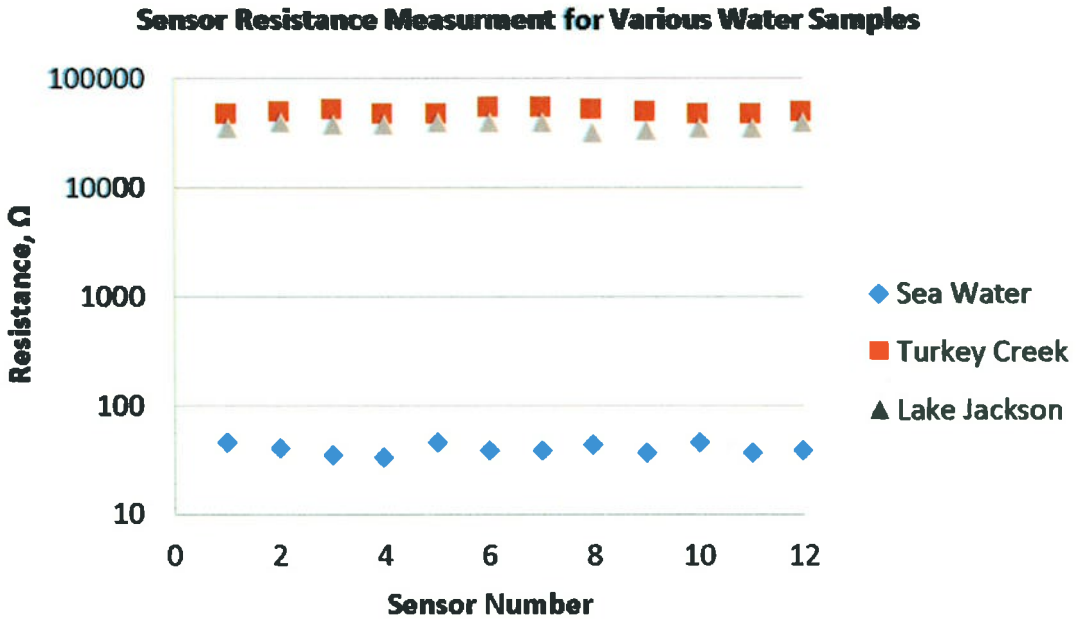


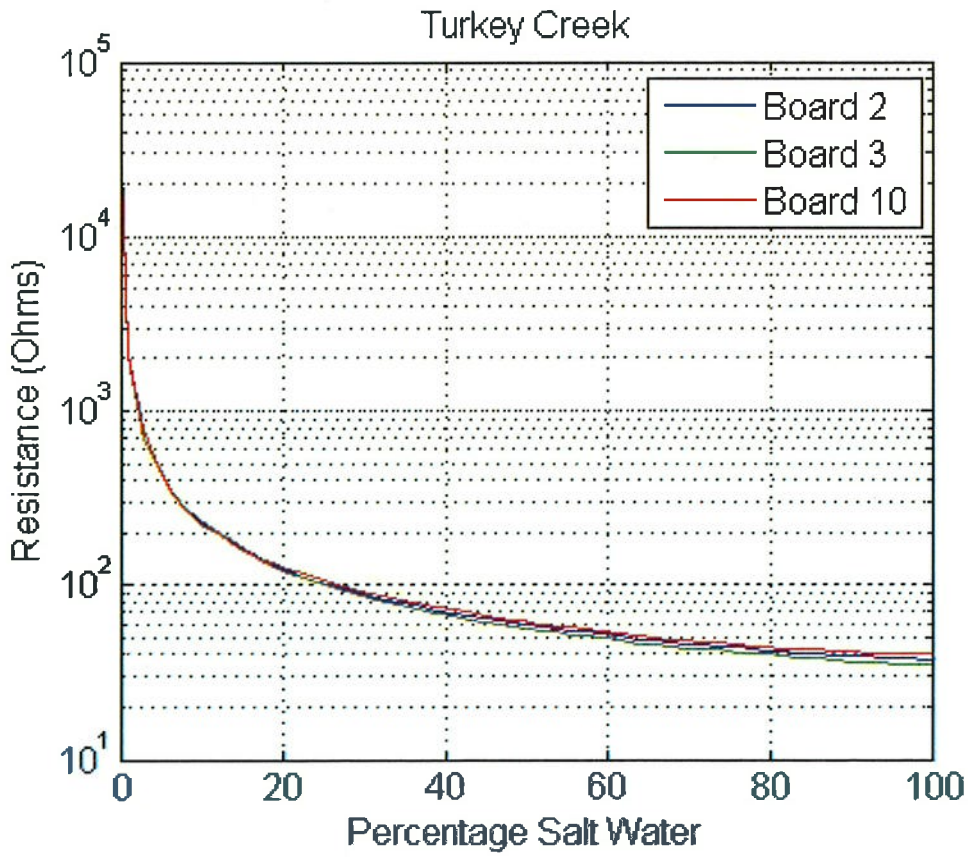
PCB's → less expensive than MEMS
→ much shorter development cycle
→ easy to attach electronics
→ can be much larger than Si die
→ cannot have nearly as small features as MEMS (Si-MEMS)

