Analog Electronics

Unit 9

Unit 9. Power Supplies in analog systems

Contents

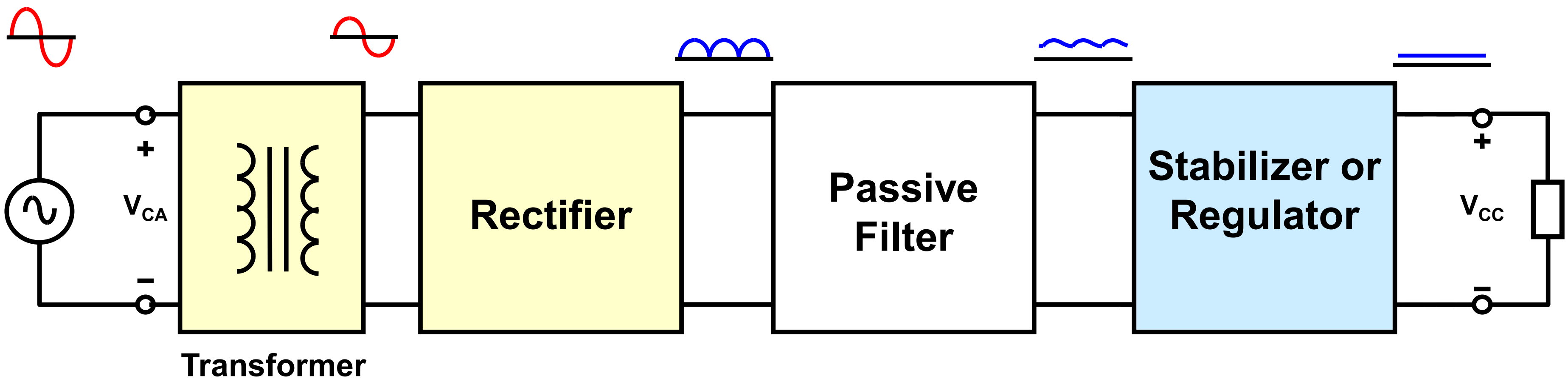
1. Introduction

- **Electronic circuits need one or several DC voltage sources to operate correctly.**

- **Voltage supply with batteries:**
  - Low autonomy and high cost
  - Acceptable for low consumption

- **Voltage supply from the net:**
  - The most common source of primary energy source
  - Alternate sinusoidal voltage
  - Net voltage must be converted to DC voltage

1. Introduction



- Adapts voltage and current levels
- Stabilizes the signal

2. Initial stages. Transformer

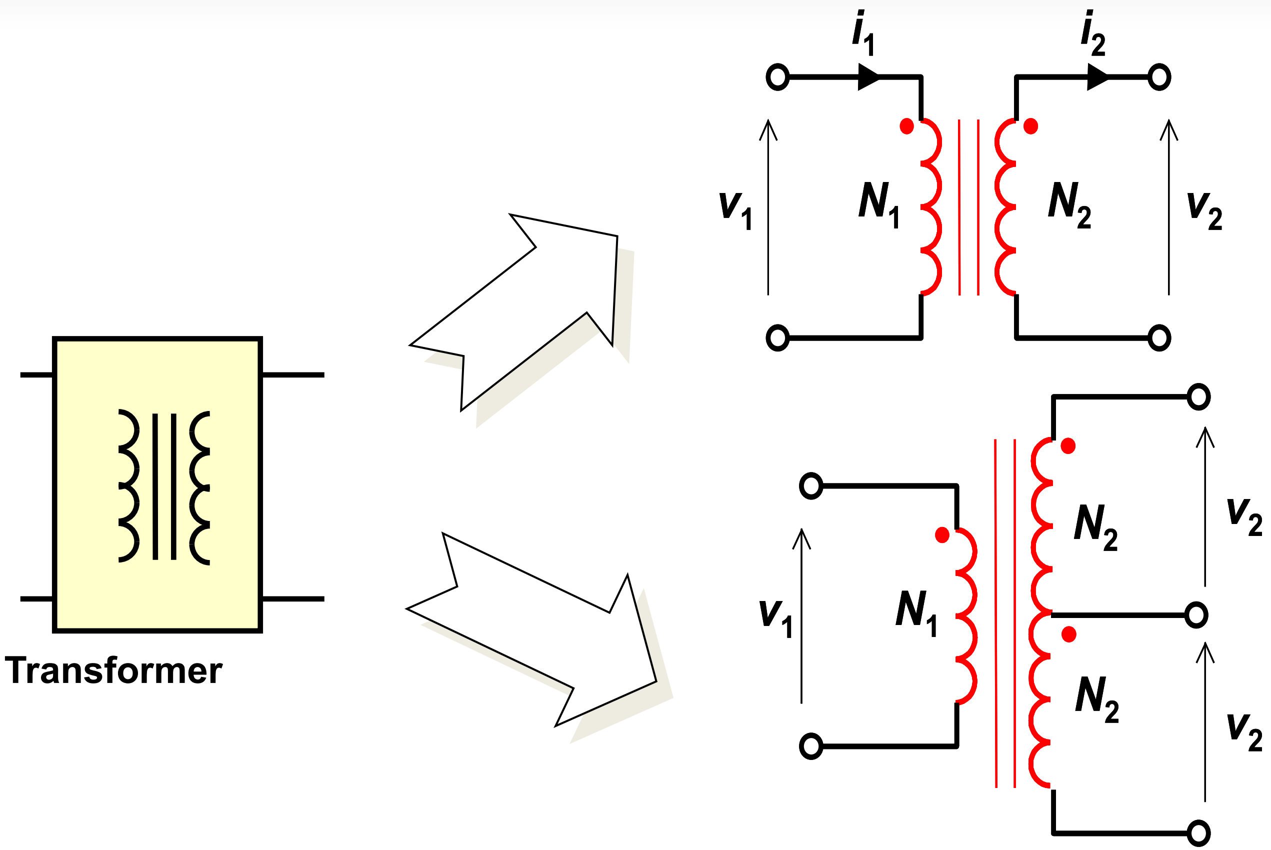
Main functions:

- Adaptation of the net voltage to the value required by the load → $N_1 : N_2$
- Provide galvanic isolation → Protection of the user

Several configurations depending on the choosed rectifier:

- Primary-secondary
- Transformer with tapped secondary (toma intermedia)

2. Initial stages. Transformer



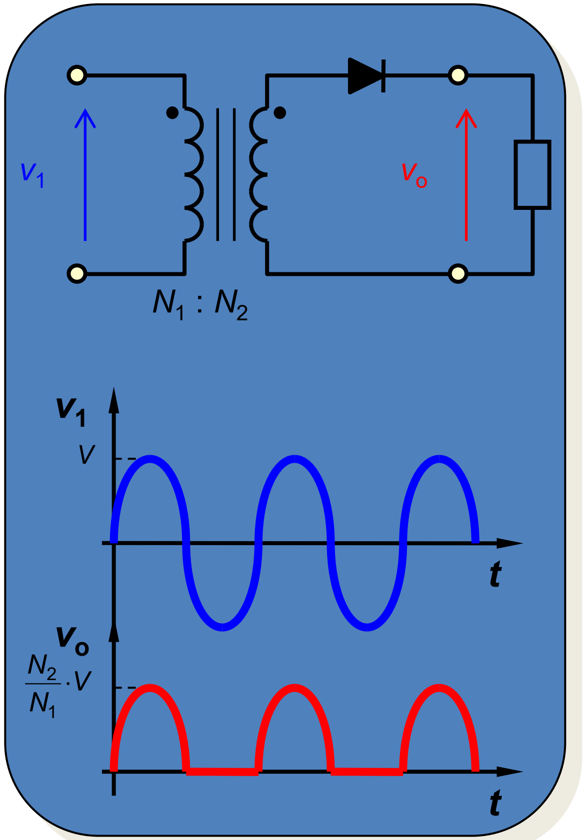
$$v_2 = \frac{N_2}{N_1} \cdot v_1$$

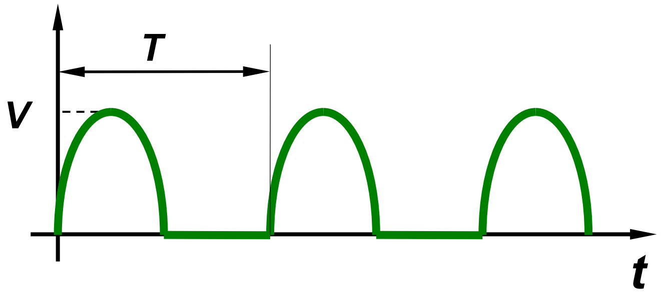
$$i_2 = \frac{N_1}{N_2} \cdot i_1$$

2. Initial stages. Rectifier

Converts tha AC voltage provided by the trafo into a pulsatory unidirectional voltage with a non-zero medium value.

Half-wave Rectifier

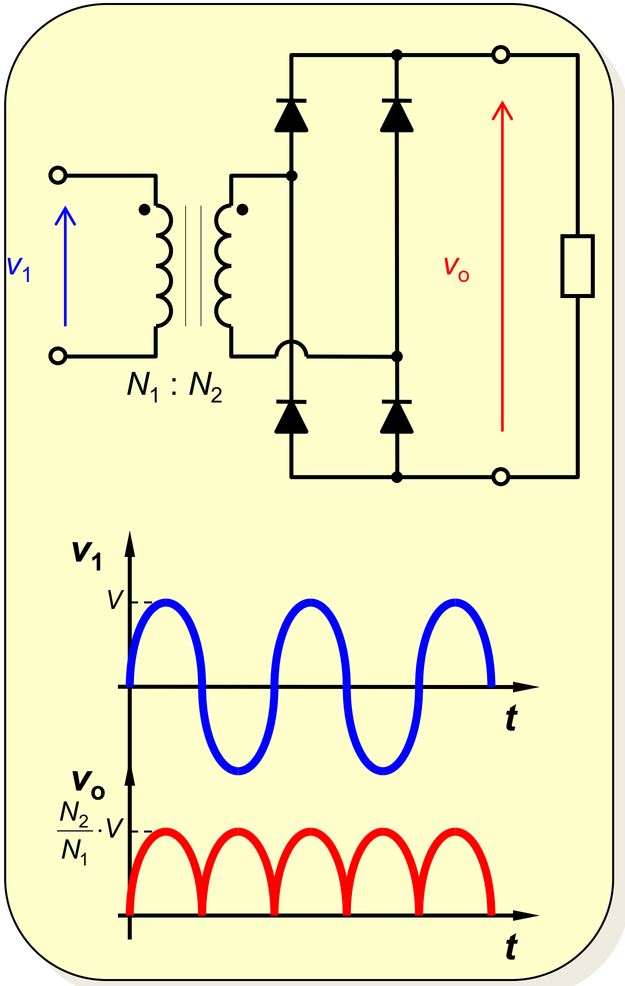




$$V_{cc} = \frac{V}{\pi}$$

2. Initial stages. Rectifier

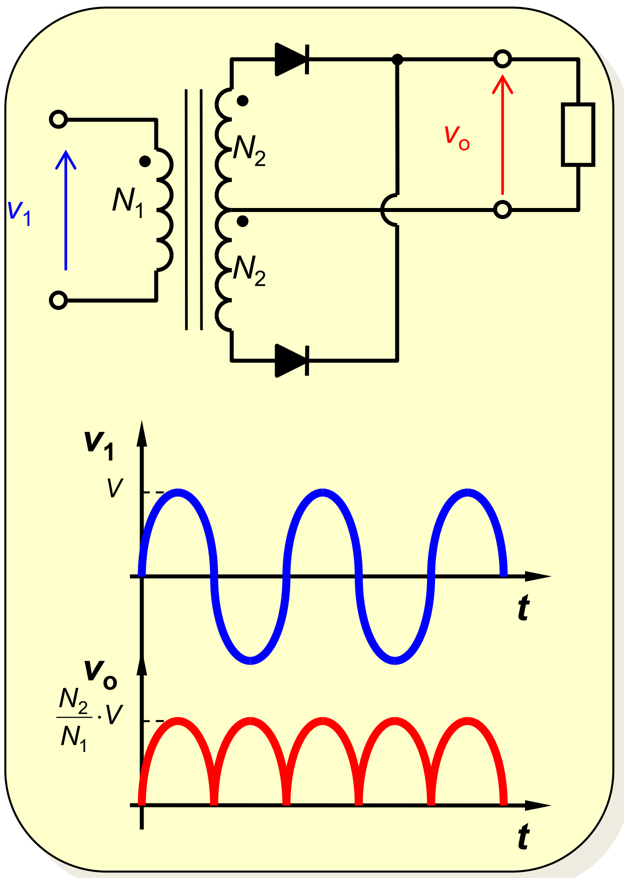
Full-wave Rectifier: Diodes bridge.



- During each hemicycle 2 diodes conduct simultaneously.
- Each diode supports an inverse voltage of the maximum voltage value of the secondary.
- This configuration is the most common.

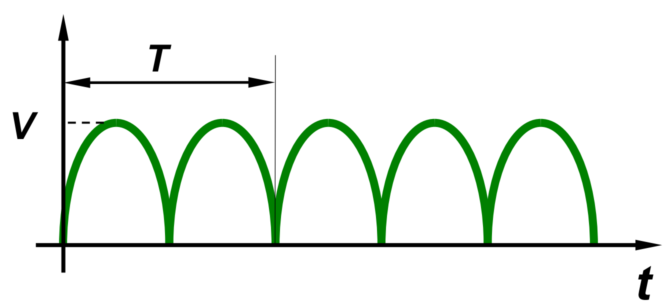
2. Initial stages. Rectifier

Full-wave Rectifier: with tapped secondary



- During each hemicycle only one diode conducts.

