Evaluation of Pressure Sensor Performance

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4-7-2012 Pressure_Sensor_Lab.ppt

OUTLINE

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SEM Pictures
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Offset, Span, Linearity, etc.
Compensation
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Frequency Response
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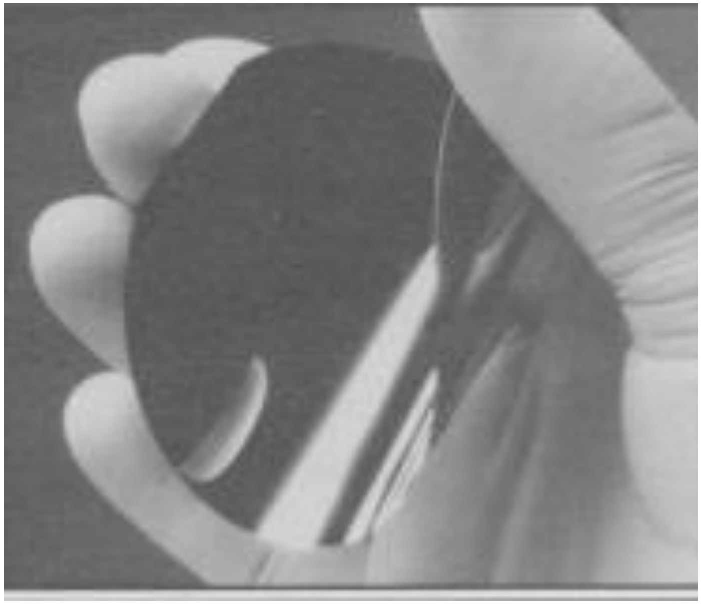
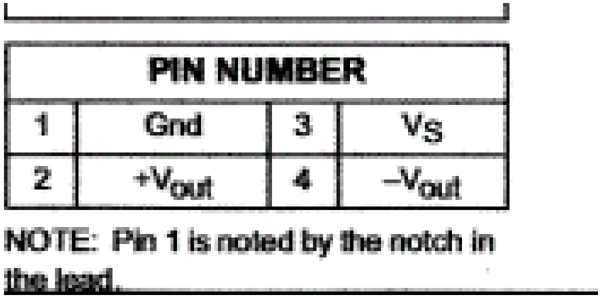


Thickness = 10 µm
Diameter 75 mm

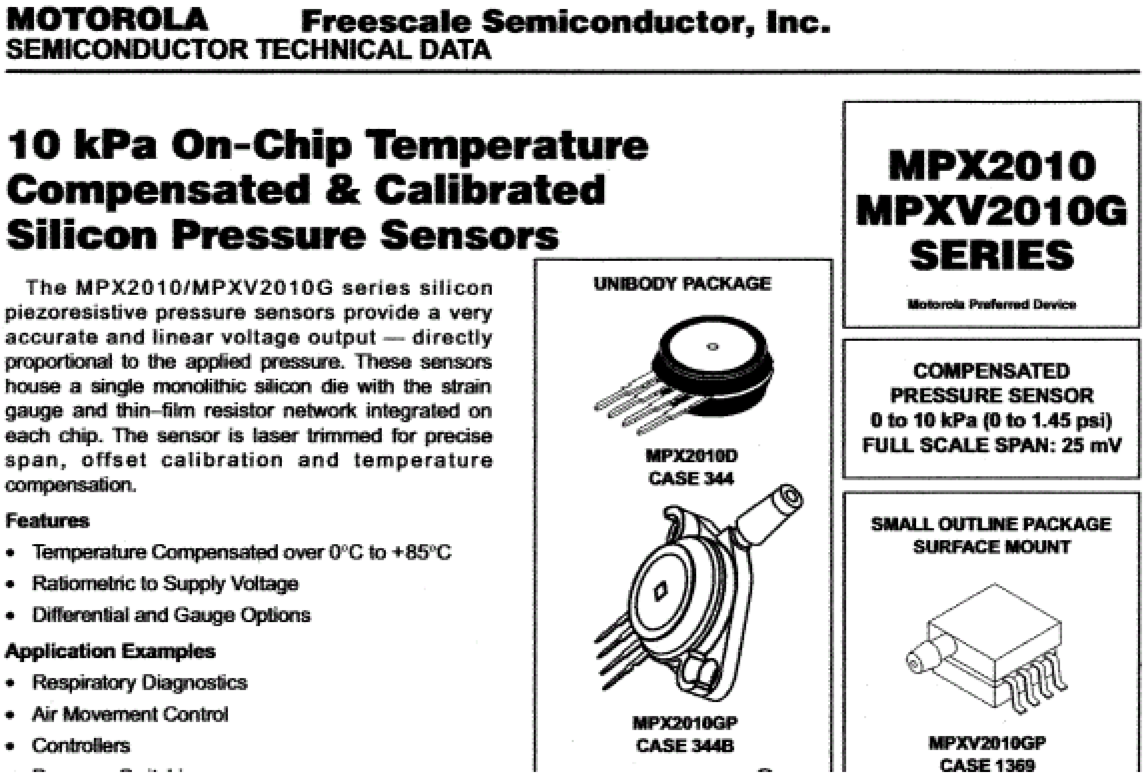
INTRODUCTION

In this lab we will test piezoresistive pressure sensors made at RIT and compare them with sensors made by Freescale Semiconductor



PIN NUMBER			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

NOTE: Pin 1 is noted by the notch in the lead.



MOTOROLA **Freescale Semiconductor, Inc.**
SEMICONDUCTOR TECHNICAL DATA

10 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

The MPX2010/MPXV2010G series silicon piezoresistive pressure sensors provide a very accurate and linear voltage output — directly proportional to the applied pressure. These sensors house a single monolithic silicon die with the strain gauge and thin–film resistor network integrated on each chip. The sensor is laser trimmed for precise span, offset calibration and temperature compensation.

Features

- Temperature Compensated over 0°C to +85°C
- Ratiometric to Supply Voltage
- Differential and Gauge Options

Application Examples

- Respiratory Diagnostics
- Air Movement Control
- Controllers

MPX2010
MPXV2010G
SERIES

Motorola Preferred Device

COMPENSATED PRESSURE SENSOR
0 to 10 kPa (0 to 1.45 psi)
FULL SCALE SPAN: 25 mV

UNIBODY PACKAGE

MPX2010D
CASE 344

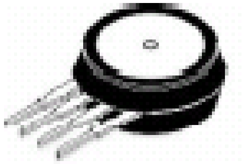
MPX2010GP
CASE 344B

SMALL OUTLINE PACKAGE SURFACE MOUNT

MPXV2010GP
CASE 1369

FREESCALE MPX2202 SERIES PRESSURE SENSORS

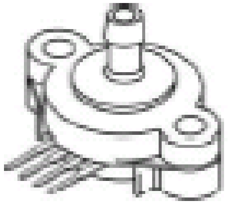
UNIBODY PACKAGES



MPX2202A
CASE 344-15

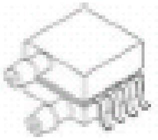
MPX2202AP/GP
CASE 344B-01

MPX2202DP
CASE 344C-01

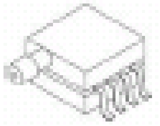


MPX2202ASX
CASE 344F-01

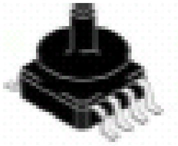
SMALL OUTLINE PACKAGES



MPXV2202GP
CASE 1351-01

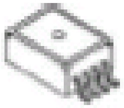


MPXV2202GP
CASE 1369-01

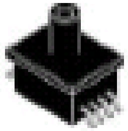


MPXV2202GP
CASE 482A-01

MPAK

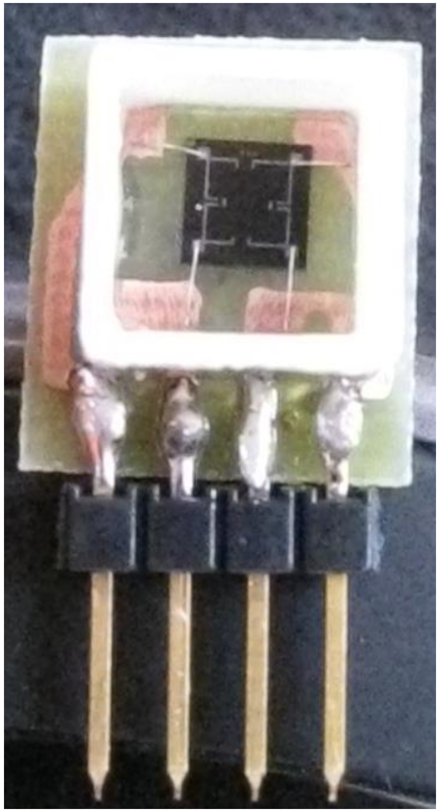


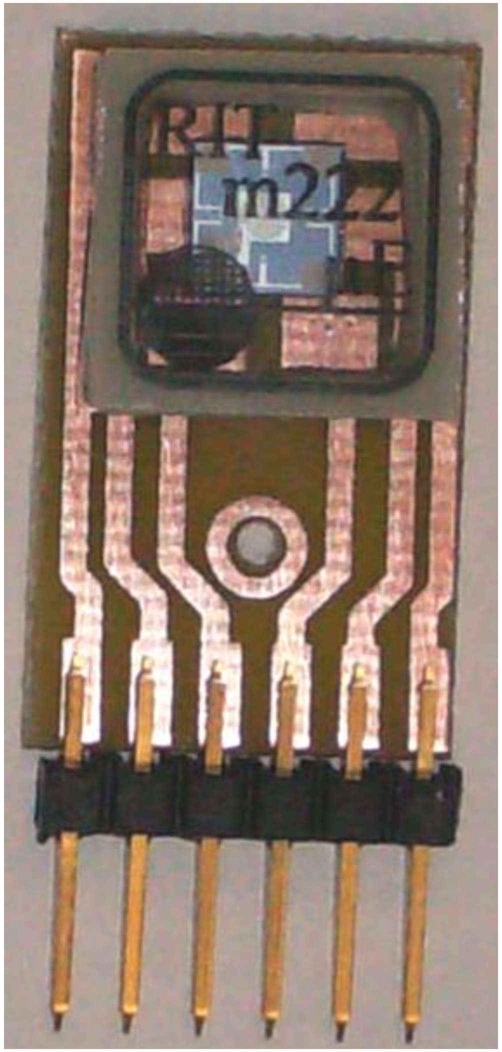
MPXM2202A
CASE 1320-02

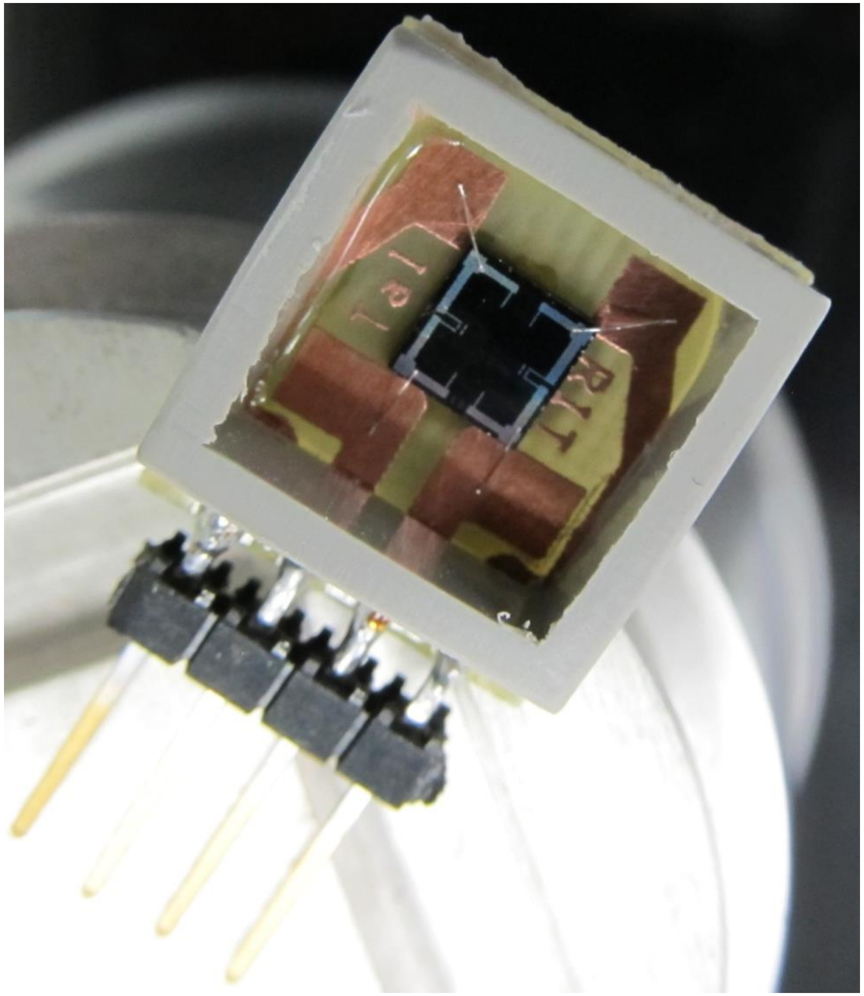


MPXM2202GS/AS
CASE 1320A-02

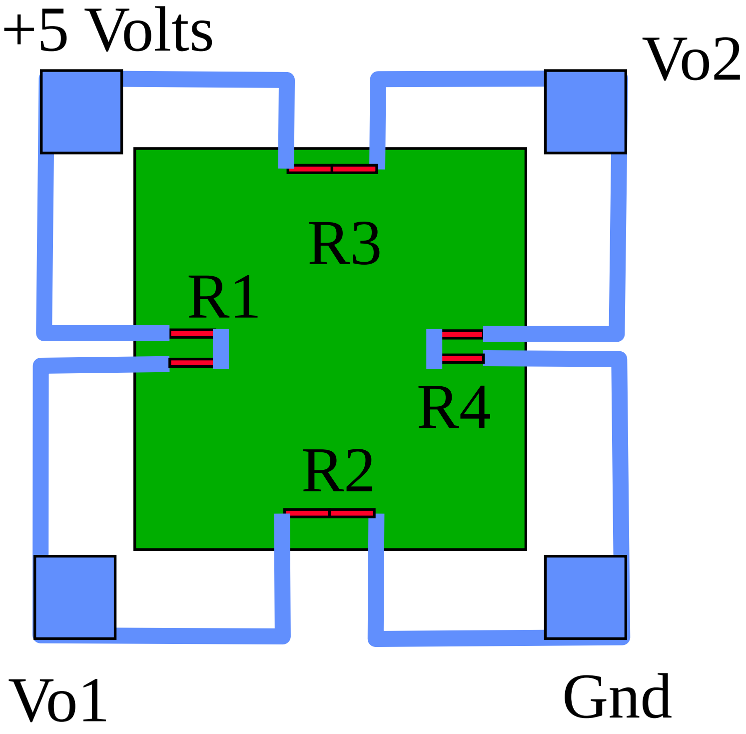
RIT PRESSURE SENSORS







CALCULATION OF EXPECTED OUTPUT VOLTAGE



The equation for stress at the center edge of a square diaphragm (S.K. Clark and K.Wise, 1979)

Stress = 0.3 P(L/H)^2 where P is pressure, L is length of diaphragm edge, H is diaphragm thickness

For a 3000µm opening on the back of the wafer the diaphragm edge length L is 3000 – 2 (500/Tan 54.74°) = 2290 µm

CALCULATION OF EXPECTED OUTPUT VOLTAGE (Cont.)

