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THIS BOOK INCLUDES STANDARD APPLICATION CIRCUITS AND CIRCUITS DESIGNED BY THE AUTHOR. EACH CIRCUIT WAS ASSEMBLED AND TESTED BY THE AUTHOR AS THE BOOK WAS DEVELOPED. AFTER THE BOOK WAS COMPLETED, THE AUTHOR REASSEMBLED EACH CIRCUIT TO CHECK FOR ERRORS. WHILE REASONABLE CARE WAS EXERCISED IN THE PREPARATION OF THIS BOOK, VARIATIONS IN COMPONENT TOLERANCES AND CONSTRUCTION METHODS MAY CAUSE THE RESULTS YOU OBTAIN TO DIFFER FROM THOSE GIVEN HERE. THEREFORE, THE AUTHOR AND RADIO SHACK ASSUME NO RESPONSIBILITY FOR THE SUITABILITY OF THIS BOOK'S CONTENTS FOR ANY APPLICATION. SINE WE HAVE NO CONTROL OVER THE USE TO WHICH THE INFORMATION IN THIS BOOK IS PUT, WE ASSUME NO LIABILITY FOR ANY DAMAGES RESULTING FROM ITS USE. OF COURSE IT IS YOUR RESPONSIBILITY TO DETERMINE IF COMMERCIAL USE, SALE OR MANUFACTURE OF ANY DEVICE THAT INCORPORATES INFORMATION IN THIS BOOK INFRINGES ANY PATENTS, COPYRIGHTS OR OTHER RIGHTS.

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INTRODUCTION

The operational amplifier or op-amp is a high-performance linear amplifier with an amazing variety of uses. The op-amp has two inputs: inverting (+) and non-inverting (−), and one output. The polarity of a signal applied to the inverting input is reversed at the output. A signal applied to the non-inverting input retains its polarity at the output.

The gain (degree of amplification) of an op-amp is determined by a feedback resistor that feeds some of the amplified signal from the output to the inverting input. This reduces the amplitude of the output signal, hence the gain. The smaller the resistor, the lower the gain.

Here is a basic inverting amplifier made with an op-amp:

\[
\text{Gain} = \frac{R_F}{R_{\text{in}}}
\]

\[
V_{\text{out}} = -V_{\text{in}} \left(\frac{R_F}{R_{\text{in}}}\right)
\]

The gain is independent of the supply voltage. Note that the unused input is grounded. Therefore the op-amp amplifies the difference between the input \((V_{\text{in}})\) and ground \((0 \text{~V})\). The op-amp is then a differential amplifier.
THE FEEDBACK RESISTOR (Rf) AND AN
OP-AMP FORM A CLOSED FEEDBACK LOOP. WHEN
Rf IS OMITTED, THE OP-AMP IS SAID TO BE IN ITS
OPEN LOOP MODE. THE OP-AMP THEN EXHIBITS MAX-
IMUM GAIN, BUT ITS OUTPUT THEN SWINGS FROM
FULL ON TO FULL OFF OR VICE VERSA FOR VERY
SMALL CHANGES IN INPUT VOLTAGE. THEREFORE,
THE OPEN LOOP MODE IS NOT PRACTICAL FOR
LINEAR AMPLIFICATION. INSTEAD, THIS MODE IS
USED TO INDICATE WHEN THE VOLTAGE AT ONE
INPUT DIFFERS FROM THAT AT THE OTHER. IN
THIS MODE THE OP-AMP IS CALLED A COMPAR-
ATOR. SINCE IT COMPARES ONE INPUT VOLTAGE
WITH THE OTHER.

POWERING OP-AMPS

MOST OP-AMPS AND OP-AMP CIRCUITS REQUIRE
A DUAL POLARITY POWER SUPPLY. HERE IS A
SIMPLE DUAL POLARITY SUPPLY MADE FROM TWO
9-VOLT BATTERIES:

\[
\begin{align*}
+9 \text{ V} & \quad \vdash \quad -9 \text{ V} \\
\vdash & \quad \vdash
\end{align*}
\]

GROUND

IMPORTANT: THE LEADS FROM THE SUPPLY TO THE
OP-AMP SHOULD BE SHORT AND DIRECT. IF THEY
EXCEED ABOUT 6 INCHES, THE OP-AMP'S
SUPPLY PIN MUST BE BYPASSED BY CONNECT-
ING A 0.1 \mu F CAPACITOR BETWEEN EACH
POWER SUPPLY PIN AND GROUND. OTHERWISE,
THE OP-AMP MAY OSCILLATE OR FAIL TO
OPERATE PROPERLY. ALWAYS USE FRESH BATTERIES.
BOTH MUST SUPPLY THE SAME VOLTAGE. BE
SURE THE BATTERY CLIPS ARE CLEAN AND
TIGHT. NEVER APPLY AN INPUT SIGNAL WHEN THE
POWER SUPPLY IS SWITCHED OFF.