- Each diode supports an inverse voltage of the double of the maximum voltage value of each winding of the secondary.



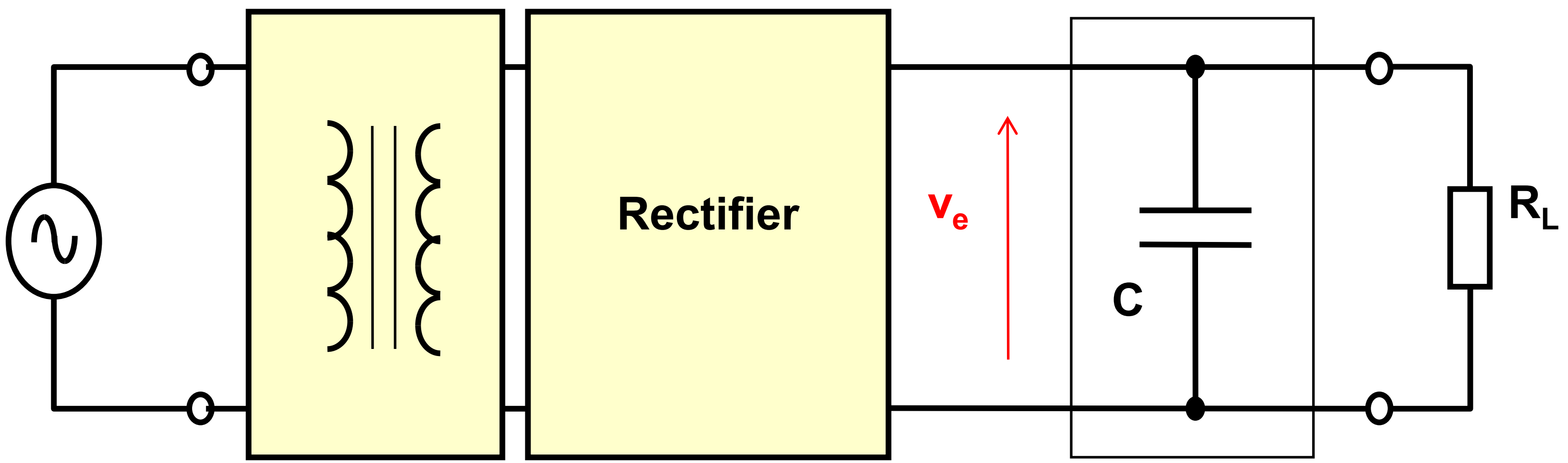
$$V_{cc} = \frac{2V}{\pi}$$

2. Initial stages. Rectifier

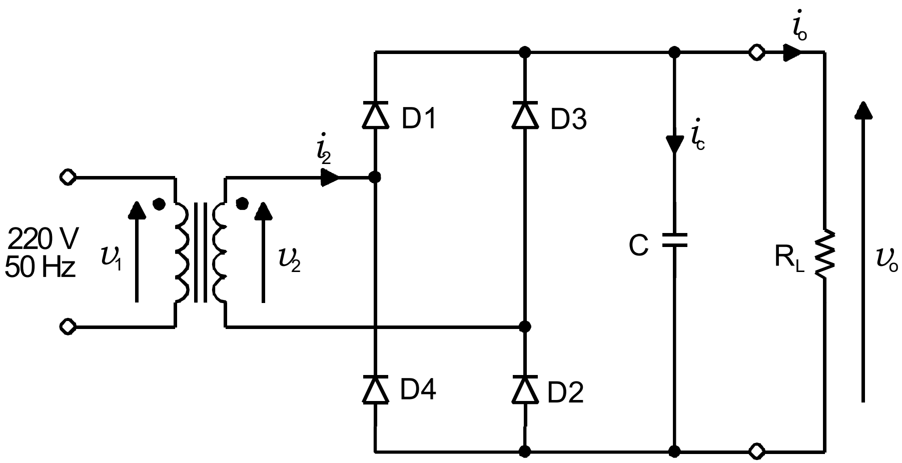
- **The selection of the diodes depends on the voltages and currents required in the specific application.**
  - Average forward current, $I_{F(AV)}$
  - Peak working reverse voltage, V_{RWM}
  - Repetitive forward peak current, I_{FRM}

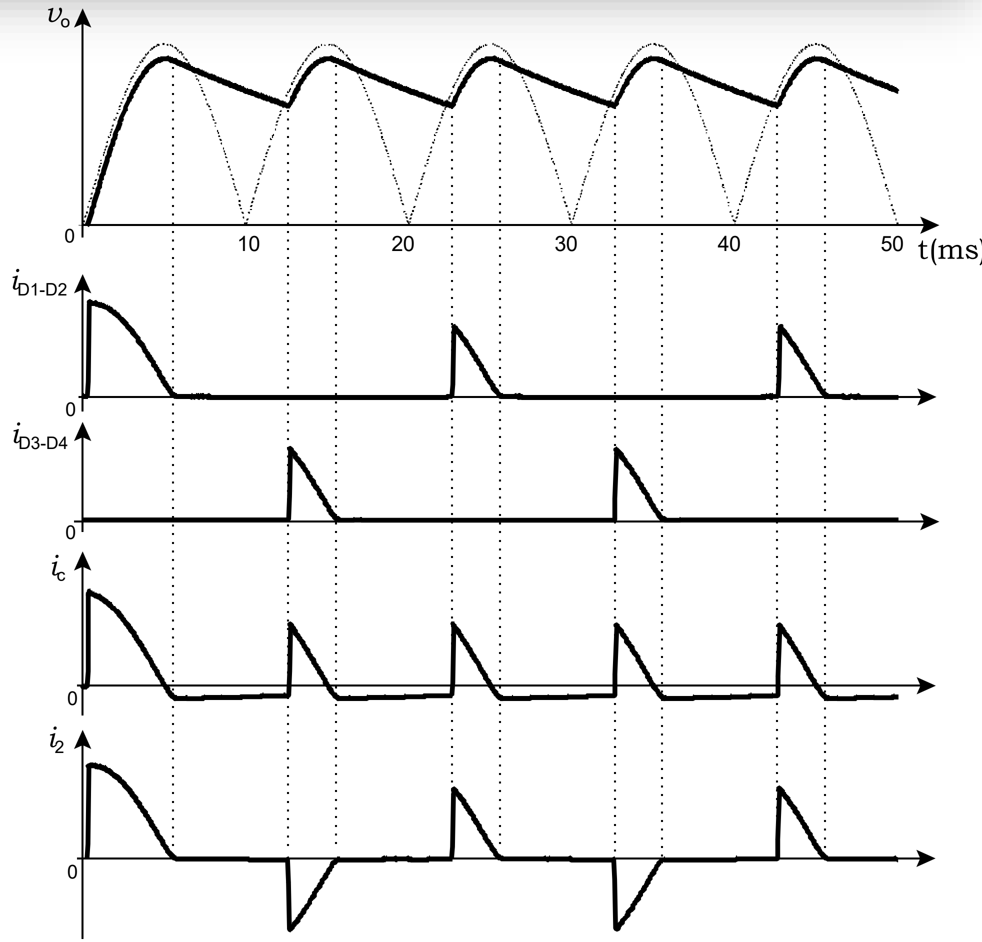
- **"General purpose" diodes are commonly used.**
  - Designed to work at low frequencies in rectification applications (< 400 Hz).
  - They can support currents of 1 to 25 A, with reverse voltages of 50 to 1000 V.
  - Rectifying bridges with 4 diodes are also available as integrated circuits.

2. Initial stages. Filter



2. Initial stages. Filter





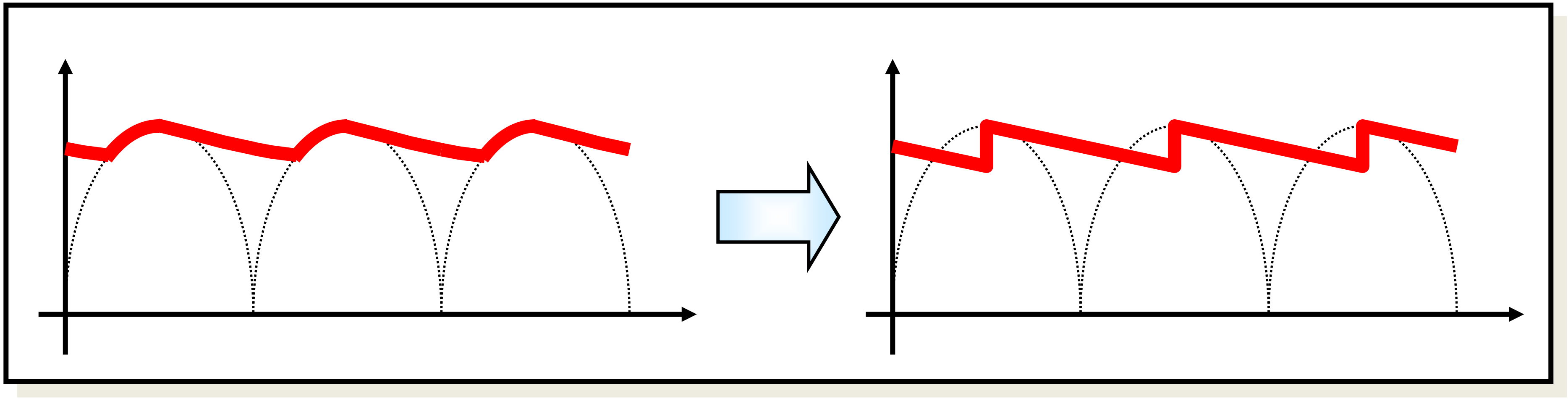
2. Initial stages. Filter

➢ Output voltage: exponential and sinusoidal

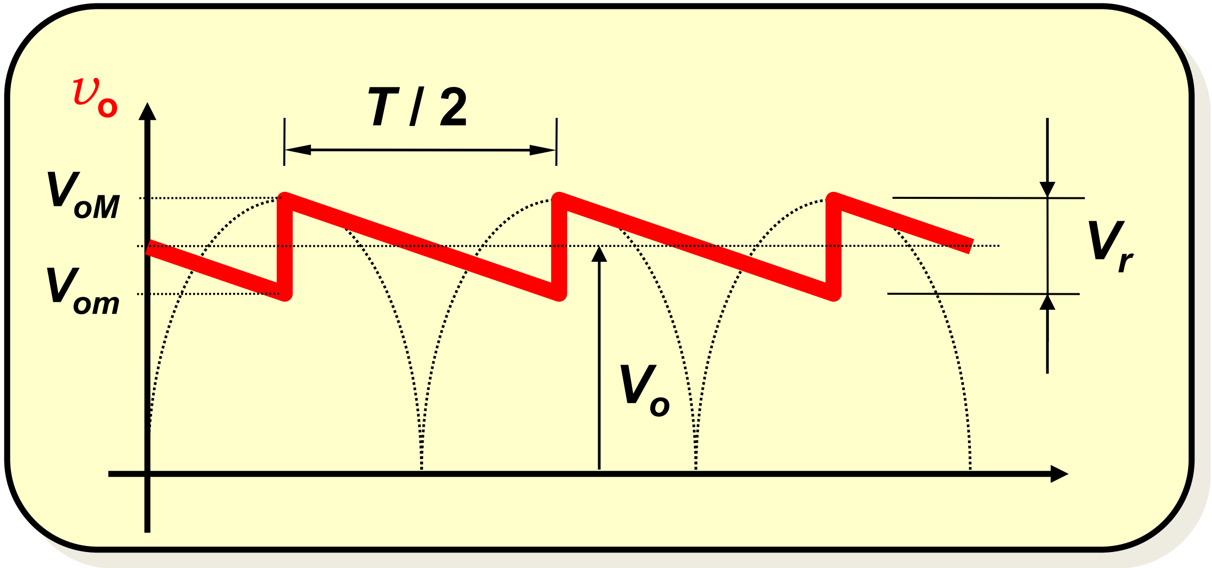
- The detailed analysis is complex

➢ Aproximation to a triangular waveform ➔ simplification

- Considers a lineal discharge of the capacitor (RL·C>>T/2)
- Supposes an instantaneous charge of C when the diodes conduct



2. Initial stages. Filter



- Supposes discharge of C at constant current.