Stress = 0.3 P $(L/H)^2$

If we apply vacuum to the back of the wafer that is equivalent to and applied pressure of 14.7 psi or 103 N/m^2

P = 103 N/m^2

L= 2290 µm

H= 25 µm

Stress = 2.49E8 N/m^2

Hooke's Law: Stress = E Strain where E is Young's Modulus

$$\sigma = E\ \varepsilon$$

Young's Modulus of silicon is 1.9E11 N/m^2

Thus the strain = 1.31E-3 or .131%

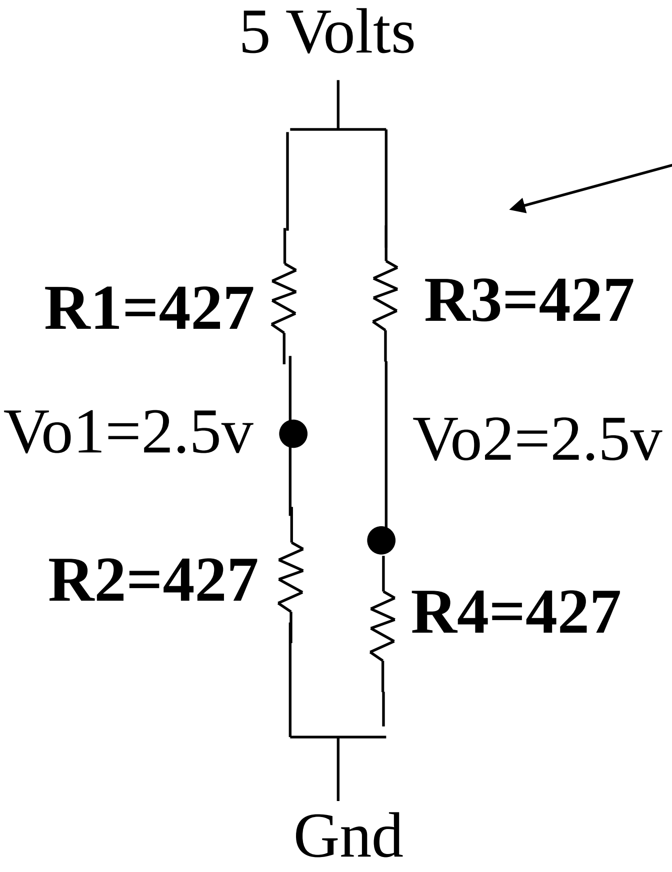
CALCULATION OF EXPECTED OUTPUT VOLTAGE (Cont.)

The sheet resistance (Rhos) from 4 point probe is 61 ohms/sq
The resistance is R = Rhos L/W
For a resistor R3 of L=350 µm and W=50 µm we find:
R3 = 61 (350/50) = 427.0 ohms

R3 and R2 decrease as W increases due to the strain
assume L is does not change, W’ becomes 50+50x0.131%
W’ = 50.0655 µm
R3’ = Rhos L/W’ = 61 (350/50.0655) = 426.4 ohms

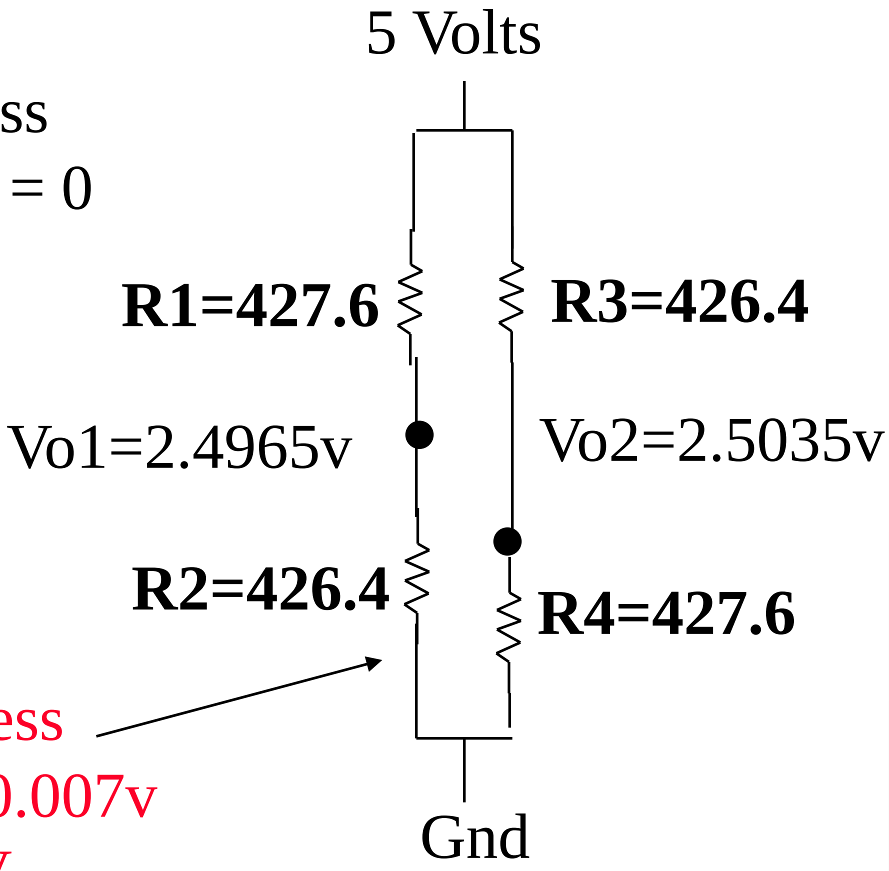
R1 and R4 increase as L increases due to the strain
assume W does not change, L’ becomes 350 + 350x0.131%
R1’ = Rhos L’/W = 61 (350.459/50) = 427.6 ohms

CALCULATION OF EXPECTED OUTPUT VOLTAGE (Cont.)



No stress

Vo2-Vo1 = 0



With stress

Vo2-Vo1 = 0.007v

=7 mV

IF RESISTORS ARE SINGLE CRYSTAL SILICON

In addition to the effects of strain on the resistance if the resistor is made of single crystal silicon there is also a significant piezoresistive effect on the resistor value. Strain effects the mobility of holes and electrons in silicon. The resistors on the diaphragm of the pressure sensor drawn above have current flow longitudinal (R1 and R4) and transverse (R2 and R3) to the strain. The strain is tensile on the top surface of the diaphragm where the resistors are located if positive pressure is applied to the top of the diaphragm. The peizoresistive coefficient for R1 and R4 is 71.8 and for R2 and R3 is -66.3 E-11/Pa. The calculations above give the stress as 2.49E8 Pa thus the hole mobility will decrease in R1 and R4 (R increases in value) by 2.49E8 x 71.8e-11 = 17.9% while R2 and R3 (decrease in value) because the mobility increases by 2.49E8 x 66.3E-11 = 16.5%, thus the overall effect will be dominated by the piezoresistance rather than the effect of strain on the dimensions.

EXPRESSION FOR RESISTANCE

$$R = Ro\,[\,1 + \pi_L\sigma_{xx} + \pi_T(\sigma_{yy} + \sigma_{zz})]$$

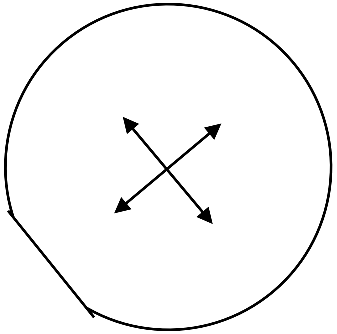
where $Ro = (L/W)(1/(q\mu(N,T)\ \text{Dose}))$

π_L is longitudinal piezoresistive coefficient
π_T is transverse piezoresistive coefficient
σ_{xx} is the x directed stress, same direction as current
σ_{yy} is the y directed stress, transverse to current flow
σ_{zz} is the z directed stress, transverse to current flow

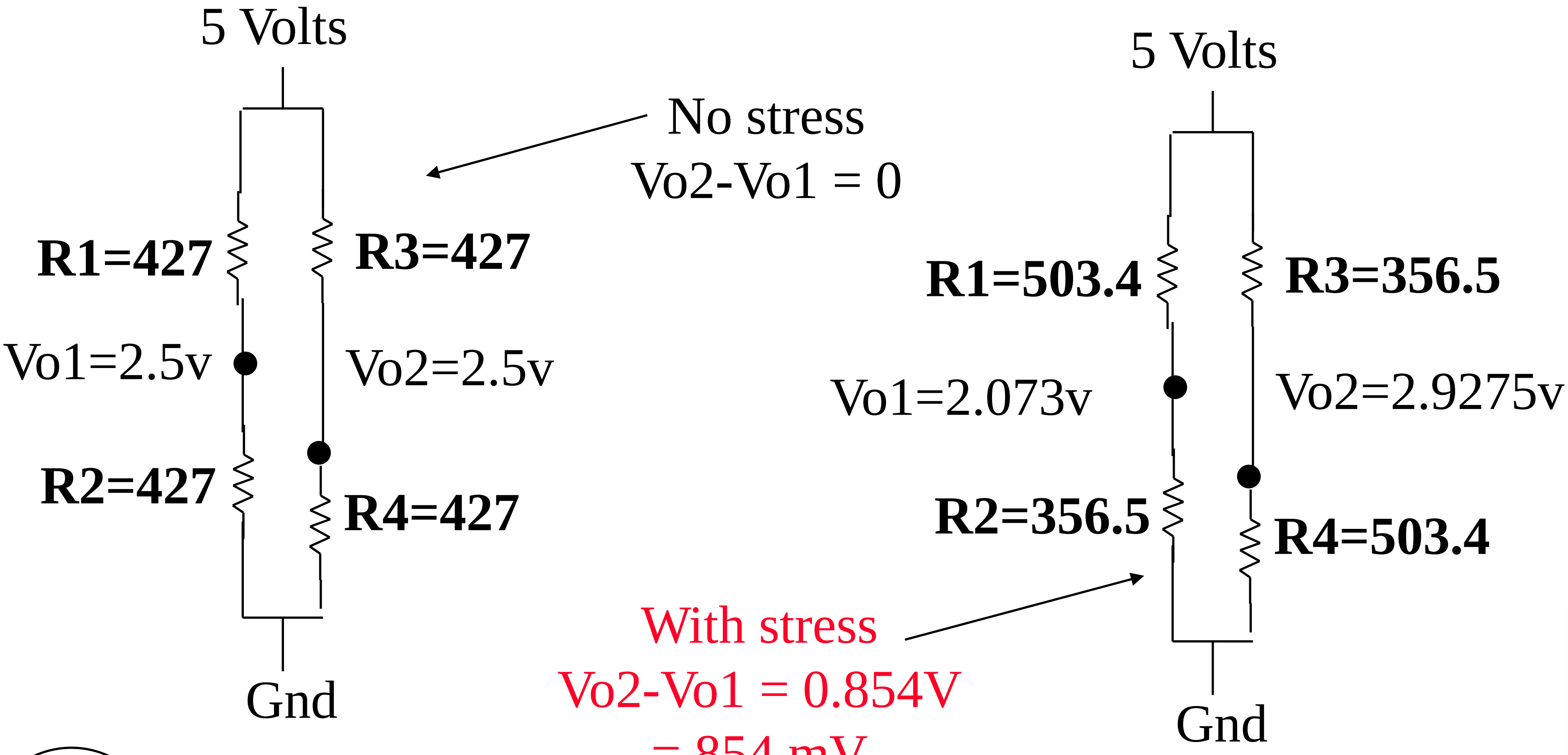
In the <110> direction

	π_L (E^{-11}/Pa)	**π_T (E^{-11}/Pa)**
Electrons	**-31.6**	**-17.6**
holes	**71.8**	**-66.3**

