OUTLINE

Introduction
Basic Dual Supply Op Amp Circuits
Power Supplies
NJU 703X Op Amp
LTC 6078 Op Amp
Single Supply Op Amp Circuits
  Virtual Ground
  Inverting Amplifier
  Non Inverting Amplifier
  Comparator
  Multivibrator
  Current to Voltage Converter
  Differential Amplifier
INTRODUCTION

This document discusses single-supply, low-voltage, rail-to-rail, Operational Amplifier (Op Amp) circuits. Although all op amps can operate with single supply or dual supply, most engineers are familiar with dual-supply Op Amp circuits such as those shown on the following page. The dual supply allows the input and output to be easily referenced to zero volts. (analog ground = earth ground)

Single supply Op Amps usually refers to low voltage Op Amps using voltages of 5, 3.3 or smaller and ground. Some types of Op Amps will not work at these voltages. (some Op Amps use BJT current source biasing that takes a couple of diode drops of voltage to work thus the output voltage of these Op Amps can only get within 1.4 volts of the supply rails. For example at 5 volts, output is limited between 1.4 volts and 3.6 volts and with 3.3 volts supply some Op Amps may not work at all. With single supply Op Amp circuits we also can not have negative output voltages. There are several techniques for working with these limitations.
VOLTAGE SUPPLIES

Single Supply

Dual DC Power Supply

Multiple Output Supplies
CREATING A SPLIT SUPPLY FROM A SINGLE SUPPLY

The simple voltage splitter draws a lot of power if R’s are low. C’s ensure AC short (for AC signals).

Example: 20V single supply can be split giving +/- 10V. If R’s are 10 ohms then I in each is 10/10=1 Amp and if the Op Amp draws only a few mA the voltages will be ~+/− 10V. Resistor Power = IV=10 watts. (be sure to get resistors for 10 watts) If C=500uf the corner will be ~1/RC = 200r/s = 31.8hz good for AC signals above ~300hz.
Virtual ground is simply a voltage reference typically half of the supply voltage.

This virtual ground can supply/sink only as much current as the maximum Op Amp output current. The output current can be increased as shown with the BJT’s.
TLE2426 RAIL SPLITTER (COMMERCIAL VIRTUAL GND)

1/2 Vᵢ Virtual Ground for Analog Systems
Self-Contained 3-terminal TO-226AA Package
Micropower Operation ... 170 µA Typ.
Vᵢ = 5 V
Wide Vᵢ Range ... 4 V to 40 V
High Output-Current Capability
- Source ... 20 mA Typ
- Sink ... 20 mA Typ

Excellent Output Regulation
- ±45 µV Typ at Iₒ = 0 to -10 mA
- ±15 µV Typ at Iₒ = 0 to +10 mA
Low-Impedance Output ... 0.0075 Ω Typ
Noise Reduction Pin (D, JG, and P Packages Only)

description

In signal-conditioning applications utilizing a single power source, a reference voltage equal to one-half the supply voltage is required for termination of all analog signal grounds. Texas Instruments presents a precision virtual ground whose output voltage is always equal to one-half the input voltage, the TLE2426 "rail splitter."

The unique combination of a high-performance, micropower operational amplifier and a precision-trimmed divider on a single silicon chip results in a precise Vᵢ/2 ratio of 0.5 while sinking and sourcing current. The TLE2426 provides a low-impedance output with 20 mA of sink and source capability while drawing less than 280 µA of supply current over the full input range of 4 V to 40 V. A designer need not pay the price in terms of board space for a conventional signal ground consisting of resistors, capacitors, operational amplifiers, and voltage references. The performance and precision of the TLE2426 is available in an easy-to-use, space-saving, 3-terminal LP package. For increased performance, the optional 8-pin packages provide a noise-reduction pin. With the addition of an external capacitor (CᵢᵢᵢR), peak-to-peak noise is reduced while line ripple rejection is improved.

TLE2426Y chip information

This chip, properly assembled, displays characteristics similar to the TLE2426C. Thermal compression or ultrasonic bonding may be used on the doped aluminum bonding pads. The chips may be mounted with conductive epoxy or a gold-silicon preform.

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The 741 Op Amp is a general purpose bipolar (BJT) 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.
1. Low Voltage operation
2. Rail to Rail input and output voltages
3. Low Input bias ~ 1pA or smaller
4. Low Output Current (depends on M6 and M7)
5. Unity Gain Bandwidth depends on Cc
LOW VOLTAGE, RAIL-TO-RAIL OP AMP

NJU7031/32/34

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 \( V_{OM}=9.58V \) typ. (@\( V_{DD}=10V \))
  - Input Common Mode Voltage Range \( V_{CM}=0V \) to 9V (@\( V_{DD}=10V \))
  - Low Bias Current \( I_{IN}=1pA \) typ.
  - Input Common Mode Voltage range includes ground.
  - External Offset Null Adjustment (Only NJU7031)
  - C-MOS Technology
  - Package Outline NJU7031 (single) DIP8, DMP8, SSOP8

