Basic Analog Electronic Circuits
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OUTLINE

Introduction
Op Amp
Comparator
Bistable Multivibrator
RC Oscillator
RC Integrator
Peak Detector
Switched Capacitor Amplifier
Capacitors
Design Examples
References
Homework
Analog electronic circuits are different from digital circuits in that the signals are expected to have any value rather than two discrete values. **Primitive** analog components include the diode, mosfet, BJT, resistor, capacitor, etc. Analog circuit **building blocks** include single stage amplifiers, differential amplifiers, constant current sources, voltage references, etc. **Basic** analog electronic circuits include the operational amplifier, inverting amplifier, non-inverting amplifier, integrator, bistable multivibrator, peak detector, comparator, RC oscillator, etc. **Mixed-mode** analog integrated circuits include D-to-A, A-to-D, etc.

This document will introduce some **Basic** analog electronic circuits.
BASIC TWO STAGE OPERATIONAL AMPLIFIER
BASIC TWO STAGE OPERATIONAL AMPLIFIER

TWO STAGE CMOS OP AMP

.include c:\SPICE\RIT_Models_For_LTSPICE.txt

[op
.dc V2 -.1 .1 .00001

I=6u w=20u ad=525p as=525p pd=52u ps=52u
I=5u w=21u ad=525p as=525p pd=52u ps=52u
I=5u w=21u ad=525p as=525p pd=52u ps=52u
I=5u w=200u ad=5000p as=5000p pd=410u ps=410u
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I=5u w=10u ad=250p as=250p pd=90u ps=90u
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I=5u w=40u ad=1000p as=1000p pd=130u ps=130u
I=5u w=40u ad=1000p as=1000p pd=130u ps=130u

Vin

V1 5
V2
V3 0

C2 3p

R1 1MEG
C1 15p
BASIC TWO STAGE OPERATIONAL AMPLIFIER

Gain = 1.5K V/V
BASIC TWO STAGE OPERATIONAL AMPLIFIER

```
.include c:\SPICE\RIT_Models_For_LTSPICE.txt
.op .ac dec 10 1 100000k
```

![Operational Amplifier Circuit Diagram]

- M1, M2, M3, M4, M5, M6, M19, M20
- C1, C2, R1
- V1, V2, V3, Vin, Vout
BASIC TWO STAGE OPERATIONAL AMPLIFIER

Small Signal gain ~ 60 dB

Frequency Response
OPERATIONAL AMPLIFIER LAYOUT

100um
Change RL to 1000 ohm
RIT OP AMP WITH OUTPUT STAGE

[Diagram of RIT OP AMP with output stage including transistor labels and connections]
RIT OP AMP WITH OUTPUT STAGE

.include c:\SPICE\RIT_Models_For_LTSPICE.txt
.dc v2 5 -5 .001
.op
RIT OP AMP WITH OUTPUT STAGE
Operational Amplifiers

The 741 Op Amp is a general purpose bipolar integrated circuit that has input bias current of 80nA, and input voltage of +/- 15 volts @ supply maximum of +/- 18 volts. The output voltage can not go all the way to the + and - supply voltage. At a minimum supply of +/- 5 volts the output voltage can go ~6 volts p-p.

The newer Op Amps have rail-rail output swing and supply voltages as low as +/- 1.5 volts. The MOSFET input bias currents are ~ 1pA. The NJU7031 is an example of this type of Op Amp.
LOW VOLTAGE C-MOS OPERATIONAL AMPLIFIER

**GENERAL DESCRIPTION**
The NJU7031/32/34 are single, dual and quad single supply, low offset, output full swing C-MOS Operational Amplifiers. The wide operating voltage 3V to 16V, high slew rate 3.5V/μs and output full swing are suitable for fast signal processing amplifiers. Additionally, low input bias current 1pA, and single supply operation offer amplification of the very small signal around the ground level.

The NJU7031 has external offset null function.