(100) wafer
<110> directions



CALCULATION OF EXPECTED OUTPUT VOLTAGE FOR SINGLE CRYSTAL RESISTORS



5 Volts

R1=427

R3=427

Vo1=2.5v

Vo2=2.5v

R2=427

R4=427

Gnd

No stress

Vo2-Vo1 = 0

5 Volts

R1=503.4

R3=356.5

Vo1=2.073v

Vo2=2.9275v

R2=356.5

R4=503.4

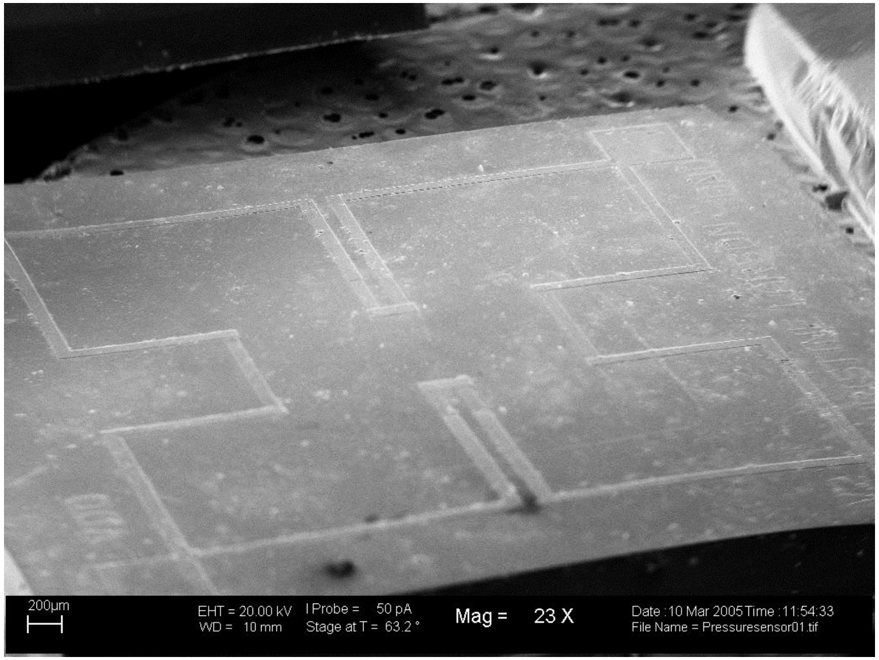
Gnd

With stress

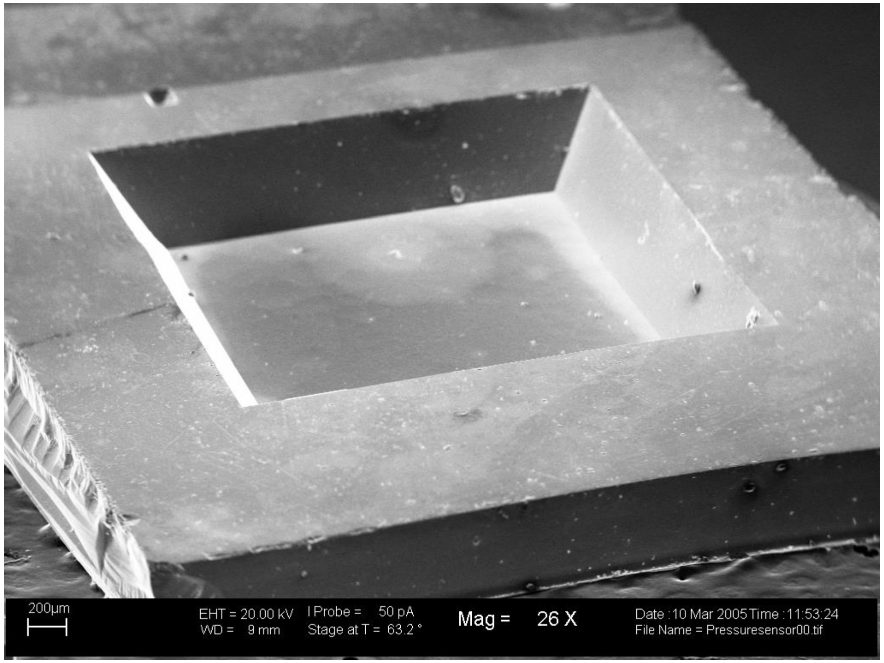
Vo2-Vo1 = 0.854V

= 854 mV

SEM OF RIT PRESSURE SENSOR

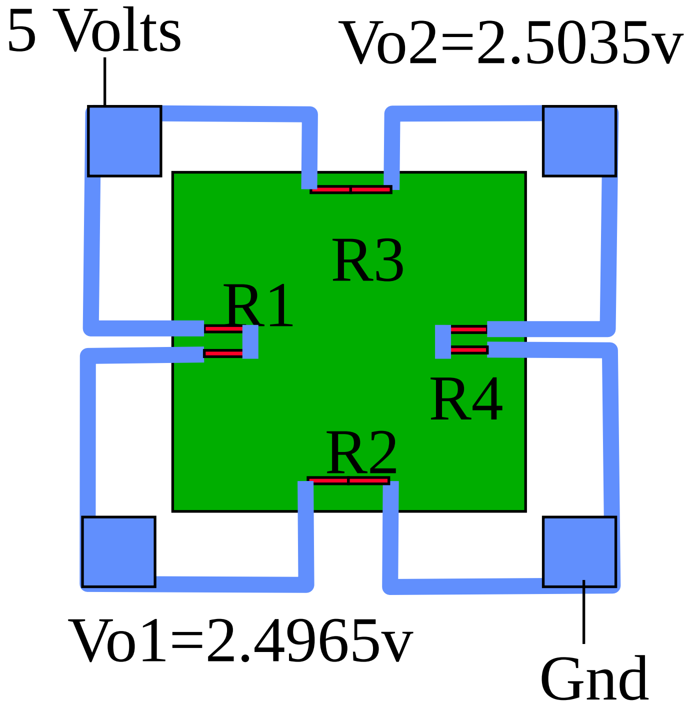


Front



Back

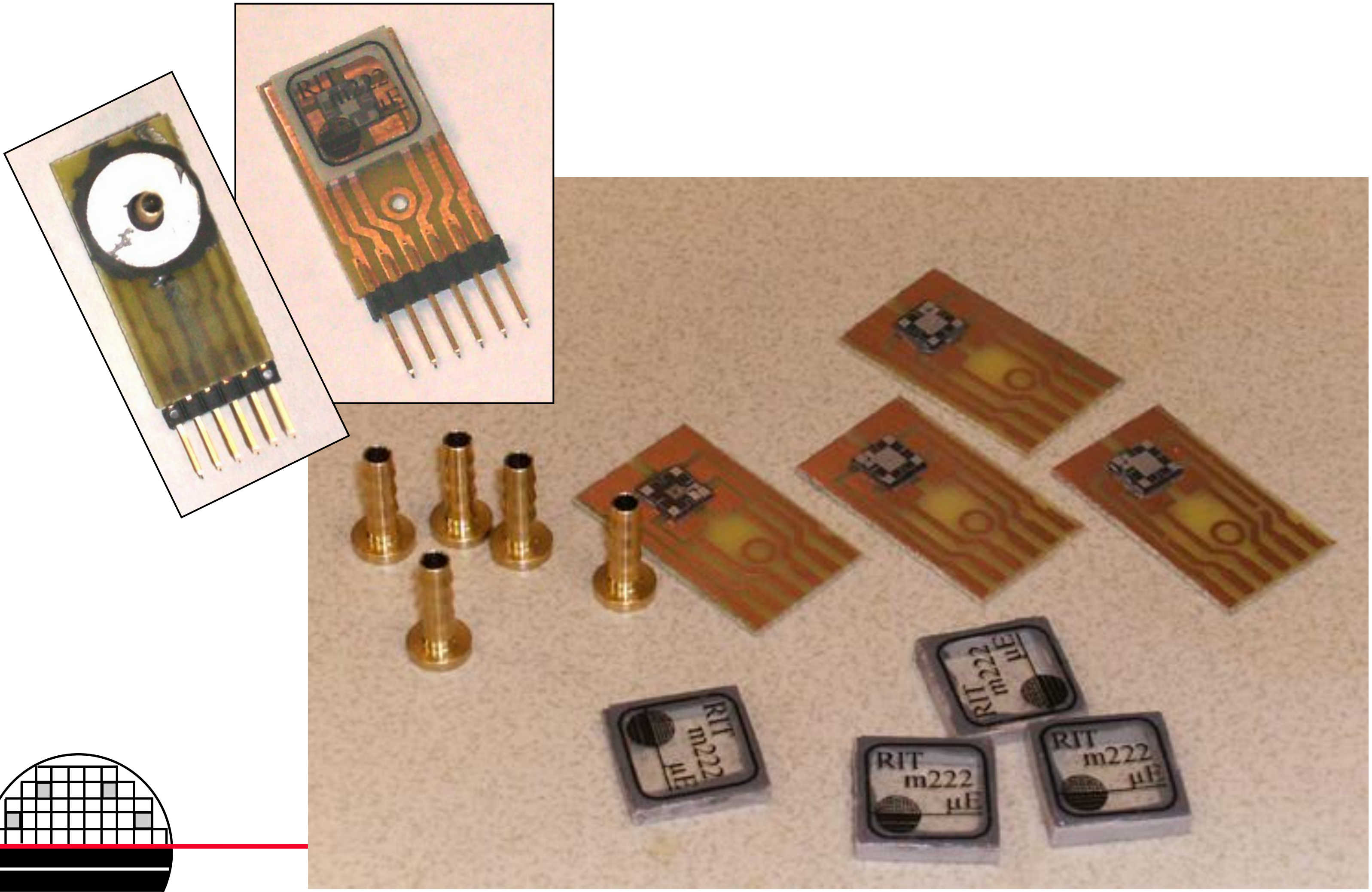
BASICS



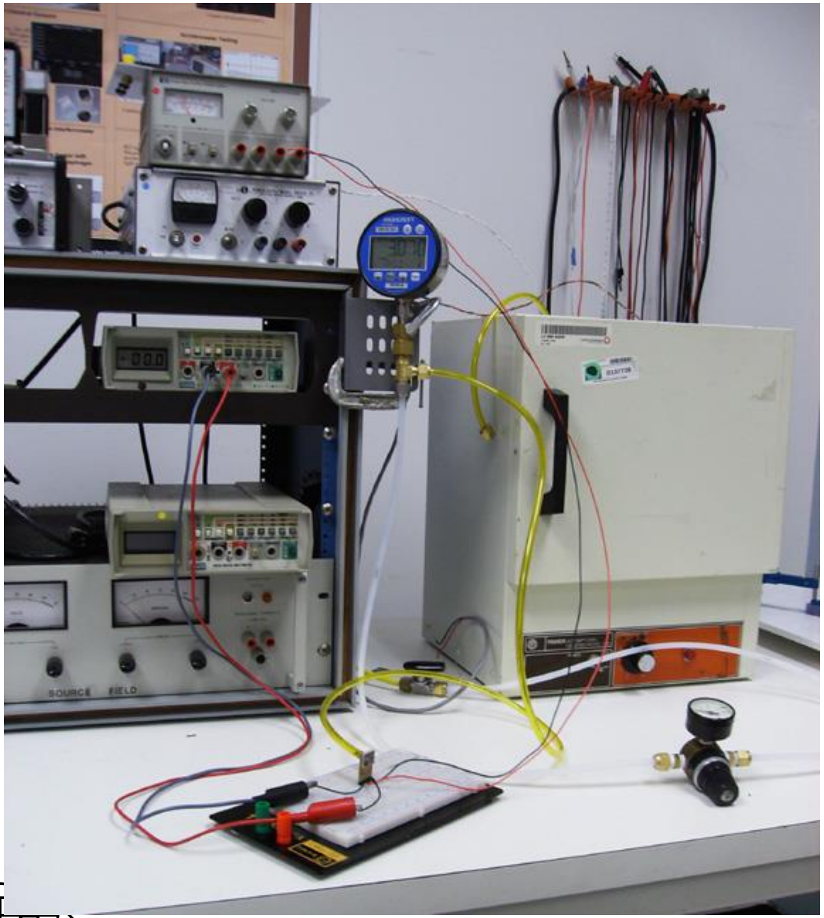
Check that vo1 and Vo2 are near Vsupply/2 and Vo ~ 0

Apply and release chuck vacuum to observe change in output voltage

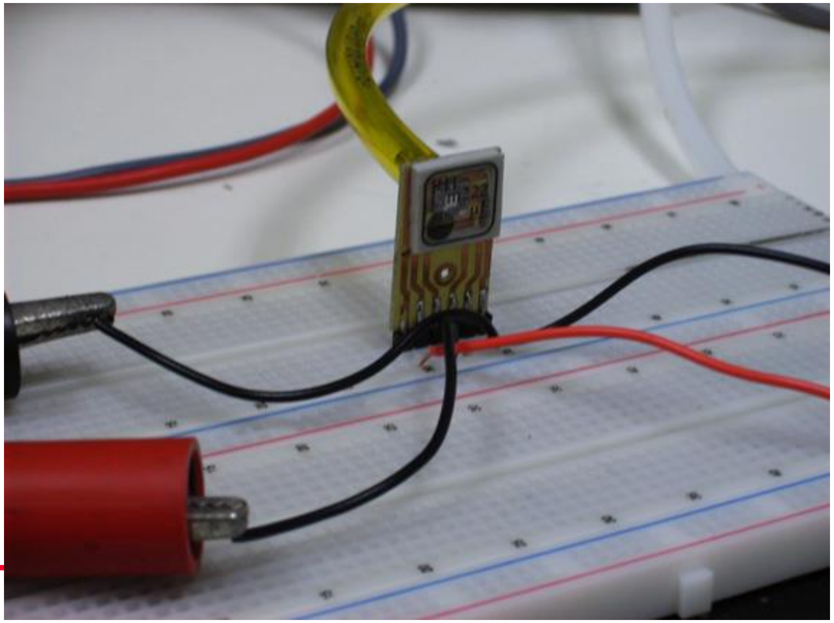
PRESSURE SENSOR PACKAGING



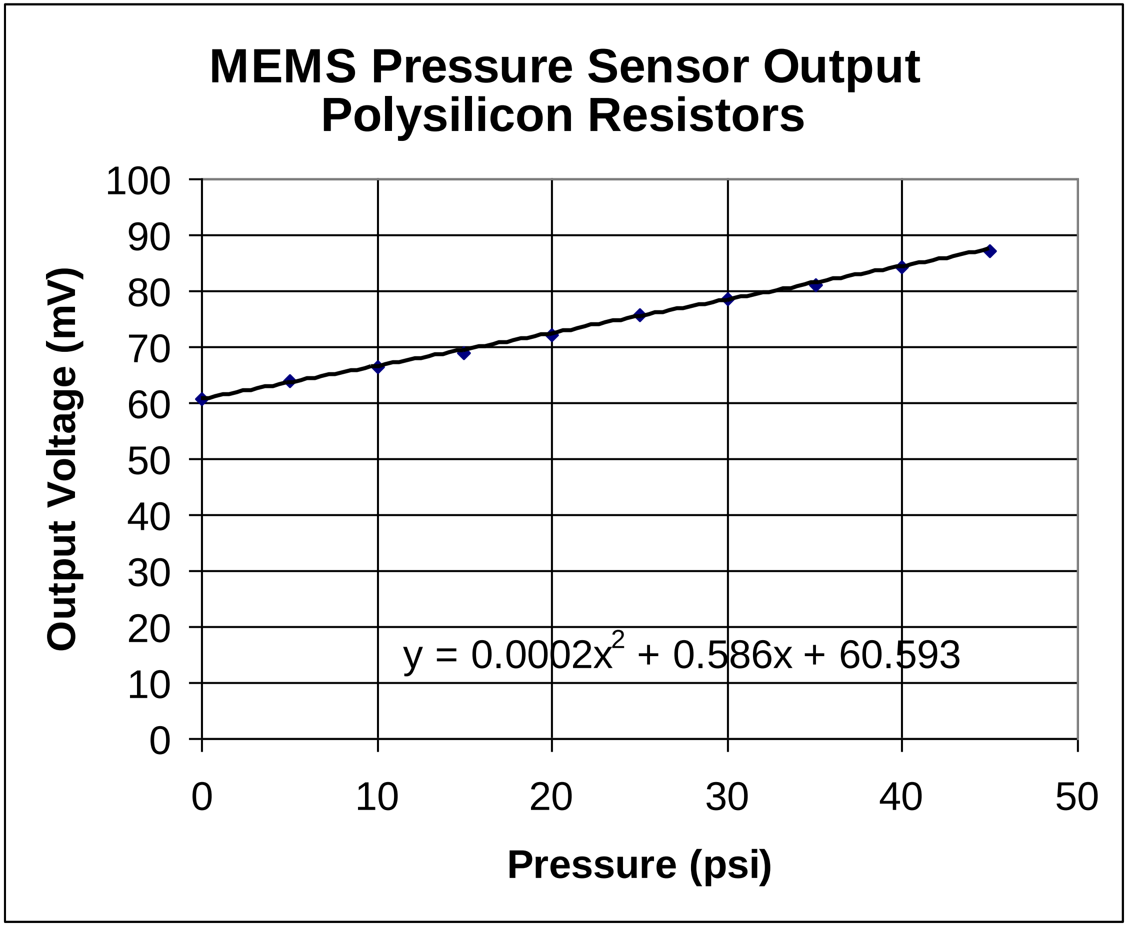
PRESSURE SENSOR TEST SETUP



Apply pressure, measure and compare with other pressure gages. Collect data.



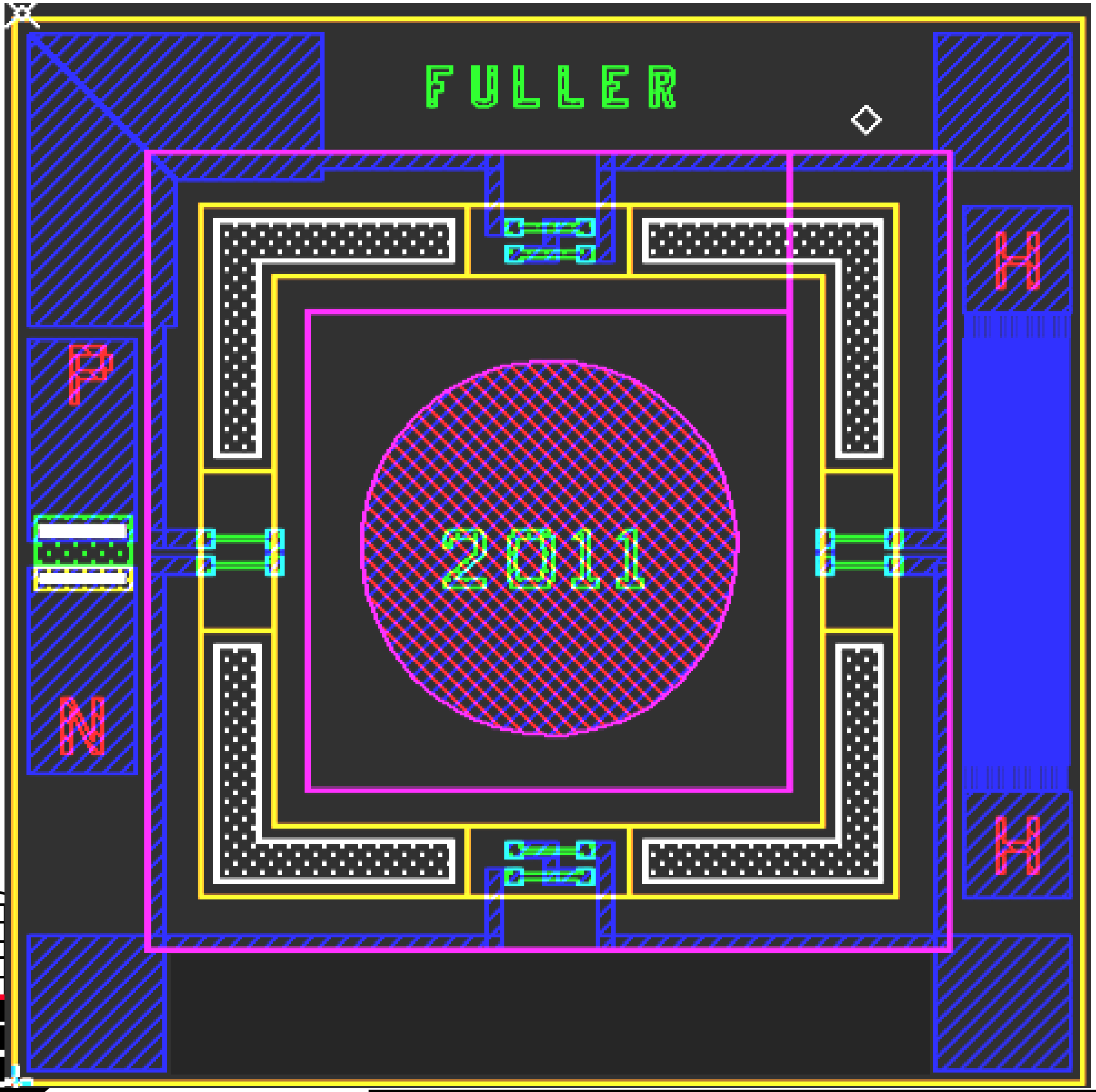
OUTPUT VOLTAGE VERSUS PRESSURE



psi	mV
0	60.6
5	63.84
10	66.32
15	68.95
20	72.28
25	75.62
30	78.68
35	81.25
40	84.39
45	87.21

5-15-03

PRESSURE SENSOR CHIP – VER 3



Pressure Sensor
Temperature Sensor
Humidity Sensor

Diffused Resistors
Length =
Width =

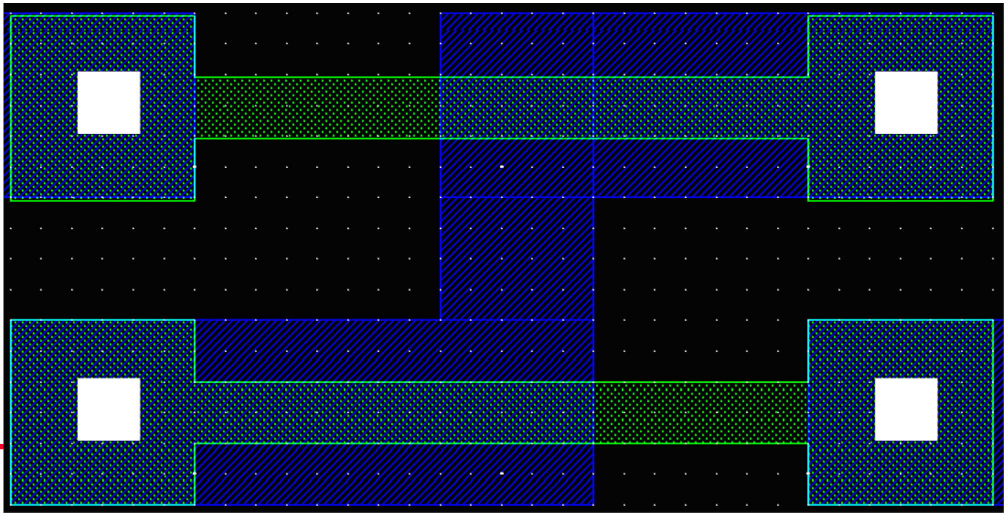
Note: upper left is not connected so individual resistances can be measured.