OP-AMP SPECIFICATIONS

OP-AMPS ARE CHARACTERIZED BY DOZENS OF
SPECIFICATIONS, SOME OF WHICH ARE GIVEN
ON THE FOLLOWING PAGES. THOSE WHOSE
MEANING IS NOT OBVIOUS ARE:

INPUT OFFSET VOLTAGE - EVEN WITH NO INPUT
VOLTAGE, AN OP-AMP GIVES A VERY SMALL
OUTPUT VOLTAGE. THE OFFSET VOLTAGE IS THAT
VOLTAGE WHICH, WHEN APPLIED TO ONE INPUT,
CAUSES THE OUTPUT TO BE AT 0 VOLTS.

COMMON MODE REJECTION RATIO - THIS IS A
MEASURE OF THE ABILITY OF AN OP-AMP TO
REJECT A SIGNAL SIMULTANEOUSLY APPLIED
TO BOTH INPUTS.

BANDWIDTH - THE FREQUENCY RANGE OVER WHICH
AN OP-AMP WILL FUNCTION. THE FREQUENCY
AT WHICH THE GAIN FALLS TO 1 IS THE
UNITY GAIN FREQUENCY.

SLEW RATE - THE RATE OF CHANGE IN THE
OUTPUT OF AN OP-AMP IN VOLTS PER
MICROSECOND WHEN THE GAIN IS 1.

CIRCUIT ASSEMBLY TIPS

YOU CAN USUALLY SUBSTITUTE DIFFERENT
OP-AMPS IN A CIRCUIT. FOR EXAMPLE, USE
A 1458 DUAL OP-AMP IN A CIRCUIT THAT
REQUIRES TWO 741 OP-AMPS. BE SURE TO
KEEP TRACK OF PIN DIFFERENCES. FOR
VERY HIGH INPUT RESISTANCE AND LOW
OPERATING CURRENT, USE CHNOS. OP-AMPS.
USE A HIGH-IMPEDEANCE VOLTMETER TO
MONITOR THE OUTPUT OF AN OP-AMP THAT
IS AMPLIFYING A D.C. VOLTAGE. IF A CIRCUIT
FAILS TO WORK, REMOVE INPUT SIGNAL FIRST.
THEN DISCONNECT POWER AND CHECK THE
WIRING. USE FRESH BATTERIES.
741 OP-AMP

The 741 is a highly popular general purpose op-amp. It is simple to use, reliable, and inexpensive. It is used in most circuits in this book.

MAXIMUM RATINGS

Supply Voltage ±18 V
Power Dissipation 500 mW
Differential Input Voltage ±5 V
Input Voltage (Note 1) ±1.5 V
Output Short Circuit Time Indefinite
Operating Temperature 0°C to 70°C

Note 1: Input voltage should not exceed supply voltage when supply voltage is less than ±15 V.

CHARACTERISTICS (Note 2)

Input Offset Voltage 2 to 6 mV
Input Resistance 1.3 to 2 MΩ
Voltage Gain 20,000 to 200,000
Common-Mode Rejection Ratio 70 to 90 dB
Bandwidth 1.5 to 1.5 MHz
Slew Rate 1.5 V/μs
Supply Current 1.7 to 2.8 mA
Power Consumption 50 to 85 mW

Note 2: Values shown are typical or minimum to typical.

1458 DUAL OP-AMP

The 1458 includes two independent, out general purpose op-amps in a single package. The amplifiers share common power supply pins. Use to replace two 741 op-amps.

MAXIMUM RATINGS

Supply Voltage ±18 V
Power Dissipation 400 mW
Differential Input Voltage ±50 V
Input Voltage (Note 1) ±15 V
Output Short Circuit Time Indefinite
Operating Temperature 0°C to 70°C

Note 1: Input voltage should not exceed supply voltage when supply voltage is less than ±15 V.

CHARACTERISTICS (Note 2)

Input Offset Voltage 1 to 6 mV
Input Resistance 1.3 to 2 MΩ
Voltage Gain 20,000 to 100,000
Common-Mode Rejection Ratio 70 to 90 dB
Supply Current (Note 3) 3 to 5.4 mA
Power Consumption 85 mW

Note 2: Values shown are typical or minimum to typical.

Note 3: Both amplifiers.
339 QUAD COMPARATOR

THE 339 CONTAINS FOUR INDEPENDENT COMPARATORS, MAKING IT AN ECONOMICAL APPROACH TO COMPARATOR CIRCUITS. IT OPERATES FROM A SINGLE POLARITY POWER SUPPLY.