→ show examples + test data

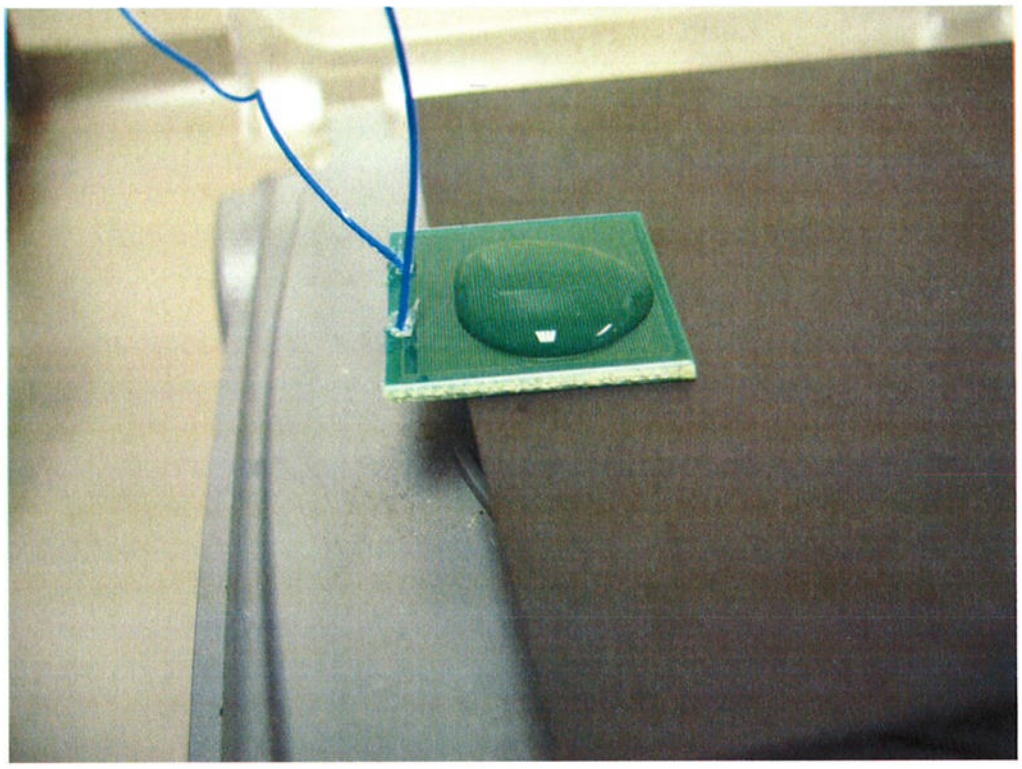
② Flexible PCB's too
→ polyimide
→ LCP

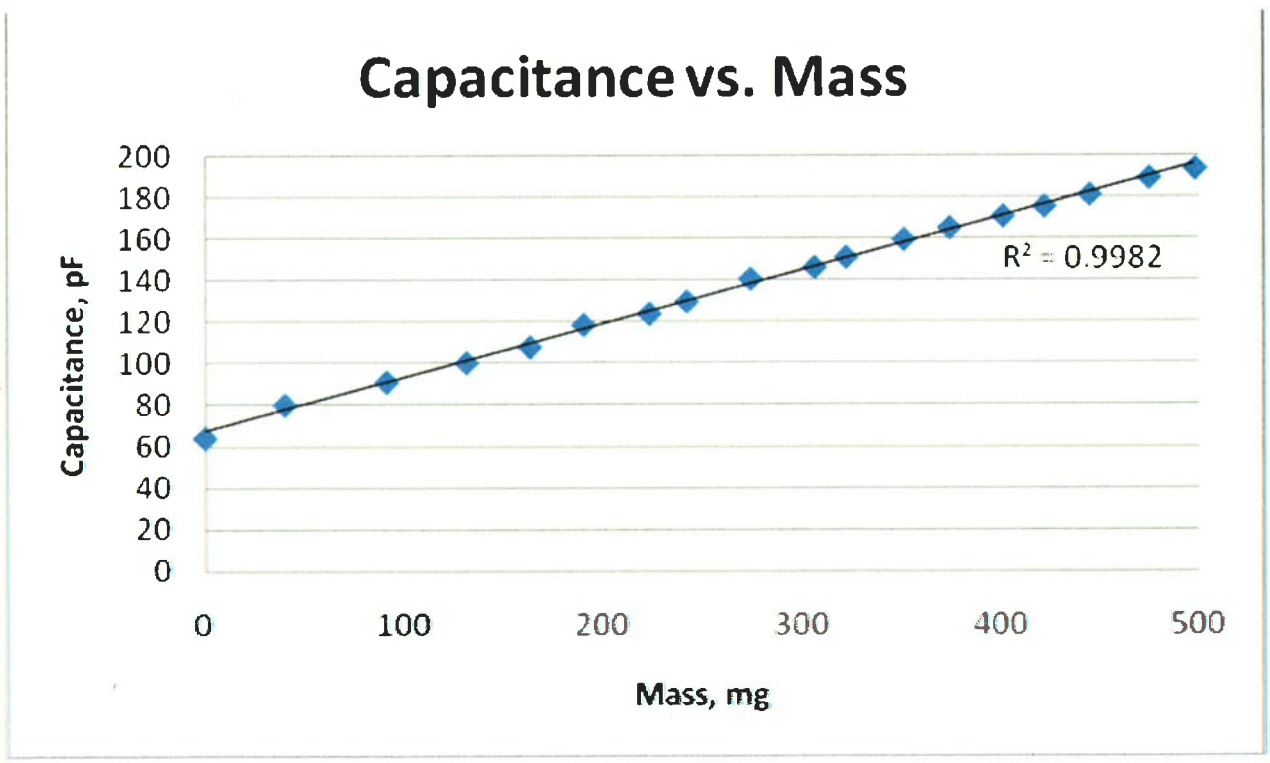
PCB EC Sensor to Measure Saltwater Intrusion





PCB Fringing Field Sensor to Measure Mass of Water Drop





PCB Fringing Field Sensor to Measure Moisture Content of Soil