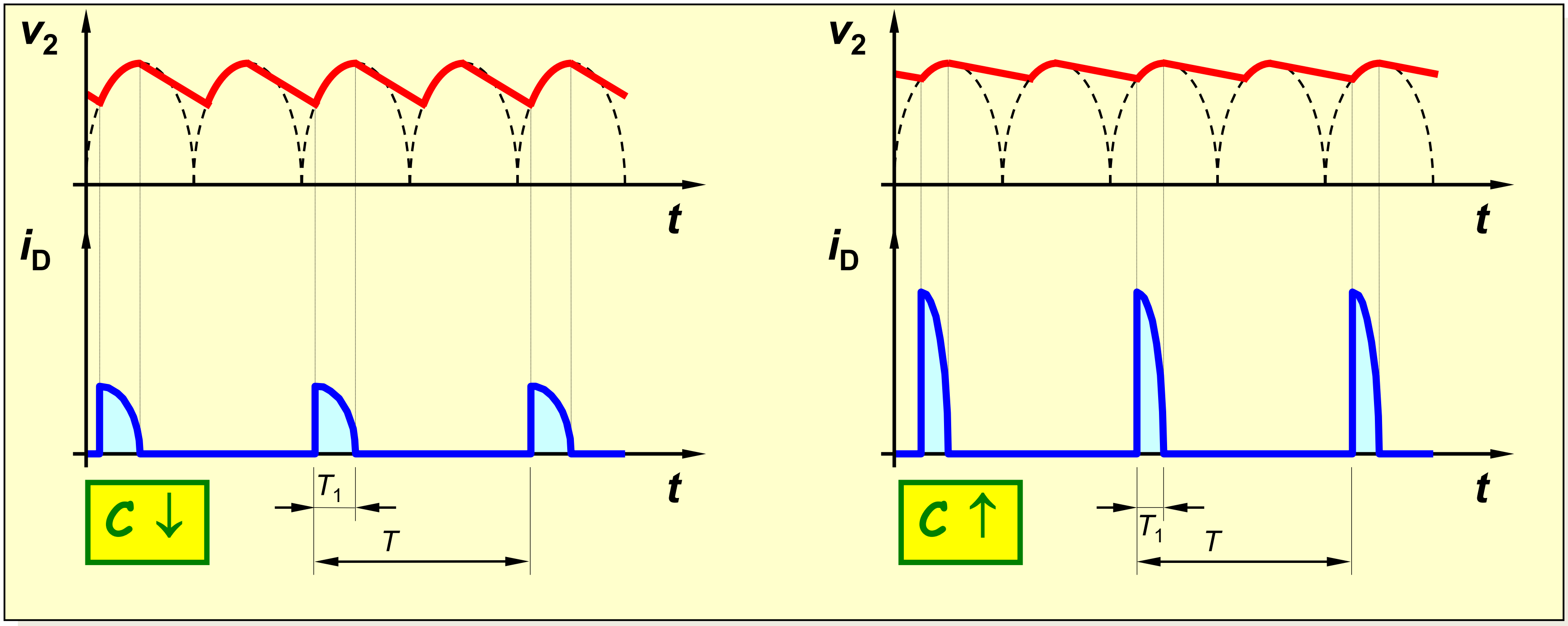
$$i_C = i_{load} = I_o$$

$$I_o \cong \frac{V_{o(cc)}}{R_L} = \frac{V_o}{R_L}$$

$$V_r = \frac{V_o}{2\,f\,R_L\,C} = \frac{I_o}{2\,f\,C}$$

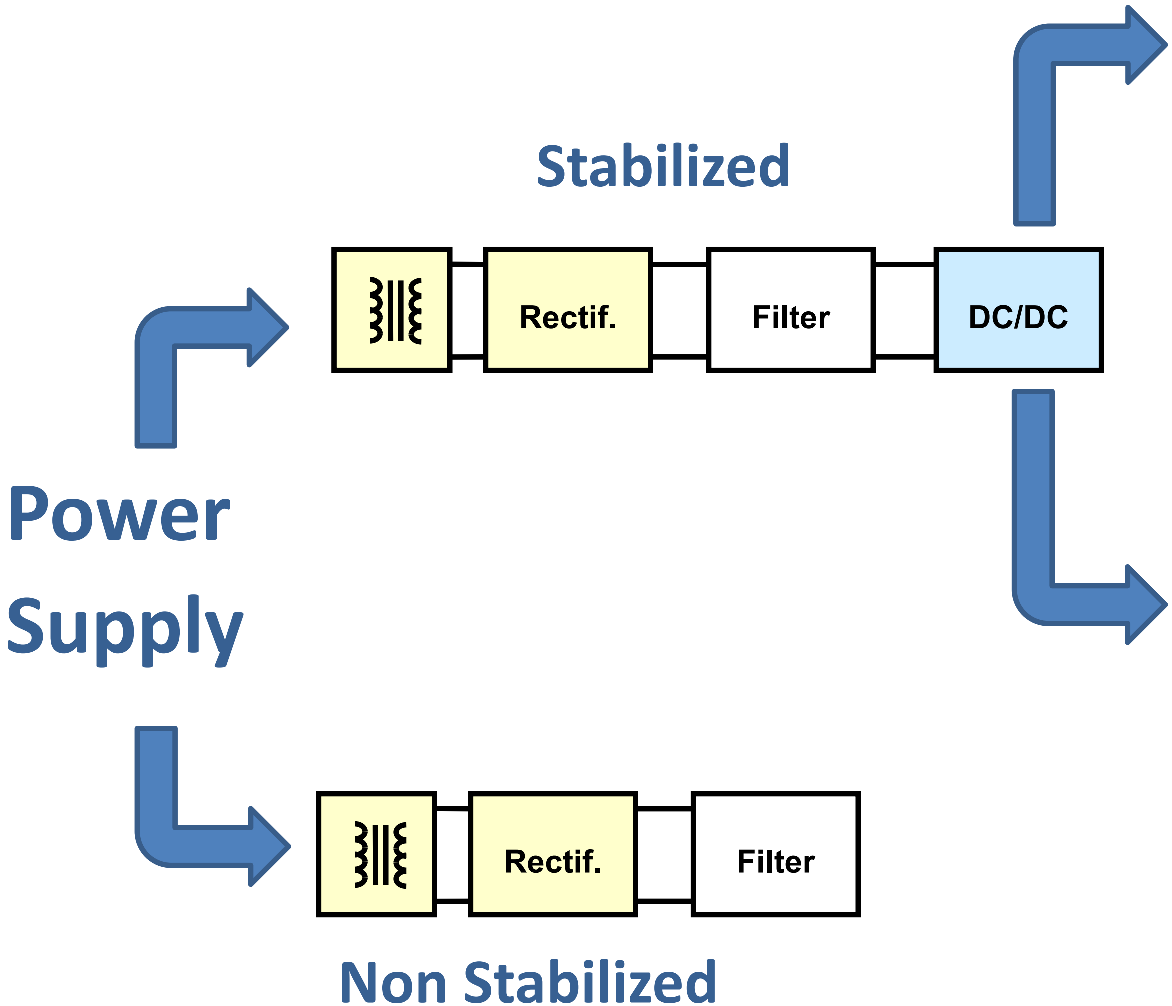
- The value of Vr is usually known
  - Limited by the specifications
  - Allows the calculation of C
  - Tolerances must be considered (±20%)

2. Initial stages. Filter



$$I_{D(peak)} \cong \frac{T}{T_1} I_{dc}$$

3. Classification



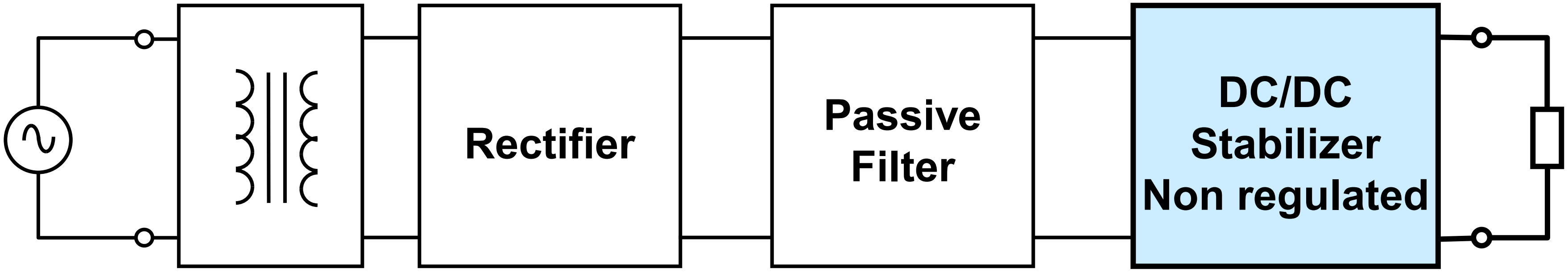
Regulated: Closed loop

Non Regulated: Open loop

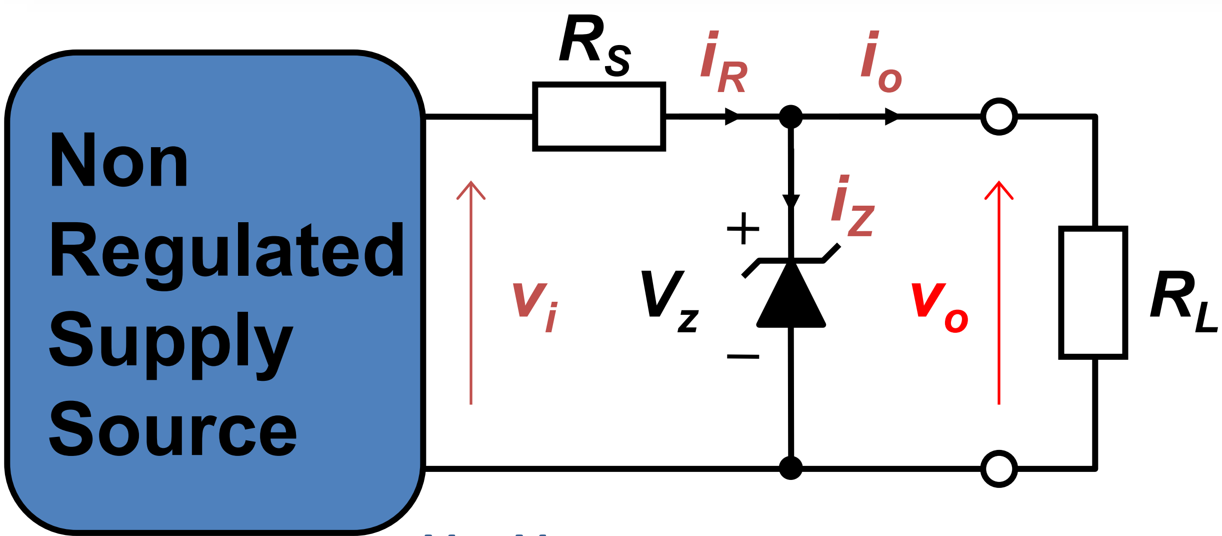
Linear: Transistors in the linear operation mode

Switch Mode: Transistors in the switching mode

4. Stabilized Power Supplies

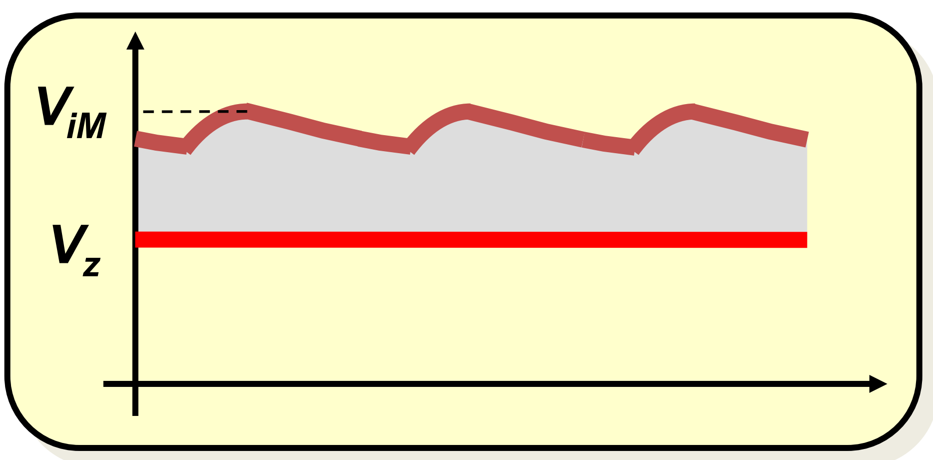


4. Stabilized Power Supplies



$V_i > V_o$

$$v_o = V_z$$



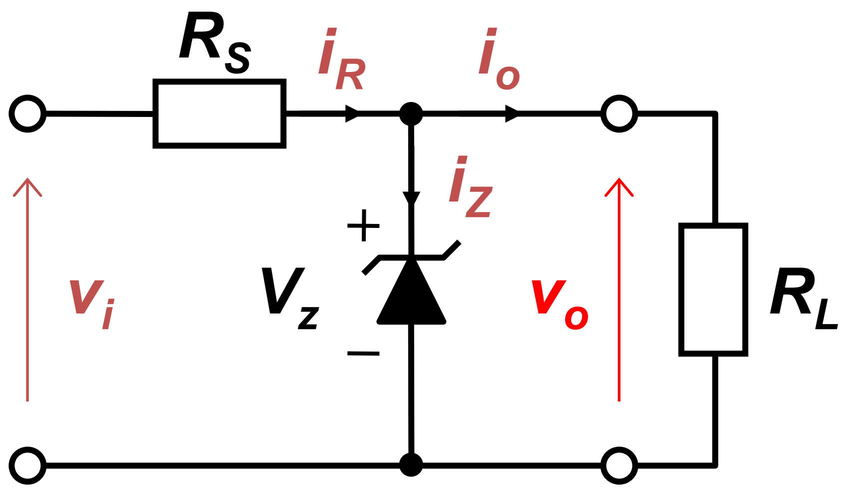
The difference of both voltages is supported by R_S

- v_i should not be much higher than v_o. Vo=ViRL/(Rl+Rs)>Vz
- Election of N_2:N_1.

