Humidity Sensor

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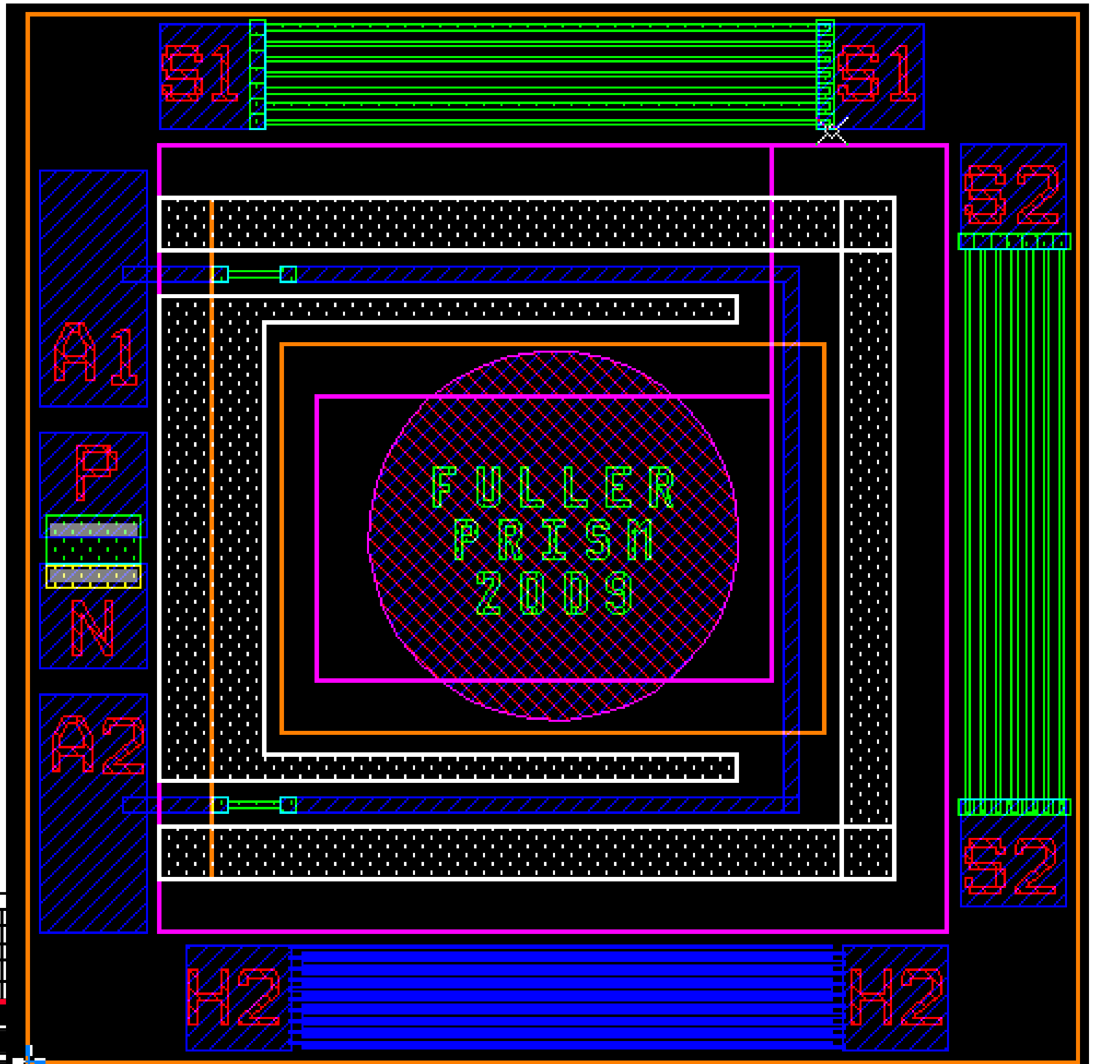
OUTLINE

Design
Layout
Calculations

PRISM MEMS MULTISENSOR CHIP – VER 2



1-AxisAccelerometer
Temperature Sensor
Humidity Sensor
Strain Sensor

Humidity Sensor
finger overlap 2000um
# of fingers 20
finger width 10
finger space 10
pad size 400 x 400
polyimide thickness

VER 2 HUMIDITY SENSOR CALCULATIONS

Capacitance of Two Parallel Plates		
Capacitance = eoer Area/d C =	2.72E-11	F
eo = Permitivitty of free space	8.85E-14	F/cm
er = relative permitivitty =	3.9	
Area =	3.15E-03	cm2
number of pairs of plates, N =	1	
distance between plates, d =	0.4	µm
If round plates, Diameter =	0	µm
If rectangular plates, length =	670	µm
If rectangular plates, width =	470	µm
Force Between Two Parallel Plates Force =	3.40E-03	N
Electrostatic Force= eoer Area $V^2/2d^2$ Voltage, V =	10	volts
Capacitance for very Thick Interdigitated Fingers		
C = (N-1) eoer L h/s Capacitance, C =	1.70E-12	F
Number of Fingers, N =	121	
relative dielectric constant, er =	8	
Length of finger overlap, L =	100	µm
height of fingers, h =	2	µm
space between fingers, s =	1	µm

Capacitance for very Thin Interdigitated Fingers on thick insulating substrate

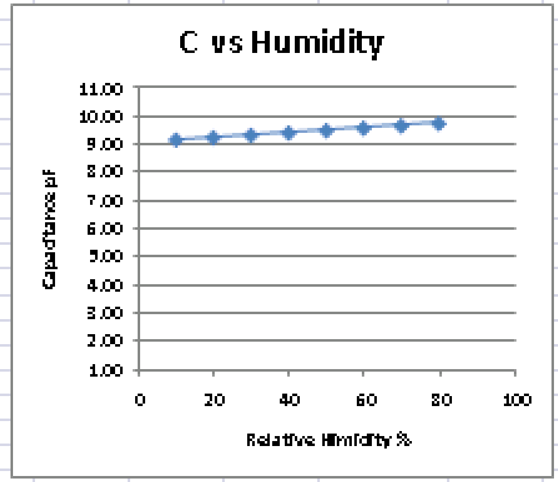
$$C = LN\left[4\frac{\varepsilon_o\varepsilon_r}{\pi}\right]\sum_{n=1}^{\infty}\frac{1}{2n-1}J_o^2\left[\frac{(2n-1)\pi s}{2(s+w)}\right]$$