ELECTRICAL MEASUREMENTS

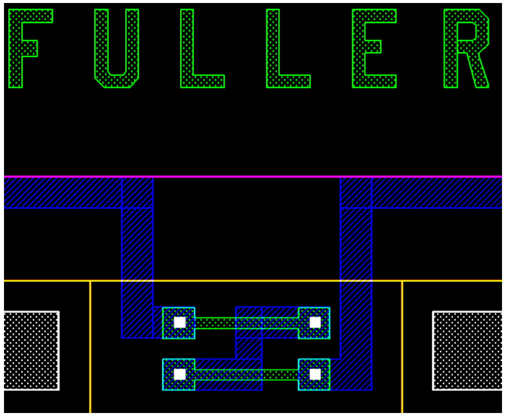
Measured resistance: Rtop = 3.538 Kohm
Rright = 3.537 Kohm
Rbottom = 3.537 Kohm
Rleft = 3.537 Kohm

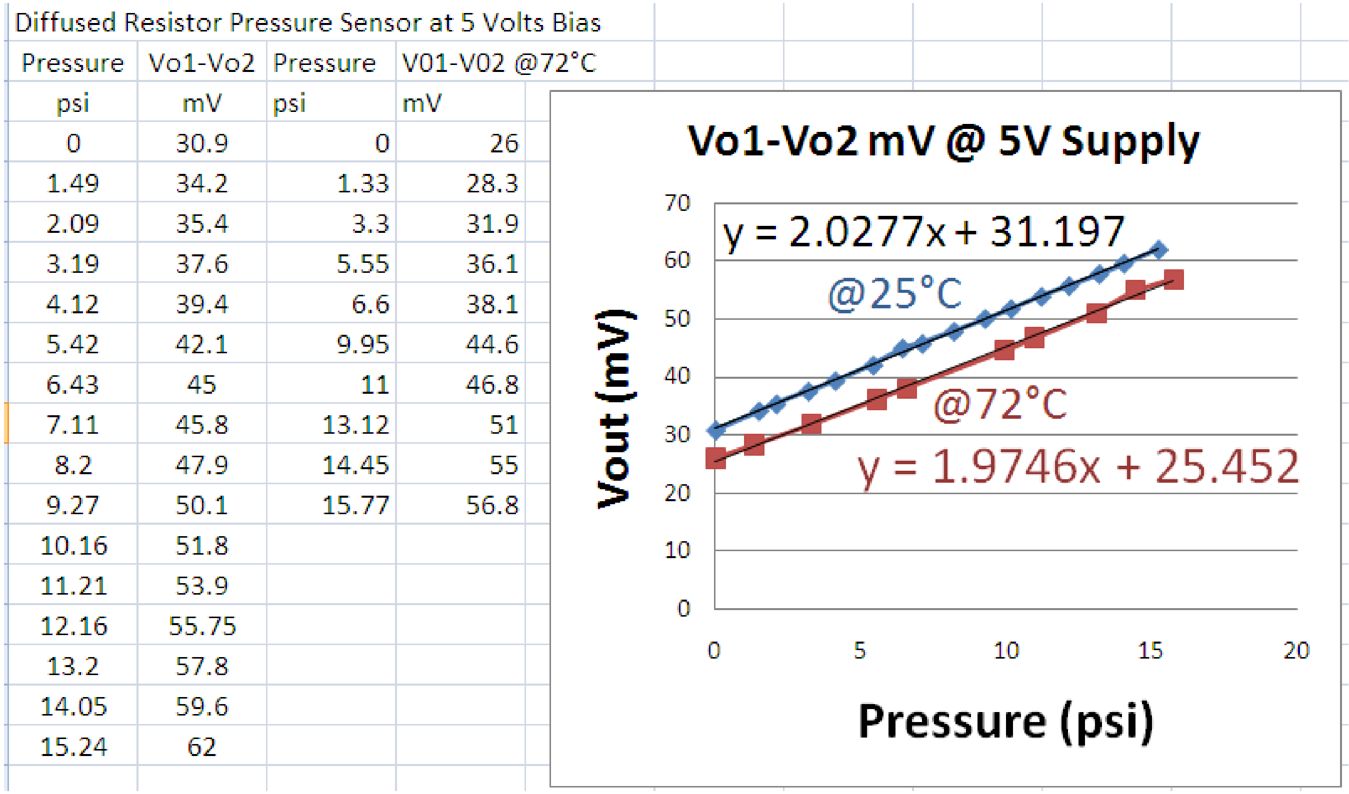
Measured Voltages: Vo1 = 2.535 V
Vo2 = 2.504 V
Vo1-Vo2 = 31.0 mV

Rhos ~= 150 ohm/sq



OUTPUT VOLTAGE VS PRESSURE





Diffused Resistor Pressure Sensor at 5 Volts Bias

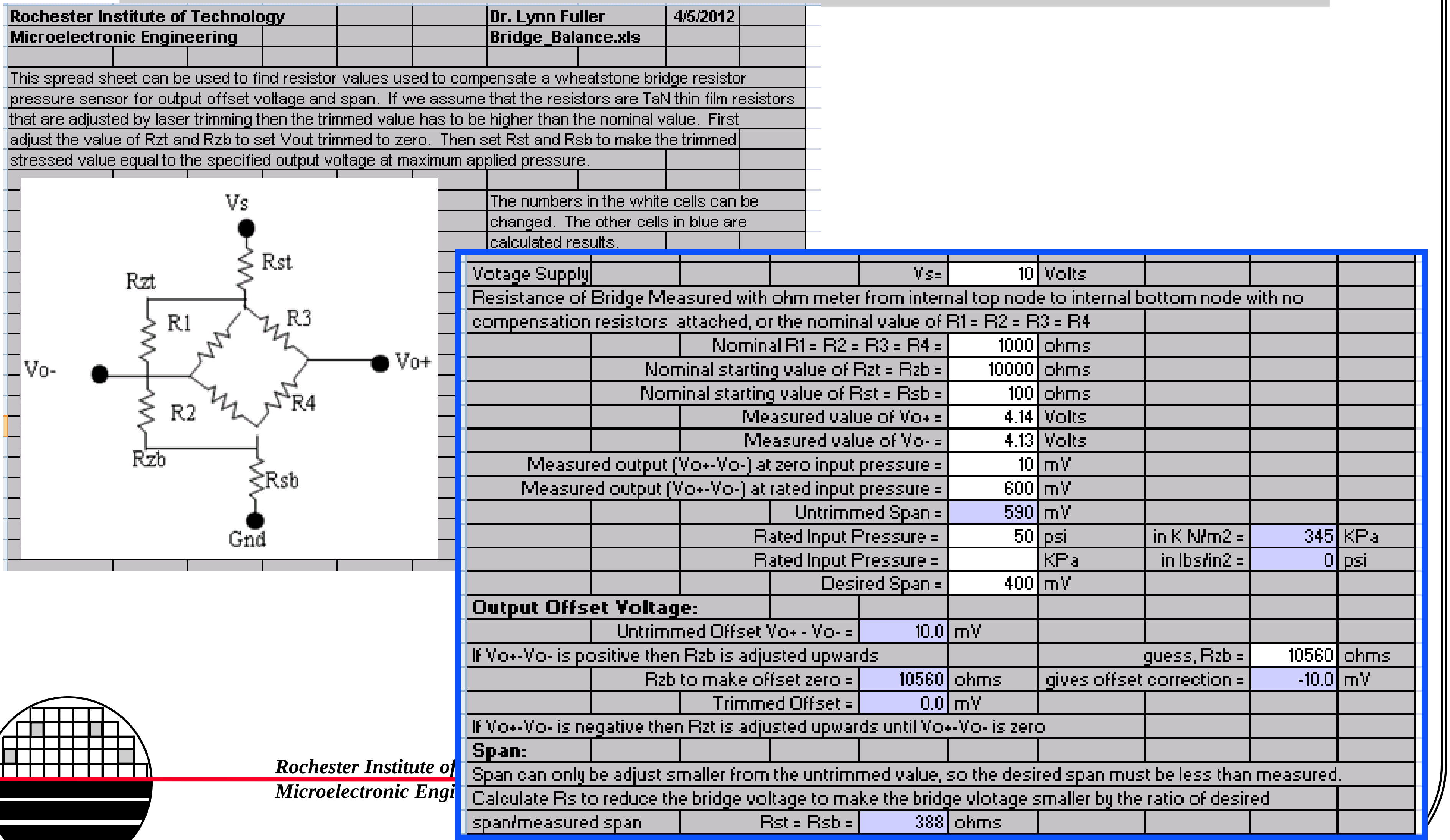
Pressure psi	Vo1-Vo2 mV	Pressure psi	V01-V02 @72°C mV
0	30.9	0	26
1.49	34.2	1.33	28.3
2.09	35.4	3.3	31.9
3.19	37.6	5.55	36.1
4.12	39.4	6.6	38.1
5.42	42.1	9.95	44.6
6.43	45	11	46.8
7.11	45.8	13.12	51
8.2	47.9	14.45	55
9.27	50.1	15.77	56.8
10.16	51.8		
11.21	53.9		
12.16	55.75		
13.2	57.8		
14.05	59.6		
15.24	62		

Sensitivity = 0.406mV/psi/V

or 0.0589 mV/KPa/V

or 0.589 mV/KPa @ 10VDC

ZERO AND SPAN COMPENSATION



Rochester Institute of Technology	**Dr. Lynn Fuller**	**4/5/2012**
Microelectronic Engineering	**Bridge_Balance.xls**	

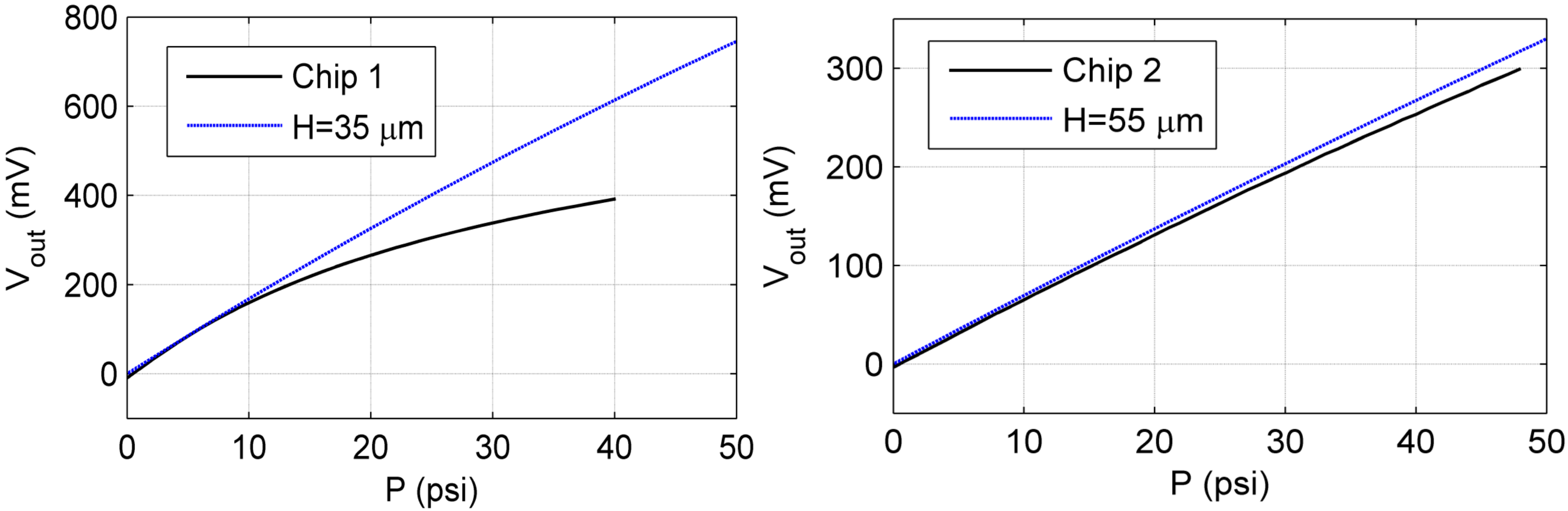
This spread sheet can be used to find resistor values used to compensate a wheatstone bridge resistor pressure sensor for output offset voltage and span. If we assume that the resistors are TaN thin film resistors that are adjusted by laser trimming then the trimmed value has to be higher than the nominal value. First adjust the value of Rzt and Rzb to set Vout trimmed to zero. Then set Rst and Rsb to make the trimmed stressed value equal to the specified output voltage at maximum applied pressure.

The numbers in the white cells can be changed. The other cells in blue are calculated results.

