Hysteresis

- Add positive feedback (Schmitt trigger)

  V_{ref} changes as v_{out} -> $+V_S$

  ie threshold falls once transition is made

  preventing immediate fall

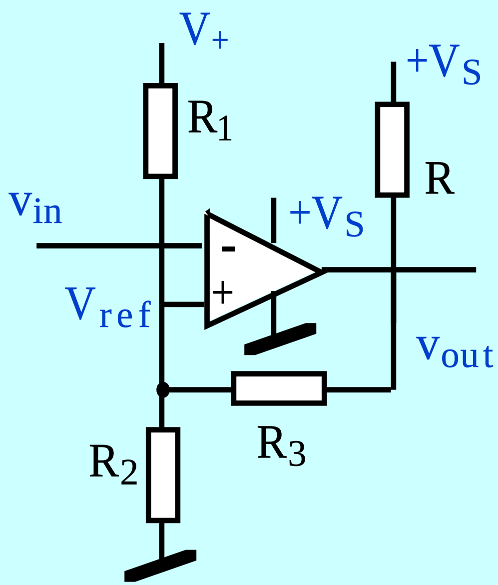
  positive feedback speeds transition

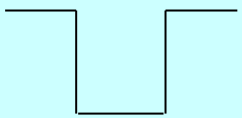
  $v_{out} = A(V_{ref} - v_-)$

  $V_{ref} > v_- \Rightarrow v_{out} = V_s \quad V_{ref} = V_{high}$

  $V_{ref} < v_- \Rightarrow v_{out} = 0V \quad V_{ref} = V_{low}$

  here, signal => logical "1": $v_{out} = 0V$





- Output depends on history

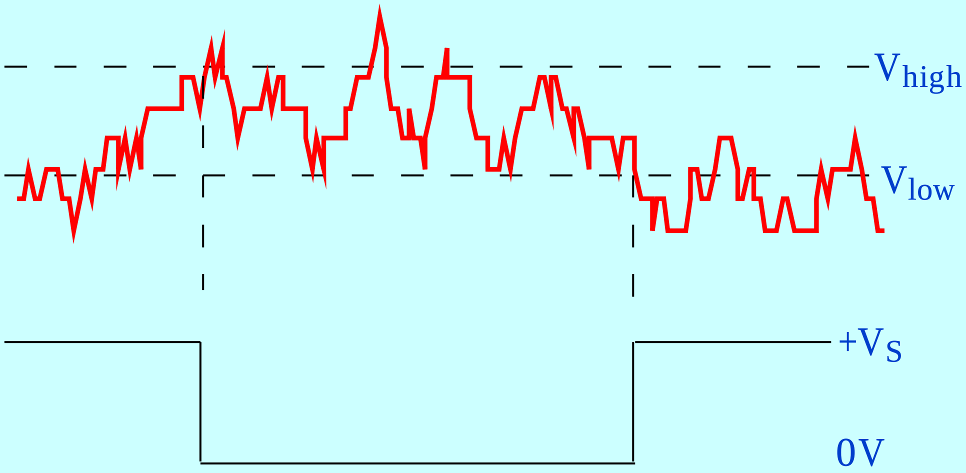
  eg $V_+ = 10V$, $V_S = +5V$, 0V

  $R_1 = 10k\Omega$, $R_2 = 10k\Omega$, $R_3 = 100k\Omega$

