MEMS Capacitor Sensors and Signal Conditioning

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MEMS Capacitor Sensors

OUTLINE

Capacitors
Capacitors as Sensors
Chemicapacitor
Diaphragm Pressure Sensor
Condenser Microphone
Capacitors as Electrostatic Actuators
Signal Conditioning
References
Homework
**CAPACITORS**

**Capacitor** - a two terminal device whose current is proportional to the time rate of change of the applied voltage:

\[ I = C \frac{dV}{dt} \]

A capacitor \( C \) is constructed of any two conductors separated by an insulator. The capacitance of such a structure is:

\[ C = \varepsilon_0 \varepsilon_r \frac{\text{Area}}{d} \]

where \( \varepsilon_0 \) is the permittivity of free space
\( \varepsilon_r \) is the relative permittivity
Area is the overlap area of the two conductor separated by distance \( d \)
\( \varepsilon_0 = 8.85 \times 10^{-14} \text{ F/cm} \)
\( \varepsilon_r \text{ air} = 1 \)
\( \varepsilon_r \text{ SiO}_2 = 3.9 \)
Two Dielectric Materials between Parallel Plates

\[ C_{\text{Total}} = \frac{C_1 C_2}{C_1 + C_2} \]

Example: A condenser microphone is made from a polysilicon plate 100 µm square with 1000Å silicon nitride on it and a second plate of aluminum with a 1µm air gap. Calculate \( C \) and \( C' \) if the aluminum plate moves 0.1 µm.
# DIELECTRIC CONSTANT OF SELECTED MATERIALS

<table>
<thead>
<tr>
<th>Material</th>
<th>Dielectric Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>1</td>
</tr>
<tr>
<td>Air</td>
<td>1.00059</td>
</tr>
<tr>
<td>Acetone</td>
<td>20</td>
</tr>
<tr>
<td>Barium strontium titanate</td>
<td>500</td>
</tr>
<tr>
<td>Benzene</td>
<td>2.284</td>
</tr>
<tr>
<td>Conjugated Polymers</td>
<td>6 to 100,000</td>
</tr>
<tr>
<td>Ethanol</td>
<td>24.3</td>
</tr>
<tr>
<td>Glycerin</td>
<td>42.5</td>
</tr>
<tr>
<td>Glass</td>
<td>5-10</td>
</tr>
<tr>
<td>Methanol</td>
<td>30</td>
</tr>
<tr>
<td>Photoresist</td>
<td>3</td>
</tr>
<tr>
<td>Plexiglass</td>
<td>3.4</td>
</tr>
<tr>
<td>Polyimide</td>
<td>2.8</td>
</tr>
<tr>
<td>Rubber</td>
<td>3</td>
</tr>
<tr>
<td>Silicon</td>
<td>11.7</td>
</tr>
<tr>
<td>Silicon dioxide</td>
<td>3.9</td>
</tr>
<tr>
<td>Silicon Nitride</td>
<td>7.5</td>
</tr>
<tr>
<td>Teflon</td>
<td>2.1</td>
</tr>
<tr>
<td>Water</td>
<td>80-88</td>
</tr>
</tbody>
</table>

http://www.asiinstruments.com/technical/Dielectric%20Constants.htm
### CALCULATIONS