Votage Supply Vs=	10	Volts			
Resistance of Bridge Measured with ohm meter from internal top node to internal bottom node with no compensation resistors attached, or the nominal value of R1 = R2 = R3 = R4					
Nominal R1 = R2 = R3 = R4 =	1000	ohms			
Nominal starting value of Rzt = Rzb =	10000	ohms			
Nominal starting value of Rst = Rsb =	100	ohms			
Measured value of Vo+ =	4.14	Volts			
Measured value of Vo- =	4.13	Volts			
Measured output (Vo+-Vo-) at zero input pressure =	10	mV			
Measured output (Vo+-Vo-) at rated input pressure =	600	mV			
Untrimmed Span =	590	mV			
Rated Input Pressure =	50	psi	in K N/m2 =	345	KPa
Rated Input Pressure =		KPa	in lbs/in2 =	0	psi
Desired Span =	400	mV			
Output Offset Voltage:					
Untrimmed Offset Vo+ - Vo- =	10.0	mV			
If Vo+-Vo- is positive then Rzb is adjusted upwards			guess, Rzb =	10560	ohms
Rzb to make offset zero =	10560	ohms	gives offset correction =	-10.0	mV
Trimmed Offset =	0.0	mV			
If Vo+-Vo- is negative then Rzt is adjusted upwards until Vo+-Vo- is zero					
Span:					
Span can only be adjust smaller from the untrimmed value, so the desired span must be less than measured.					
Calculate Rs to reduce the bridge voltage to make the bridge vlotage smaller by the ratio of desired span/measured span Rst = Rsb =	388	ohms			

COMPARISON OF THIN AND THICK DIAPHRAGM

Diffused Resistors



Sensitivity ~ = 200mV/12psi
= 10 mV/psi

Sensitivity ~ = 100mV/15psi
= 6.67 mV/psi

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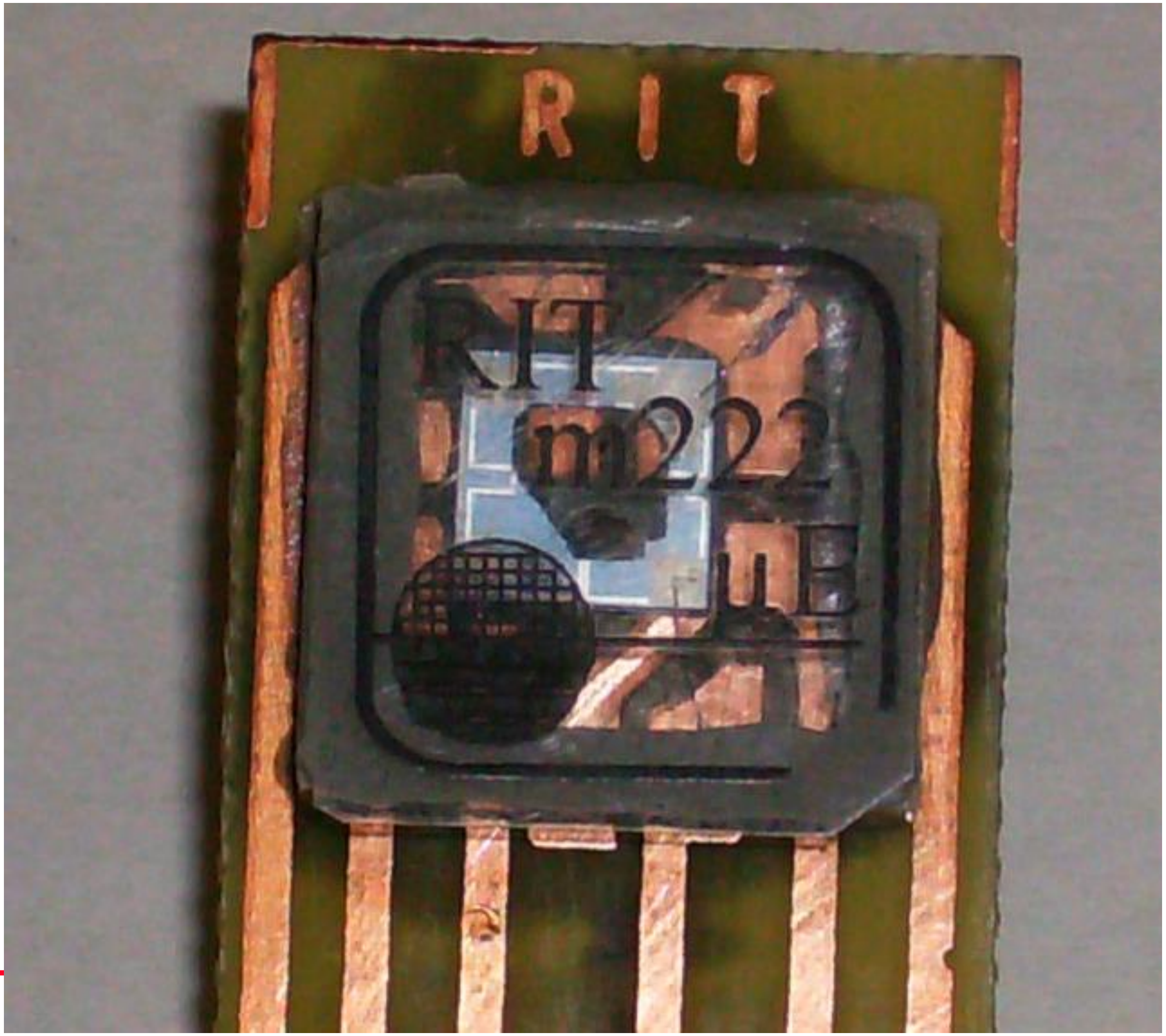
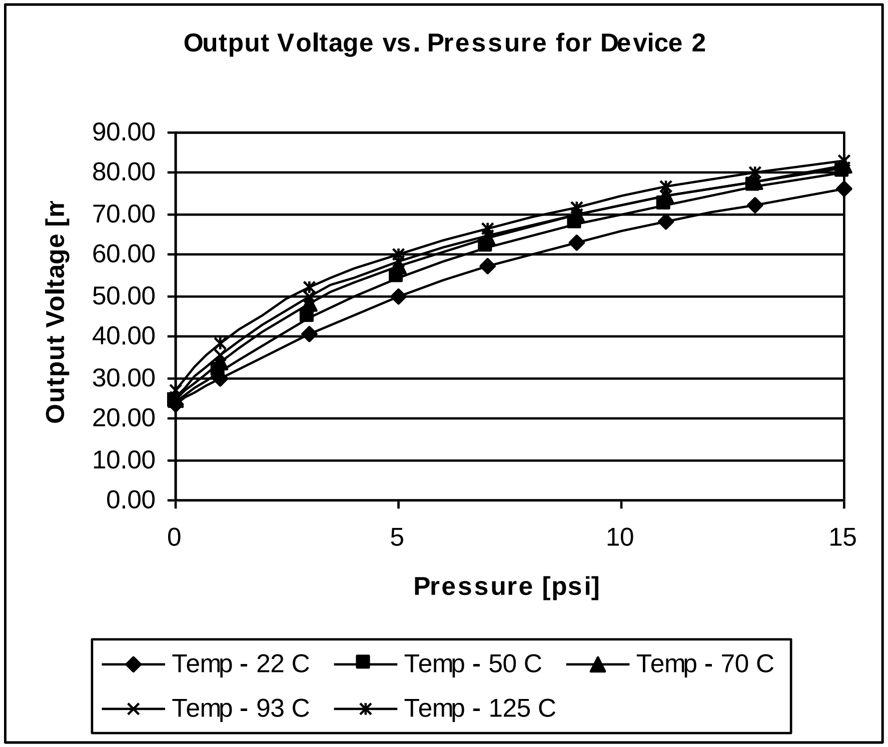
EXCESSIVE PRESSURE

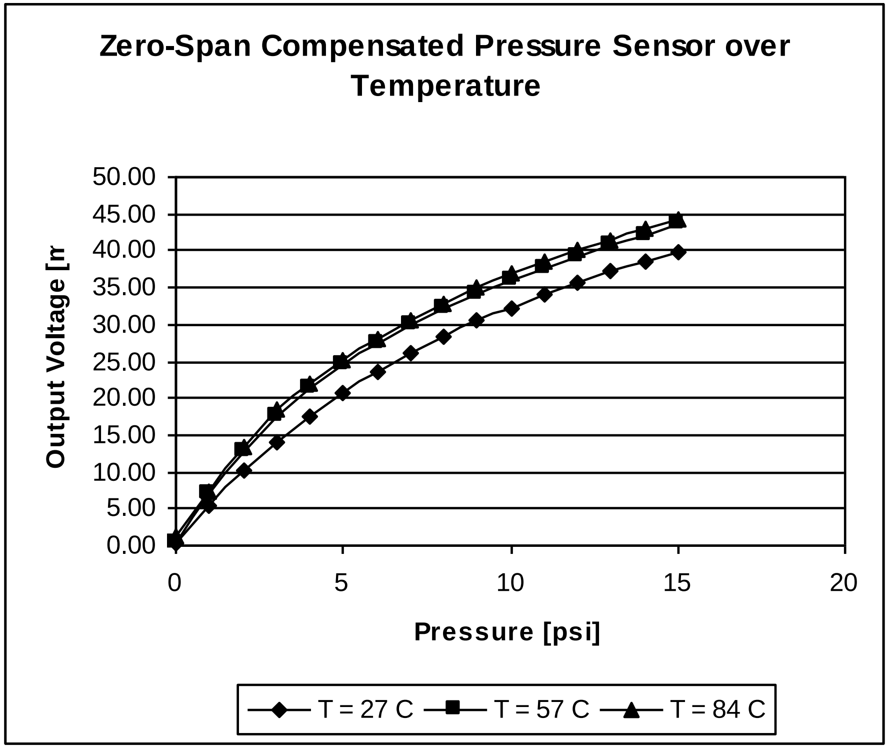


EVALUATION OVER TEMPERATURE

Polysilicon Resistors

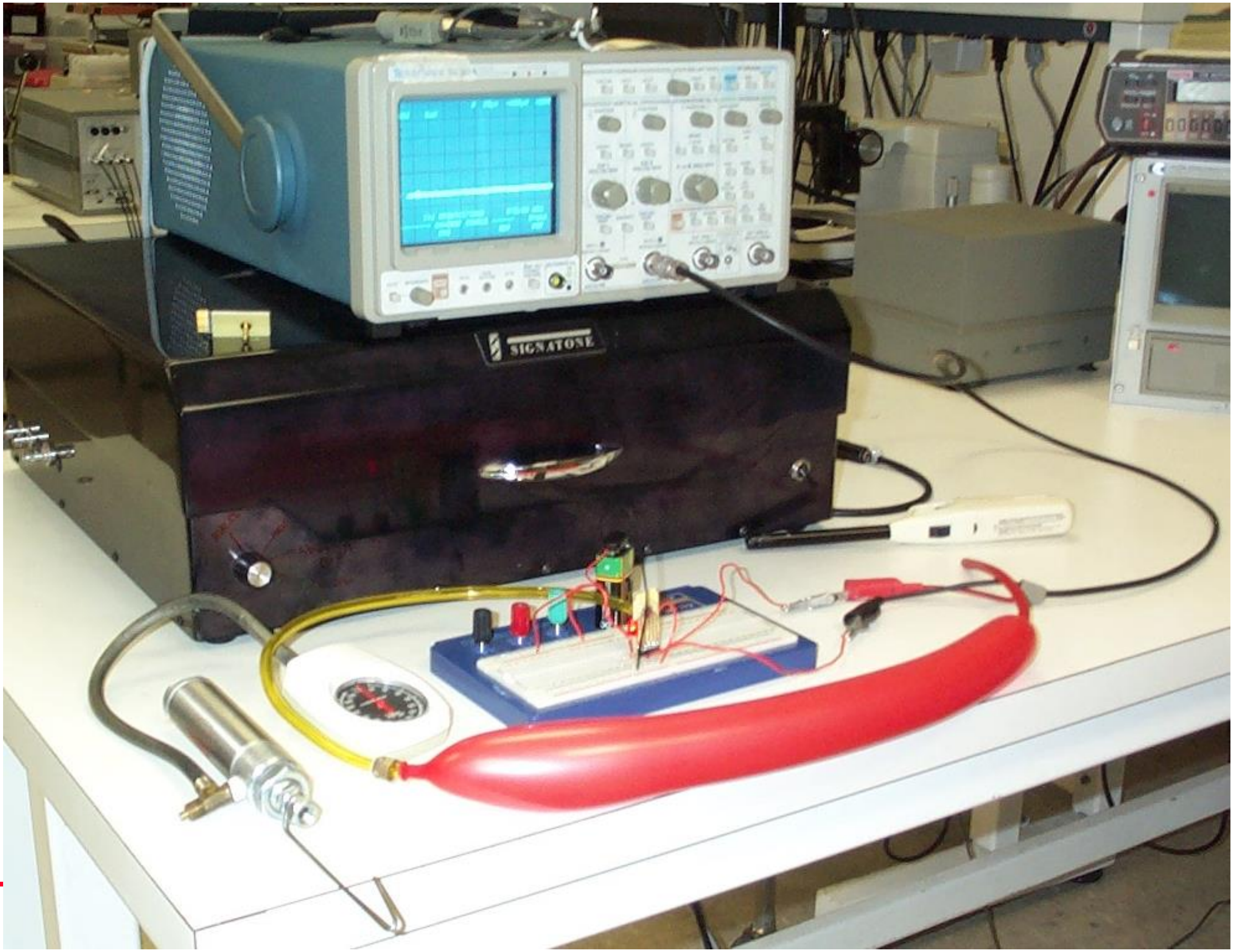


No Compensation



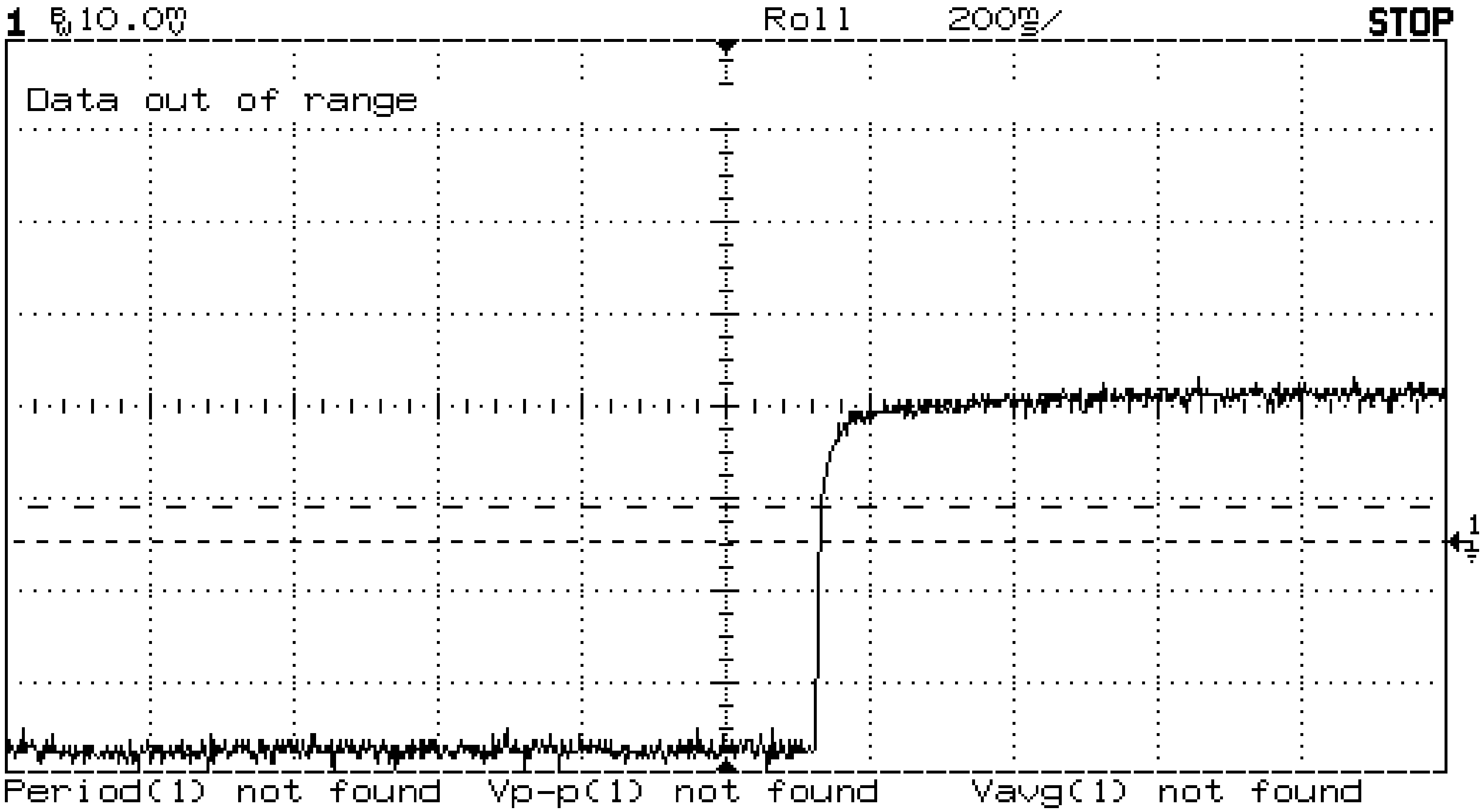
Compensated

TEST SETUP FOR FREQUENCY MEASUREMENT



BALLOON ABOUT TO POP

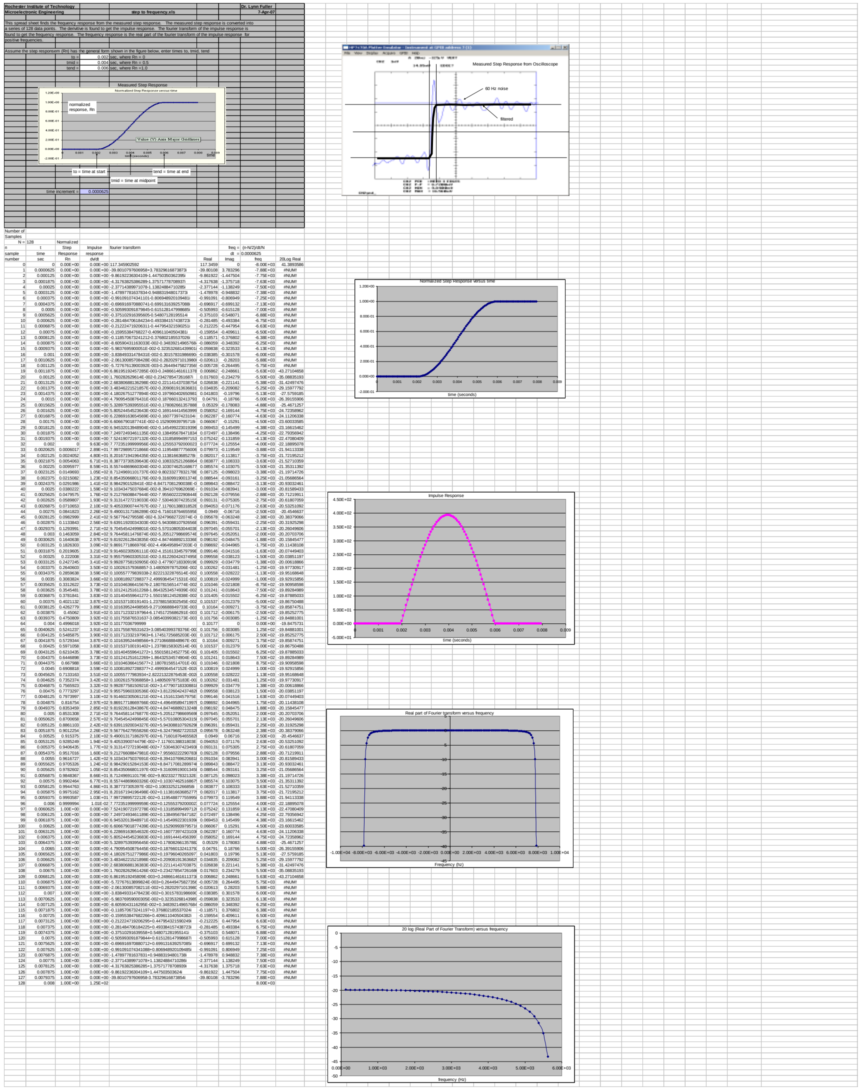
MEASURED STEP RESPONSE



```
Data out of range
Period(1) not found  Vp-p(1) not found   Vavg(1) not found
```