4. Stabilized Power Supplies

Operation Limits

- $I_{z(min)} \leq i_z \leq I_{z(max)}$
- Current in R_S: $I_{R(min)} = I_{o(max)} + I_{Z(min)}$



$$\frac{V_{i(\min)} - V_Z}{I_{o(\max)} + I_{Z(\min)}} \geq R_S \geq \frac{V_{i(\max)} - V_Z}{I_{o(\min)} + I_{Z(\max)}}$$

R_S should be big enough:

- Less warming up of the zener
- V_o is less affected by fluctuations in V_i

Main drawback:

- If the circuit is designed for high I_o, the zener diode should support such currents ➔ power zener diode

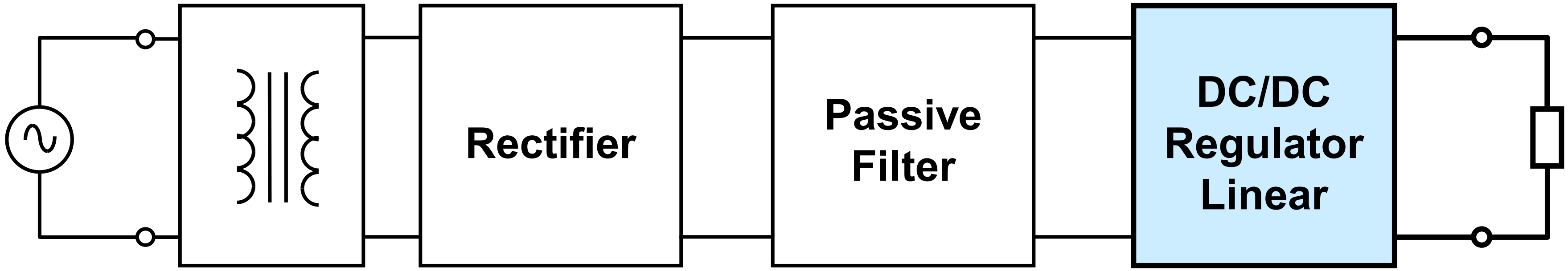
5. Regulated Power Supplies

➢ Limitations of stabilizing circuits:

- The accuracy of the output voltage depends on the features of the used electronic devices.
- Lack of control of the output voltage.

➢ Linear Regulator → mantains constant the output voltage

- System with negative feedback to mantain constant the output voltage when the load or the input voltage variates.

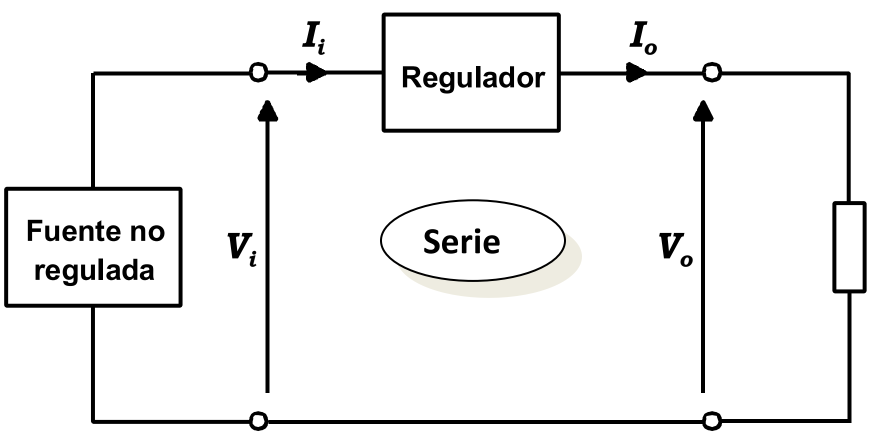


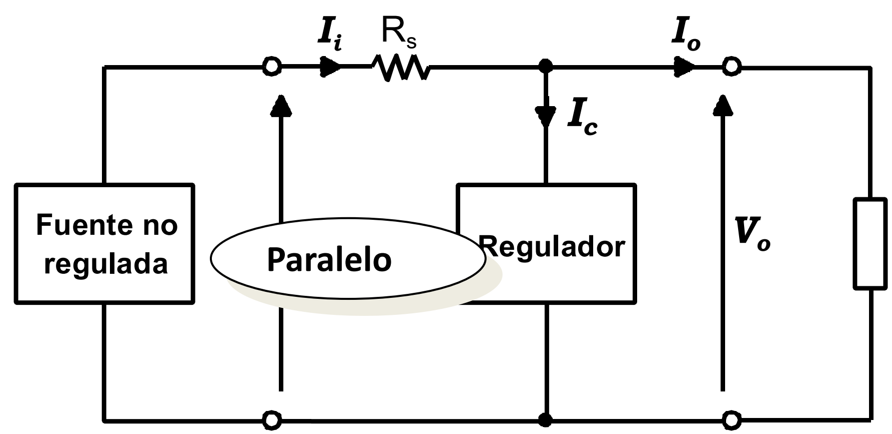
5. Regulated Power Supplies

➢Two kinds of regulators: series and shunt

Variations in the output voltage provoked by changes in the non-regulated voltage and in the output current are compensated by variations in:

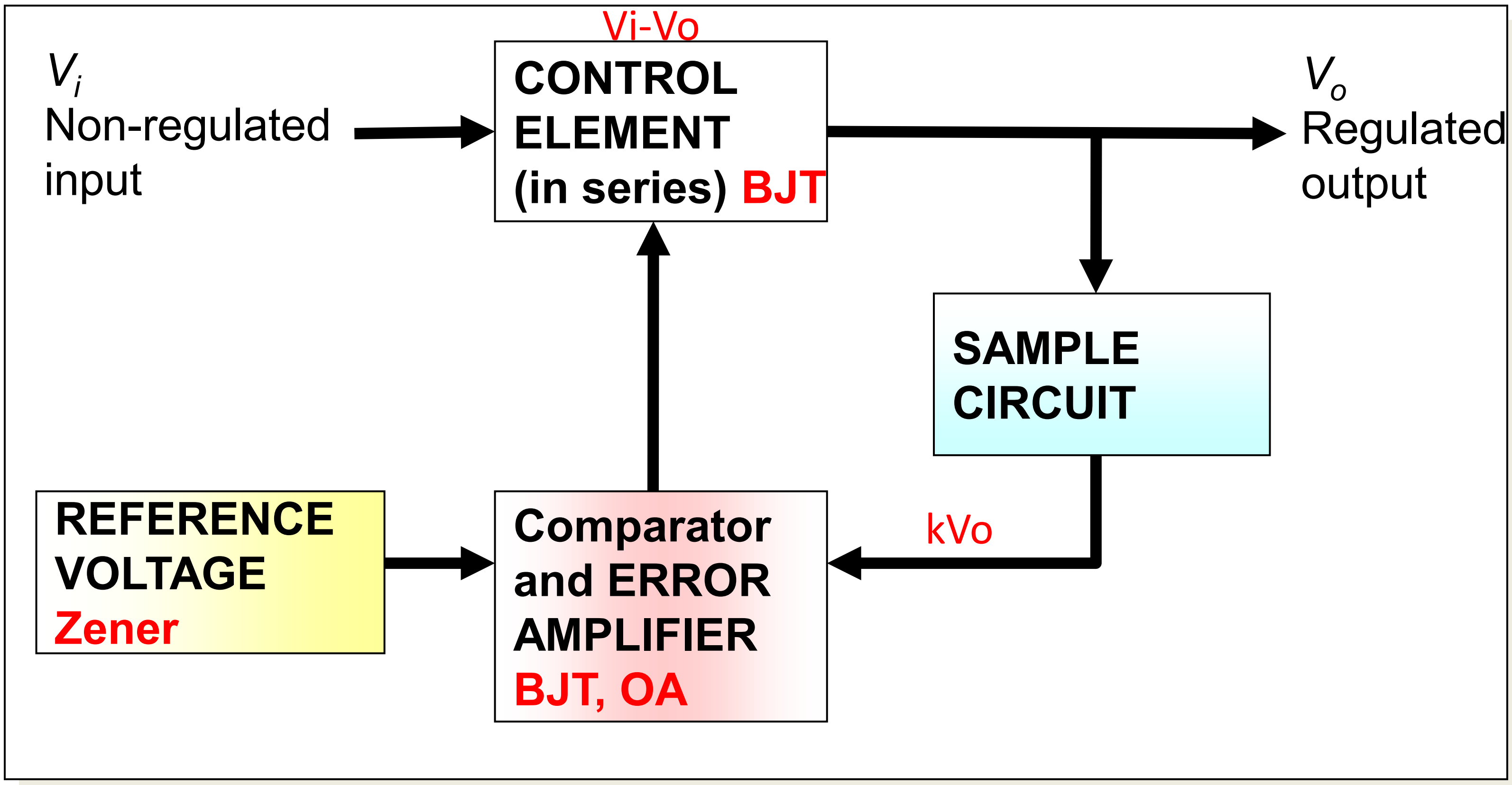
- The voltage drop of an element situated in series with the load ➔ **Series Regulator** (the most common)
- The current of an element situated in parallel with the load ➔ **Shunt Regulator**





5. Regulated Power Supplies. Series.

Blocks diagram of a serie regulator:



Feedback: $\uparrow V_o \rightarrow$ control $\uparrow (V_i - V_o) \rightarrow \downarrow V_o$

5. Regulated Power Supplies. Series.

➢ Reference circuit:

- Provides a stable reference voltage.
- Usually based on a zener diode.
- Simplest solution ➔ zener diode + polarizing resistor.

➢ Sample circuit:

- Provides a signal proportional to the output signal.
- Usually composed by a resistor divider connected to the output.

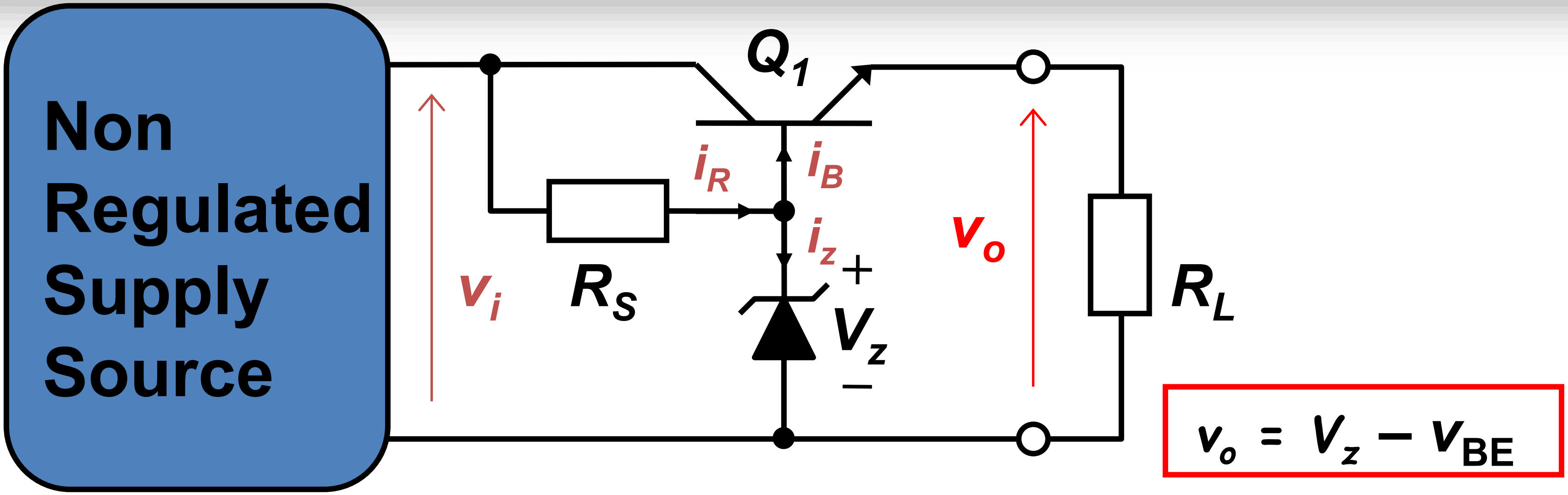
➢ Error amplifier:

- Compares the sampled voltage with the reference voltage and generates an error signal proportional to the difference.

➢ Control element:

- Recieves the error signal and corrects the variations of the output voltage.
- Is usually composed by a bipolar transistor (NPN usually) connected in series between the input and output of the regulator.

5. Regulated Power Supplies. Series.



- The transistor dissipates the power generated by v_i - v_o .
- Design of R_S ➔

$$R_{S(\max)} = \frac{V_{i(\min)} - V_Z}{I_{Z(\min)} + \dfrac{I_{o(\max)}}{\beta + 1}}$$

- The zener diode does not need to support elevated currents.

