Filter

Filter is a frequency selective circuit that passes signal of specified Band of frequencies and attenuates the signals of frequencies outside the band

Type of Filter

1. Passive filters
2. Active filters

Passive filters

Passive filters works well for high frequencies. But at audio frequencies, the inductors become problematic, as they become large, heavy and expensive. For low frequency applications, more number of turns of wire must be used which in turn adds to the series resistance degrading inductor’s performance ie, low Q, resulting in high power dissipation

Active filters

Active filters used op- amp as the active element and resistors and capacitors as passive elements. By enclosing a capacitor in the feed back loop , inductor less active filters can be obtained

some commonly used active filters

1. Low pass filter
2. High pass filter
3. Band pass filter
4. Band reject filter

Active Filters

- Active filters use op-amp(s) and RC components.
- Advantages over passive filters:
  - op-amp(s) provide gain and overcome circuit losses
  - increase input impedance to minimize circuit loading
  - higher output power
  - sharp cutoff characteristics can be produced simply and efficiently without bulky inductors
- Single-chip universal filters (e.g. switched-capacitor ones) are available that can be configured for any type of filter or response.

Review of Filter Types & Responses

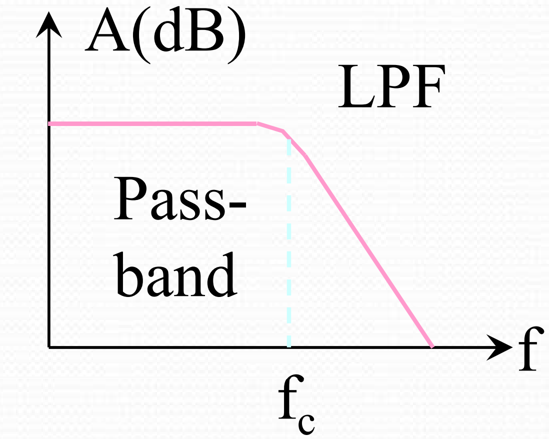
- 4 major types of filters: low-pass, high-pass, band pass, and band-reject or band-stop
- 0 dB attenuation in the pass band (usually)
- 3 dB attenuation at the *critical* or *cutoff frequency*, f_c (for Butterworth filter)
- Roll-off at 20 dB/dec (or 6 dB/oct) per *pole* outside the passband (# of poles = # of reactive elements). Attenuation at any frequency, f, is:

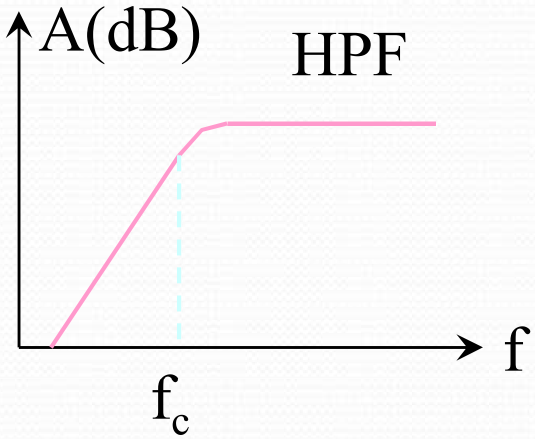
$$atten.(dB)\,at\,f = \log\left(\frac{f}{f_c}\right) x\,atten.(dB)\,at\,f_{dec}$$

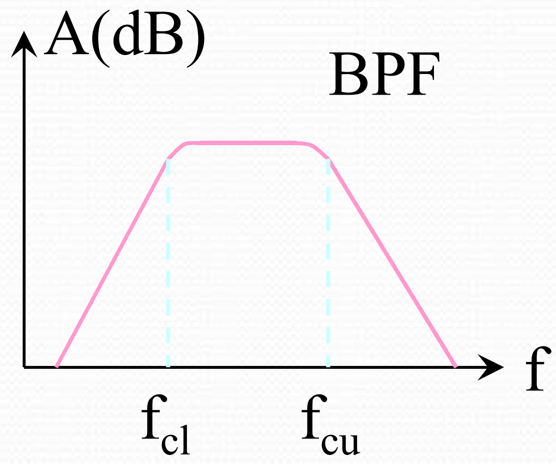
Review of Filters (cont'd)

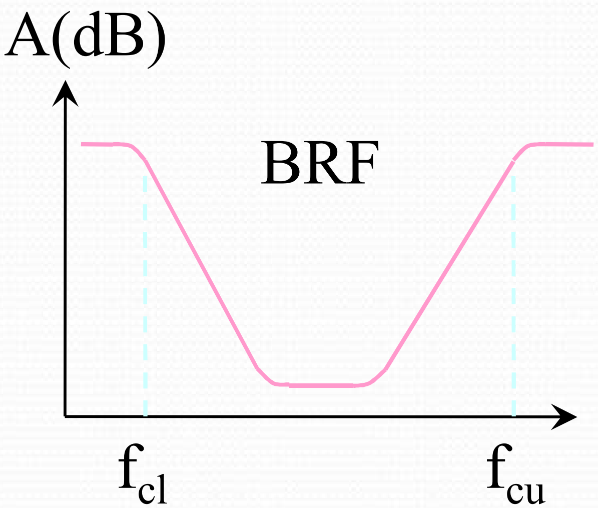
- Bandwidth of a filter: $BW = f_{cu} - f_{cl}$
- Phase shift: 45°/pole at f_c; 90°/pole at >> f_c
- 4 types of filter responses are commonly used:
  - Butterworth - maximally flat in passband; highly non-linear phase response with frequency
  - Bessel - gentle roll-off; linear phase shift with freq.
  - Chebyshev - steep initial roll-off with ripples in passband
  - Cauer (or elliptic) - steepest roll-off of the four types but has ripples in the passband and in the stop band