1. 3 to 16 Volt operation
2. Rail to Rail input and output voltages
3. Low Input bias ~ 1pA
4. Output Current ~1mA
5. Unity Gain Bandwidth 1.5 MHz
6. Power Dissipation 1mA at 3 V = 3000uW
NJU7031/32/34

Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>RATING</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>V_{DD}</td>
<td>18</td>
<td>V</td>
</tr>
<tr>
<td>Differential Input Voltage</td>
<td>V_{ID}</td>
<td>± 18 (note 1)</td>
<td>V</td>
</tr>
<tr>
<td>Common Mode Input Voltage</td>
<td>V_{CM}</td>
<td>-0.3~18</td>
<td>V</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td>P_D</td>
<td>(DIP14) 700</td>
<td>mW</td>
</tr>
<tr>
<td>(DIP8) 500</td>
<td></td>
<td>(DMP8,14) 300</td>
<td></td>
</tr>
<tr>
<td>(SSOP8,14) 300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>T_{OP}</td>
<td>-40~+85</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>T_{ST}</td>
<td>-40~+125</td>
<td>°C</td>
</tr>
</tbody>
</table>

*(note 1) If the supply voltage (V_{DD}) is less than 18V, the input voltage must not exceed the V_{DD} level though 18V is the limit specified.

Electrical Characteristics

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>TEST CONDITION</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Offset Voltage</td>
<td>V_O</td>
<td>Re=50Ω</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>mV</td>
</tr>
<tr>
<td>Input Offset Current</td>
<td>I_O</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>pA</td>
</tr>
<tr>
<td>Input Bias Current</td>
<td>I_B</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>pA</td>
</tr>
<tr>
<td>Input Impedance</td>
<td>R_I</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Ω</td>
</tr>
<tr>
<td>Large Signal Voltage Gain</td>
<td>A_{V}</td>
<td></td>
<td>80</td>
<td>95</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>Input Common Mode Voltage Range</td>
<td>V_{CM}</td>
<td>Re=1MΩ</td>
<td>9.80</td>
<td>9.98</td>
<td>-</td>
<td>V</td>
</tr>
<tr>
<td>Maximum Output Swing Voltage</td>
<td>V_{OM}</td>
<td></td>
<td>60</td>
<td>75</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>Common Mode Rejection Ratio</td>
<td>CMR</td>
<td></td>
<td>60</td>
<td>75</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>Supply Voltage Rejection Ratio</td>
<td>SVR</td>
<td></td>
<td>60</td>
<td>75</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>Operating Current/Circuit</td>
<td>I_O</td>
<td></td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>mA/Cir</td>
</tr>
<tr>
<td>Slew Rate</td>
<td>SR</td>
<td></td>
<td>-</td>
<td>3.5</td>
<td>-</td>
<td>V/µs</td>
</tr>
<tr>
<td>Unity Gain Bandwidth</td>
<td>F_U</td>
<td>A_{V}=40dB, C_{G}=10pF</td>
<td>-</td>
<td>1.5</td>
<td>-</td>
<td>MHz</td>
</tr>
</tbody>
</table>

Offset Adjustment Circuit (Only for NJU7031)
LTC6078 OP AMP

1. 2.7 to 5.5 Volt operation
2. Rail to Rail input and output voltages
3. Low Input bias ~ 1pA
4. Output Current ~5mA
5. Unity Gain Bandwidth ~350Khz
6. Power dissipation 54 uA at 3 V = 162uW
SOME BASIC DUAL SUPPLY OP AMP CIRCUITS

These dual supply 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

These dual supply circuits should be familiar:

**Inverting Summer**

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

**Difference Amplifier**

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

1. This is a DC and AC amplifier.
2. The input is referenced to the analog ground typically ½ of +V
3. The output voltage is referenced to the virtual ground or to earth ground.
4. If using a scope to measure Vo the scope ground is earth ground. If the Vin is ac you can AC couple the scope.
5. If the input Vin is DC you can measure the output relative to the analog ground using a multimeter (not the oscilloscope)
INVERTING AMPLIFIER EXAMPLES

Single Supply DC Inverting Amplifier

\[ V_o = -\frac{R_2}{R_1} V_{in} \]

Gnd1 is analog ground \(~1/2\) of supply voltage. Vout can be taken relative to Gnd1 or Gnd2 however there is a \(+V/2\) DC added to Vo if relative to Gnd2.
INVERTING AMPLIFIER EXAMPLES

The two 100K resistors create an analog ground \( \sim 1/2 \) V+
the gain = \(-R2/R1\), offset of \(V+\)/2 or virtual ground
SINGLE RESISTOR SENSOR AMPLIFIER DESIGN

Non-Inverting Amp
Gain = \( 1 + \frac{R3}{R4} \)
1. The two 20K resistors can be replaced by its Thevenin equivalent of $V/2$ and 10K
2. This sets up the analog ground at $V/2$ and the voltage gain to 11
3. $V_{in}$ is $V/2$ (or zero if referenced to analog ground) if the sensor is 10K
4. If the sensor is not exactly 10K then $V_o$ will have a value of $11 \times (V_{in} - (V/2))$
DC Amplifier (Single Supply)
R4, R3 are resistor sensors in half bridge
Gain ~ 1000 V/V
Supply Voltage 2.5V to 10V (or more)