Feedback: $\uparrow V_o \rightarrow \downarrow V_{BE} \rightarrow \downarrow I_E = (1+\beta) I_{ss} e^{VBE/VT} \rightarrow \downarrow I_o \rightarrow \downarrow V_o$

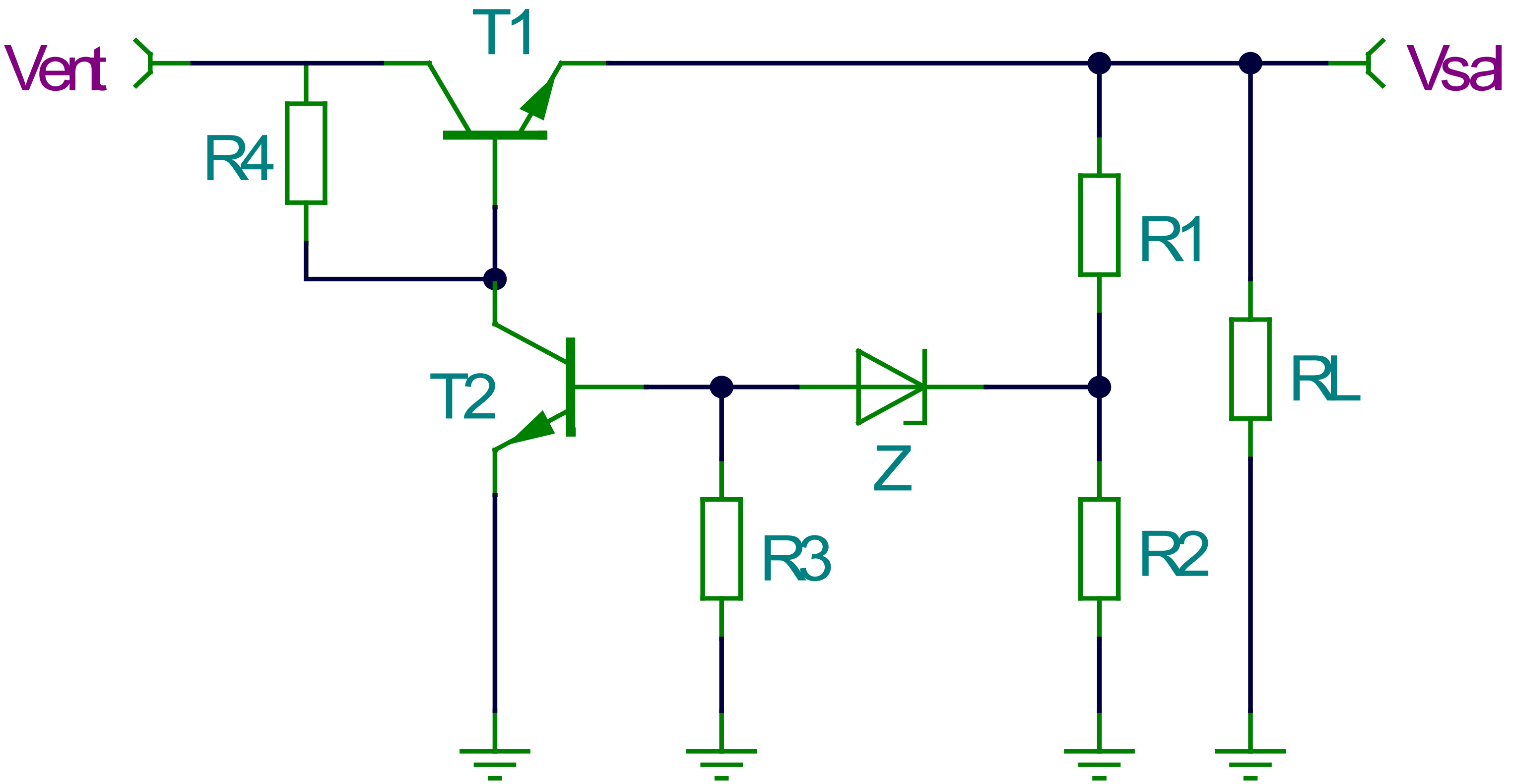
P50. *En el circuito de la figura calcular:*

a) Tensión de salida que fija el regulador en la carga R_L

b) Tensión y corriente en cada una de las resistencias del circuito.

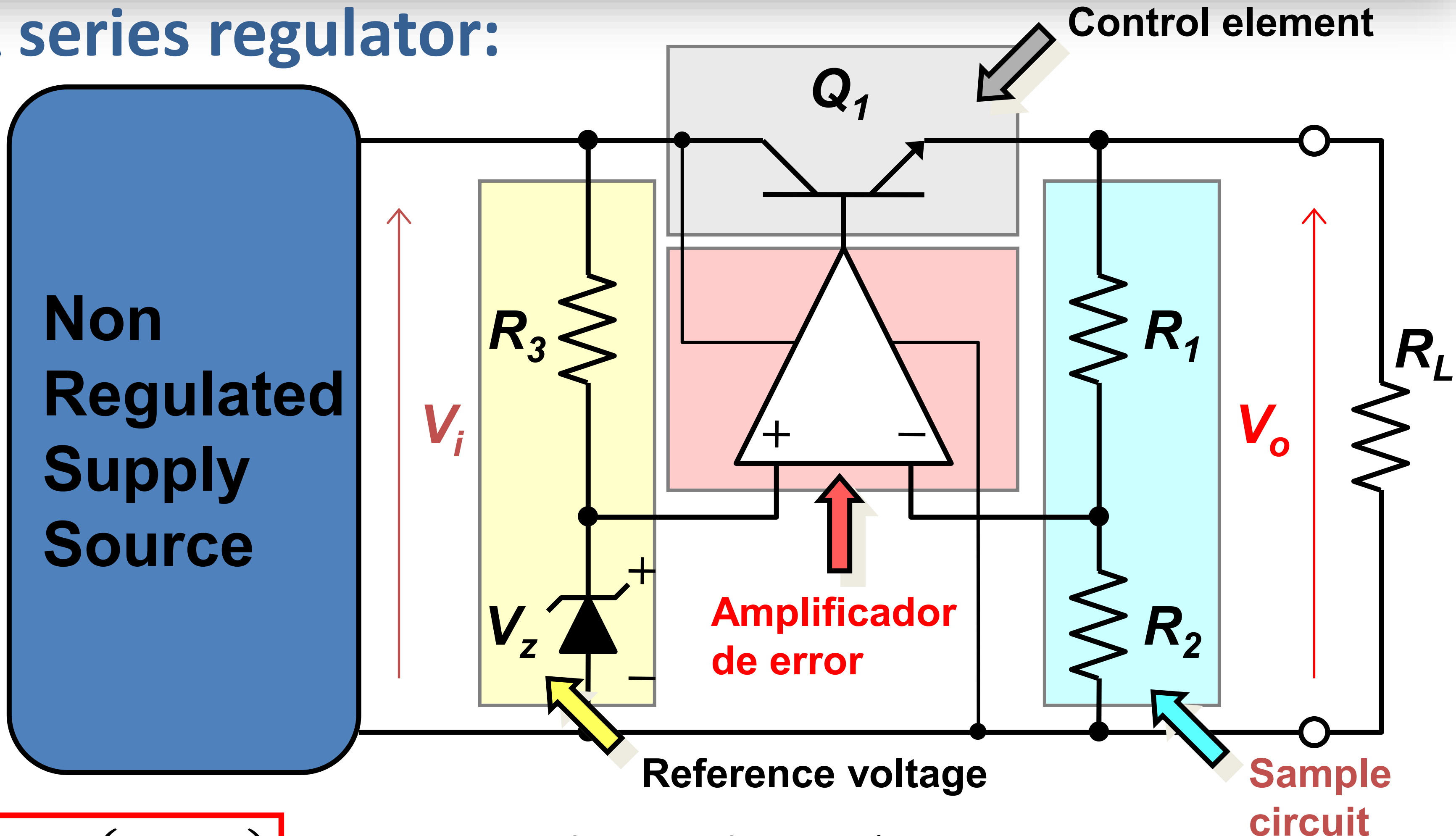
Datos: R1 = 3.3 kΩ, R2 = 2.2 kΩ, R3 = 5 kΩ, R4 = 10 kΩ, RL = 2 kΩ

Vent = 40 V, V_Z *= 10 V. Para T1 y T2:* V_{BE} *= 0.7 V,* β *=100*



5. Regulated Power Supplies. Series.

OA series regulator:

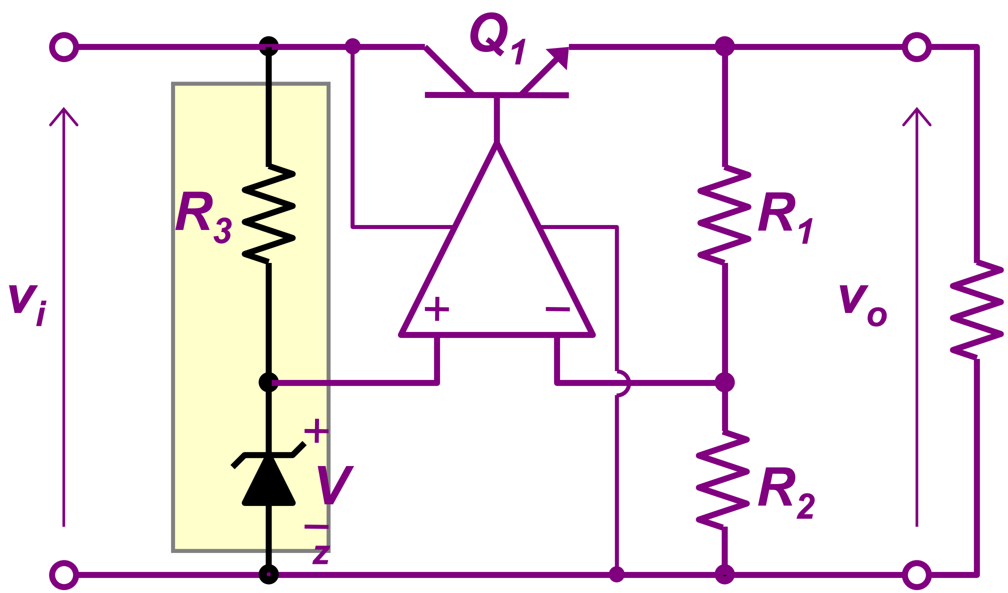


$$v_o = V_R\left(1+\frac{R_1}{R_2}\right)$$

Feedback: $\downarrow V_o \rightarrow \downarrow V_- \rightarrow \uparrow V_{AO} = V_B \rightarrow \uparrow I_B \rightarrow \uparrow I_O \rightarrow \uparrow V_o$

5. Regulated Power Supplies. Series.

OA series regulator:



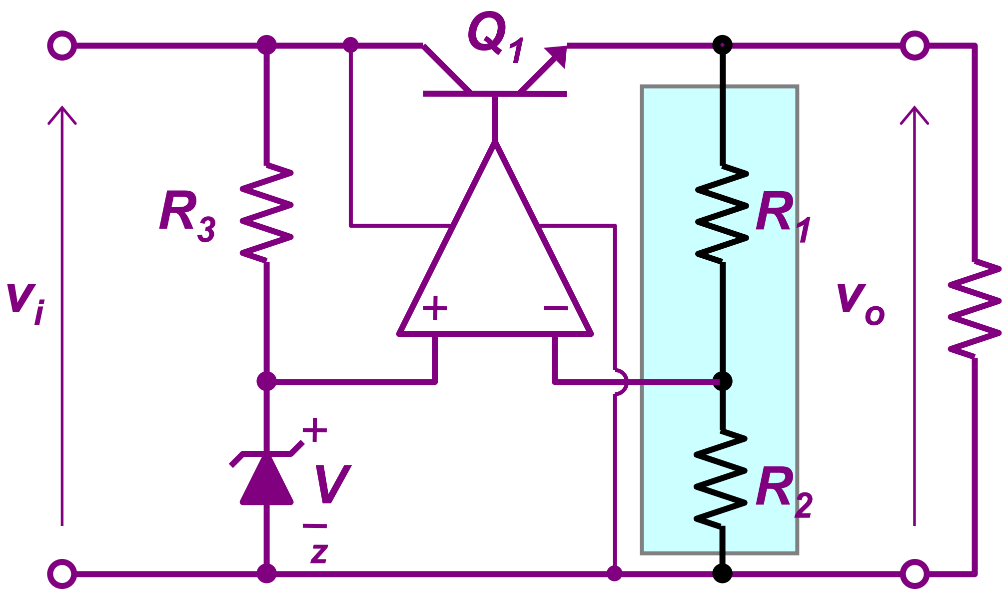
Reference Voltage:

- Simple circuit.
- Select R_3 high enough to reduce the effect of the ripple of v_i.
- Also LEDs, rectifying diodes, IC reference circuits (LM336).

5. Regulated Power Supplies. Series.

OA series regulator:

Sample circuit

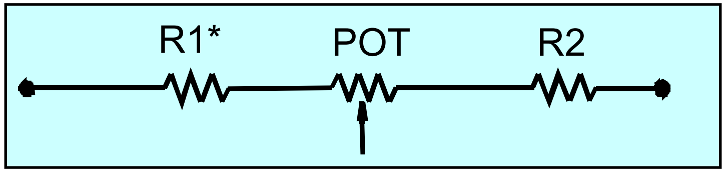


- Very simple circuit.
- The supported current must be negligible versus the load current.

R_1 and R_2 high values compared to the load.