STEP TO IMPULSE TO FREQUENCY RESPONSE

Excel
Spreadsheet



Rochester Institute of Technology | **Dr. Lynn Fuller**
Microelectronic Engineering | **step to frequency.xls** | **7-Apr-07**

This spread sheet finds the frequency response from the measured step response. The measured step response is converted into a series of 128 data points. The derivitive is found to get the impulse response. The fourier transform of the impulse response is found to get the frequency response. The frequency response is the real part of the fourier transform of the impulse response for positive frequencies.

Assume the step responsem (Rn) has the general form shown in the figure below, enter times to, tmid, tend

to = 0.002 sec, where Rn = 0
tmid = 0.004 sec, where Rn = 0.5
tend = 0.006 sec, where Rn =1.0

Measured Step Response

time increment = 0.0000625

Number of Samples
N = 128
freq = (n-N/2)/dt/N
dt = 0.0000625

n sample number	t time sec	Normalized Step Response Rn	Impulse response dv/dt	fourier transform	Real	Imag	freq	20Log Real
0	0	0.00E+00	0.00E+00	117.345902592	117.3459	0	-8.00E+03	41.3893586
1	0.0000625	0.00E+00	0.00E+00	-39.8010797606958+3.78329616873873i	-39.80108	3.783296	-7.88E+03	#NUM!
2	0.000125	0.00E+00	0.00E+00	-9.86192236304109-1.44750350362395i	-9.861922	-1.447504	-7.75E+03	#NUM!
3	0.0001875	0.00E+00	0.00E+00	-4.31763825386289-1.37571778708937i	-4.317638	-1.375718	-7.63E+03	#NUM!
4	0.00025	0.00E+00	0.00E+00	-2.37714389971078-1.13824884710285i	-2.377144	-1.138249	-7.50E+03	#NUM!
5	0.0003125	0.00E+00	0.00E+00	-1.47897781637834-0.948831948017373i	-1.478978	-0.948832	-7.38E+03	#NUM!
6	0.000375	0.00E+00	0.00E+00	-0.991091074341101-0.806948920109481i	-0.991091	-0.806949	-7.25E+03	#NUM!
7	0.0004375	0.00E+00	0.00E+00	-0.696916970880741-0.699131639257088i	-0.696917	-0.699132	-7.13E+03	#NUM!
8	0.0005	0.00E+00	0.00E+00	-0.505993091879845-0.615128147998685i	-0.505993	-0.615128	-7.00E+03	#NUM!
9	0.0005625	0.00E+00	0.00E+00	-0.375102916395605-0.54807128195514i	-0.375103	-0.548071	-6.88E+03	#NUM!
10	0.000625	0.00E+00	0.00E+00	-0.281484706184234-0.493384157438723i	-0.281485	-0.493384	-6.75E+03	#NUM!
11	0.0006875	0.00E+00	0.00E+00	-0.212224719206311-0.447954321590251i	-0.212225	-0.447954	-6.63E+03	#NUM!
12	0.00075	0.00E+00	0.00E+00	-0.15955384768227-0.409611040504381i	-0.159554	-0.409611	-6.50E+03	#NUM!
13	0.0008125	0.00E+00	0.00E+00	-0.118570673241212-0.376802185537026i	-0.118571	-0.376802	-6.38E+03	#NUM!
14	0.000875	0.00E+00	0.00E+00	-8.60590431163033E-002-0.34839214965768	-0.086059	-0.348392	-6.25E+03	#NUM!
15	0.0009375	0.00E+00	0.00E+00	-5.98376959000051E-002-0.323532681439901	-0.059838	-0.323533	-6.13E+03	#NUM!
16	0.001	0.00E+00	0.00E+00	-3.83849331478431E-002-0.30157831986690	-0.038385	-0.301578	-6.00E+03	#NUM!
17	0.0010625	0.00E+00	0.00E+00	-2.06130085708428E-002-0.28202971013980	-0.020613	-0.28203	-5.88E+03	#NUM!
18	0.001125	0.00E+00	0.00E+00	-5.72767613900392E-003-0.26449475827356	-0.005728	-0.264495	-5.75E+03	#NUM!
19	0.0011875	0.00E+00	0.00E+00	6.86195192457285E-003-0.248661461611378	0.006862	-0.248661	-5.63E+03	-43.27104658
20	0.00125	0.00E+00	0.00E+00	1.760282629614E-002-0.234278547261687i	0.017603	-0.234279	-5.50E+03	-35.08835193
21	0.0013125	0.00E+00	0.00E+00	2.68380688136298E-002-0.221141437038754	0.026838	-0.221141	-5.38E+03	-31.42497476
22	0.001375	0.00E+00	0.00E+00	3.48346221521857E-002-0.209081913636831	0.034835	-0.209082	-5.25E+03	-29.15977792
23	0.0014375	0.00E+00	0.00E+00	4.18026751277894E-002-0.197960402650981	0.041803	-0.19796	-5.13E+03	-27.5759185
24	0.0015	0.00E+00	0.00E+00	4.79095450876431E-002-0.187660132413793	0.04791	-0.18766	-5.00E+03	-26.39155906
25	0.0015625	0.00E+00	0.00E+00	5.32897539395551E-002-0.178082661357888	0.05329	-0.178083	-4.88E+03	-25.4671257
26	0.001625	0.00E+00	0.00E+00	5.80524454523643E-002-0.169144414563999	0.058052	-0.169144	-4.75E+03	-24.72358962
27	0.0016875	0.00E+00	0.00E+00	6.22869163654569E-002-0.16077397423104i	0.062287	-0.160774	-4.63E+03	-24.11206338
28	0.00175	0.00E+00	0.00E+00	6.6066790187741E-002-0.152909939795718i	0.066067	-0.15291	-4.50E+03	-23.60033585
29	0.0018125	0.00E+00	0.00E+00	6.94532013948904E-002-0.145499223019396	0.069453	-0.145499	-4.38E+03	-23.16615462
30	0.001875	0.00E+00	0.00E+00	7.24972493461135E-002-0.138495678471834	0.072497	-0.138496	-4.25E+03	-22.79356942
31	0.0019375	0.00E+00	0.00E+00	7.52419072197132E-002-0.131858994997153	0.075242	-0.131859	-4.13E+03	-22.47080409
32	0.002	0	9.63E+00	7.77235199999956E-002-0.125553792000023	0.077724	-0.125554	-4.00E+03	-22.18895078
33	0.0020625	0.0006017	2.89E+01	7.99729895721866E-002-0.119548877756006	0.079973	-0.119549	-3.88E+03	-21.94113338
34	0.002125	0.0024052	4.80E+01	8.20167194196435E-002-0.11381663685278	0.082017	-0.113817	-3.75E+03	-21.72195212
35	0.0021875	0.0054063	6.71E+01	8.38773730539643E-002-0.108332521266864	0.083877	-0.108333	-3.63E+03	-21.52710359
36	0.00225	0.0095977	8.59E+01	8.55744869660304E-002-0.103074625168677	0.085574	-0.103075	-3.50E+03	-21.35311392
37	0.0023125	0.0149693	1.05E+02	8.71249691101737E-002-9.80233277832178E	0.087125	-0.098023	-3.38E+03	-21.19714726
38	0.002375	0.0215082	1.23E+02	8.85435066801176E-002-9.31609919001374E	0.088544	-0.093161	-3.25E+03	-21.05686564
39	0.0024375	0.0291986	1.41E+02	8.984290152841E-002-8.84717081290038E-0	0.089843	-0.088472	-3.13E+03	-20.93032461
40	0.0025	0.0380222	1.59E+02	9.10343475037684E-002-8.3941076962069E-	0.091034	-0.083941	-3.00E+03	-20.81589433
41	0.0025625	0.0479575	1.76E+02	9.21276608847944E-002-7.95560222290844E	0.092128	-0.079556	-2.88E+03	-20.71219911
42	0.002625	0.0589807	1.93E+02	9.31314727219033E-002-7.53046307423515E	0.093131	-0.075305	-2.75E+03	-20.61807059
43	0.0026875	0.0710653	2.10E+02	9.40533900744767E-002-7.11760138831852E	0.094053	-0.071176	-2.63E+03	-20.53251092
44	0.00275	0.0841823	2.26E+02	9.49001317186289E-002-6.71601876465595E	0.0949	-0.06716	-2.50E+03	-20.4546637
45	0.0028125	0.0982999	2.41E+02	9.567764279558E-002-6.32479682722074E-0	0.095678	-0.063248	-2.38E+03	-20.38379066
46	0.002875	0.1133843	2.56E+02	9.63911920034303E-002-5.94308810792656E	0.096391	-0.059431	-2.25E+03	-20.31925298
47	0.0029375	0.1293991	2.71E+02	9.70454542499801E-002-5.57010805304403E	0.097045	-0.055701	-2.13E+03	-20.26049606
48	0.003	0.1463059	2.84E+02	9.76445811476874E-002-5.20512798669574E	0.097645	-0.052051	-2.00E+03	-20.20703706
49	0.0030625	0.1640638	2.97E+02	9.81922612843835E-002-4.84746889213336E	0.098192	-0.048475	-1.88E+03	-20.15845477
50	0.003125	0.1826303	3.09E+02	9.8691771866976E-002-4.4964958947203E-0	0.098692	-0.044965	-1.75E+03	-20.11438108
51	0.0031875	0.2019605	3.21E+02	9.91460230506111E-002-4.15161334579799E	0.099146	-0.041516	-1.63E+03	-20.07449403
52	0.00325	0.222008	3.31E+02	9.95575960330531E-002-3.81226042437495E	0.099558	-0.038123	-1.50E+03	-20.03851197
53	0.0033125	0.2427245	3.41E+02	9.99287758150905E-002-3.47790718330919E	0.099929	-0.034779	-1.38E+03	-20.00618866
54	0.003375	0.2640603	3.50E+02	0.100261579368857-3.14805097875206E-002	0.100262	-0.031481	-1.25E+03	-19.97730917
55	0.0034375	0.2859638	3.59E+02	0.100557779839338-2.82221322876514E-002	0.100558	-0.028222	-1.13E+03	-19.95168648
56	0.0035	0.3083824	3.66E+02	0.100818927288377-2.49993645471531E-002	0.100819	-0.024999	-1.00E+03	-19.92915856
57	0.0035625	0.3312622	3.73E+02	0.101046366415676-2.18078156514774E-002	0.101046	-0.021808	-8.75E+02	-19.90958598
58	0.003625	0.3545481	3.78E+02	0.101241251612268-1.86432534574939E-002	0.101241	-0.018643	-7.50E+02	-19.89284989
59	0.0036875	0.3781841	3.83E+02	0.101404559641272-1.55015812452838E-002	0.101405	-0.015502	-6.25E+02	-19.87885033
60	0.00375	0.4021132	3.87E+02	0.101537100191401-1.23788158302545E-002	0.101537	-0.012379	-5.00E+02	-19.86750488
61	0.0038125	0.4262779	3.89E+02	0.101639524498565-9.27106688849733E-003	0.10164	-0.009271	-3.75E+02	-19.85874751
62	0.003875	0.45062	3.91E+02	0.101712332197964-6.17451725686291E-003	0.101712	-0.006175	-2.50E+02	-19.85252775
63	0.0039375	0.4750809	3.92E+02	0.101755876531637-3.08540399382173E-003	0.101756	-0.003085	-1.25E+02	-19.84881001
64	0.004	0.4996018	3.92E+02	0.10177036799999	0.10177	0	0.00E+00	-19.8475731
65	0.0040625	0.5241237	3.91E+02	0.101755876531623+3.08540399378376E-00	0.101756	0.003085	1.25E+02	-19.84881001
66	0.004125	0.5485875	3.90E+02	0.101712332197963+6.17451725685203E-00	0.101712	0.006175	2.50E+02	-19.85252775
67	0.0041875	0.5729344	3.87E+02	0.101639524498566+9.27106688848967E-00	0.10164	0.009271	3.75E+02	-19.85874751
68	0.00425	0.5971058	3.83E+02	0.101537100191402+1.23788158302514E-00	0.101537	0.012379	5.00E+02	-19.86750488
69	0.0043125	0.6210435	3.78E+02	0.101404559641272+1.55015812452775E-00	0.101405	0.015502	6.25E+02	-19.87885033
70	0.004375	0.6446898	3.73E+02	0.101241251612269+1.86432534574904E-00	0.101241	0.018643	7.50E+02	-19.89284989
71	0.0044375	0.667988	3.66E+02	0.101046366415677+2.18078156514701E-00	0.101046	0.021808	8.75E+02	-19.90958598
72	0.0045	0.6908818	3.59E+02	0.100818927288377+2.4999364547152E-002	0.100819	0.024999	1.00E+03	-19.92915856
73	0.0045625	0.7133163	3.51E+02	0.10055777983934+2.82221322876453E-002	0.100558	0.028222	1.13E+03	-19.95168648
74	0.004625	0.7352374	3.42E+02	0.100261579368858+3.14805097875183E-00	0.100262	0.031481	1.25E+03	-19.97730917
75	0.0046875	0.7565923	3.32E+02	9.99287758150921E-002+3.47790718330881	0.099929	0.034779	1.38E+03	-20.00618866
76	0.00475	0.7773297	3.21E+02	9.95575960330536E-002+3.81226042437482	0.099558	0.038123	1.50E+03	-20.03851197
77	0.0048125	0.7973997	3.10E+02	9.91460230506121E-002+4.1516133457975E	0.099146	0.041516	1.63E+03	-20.07449403
78	0.004875	0.816754	2.97E+02	9.86917718669766E-002+4.49649589471997	0.098692	0.044965	1.75E+03	-20.11438108
79	0.0049375	0.8353459	2.85E+02	9.81922612843867E-002+4.84746889213248	0.098192	0.048475	1.88E+03	-20.15845477
80	0.005	0.8531308	2.71E+02	9.76445811476877E-002+5.20512798669569	0.097645	0.052051	2.00E+03	-20.20703706
81	0.0050625	0.8700658	2.57E+02	9.70454542499845E-002+5.57010805304315	0.097045	0.055701	2.13E+03	-20.26049606
82	0.005125	0.8861103	2.42E+02	9.63911920034327E-002+5.94308810792629	0.096391	0.059431	2.25E+03	-20.31925298
83	0.0051875	0.9012254	2.26E+02	9.56776427955826E-002+6.32479682722032	0.095678	0.063248	2.38E+03	-20.38379066
84	0.00525	0.915375	2.10E+02	9.49001317186297E-002+6.71601876465582	0.0949	0.06716	2.50E+03	-20.4546637
85	0.0053125	0.9285249	1.94E+02	9.4053390074479E-002+7.11760138831803E	0.094053	0.071176	2.63E+03	-20.53251092
86	0.005375	0.9406435	1.77E+02	9.31314727219048E-002+7.53046307423493	0.093131	0.075305	2.75E+03	-20.61807059
87	0.0054375	0.9517016	1.60E+02	9.21276608847981E-002+7.95560222290783	0.092128	0.079556	2.88E+03	-20.71219911
88	0.0055	0.9616727	1.42E+02	9.10343475037691E-002+8.39410769620681	0.091034	0.083941	3.00E+03	-20.81589433
89	0.0055625	0.9705326	1.24E+02	8.98429015284153E-002+8.84717081289974	0.089843	0.088472	3.13E+03	-20.93032461
90	0.005625	0.9782602	1.05E+02	8.85435066801197E-002+9.31609919001345	0.088544	0.093161	3.25E+03	-21.05686564
91	0.0056875	0.9848367	8.66E+01	8.7124969110179E-002+9.80233277832132E	0.087125	0.098023	3.38E+03	-21.19714726
92	0.00575	0.9902464	6.77E+01	8.55744869660326E-002+0.10307462516867	0.085574	0.103075	3.50E+03	-21.35311392
93	0.0058125	0.9944763	4.86E+01	8.387737305397E-002+0.108332521266858i	0.083877	0.108333	3.63E+03	-21.52710359
94	0.005875	0.9975162	2.95E+01	8.20167194196498E-002+0.11381663685277	0.082017	0.113817	3.75E+03	-21.72195212
95	0.0059375	0.9993587	1.03E+01	7.9972989572212E-002+0.119548877755995	0.079973	0.119549	3.88E+03	-21.94113338
96	0.006	0.9999994	1.01E-02	7.77235199999959E-002+0.12555379200002	0.077724	0.125554	4.00E+03	-22.18895078
97	0.0060625	1.00E+00	0.00E+00	7.52419072197278E-002+0.13185899499712	0.075242	0.131859	4.13E+03	-22.47080409
98	0.006125	1.00E+00	0.00E+00	7.24972493461189E-002+0.13849567847182	0.072497	0.138496	4.25E+03	-22.79356942
99	0.0061875	1.00E+00	0.00E+00	6.94532013948971E-002+0.14549922301939	0.069453	0.145499	4.38E+03	-23.16615462
100	0.00625	1.00E+00	0.00E+00	6.60667901877439E-002+0.15290993979571	0.066067	0.15291	4.50E+03	-23.60033585
101	0.0063125	1.00E+00	0.00E+00	6.22869163654632E-002+0.16077397423103	0.062287	0.160774	4.63E+03	-24.11206338
102	0.006375	1.00E+00	0.00E+00	5.80524454523683E-002+0.16914441456399	0.058052	0.169144	4.75E+03	-24.72358962
103	0.0064375	1.00E+00	0.00E+00	5.32897539395645E-002+0.17808266135788	0.05329	0.178083	4.88E+03	-25.4671257
104	0.0065	1.00E+00	0.00E+00	4.79095450876445E-002+0.18766013241379	0.04791	0.18766	5.00E+03	-26.39155906
105	0.0065625	1.00E+00	0.00E+00	4.18026751277986E-002+0.19796040265097	0.041803	0.19796	5.13E+03	-27.5759185
106	0.006625	1.00E+00	0.00E+00	3.48346221521898E-002+0.20908191363682	0.034835	0.209082	5.25E+03	-29.15977792
107	0.0066875	1.00E+00	0.00E+00	2.68380688136383E-002+0.22114143703875	0.026838	0.221141	5.38E+03	-31.42497476
108	0.00675	1.00E+00	0.00E+00	1.76028262961426E-002+0.23427854726168	0.017603	0.234279	5.50E+03	-35.08835193
109	0.0068125	1.00E+00	0.00E+00	6.8619519245809E-003+0.248661461611373	0.006862	0.248661	5.63E+03	-43.27104658
110	0.006875	1.00E+00	0.00E+00	-5.72767613899824E-003+0.26449475827356	-0.005728	0.264495	5.75E+03	#NUM!
111	0.0069375	1.00E+00	0.00E+00	-2.06130085708211E-002+0.28202971013980	-0.020613	0.28203	5.88E+03	#NUM!
112	0.007	1.00E+00	0.00E+00	-3.83849331478423E-002+0.30157831986690	-0.038385	0.301578	6.00E+03	#NUM!
113	0.0070625	1.00E+00	0.00E+00	-5.98376959000305E-002+0.32353268143989	-0.059838	0.323533	6.13E+03	#NUM!
114	0.007125	1.00E+00	0.00E+00	-8.6059043116295E-002+0.348392149657684	-0.086059	0.348392	6.25E+03	#NUM!
115	0.0071875	1.00E+00	0.00E+00	-0.118570673241197+0.376802185537024i	-0.118571	0.376802	6.38E+03	#NUM!
116	0.00725	1.00E+00	0.00E+00	-0.159553847682266+0.409611040504382i	-0.159554	0.409611	6.50E+03	#NUM!
117	0.0073125	1.00E+00	0.00E+00	-0.212224719206295+0.447954321590249i	-0.212225	0.447954	6.63E+03	#NUM!
118	0.007375	1.00E+00	0.00E+00	-0.281484706184225+0.493384157438723i	-0.281485	0.493384	6.75E+03	#NUM!
119	0.0074375	1.00E+00	0.00E+00	-0.37510291639558+0.548071281955141i	-0.375103	0.548071	6.88E+03	#NUM!
120	0.0075	1.00E+00	0.00E+00	-0.505993091879844+0.615128147998687i	-0.505993	0.615128	7.00E+03	#NUM!
121	0.0075625	1.00E+00	0.00E+00	-0.696916970880712+0.699131639257085i	-0.696917	0.699132	7.13E+03	#NUM!
122	0.007625	1.00E+00	0.00E+00	-0.991091074341088+0.806948920109485i	-0.991091	0.806949	7.25E+03	#NUM!
123	0.0076875	1.00E+00	0.00E+00	-1.47897781637831+0.94883194801738i	-1.478978	0.948832	7.38E+03	#NUM!
124	0.00775	1.00E+00	0.00E+00	-2.37714389971078+1.13824884710286i	-2.377144	1.138249	7.50E+03	#NUM!
125	0.0078125	1.00E+00	0.00E+00	-4.31763825386285+1.37571778708939i	-4.317638	1.375718	7.63E+03	#NUM!
126	0.007875	1.00E+00	0.00E+00	-9.86192236304109+1.447503503624i	-9.861922	1.447504	7.75E+03	#NUM!
127	0.0079375	1.00E+00	0.00E+00	-39.8010797606958-3.78329616873854i	-39.80108	-3.783296	7.88E+03	#NUM!
128	0.008	1.00E+00	1.25E+02				8.00E+03	

