ELECTRONIC DEVICES

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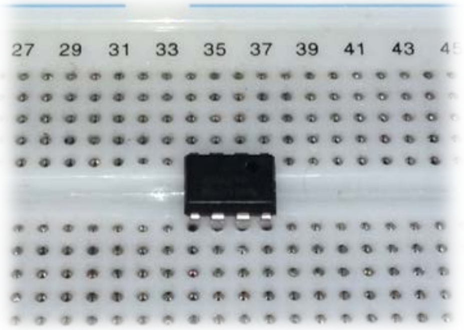
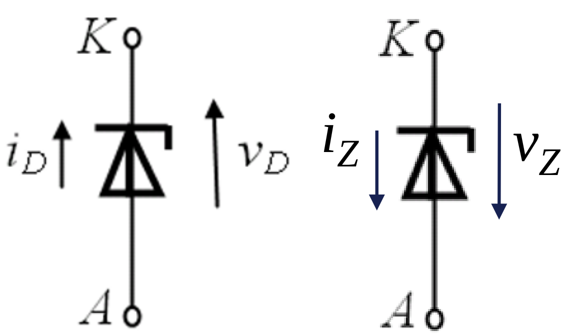
C5 – Zener diodes. Operational amplifiers.



Contents

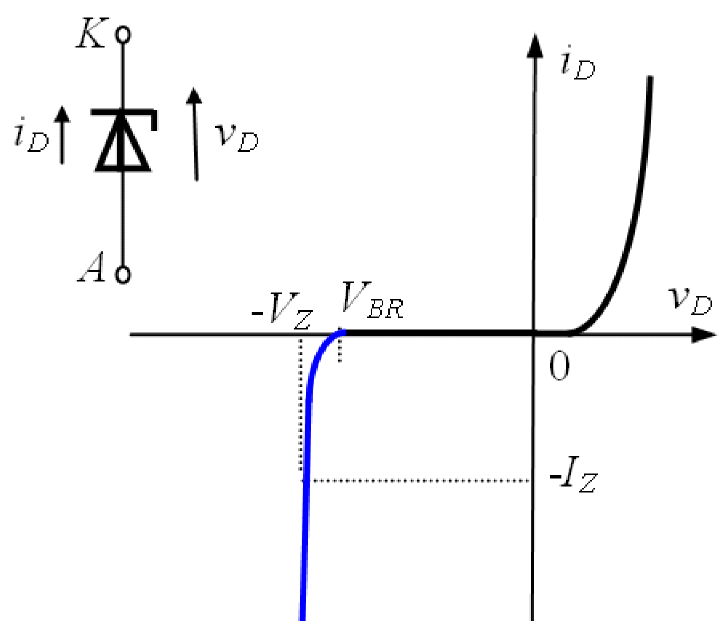
Zener diodes (ZD)

- named after CM Zener (American physicist)
- ZDs are used in the breakdown region (regulation region)
- working w/ negative values is usually frowned upon -> inverted *i* and *V*



