ROCHESTER INSTITUTE OF TECHNOLOGY
MICROELECTRONIC ENGINEERING

MEMS Microphone Design and Signal Conditioning

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4-4-2012 MicrophoneDesign.ppt

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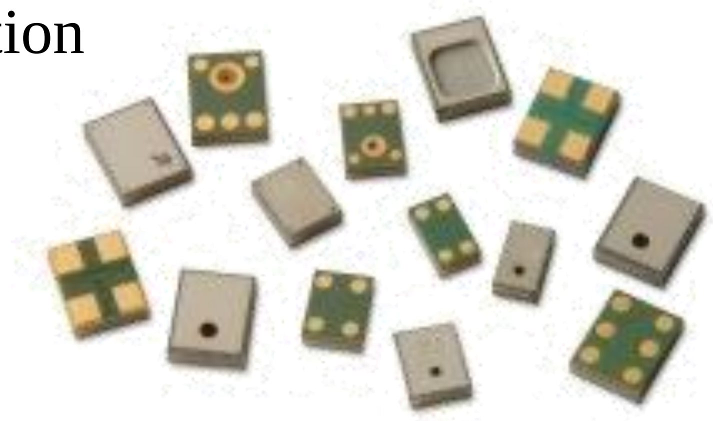
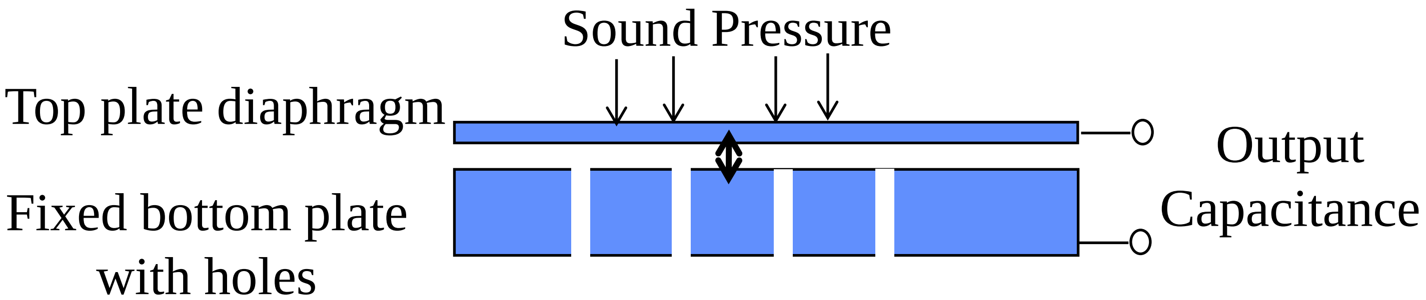
OUTLINE

Introduction
Basic Capacitive Microphone
Pressures
Diaphragm Calculations
Microphone Design
Microphone Fabrication
Signal Conditioning
Microphone Evaluation
Results

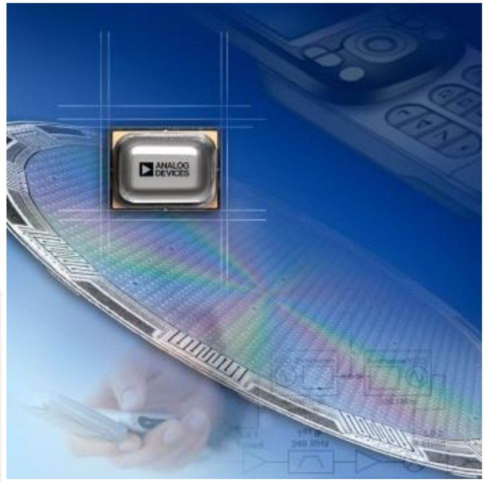


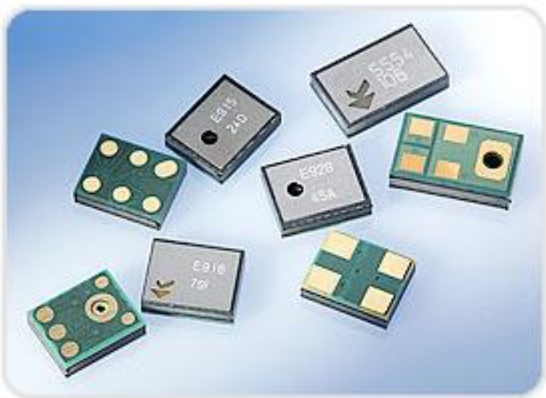
INTRODUCTION

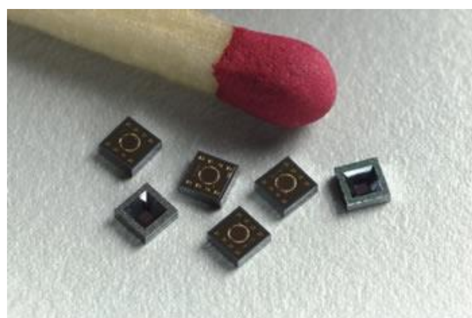
This document presents theoretical and experimental results for capacitive microphone design, fabrication and evaluation. The microphone was fabricated using a PCB for the rigid backing capacitor plate of the microphone. Aluminum foil was used for the flexible sensing capacitor plate of the microphone. Simple signal conditioning electronics converts the change in capacitance to a change in voltage. The analog output was obtained for various frequency audio tones generated using speakers connected to a personal computer.

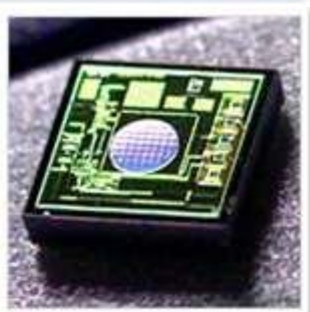


COMMERCIAL MICROPHONES



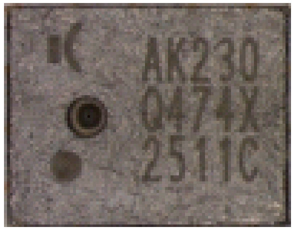






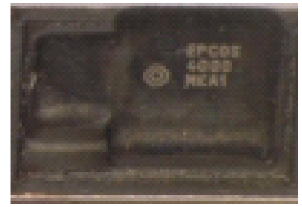
Akustica
Analog Devices
Boesch
Emkay Sisonic
Futurlec
Infineon
Knowles
Motorola
STMicroelectronics
TI
Others

YOLE CONSULTING REPORTS



Akustica AKU230

It uses a free-floating diaphragm, and a capacitive sensing based on a silicon circuit combining the MEMS process on the ASIC process in a single die. This microphone targets high end consumer applications: notebooks, laptops...



Epcos T4060

Manufactured in the EPCOS "Chip Size MEMS Package" technology, the component targets high end consumer applications: mobile phones, MP3 players and digital cameras.

Knowles SPU0410LR5H

It uses free floating diaphragm with capacitive sensing. It is the 4th generation of MEMS microphones from Knowles. This device is found in high volume consumer applications: cell & smart phones (iPhone4)...

Analog Devices ADMP421

It uses a free floating diaphragm and a capacitive sensor and offers a full integration of a MEMS microphone & ASIC. It targets high end consumer applications: tablets, smart phones.

AAC Acoustic iPhone 4

This MEMS Microphone uses a free floating diaphragm & a capacitive sensing and offers a full integration of a MEMS microphone and ASIC, both provided by Infineon. It is for consumer applications: cell & smart phones...

STM MP45DT01

The MP45DT01 microphone uses a MEMS die manufactured by Omron using a free floating diaphragm, and a capacitive sensing. It is for high-end consumer applications: note book, tablets...