  $V_{out} = 0V$, $V_{ref} = 4.76V$

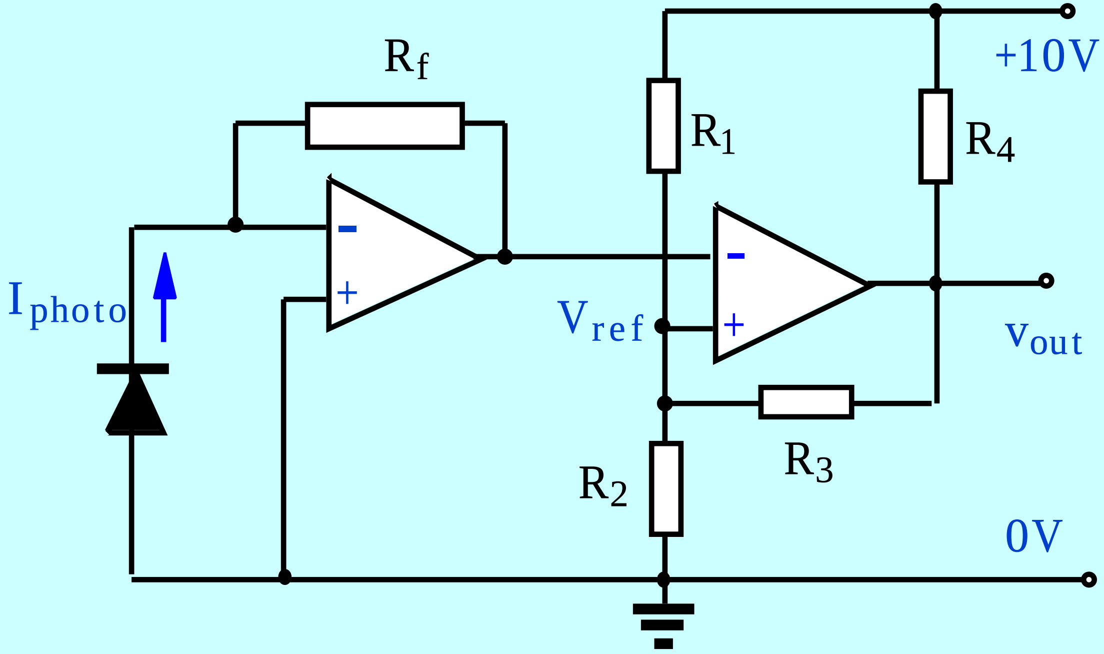
  $V_{out} = 5V$, $V_{ref} = 5V$

  hysteresis = $\Delta V_{ref} = 0.24V$



Example - alarm

•



Oscillators

- Basic building block of many systems

  clock or timer, signal generators, function generators,...

  can exploit positive feedback

- Relaxation oscillator

  charge capacitor C through R ~exp(-t/RC)

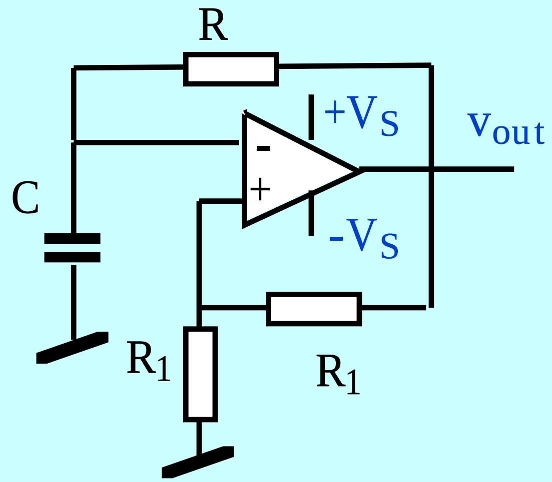
  v_- crosses threshold at V_{ref}, V_{out} => $\pm V_S$

  V_{ref} changes sign

  etc, etc...

  square wave output: $[+V_S, -V_S]$

  Period T = 2.2RC



- many more types of oscillator design available

  IC classic = 555 (many versions)

