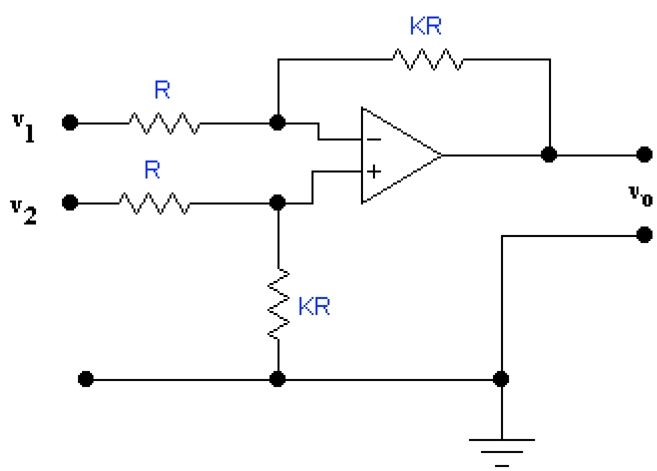
Physics 214 **INTRODUCTION TO LABORATORY ELECTRONICS** **Lecture 13**

Topics: Difference Amplifiers and Comparators
Text: Bugg, Sections 7.6, 7.7, 19.5, 21.1

A Difference Amplifier measures the difference between two sources in the presence of a potentially large common voltage signal. The large signal could be a DC offset or large noise.

A typical application is the measurement of temperature using a thermocouple. The thermocouple relies on the thermoelectric effect: two dissimilar metals in contact have a potential between them roughly proportional to the temperature of the point of contact (or junction). eg Fe/Constantan develops a potential of 70 V/^{o}C. Measuring the difference in potential gives a measure of the temperature.

An op-amp difference amplifier circuit looks like:



$v_o = K(v_2 - v_1)$

First consider the non-inverting input by setting v_1 at ground:

$$v_o = \frac{KR}{KR+R} v_2 \times \frac{R+KR}{R} = K v_2$$

(first term is voltage divider at non-inverting input. second term is 1/B feedback factor for a non-inverting op-amp)

Next consider the inverting input by setting v_2 at ground:

$$v_o = \frac{-KR}{R} v_1 = -K v_1$$

So: $v_o = K(v_2 - v_1)$

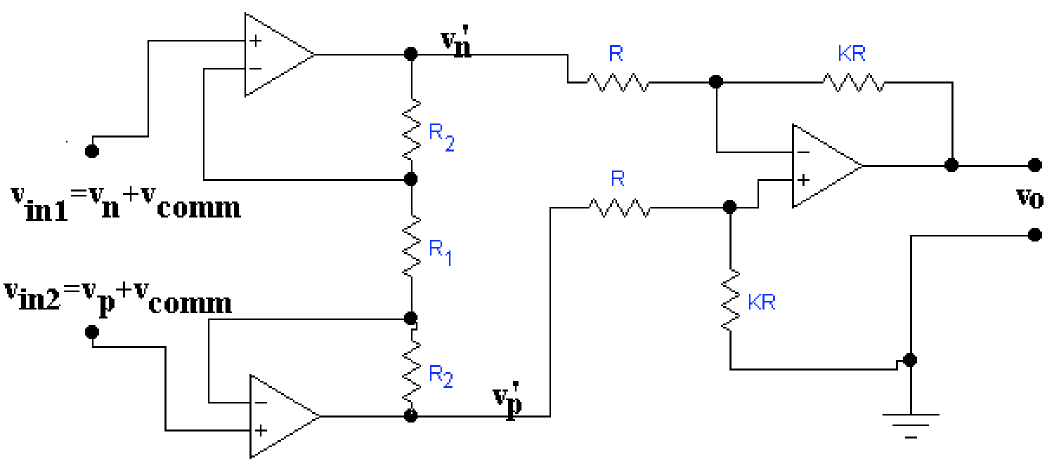
A difference amplifier should have good 'common-mode rejection':