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
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<tr>
<td>1</td>
<td><strong>Rochester Institute of Technology</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8-Apr-08</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>Dr. Lynn Fuller</td>
<td>Microelectronic Engineering, 82 Lomb Memorial Dr., Rochester, NY 14623</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>To use this spreadsheet 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.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td><strong>Capacitance of Two Parallel Plates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td><strong>Capacitance = ( \varepsilon_0 \text{ Area} / d )</strong></td>
<td>( C = )</td>
<td>8.85E-12</td>
<td>( F )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>( \varepsilon_0 = \text{Permitivity of free space} )</td>
<td>( = 8.85E-14 ) F/cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>( \varepsilon_r = \text{relative permitivitty} )</td>
<td>( = 1 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td><strong>Area =</strong></td>
<td>( 1.00E-02 ) cm²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>number of pairs of plates, ( N = )</td>
<td>( = 1 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>distance between plates, ( d = )</td>
<td>( = 1 \mu m )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>14</td>
<td>If round plates, Diameter =</td>
<td>( = 0 \mu m )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>If rectangular plates, length =</td>
<td>( = 1000 \mu m )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>If rectangular plates, width =</td>
<td>( = 1000 \mu m )</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>17</td>
<td><strong>Force Between Two Parallel Plates</strong></td>
<td><strong>Force =</strong></td>
<td>4.43E-04</td>
<td>( N )</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>18</td>
<td><strong>Electrostatic Force = ( \varepsilon_0 \text{ Area} V^2 / 2d^2 )</strong></td>
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<tr>
<td>19</td>
<td>Applied Voltage, ( V = )</td>
<td>( = 10 ) volts</td>
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<td></td>
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<td><strong>Capacitance for very Thick Interdigitated Fingers</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>( C = (N-1) \varepsilon_0 \text{ Area} ) ( L ) ( h/s )</td>
<td>Capacitance, ( C = )</td>
<td>1.77E-13</td>
<td>( F )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Number of Fingers, ( N = )</td>
<td>( = 101 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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*Microelectronic Engineering*
OTHER CAPACITOR CONFIGURATIONS

Interdigitated Fingers with Thickness > Space between Fingers

\[ C = (N-1) \varepsilon_o \varepsilon_r \frac{L \cdot h}{s} \]

- \( h \) = height of fingers
- \( s \) = space between fingers
- \( N \) = number of fingers
- \( L \) = length of finger overlap

Example:

A 2 g full-scale, 3 V operations surface micromachined accelerometer. The movable plates swing closer to or farther from the fixed plate when motion is sensed.
OTHER CAPACITOR CONFIGURATIONS

Interdigitated Fingers with Thickness $<<$ Space between Fingers

$$C = \ln\left(4 \frac{\varepsilon_r}{\varepsilon_0} \right) \sum_{n=1}^{\infty} \frac{1}{2n-1} \frac{1}{2(s+w)} \frac{J_0^2\left(\frac{(2n-1)\pi s}{2(s+w)}\right)}{J_0(0)}$$

$J_0$ = zero order Bessel function
$w$ = width of fingers
$s$ = space between fingers
$N$ = number of fingers
$L$ = length of finger overlap

Reference:
Lvovich, Liu and Smiechowski,
**OTHER CAPACITOR CONFIGURATIONS**

Two Long Parallel Wires Surrounded by Dielectric Material

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 $h$)

Reference: Kraus and Carver

Example: Calculate the capacitance of a meter long connection of parallel wires.

Solution: let, $h = 1$ mm, $r = 0.5$ mm, plastic $\varepsilon_r = 3$ the equation above gives

$C/L = 63.5 \text{ pF/m}$

$C = 63.5 \text{ pF}$
Coaxial Cable

 Capacitance per unit length C/L

\[ \frac{C}{L} = 2 \pi \varepsilon_0 \varepsilon_r / \ln(b/a) \]

- \( b \) = inside radius of outside conductor
- \( a \) = radius of inside conductor

Reference: Kraus and Carver

Example: Calculate the capacitance of a meter long coaxial cable.

Solution: let \( b = 5 \text{ mm} \), \( a = 0.2 \text{ mm} \), plastic \( \varepsilon_r = 3 \) the equation above gives

\[ \frac{C}{L} = 51.8 \ \text{pF/m} \]
\[ C = 51.8 \ \text{pF} \]
CAPACITORS AS SENSORS

One plate moves relative to other changing gap (d)

Center plate moves relative to the two fixed plates

One plate moves relative to other changing overlap area (A)
CAPACITORS AS SENSORS

Change in Space Between Plates (d)

Change in Area (A)

Figure 1: Cross section of the polysilicon diaphragm condenser microphone

microphone

gyroscope

Change in Dielectric Constant (er)

position sensor
CHEMICAL SENSOR

Two conductors separated by a material that changes its dielectric constant as it selectively absorbs one or more chemicals. Some humidity sensors are made using a polymer layer as a dielectric material.