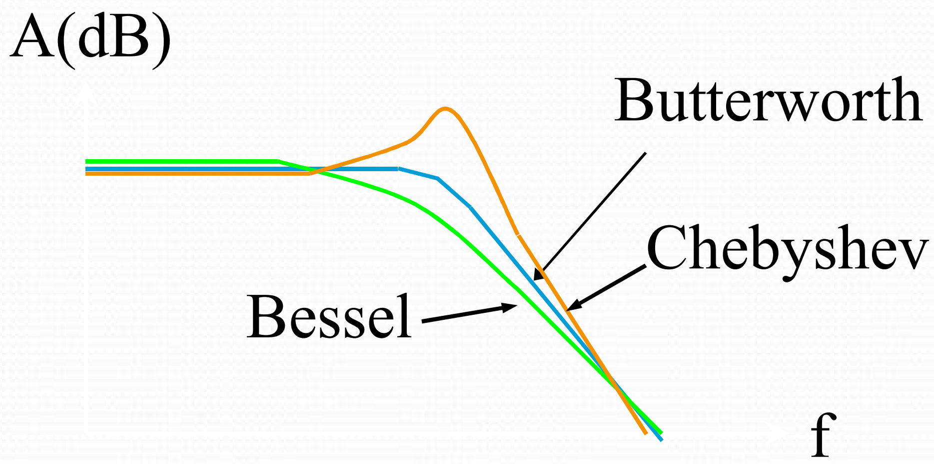
Frequency Response of Filters



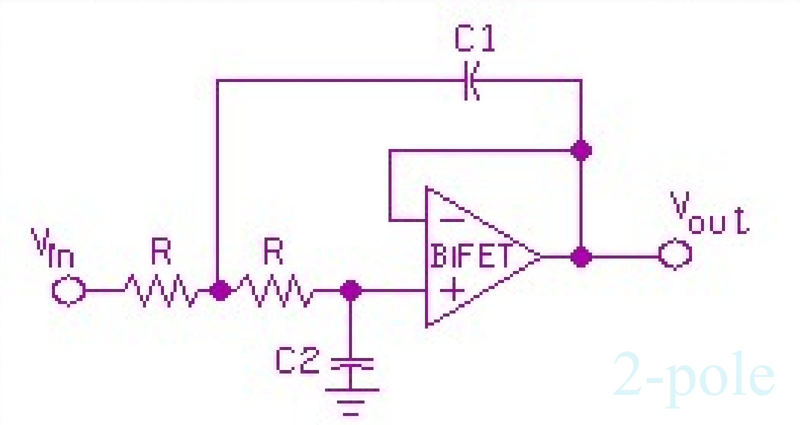


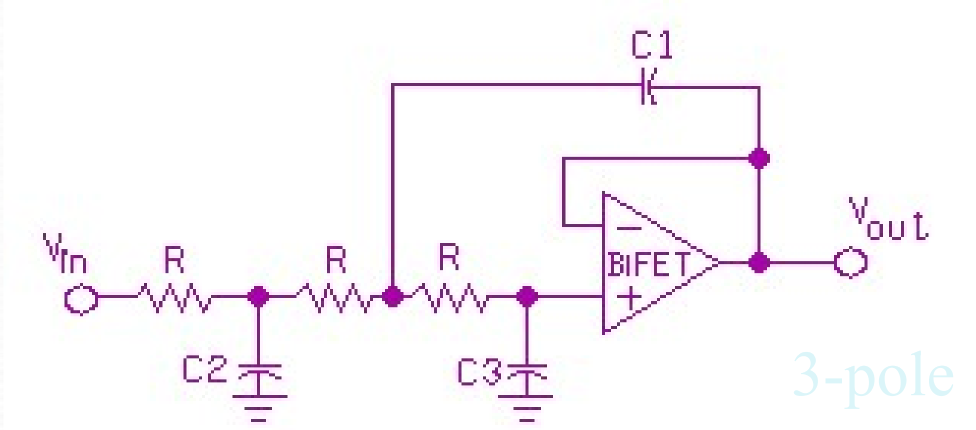


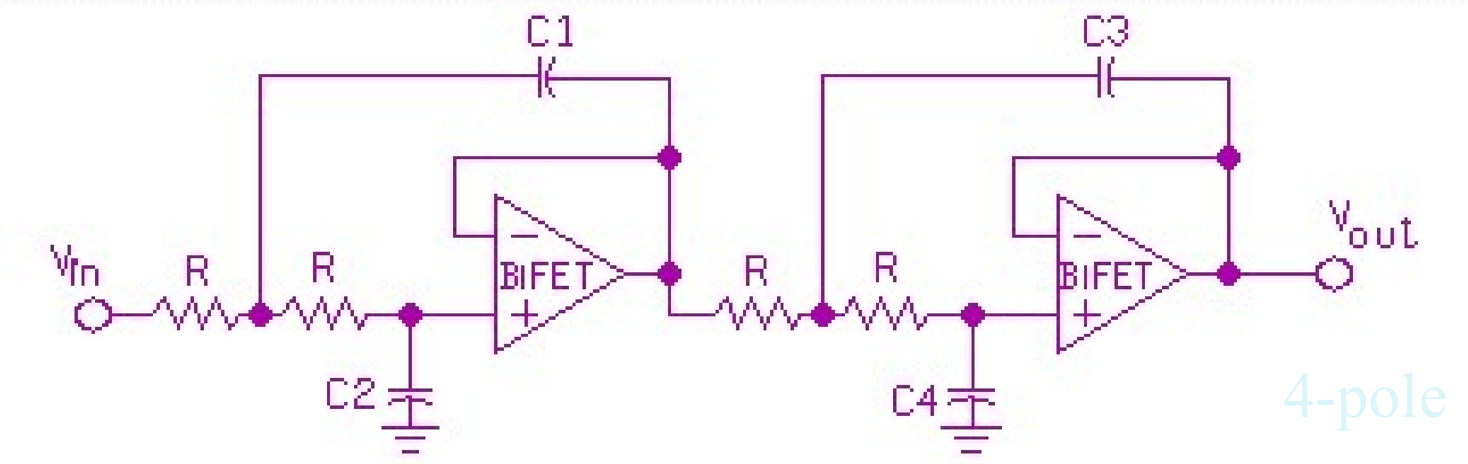




Unity-Gain Low-Pass Filter Circuits







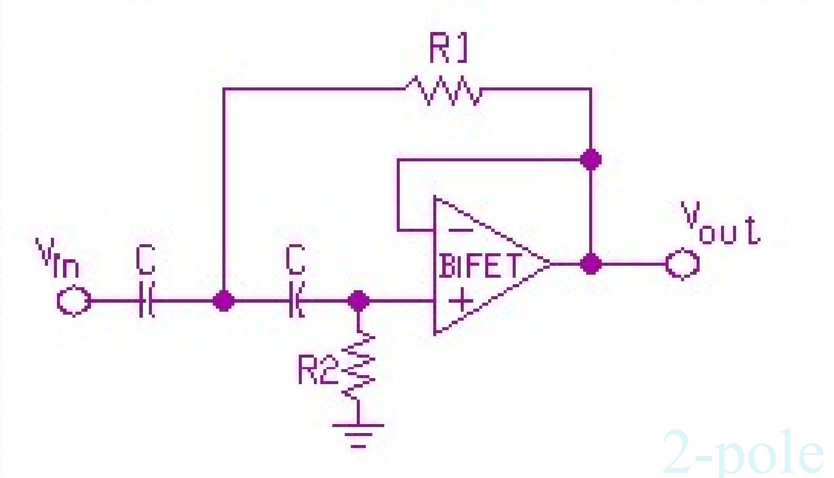
Design Procedure for Unity-Gain LPF

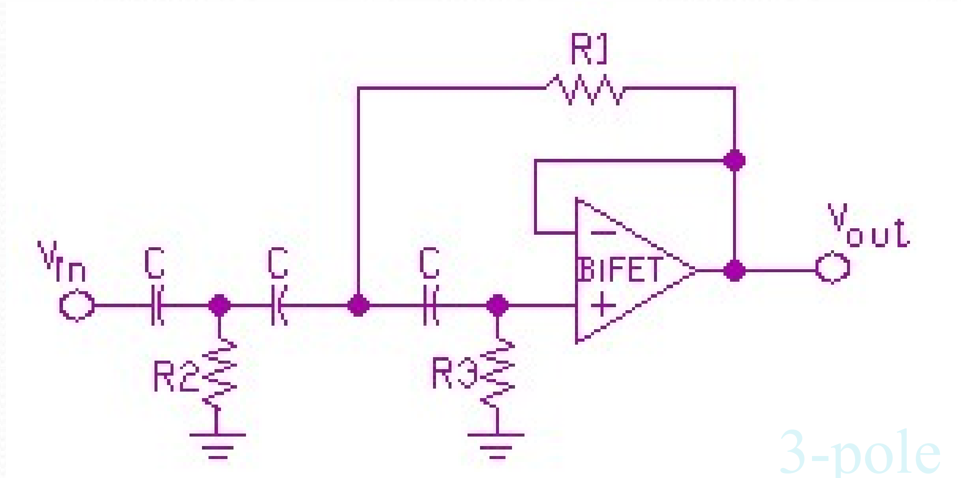
- Determine/select number of poles required.
- Calculate the frequency scaling constant, $K_f = 2\pi f$
- Divide normalized C values (from table) by K_f to obtain frequency-scaled C values.
- Select a desired value for one of the frequency-scaled C values and calculate the impedance scaling factor:

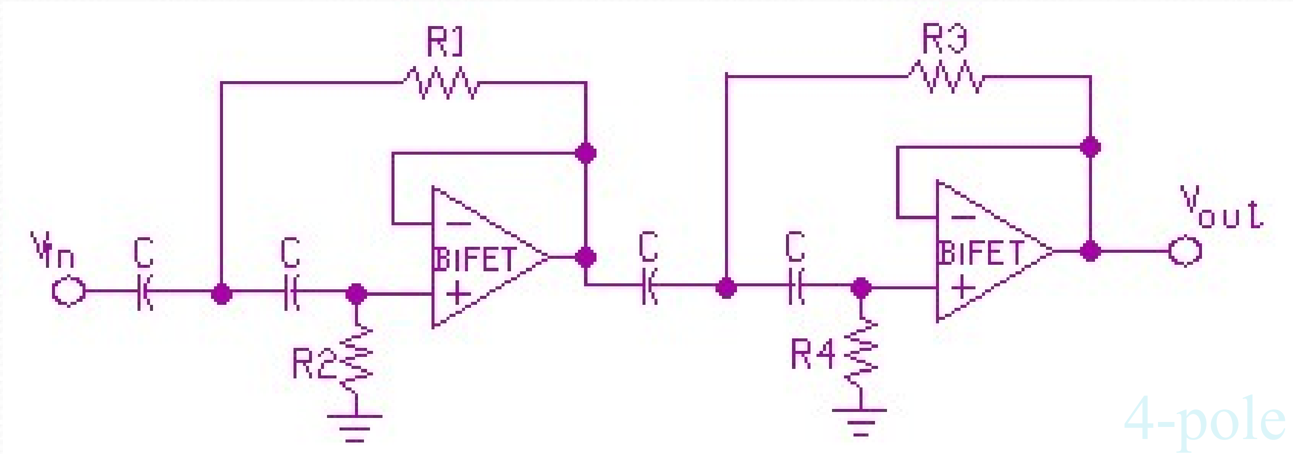
$$K_x = \frac{frequency - scaled\ C\ value}{desired\ C\ value}$$