Capacitance, C =	1.83E-12	F	3.8	er Top
Number of Fingers, N =	20		0	er Bottom
relative dielectric constant, er =	5.24		60	RH%
Length of finger overlap, L =	2000	µm	5.24	er'
width of fingers, w =	10	µm		
space between fingers, s =	10	µm		

If an oxide over silicon use equation above with eo for material above the fingers added to the Capacitance to silicon substrate calculated below

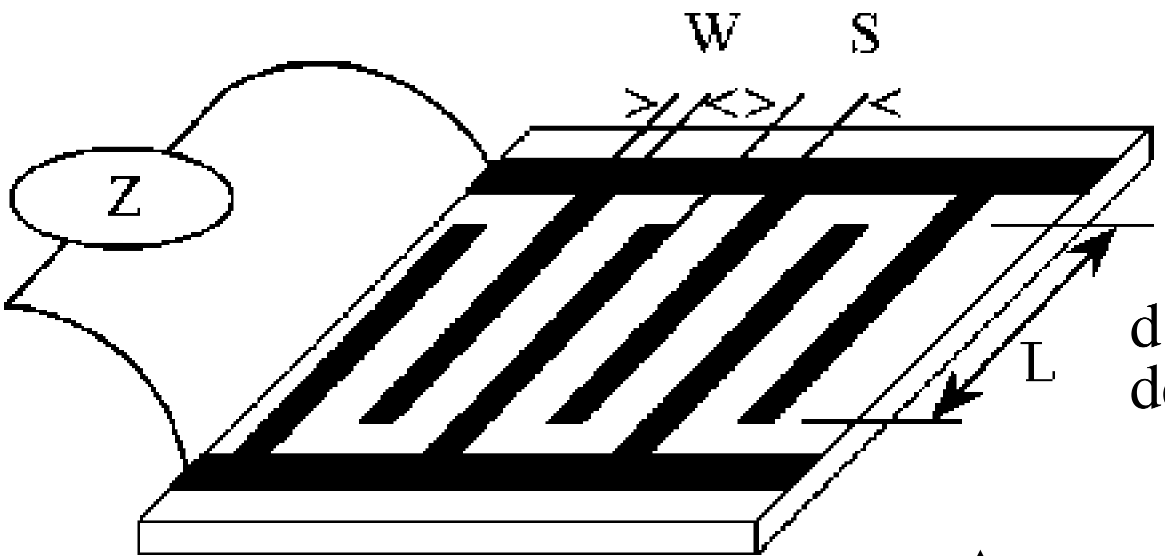
Capacitance to Silicon Substrate =	7.77E-12	F
er (oxide) =	3.9	
Oxide thickness =	8000	Å
Total area of pads and other layout features =	320000	um2
Total Capacitance =	9.60E-12	F

RH%	C pF
10	9.18
20	9.26
30	9.35
40	9.43
50	9.51
60	9.60
70	9.68
80	9.77



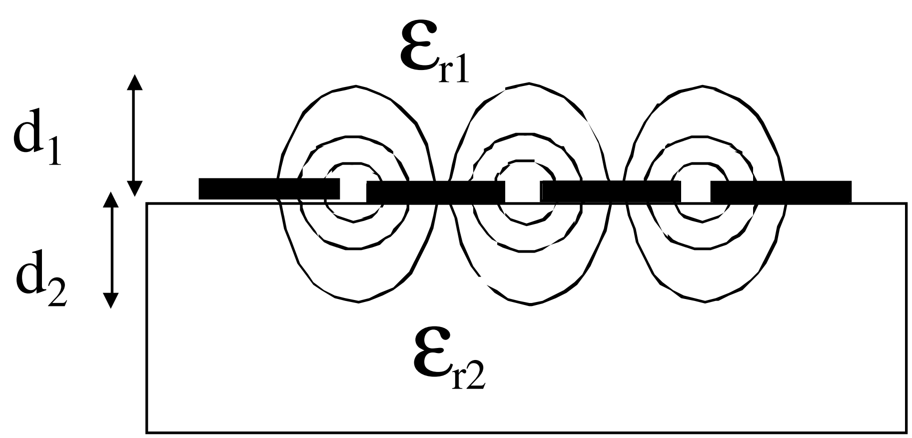
	(2n-1)(pi)s/2(s+w	zero order Bessel			sum
n	x	Jo(x)	Jo^2	Jo^2/2n-1	0.7755072
1	0.785	0.8518	0.7255	0.7255	
2	2.355	0.0261	0.0007	0.0002	
3	3.925	-0.401	0.1608	0.0322	
4	5.495	-0.0086	7E-05	1E-05	
5	7.065	0.2998	0.0899	0.01	
6	8.635	0.0051	3E-05	2E-06	
7	10.205	-0.2496	0.0623	0.0048	
8	11.775	-0.0038	1E-05	1E-06	
9	13.345	0.2183	0.0477	0.0028	
10	14.915	0.0033	1E-05	6E-07	

MODELING OF INTERDIGITATED CAPACITOR



d1 and d2 (interrogation depth)