Yole Developpement
David Jourdan - jourdan@yole.fr
Le Quartz, 75 Cours Emile Zola – 69100 Villeurbanne – Lyon – FRANCE

AKU1126 MICROPHONES

AKUSTICA

Datasheet

September 2009

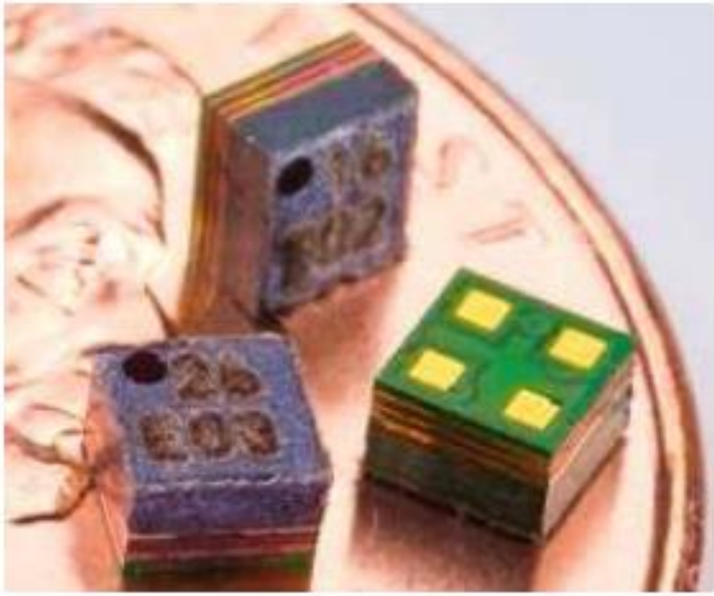
AKU1126 Single-Chip Analog Microphone

GENERAL DESCRIPTION

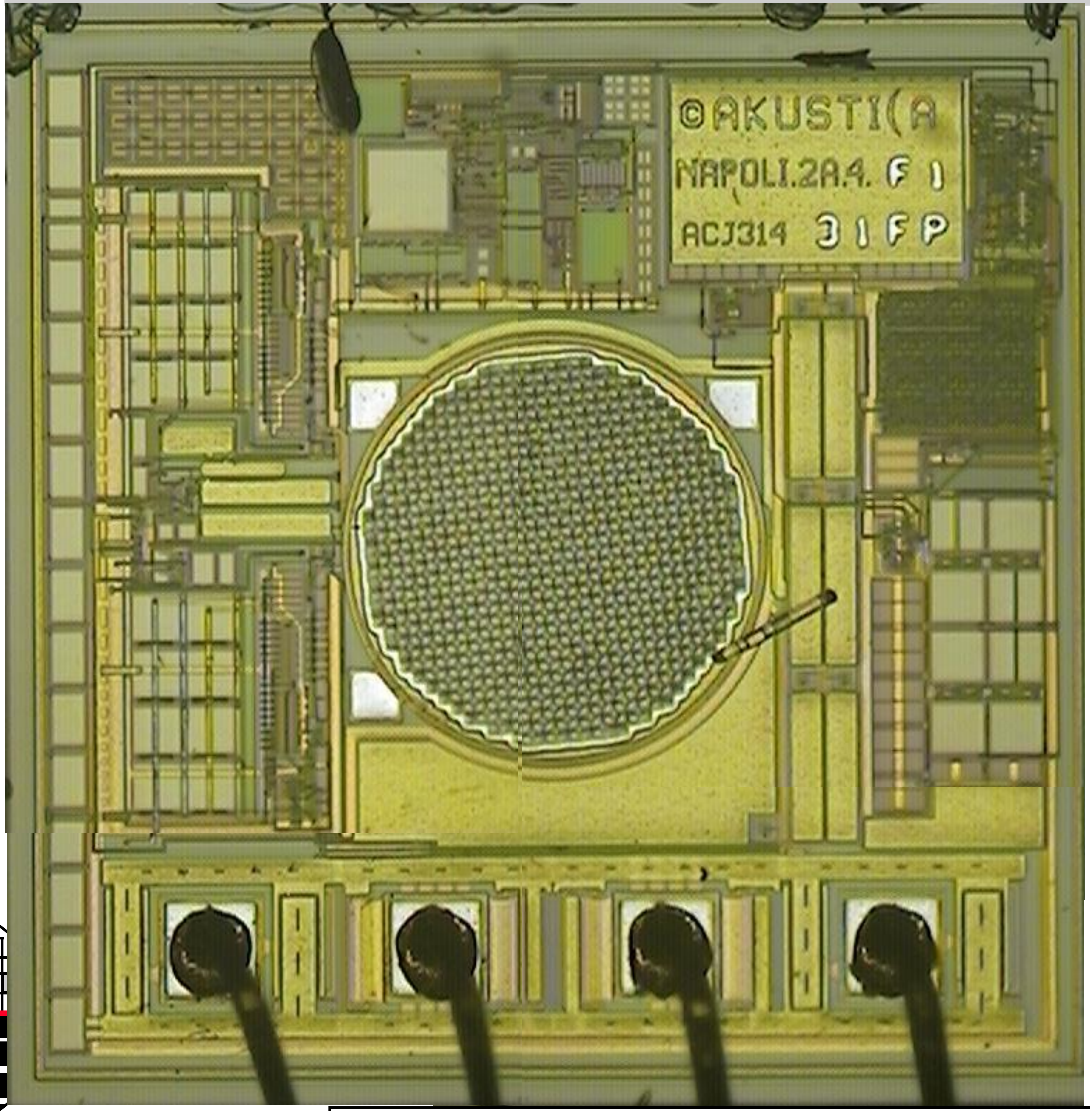
The AKU1126 is the world's smallest, analog-output microphone that uses standard semiconductor packaging technology and materials. While other microphones degrade in performance as they shrink in size, the AKU1126 maintains superior performance in an ultra-small form factor.

The AKU1126's gain select feature, accessed by use of a single external resistor, allows the microphone to be used in both near-ear applications as well as far-field applications - such as speaker phones or headsets - without the use of additional amplifiers.

The AKU1126 is the first microphone product to leverage Akustica's 1mm x 1mm CMOS MEMS microphone die – a monolithic solution which integrates the acoustic transducer and accompanying electronics in a single chip of silicon. In contrast to other silicon microphones, Akustica's one die approach eliminates the need for inter-die wirebonds, allowing for smaller, higher performance, more reliable products.