MAXIMUM RATINGS

SUPPLY VOLTAGE +36 V OR ±18 V
POWER DISSIPATION 570 mW
DIFFERENTIAL INPUT VOLTAGE 36 V
INPUT VOLTAGE ±3 V TO +36 V
OUTPUT SHORT CIRCUIT (NOTE 1) CONTINUOUS OPERATING TEMPERATURE 0°C TO 70°C

NOTE 1: OK TO SHORT OUTPUT TO GROUND. DO NOT SHORT OUTPUT TO +V SINCE CHIP WILL OVERHEAT.

CHARACTERISTICS (NOTE 2)

INPUT OFFSET VOLTAGE ±3 TO ±20 mV
VOLTAGE GAIN 2,000 TO 30,000
SUPPLY CURRENT 18 TO 2 mA
OUTPUT SINK CURRENT 1/2 TO 16 mA

NOTE 2: VALUES SHOWN ARE MINIMUM TO TYPICAL, 10

386 AUDIO AMPLIFIER

SIMPLE TO USE AUDIO AMPLIFIER WITH GAIN OF 20 OPERATES FROM SINGLE POLARITY SUPPLY. CONNECT 10 μF CAPACITOR BETWEEN GND AND 3 FOR GAIN OF 200.

MAXIMUM RATINGS

SUPPLY VOLTAGE +15 V
POWER DISSIPATION 660 mW
INPUT VOLTAGE ±0.4 V
OPERATING TEMPERATURE 0°C TO 70°C

CHARACTERISTICS

SUPPLY VOLTAGE RANGE ±4 TO ±12 V
STANDBY CURRENT 14 TO 8 mA
OUTPUT POWER 2.5 TO 325 mW
VOLTAGE GAIN 10 TO 200
BANDWIDTH 300 kHz
TOTAL HARMONIC DISTORTION 0.2 %
INPUT RESISTANCE 50 kΩ

TYPICAL APPLICATION

GAIN = 20

IN + V 10K SPKR
1K

VOLUME CONTROL

8.0
**BASIC INVERTING AMPLIFIER**

\[ V = \pm 3 \text{ TO } \pm 15 \text{ V} \]

- **IN**
- **R1**
- **R2**
- **R3**

Input is inverted at output.

\[ \text{Gain} = -(R_2 / R_1) \]

\[ R_3 = (R_1 R_2) / (R_1 + R_2) \]

**EXAMPLE:** If \( R_1 = 1000 \text{ ohms} \) and \( R_2 = 10,000 \text{ ohms} \), then gain is \(-(10,000/1000)\) or \(-10\).

This is one of the most common op-amp circuits. For a non-inverted output, use the amplifier on the facing page.

**UNITY-GAIN INVERTER**

\[ R_1 = 1\text{K} \]

\[ V_{IN} \text{ TO } +V \text{ R}_2 \]

\[ V_{OUT} = -V_{IN} \]

**NON-INVERTING AMPLIFIER**

\[ V = \pm 3 \text{ TO } \pm 15 \text{ V} \]

- **IN**
- **R1**
- **R2**

\[ \text{Gain} = 1 + (R_2 / R_1) \]

**EXAMPLE:** If \( R_1 = 1000 \text{ ohms} \) and \( R_2 = 10,000 \text{ ohms} \), then gain is \(1 + (10,000/1,000)\) or \(11\). Note that \( V_{OUT} \) is an amplified but not inverted version of \( V_{IN} \).

**UNITY-GAIN FOLLOWER**

\[ V = \pm 3 \text{ TO } \pm 15 \text{ V} \]

- **IN**
- **Vout**

Use to buffer signal from another circuit.

\[ V_{OUT} = V_{IN} \]
**Transconductance Amplifier**

\[ V_{in} \text{ to } +15V \]

\[ I_{out} = \text{Current Through Load} \]

\[ V_{out} = \frac{V_{in} \cdot (R_1 + R_2)}{R_2} \]

\[ I_{out} = \frac{V_{out}}{R_1} \]

\[ I_{out} = \frac{V_{in}}{R_2} \]

This circuit is a voltage-to-current converter. Here's how it permits an input voltage to control the brightness of an LED:

**Transimpedance Amplifier**

\[ V_{in} \text{ to } +15V \]

\[ R_1 \]

\[ i_{in} \]

\[ V_{out} \]

\[ \text{Gain} = \frac{V_{out}}{i_{in}} \]

\[ \text{Gain} = -R_1 \]

Example: If \( R_1 = 1000 \text{ ohms} \), then \( \text{Gain} = -1000 \).

This circuit is a current-to-voltage converter. Here's how it transforms the current generated by a solar cell into an output voltage:

Silicon Solar Cell

\[ +9V \]

\[ -9V \]

\[ R_1 \]

\[ 1M \]

\[ V_{out} \]

Use \( R_1 \) to vary the circuit's gain.