N = number of fingers



$$\varepsilon_r = \varepsilon_{r1} + \varepsilon_{r2}$$

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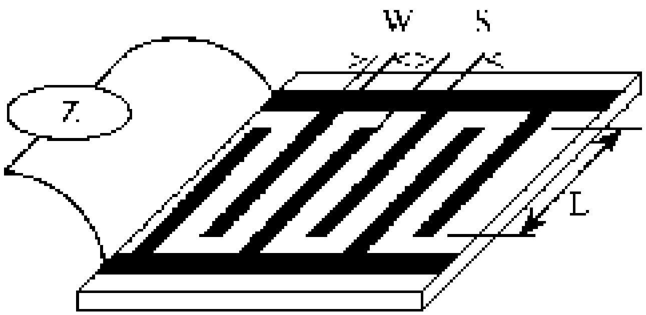
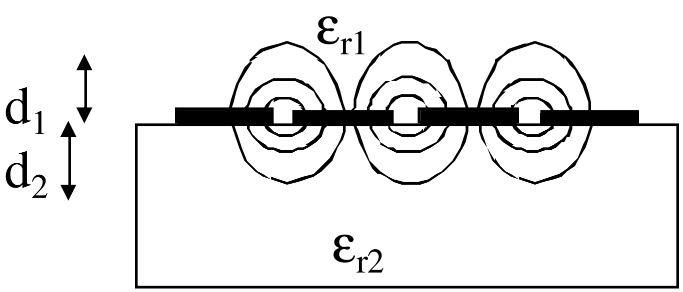
PLANAR INTERDIGITATED SENSOR



$$C = (N-1)L\frac{(\varepsilon_{r1}+\varepsilon_{r2})\varepsilon_0 K[(1-k^2)^{\frac{1}{2}}]}{2K(k)}$$

$$k = \cos\left(\frac{\pi}{2}\frac{w}{(s+w)}\right)$$

$$K(k) = \int_0^1 \frac{1}{\sqrt{(1-t^2)(1-k^2t^2)}}dt$$



$$C = LN\left(4\frac{\varepsilon_0\varepsilon_r}{\pi}\right)\sum_{n=1}^{\infty}\frac{1}{2n-1}\,Jo^2\left[\frac{(2n-1)\pi s}{2(s+w)}\right]$$

$$\varepsilon_r = \varepsilon_{r1} + \varepsilon_{r2}$$

Jo is zero order Bessel function

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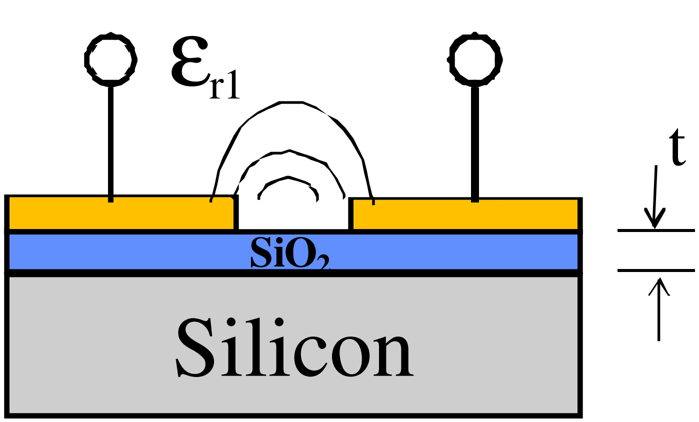
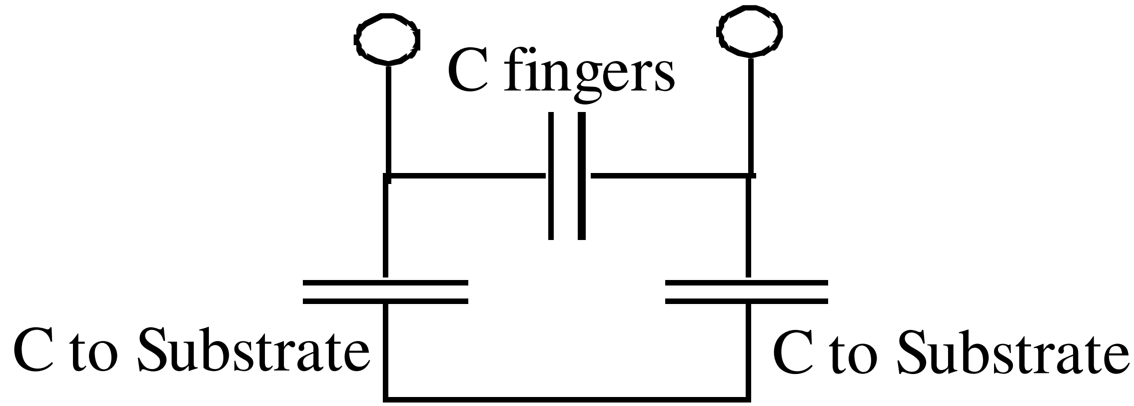
FINGERS ON SILICON SUBSTRATE





C = C fingers + C to substrate / 2
(if silicon substrate is treated as a conductor)