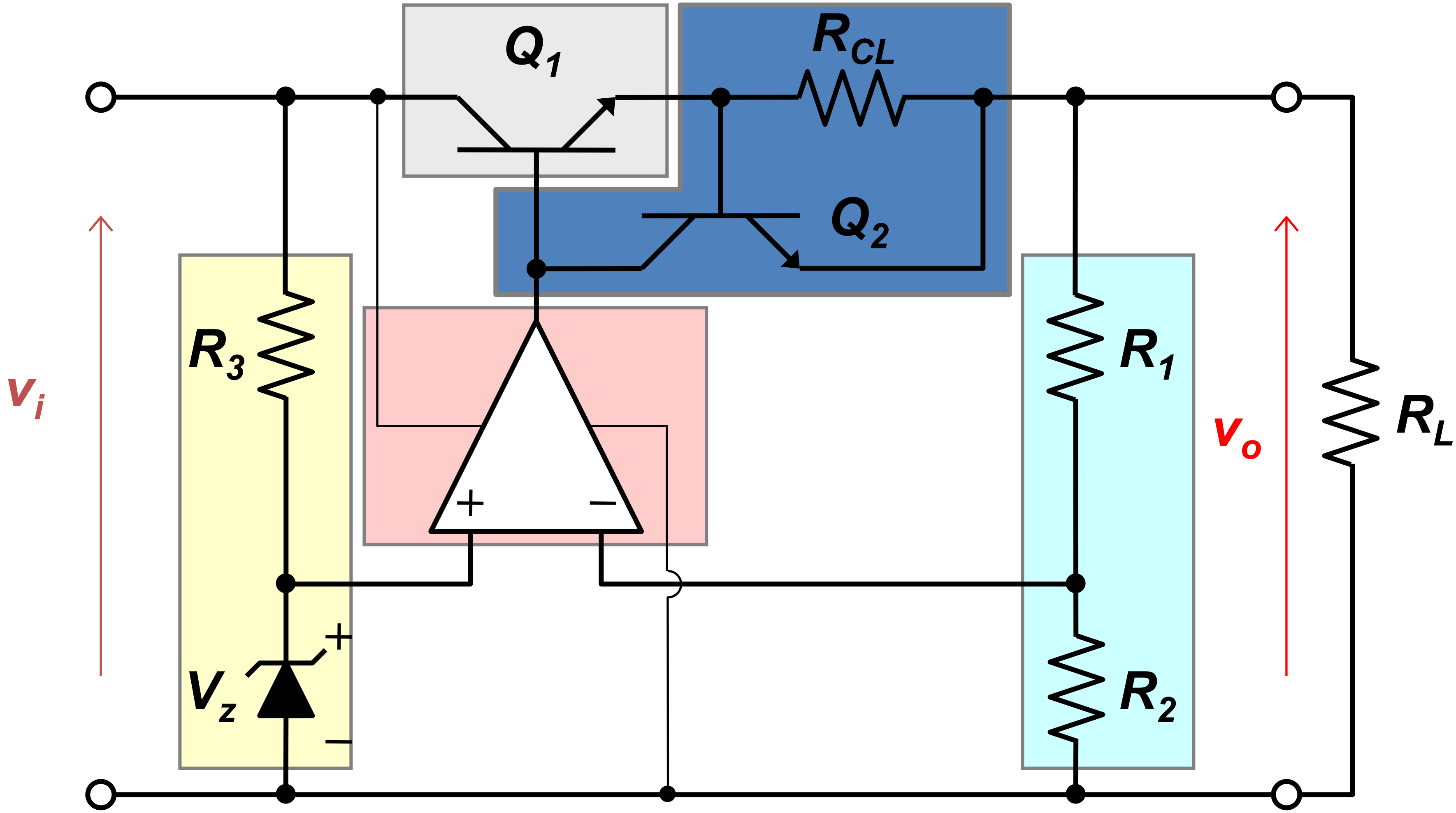
To allow Vo adjustment:

A potentiometer should be used in the voltage divider.



5. Regulated Power Supplies. Series.

OA series regulator: current limitation

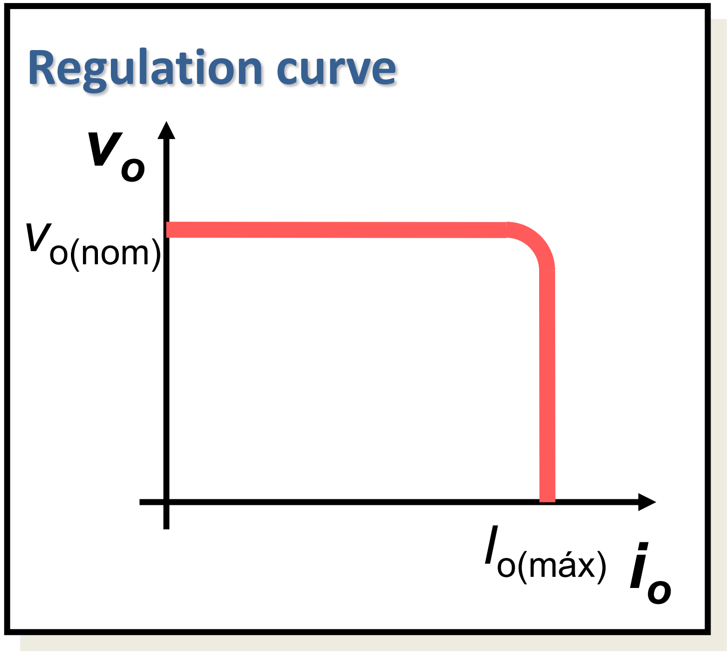


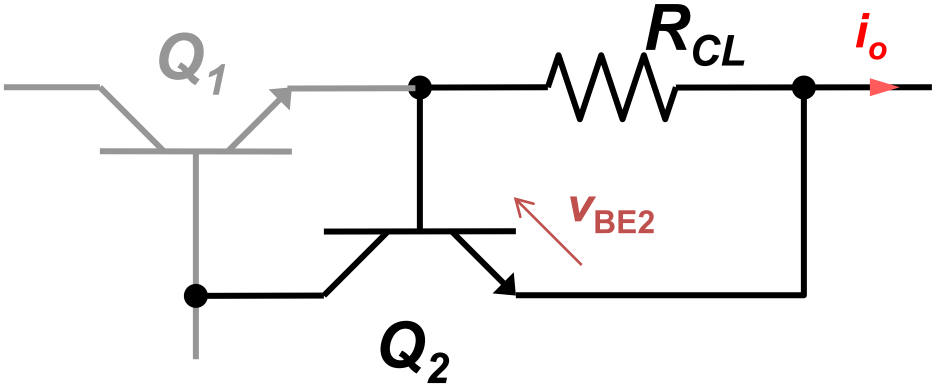
5. Regulated Power Supplies. Series.

OA series regulator:

$$I_{o(max)} = I_{SC} = \frac{v_{BE2(ON)}}{R_{CL}}$$

- **Limitation at constant current.**
  - If $i_o < I_{o(max)}$, then $v_o = v_{o(nom)}$.
  - If $i_o > I_{o(max)}$, v_o decreases ➔ $0 \leq v_o \leq v_{o(nom)}$.





If Q_2 conducts, it "steals" base current to Q_1.

- i_o is then limited.
- The value of $I_{o(máx)}$ is fixed by R_{CL}.

In shortcircuit: $P_{Q1} \approx v_i \cdot I_{o(max)}$

P52. *En el circuito de la figura calcular:*

a)Tensión de salida que fija el regulador

b) Corriente en la resistencia R3

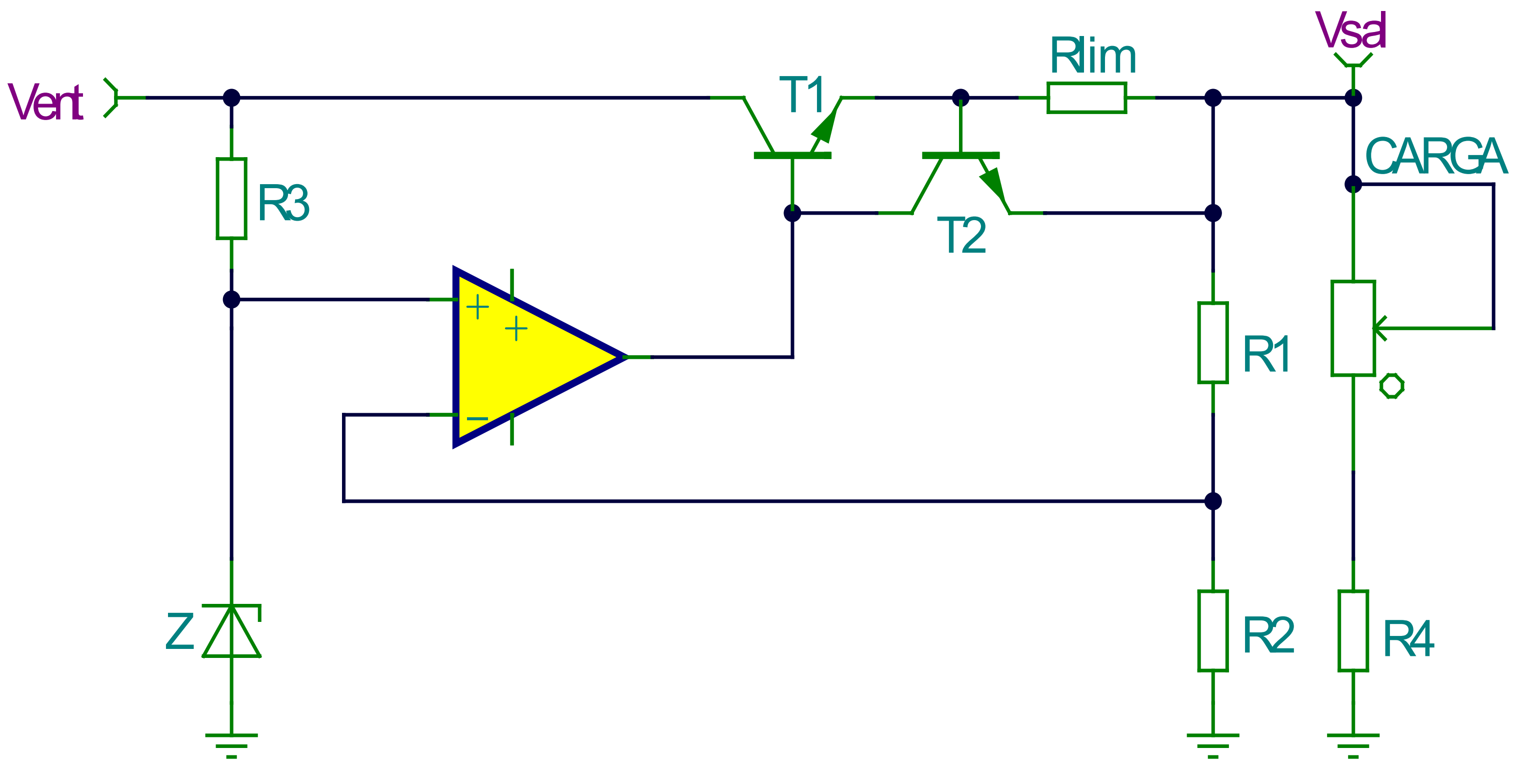
c) Corriente mínima y máxima en la resistencia R4.

d) Calcular la resistencia limitadora Rlim

Podemos despreciar las corrientes por R1 y R2 para facilitar los cálculos.

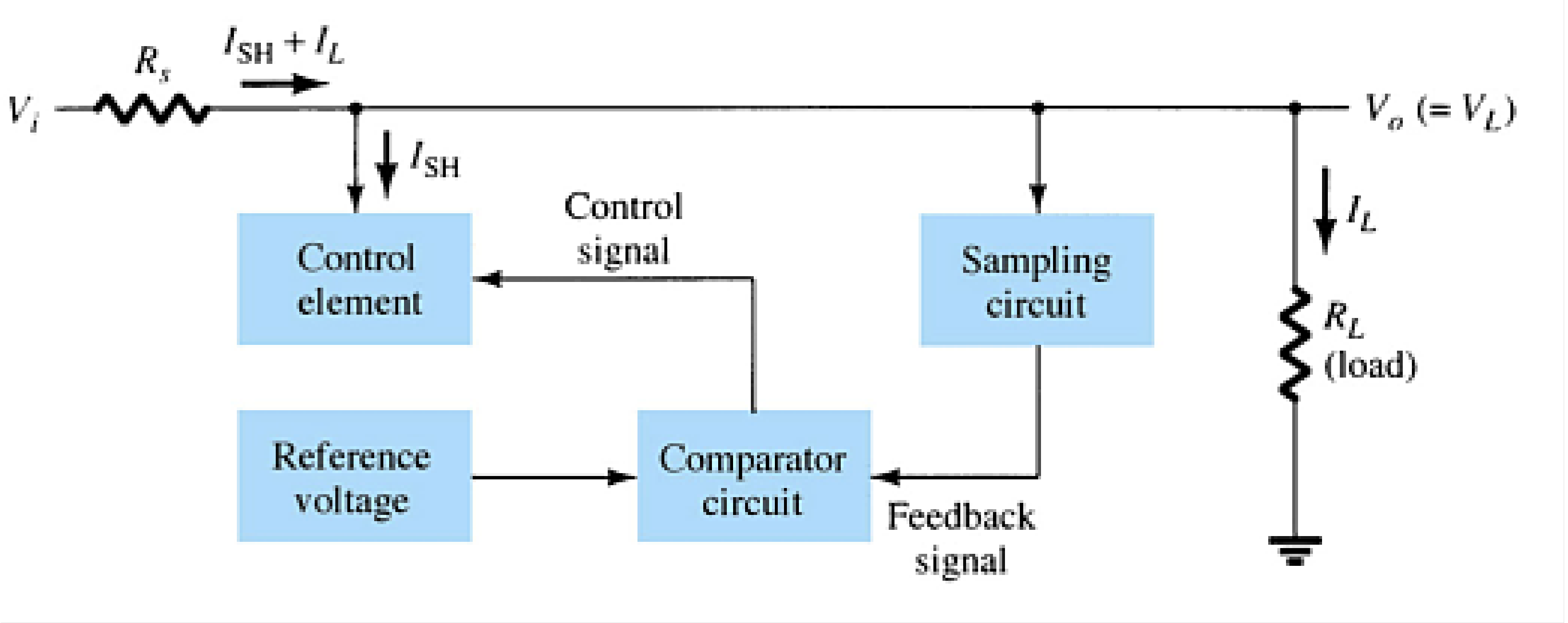
Datos: R1 = 100 kΩ, R2 = 50 kΩ, R3 = 5 kΩ, R4 = 50 Ω, POT= 0.55 kΩ / 3 W

Vent = 35 V, $V_Z = 10$ *V,* $I_{Zmin} = 1$ *mA,* $P_{Zmax} = 0.5$ *W,* $V_{BE} = 0.6$ *V*