This circuit can amplify the signal from non-current generators like thermistors and photoreceivers. Connect one side of the device to +9V and the other to pin 2, ground pin 3.
SINGLE-SUPPLY AMPLIFIER

\[ V_{out} = -\left(\frac{R_2}{R_1}\right) \]

\[ +5 \text{ to } +15 \text{ V} \]

\[ V_{in} \]

\[ C_1, 1 \mu F \]

\[ R_1, 1 \text{ kΩ} \]

\[ R_2, 100 \text{ kΩ} \]

\[ C_2, 0.47 \mu F \]

\[ R_3, 47 \text{ kΩ} \]

\[ R_4, 47 \text{ kΩ} \]

\[ R_4 \]

\[ R_2 \]

\[ \text{This point is } \frac{1}{2} +V. \]

\[ V_{out} \]

This is an inverting amplifier designed to operate from a single-polarity supply. With the values for \( R_1 \) and \( R_2 \) given above, the gain is 100. Capacitors \( C_1 \) and \( C_2 \) must be used. Therefore, this circuit will amplify a fluctuating AC signal but not a DC signal.

\( C_1 \) should be approximately \( \frac{1}{(2 \pi f \text{ and } R_1)} \). (\( f_0 \) is the low frequency cutoff or 300 Hz for the circuit above.) \( C_2 \) should be approximately \( \frac{1}{(2 \pi f \text{ and } R_4)} \). (\( R_4 \) is the load resistance.)

The output from a dual-supply op-amp can fluctuate above and below ground (0 volts). Here, the divider formed by \( R_3 \) and \( R_4 \) sets \( V_{out} \) at \( \frac{1}{2} +V \). The output then fluctuates above and below \( \frac{1}{2} +V \) like this:

\[ +V \]

\[ 0 \text{ V} \]

\[ \frac{1}{2} +V \]

\[ V_{out} \text{ signal} \]

Audio Amplifier

\[ +9 \text{ V} \]

\[ V_{in} \]

\[ C_1, 1 \mu F \]

\[ R_1, 1 \text{ kΩ} \]

\[ R_2, 100 \text{ kΩ} \]

\[ R_3, 1 \text{ kΩ} \]

\[ R_4, 1 \text{ kΩ} \]

\[ \text{Rf} \]

\[ \text{8 Ohm speaker} \]

The \( \text{741} \) is a preamplifier. \( R_2 \) controls its gain. The \( 386 \) is a power amplifier. \( R_3 \) controls the volume of the speaker. Ok to use fixed 10k resistor for \( R_2 \). (Reduce resistance of \( R_2 \) if circuit oscillates or gives distorted output.) Important: bypass the power supply connections with 0.1 \( \mu F \) capacitors.

Audio Mixer

\[ \text{OK to use with amplifier above.} \]

\[ \text{IN 1, 2, 3} \]

\[ +9 \text{ V} \]

\[ \text{Output} \]

\[ \text{IN 1, 2, 3} \]

\[ \text{10k} \]

\[ \text{Output} \]

\[ -9 \text{ V} \]

\[ \text{Use with multiple microphones.} \]
**SUMMING AMPLIFIER**

\[ V_{out} = -(V_{in1} + V_{in2}) \]

**TEST RESULT:**
- \( V_{in1} = +4.0\, V \)
- \( V_{in2} = +1.8\, V \)
- \( V_{out} = -4.8\, V \)

The output of the summing amplifier is the sum of the input voltages. The sum of the inputs should not exceed \( \pm 5\, V \). Less than two OK to add more inputs. (Use 10k resistor to pin 2 for each input.) The circuit below preserves the polarity of \( V_{in1} \):

\[ V_{out} = V_{in1} + V_{in2} \]

**DIFFERENCE AMPLIFIER**

\[ V_{out} = V_{in2} - V_{in1} \]

**TEST RESULT:**
- \( V_{in1} = 0.9\, V \)
- \( V_{in2} = 5.0\, V \)
- \( V_{out} = 4.1\, V \)

The output of the difference amplifier is \( V_{in2} - V_{in1} \). The input voltages should not exceed \( \pm 5\, V \). The circuit below reverses the polarity of \( V_{in2} - V_{in1} \):

\[ V_{out} = -(V_{in2} - V_{in1}) \]
DUAL-SUPPLY INTEGRATOR

The output of the integrator is proportional to amplitude of input times duration of input. Use to make triangle waves, for low-pass filter, etc.

\[ R_3 = \frac{R_1 \times R_2}{R_1 + R_2} \]

\[ f = \frac{1}{(R_1 \times C_1)} \]

For values shown and \( f = 2,000 \text{ Hz} \), \( \pm 2.5 \text{ V} \) square wave, the output is \( \pm 1.3 \text{ V} \) triangle.