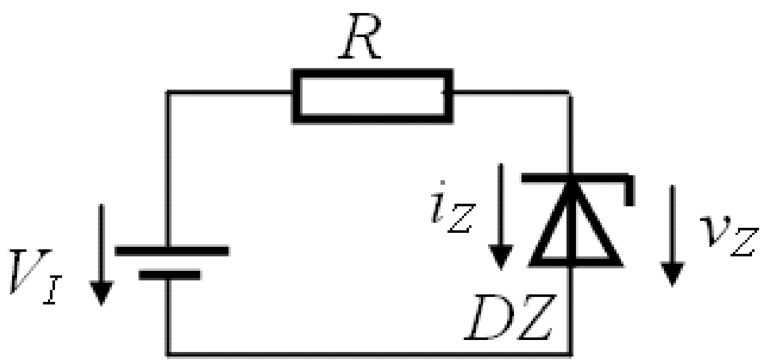
$$i_Z = -i_D$$

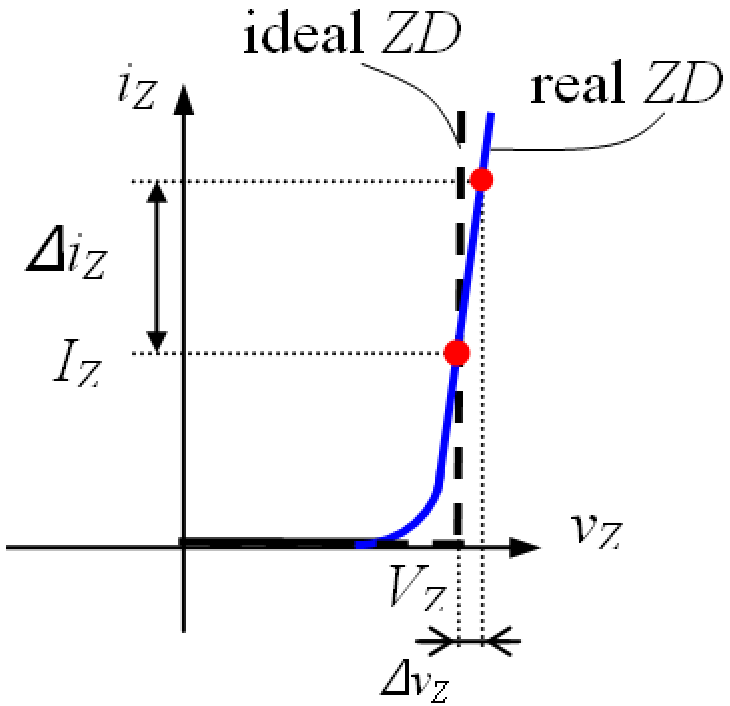
$$v_Z = -v_D$$



Zener diodes (ZD)

- typically used for regulation purposes – ZD provides a constant V_Z , if I_Z stays between certain boundaries

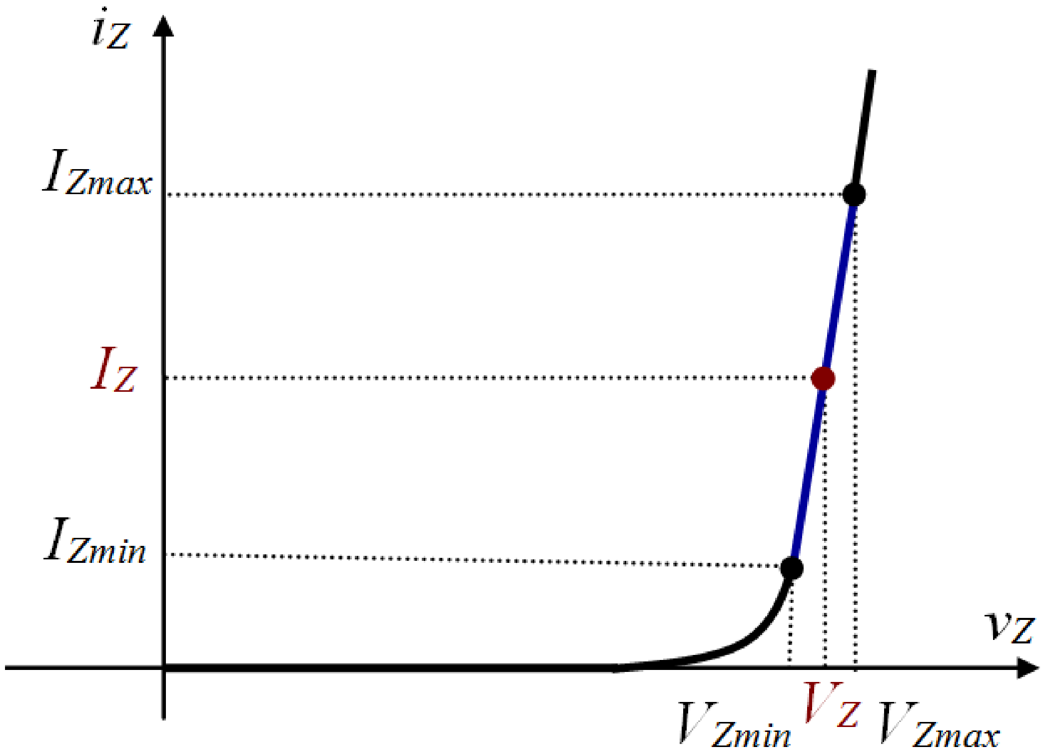




Relative regulation factor of ZD

$$F_Z = \frac{\frac{\Delta v_Z}{V_Z}}{\frac{\Delta i_Z}{I_Z}}$$

Zener diodes (ZD) – regulation region



$$I_{Z\max} = \frac{P_{d\max}}{V_Z}$$

$$V_Z @ I_Z$$

Excerpt from the datasheet

FAIRCHILD SEMICONDUCTOR®

1N4728A - 1N4758A
Zener Diodes

Tolerance = 5%

DO-41 Glass case
COLOR BAND DENOTES CATHODE

$$P_{Dmax} = 1\text{W}$$

Electrical Characteristics T_a = 25°C unless other

Device	V_Z (V) @ I_Z (Note 1)			Test Current I_Z (mA)
	Min.	Typ.	Max.	
1N4728A	3.135	3.3	3.465	76
1N4729A	3.42	3.6	3.78	69
1N4730A	3.705	3.9	4.095	64
1N4731A	4.085	4.3	4.515	58
1N4732A	4.465	4.7	4.935	53
1N4733A	4.845	5.1	5.355	49
1N4734A	5.32	5.6	5.88	45
1N4735A	5.89	6.2	6.51	41
1N4736A	6.46	6.8	7.14	37
1N4737A	7.125	7.5	7.875	34
1N4738A	7.79	8.2	8.61	31
1N4739A	8.645	9.1	9.555	28
1N4740A	9.5	10	10.5	25
1N4741A	10.45	11	11.55	23
1N4742A	11.4	12	12.6	21