  - Divide all frequency-scaled C values by K_x
  - Set $R = K_x\ \Omega$

Unity-Gain High-Pass Filter Circuits





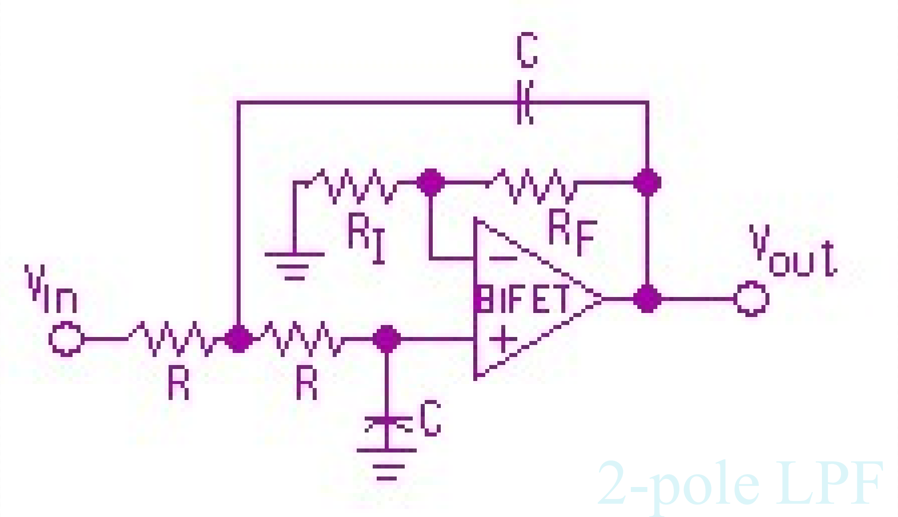


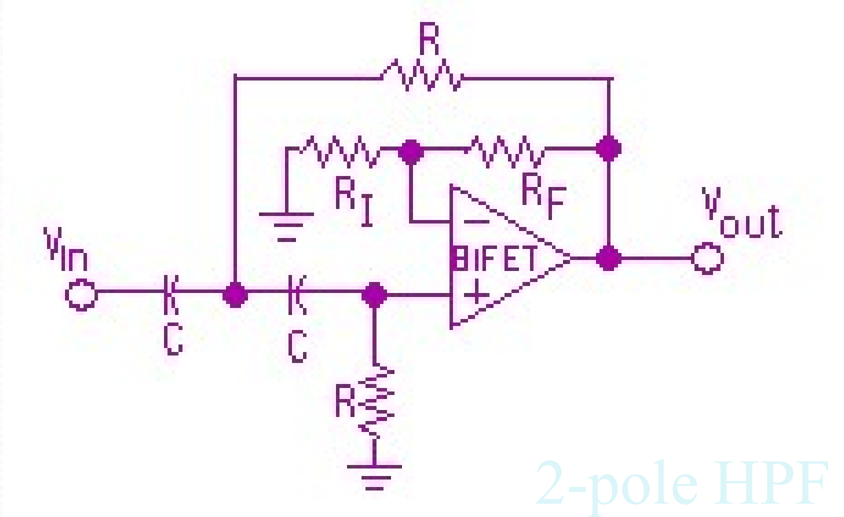
Design Procedure for Unity-Gain HPF

- The same procedure as for LP filters is used except for step #3, the normalized C value of 1 F is divided by K_f. Then pick a desired value for C, such as 0.001 μF to 0.1 μF, to calculate K_x. (Note that all capacitors have the same value).
- For step #6, multiply all normalized R values (from table) by K_x.

E.g. Design a unity-gain Butterworth HPF with a critical frequency of 1 kHz, and a roll-off of 55 dB/dec. (Ans.: C = 0.01 μF, R_1 = 4.49 kΩ, R_2 = 11.43 kΩ, R_3 = 78.64 kΩ.; pick standard values of 4.3 kΩ, 11 kΩ, and 75 kΩ).

Equal-Component Filter Design





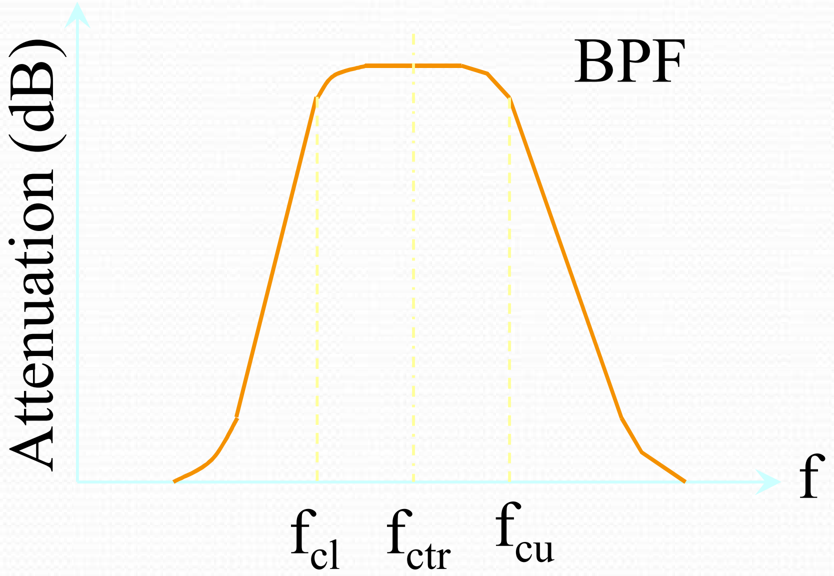
Same value R & same value C are used in filter.

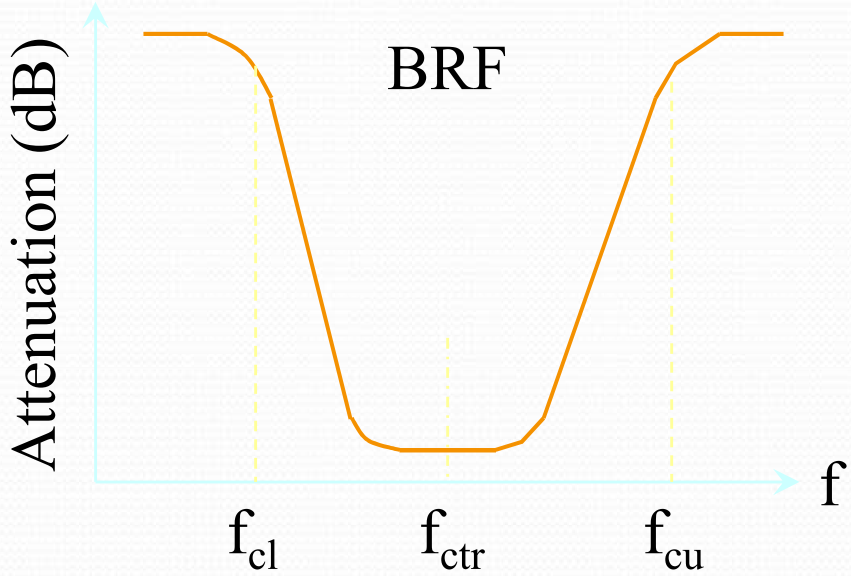
Select C (e.g. 0.01 μF), then:

A_v for # of poles is given in a table and is the same for LP and HP filter design.

$$A_v = \frac{R_F}{R_I} + 1$$

Bandpass and Band-Rejection Filter





The quality factor, Q, of a filter is given by:

$$Q = \frac{f_{ctr}}{BW}$$

where BW = f_{cu} - f_{cl} and

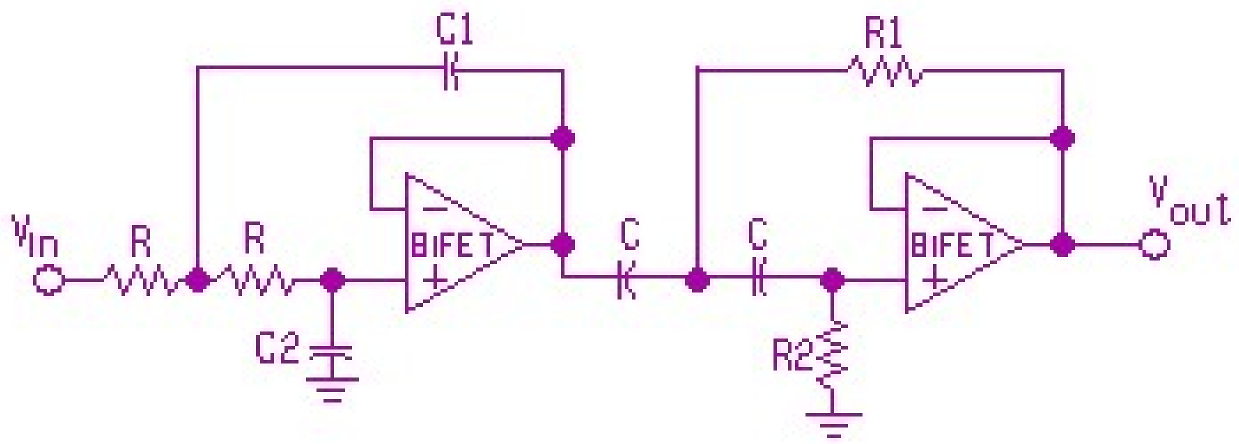
$$f_{ctr} = \sqrt{f_{cu} f_{cl}}$$

More On Bandpass Filter

If BW and f_{centre} are given, then:

$$f_{cl} = \sqrt{\frac{BW^2}{4} + f_{ctr}^2} - \frac{BW}{2} \; ; \; f_{cu} = \sqrt{\frac{BW^2}{4} + f_{ctr}^2} + \frac{BW}{2}$$