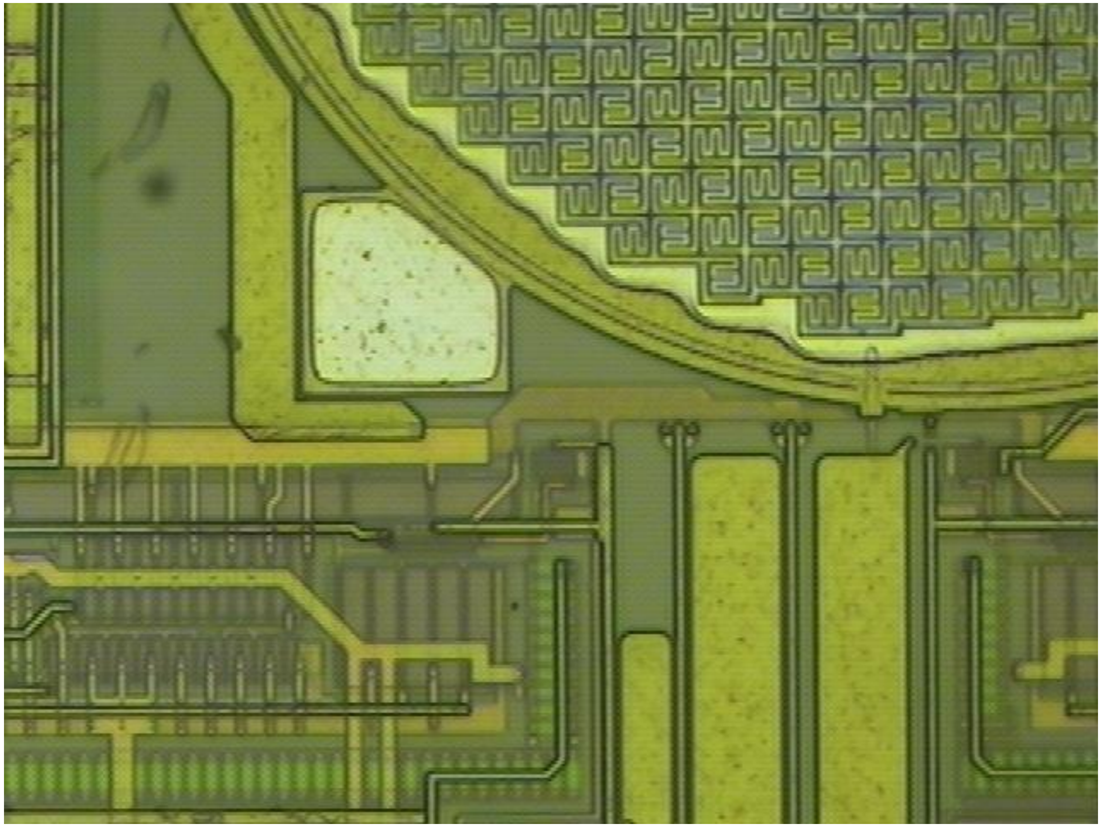


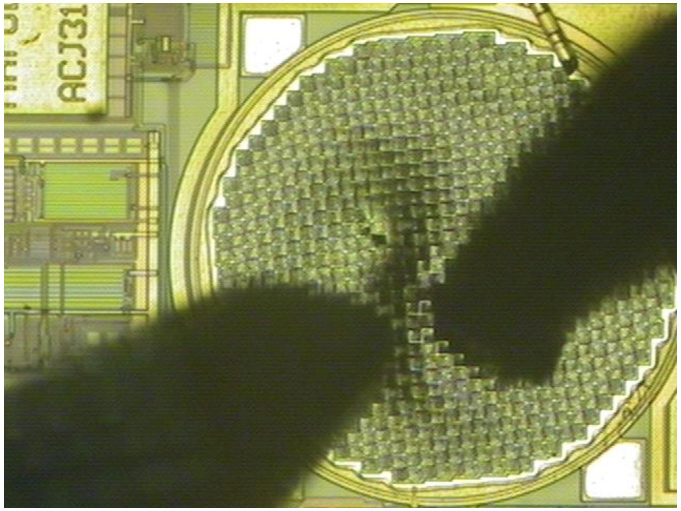
AKU1126 MICROPHONE

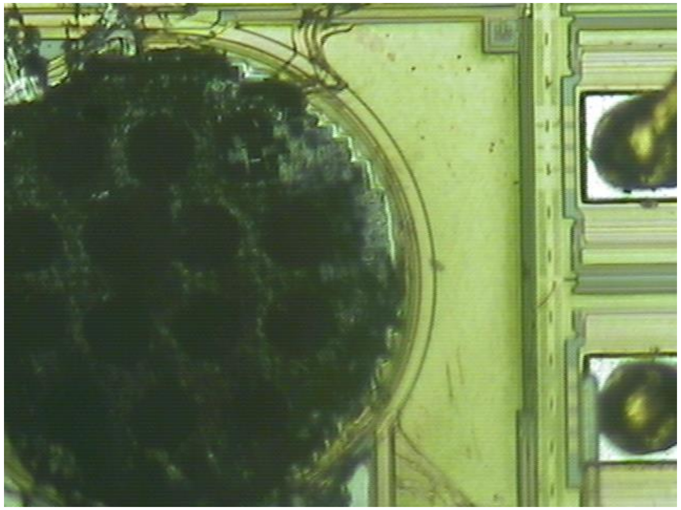


1mm x 1mm
MEMS Chip

AKU1126 MICROPHONE







POSSIBLE MICROPHONE STRUCTURE

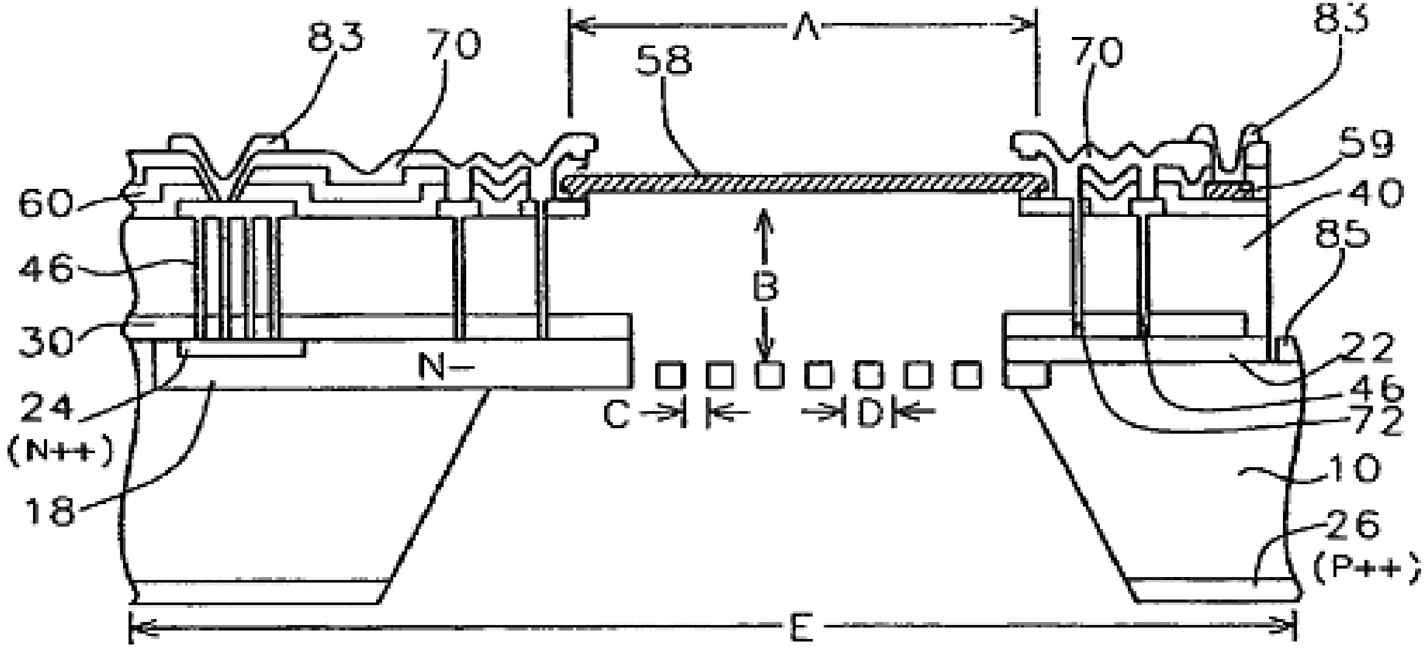
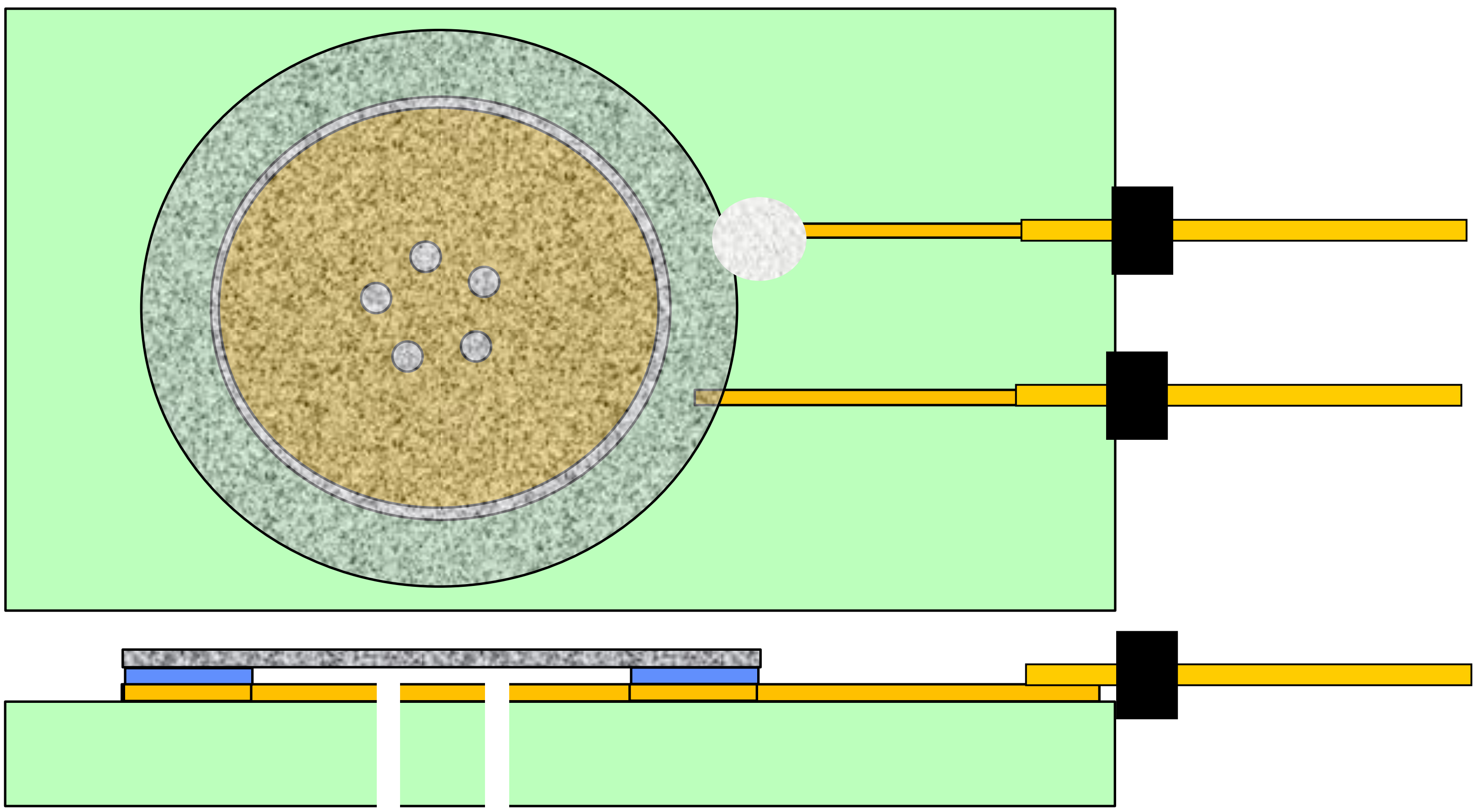