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1N4728A - 1N4758A Rev. H3

OPTIONAL

Example

I_Z = 5 mA:

1) DZ 3V6 V_Z = 3.6 V; r_{zmax} = 95 Ω; r_Z = 0.72 KΩ
2) DZ 5V1 V_Z = 5.1 V; r_{zmax} = 60 Ω; r_Z = 1.02 KΩ
3) DZ 10 V_Z = 10 V; r_{zmax} = 15 Ω; r_Z = 2 KΩ

$$F_{Z1} = \frac{95}{720} = 0.132$$

$$F_{Z2} = \frac{60}{1020} = 0.059$$

$$F_{Z3} = \frac{15}{2000} = 0.0075$$

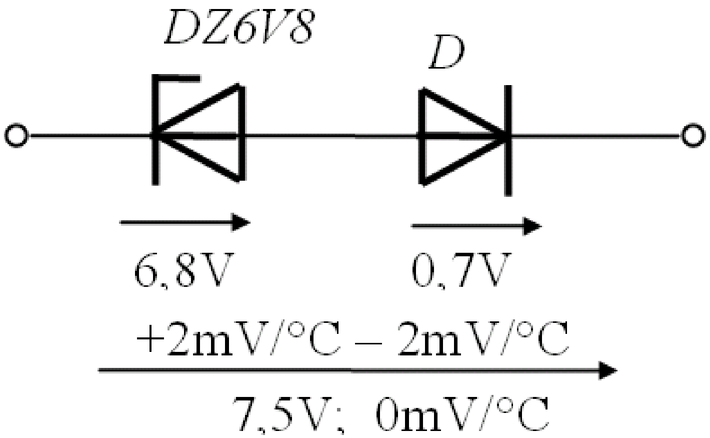
Temperature dependence

- The thermal coefficients TC of ZDs depend on the operating current and voltage.

- ZDs w/ Zener effect (V_Z = 2...5 V): negative TC
- ZDs w/ avalanche multiplication (V_Z > 5 V): positive TC

- DZ5V1 V_Z = 5.1 V, TC ~ 0 mV/°C, for small currents.
- DZ6V8 V_Z = 6.8V, TC ~ 2 mV/°C.

Cancelling the temperature dependence

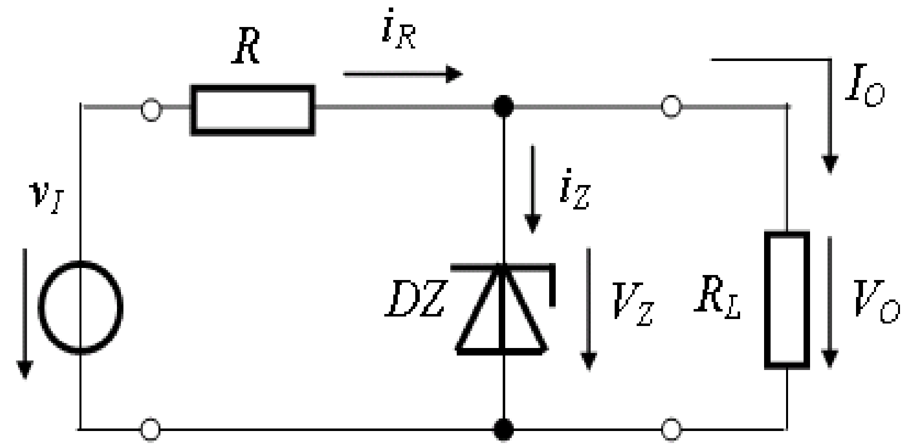


Zener diodes - applications

- Parametric voltage regulator

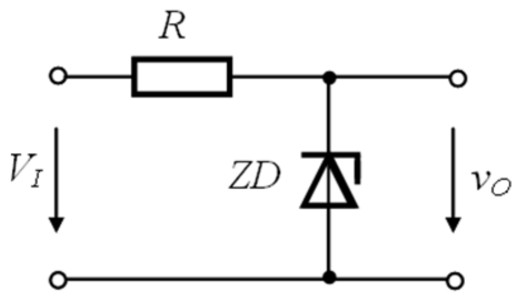
$$i_z = \frac{V_I - V_Z}{R} - I_O$$

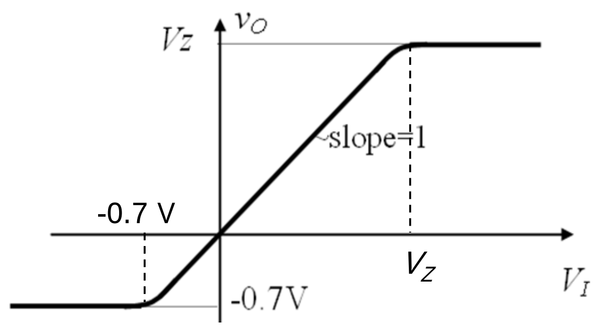
$$R = \frac{V_I - V_Z}{I_{Znom} + I_O}$$