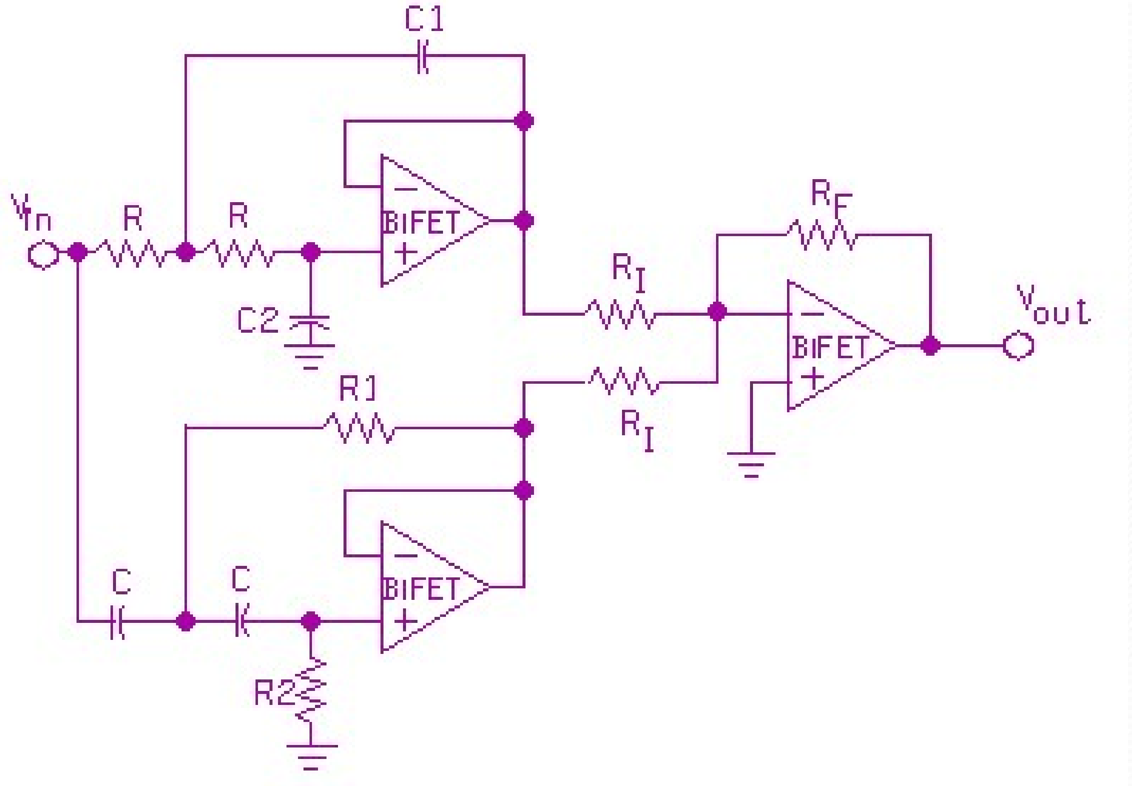
A *broadband* BPF can be obtained by combining a LPF and a HPF:



The Q of this filter is usually > 1.

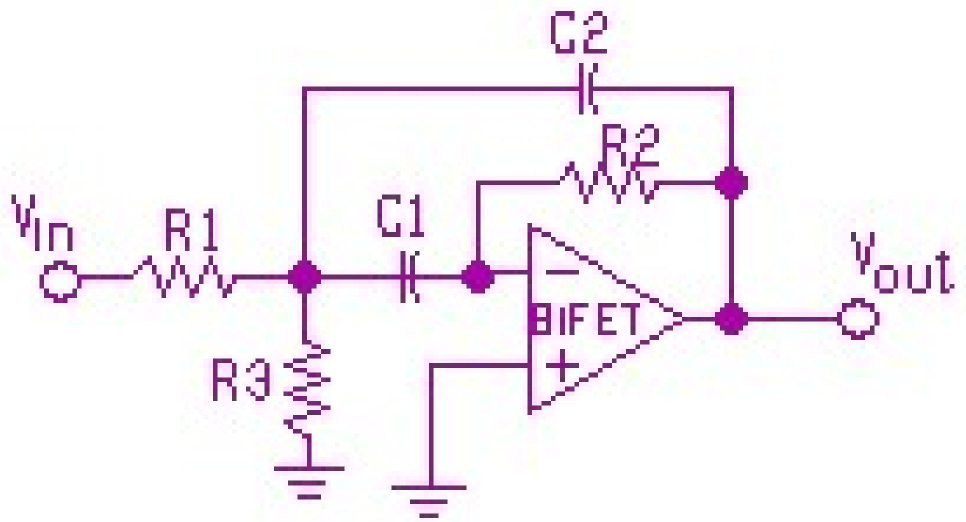
Broadband Band-Reject Filter

A LPF and a HPF can also be combined to give a broadband BRF:



2-pole band-reject filter

Narrow-band Bandpass Filter



$$BW = \frac{f_{ctr}}{Q} = \frac{1}{2\pi R_1 C}$$

C1 = C2 = C

$R_2 = 2\ R_1$

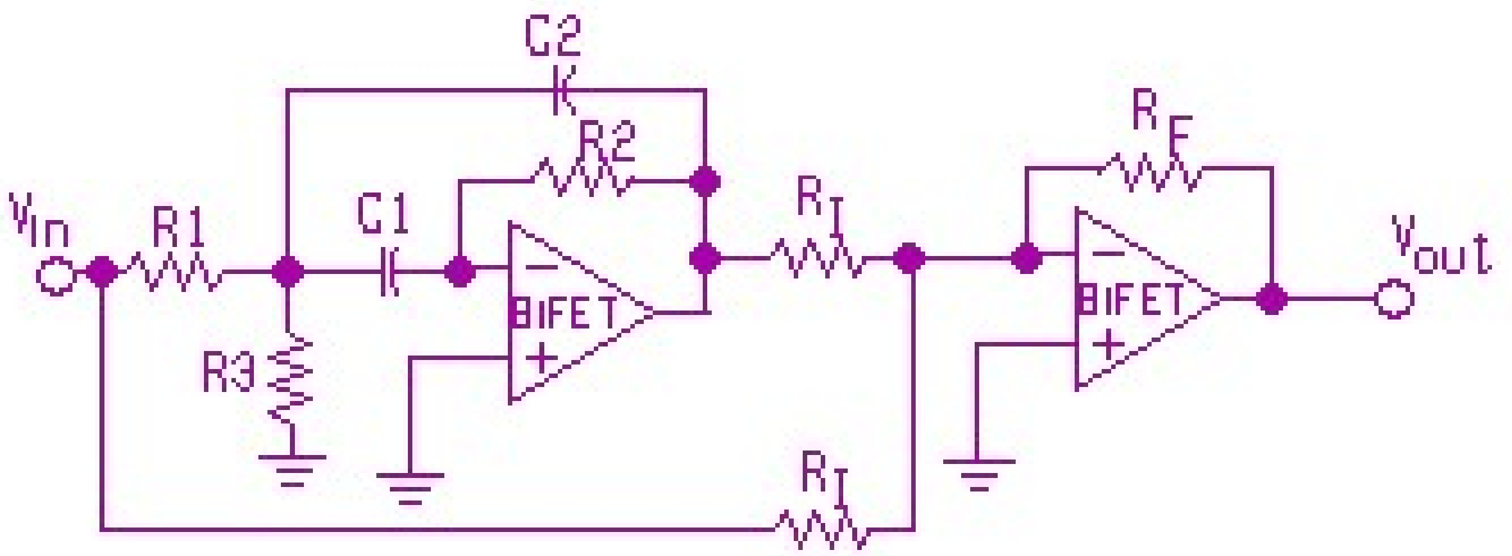
$$R_3 = \frac{R_1}{2Q^2 - 1}$$

$$f_{ctr} = \frac{1}{2\sqrt{2}\pi R_1 C}\sqrt{1 + \frac{R_1}{R_3}}$$

R_3 can be adjusted or trimmed to change f_{ctr} without affecting the BW. Note that $Q < 1$.

Narrow-band Band-Reject Filter

Easily obtained by combining the inverting output of a narrow-band BRF and the original signal:



The equations for R1, R2, R3, C1, and C2 are the same as before. $R_I = R_F$ for unity gain and is often chosen to be >> R1.