**FEATURES**
- High Slew Rate: 3.5V/μs
- Wide Operating Voltage: +3V to +16V
- Output Voltage with full Swing: $V_{CM}=9.98V$ typ. (@$V_{DD}=10V$)
- Input Common Mode Voltage Range: $V_{CM}=0V$ to 9V (@$V_{DD}=10V$)
- Low Bias Current: $I_{b}=1pA$ typ.
- Input Common Mode Voltage range includes ground.
- External Offset Null Adjustment (Only NJU7031)
- C-MOS Technology
- Package Outline: NJU7031 (single) DIP8, DMP8, SSOP8
  NJU7032 (dual) DIP8, DMP8
  NJU7034 (quad) DIP14, DMP14, SSOP14

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SOME BASIC ANALOG ELECTRONIC CIRCUITS

These circuits should be familiar:

- **Inverting Amplifier**
  - $V_o = -V_{in} \frac{R_2}{R_1}$

- **Non-Inverting Amplifier**
  - $V_o = V_{in} \left(1 + \frac{R_2}{R_1}\right)$

- **Unity Gain Buffer**
  - $V_o = V_{in}$

- **Integrator**
  - $V_o = -\frac{1}{RC} \int V_{in} \, dt$
SOME BASIC ANALOG ELECTRONIC CIRCUITS

Inverting Summer

\[ V_o = \left( -\frac{R_3}{R_1} \right) (V_1 + V_2) \]

Difference Amplifier

\[ V_o = \frac{R_f}{R_{in}} (V_1 - V_2) \]
**COMPARATOR**

![Comparator Diagram]

**Theoretical**

**Measured**

---

**NJU7034D Comparator Vref~3.1 volts**

- **Conditions:**
  - Con. SMU2
  - Vol. 3.00 V
  - Step. SMU1
  - Start. -5.00 V
  - Step. 5.00 V
  - Pts. 201
  - Con. SMU3
  - Vol. 0.00 A

<table>
<thead>
<tr>
<th>F1#1</th>
<th>F1#2</th>
<th>Cursor X</th>
<th>Y</th>
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<tr>
<td></td>
<td></td>
<td>4.20</td>
<td>-5.30</td>
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<tr>
<td></td>
<td></td>
<td>0.00</td>
<td>5.18</td>
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BISTABLE CIRCUIT WITH HYSTERESIS

\[ \text{Vin} \quad \rightarrow \quad \text{R1} \quad \rightarrow \quad \text{R2} \quad \rightarrow \quad \text{Op Amp} \quad \rightarrow \quad \text{Vo} \]

\[ +V \quad \rightarrow \quad \text{Op Amp} \quad \rightarrow \quad -V \]

\[ \text{Vo} \quad \rightarrow \quad \text{Theoretical} \]

\[ \text{V}_{\text{TH}} \quad \rightarrow \quad \text{V}_{\text{TL}} \quad \rightarrow \quad \text{Measured} \]

Sedra and Smith pg 1187
RC INTEGRATOR

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

If $R=1\text{MEG}$ and $C=10\text{pF}$ find $RC=10\text{us}$
so $t_1$ might be $\sim20\text{us}$
**OSCILLATOR (MULTIVIBRATOR)**

Bistable Circuit with Hysteresis and RC Integrator

\[
\text{Period} = T = 2RC \ln \left( \frac{1+V_t/V}{1-V_t/V} \right)
\]
**PEAK DETECTOR**

Diode reverse leakage current ~100nA
**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

\( \varepsilon_0 = 8.85 \times 10^{-14} \text{ F/cm} \)

\( \varepsilon_r \) is the relative permittivity

\( \varepsilon_r \text{ air} = 1 \)

\( \varepsilon_r \text{ SiO}_2 = 3.9 \)
### DIELECTRIC CONSTANT OF SELECTED MATERIALS