Zener diodes - applications

➢ Double voltage clamp (limiter)



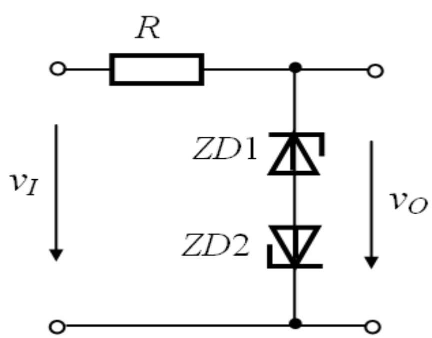


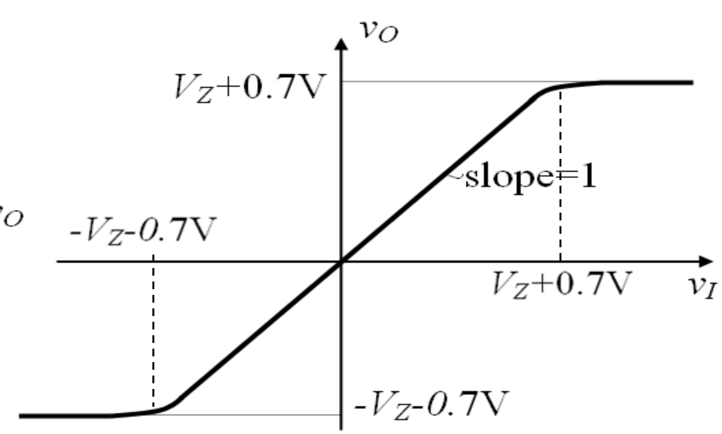
$$-0.7 < v_I < V_Z,\ ZD-(off),\ v_O = v_I$$

Typical use: protection circuits

$$v_I > V_Z,\ ZD-(on) \text{ in reverse bias (voltage regulation region)}, v_O = V_Z$$

$$v_I < -0.7\text{V},\ ZD-(on) \text{ in forward bias},\ v_O = -0.7\text{V}$$



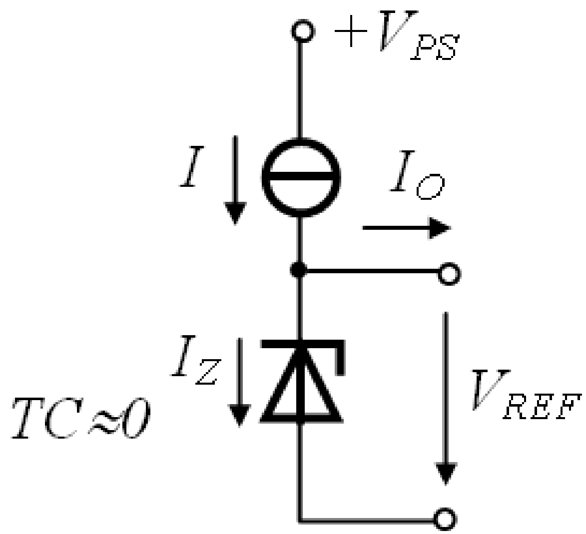


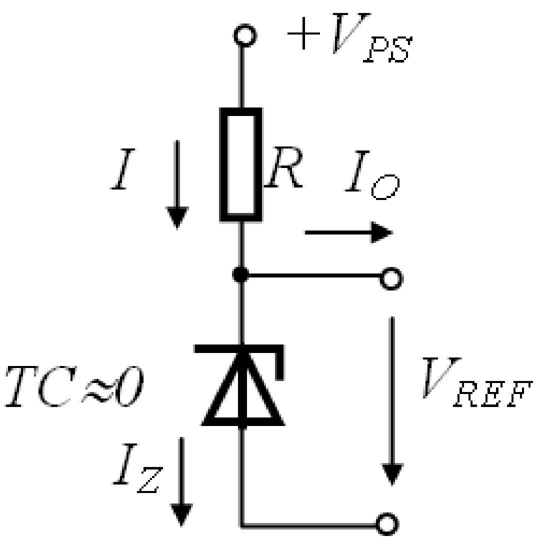
Zener diodes - applications

➢ Voltage reference

= electronic device that ideally produces a constant voltage, regardless of the loading on the device, power supply variations, temperature changes, and the passage of time.