FIG. 21

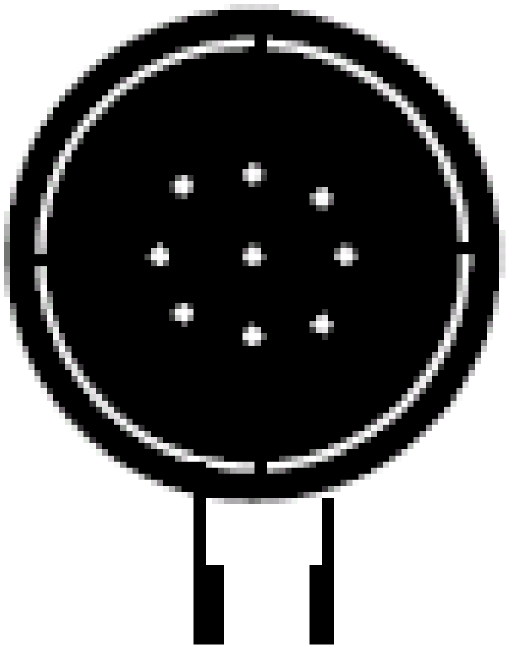
LAYOUT AND CROSSECTION FOR RIT MICROPHONE



DIAPHRAGM EXAMPLE CALCULATIONS

Diaphragm
- 20 mm diameter
- 50 um thickness
- Aluminum foil material

Baking plate
- rigid copper PCB
- 9 vent holes
- air gap = double sided tape ~50um thickness around outer ring



Pressure is ~0.1Pa or ~0.15E-4 lb/in2

DC voltage 5 volts

PRESSURE UNITS

Table of Pressure Conversions

1 atm = 14.696 lbs/in^2 = 760.00 mmHg

1 atm = 101.32 kPa = 1.013 x 10^6 dynes/cm^2

1Pascal = 1.4504 x 10^{-4} lbs/in^2 =1 N/m^2 = 10 dyne/cm^2

1SPL (Sound Pressure Levels) = 0.0002 dynes/cm^2

Average speech = 70 dB$_{SPL}$ = 0.645 dynes/cm^2

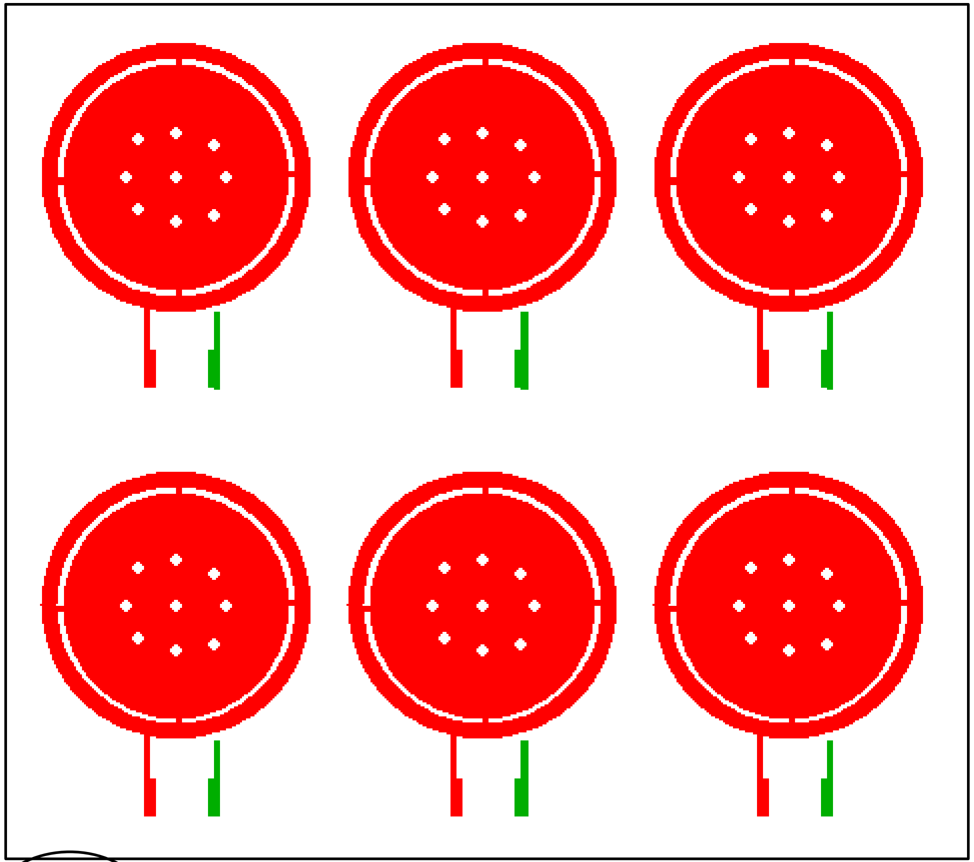
Pain = 130 dB$_{SPL}$ = 645 dyne/cm^2

Whisper = 18 dB$_{SPL}$ = 1.62 x 10^{-3} dyne/cm^2

DIAPHRAGM EXAMPLE CALCULATIONS

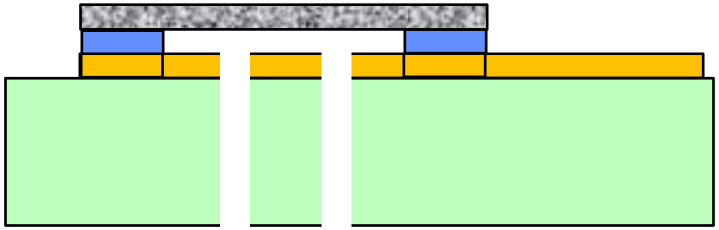
Rochester Institute of Technology					1-Apr-12
Dr. Lynn Fuller	Microelectronic Engineering, 82 Lomb Memorial Dr., Rochester, NY 14623				
To use this spread sheet enter values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The results are displayed in the purple boxes.					
Diaphragm					
Deflection Ymax = 0.0151 P $L^4(1-Nu^2)/EH^3$		Ymax =	2.61E-02	µm	
	P = Pressure	P =	1.50E-05	lbs/in2	
	L = Length of side of square diaphragm	L =	20000	µm	
	E = Youngs Modulus	E =	6.80E+10	N/m2	
	Nu = Poissons Ratio	Nu =	0.33		
	H = Diaphragm Thickness	H =	50	µm	
		P =	1.03E-01	Pascal	
Diaphragm					
Stress = 0.3 P $(L/H)^2$ (at center of each edge)		Stress =	4.96E+03	Pascal	
	P = Pressure	Yield Strength =	1.70E+08	Pascal	
	L = Square Diaphragm Side Length				
	H = Diaphragm Thickness			1 N/m2 = 1 Pascal = 10 dyne/cm2	
Two Parallel Plates					
Capacitance = eoer Area/d		C =	5.56E-11	F	
	eo = Permitivity of free space = 8.85E-14 F/cm				
	er = relative permitivitty = 1 for air	Area =	3.14E+00	cm2	
	Area = area of plates x number of plates	N =	1		
	d = distance between plates	d =	50	µm	
		If round plates, Diameter =	20000	µm	
		If square plates, Side =	0	µm	
		Capacitance Change for Ymax Deflection =	2.90E-14	F	
Two Parallel Plates					
Electrostatic Force= eoer Area $V^2/2d^2$		Felec =	1.39E-05	N	
	V = applied voltage	V =	5	volts	
Single Plate					
Pressure Force = Pressure x Area		Fpress =	4.14E-05	N	

LAYOUT FOR PCB MICROPHONE DEMO



3" x 3" PCB

Microphone
Diameter = 20 mm



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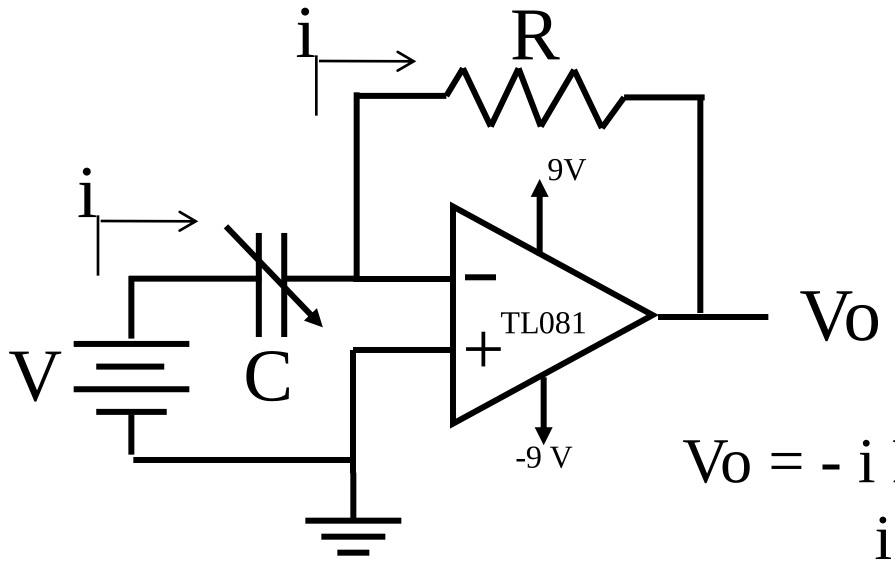
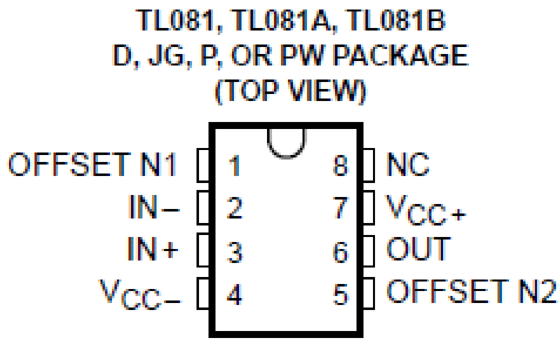
SIGNAL CONDITIONING