<table>
<thead>
<tr>
<th>Material</th>
<th>Dielectric Constant</th>
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<tbody>
<tr>
<td>Vacuum</td>
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<tr>
<td>Air</td>
<td>1.00059</td>
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<tr>
<td>Acetone</td>
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<tr>
<td>Barium strontium titanate</td>
<td>500</td>
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<tr>
<td>Benzene</td>
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<td>Conjugated Polymers</td>
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<td>Ethanol</td>
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<td>Glycerin</td>
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<td>Glass</td>
<td>5-10</td>
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<td>Methanol</td>
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<td>Photoresist</td>
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<td>Silicon dioxide</td>
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<td>Silicon Nitride</td>
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<td>Teflon</td>
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<td>Water</td>
<td>80-88</td>
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# CALCULATIONS

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<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<td>2</td>
<td>Dr. Lynn Fuller</td>
<td>Microelectronic Engineering, 82 Lomb Memorial Dr., Rochester, NY 14623</td>
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<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>
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<tr>
<td>7</td>
<td>Capacitance of Two Parallel Plates</td>
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<td></td>
</tr>
<tr>
<td>8</td>
<td>Capacitance = ( \varepsilon_0 \varepsilon_r \text{Area}/d )</td>
<td>C =</td>
<td>8.85E-12</td>
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<tr>
<td>9</td>
<td>( \varepsilon_0 = ) Permittivity of free space</td>
<td>( \varepsilon_0 = 8.85E-14 ) F/cm</td>
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<td>( \varepsilon_r = ) relative permittivity =</td>
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<td>number of pairs of plates, ( N = )</td>
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<td>13</td>
<td>distance between plates, ( d = )</td>
<td>1 ( \mu )m</td>
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<td>If round plates, Diameter =</td>
<td>0 ( \mu )m</td>
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<td></td>
<td></td>
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<tr>
<td>15</td>
<td>If rectangular plates, length =</td>
<td>1000 ( \mu )m</td>
<td></td>
<td></td>
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<tr>
<td>16</td>
<td>If rectangular plates, width =</td>
<td>1000 ( \mu )m</td>
<td></td>
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<tr>
<td>17</td>
<td>Force Between Two Parallel Plates</td>
<td>Force =</td>
<td>4.43E-04 N</td>
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<td>Electrostatic Force = ( \varepsilon_0 \varepsilon_r \text{Area} V^2/2d^2 )</td>
<td>Applied Voltage, ( V = )</td>
<td>10 volts</td>
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<td>Capacitance for very Thick Interdigitated Fingers</td>
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<td>21</td>
<td>( C = (N-1) \varepsilon_0 \varepsilon_r \text{Lh}/s )</td>
<td>Capacitance, ( C = )</td>
<td>1.77E-13</td>
<td>F</td>
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<tr>
<td>22</td>
<td>Number of Fingers, ( N = )</td>
<td>101</td>
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</tbody>
</table>
DESIGN EXAMPLE

Square Wave Generator

RC Integrator & Capacitor Sensor

Peak Detector

Comparator
DESIGN EXAMPLE – CAPACITOR SENSOR

Square Wave Generator

RC Integrator & Capacitor Sensor

Buffer

Peak Detector

Comparator

Display
EXAMPLE LABORATORY RESULTS

Square Wave Generator Output

Smaller Capacitance

Larger Capacitance

Buffer Output

Display
**CAPACITOR MICROPHONE PLUS AMPLIFIER**

\[ V_0 = -iR \]

\[ i = d(CV)/dt, \text{ V is constant } C = C_0 + C_m \sin(2\pi ft) \]

\[ i = V C_m 2\pi f \cos(2\pi ft) \]
PHOTODIODE I TO V LINEAR AMPLIFIER

IR LED

Gnd

R1
10K
3.3V

R2
20K

R3
10K

R4
100K

Vout
0 to 1V

NJU703

-3.3

-3.3

3.3V

3.3V
PHOTO DIODE I TO V LOG AMPLIFIER

The circuit diagram shows a photodiode connected to an amplifier. The photodiode is labeled as IR LED, and the current (I) flows through it, generating a voltage (Vout) that varies with the diode current. The amplifier uses a 1N4448 diode in the reverse bias mode to operate in the log amplifier mode. The linear amplifier uses a 100K ohm resistor in place of the 1N4448.