C substrate

$$C = \varepsilon_o \, \varepsilon_r \; area / t$$

$\varepsilon_r = \varepsilon_{oxide}$

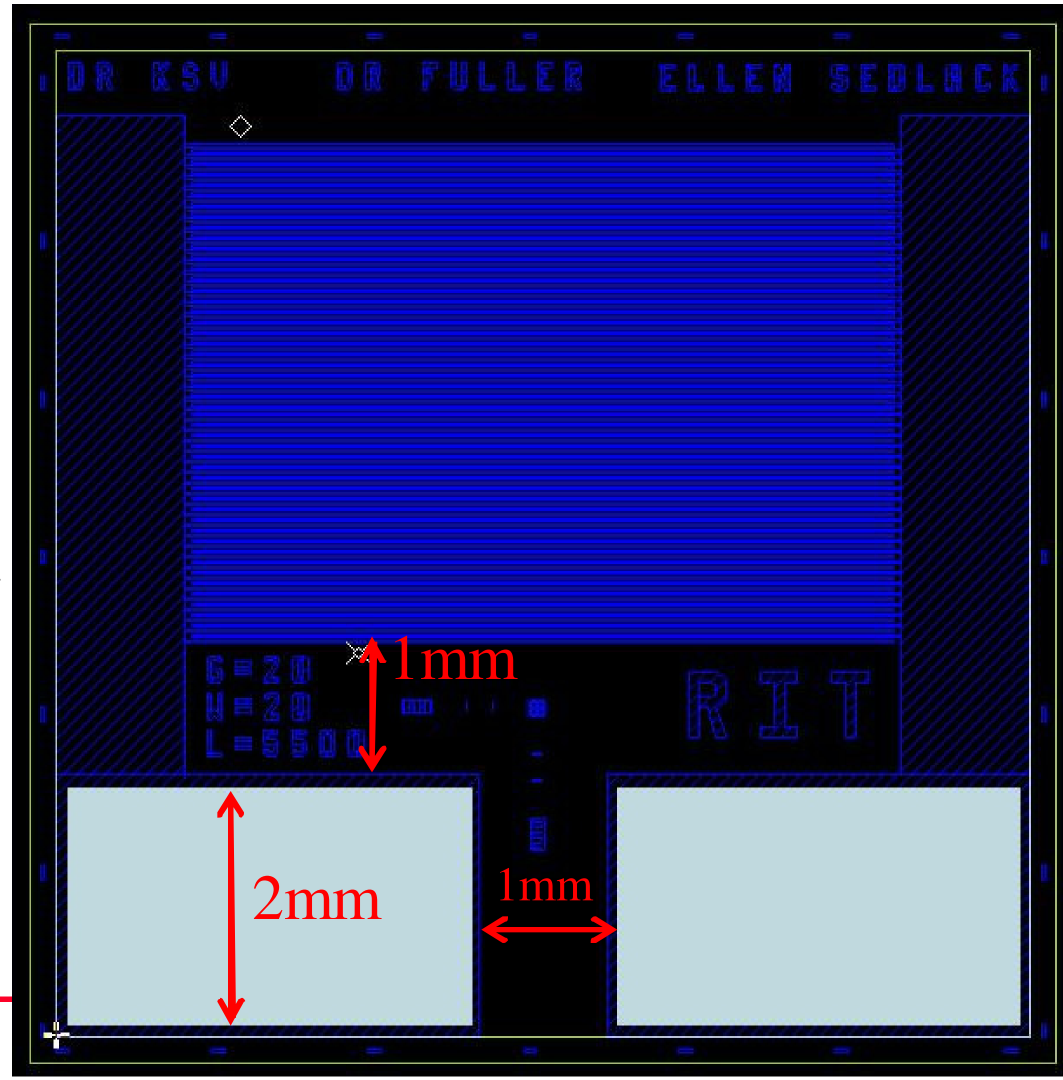
C fingers

$$C = LN\left(4\,\frac{\varepsilon_o \varepsilon_r}{\pi}\right) \sum_{n=1}^{\infty} \frac{1}{2n-1}\, Jo^2\left[\frac{(2n-1)\pi s}{2(s+w)}\right]$$

$\varepsilon_r = \varepsilon_{r1}$

HUMIDITY SENSOR CHIP EXAMPLE

- Chip size: 7.9mm x 7.9mm
- 232 dies
- 95 Fingers:
    - Overlap Length: 4.5mm
    - Width: 20µm (10um)
    - Spaces: 20µm (30um)
- Pads and Other Layout Area
    - 2mm x 3mm Qty 2
    - 1mm x 5mm Qty 2
    - Total of 22000000um2



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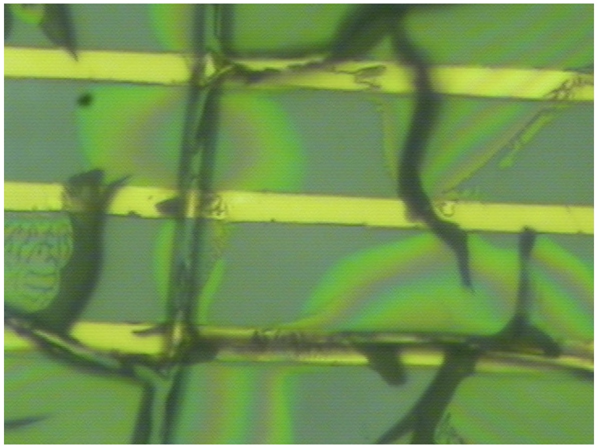
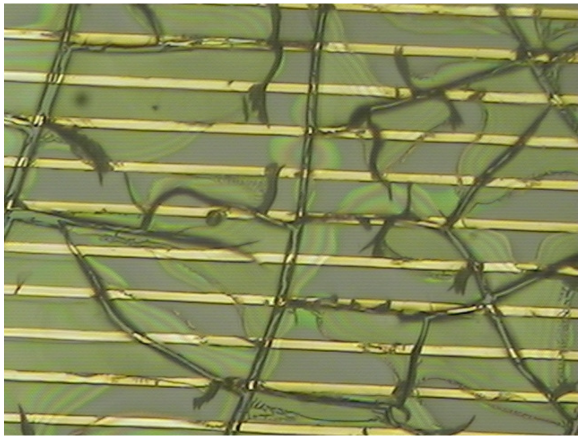
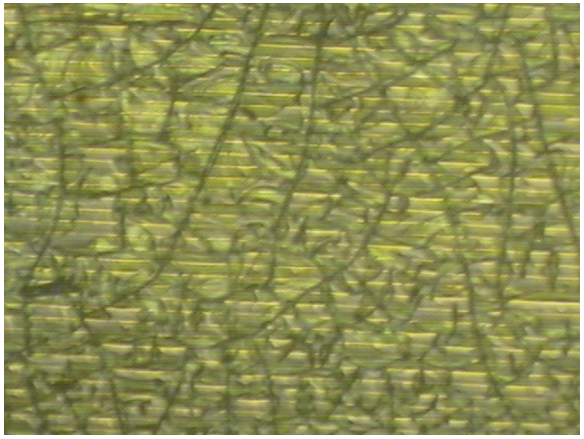
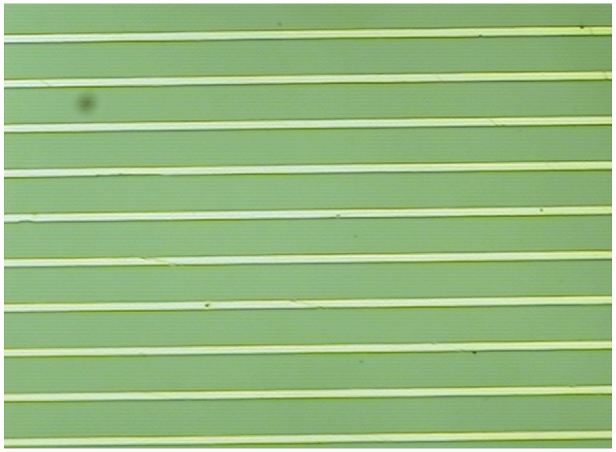
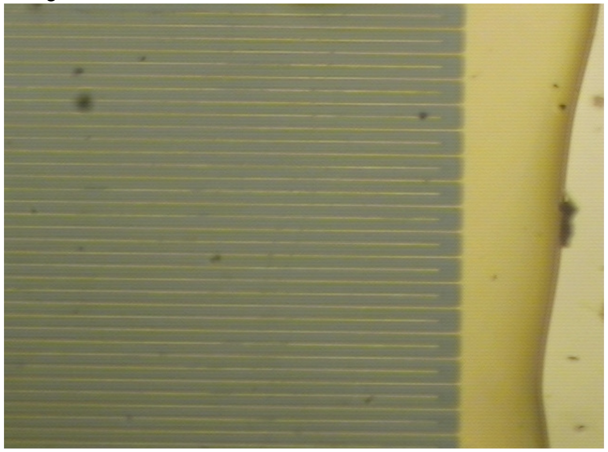
FILM CRACKING