Switching regulator

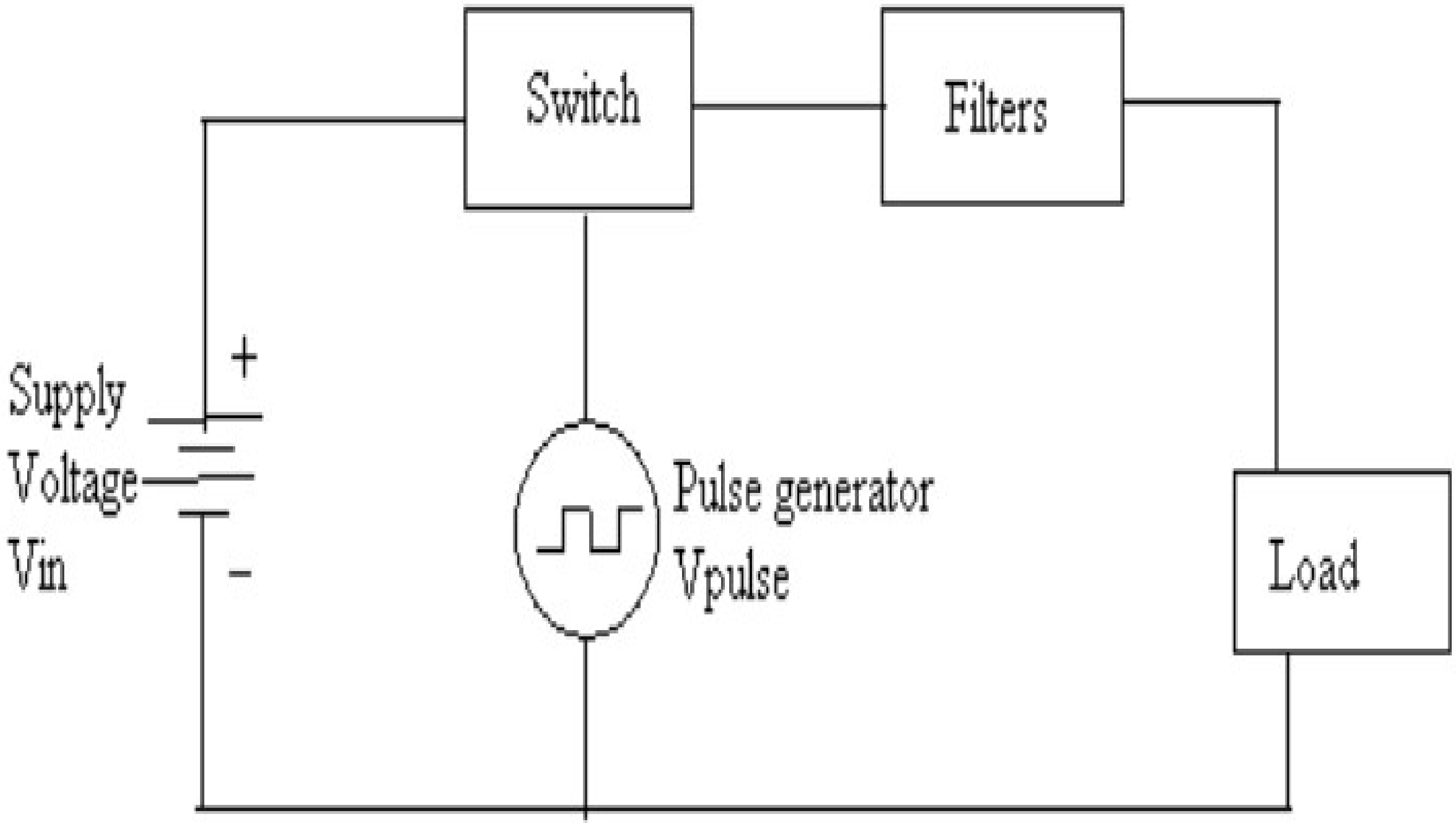
- To minimize the power dissipation during switching, the external transistor used must be a switching power transistor.
- To improve the efficiency of a regulator, the series pass transistor is used as a switch rather than as a variable resistor as in the linear mode.

➢ In such regulators the series pass transistor is switched between cut off & saturation at a high frequency which produces a pulse width modulated (PWM) square wave output.

Switching regulator

- This output is filtered through a low pass LC filter to produce an average dc output voltage.
- Thus the output voltage is proportional to the pulse width and frequency
- The efficiency of a series switching regulator is independent of the input & output differential & can approach 95%

Basic Switching regulator



Major Components Switching Regulator

- A basic switching regulator consists of 4 major components
  1. Voltage source V_{in}
  2. Switch S_1
  3. Pulse generator V_{pulse}
  4. Filter F_1

1. Voltage Source V_{in}

- It may be any dc supply – a battery or an unregulated or a regulated voltage. The voltage source must satisfy the following requirements.
- It must supply the required output power & the losses associated with the switching regulator.
- It must be large enough to supply sufficient dynamic range for line & load regulations.
- It must be sufficiently high to meet the minimum requirement of the regulator system to be designed.
- It may be required to store energy for a specified amount of time during power failures.

2. Switch S_1

- It is typically a transistor or thyristor connected as a power switch & is operated in the saturated mode.
- The pulse generator output alternately turns the switch ON & OFF

3. Pulse generator V_{pulse}

- It provides an asymmetrical square wave varying in either frequency or pulse width called frequency modulation or pulse width modulation respectively.
- The most effective frequency range for the pulse generator for optimum efficiency 20 KHz.
- This frequency is inaudible to the human ear & also well within the switching speeds of most inexpensive transistors & diodes.
- The duty cycle of the pulse wave form determines the relationship between the input & output voltages.

Contd …….

- The duty cycle is the ratio of the on time ton, to the period T of the pulse waveform.

$$\text{Duty cycle} = \frac{ton}{ton + toff}$$

- Switching regulator can operate in any of 3 modes

$$= \frac{ton}{T} = \text{ton f.}$$

Where

ton = On-time of the pulse waveform
toff = Off-time of the pulse wave form
T = time period = ton + toff
T = 1/frequency or
T = 1/f

Contd ....

- Typical operating frequencies of switching regulator range from 10 to 50khz.
- Lower operating frequency improve efficiency & reduce electrical noise, but require large filter components (inductors & capacitors).

4. Filter F1

- It converts the pulse waveform from the output of the switch into a dc voltage.
- Since this switching mechanism allows a conversion similar to transformers, the switching regulator is often referred to as a dc transformer.
- The output voltage Vo of the switching regulator is a function of duty cycle & the input voltage Vin.
- Vo is expressed as follows,

$$V_o = \frac{t_{on}}{T} V_{in}$$

- This equation indicates that, if time period T is constant, Vo is directly proportional to the ON-time, ton for a given value of Vin.

Contd …….

- This method of changing the output voltage by varying ton is referred to as a pulse width modulation.
- Similarly, if ton is held constant, the output voltage Vo is inversely proportional to the period T or directly proportional to the frequency of the pulse waveform.
- This method of varying the output voltage is referred to as frequency modulation (FM).

    i) Step – Down
    ii) Step – Up
    iii) Polarity inverting

THANK YOU

LM317 variable voltage regulators

- LM317 variable voltage regulators is Adjustable voltage regulators
- Adjustable voltage regulators are those who voltage can be varied and utilized
- Advantage of adjustable voltage regulators
    - Improved system performance
    - Improved overload protection
    - Improved system reliability

Terminals of adjustable-voltage regulator

- LM317 voltage regulators is a three-terminal adjustable-voltage regulator. The three terminals are
- Input pin (V_{in}) ,
- Output pin (V_{out}) and
- Adjustment pin (adj)

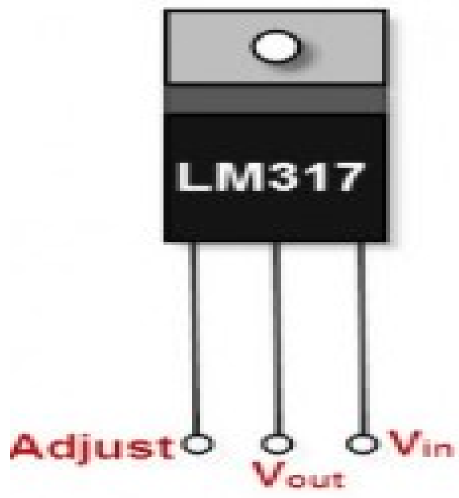
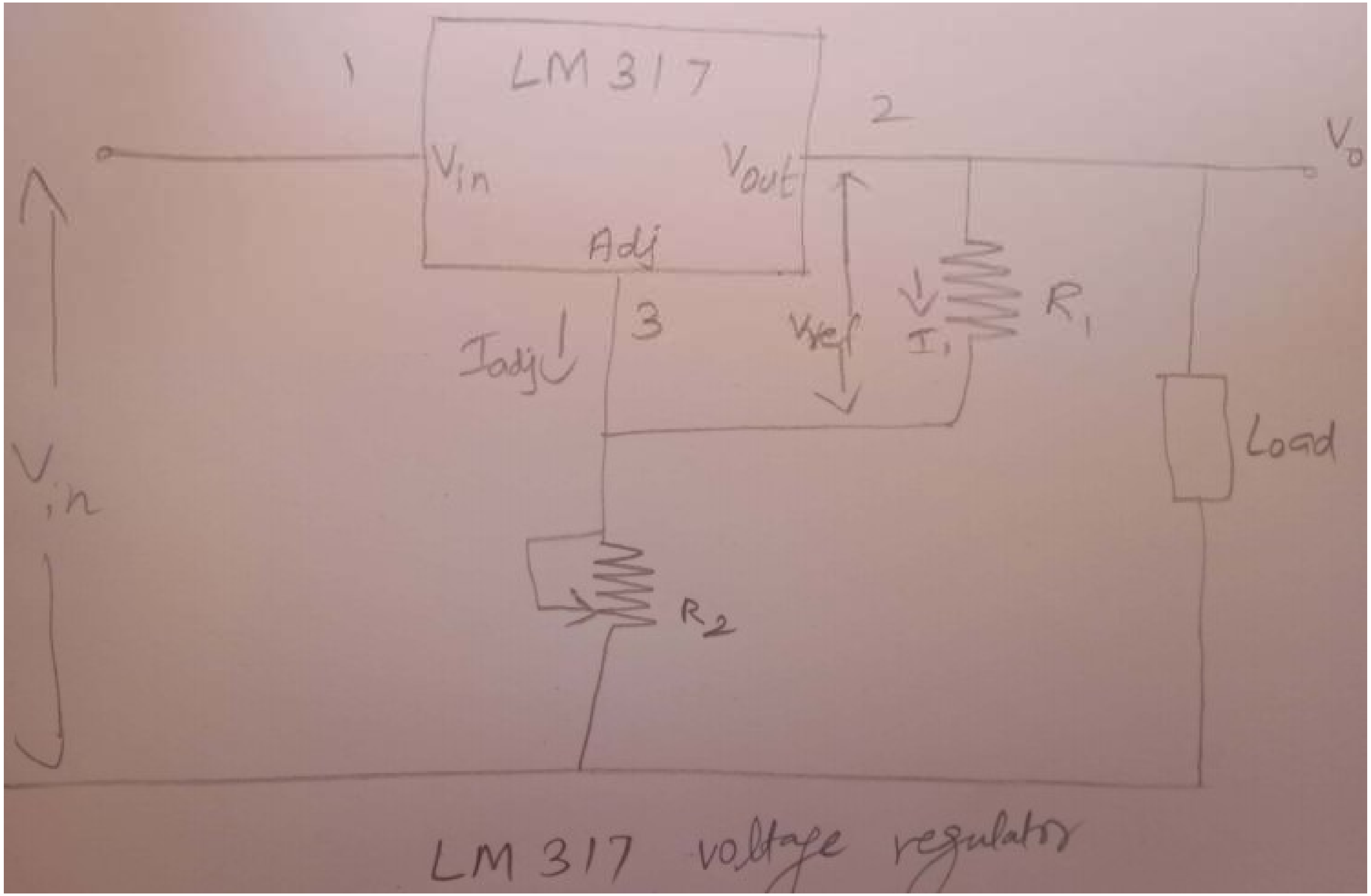