Change in Dielectric Constant (εr)
DIAPHRAGM PRESSURE SENSOR

Diaphragm: Displacement

Equation for deflection at center of diaphragm

\[ y = \frac{3PR^4[(1/\nu)^2-1]}{16E(1/\nu)^2\delta^3} = \frac{(249.979)PR^4[(1/\nu)^2-1]}{E(1/\nu)^2\delta^3} \]

\( E = \) Young’s Modulus, \( \nu = \) Poisson’s Ratio

for Aluminum \( \nu = 0.35 \)

*The second equation corrects all units assuming that pressure is mmHg, radius and diaphragm is \( \mu \)m, Young’s Modulus is dynes/cm\(^2\), and the calculated displacement found is \( \mu \)m.
PV = nRT

F1 = force on diaphragm = external pressure times area of diaphragm
F2 = force due to captured volume of air under the diaphragm
F3 = force to mechanically deform the diaphragm

F1 = F2 + F3
F1 = P x Ad
F2 = nRT Ad / (Vd + Vs)
where Vd = Ad (d-y) and Vs = G1 Pi (rs^2 – rd^2)(d)
G1 is the % of spacer that is not oxide
F3 = (16 E (1/ ν)^2 h^3 y)/(3 rd^4[(1/ ν)^2-1])
<table>
<thead>
<tr>
<th>y (µm)</th>
<th>P (N/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.1</td>
<td>5103.44</td>
</tr>
<tr>
<td>0.2</td>
<td>10748.09</td>
</tr>
<tr>
<td>0.3</td>
<td>17025.03</td>
</tr>
<tr>
<td>0.4</td>
<td>24047</td>
</tr>
<tr>
<td>0.5</td>
<td>31955.23</td>
</tr>
<tr>
<td>0.6</td>
<td>40929.06</td>
</tr>
<tr>
<td>0.7</td>
<td>51199.69</td>
</tr>
<tr>
<td>0.8</td>
<td>63070.47</td>
</tr>
<tr>
<td>0.9</td>
<td>76947.31</td>
</tr>
<tr>
<td>1</td>
<td>93386.12</td>
</tr>
<tr>
<td>1.1</td>
<td>113169.1</td>
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<tr>
<td>1.2</td>
<td>137433.1</td>
</tr>
<tr>
<td>1.3</td>
<td>167895.7</td>
</tr>
<tr>
<td>1.4</td>
<td>207281.3</td>
</tr>
<tr>
<td>1.5</td>
<td>260184.8</td>
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<tr>
<td>1.6</td>
<td>335009.7</td>
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<tr>
<td>1.7</td>
<td>448945.4</td>
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<tr>
<td>1.8</td>
<td>643513.4</td>
</tr>
<tr>
<td>1.9</td>
<td>1051199</td>
</tr>
<tr>
<td>2</td>
<td>2446196</td>
</tr>
</tbody>
</table>

**P (N/m²) vs displacement y (µm)**
CONDENSER MICROPHONE

ALUMINUM DIAPHRAGM

1 µm Aluminum

2.0 µm Gap
ALUMINUM DIAPHRAGM PRESSURE SENSOR

Kerstin Babbitt - University of Rochester
Stephanie Bennett - Clarkson University
Sheila Kahwati - Syracuse University
An Pham - Rochester Institute of Technology
Delta Capacitance to AC Voltage
Static Capacitance to DC Voltage
Capacitance to Current
Ring Oscillator Capacitance to Frequency
RC Oscillator Capacitance to Frequency
Frequency to Digital
Capacitance to Analog Voltage to Digital
Other
Wireless
DELTA CAPACITANCE TO AC VOLTAGE

If $C_x$ is fixed $V_o$ is zero. If $C_x$ changes there will be a change in current and a corresponding change in $V_o$.