The graph shows the output voltage (Vout) vs. diode current (uA). The x-axis represents the diode current ranging from 0.01 to 10000 uA, and the y-axis represents the output voltage ranging from 0.0 to 3.5 V.

The graph distinguishes between linear and log amplifiers, with the log amplifier displaying a steeper voltage increase compared to the linear amplifier for lower currents.
PHOTO DIODE I TO V INTEGRATING AMPLIFIER

Integrator and amplifier allow for measurement at low light levels
DIODE AS A TEMPERATURE SENSOR

Poly Heater, Buried pn Diode, N+ Poly to Aluminum Thermocouple

Compare with theoretical -2.2mV/°C
SIGNAL CONDITIONING FOR TEMPERATURE SENSOR

\[ 0.2 < V_{out} < 0.7 \text{V} \]

Diagram:
- A diode (p-n junction) with a forward bias of 3.3V, indicated by the current (I) flow through it.
- Resistor R1 of 20K ohms connected to the diode, limiting the current.
- The output voltage range is 0.2V to 0.7V.

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OP AMP CONSTANT CURRENT SOURCE

**Floating Load**
- $V_s$ is connected to the inverting input of the OP AMP.
- The load resistance $R$ is connected between the output $V_o$ and the ground.
- The current $I = \frac{V_s}{R}$.

**Grounded Load**
- $V_s$ is connected to the non-inverting input of the OP AMP.
- The load resistance $R$ is connected between the output $V_o$ and the ground.
- The current $I = \frac{V_s}{R_2}$.

### Equations
- For a floating load: $I = \frac{V_s}{R}$
- For a grounded load: $I = \frac{V_s}{R_2}$
RESISTIVE PRESSURE SENSOR

Resistors on a Diaphragm

Vo1 = 2.5V  
Vo2 = 2.5V  
R1 = 427  
R2 = 427  
R3 = 427  
R4 = 427

No Pressure  
Vo2 - Vo1 = 0
**INSTRUMENTATION AMPLIFIER**

- R1 = 427.6
- R3 = 426.4
- R2 = 426.4
- R4 = 427.6
- Vo1 = 2.4965V
- Vo2 = 2.5035V
- Vo = (V2 - V1) \( \frac{2R_4}{R_3} \left( 1 + \frac{R_2}{R_1} \right) \)

With Pressure

Vo2 - Vo1 = 0.007V

= 7 mV
POWER OUTPUT STAGE

Vin → +V → +V
   |       |       |
   |       |       |
   -V     -V

Vo

Rload
REFERENCES


1. Create one good homework problem and the solution related to the material covered in this document. (for next year's students)

2. Design a bistable multivibrator with Vth of +/- 7.5 volts and frequency of 5 KHz.

3. Design a temperature sensor circuit that will shut down a heater if the temperature exceeds 90°C.

4. Design a peak detector that will respond to changes in input in less than one second.

5. Derive the equation for the oscillator on page 15 (multivibrator).

6. Derive the voltage gain equation for the difference amplifier.
**DERIVE GAIN EQUATION FOR DIFFERENCE AMP**

\[ V_o = \frac{R_f}{R_{in}} (V_1 - V_2) \]

**Difference Amplifier**

- \( V_2 \) connected to the non-inverting input
- \( V_1 \) connected to the inverting input
- \( V_x \) connected to the inverting input

\[ I = \frac{(V_2 - V_x)}{R_{in}} \]

\[ V_x = V_1 \frac{R_f}{R_f + R_{in}} \]

\[ V_o = -I \frac{R_f}{R_f + R_{in}} + V_x \]