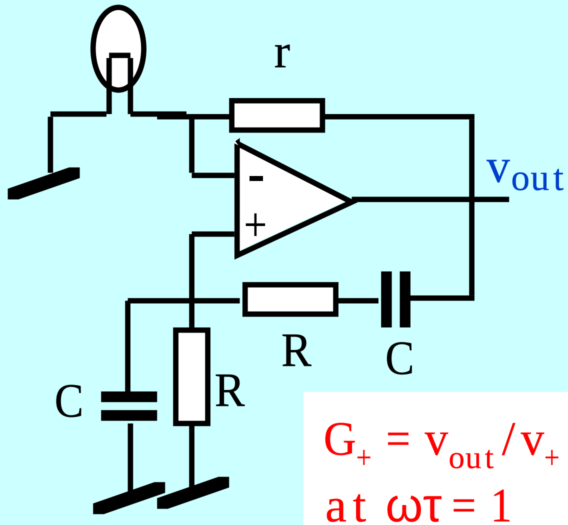
  external components set period and duty cycle

Wien bridge oscillator

- Sine wave oscillators also often required

favourite circuit for audio test applications:

low harmonic distortion at f ~ few kHz



$G_+ = v_{out}/v_+ = 3$

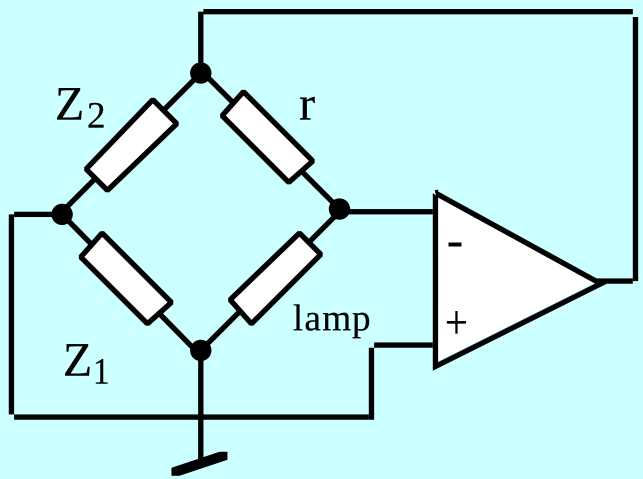
at $\omega\tau = 1$

Gain = real at $\omega_0 = 1/RC$

so positive feedback

Lamp provides temperature dependent resistor

so negative feedback controls amplitude



What values to choose for lamp resistance and r?

What determines amount of harmonic distortion?

Temperature controller

•A frequent requirement - similar to many other control applications

eg cryostat with stable temperature maintained by resistive heater, or oven, ...