Diagram of LM317 voltage regulators



Contd……

- LM317 voltage regulators is easy to use because it requires only 2 external resistors to set the output voltage.
- LM317 produces a voltage of 1.25V between its output & adjustment terminals. This voltage is called as V_{ref}
- V_{ref} (Reference Voltage) is a constant,

  hence current I_1 flows through R_1 will also be constant.

  Because resistor R_1 sets current I_1.

  It is called current set or program resistor.

Contd……

- Resistor R_2 is called as Output set resistors, hence current through this resistor is the sum of I_1 & I_{adj}
- LM317 is designed in such as that I_{adj} is very small & constant with changes in line voltage & load current
- The output voltage V_o is,

$$Vo = R_1 I_1 + (I_1 + I_{adj}) R_2 \qquad \text{------------- (1)}$$

Where

$$I_1 = V_{ref}/R_1$$

Contd……

- Sub I_1 in equation 1

$$V_o = (V_{ref} / R_1) R_1 + (V_{ref} / R_1 + I_{adj}) R_2$$
$$= V_{ref} + (V_{ref} / R_1) R_2 + I_{adj} R_2$$
$$V_o = V_{ref} [1 + R_2/R_1] + I_{adj} R_2$$

------------- (2)

Where

R_1 = Current (I_1) set resistor

R_2 = output (V_o) set resistor

V_{ref} = 1.25V which is a constant voltage between output and ADJ terminals.

Contd……

- Current I_{adj} is very small. Therefore the second term in (2) can be neglected
- Thus the final expression for the output voltage is given by

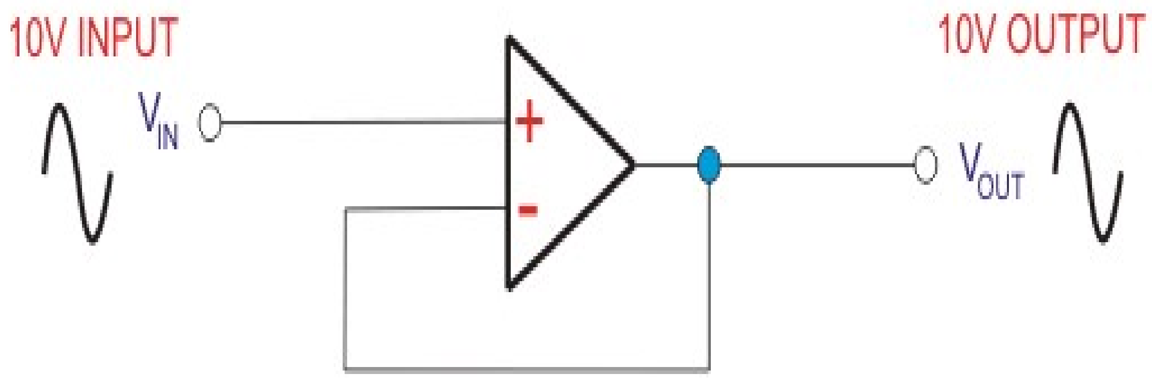
$$V_o = 1.25V[1 + R_2/R_1] \qquad \text{------------} \; (3)$$

- The Eqn (3) indicates that we can vary the output voltage by varying the resistance R_2.

THANK YOU

Voltage Follower

- **Voltage follower** is an Op-amp circuit whose output voltage straight away follows the input voltage. That is output voltage is equivalent to the input voltage.
- Op-amp circuit does not provide any amplification. Thus, voltage gain is equal to 1.
- They are similar to discrete emitter follower.
- The other names of voltage follower are Isolation Amplifier, Buffer Amplifier, and Unity-Gain Amplifier.
- The voltage follower provides no attenuation or no amplification but only buffering. This circuit has an advantageous characteristic of very high input impedance.