Polyimide film if not cured correctly will crack as it absorbs water

Properly cured (baked) Polyimide does not crack

PROPERTIES OF POLYIMIDE

Polyimide - Kapton, Apical, Upilex and other names. Polyimide films are available in differing chemistries with different properties. The curing and annealing cycles are important in defining film properties.

Stable to 400°C (and above without oxygen available)

Relative Dielectric Constant	3.0 to 3.7
Water absorption (%)	2.1 to 3.7
CTE 100-200C (ppm/C)	15 to 35
CHE (ppm/%RH)	10 to 20
Youngs Modulus (Gpa)	2.7 to 5.5

MODELING OF DIELECTRIC CONSTANT VS % RH

Simple Model for relative dielectric constant of polyimide vs Relative Humidity

$$\varepsilon_{rPI} = \varepsilon_{rPI0} + \varepsilon_{rH2O} * A * RH/100$$

Relative Humidity (%) – RH
Relative Dielectric Constant at a given RH - ε_{rPI}
Relative Dielectric Constant of Dry Polyimide – ε_{rPI0}
Relative Dielectric Constant of Water – ε_{rH2O}
Maximum Water Absorption in Polyimide (%) – A

Example: at 50% RH $\varepsilon_{rPI} = \varepsilon_{rPI0} + \varepsilon_{rH2O} * A * RH/100$

$$= 3.7 + 80 * 0.03 * 50/100$$

$$= 4.9$$

CALCULATIONS FOR EXAMPLE

Capacitance of Two Parallel Plates		
Capacitance = eoer Area/d C =	2.72E-11	F
eo = Permitivitty of free space	8.85E-14	F/cm
er = relative permitivitty =	3.9	
Area =	3.15E-03	cm2
number of pairs of plates, N =	1	
distance between plates, d =	0.4	µm
If round plates, Diameter =	0	µm
If rectangular plates, length =	670	µm
If rectangular plates, width =	470	µm
Force Between Two Parallel Plates Force =	3.40E-03	N
Electrostatic Force= eoer Area V²/2d² Applied Voltage, V =	10	volts
Capacitance for very Thick Interdigitated Fingers		
C = (N-1) eoer L h/s Capacitance, C =	1.70E-12	F
Number of Fingers, N =	121	
relative dielectric constant, er =	8	
Length of finger overlap, L =	100	µm
height of fingers, h =	2	µm
space between fingers, s =	1	µm

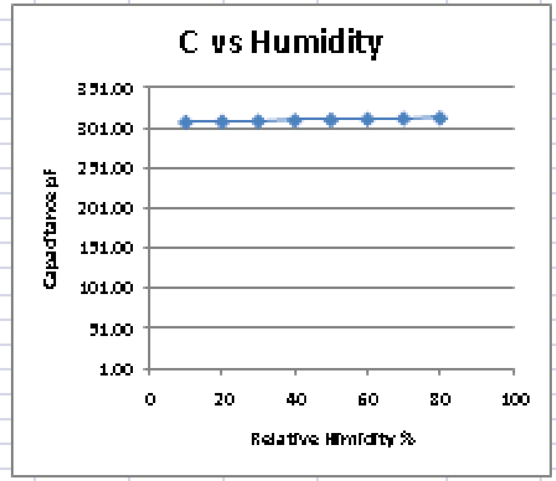
Capacitance for very Thin Interdigitated Fingers on thick insulating substrate

Capacitance, C =	1.70E-11	F	3.8	er Top
Number of Fingers, N =	100		0	er Bottom
relative dielectric constant, er =	5.24		60	RH%
Length of finger overlap, L =	5400	µm	5.24	er*
width of fingers, w =	10	µm		
space between fingers, s =	30	µm		

If on oxide over silicon use equation above with eo for material above the fingers added to the Capacitance to silicon substrate calculated below

Capacitance to Silicon Substrate =	2.96E-10	F
er (oxide) =	3.9	
Oxide thickness =	8000	Å
Total area of pads and other layout features =	22000000	um2
Total Capacitance =	3.13E-10	F