•On-Off control

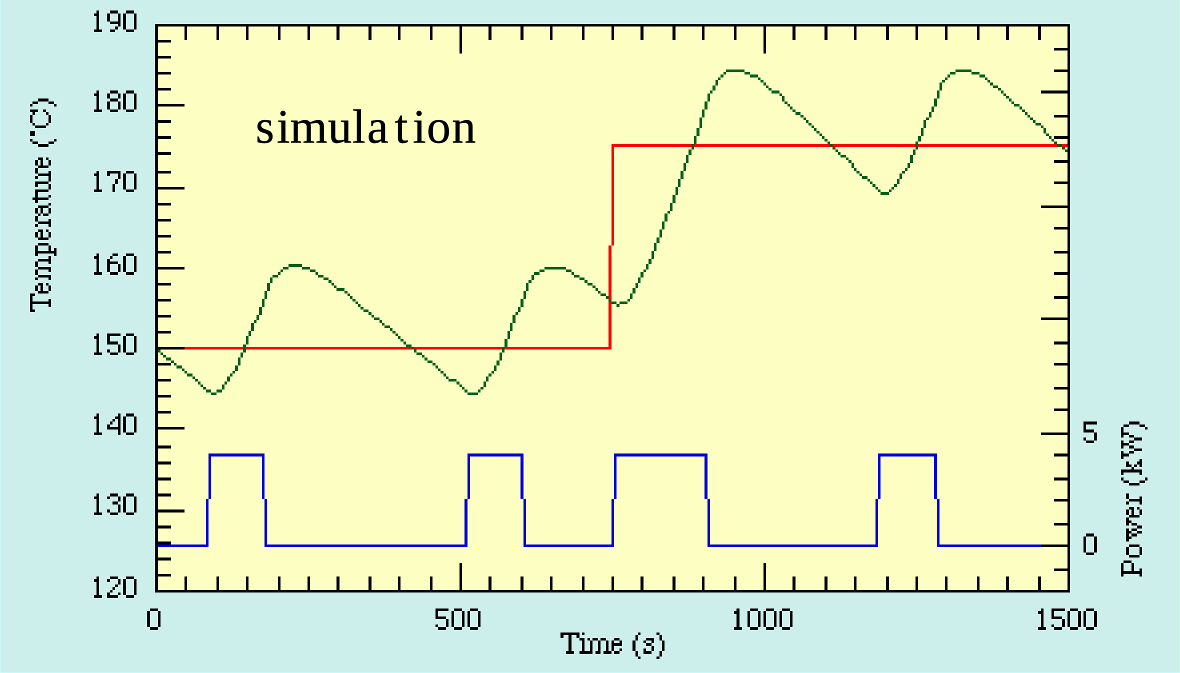
$T < T_0$

set heater to maximum power

add hysteresis (T_{01}, T_{02})

to prevent noise from

switching too rapidly



ok for central heating or

domestic oven but not good

for stable measurements - try to improve

P & PD Temperature control

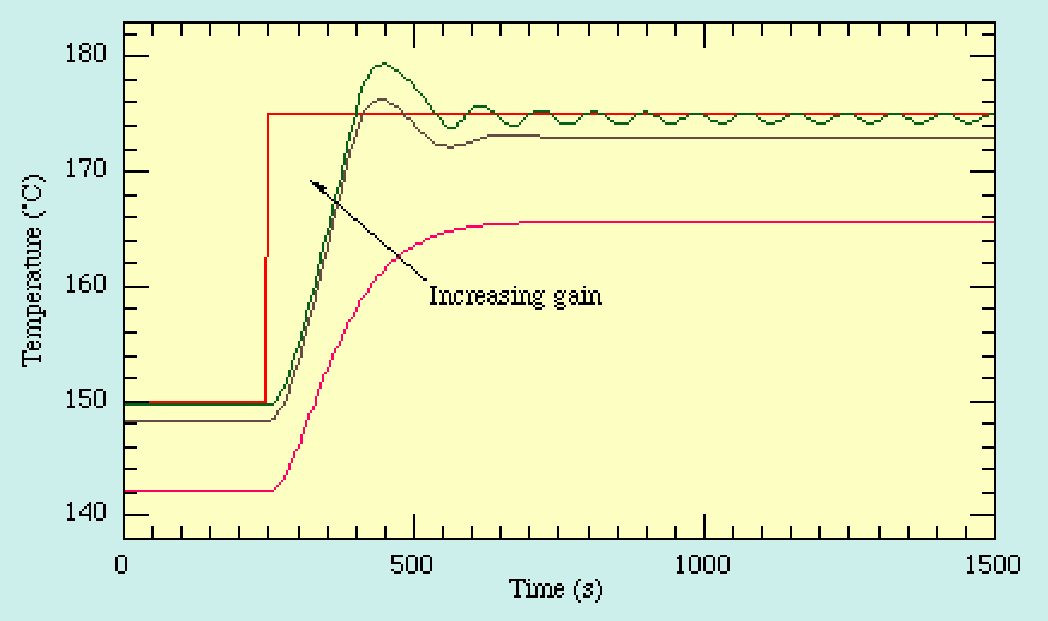
- Set heater power, proportional to temperature difference (P)