Example: Let $V_{in} = 3$ volts, $C = 10$ pF, microphone action causes $C$ to change by 0.1 pF at 1000 Hz. Calculate the output voltage.
STATIC CAPACITANCE TO DC VOLTAGE

\[ Q = CV \]

\[ V_o = - \frac{V_i}{C_x} \frac{C_x}{C_f} \]
SWITCHED CAPACITOR EQUIVALENT RESISTOR

\[ I = C_{fs} (V_1 - V_2) \]

If the switches operate at a switching frequency \( f_s \), then \( I = Q_{fs} = C_{fs} (V_1 - V_2) \) and \( R_{eq} = 1/(C_{fs}) \)

- S1 closed: C charges to \( V_1 \), charge transferred is \( Q = CV_1 \)
- S1 is opened
- S2 closed: C charges to \( V_2 \), charge transferred is \( Q = CV_2 \)
1. The sampling frequency $f_s$ must be much higher than the signal frequencies.
2. The voltages at node 1 and 2 must be unaffected by switch closures.
3. The switches are ideal.
4. $S_1$ and $S_2$ are not both on at the same time. (use non-overlapping clocks)

$\text{Req} = 1/(C_{fs})$

Example: for audio applications with frequencies up to 10KHz, we select switch frequency of 500KHz, for a 1 MEG ohm resistor we find that

\[ C = \frac{1}{(500K \ 1MEG)} = 2 \text{ p/F} \]

If $X_{ox} = 500 \, \text{Å}$, then the capacitor will be about 30 µm by 30 µm.
The diagram illustrates the concept of capacitance to current conversion. The equation is:

\[ I_2 - I_1 = V_{dd} f (C_2 - C_1) \]

where \( f \) is the clock frequency.
RING OSCILLATOR, C TO FREQUENCY

\[ t_d = \frac{T}{2N} \]

\( T = \text{period of oscillation} \)
\( N = \text{number of stages} \)

VDD = -10V
C sensor = 5 to 25 pF
C parasitic = 10pF
R load 1 Meg
C load 20 pF

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RC OSCILLATOR USING INVERTER WITH HYSTERESIS

V1 = 5V

V2 = 0-5 or 5-0

R = 10K

M1

M2

M3

Vout

Inverter with Hysteresis

RC Oscillator

R

C

Vout
INVERTER WITH HYSTERESIS USING RIT SUB-CMOS NMOSFET, Dr. Lynn Fuller,

*LINE ABOVE IS TITLE
*START WIN SPICE AND ENTER LOCATION AND NAME OF INPUT FILE
*THIS FILE IS HYSTERESIS.TXT
*EXAMPLE: winspice> source c:/spice/Hysteresis.txt
*THE TRANSISTOR MODELS ARE IN THE FILE NAMED BELOW
.INCLUDE E:\SPICE\WINSPICE\RIT_MICROE_MODELS.TXT
*CIRCUIT DESCRIPTION
*VOLTAGE SOURCES
V1 1 0 DC 5
V2 2 0 DC 0
*TRANSISTORS
M1 7 2 0 0 RITSUBN49 L=2U W=16U ad=96e-12 as=96e-12 pd=44e-6 ps=44e-6 nrd=0.025 nrs=0.025
M2 3 2 7 0 RITSUBN49 L=2U W=16U ad=96e-12 as=96e-12 pd=44e-6 ps=44e-6 nrd=0.025 nrs=0.025
M3 1 3 7 0 RITSUBN49 L=2U W=16U ad=96e-12 as=96e-12 pd=44e-6 ps=44e-6 nrd=0.025 nrs=0.025
*RESISTORS
R1 1 3 10000
*REQUESTED ANALYSIS
.OP
.DC V2 5 0 -1.1
*.DC V2 0 5 1
.PLOT DC V(3)
.END
RC OSCILLATOR, INVERTER WITH HYSTERESIS