Vo = - i R

i = d (CV)/dt

i = V Cm 2 π f cos (2πft)

Co = Average value of C
Cm = amplitude of C change
C = Co +Cm sin (2pft)
V is constant across C

Vo = - 2πf V R Cm cos (2πft)

(2πf V R Cm: amplitude of Vo)

EXAMPLE CALCULATIONS

$$V_o = -\,i\,R = -\,2\pi f\,V\,R\,C_m \cos(2\pi f t)$$

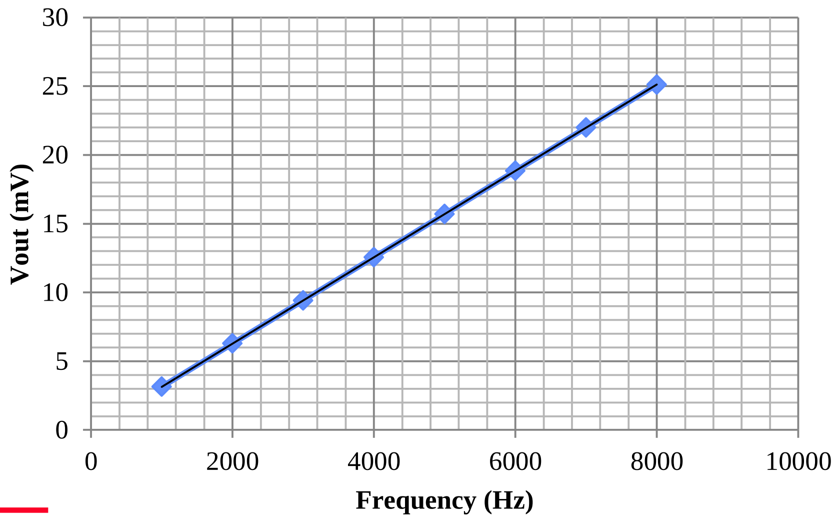
Let f = 5 Khz, V=5, Cm= 100fF, R=1MEG

$$V_o = -\;0.0157 \cos(2\pi f t) \text{ volts}$$

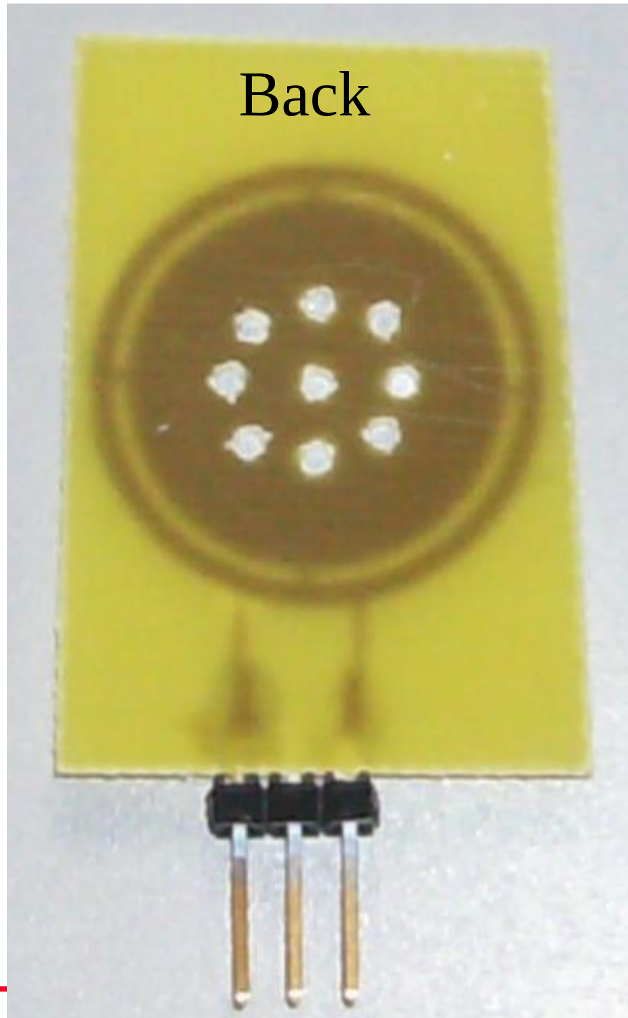
(15.7 mV amplitude sinusoid)