  $W = P(T_{meas} - T_0)$

  T still oscillates and

  undershoots desired value

  unstable if heat too fast

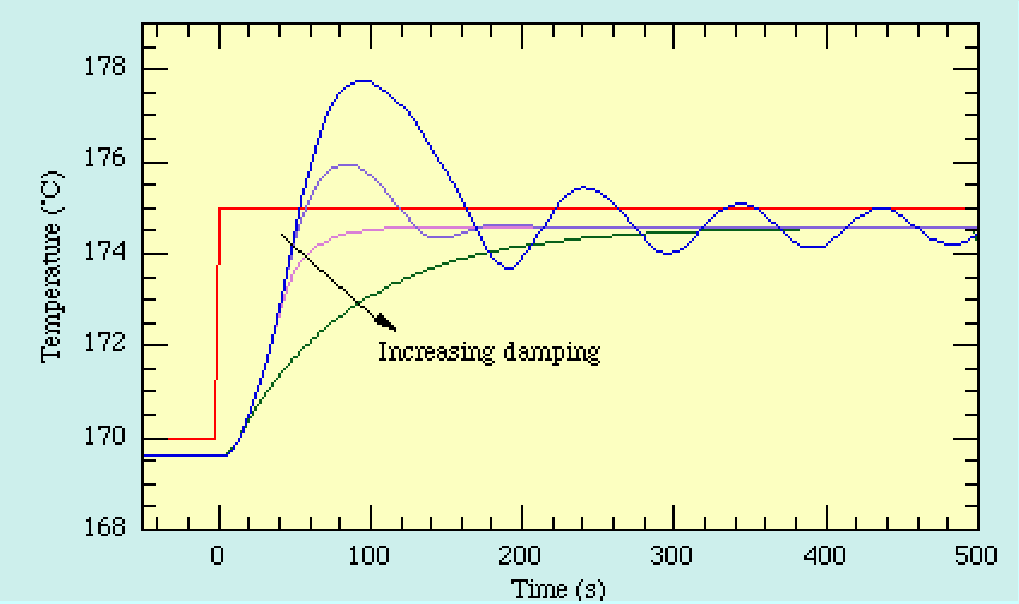


- Add control term proportional to rate of change (PD)