All PMOS Realization

3.0pF
DESIGN EXAMPLE

Square Wave Generator

RC Integrator

Peak Detector

Comparator
BISTABLE MULTIVIBRATOR

\[ \text{Vo} \]

\[ \text{Vin} \]

\[ +V \]

\[ -V \]

\[ V_{TH} \]

\[ V_{TL} \]

Sedra and Smith pg 1187
**RC INTEGRATOR**

\[ V_{\text{out}} = (-V_a) + [2V_a(1-e^{-t/RC})] \quad \text{for } 0 < t < t_1 \]

If \( R = 1 \text{MEG} \) and \( C = 10\) pF find \( RC = 10\) us
OSCILLATOR USING BISTABLE MULTIVIBRATOR

\[ V_{o} \]

\[ +V \]

\[ -V \]

\[ +R2 \]

\[ R1 \]

\[ R \]

\[ C \]

\[ V_{T} \]
LIQUID LEVEL DETECTOR

Square Wave Generator

RC Integrator

Buffer

Peak Detector

Comparator

Display

Rochester Institute of Technology
Microelectronic Engineering

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CAPACITANCE TO ANALOG VOLTAGE TO DIGITAL

Square Wave Generator → RC Integrator → Peak Detector

C to Analog Voltage

LED Bar Display

Voltage Divider And Comparators A to D
CAPACITOR SENSOR ELECTRONICS

Square Wave Generator

RC Integrator

Buffer

Peak Detector

Voltage Divider & Comparators
MEMS Capacitor Sensors

BLUETOOTH WIRELESS CAPACITOR SENSOR

- BT: Serial Port Profile (RS232)
- Packet Specification:
  - Baud rate: 2400
  - Data bits: 8
  - Parity: None
  - Stop bits: 1
WIRELESS REMOTE SENSING OF L OR C

Capacitive Pressure Sensor

External Electronics

Antenna

R

~ 13MHz

Normal Eye
**BLOCK DIAGRAM FOR REMOTE SENSING ELECTRONICS**

- **Digital Controlled Oscillator**
- **Power Amp**
- **Remote Resonant LC**
- **RS 232**
- **Microchip PIC18F452 μP**
- **A to D**
- **Memory**
- **Filter**
- **Antenna**
- **Amp**
- **Gnd**
- **I**
- **R**
- **C**
- **L**
- **To Display**
- **Realistic Antenna**
SIMILAR IDEA FOR WIRELESS TEMPERATURE

Network Analyzer

I vs. Frequency
PICKUP COIL CURRENT

Due to nearby LC

No Resonant Circuit Present  Resonant LC Circuit Present
Resonant Frequency

\[ \omega_0 = \left( \frac{1}{LC} \right)^{0.5} \]

\[ f_0 = \frac{\omega_0}{2\pi} \]

Frequency at Which this Dip Occurs Changes with Temperature
MS3110 Universal Capacitive Read-out IC (left) and its block diagram (right).
Operational Amplifier
Analog Switches
Non-Overlapping Clock
CMOS OPERATIONAL AMPLIFIER

p-well CMOS

dimensions
L/W
(µm/µm)
VERSION 1 OP AMP

Gain ~5000
Offset 1.17 mV
GBW = 500KHz

Rochester Institute of Technology
Microelectronic Engineering
BASIC TWO STAGE OPERATIONAL AMPLIFIER
SPICE ANALYSIS OF OP AMP VERSION 2