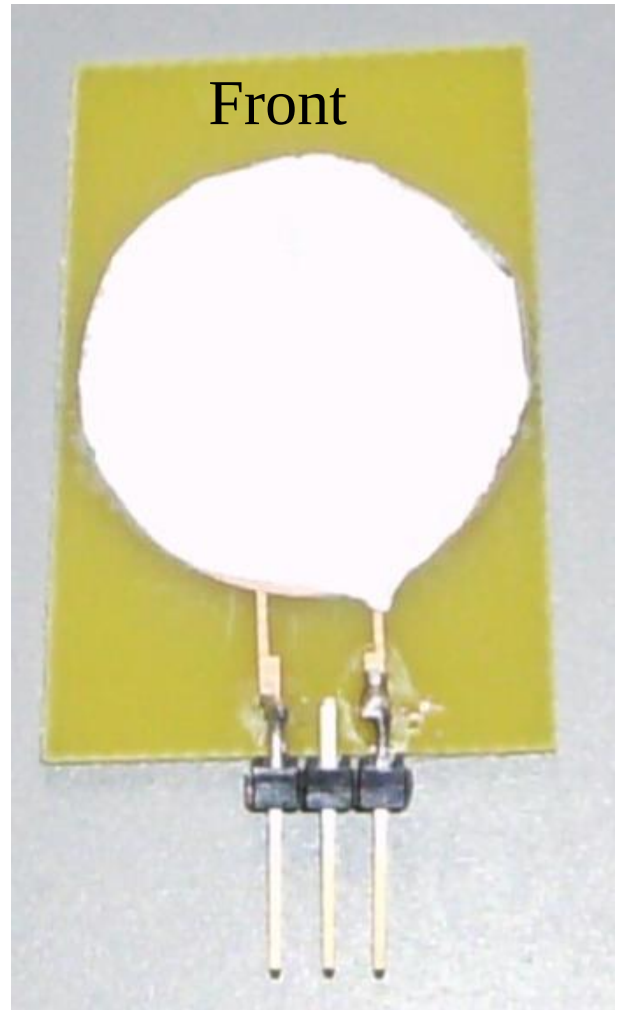
Amplitude of Vo = - 2π f V R Cm

Predicted Frequency Response



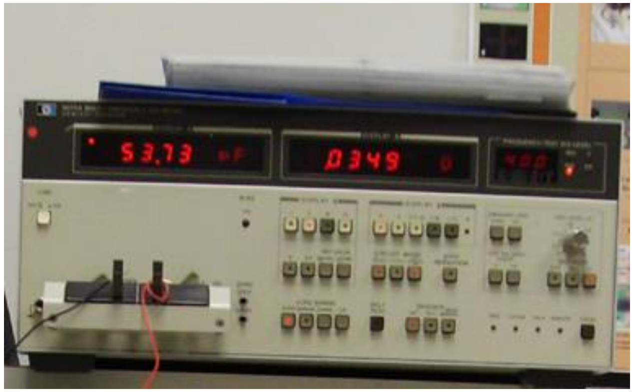
PICTURES OF FABRICATED PCB MICROPHONE





MEASURED CAPACITANCE RESULTS

HP LCR Meter



Measured Capacitance 54pF
Calculated = 56 pF

Puff of air causes 100’s of fF capacitance change
Calculated = 100’s fF

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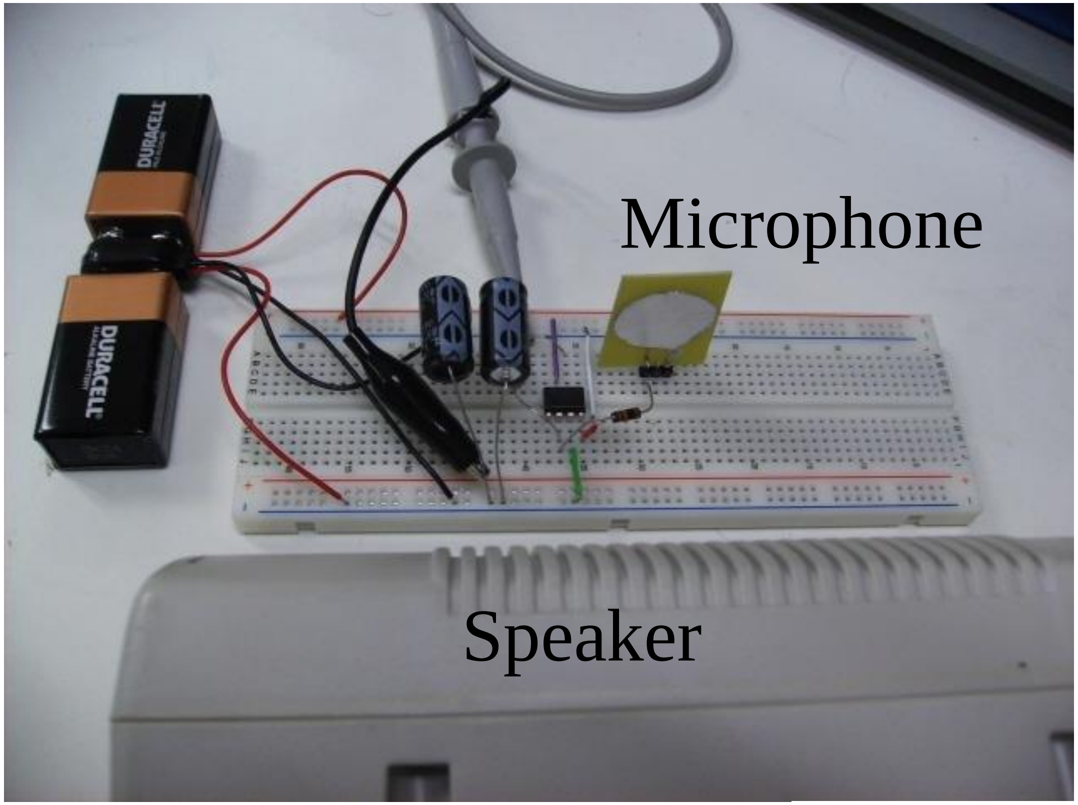
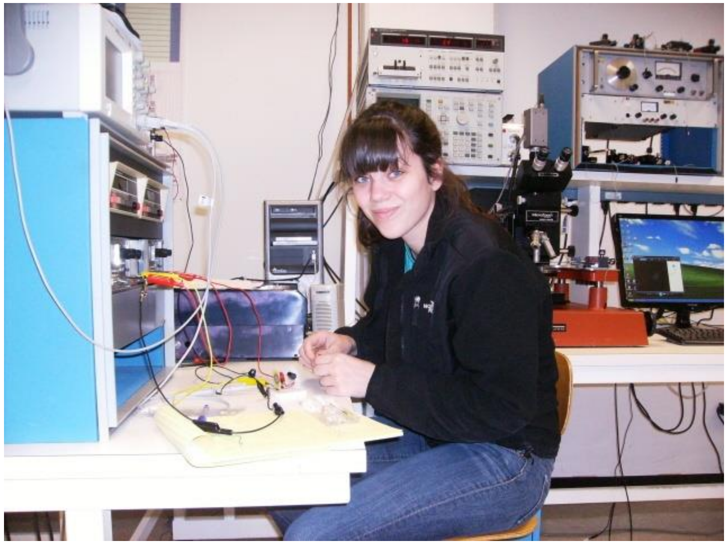
MAKING THE LOW NOISE AMPLIFIER