  $W = P[(T_{meas} - T_0) + Dd(T_{meas} - T_0)/dt]$

  D too large: overshoot & ringing

  D too small: slow response



PID Temperature control

- PD can eliminate ringing & overshoot but undershoot error remains

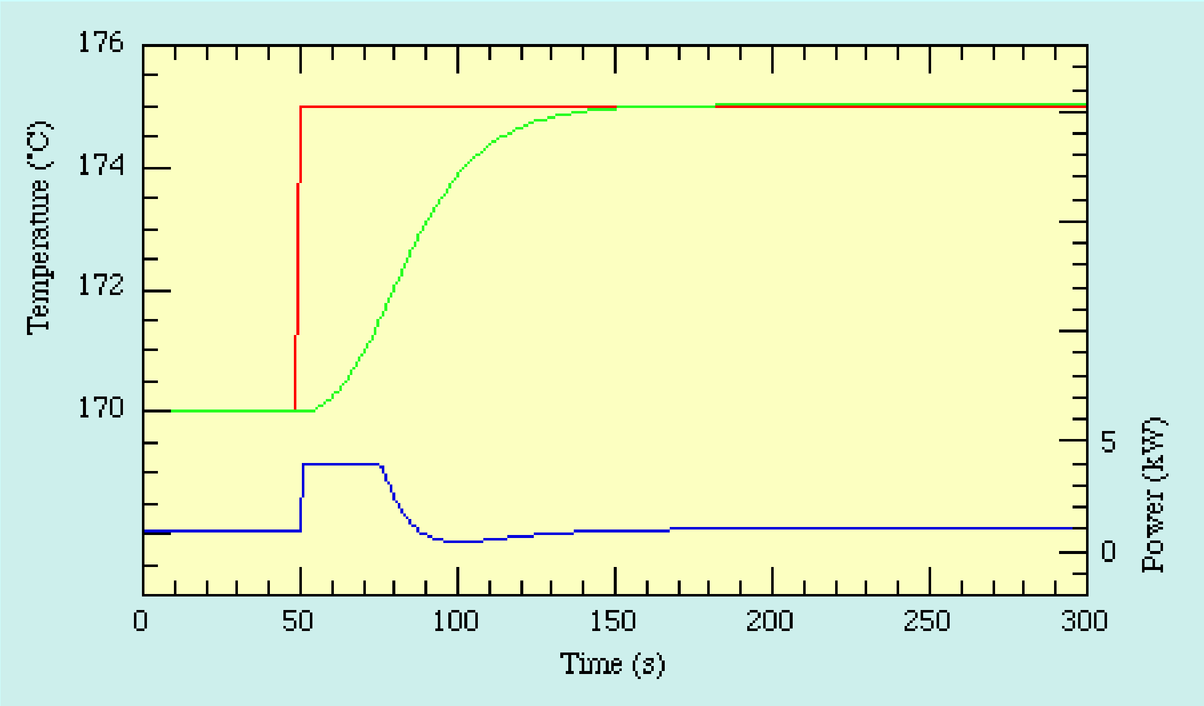
  add integral term

- PID control

  $W = P[(T_{meas} - T_0) + D\,d(T_{meas} - T_0)/dt + I\int(T_{meas} - T_0)\,dt]$

good results but
need to choose coefficients
P, D, I empirically to ensure
stability