RH%	C pF
10	308.63
20	309.41
30	310.19
40	310.97
50	311.74
60	312.52
70	313.30
80	314.08



	(2n-1)(pi)s/2(s+w	zero order Bessel			sum
n	x	Jo(x)	Jo²	Jo²/2n-1	0.5325365
1	1.1775	0.6823	0.4655	0.4655	
2	3.5325	-0.3844	0.1477	0.0492	
3	5.8875	0.1183	0.014	0.0028	
4	8.2425	0.1112	0.0124	0.0018	
5	10.5975	-0.2279	0.0519	0.0058	
6	12.9525	0.2033	0.0414	0.0038	
7	15.3075	-0.075	0.0056	0.0004	
8	17.6625	-0.0754	0.0057	0.0004	
9	20.0175	0.1658	0.0275	0.0016	
10	22.3725	-0.1547	0.0239	0.0013	

HUMIDITY SENSOR DESIGN SUMMARY

1. Polyimide coating should be 2 times the finger spacing
2. Stray capacitance to the substrate should be minimized by:
    1. Using thick oxide between metal and silicon
    2. Minimize wire bond pad size
    3. Minimize size of metal connections to fingers
3. Maximize the number of metal fingers
4. Response time maybe related to polyimide thickness
5. Cure of polyimide is important to prevent cracking of film

BETTER DESIGN

Capacitance = eoer Area/d C =	2.72E-11	F		
eo = Permitivitty of free space	8.85E-14	F/cm		
er = relative permitivitty =	3.9			
Area =	3.15E-03	cm2		
number of pairs of plates, N =	1			
distance between plates, d =	0.4	µm		
If round plates, Diameter =	0	µm		
If rectangular plates, length =	670	µm		
If rectangular plates, width =	470	µm		
Force Between Two Parallel Plates Force =	3.40E-03	N		
Electrostatic Force= eoer Area $V^2/2d^2$ Applied Voltage, V =	10	volts		
Capacitance for very Thick Interdigitated Fingers				
C = (N-1) eoer L h/s Capacitance, C =	2.82E-12	F		
Number of Fingers, N =	200			
relative dielectric constant, er =	8			
Length of finger overlap, L =	100	µm		
height of fingers, h =	2	µm		
space between fingers, s =	1	µm		
Capacitance for very Thin Interdigitated Fingers on thick insulating substrate				
Capacitance, C =	4.08E-11	F	3.8	er Top
Number of Fingers, N =	400		0	er Bottom
relative dielectric constant, er =	4.04		10	RH%
Length of finger overlap, L =	2500	µm	4.04	er*
width of fingers, w =	3	µm		
space between fingers, s =	2	µm		
If on oxide over silicon use equation above with eo for material above the fingers				
added to the Capacitance to silicon substrate calculated below				
Capacitance to Silicon Substrate =	2.60E-11	F		
er (oxide) =	3.9			
Oxide thickness =	10000	Å		
Total area of pads and other layout features =	12000	um2		
Total Capacitance =	6.68E-11	F		
Capacitance Between Two Closely Spaced Wires				
Capacitance per unit length, C =	63.47	pF/m		
relative dielectric constant, er =	3			
half center to center space, h =	1	mm		
conductor radius, r =	0.5	mm		

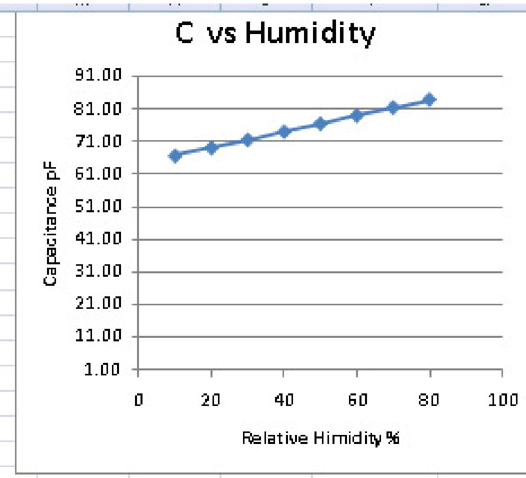
$$C = LN\left(4\frac{\varepsilon_o\varepsilon_r}{\pi}\right)\sum_{n=1}^{\infty}\frac{1}{2n-1}\,Jo^2\left[\frac{(2n-1)\pi s}{2(s+w)}\right]$$

Capacitance per unit length C/L

$$C/L = 12.1\ \varepsilon_r / (\log[(h/r) + ((h/r)^2-1)^{1/2}])$$

h = half center to center space
r = conductor radius (same units as h)

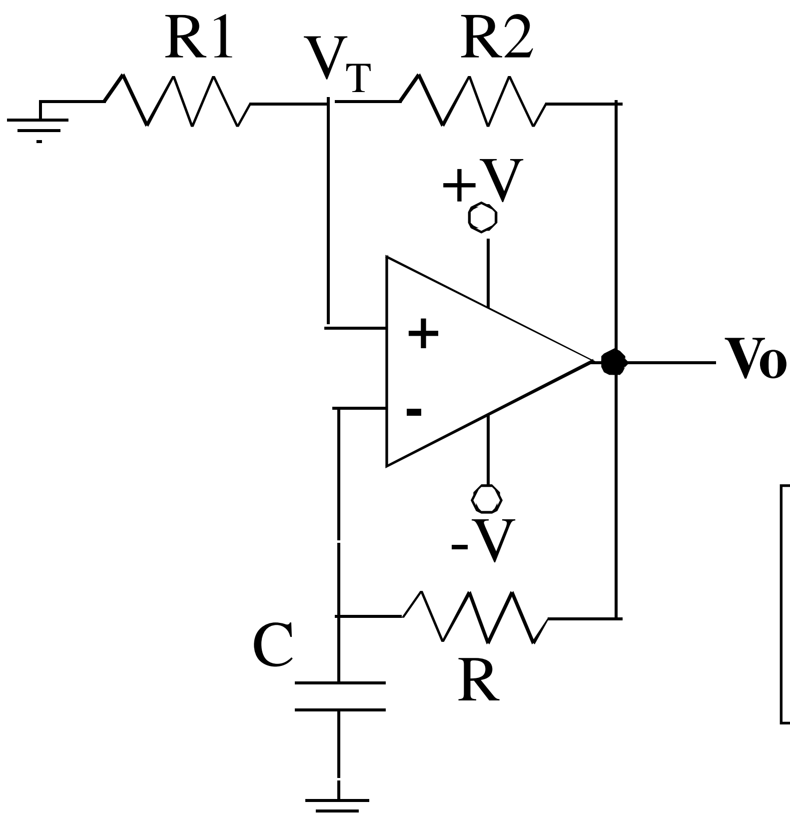
RH%	C pF
10	66.76
20	69.18
30	71.60
40	74.02
50	76.45
60	78.87
70	81.29
80	83.71