Common-mode: if some voltage is applied to both inputs of the difference amplifier, ideally the output is zero. In practice, small differences in the transistors on the two sides of the input produce an output which depends on v_1+v_2 so :
$v_o = G_{diff}(v_2 - v_1) + G_{com}(v_2 + v_1)/2$.
It is desirable to reject the common-mode gain. Amplifiers are characterized in terms of a ***common-mode rejection ratio (CMRR)=*** $\boldsymbol{G_{diff}/G_{com}}$
We want this to be high. Usually quoted as dB= 20log($\boldsymbol{G_{diff}/G_{com}}$).

A very useful design which gives high CMMR is the three op-amp '***instrumentation amplifier***' : This is a high-gain DC coupled amplifier with

1. single ended output
2. high input impedance
3. high CMRR

Used to amplify small differential signals from transducers where there could be a large common-mode signal. Here the signal we want to amplify is (v_p-v_n). But the v_p and v_n signals have a common-mode noise term, v_{comm}, added to them, so the inputs the amplifier actually sees is v_p+v_{comm} and v_n+v_{comm}.



The output stage is just the normal difference amplifier:
$v_o=K(v_p' - v_n')$

Now we need to know the relation connecting v_{in1} and v_{in2} and v_p' and v_n'. First consider the input stage to the inverting input of the output stage, v_n'. To determine the relation connecting v_n' and v_{in1} and v_{in2}, first ground v_{in2}, determine v_n' then ground v_{in1} and determine v_n', then use: $v_n'=v_n'(v_{in1}=0) + v_n'(v_{in2}=0)$.
If $v_{in2}=0$, then there is a virtual ground at the inverting input of the lower input-stage OPAMP and $v_n' = (R_1+R_2)/R_1\ v_{in1}$ as with a conventional non-inverting single OPAMP amplifier. If v_{in1}=0, then the upper input stage OPAMP looks like a conventional inverting single-OPAMP amplifier with input v_{in2} (Golden Rule I at the lower OPAMP), input resistance R_1 and feedback resistance R_2 so: $v_n' = -(R_2/R_1)\ v_{in2}$
So: $v_n'=v_n'(v_{in1}=0) + v_n'(v_{in2}=0) = (R_1+R_2)/R_1\ v_{in1} - (R_2/R_1)\ v_{in2}$
$=(1+R_2/R_1)v_n - (R_2/R_1)\ v_p + v_{comm}$

From the symmetry of the circuit, a similar expression holds for v_p':
$v_p' = (1+R_2/R_1)v_p - (R_2/R_1) v_n + v_{comm}$
Putting these back into the expression for v_o :
$v_o = K(1+2R_2/R_1)(v_p - v_n)$

NOTE: v_{comm} terms cancel!

The design of the input stage ensures that there is high differential gain and unity common mode gain. It also ensures that there is a high input impedance. (non-inverting input)

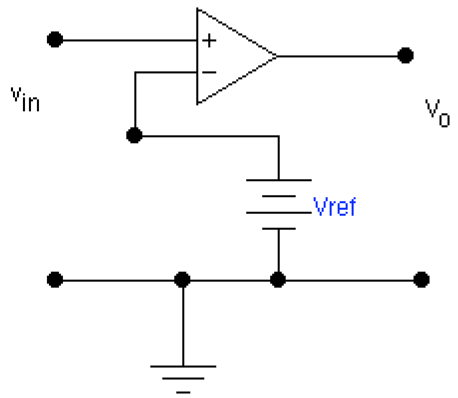
The output stage is often chosen with unity differential gain. It can 'polish off' the residual common-mode.

Normally packaged as IC with R_1 as the only external resistor and a trim offset adjustment for one of the input op-amps.
(eg AD624, gain: 1-1000, CMRR=100dB, Z_{in}=100MΩ)

In order to ensure stability (i.e. no oscillations from positive feedback) the open-loop phase shift should be less than 180^o at the frequency where the open loop gain is unity.

