Basic Analog Electronic Circuits

Dr. Lynn Fuller

Webpage: http://people.rit.edu/lffeee
Microelectronic Engineering
Rochester Institute of Technology
82 Lomb Memorial Drive
Rochester, NY 14623-5604
Tel (585) 475-2035
Email: Lynn.Fuller@rit.edu
MicroE webpage: http://www.microe.rit.edu
OUTLINE

Introduction
Op Amp
Comparator
Bistable Multivibrator
RC Oscillator
RC Integrator
Peak Detector
Switched Capacitor Amplifier
Capacitors
Design Examples
References
Homework
INTRODUCTION

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
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
-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 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 cannot 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, RAIL-TO-RAIL 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 $V_{OM}=9.98V$ typ. (@$V_{DD}=10V$)
  - Input Common Mode Voltage Range $V_{OM}=0V$ 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

---

Rochester Institute of Technology
Microelectronic Engineering
SOME BASIC ANALOG ELECTRONIC CIRCUITS

These circuits should be familiar:

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

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

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

- **Integrator**
  - Input: $V_{in}$
  - Output: $V_o = -\frac{1}{RC} \int V_{in} \, dt$
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**

Theoretical

Measured

NJU7034D Comparator Vref~3.1 volts

---

**Conditions:**
- Con: SMU2
- Vol: 0.00 V
- Step: SMU1
- Start: -5.00 V
- Step: 5.00 V
- Step: 0.05 V
- Pts: 201
- Con: SMU3
- Vol: 0.00 A

---

**Table:**

<table>
<thead>
<tr>
<th>VIN</th>
<th>VN</th>
<th>Volt X</th>
<th>Volt Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.15</td>
<td>-5.15</td>
<td>3.15</td>
<td>-5.15</td>
</tr>
<tr>
<td>4.30</td>
<td>-5.30</td>
<td>4.30</td>
<td>-5.30</td>
</tr>
<tr>
<td>0.15</td>
<td>5.15</td>
<td>0.15</td>
<td>5.15</td>
</tr>
</tbody>
</table>
BISTABLE CIRCUIT WITH HYSTERESIS

\[ \text{Theoretical} \]

\[ V_{TH} \]

\[ V_{TL} \]

\[ V_{in} \]

\[ +V \]

\[ -V \]

Measured

Sedra and Smith pg 1187

NJU7034D Bistable Multivibrator Vref=3.1 volts

<table>
<thead>
<tr>
<th>Plot</th>
<th>Fit #2</th>
<th>Cursors X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
<td>1.50</td>
<td>5.00</td>
</tr>
<tr>
<td>none</td>
<td>none</td>
<td>0.15</td>
<td>5.20</td>
</tr>
<tr>
<td>none</td>
<td>none</td>
<td>0.15</td>
<td>5.20</td>
</tr>
<tr>
<td>none</td>
<td>none</td>
<td>0.00</td>
<td>5.00</td>
</tr>
<tr>
<td>ICS</td>
<td>16.43</td>
<td>20.00</td>
<td></td>
</tr>
</tbody>
</table>
**RC INTEGRATOR**

Vout = (-Va) + [2Va(1-e\(^{-t/RC}\))] for 0<t<t₁

If R=1MEG and C=10pF find RC=10us
so t₁ might be ~20us
OSCILLATOR (MULTIVIBRATOR)

Bistable Circuit with Hysteresis and RC Integrator

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

\( \varepsilon_r \) is the relative permittivity

Area is the overlap area of the two conductor separated by distance \( d \)

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

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

\( \varepsilon_r \text{ SiO}_2 = 3.9 \)
### 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>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rochester Institute of Technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8-Apr-08</td>
<td></td>
</tr>
<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>
</tr>
<tr>
<td>7</td>
<td>Capacitance of Two Parallel Plates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Capacitance = ( \varepsilon_0 \varepsilon_r \text{Area}/d )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( C = 8.85E-12 ) F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>( \varepsilon_0 = \text{Permitivity of free space} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( 8.85E-14 ) F/cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>( \varepsilon_r = \text{relative permitivity} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Area = ( 1.00E-02 ) cm²</td>
<td></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></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>distance between plates, ( d = )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( 1 ) μm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>If round plates, Diameter = ( 0 ) μm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>If rectangular plates, length = ( 1000 ) μm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>If rectangular plates, width = ( 1000 ) μm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Force Between Two Parallel Plates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( 4.43E-04 ) N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Electrostatic Force = ( \varepsilon_0 \varepsilon_r \text{Area} V^2/2d^2 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Applied Voltage, ( V = ) ( 10 ) volts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Capacitance for very Thick Interdigitated Fingers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>( C = (N-1) \varepsilon_0 \varepsilon_r L h/s )</td>
<td></td>
<td></td>
<td></td>
<td>Capacitance, ( C = ) ( 1.77E-13 ) F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Number of Fingers, ( N = ) ( 101 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</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**

\[
V_o = -i R
\]

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

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

[Diagram showing a circuit with photodiode, IR LED, resistors (R1, R2, R3, R4), and an operational amplifier (NJU703) with labels for input (I), ground (Gnd), and output (Vout) voltages.]
PHOTO DIODE I TO V LOG AMPLIFIER

**Photodiode**

Linear amplifier uses 100K ohm in place of the 1N4448

![Diode Circuit Diagram](image)

**Vout vs. Diode Current**

- **Linear Amplifier**
- **Log Amplifier**

![Graph](image)
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

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

\[ R1 \]
\[ 20K \]

3.3V

Gnd

\[ \text{3.3Vdc} \]
**OP AMP CONSTANT CURRENT SOURCE**

**Floating Load**

\[ I = \frac{V_s}{R} \]

**Grounded Load**

\[ R_{x/R1} = \frac{R_3}{R_2} \]

\[ I = \frac{V_s}{R_2} \]
RESISTIVE PRESSURE SENSOR

Resistors on a Diaphragm

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

Vo2 - Vo1 = 0

No Pressure
INSTRUMENTATION AMPLIFIER

With Pressure

\[ V_o - V_1 = 0.007 \text{v} \]
\[ = 7 \text{ mV} \]
POWER OUTPUT STAGE

\[ +V \]

Vin

\[ -V \]

Vo

Rload

\[ +V \]

-
REFERENCES


1. Create one good homework problem and the solution related to the material covered in this document. (for next years 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 = R_f/R_in (V_1 - V_2)

V_x = V_1 \frac{R_f}{R_f + R_in}

I = \frac{V_2 - V_x}{R_in}

V_o = -I R_f + V_x

Difference Amplifier