we'll later look at methods
to solve such system
equations using transforms



Temperature control circuit

- Notes
- $R_1 >> R_2$ to avoid loading
- still need heating circuit

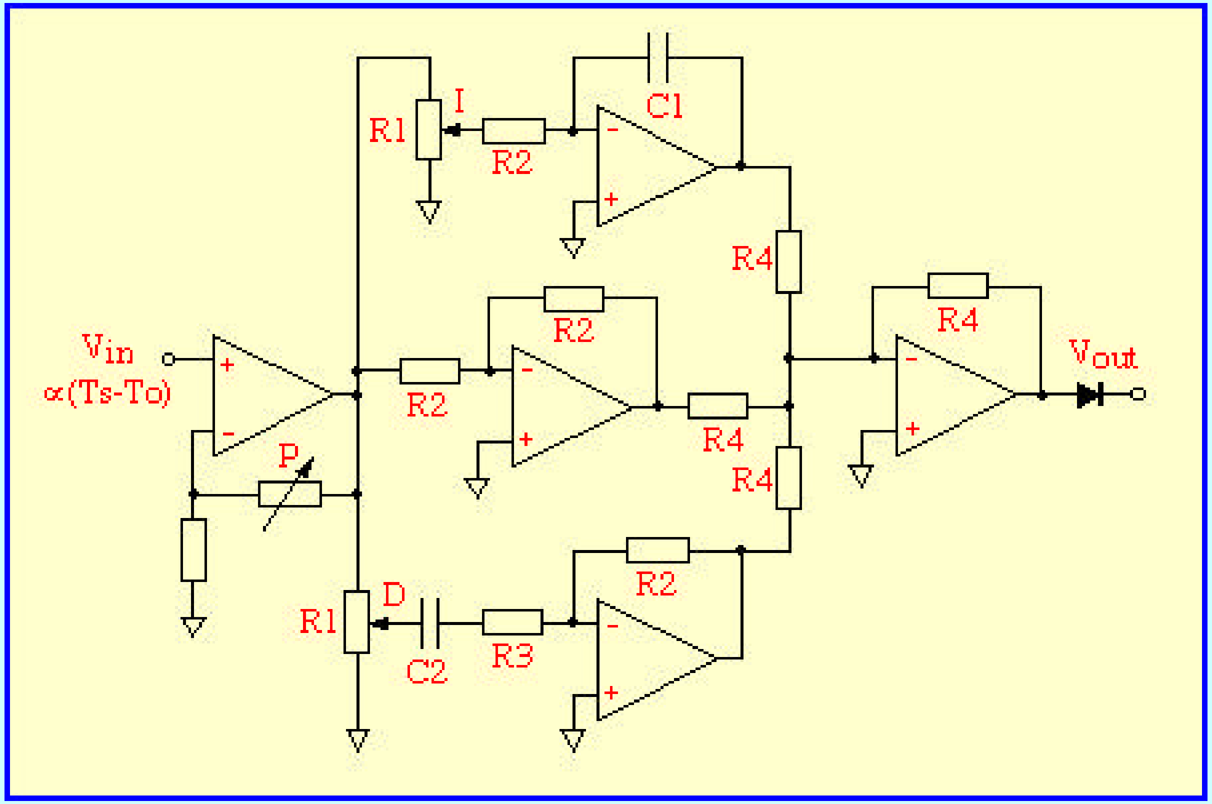
  want W α V_{out}
- Diode ensures W≥ 0

  V_{diode}?
- Time constants to be selected

  depend on appliance chosen

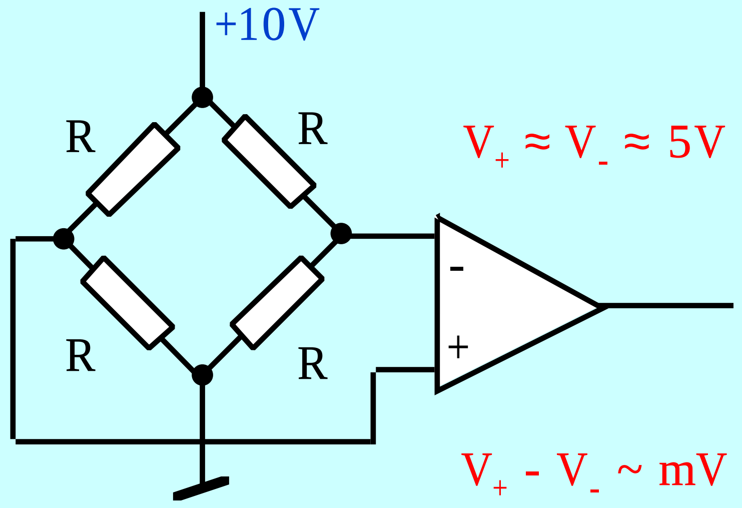
  commercial devices will recommend values
- Need to consider offset currents and voltages

  null, or consider more complex circuit design



Instrumentation amplifier

- High gain, dc-coupled differential amplifier
  - single ended output
  - high input impedance
  - high CMRR
  - use to amplify small differential signals where large CM signal may be present but small normal mode
    - eg strain gauge, other bridge circuits
    - "weak" voltage source



To measure 5mV signal with 1% error

CMRR = 0.05/5000 = 100dB

- Drawback of differential amplifier
  - relatively low input impedance
  - CMRR relies on excellent resistor matching
  - cheap op-amps may have CMRR ~80dB

Improved differential amplifier

- Add voltage buffers and choose precise resistors

    improves input impedance

    0.1% resistors available

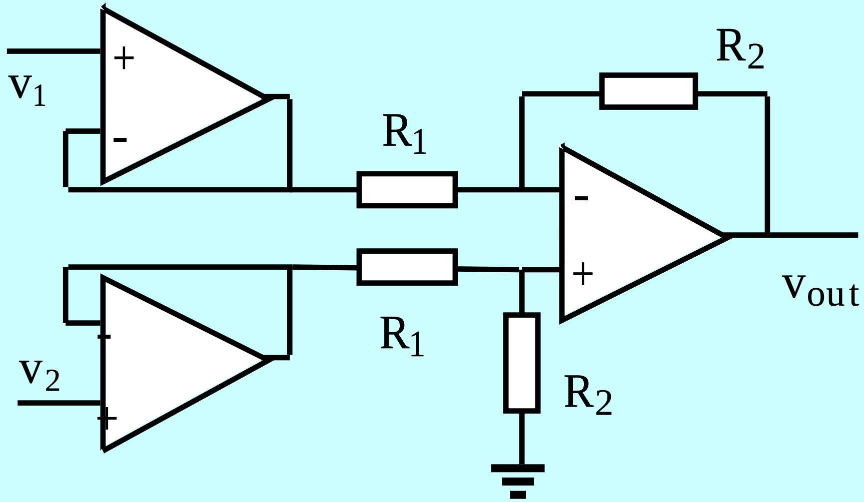
    careful nulling of circuits

    still need high CMRR from output amplifier

        big demands on R precision

    often find restrictions on driving circuit

        ie source



Classic instrumentation amplifier

- Input stage differential gain

$v_{10} - v_1 = iR_2 = v_2 - v_{20}$ (1)