V= +/- 9 Volts, R=5.6 MEG

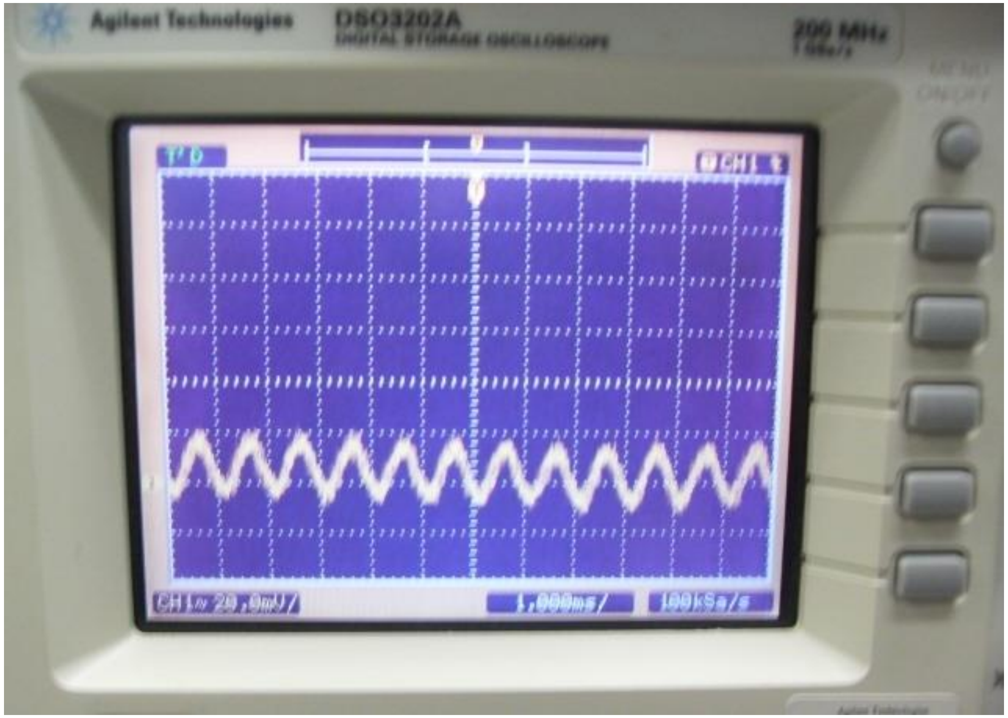




Click to Play Tones.wav

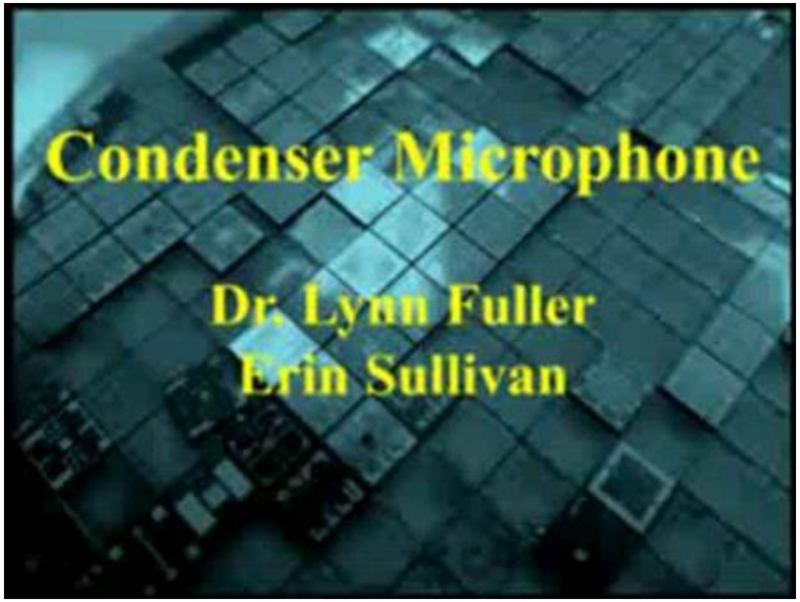
http://people.rit.edu/lffeee/Tones.wmv

MOVIE OF MICROPHONE AND AMP OUTPUT



Vout = ~20mV p-p

Video

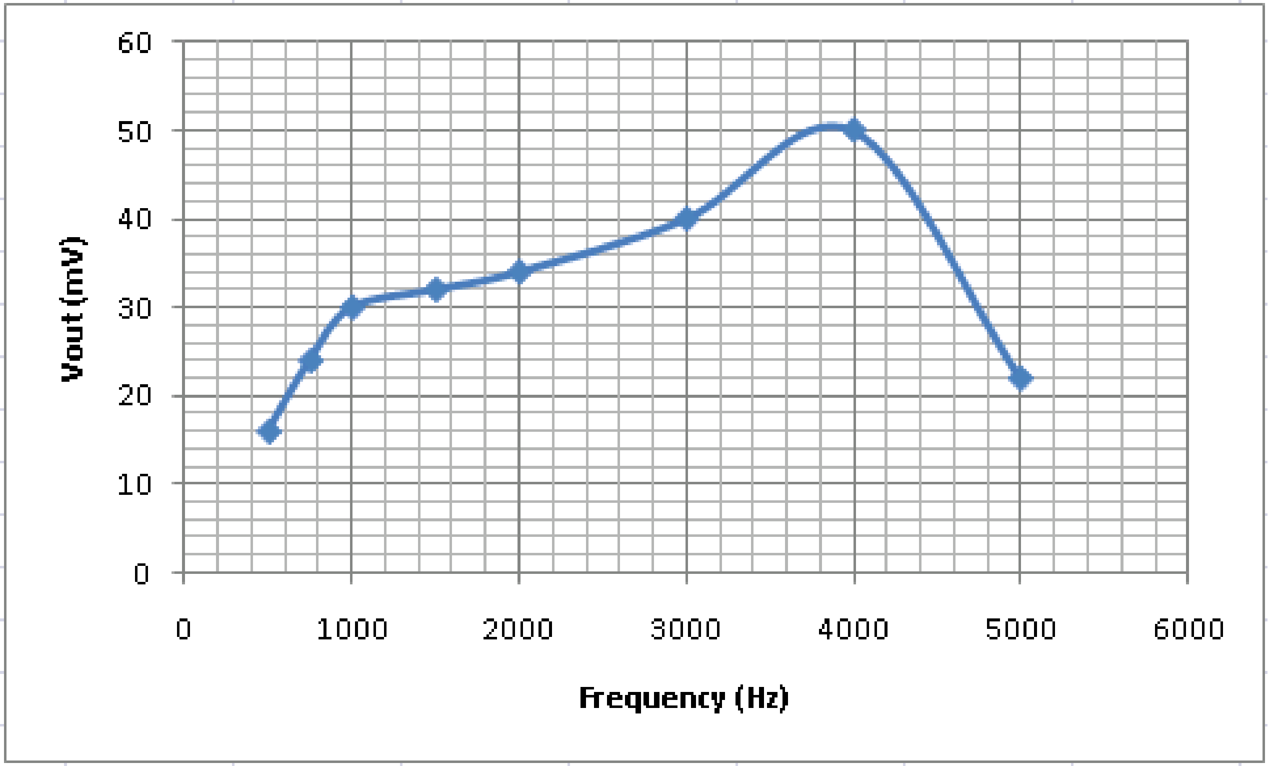


RITMicrophone.wmv

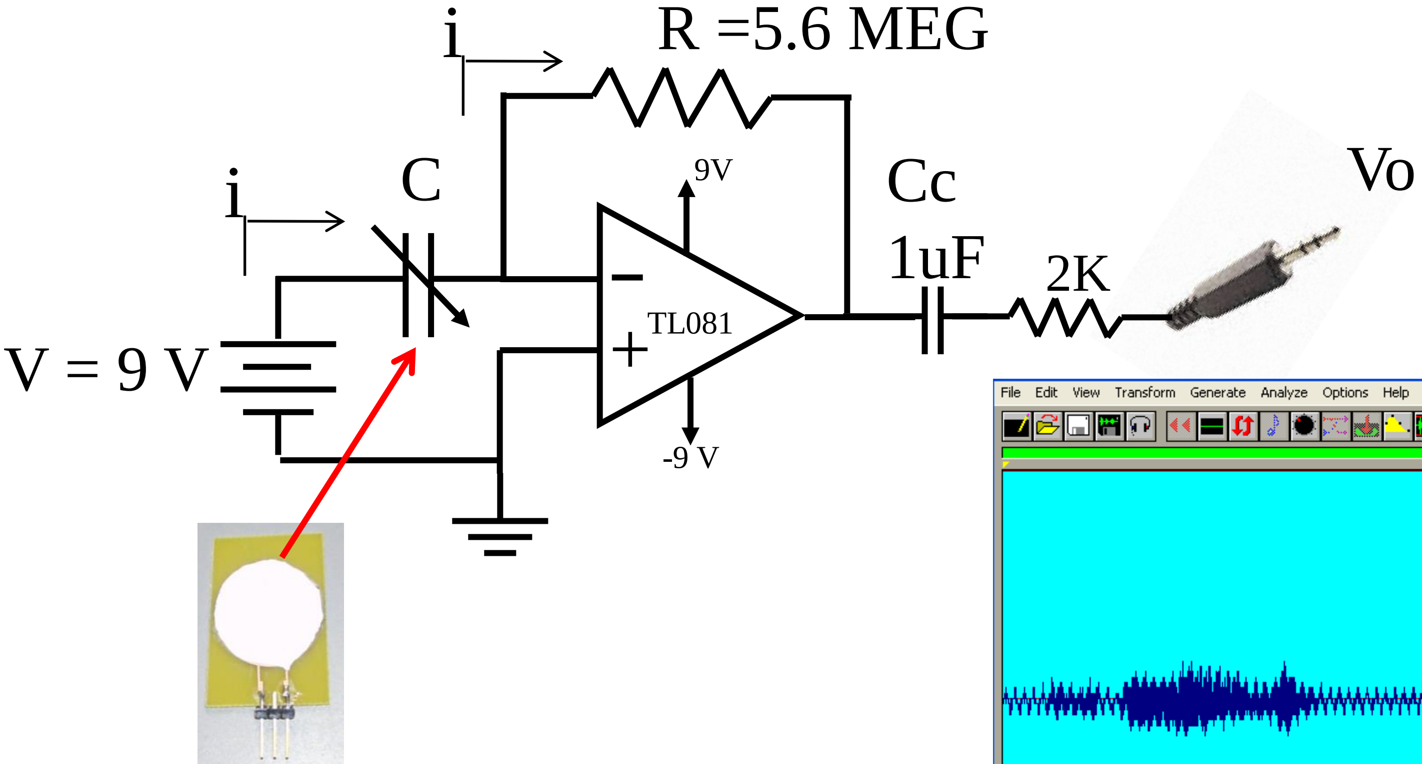
http://people.rit.edu/lffeee/RITMicrophone.wmv

MEASURED VOUT VS FREQUENCY (HZ)

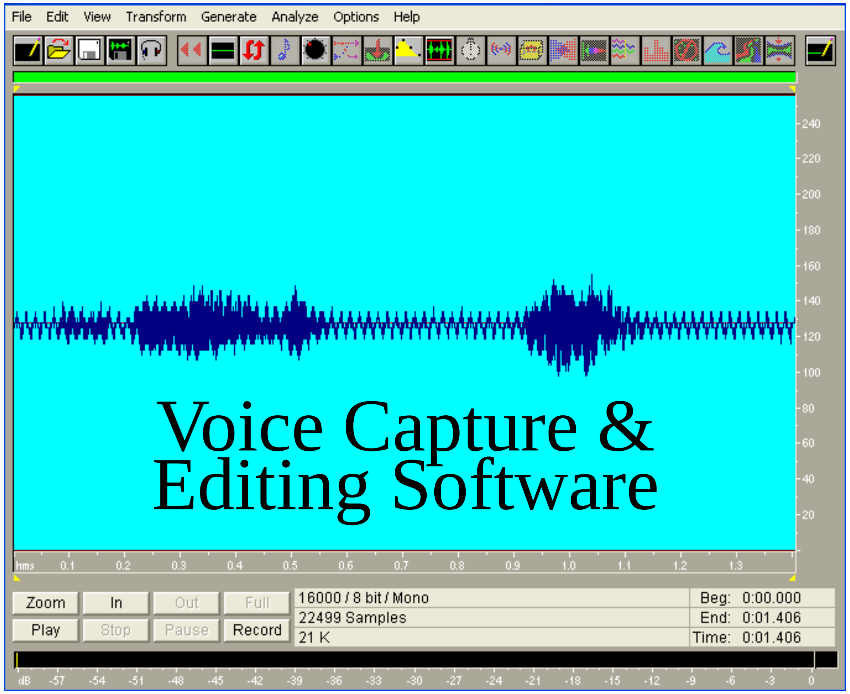
Freq (Hz)	Vout (mV)
500	16
750	24
1000	30
1500	32
2000	34
3000	40
4000	50
5000	22