\[ V = \pm 5 \text{ V to } \pm 15 \text{ V} \]

SINGLE-SUPPLY INTEGRATOR

\[ R_3 = \frac{1}{10k} \]

\[ f = \frac{1}{(R_1 \times C_1)} \]

For values shown and \( f = 2,000 \text{ Hz} \), \( \pm 2.5 \text{ V} \) square wave, the output is \( \pm 1.3 \text{ V} \) triangle.

\[ V = \pm 5 \text{ V to } \pm 15 \text{ V} \]

DUAL-SUPPLY DIFFERENTIATOR

The output of the differentiator is proportional to the derivative of the input.

\[ V = \pm 5 \text{ V to } \pm 15 \text{ V} \]

\[ f = \frac{1}{R_2 C_2} \]

For values shown and \( f = 2,000 \text{ Hz} \), \( \pm 2.5 \text{ V} \) triangle wave, the output is \( \pm 10 \text{ V} \) square wave.

\[ V = \pm 5 \text{ V to } \pm 15 \text{ V} \]

SINGLE-SUPPLY DIFFERENTIATOR

\[ R_4 = 10k \]

\[ V = \pm 5 \text{ V to } \pm 15 \text{ V} \]

\[ f = \frac{1}{R_2 C_2} \]

For values shown and \( f = 2,000 \text{ Hz} \), \( \pm 2.5 \text{ V} \) square wave, the output is \( \pm 2 \text{ V} \) square wave.
PEAK DETECTOR

This circuit follows an incoming voltage signal and stores the maximum voltage in C1. Press S1 to discharge C1 and reset circuit. Connect a voltmeter from output to ground to measure the peak voltage stored in C1. The circuit functions like this:

THE CIRCUIT IS A VOLTAGE FOLLOWER THAT BUFFERS C1 FROM THE OUTPUT.

INVERTING CLIPPER

V = ±5 TO ±15 V

D1 AND D2 ARE ZENER DIODES. THEIR BREAKDOWN VOLTAGE IS WHAT DETERMINES THE CLIPPING LEVEL.

Non-Inverting Clipper

V = ±5 TO ±15 V

D1 = D2 = 5 V

Gain = 1 + R2/R1

VALUES SHOWN GIVE x11 GAIN.
**Bistable RS Flip-Flop**

V = 3.5 V to 16 V Volts

- R3 10k
- R1 4.7k
- R2 4.7k
- R7 1k
- R9 1k
- R8 1k
- Q1 2N2212
- Q2 2N2212

D1 and D2 are optional 5.1V Zener diodes. See below. 1N4148.

**Monostable Multivibrator**

- CL 1nF
- V = 3.5 V to 16 V

A negative trigger pulse causes the op-amp output to swing from low to high for a time approximately equal to R2 * C2. Use to divide an incoming signal and to convert an irregular input pulse to a uniform output pulse. Typical results:

<table>
<thead>
<tr>
<th>TRIGGER PULSES</th>
<th>V = ±9 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5</td>
<td>+5.5</td>
</tr>
<tr>
<td>0</td>
<td>+1.5</td>
</tr>
<tr>
<td>+5</td>
<td>+1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DIVIDE-BY-1</th>
<th>C2 = 0.1µF</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTPUT</td>
<td>R2 = 25 k</td>
</tr>
<tr>
<td>0</td>
<td>7.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DIVIDE-BY-2</th>
<th>C1 = 0.1µF</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTPUT</td>
<td>R2 = 10 k</td>
</tr>
<tr>
<td>0</td>
<td>7.5</td>
</tr>
</tbody>
</table>

NOTE: USE THE 555 FOR MORE VERSATILITY.

**Input LED Truth Table**

<table>
<thead>
<tr>
<th>INPUT</th>
<th>LED</th>
<th>THESE OUTPUTS HAVE MEMORY AND HOLD THEIR STATE EVEN WHEN S INPUT FLOATS.</th>
<th>USB D1 AND D2 TO LIMIT OUTPUT LEVEL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GND +V</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GND -V</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+V GND</td>
<td>ON</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-V GND</td>
<td>OFF</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

24
A comparator is an analog circuit that monitors two input voltages, one voltage is called the reference voltage \( V_{REF} \) and the other is called the input voltage \( V_{IN} \). When \( V_{IN} \) rises above or falls below \( V_{REF} \), the output of the comparator changes states. Some circuits (like the 339) are designed specifically as comparators. Due to its very high open-loop gain, an op-amp without a feedback resistor can function as a comparator.

**Non-Inverting Comparator**

When \( V_{IN} \) exceeds \( V_{REF} \), output switches from low to high.

**Inverting Comparator**

When \( V_{IN} \) exceeds \( V_{REF} \), output switches from high to low.