$iR_1 = v_1 - v_2$

$(v_{10} - v_{20}) - (v_1 - v_2) = 2iR_2$

$(v_{10} - v_{20}) = 2iR_2 + iR_1$

$= (v_1 - v_2)(2R_2 + R_1)/R_1$

$G_{diff} = 1 + 2R_2/R_1$

- Input stage common mode gain

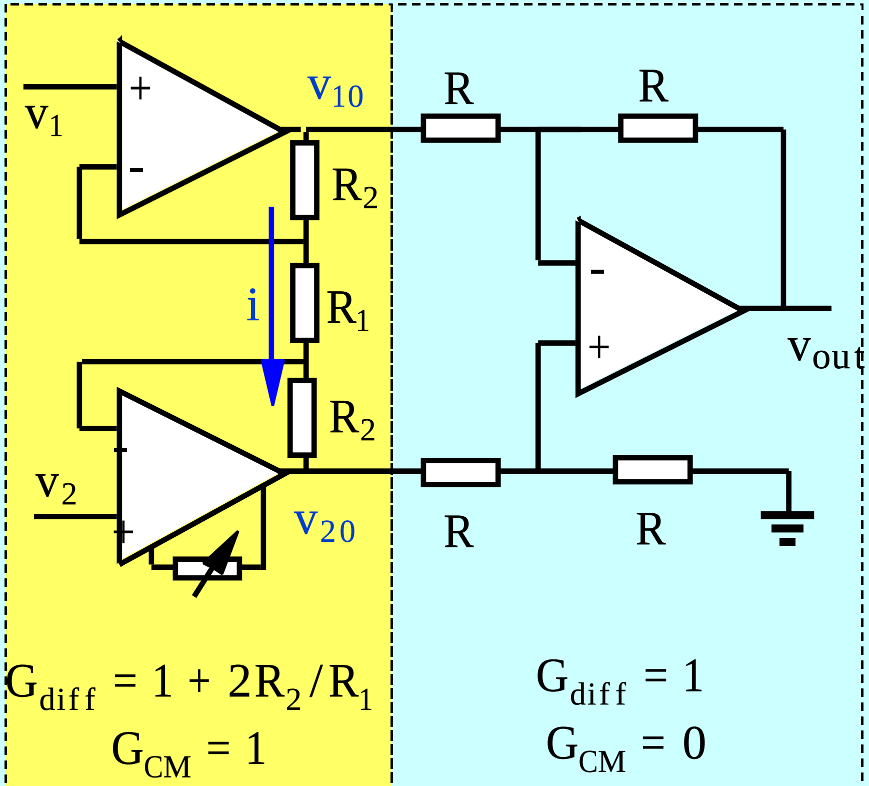
$v_1 = v_{CM} + u_1$

$v_2 = v_{CM} + u_2$

$2v_{CM} = v_1 + v_2$ with signal $u_1 = u_2 = 0$

From (1) $v_{10} + v_{20} = v_1 + v_2$

$G_{CM} = 1$



Reduce requirements on second stage
still choose input amps for good CMRR
and null carefully

- Remainder is normal differential amplifier, (G = 1 in this case)

Instrumentation ICs available

The Instrumentation Amplifier in practice

- Can add some more useful features

  feed common mode level back as guard

  connect to cable shield

  reduce effects of cable capacitance, leakage currents

  sense voltage at load

  allows feedback to correct for losses in wiring

  or offset of DC conditions