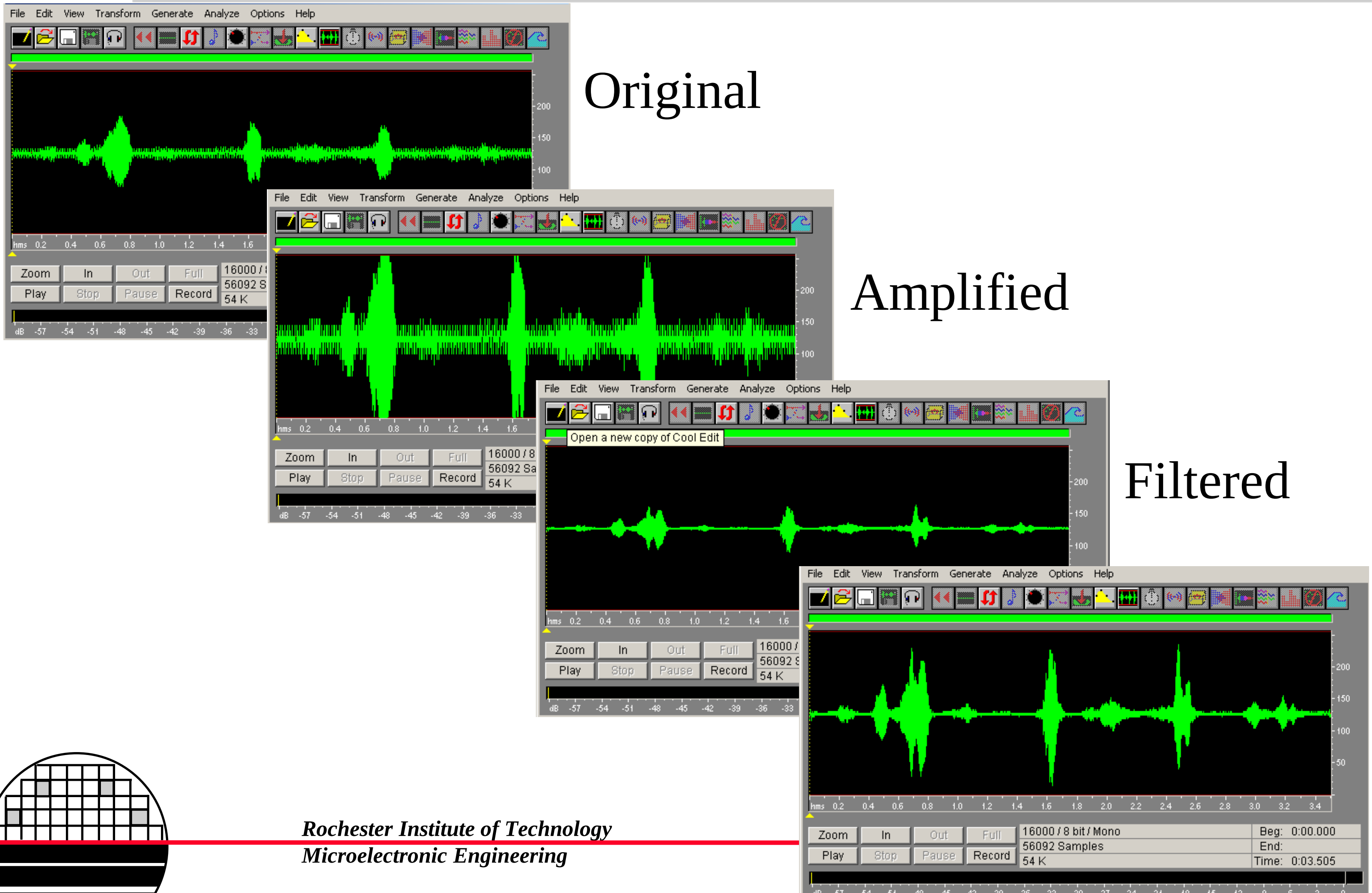
VOICE RECORDING



RIT Microphone



SIGNAL PROCESSING



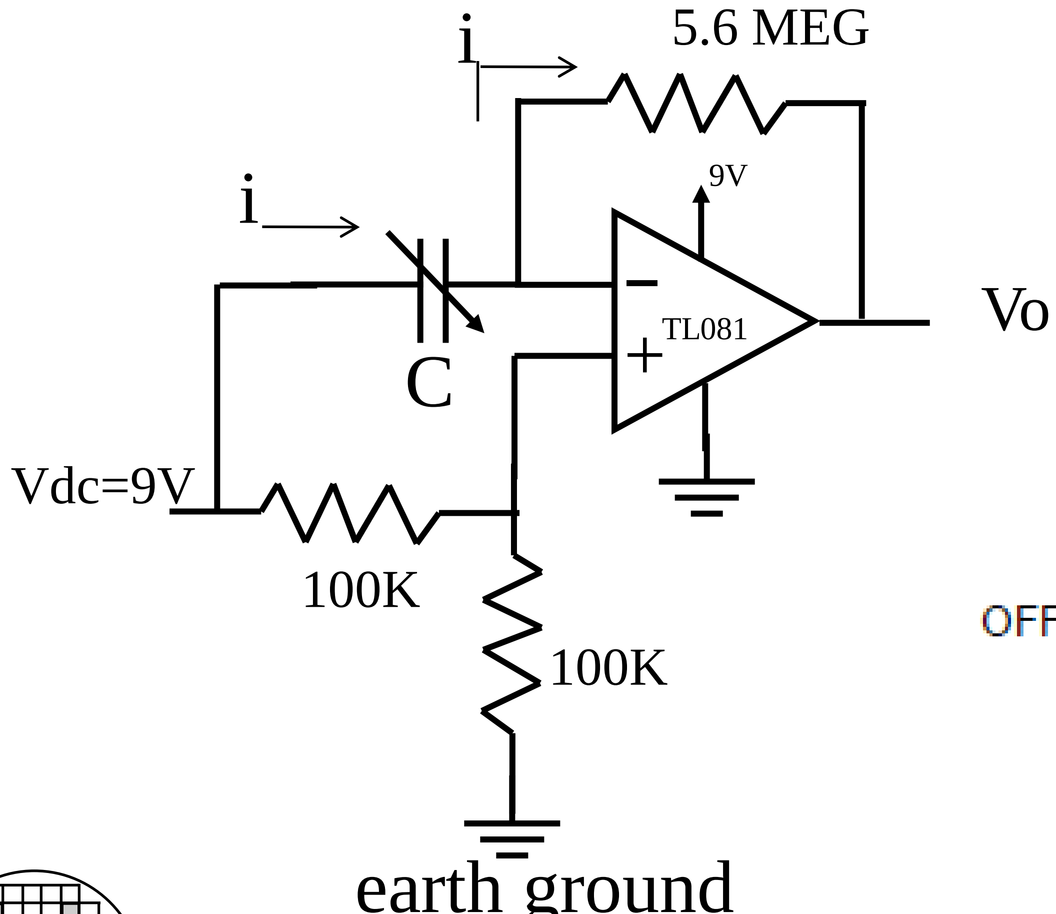
Original

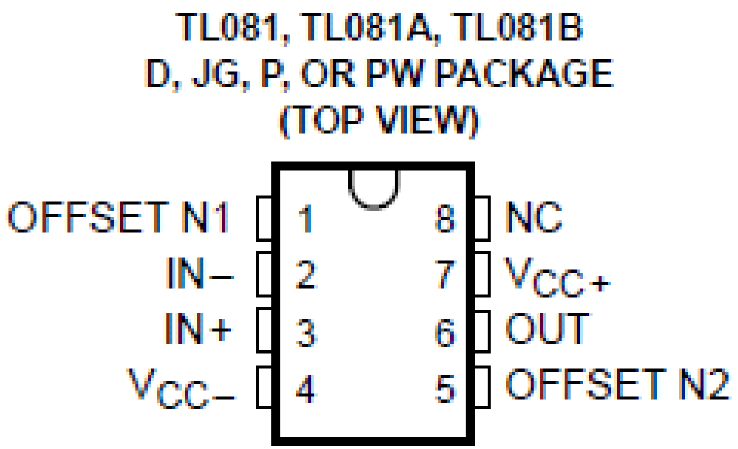
Amplified

Filtered

Final

SINGLE SUPPLY VERSION OF SIGNAL PROCESSING





CONCLUSION

This document presents theoretical and experimental results for capacitive microphone design, fabrication and evaluation. The microphone was fabricated using a PCB for the rigid backing capacitor plate of the microphone. Aluminum foil was used for the flexible sensing capacitor plate of the microphone. Simple signal conditioning electronics converts the change in capacitance to a change in voltage.

The analog output was obtained for various frequency audio tones generated using speakers connected to a personal computer. The amplified microphone output voltage was measured at various frequencies. The microphone was used to make a voice recording.

REFERENCES

1. Journal of Microelectromechanical Systems, IEEE

2. Acustica

3. USPTO - Knowles patents, 7132307 Dec 15, 2003, 5870482 Feb 25, 1997

HOMEWORK – RIT MICROPHONE

1. Write an expression for the output of the single supply version of the capacitor microphone amplifier circuit.

2. Make an accurate calculation of the microphone capacitance, change in capacitance and amplifier output voltage for pressures corresponding to loud speech. Let V = 9 volts, R = 5.6 MEG and f=2000 hz.

3. "Mr. Watson… come here … I want to see you" is a famous statement. Who made this statement, when and why.

4. Find a data sheet for a commercial MEMS microphone. What is the sensitivity at 2000 Hz, what is the price for small quantities.