Build this simple circuit on a plastic breadboard to learn basics of the comparator. \( R_1 \) and \( R_2 \) function as voltage dividers that supply a range of voltages to both 741 inputs. \( Q_1 \) switches current to the LED when the output of the 741 goes high. The circuit works like this:

Assume \( R_2 \) is set to its center position to give \( V_{REF} = 4.5 \text{ volts} \) \((9 \text{ volts} / 2 = 4.5 \text{ volts})\). \( R_1 \) then controls \( V_{IN} \).

When \( V_{IN} = 1.9 \text{ volts} \),

\[ V_{OUT} = 8.2 \text{ volts} \]

When \( V_{REF} = 4.5 \text{ volts} \),

\[ V_{OUT} = 1.9 \text{ volts} \]
BASIC WINDOW COMPARATOR

Vref (HIGH) 2.5 to 1.5 V

Vref (LOW) 0.2 V

This is among the most versatile of comparator circuits. Assume Vref (HIGH) is 5.5 volts and Vref (LOW) is 2.5 volts. Circuit then operates like this:

BUILD THIS CIRCUIT ON A BREADBOARD TO LEARN BASICS OF THE WINDOW COMPARATOR. USE VOLTOMETER TO SET VREF HIGH (R1) AND VREF LOW (R3). CONNECT PROBES ACROSS PIN 2 OF 1458 AND GROUND; ADJUST R1. REPEAT FOR PIN 5 AND GROUND; ADJUST R3. ADJUST R2 TO VARY VIN.

VIN AT OR ABOVE VREF HIGH: LED 1 ON
VIN WITHIN WINDOW: LED 2 ON
VIN AT OR BELOW VREF LOW: LED 3 ON

WHEN VIN IS BELOW 0.6 Volt, BOTH LED 1 AND LED 3 SWITCH ON.
3-STEP SEQUENCER

PRESS S1 +9V USE TO START AN AUTOMATIC 3-STEP SEQUENCE

OK TO DRIVE EXTERNAL CIRCUIT.

OUTPUT L = 0 DELAY IN SECONDS

THIS IS A WINDOW COMPARATOR THAT SUPPLIES A 3-STEP SEQUENCE OF OUTPUT SIGNALS. PRESSING S1 DISCHARGES C1 AND LIGHTS LED 1 (AND LED 2 BRIEFLY). C1 THEN CHARGES THROUGH R4. AS CHARGE ON C1 PASSES 3V AND 6V, LEDS 2 AND 3 GLOW IN SEQUENCE. REDUCE R2 TO BALANCE TIME DELAY SEQUENCE AND REDUCE DELAY TIME. DELAYS SHOWN WILL VARY WITH TOLERANCE OF C1.

BARGRAPH VOLTMETER

R1 CONTROLS SENSITIVITY. OK TO USE 741 OP-AMPS.

LEDs GLOW IN SEQUENCE AS INPUT VOLTAGE RISES. LEDs ALSO RESPOND TO CHANGE IN RESISTANCE AT INPUT. TOUCH INPUTS WITH FINGER TO OBSERVE. CONNECT CdS CELL ACROSS INPUTS TO MAKE LIGHTMETER.
LIGHT-ACTIVATED RELAYS

PHOTOTRANSISTOR:

ILLUMINATE Q1 TO ACTIVATE RELAY.

PHOTORESISTOR:

ILLUMINATE CDS CELL TO ACTIVATE RELAY.

R 100K
R 1M
R3 5K
R2 1K
R4 4.7K
R1 10K
R2 10K
R3 10K
R4 10K

RELAY (RADIO SHACK 275-004)

BUZZER EMITS TONE WHEN PHOTOCELL IS ILLUMINATED. R2 CONTROLS SENSITIVITY. R4 KEEPS Q1 OFF UNTIL THE 741 OUTPUT GOES HIGH. USE AS SUN-ACTIVATED WAKEUP ALARM AND OPEN REFRIGERATOR DOOR ALARM.

DARK-ACTIVATED ALERTER

IDENTICAL TO ABOVE CIRCUIT EXCEPT INPUTS TO 741 REVERSED. OK TO REPLACE PIEZO BUZZER WITH RELAY (NO. 275-004).
LIGHT-SENSITIVE OSCILLATORS

- Cds Photocell
- Frequency increases as light level at Cds cell rises.
- OK to connect to speaker amplifier.

- Cds 1
- Illuminate Cds 1 to increase time frequency and Cds 2 to reduce.
- Adjust Rs for balance. Rs in k.
- Piezo speaker.

HIGH-SENSITIVITY LIGHT METER

- Caution: This circuit is very sensitive. Too much light will "slam" the needle of an analog meter.