Data

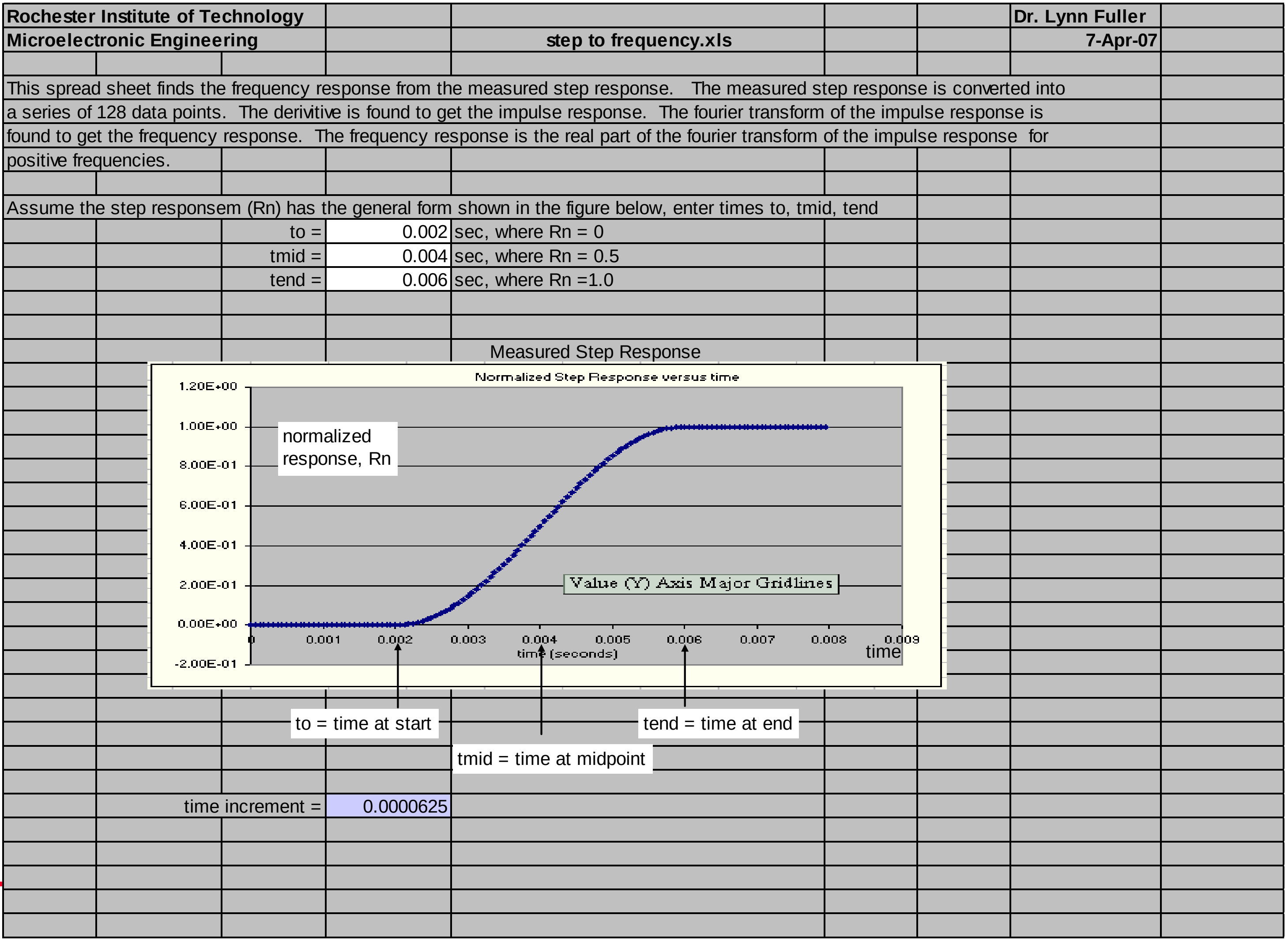
Filtered
Normalized Step
Response

Derivative gives
Impulse Response

Fourier Transform
Gives frequency
response

Real Part in dB

STEP TO FREQUENCY.XLS



Rochester Institute of Technology **Dr. Lynn Fuller**
Microelectronic Engineering **step to frequency.xls** **7-Apr-07**

This spread sheet finds the frequency response from the measured step response. The measured step response is converted into a series of 128 data points. The derivitive is found to get the impulse response. The fourier transform of the impulse response is found to get the frequency response. The frequency response is the real part of the fourier transform of the impulse response for positive frequencies.

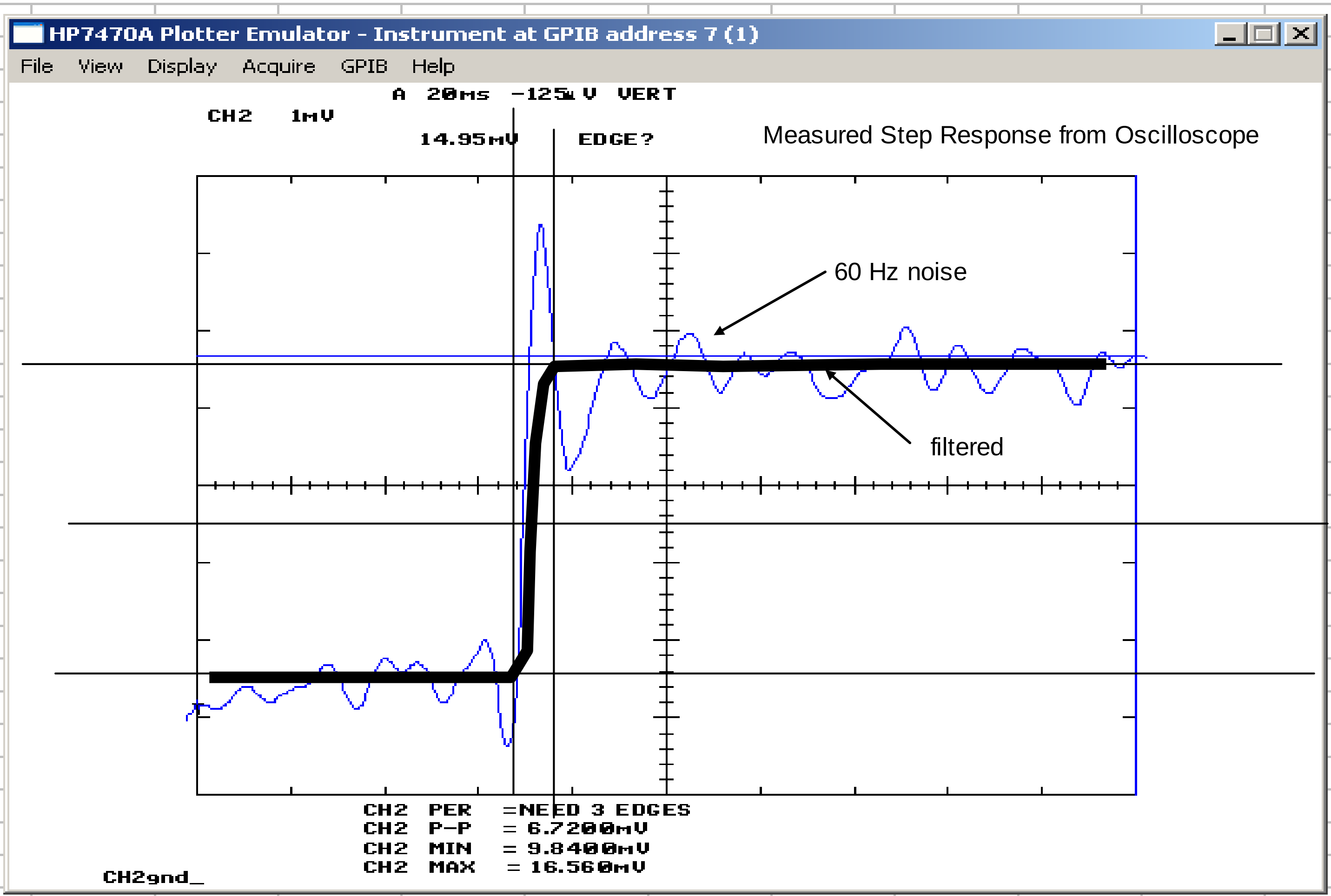
Assume the step responsem (Rn) has the general form shown in the figure below, enter times to, tmid, tend

to = 0.002 sec, where Rn = 0
tmid = 0.004 sec, where Rn = 0.5
tend = 0.006 sec, where Rn =1.0