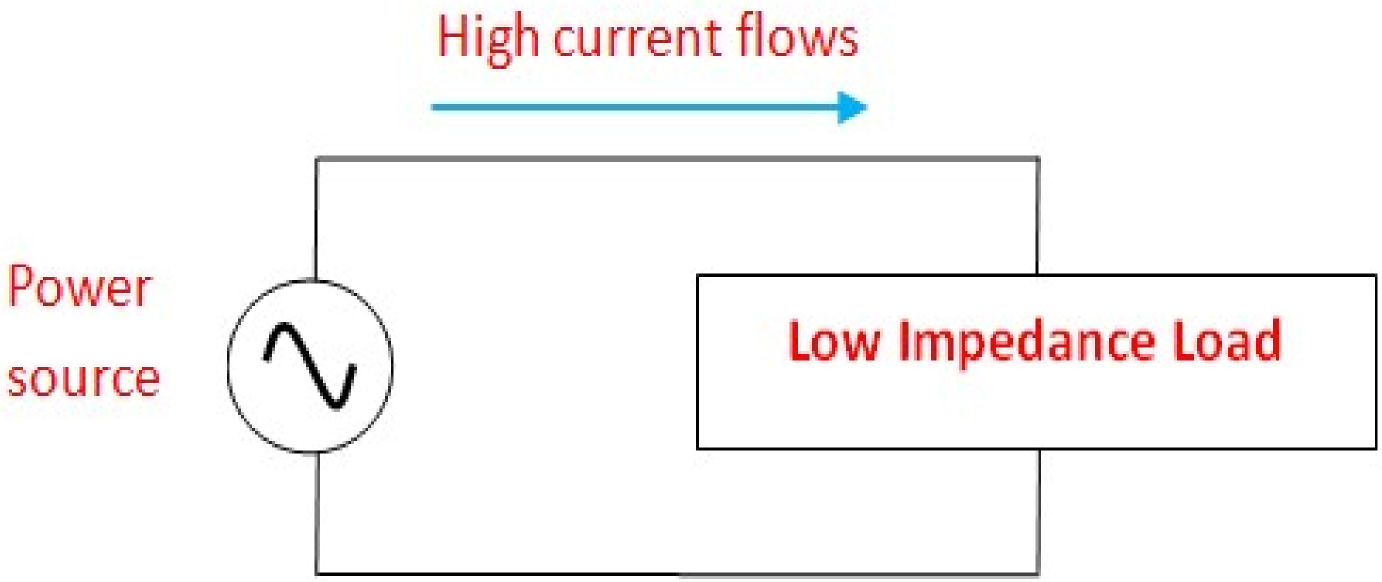


$$Current = \frac{Voltage}{Resistance}$$

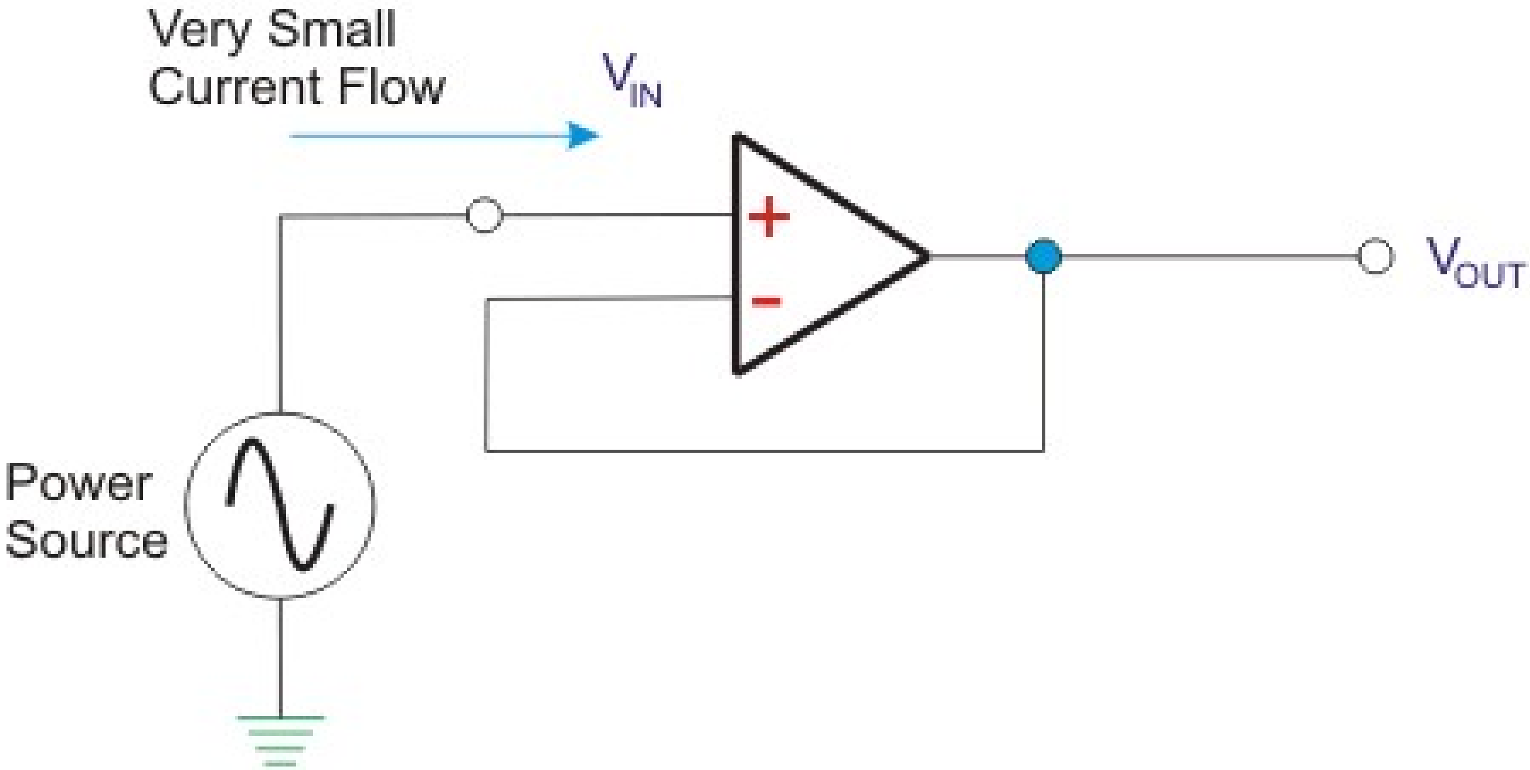
Voltage Follower

- So, we can say that when resistance increases, the current drawn from the power source decreases.
- Thus, we conclude that the power is unaffected if the current is feeding a load of high impedance.
- First, we can consider a circuit of low impedance load and a power source is feeding it shown below.
- Here, a large amount of current is drawn by the load due to the low resistance load as explained by Ohm's law.
- Thus, the circuit takes a large amount of power from the power source, resulting in high disturbances in the source.

Voltage Follower



Voltage Follower



Voltage Follower

- **Advantages of Voltage Follower**
- Provides power gain and current gain.
- Low output impedance to the circuit which uses the output of the voltage follower.
- The Op-amp takes zero current from the input.
- Loading effects can be avoided.

Voltage Follower

- **Applications of Voltage Follower**
- Buffers for logic circuits.
- In Sample and hold circuits.
- In Active filters.
- In Bridge circuits via transducer.

LM 723 Variable Voltage Regulator

- Disadvantages of fixed voltage regulator:

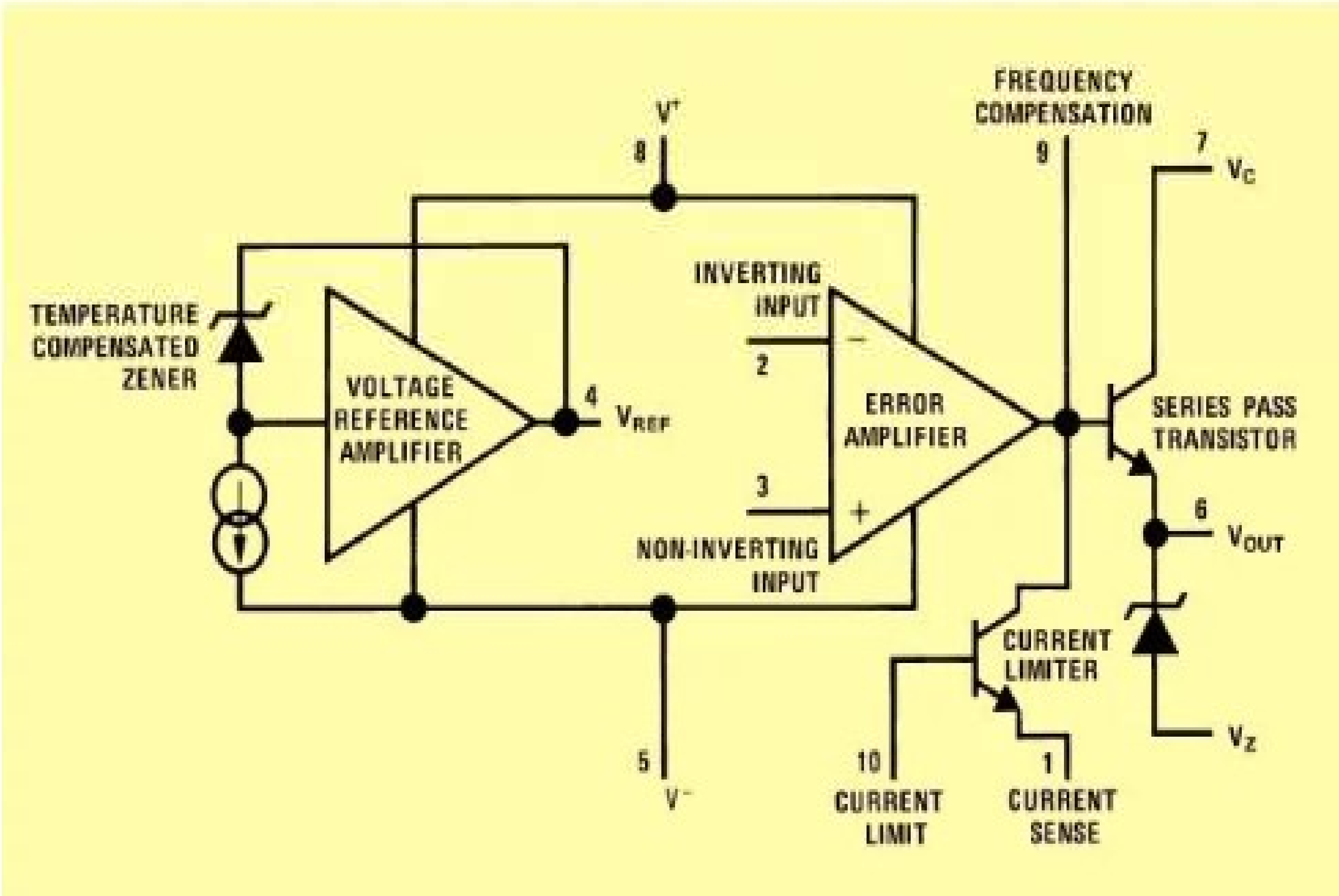
  - Do not have the shot circuit protection
  - Output voltage is not adjustable

- These limitations can be overcomes in IC723

Features of IC723

- Unregulated dc supply voltage at the input between 9.5V & 40V
- Adjustable regulated output voltage between 2 to 3V.
- Maximum load current of 150 mA
- Positive or Negative supply operation
- Internal Power dissipation of 800mW.
- Built in short circuit protection.
- Very low temperature drift.
- High ripple rejection

Functional block diagram of IC723



Four blocks of functional block diagram

- The simplified functional block diagram can be divided in to 4 blocks.
    1. Reference generating block
    2. Error Amplifier
    3. Series Pass transistor
    4. Circuitry to limit the current

1. Reference Generating block

- The temperature compensated Zener diode, constant current source & voltage reference amplifier together from the reference generating block.
- The Zener diode is used to generate a fixed reference voltage internally.
- Constant current source will make the Zener diode to operate at affixed point & it is applied to the Non – inverting terminal of error amplifier.
- The Unregulated input voltage $\pm V_{cc}$ is applied to the voltage reference amplifier as well as error amplifier.

2. Error Amplifier

- Error amplifier is a high gain differential amplifier with 2 input

  Inverting &

  Non-inverting
- The Non-inverting terminal is connected to the internally generated reference voltage.
- The Inverting terminal is connected to the full regulated output voltage.

3. Series Pass Transistor

- Q1 is the internal series pass transistor which is driven by the error amplifier. This transistor actually acts as a variable resistor & regulates the output voltage.
- The collector of transistor Q1 is connected to the Un-regulated power supply.
- The maximum collector voltage of Q1 is limited to 36Volts.
- The maximum current which can be supplied by Q-1 is 150mA.