$I_o << I_z$

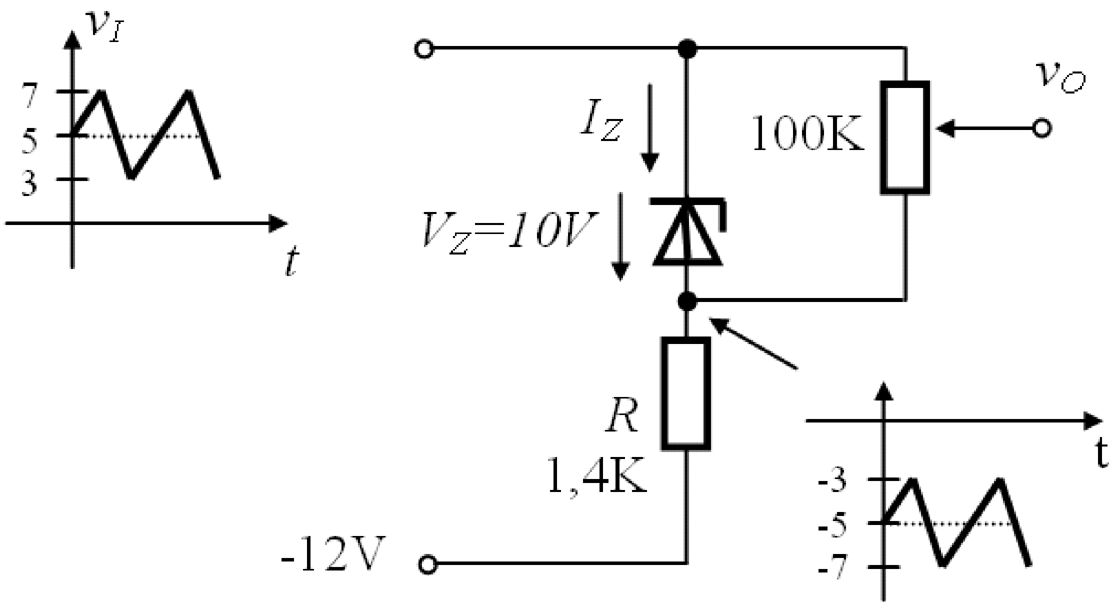




Typical uses: power supplies, AD/DA converters, measurement and control systems.

OPTIONAL

- DC component adjustment for a variable signal



OpAmp

- invented by Karl D. Swartzel Jr., Bell Labs, 1941
- IC containing a relatively large number of transistors and passive components (R)

on the same chip (e.g. OpAmp 741 contains 24 T, 12 R and 1 C).

OpAmps are packed in plastic or metal cases, with 8, 14 or 16 terminals.

Surface-mount technology (SMT)

Through-hole technology

OpAmp

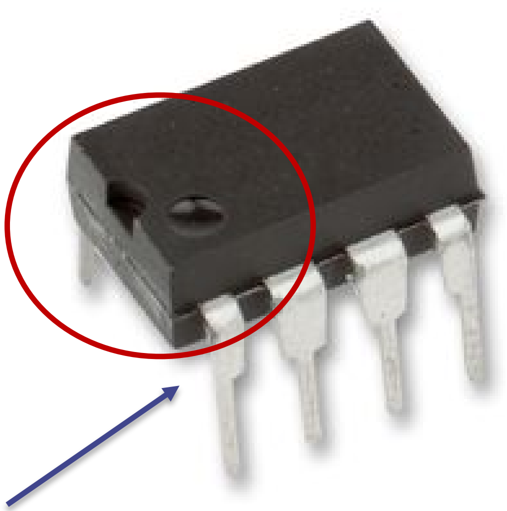
- very popular ICs, due to versatility and ease of use
- terminal characteristic that closely approach the ideal amplifier
- wide variety, optimized for: speed, low noise, low power consumption, high gain, maximum output swing (rail-to-rail), etc

OpAmps will be discussed as electronic devices, focusing on the terminal characteristics and main applications.

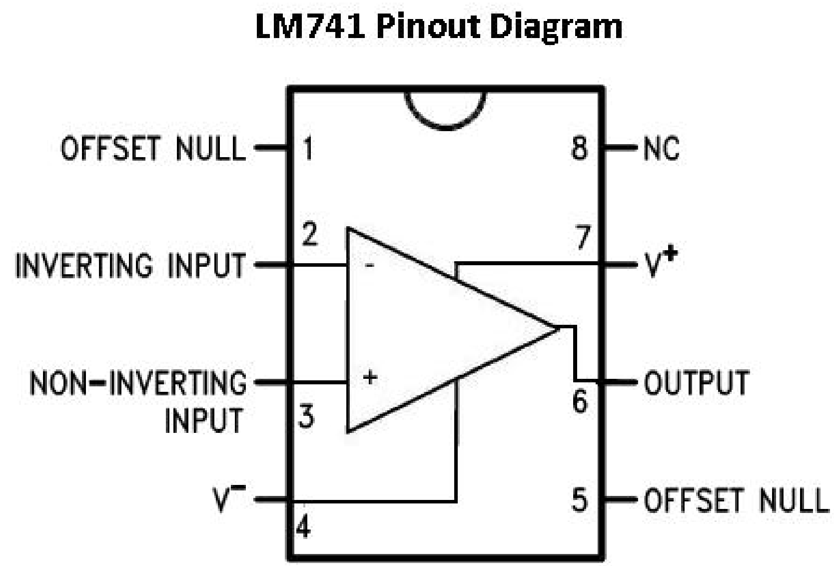
The internal structure is of no interest, at this point.