COMPARATORS
This is a use of the op-amp which makes use of positive feedback or simply the large open-loop gain.
A ***comparator*** is a ***dual state*** device:
ON if $v_2 - v_1 > 0$
OFF if $v_2 - v_1 < 0$
With a simple circuit with no feedback,
If $A=10^5$ and $v_2 - v_1 > 0.1$mA, then $v_o > 10$V. If $v_2 - v_1 < -0.1$mA, then $v_o < -10$V.

If the inverting input is fixed to some reference voltage, the comparitor is called a ***discriminator***.

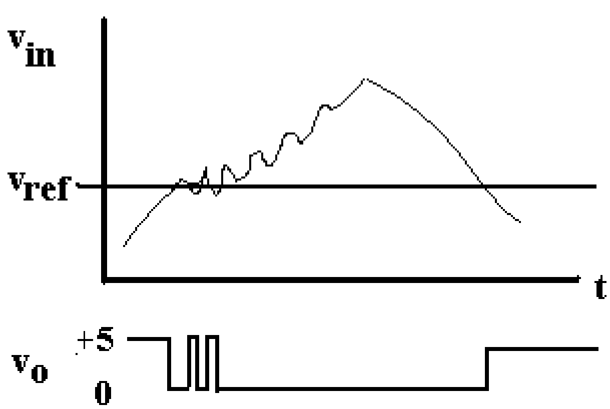


if Vref=0, then this is called a NULL COMPARITOR

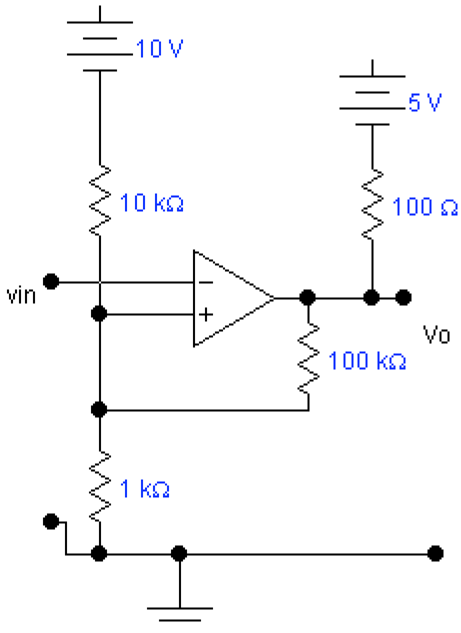
or

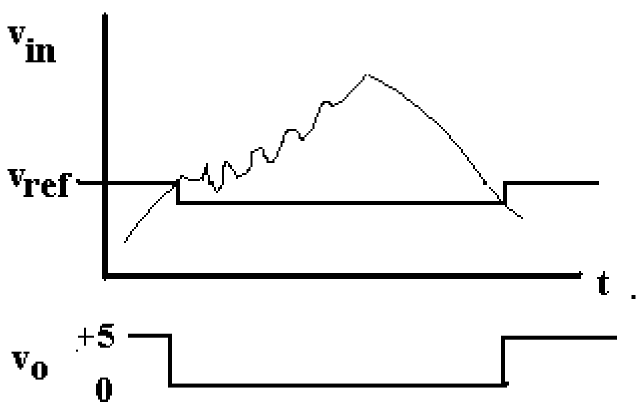
Zero crossing discriminator

The trouble with this simple circuit is that the output swings between ON and OFF if there a bit of noise.



We'd like to add some hysteresis to the Vref: if the threshold has been crossed, raise Vref. In practice, this is accomplished using a bit of ***positive feedback*** in what is called a ***Schmidt Trigger.*** This provides reasonable protection against noise.


10 V
5 V
10 kΩ
100 Ω
vin
Vo
100 kΩ
1 kΩ


vin
vref
t
vo
+5
0