Measured Step Response

time increment = 0.0000625

MEASURED STEP RESPONSE



```
A  20ms  -125µV  VERT
CH2   1mV
14.95mV    EDGE?
```

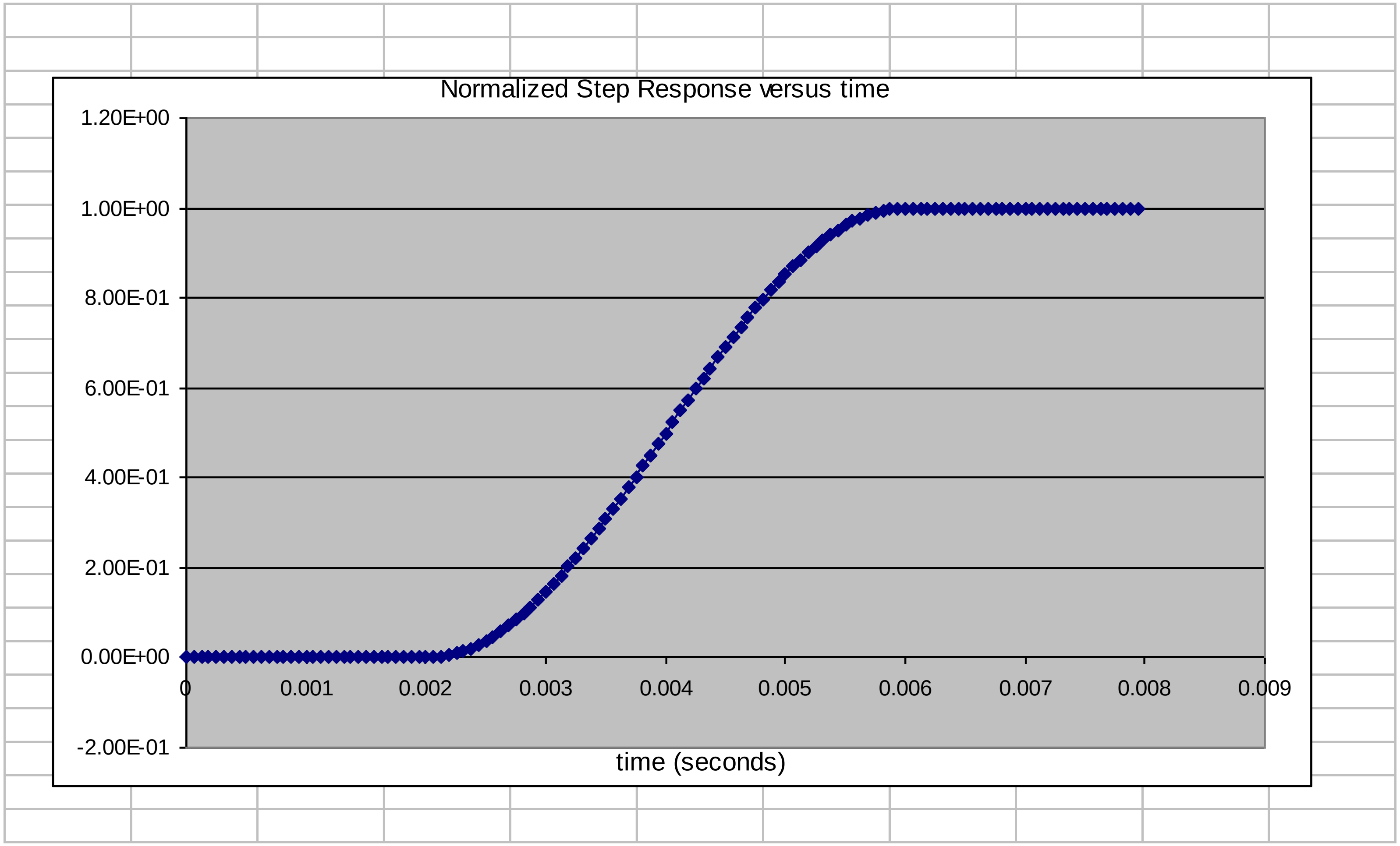
Measured Step Response from Oscilloscope

60 Hz noise

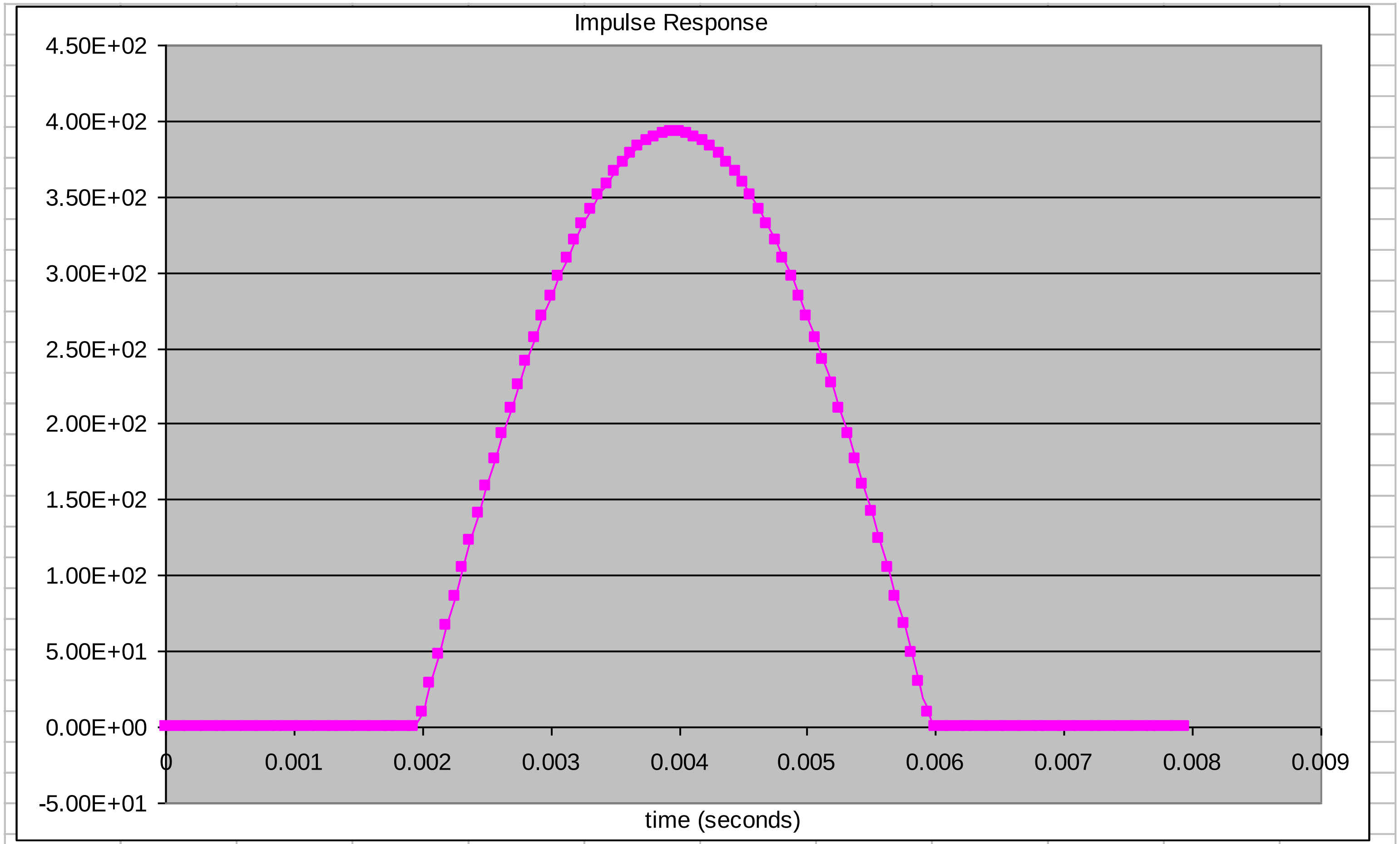
filtered

```
CH2  PER   =NEED 3 EDGES
CH2  P-P   = 6.7200mV
CH2  MIN   = 9.8400mV
CH2  MAX    = 16.560mV
CH2gnd_
```

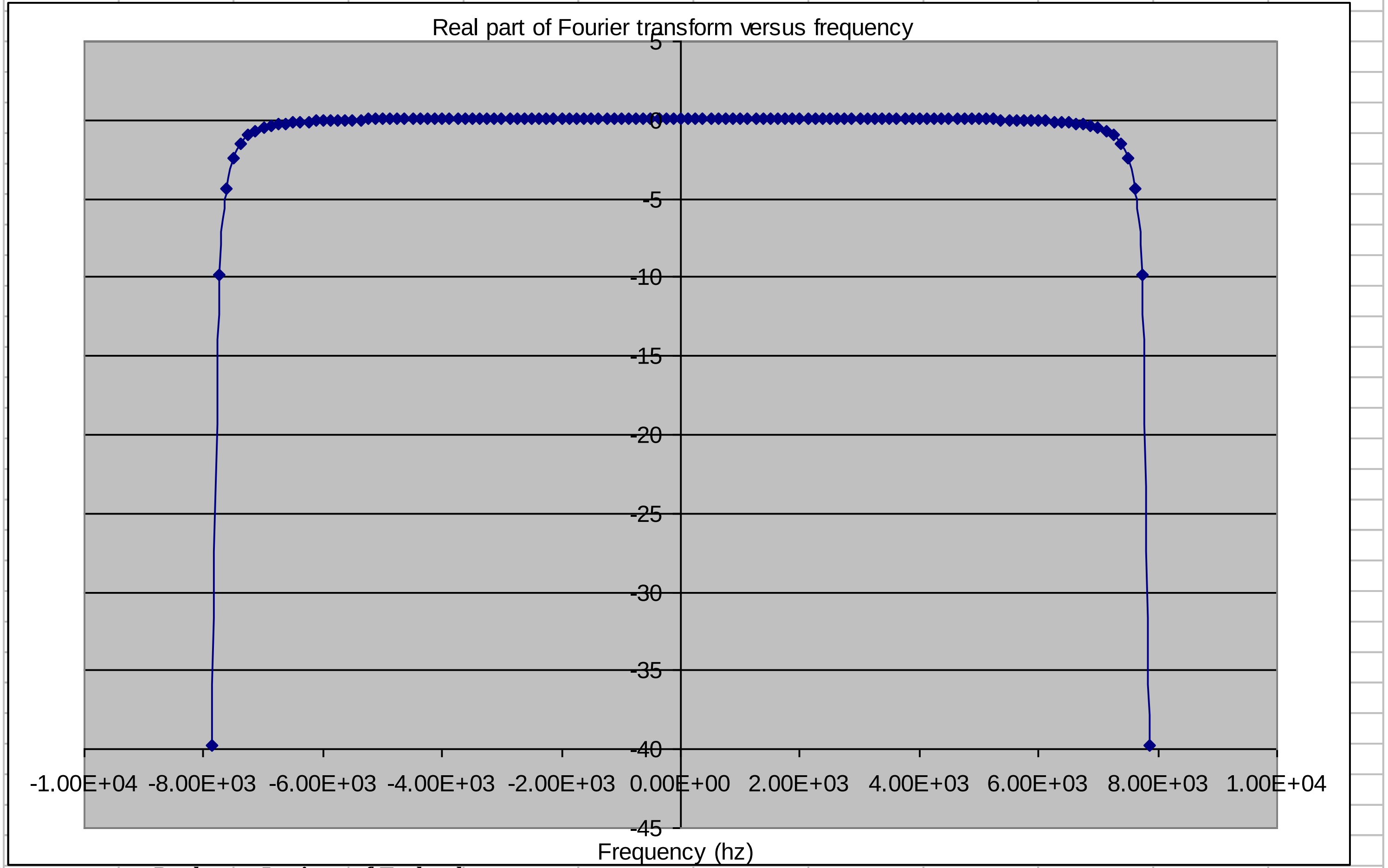
FILTERED NORMALIZED STEP RESPONSE



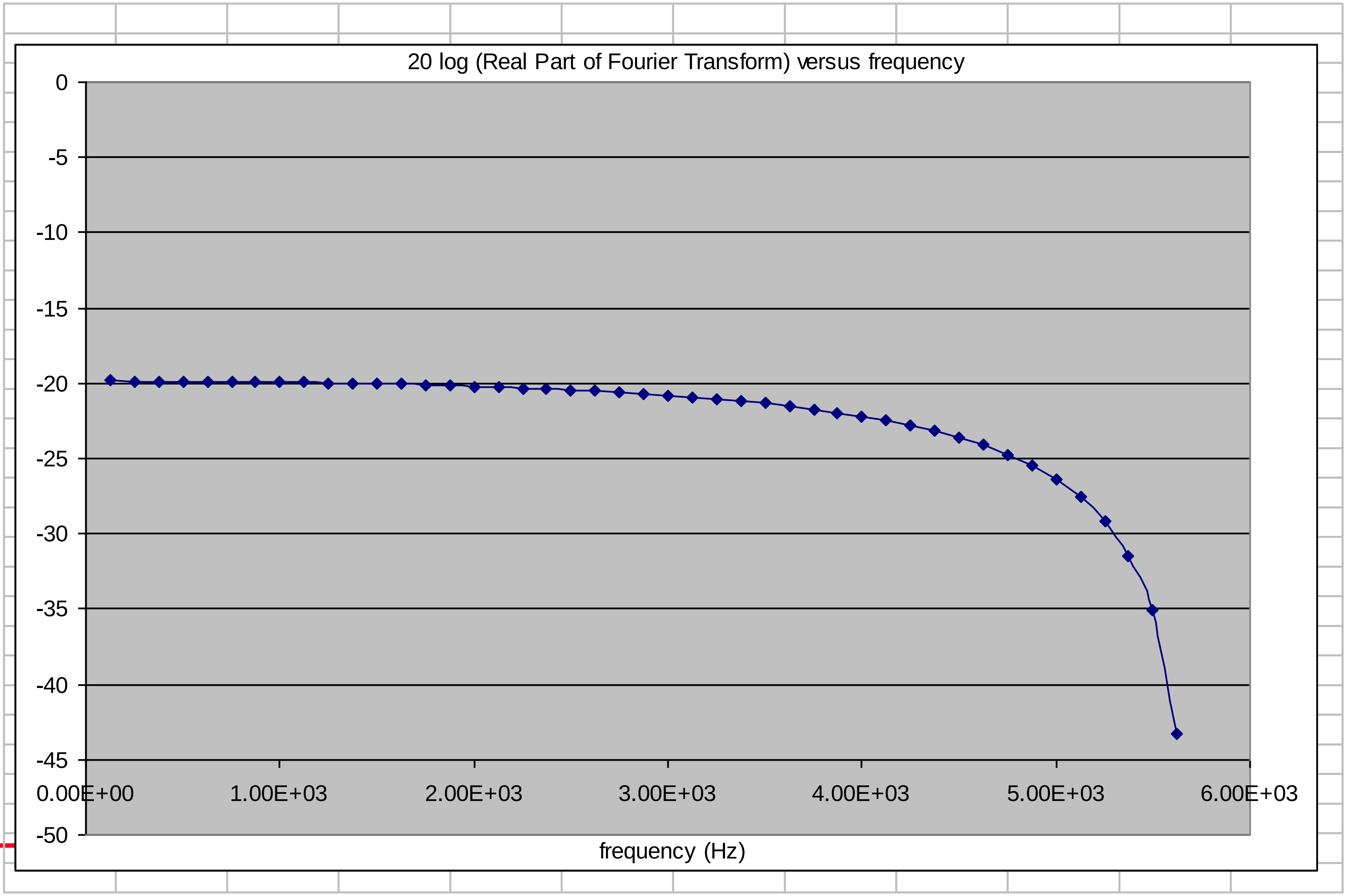
IMPULSE RESPONSE



FOURIER TRANSFORM



FREQUENCY RESPONSE



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2. Microsystem Design, Stephen D, Senturia, Kluwer Academic Publishers, 2000, pg 488-494
3. Micromachined Transducers, McGraw Hill, 1998,Kovacs, pg 253
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HOMEWORK – PRESSURE SENSOR LAB

1. The example calculations shown on page 4-10 make a lot of assumptions about the fabrication process such as the starting wafer is 500um thick. In fact the starting wafer is thinned and polished to reduce the KOH etch time and the back grinding process is not that exact giving variation of starting wafer thickness between 250 and 350um. List other variables that might vary by more than 10% and discuss how that would effect the sensitivity and offset of the pressure sensor.

2. Discuss the linearity of the pressure sensor. Why do thicker diaphragms give more linear results over a given pressure range. How is the sensitivity affected by thicker diaphragms.

3. Should the pressure be applied to the top or bottom of the sensor? Why?

4. If the compensation network uses laser trimmed resistors which resistor should be trimmed to make the output zero if Vo+ is +50mV to begin with?

5. Use the bridge balance Excel spread sheet to adjust the zero and span of the pressures sensor on page 20

LAB INSTRUCTORS NOTES

Show MEMS chip
Take Picture
Apply Vacuum
Take Picture
Measure Vo1, Vo2 and Vo1-Vo2 with no pressure
Measure Vo1, Vo2 and Vo1-Vo2 with pressure
For RIT packaged device take data for Vo1-Vo2 versus Pressure
Determine Offset and span
Correct offset and span
Take data for Vo1-Vo2 with corrections.
Take data for Commercial Pressure Sensor