**incl rit_sub_param.txt**
m1 8 9 7 6 cmosn w=9u l=5u nrd=1 nrs=1 ad=45p pd=28u as=45p ps=28u
m2 1 10 7 6 cmosn w=9u l=5u nrd=1 nrs=1 ad=45p pd=28u as=45p ps=28u
m3 8 8 4 4 cmosp w=21u l=5u nrd=1 nrs=1 ad=102p pd=50u as=102p
ps=50u
m4 1 8 4 4 cmosp w=21u l=5u nrd=1 nrs=1 ad=102p pd=50u as=102p
ps=50u
m5 7 5 6 6 cmosn w=40u l=5u nrd=1 nrs=1 ad=205p pd=90u as=205p
ps=90u
m6 2 1 4 4 cmosp w=190u l=5u nrd=1 nrs=1 ad=950p pd=400u as=950p
ps=400u
m7 2 5 6 6 cmosn w=190u l=5u nrd=1 nrs=1 ad=950p pd=400u as=950p
ps=400u
m8 5 5 6 6 cmosn w=40u l=5u nrd=1 nrs=1 ad=205p pd=90u as=205p
ps=90u
vdd 4 0 3
vss 6 0 -3
cprobe 2 0 30p
Rprobe 2 0 1meg
cc 1 2 0.6p
mr1 20 20 4 4 cmosp w=6u l=10u nrd=1 nrs=1 ad=200p pd=60u as=200p
ps=60u
mr2 5 5 20 4 cmosp w=6u l=10u nrd=1 nrs=1 ad=200p pd=60u as=200p
ps=60u

****dc open loop gain*****
vi1 9 0 0
vi2 10 0 0
*.dc vi2 -0.002 0.002 1u
.dc vi2 -1 1 0.1m
*****open loop frequency characteristics*****
*vi1 9 0 0
*vi2 10 0 dc 0 ac 1u
*.ac dec 100 10 1g
.end

13.5kV/V gain
OPERATIONAL AMPLIFIER
For current flowing to the right (ie V1>V2) the PMOS transistor will be on if V1 is greater than the threshold voltage, the NMOS transistor will be on if V2 is <4 volts. If we are charging up a capacitor load at node 2 to 5 volts, initially current will flow through NMOS and PMOS but once V2 gets above 4 volts the NMOS will be off. If we are trying to charge up V2 to V1 = +1 volt the PMOS will never be on. A complementary situation occurs for current flow to the left. Single transistor switches can be used if we are sure the Vgs will be more than the threshold voltage for the specific circuit application. (or use larger voltages on the gates)
(+V to -V) ANALOG SWITCH WITH (0 to 5 V) CONTROL
Synchronous circuits that use the two phase non overlapping clock can separate input quantities from output quantities used to calculate the results in feedback systems such as the finite state machine.
TWO-PHASE CLOCK GENERATORS

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
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CLOCK

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<th>S</th>
<th>Q</th>
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<td>1</td>
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<tr>
<td>1</td>
<td>1</td>
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</tbody>
</table>

CLOCKBAR

\[ t_1 \quad t_2 \quad t_3 \]

QS

0 0 1 0 1 0 1 0 0 1 1 0

R

CB

0 0 1 0 1 0 1 0 0 1 1 0

A

S

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TRANSISTOR LEVEL SCHEMATIC OF 2 PHASE CLOCK

Clock

Layout
TWO PHASE NON OVERLAPPING CLOCK

Clock
Input
Φ1
Φ2

Graph Display
A Low High Low High Low High Low
B Low Low Low Low Low Low

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Microelectronic Engineering

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WINSPICE SIMULATION FOR VERSION TWO + BUFFERS

\[ \text{CLOCK} \quad \text{R} \quad \text{t}_1 \quad \text{S} \quad \text{t}_2 \quad \text{t}_3 \quad \Phi_1 \quad \Phi_2 \]

\[ \Psi \quad v(13) \quad v(15) \]

\[ \begin{align*}
 &-2.0 \quad 0.0 \quad 2.0 \quad 4.0 \quad 6.0 \\
 &0.0 \quad 10.0 \quad 20.0 \quad 30.0 \quad 40.0 \quad 50.0 \quad \text{time (nS)}
\end{align*} \]
REFERENCES

1. Calculate the capacitance for a round plate of 100µm diameter with an air gap space of 2.0 µm.
2. If the capacitor in 1 above has the air gap replaced by water what will the capacitance be?
3. Design an apparatus that can be used to illustrate the attractive force between two parallel plates when a voltage is applied.
4. Design an electronic circuit that can measure the capacitance of two metal plates (the size of a quarter) separated by a thin foam insulator for various applied forces.