Resistor changes by +/- 0.1 ohm and supply voltage sweeps from 3.5V to 5V
Noninverting Amplifier (Single Supply)

V1 represents a voltage input

Gain \( \approx (1+R2/R1) \) where \( R1 = R3//R4 \)

SINE(0.005 1 0 0 0 4)
.tran 0 4 0

Diagram of non-inverting amplifier with schematic and waveform diagrams.
SINGLE SUPPLY COMPARATOR

Vin → Op Amp → Vo

Vref

Theoretical

Vo

0

+V

+V

Vin
1. The R’s set up the threshold voltage at V/3 and 2V/3
2. Vout is either +V or Ground
SINGLE SUPPLY OSCILLATOR (MULTIVIBRATOR)

Let $R_1 = 100\, \text{K}$, $R_2 = R_3 = 100\, \text{K}$
and $+V = 3.3$

Then $V_{TH} = 2.2$ when $Vo = 3.3$

$V_{TL} = 1.1$ when $Vo = 0$
OP AMP COMPARATOR WITH HYSTERESIS

RC OSCILLATOR

C2 Represents Scope Probe
CAPACITANCE CHANGE TO VOLTAGE

\[ i = \frac{d}{dt}(CV) \]

\[ i = V \ C_m \ 2 \pi \ f \ \cos \ (2\pi ft) \]

\[ V_o = -2\pi f \ V R \ C_m \ \cos \ (2\pi ft) \]

Amplitude of \( V_o \)

\( C_0 = \) Average value of \( C \)

\( C_m = \) amplitude of \( C \) change

\( C = C_0 + C_m \ \sin \ (2\pi ft) \)

\( V \) is constant across \( C \)
**DUAL SUPPLY OP AMP ΔC TO VOLTAGE**

- `.step param freq list 500 2000 5000`
- `.tran 4ms`

**Op Amp Dual Supply Microphone Amp**

- LT1881
- C1: 50fF
- V3: SINE(0 15.7 {freq})
- R4: 1MEG
- Output

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SINGLE SUPPLY VERSION OF SIGNAL PROCESSING

\[
\begin{align*}
\text{Vdc} &= 9V \\
\text{100K} &\quad \text{100K} \\
\text{earth ground} &\quad \text{5.6 MEG}
\end{align*}
\]

TL081, TL081A, TL081B
D, JG, P, OR PW PACKAGE
(TOP VIEW)

OFFSET N1
IN- 1 8 NC
IN+ 2 7 \text{VCC+}
VCC- 4 5 OFFSET N2
OUT 3 6
SINGLE SUPPLY MICROPHONE AC TO VOLTAGE
The voltage across the diode is zero volts in the dark and the current is zero.

In the light I is 5μA (in direction shown, i.e. out of p-side).

What is Vout?
SIGNAL CONDITIONING FOR TEMPERATURE SENSOR

Commercial Diode Room Temp/ 79.0°C

\[ V_{out} \approx -2 \text{ mV/°C} \]

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

Resistors on a Diaphragm

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

No Pressure
Vo2 - Vo1 = 0
1. The $R_1=R_2=R_3=R_4$ make a Wheatstone bridge and are sensor resistors that will change in response to pressure.
2. $V_{o+}$ and $V_{o-}$ should be equal to each other and $\sim V_s/2$ with no pressure.
 SENSOR AND INTERNAL ELECTRONICS

- Sensor
- PTAT Temperature Reference
- MUX
- PREAMP (14 Bits)
- Calibration uC
- A
- D (12 Bits)
- Sensor Signal Conditioner
- MS45X5
- GND
- OUTPUT
- SUPPLY

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SUMMARY

Low voltage Op Amps are often used with a single supply.

Some circuits work just fine with single supply such as the comparator.

Other circuits use a virtual ground typically ½ of the supply voltage.

Since signal generators and oscilloscopes are referenced to earth ground. Op Amp circuits need to consider this if powered by a single supply referenced to earth ground. In that case earth ground and virtual ground are at different voltages.
REFERENCES

7. ICCAP Manual, Hewlet Packard
8. PSpice Users Guide.
9. Using Single Supply Operational Amplifiers – from Microchip
11. Designing Circuits for Single Supply Operation – from Linear Technology
12. Single Supply Design – from TI
1. Do SPICE analysis for a single op amp with dual supply to amplify the output for a single resistor sensor similar to that shown on page 18 (but with only one op amp).
2. If you want to measure a small value (0.1pF) slowly changing capacitance, what circuit could be used? Show it works using SPICE.
1. The $R_1=R_2=R_3=R_4$ make a Wheatstone bridge and are sensor resistors that will change in response to pressure.
2. $V_{o+}$ and $V_{o-}$ should be equal to each other and $\sim V_s/2$ with no pressure.