OpAmp terminals

OpAmp – plastic case, 8 terminals (pins)

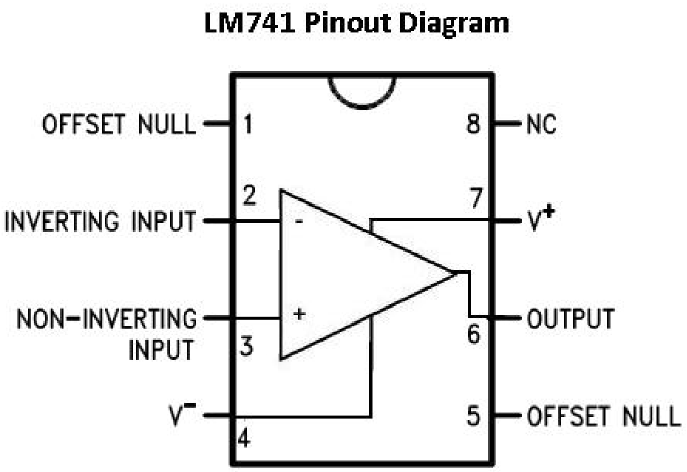


#1



The Operational Amplifier

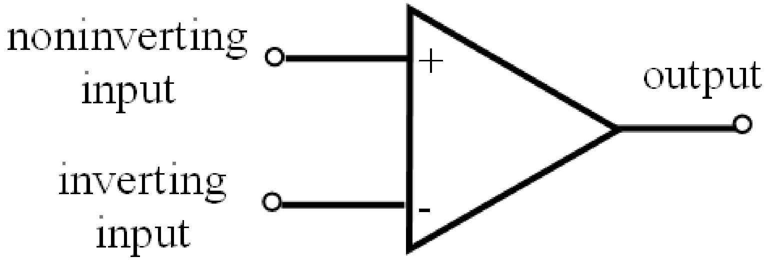
OpAmp terminals

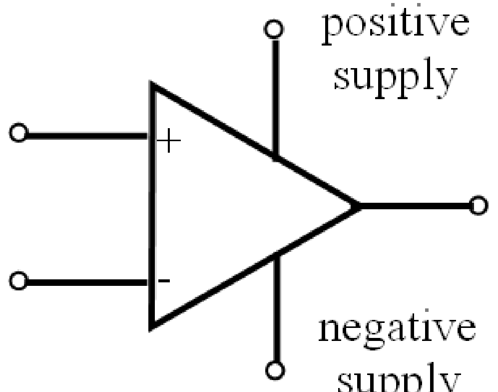


5 terminals - 2 for input voltages (#2 & #3)

- 2 for power supplies (#4 & #7)

- 1 for output voltage (#6)