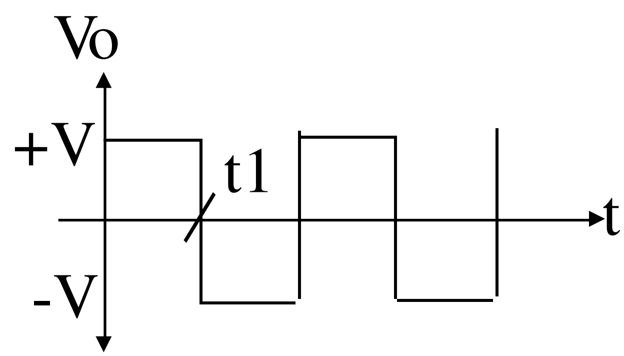


n	x (2n-1)(pi)s/2(s+w	zero order Bessel Jo(x)	Jo^2	Jo^2/2n-1	sum
					0.89508275
1	0.628	0.90381	0.81687	0.81687	
2	1.884	0.29112	0.08475	0.02825	
3	3.14	-0.30379	0.09229	0.01846	
4	4.396	-0.34307	0.11769	0.01681	
5	5.652	0.04423	0.00196	0.00022	
6	6.908	0.29837	0.08903	0.00809	
7	8.164	0.13144	0.01728	0.00133	
8	9.42	-0.18036	0.03253	0.00217	
9	10.676	-0.21932	0.0481	0.00283	
10	11.932	0.03235	0.00105	5.5E-05	