- Full-scale meter readings:
  - 0-10 mA
  - 0-1 mA
  - 0-0.1 mA

- Silicon solar cell

- This circuit is based upon those used in some precision, laboratory-quality light meters. To zero meter, connect pin 2 to ground and adjust offset (Rs) until meter reads 0. Then disconnect pin 2 from ground. Rs is an optional control for altering sensitivity of the circuit.
**SOUND-LEVEL METER**

![Circuit Diagram for Sound-Level Meter]

*Microphone (Radio Shack 270-092 or similar).*

This simple circuit is an effective sound-level meter. R1 controls the gain of the 741 op-amp, hence the sensitivity of the circuit. The meter can be a panel meter or a multimeter set to read current. The circuit was tested with a piezo buzzer that emitted a 4.5-kHz tone at a sound pressure of 90 dB. When the buzzer was 2" from the microphone and R1 was set for maximum gain, the meter indicated 1 mA. At 12" the output fell to 0.4 mA. Normal speech at 12" gave fluctuating signal up to 10 μA.

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**SOUND-ACTIVATED RELAY**

![Circuit Diagram for Sound-ACTivated Relay]

*Microphone (Radio Shack 270-092 or similar).*

This circuit trips relay in response to loud sound (voice, clap, etc.). R5 and C3 control time relay stays pulled in (values shown give 12 seconds). Important: Use 0.1μF capacitor across power supply pins of both the 741 and 555, reduce resistance of R3 to reduce sensitivity.

37
PIEZO ELEMENT DRIVERS

GATED:

V= +9.5 to 12 volts

PIEZO ELEMENT

HIGH

R2 4.7K

R3 100K

LOW

R1 4.7K

R4 22K

HIGH = TONE OFF
LOW = TONE ON

THIS CIRCUIT IS AN ASTABLE MULTIVIBRATOR IN WHICH A PIEZO ELEMENT DURABLES AS THE TIMING CAPACITOR AND THE TONE SOURCE. TRIGGER THE TONE SIGNAL OR BY CONNECTING SWITCH FROM INPUT TO GROUND.

VARIABLE FREQUENCY

V= +3 to +15 volts

R1 4.7K

R3 1M

ADJUST R3 TO ALTER FREQUENCY OF TONE FROM PIEZO ELEMENT.

PERCUSSION SYNTHESIZER

THIS CIRCUIT PRODUCES A SERIES OF PERCUSSION SOUNDS AT A RATE CONTROLLED BY RL BELLS AND DRUM SOUNDS CAN BE PRODUCED.

FOR MANUAL CONTROL REMOVE R1 FROM PIN 1 AND PLACE SWITCH FROM R7 TO GROUND.

R8 100K

R9 1K

R5 CONTROLS VOLUME.

CAUTION: PROTECT YOUR EARS BY KEEPING SOUND LEVEL LOW.

TO OPERATE, SET R1, R2 AND R3 TO CENTER POSITIONS. THEN ADJUST R1 UNTIL 2 OR 3 CLICKS PER SECOND ARE Emitted BY THE SPEAKER. NOW ADJUST R3 UNTIL SPEAKER EMITS A TONE. BACK OFF UNTIL TONE JUST STOPS. R1 AND R4 CONTROL PITCH.

3B
LOW-PASS FILTER

\[ V = \pm 5 \text{ TO } \pm 15 \text{ VOLTS} \]

\[ R_1 = R_2 = R \]
\[ C_1 = C_2 = C \]

CUT-OFF FREQUENCY \( f_c \)
15 x 0.707 TIMES MAXIMUM OUTPUT.

\[ f_c = \frac{1}{2\pi RC} \]

GAIN = \( R_4 / R_3 \) (ABOUT 1.59).

\[ R_2 = 4.700 \Omega \]
\[ C = 0.1 \mu F \]
\[ \text{CALCULATED } f_c = 3,386 \text{ Hz} \]
\[ \text{MEASURED } f_c = 3,000 \text{ Hz} \]

OUT-PUT (VOLTS)

FREQUENCY (KHz)

40

HIGH-PASS FILTER

\[ V = \pm 5 \text{ TO } \pm 15 \text{ VOLTS} \]

\[ R_1 = R_2 = R \]
\[ C_1 = C_2 = C \]

CUT-OFF FREQUENCY
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\[ \text{CALCULATED } f_c = 3,386 \text{ Hz} \]
\[ \text{MEASURED } f_c = 3,000 \text{ Hz} \]

OUT-PUT (VOLTS)

FREQUENCY (KHz)

41
60-Hz Notch Filter

Wien Bridge

Tunable Bandpass Filter

Twin Tee

Use these filters to block power line hum.

Graph shows results for test versions of both filters. Input was 1-volt peak-to-peak sine wave, 60 Hz.