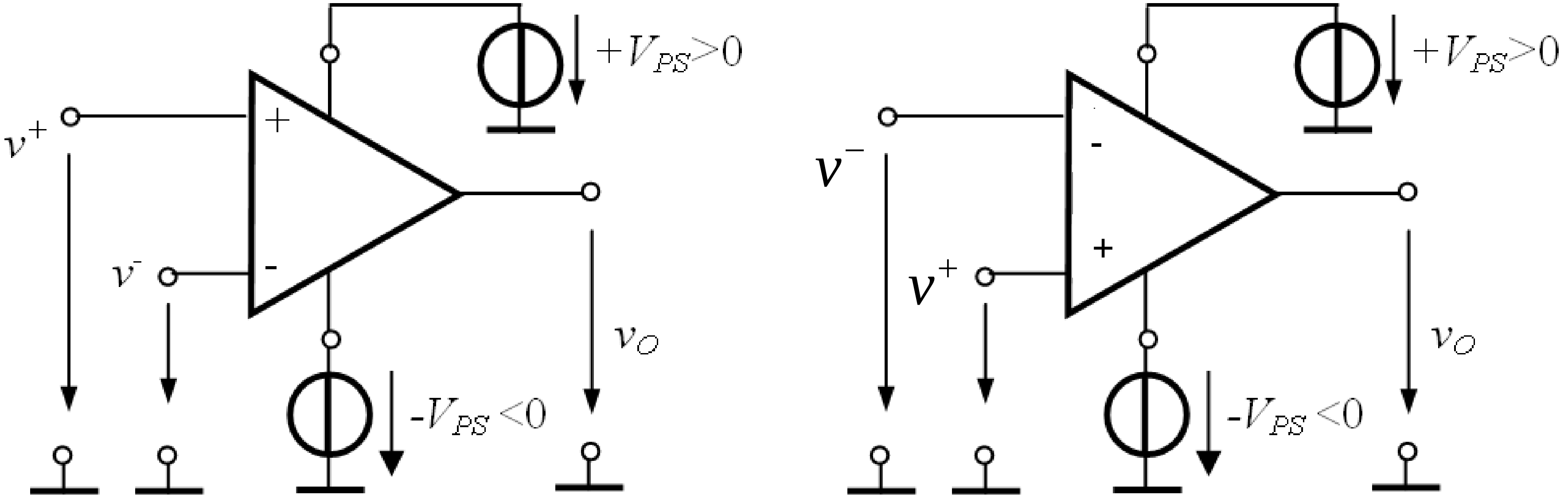




OpAmp terminals

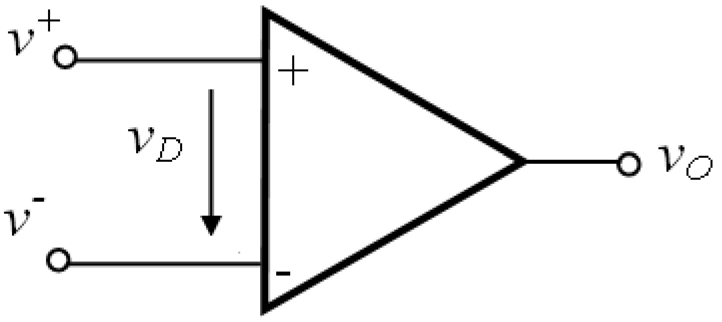
The supply terminals are frequently omitted from circuit schematics, assuming a correct supply.

!Find the difference!



OpAmp operation

a – OpAmp gain (very large, i.e. 2*10^6)



$$v_O = a v_D$$

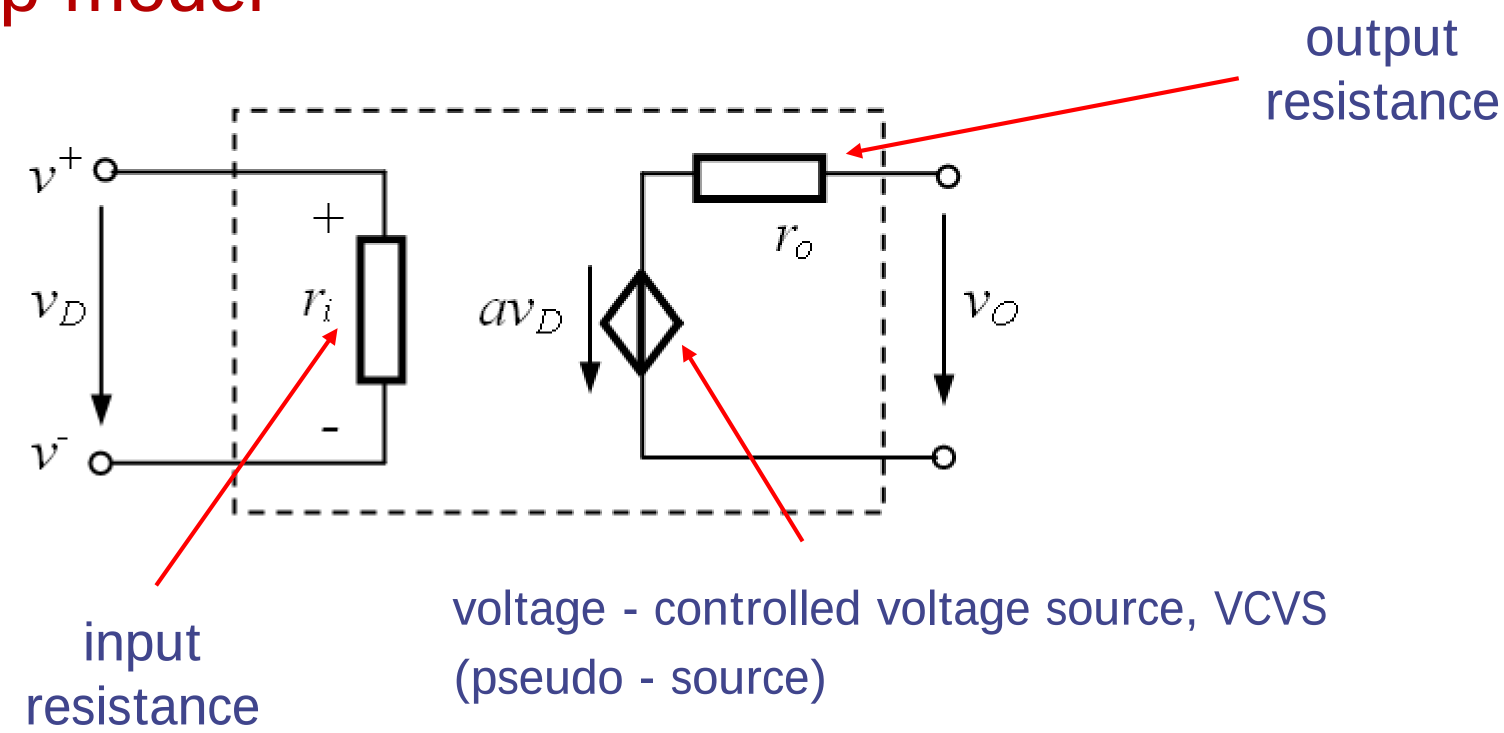
$$v_D = v^+ - v^-$$

$$\begin{cases} v_{O\max} = +V_{PS} \\ v_{O\min} = -V_{PS} \end{cases}$$

!Do not confuse:

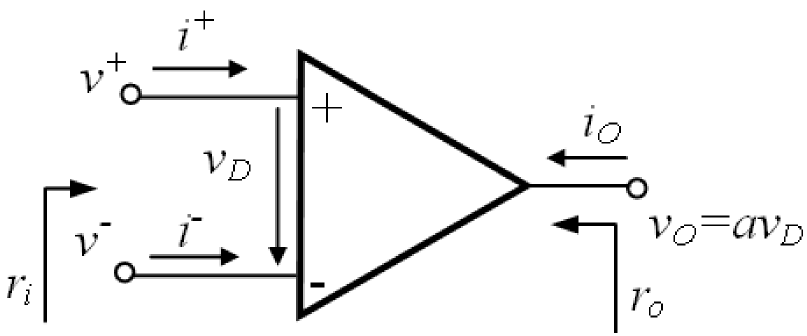
- differential voltage of OpAmp v_D
- diode voltage drop $v_D = 0.7V$

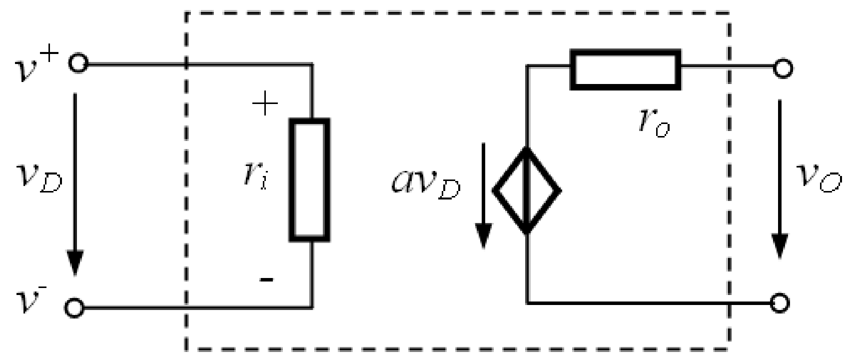
OpAmp model



- input voltage is $v_D = v^+ - v^-$
- if none of the inputs are connected to ground, there is no common terminal between input and output

Ideal OpAmp





Parameter	Ideal value	Effect
Input resistance	$r_i = \infty$	OpAmp does not draw any input currents $i_+ = i_- = 0$
Output resistance	$r_o = 0$	The output voltage is independent of the current into the load.
Bandwidth	$B = \infty$	The gain is constant over all the frequency range, from zero frequency (dc) and to infinite frequency.
Gain	$a = \infty$	

Relation between output and input voltages

Assuming an ideal OpAmp, what is the value of the output voltage?

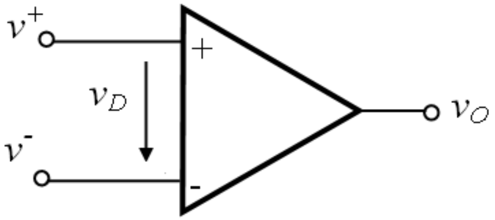
$$v_O = a v_D = \infty \cdot v_D$$

But $\begin{cases} v_{O\max} = +V_{PS} \\ v_{O\min} = -V_{PS} \end{cases}$

Solution?

Relation between output and input voltages

$$v_O = av_D = \infty \cdot v_D$$



I. Utilization as **comparator**, in switching mode

$$\mathbf{v_O \in \{V_{OL} ; V_{OH}\}}$$

$\mathbf{v_D > 0, v_O \to +\infty, v_O}$ limited by the positive supply $\mathbf{v_O = V_{OH} \approx +V_{PS}}$

$\mathbf{v_D < 0, v_O \to -\infty, v_O}$ limited by the negative supply $\mathbf{v_O = V_{OL} \approx -V_{PS}}$

II. Utilization as **amplifier**

$$\mathbf{v_O \in (V_{OL} ; V_{OH})}$$

It is mandatory that $v_D = 0$, so then $v_O = a \cdot v_D = \infty \cdot 0$ - indetermination

v_D is kept at 0 by means of external components (R)

Summary

- Zener diodes

The first encounter with the *little black bug* (OpAmp) revealed details about:

- The Operational Amplifier (OpAmp)
  - OpAmp terminals
  - OpAmp operation
  - OpAmp model
  - Ideal OpAmp
  - Relation between output and input voltages

Next week: Simple comparators with OpAmp.

To do: Homework 3