Sheet1 Sheet2 Sheet3

MULTIVIBRATOR





$$\text{Period} = T = 2RC \ln \left(\frac{1+Vt/V}{1-Vt/V} \right)$$

Bistable Circuit with Hysteresis and RC Integrator

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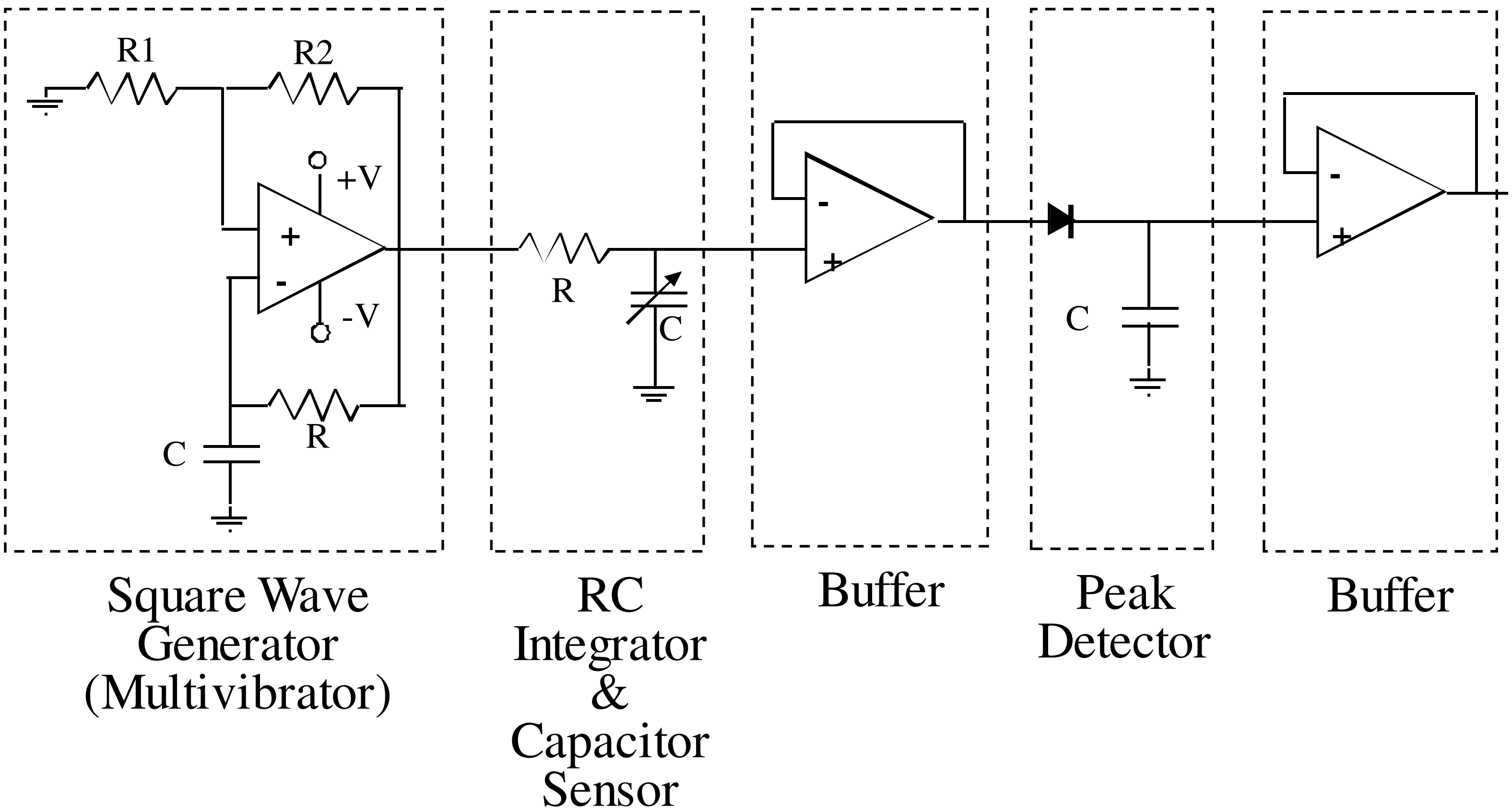
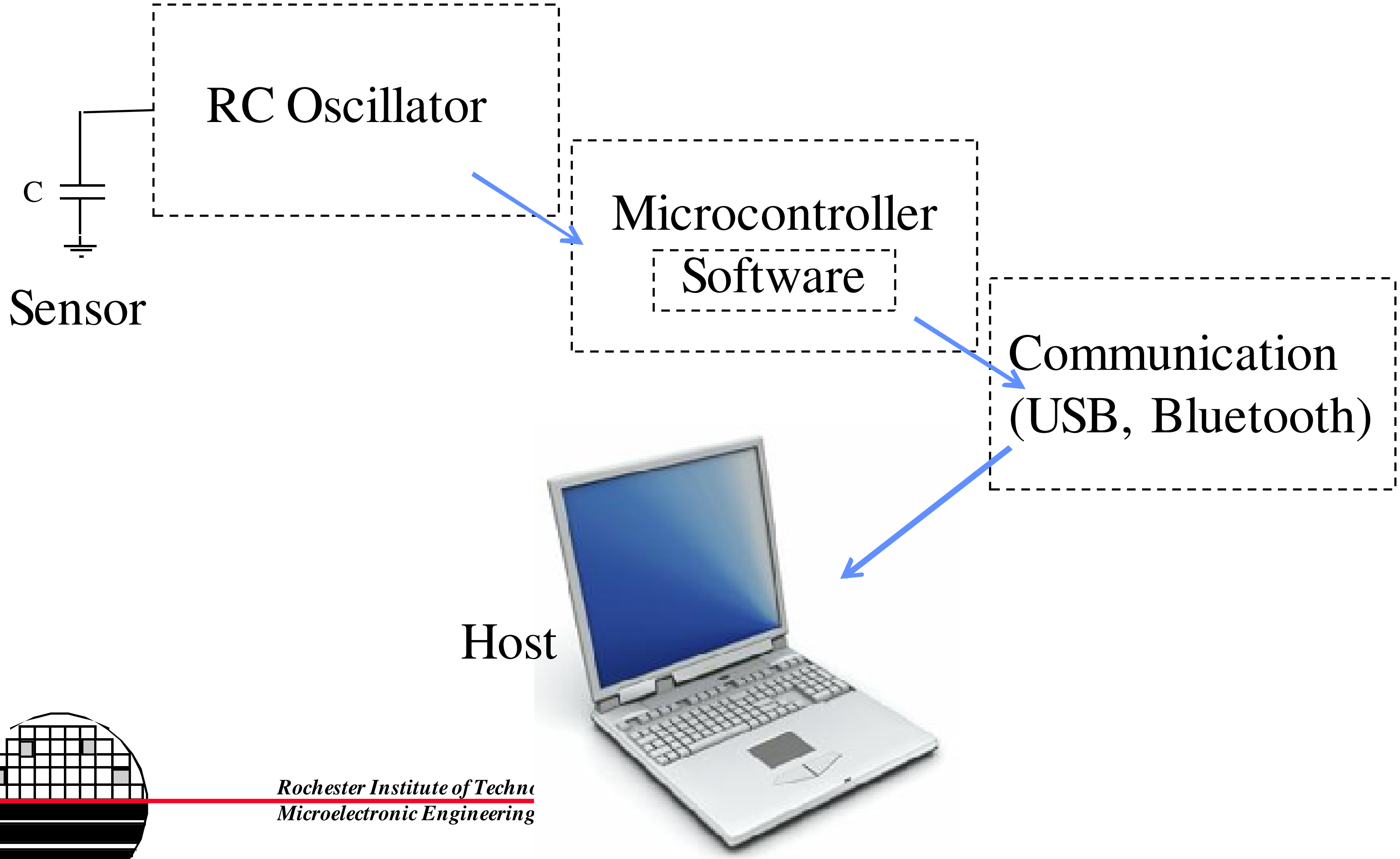
CAPACITOR SENSOR TO ANALOG VOUT



CAPACITOR OSCILLATOR - MICROCONTROLLER



CAPACITOR SENSOR OSCILLATOR EXAMPLE

Let R1=R2=10K and R=1MEG

$$\text{Period} = T = 2RC \ln\left(\frac{1+Vt/V}{1-Vt/V}\right)$$

If C = 34.4pF then T = (2)1M(34.4pF) ln(1.5/0.5)
= 68.8E-6sec or 14.5Khz

If C = 37.9pF then T = 75.8E-6 sec or 13.2Khz

HUMIDITY SENSOR AND BLUE TOOTH WIRELESS

REFERENCES

1. "Polyimide Film as a Vacuum Coating Substrate", Donald J. McClure, Vacuum Coating Technology, December 2010
2. "Capacitive Humidity Sensor using Polyimide Sensing Film", J. Laconte, V. Wilmart, J.P. Raskin, D. Flandre,DTIP, 2003.

HOMEWORK – HUMIDITY SENSOR

1. Look up the Honeywell HCH-1000 humidity sensor data sheet. What is the sensitivity of this sensor?

2. Using the Excel spreadsheet for capacitor calculations design a thin film interdigitated conductor humidity sensor that will be in the same capacitance range as the Honeywell humidity sensor in problem 1.