This filter can be tuned by R2 to pass a narrow frequency band between a few hundred Hz and about 3,000 Hz. Use to detect presence of a tone in a signal. Actual response to a 1-volt sine wave:

Output (volts)

Frequency (Hz)
MINI-COLOR ORGAN

This array of active filters will convert the audio signal from a small radio or tape player into a flickering pattern of colors. R2 controls gain of the input amplifier below. Use radio/tape player volume control and R2 to adjust intensity of LEDs.

H±Z INPUT FROM OUTPUT STAGE (VR)
LOW INPUT FROM B.I.L. PHONE JACK, T1 BLUE

*Insert phone plug connected to T1 part way in phone jack so speaker will not be switched off.

LEDs vary in brightness. Experiment with different LEDs for best results. Here is actual response of circuit:

LED BRIGHTNESS (%)
0 10 100 1,000 10,000
YELLOW, RED (LOW) (MID) GREEN (HIGH)

FREQUENCY (Hz)

MINI-COLOR ORGAN (CONT.)

Good project for advanced experimenters.

R4 4.7K 1µF 1µF
R5 210K
R6 2K
R7 1µF
R8 10K
R9 1K
R10 68K
R11 10K
C1 1µF
C2 1µF
C3 1µF
C4 1µF
C5 1µF
C6 1µF

LED RED
LED GREEN
LED YELLOW
LED MID
LED HIGH

Reduce R4 and R7 to increase red and yellow brightness. Increase R11 to increase green brightness.
SQUARE WAVE GENERATOR

This circuit is an easily adjustable square wave generator. The timing components are C1, R4, R5, R6, and R7. R1-R2-R3 control the duration (or "width") of the pulses. The pulses are symmetrical when R2 is at its center position. OK to connect R2 directly to +V and GND, thereby eliminating R1 and R3. Typical results:

<table>
<thead>
<tr>
<th>C1 (µF)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.001</td>
<td>114.80</td>
</tr>
<tr>
<td>.047</td>
<td>2.81</td>
</tr>
<tr>
<td>.01</td>
<td>1.15</td>
</tr>
<tr>
<td>.01</td>
<td>4.42</td>
</tr>
<tr>
<td>.01</td>
<td>2.27</td>
</tr>
<tr>
<td>.01</td>
<td>4.42</td>
</tr>
<tr>
<td>.01</td>
<td>2.27</td>
</tr>
</tbody>
</table>

R3 = R7 = 22K, and R4 = R5 = 10K; +V = 12V.

OK to add follower stage to buffer output.

SINE WAVE OSCILLATOR

R1 = R2 = 1K
R3 = 10K
C1 = C2 = C3 = C4 = 0.01 µF

See below.

R2 = R3 = R4
C1 = C2

Adjust R5 until circuit oscillates.

R3, R4, R5, C1, C2, C3, and C4 form a twin-tee filter. When connected in the feedback loop of an op-amp, the resulting circuit generates a sine wave. The frequency is 1/(2πRQ).

Typical results:

<table>
<thead>
<tr>
<th>R3 (K)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7</td>
<td>2924</td>
</tr>
<tr>
<td>10</td>
<td>1354</td>
</tr>
<tr>
<td>15</td>
<td>927</td>
</tr>
</tbody>
</table>

Circuit:
FUNCTION GENERATOR

CIRCUIT AS SHOWN OPERATES AT 1 KHz.
USE 1M POT FOR R9 TO VARY THE RATE.
INCREASE C3 FOR SLOWER RATE.

RESISTOR COLOR CODE

- BLACK 0 0 x 1
- BROWN 1 1 x 10
- RED 2 2 x 100
- ORANGE 3 3 x 1,000
- YELLOW 4 4 x 10,000
- GREEN 5 5 x 100,000
- BLUE 6 6 x 1,000,000
- VIOLET 7 7 x 10,000,000
- GRAY 8 8 x 100,000,000
- WHITE 9 9

FOURTH BAND INDICATES TOLERANCE (ACCURACY):
GOLD = ±5%  SILVER = ±10%  NONE = ±20%

OHM'S LAW: \( V = IR \)  \( R = \frac{V}{I} \)  \( I = \frac{V}{R} \)  \( P = VI = I^2R \)

ABBREVIATIONS

A - AMPERE  R - RESISTANCE
F - FARAD  V (or E) - VOLT
I - CURRENT  W - WATT
P - POWER  \( \Omega \) - OHM

M (MEG-\(-\)) = \( \times 1,000,000 \)
K (KIL-\(-\)) = \( \times 1,000 \)
\( m \) (MILLI-\(-\)) = \( \times 0.001 \)
\( \mu \) (MICRO-\(-\)) = \( \times 0.000001 \)
\( n \) (NANO-\(-\)) = \( \times 0.000000001 \)
\( p \) (PICO-\(-\)) = \( \times 0.000000000001 \)