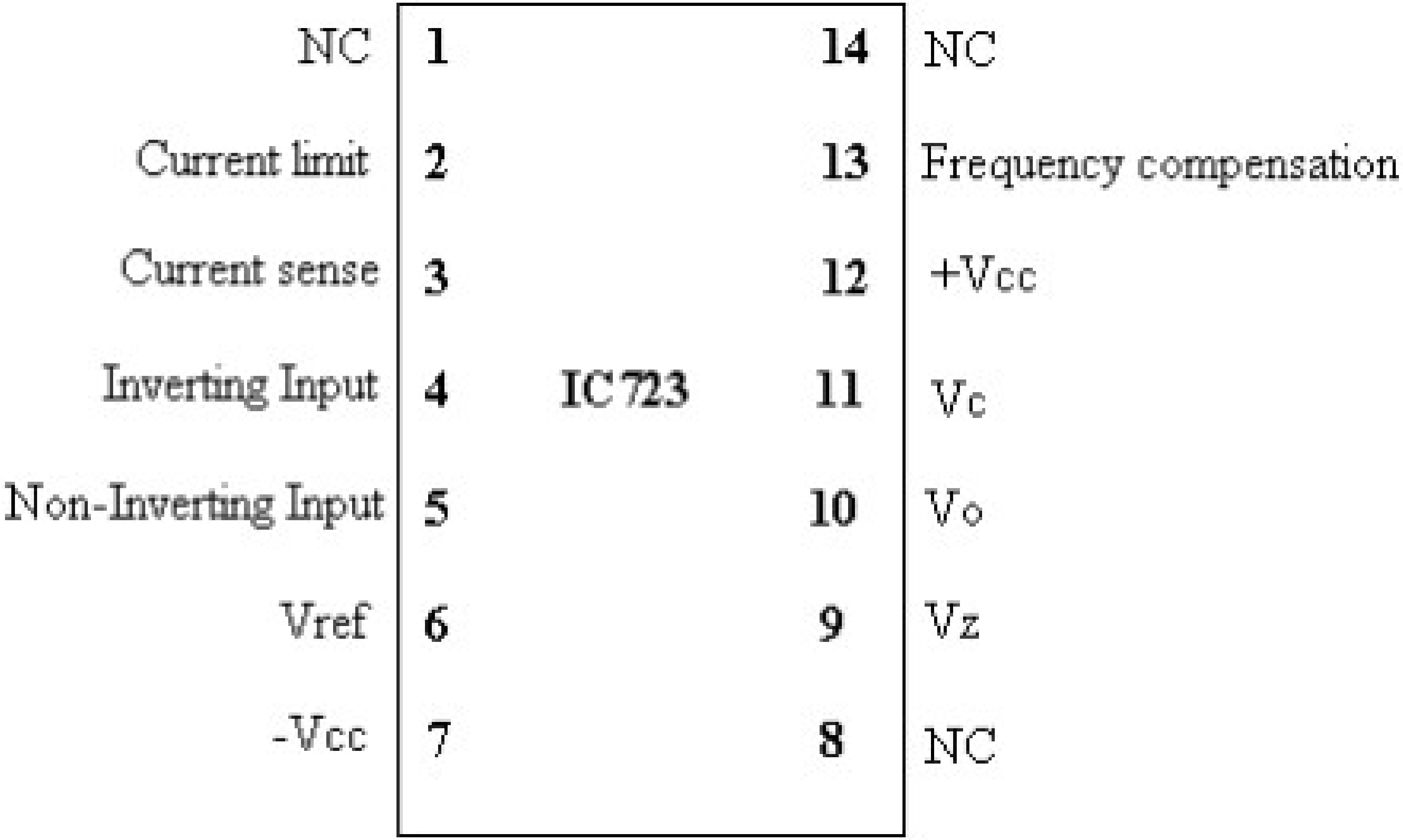
4. Circuitry to limit the current

- The internal transistor Q2 is used for current sensing & limiting.
- Q2 is normally OFF transistor.
- It turns ON when the I_L exceeds a predetermined limit.
- Low voltage, Low current is capable of supplying load voltage which is equal to or between 2 to 7Volts.

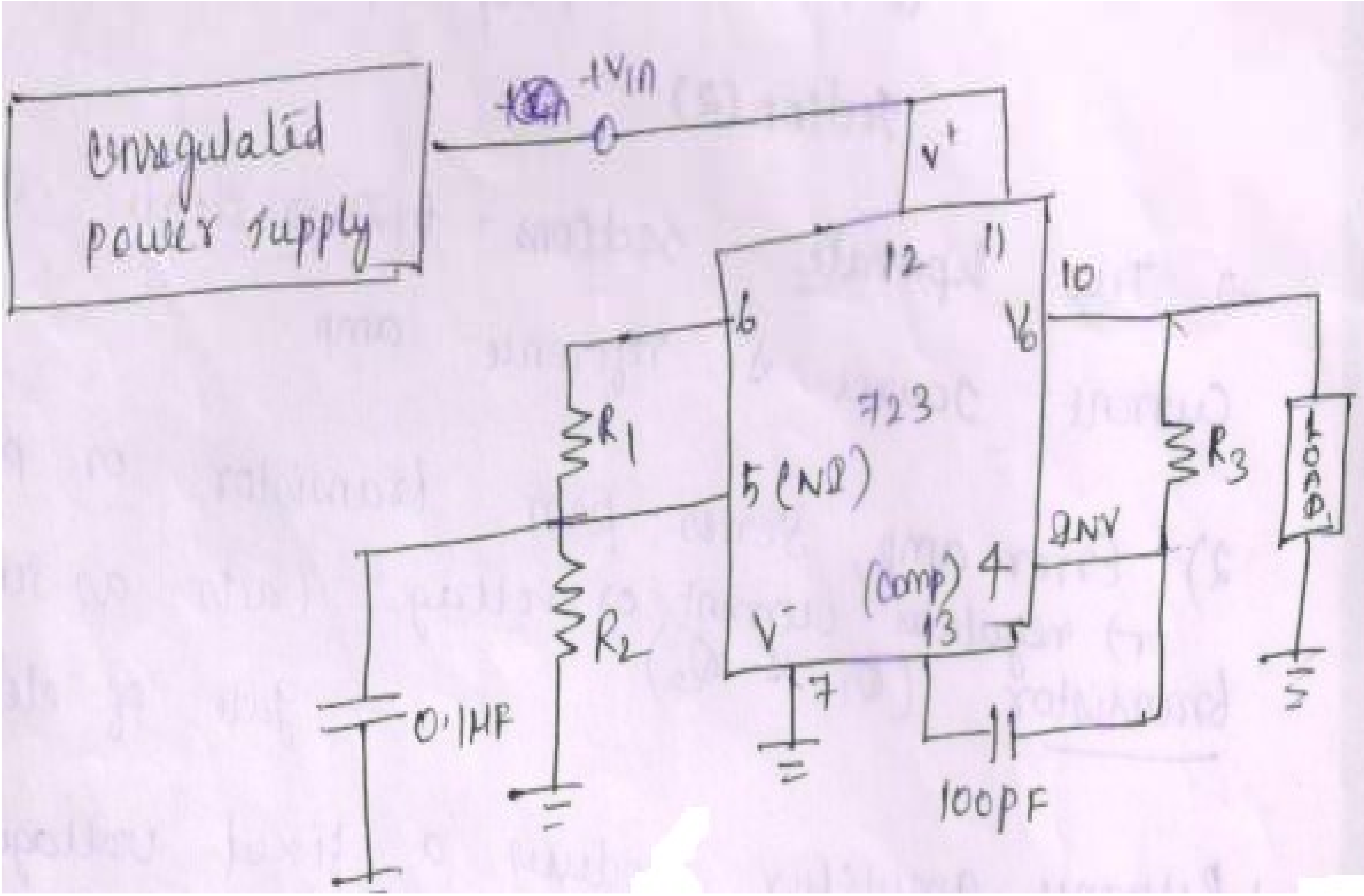
V_{load} = 2 to 7 V

I_{load} = 150 mA

Pin diagram of IC723



IC723 as a LOW voltage LOW current



Contd…..

- R_1 & R_2 from a potential divider between V_{ref} & Gnd.
- The Voltage across R_2 is connected to the Non – inverting terminal of the regulator IC

$$V_{non\text{-}inv} = \frac{R2}{R1 + R2} V_{ref}$$

- Gain of the internal error amplifier is large

$$V_{non\text{-}inv} = V_{in}$$

- Therefore the V_o is connected to the Inverting terminal through R_3 & R_{SC} must also be equal to $V_{non\text{-}inv}$

Contd…..

$$Vo = Vnon\text{-}inv = \frac{R2}{R1 + R2} Vref$$

- R_1 & R_2 can be in the range of 1 KΩ to 10KΩ & value of R_3 is given by

$$R3 = R1 ll R2 = \frac{R1R2}{R + R2}$$

- R_{sc} (current sensing resistor) is connected between C_s & C_L. The voltage drop across R_{sc} is proportional to the I_L.

Contd…..

- The current sourcing capacity is increased by including a transistor Q in the circuit

$$\text{The output voltage , Vo} = \frac{R2}{R1 + R2}\text{Vref}$$

THANK YOU