5. Regulated Power Supplies. Shunt.

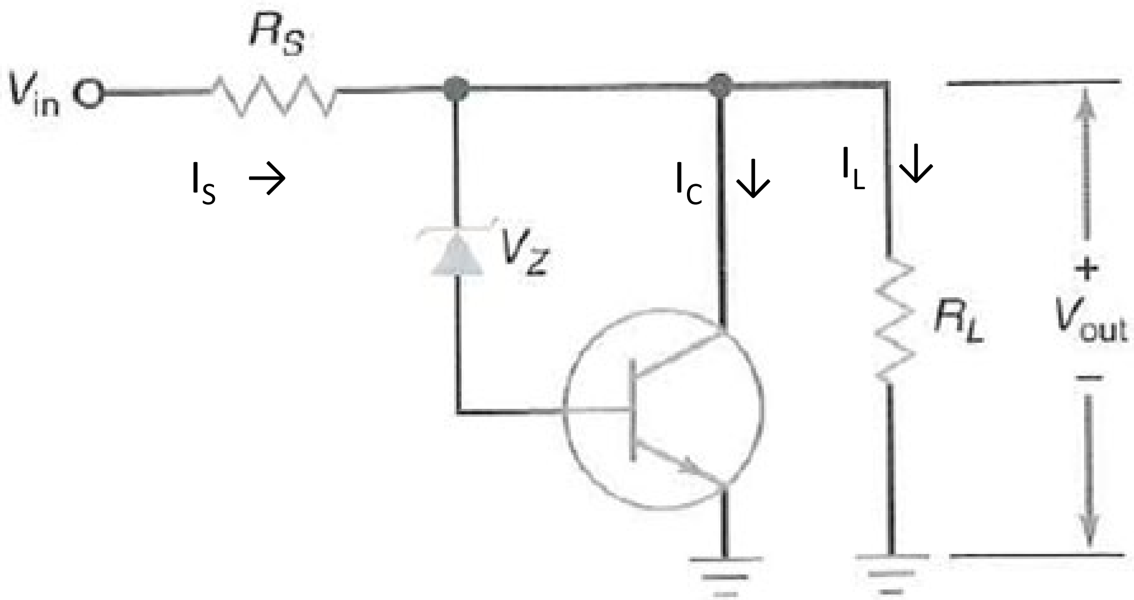
Shunt regulator:



Feedback: $\uparrow V_o \rightarrow$ control $\uparrow I_{SH} \rightarrow \downarrow I_L \rightarrow \downarrow V_o$

5. Regulated Power Supplies. Shunt.

Shunt regulator:



$$V_{out} = V_z + V_{BE}$$

$$I_S = \frac{(V_{in} - V_{out})}{R_S}$$

$$I_L = \frac{V_{out}}{R_L}$$

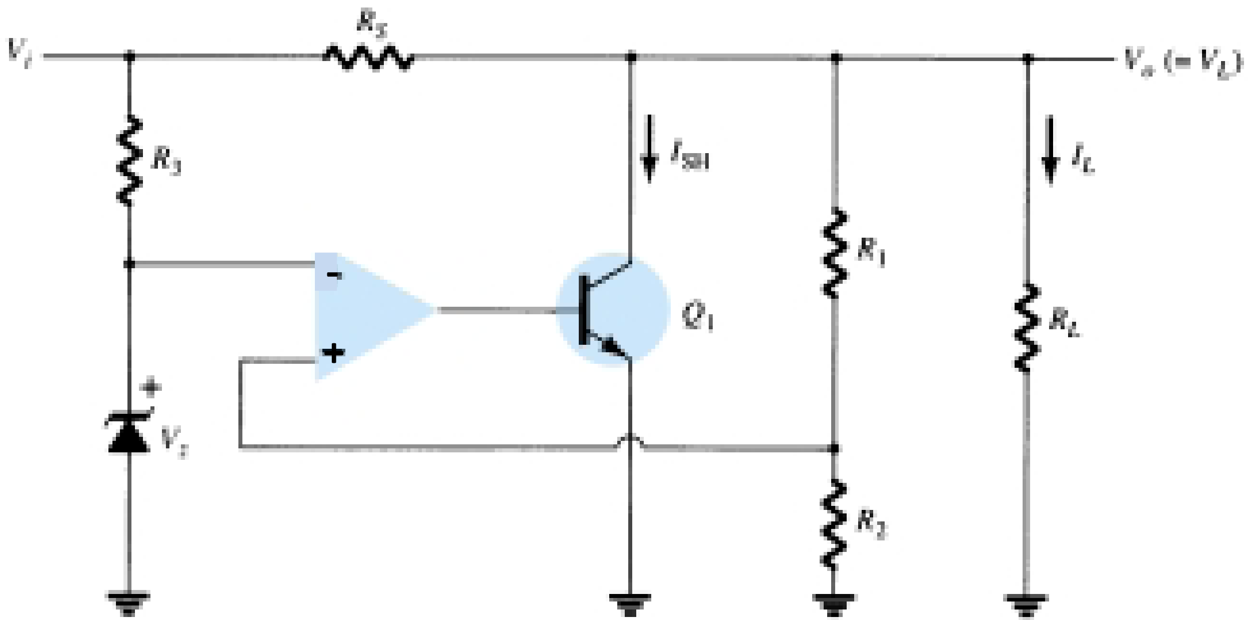
$$I_C \cong I_S - I_L$$

Feedback: $\downarrow R_L \rightarrow \downarrow Vo \rightarrow \downarrow V_{BE} \rightarrow \downarrow I_Z \rightarrow \downarrow I_C \rightarrow \uparrow I_L \rightarrow \uparrow V_o$

V_o remains constant (R_L fluctuations compensated by I_L fluctuations)

5. Regulated Power Supplies. Shunt.

OA shunt regulator with OA:



$$V_{out} = \frac{R_1 + R_2}{R_1} \cdot V_z$$

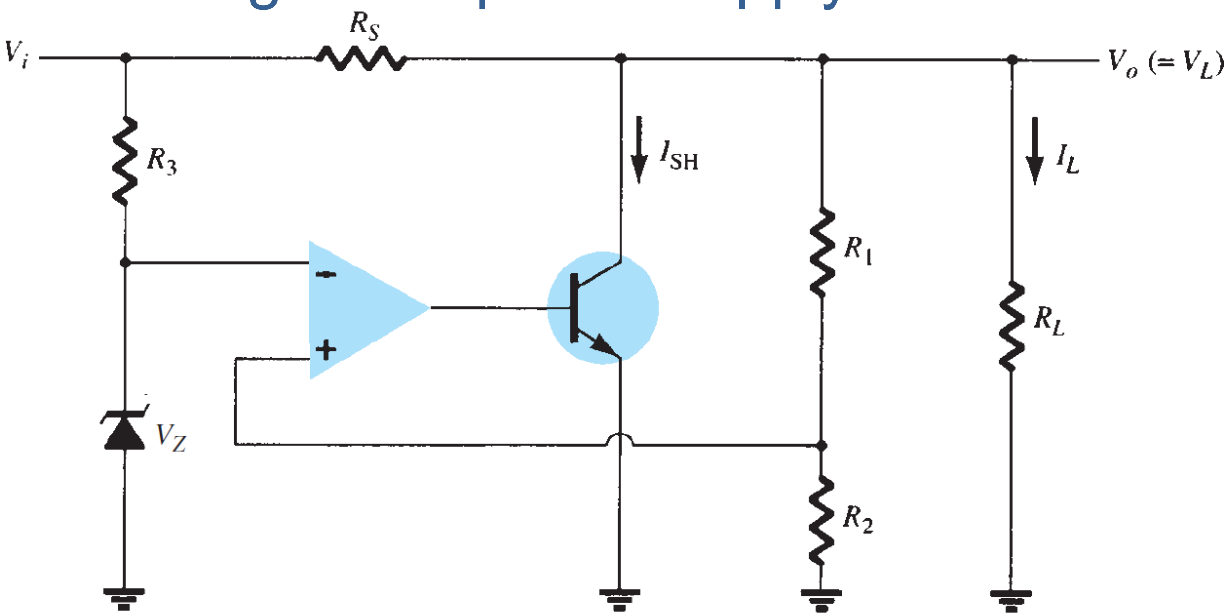
$$I_L = \frac{V_{out}}{R_L}$$

$$P_D \cong (V_{in} - V_{out}) \cdot I_L$$

Feedback: $\downarrow V_o \rightarrow \downarrow V_+ \rightarrow \downarrow V_{AO} = V_B \rightarrow \downarrow I_{SH} \rightarrow \uparrow I_L \rightarrow \uparrow V_o$

5. Regulated Power Supplies. Shunt.

Shunt regulated power supply with OA



Exercise. *OA (741C, ±15 V, Io-max=25 mA), Rs=1.5 Ω, Vi=20-22 V, IL=0.8-1.2 A, Vz=5 V, BJT(β=100-400, Vbe-on=0.65 V)*
1) Design R1 and R2 for Vo=18 V. Calculate: 2) Range of ISH and check the non-saturation of the OA. 3) Maximum power in Rs and BJT.

6. Integrated Power Supplies

- **They appeared because of the need of regulators in the power supplies.**
  - First generation ➔ components of general application.
  - The big demand of specific voltage supplies (5V for instance) led to the manufacturing of fixed voltage regulators with only 3 terminals.
  - Low cost, easy to use.

  - Later voltage regulators with 3 terminals but with adjustable voltage were developped.
    - Low cost + easy to use + versatility.

6. Integrated Power Supplies

Classification:

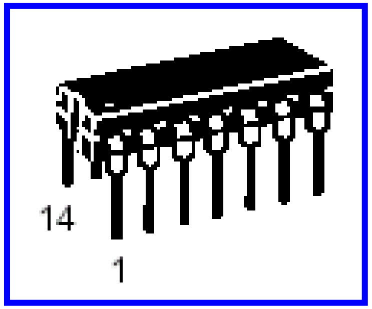
- Regulators of multiple terminals.
- Regulators of 3 terminals:
  - fixed voltage:
    - positive
    - negative
  - adjustable voltage:
    - positive
    - negative

6. Integrated Power Supplies

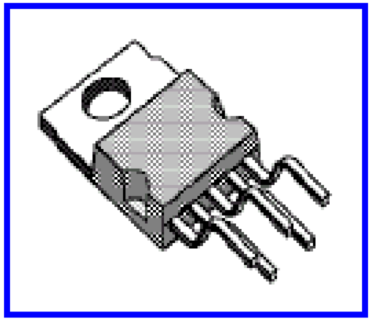
Regulators of multiple terminals

- Based on the linear basic regulator.
- Several parts of the circuit are independent and can be connected by the user.
- Most representative examples:

- **µA723 (14 terminales)**



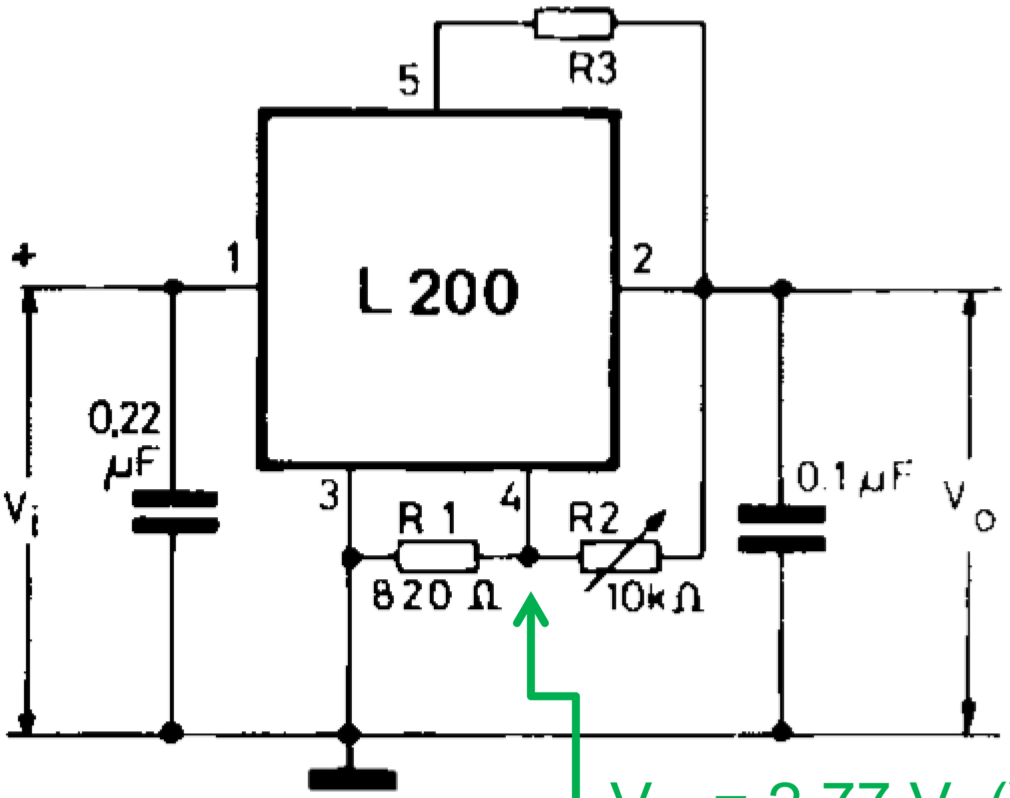
- **L200 (5 terminales).**



6. Integrated Power Supplies

Regulators of multiple terminals: L200

<40 V



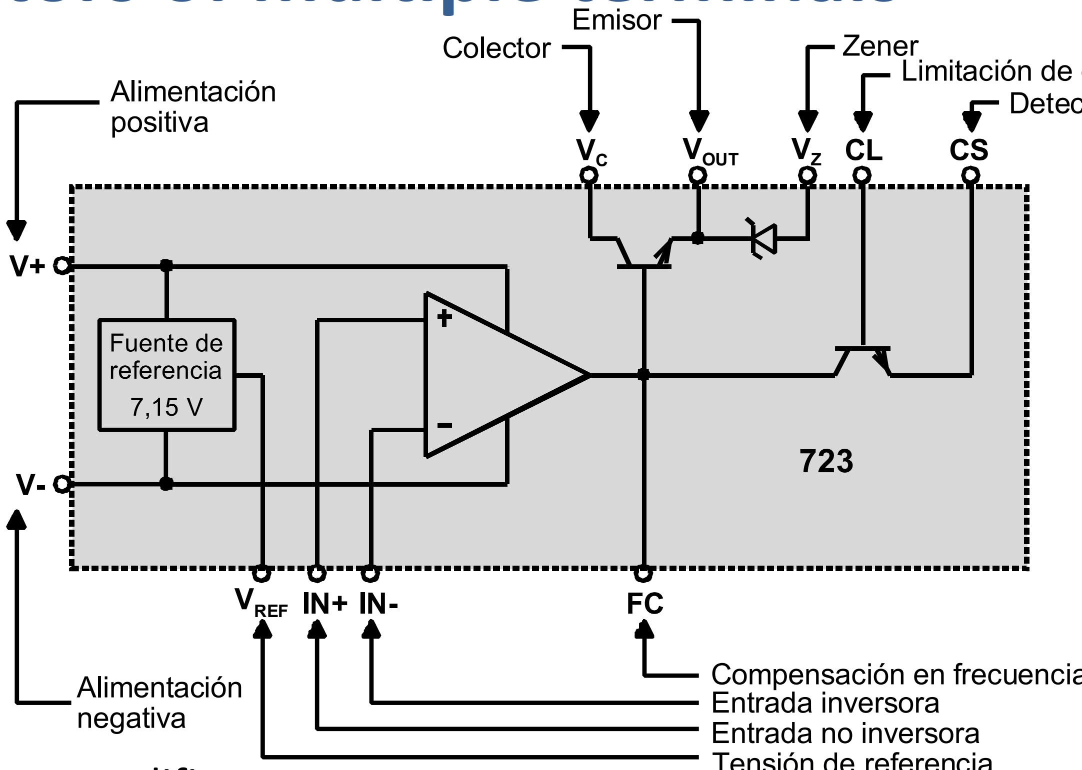
$V_O = V_{ref} \cdot (1 + R2/R1)$

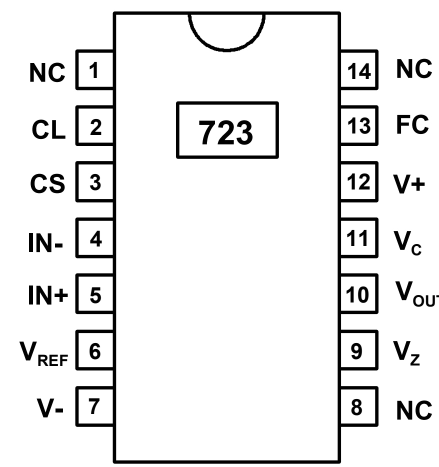
V_{ref} = 2.77 V (V_i=20 V)

6. Integrated Power Supplies

Regulators of multiple terminals

µA723





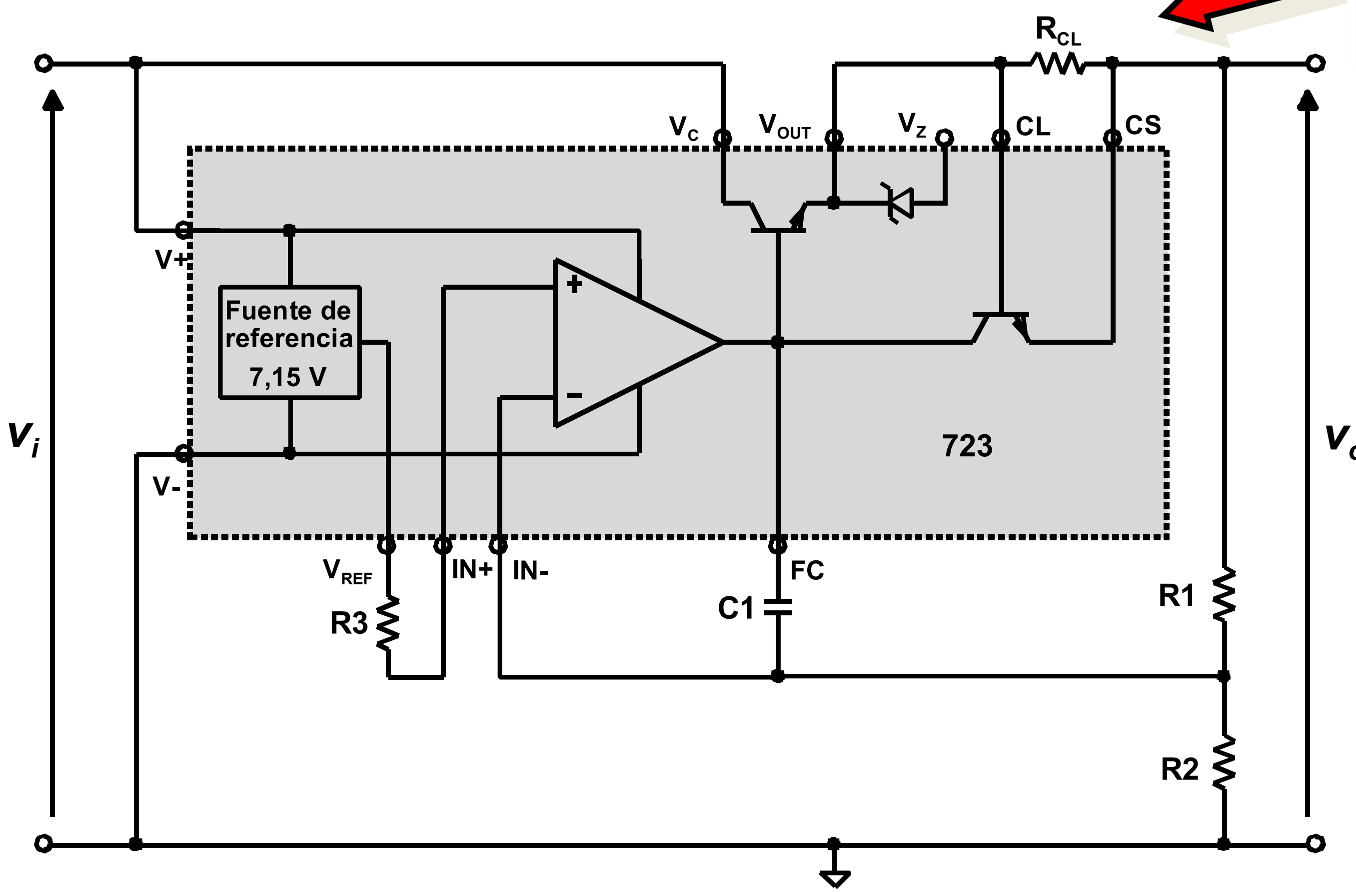
- An error amplifier
- A reference voltage source
- A transistor as control element
- A transistor to limit current
- A zener diode for specific applications
- A terminal for frequency compensation

6. Integrated Power Supplies

Regulators of multiple terminals

μA723

$$I_{o(max)} = \frac{0,65}{R_{CL}}$$



$$V_o = V_{REF}\left(1+\frac{R_1}{R_2}\right)$$

Output voltage higher than the reference voltage (7 to 37 V)

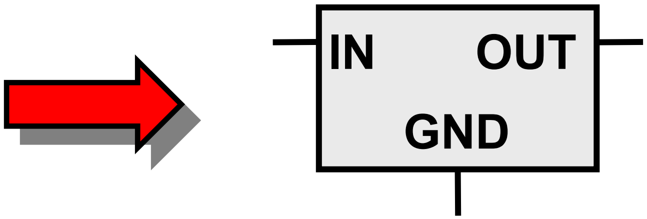
6. Integrated Power Supplies

Regulators of 3 terminals

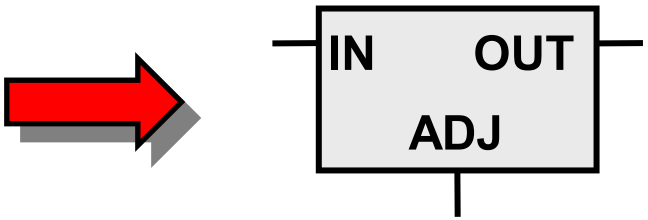
- Regulated output.
- Simple use and low cost.

- Two types:

• **Fixed regulators:** provide a fixed voltage (positive or negative).



• **Adajustable regulators**: the output voltage (positive or negative) can be adjusted using external components.



6. Integrated Power Supplies

Regulators of 3 terminals

- Regulators 78XX provide positive voltages, whereas 79XX provide negative voltages.
- The last 2 digits XX, indicate the output regulated voltage.

Type	$I_{o(max)}$ (A)
78LXX-79LXX	0,1
78MXX-79MXX	0,5
78XX-79XX	1
78TXX-79TXX	3

Tipo	V_o (V)	$V_{i(min)}$ (V)	$V_{i(max)}$ (V)
7805	5	7	35
7806	6	8	35
7808	8	10	35
7809	9	11	35
7810	10	12	35
7812	12	14	35
7815	15	17	35
7818	18	20	35
7824	24	26	40
79XX	Same values but negative		

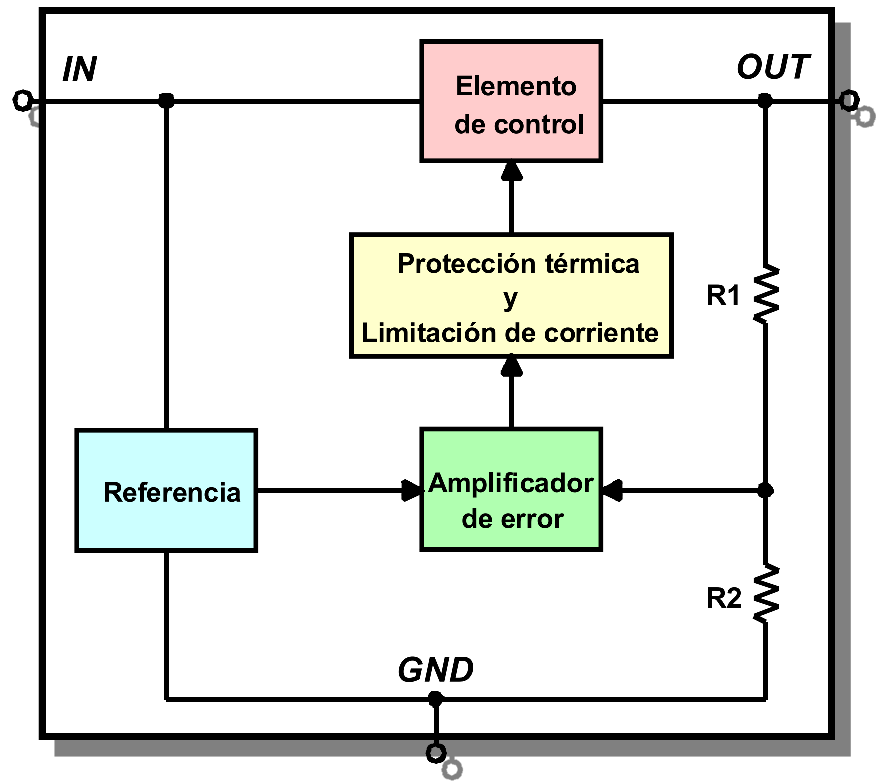
- Datasheets:
  - LM78XX ⇨ National Semiconductor, Fairchild.
  - UA78XX ⇨ Texas Instruments
  - MC78XX ⇨ Motorola, ON Semiconductors,...

6. Integrated Power Supplies

Regulators of 3 terminals

Linear basic regulator with additional elements:

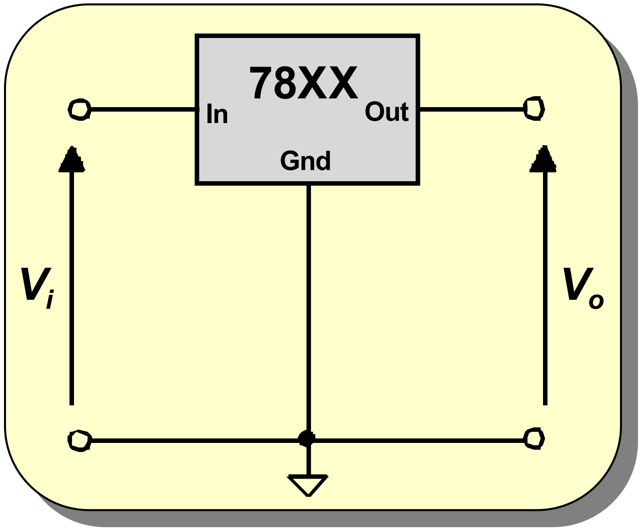
- Limitation of the maximum output current as a function of the difference in input-output voltage ➔ power limitation.
- Thermic protection ➔ the control element can be disconnected.
- Error amplifier internally compensated
- Reference voltage of low noise and high stability.



6. Integrated Power Supplies

Regulators of 3 terminals. Positive.

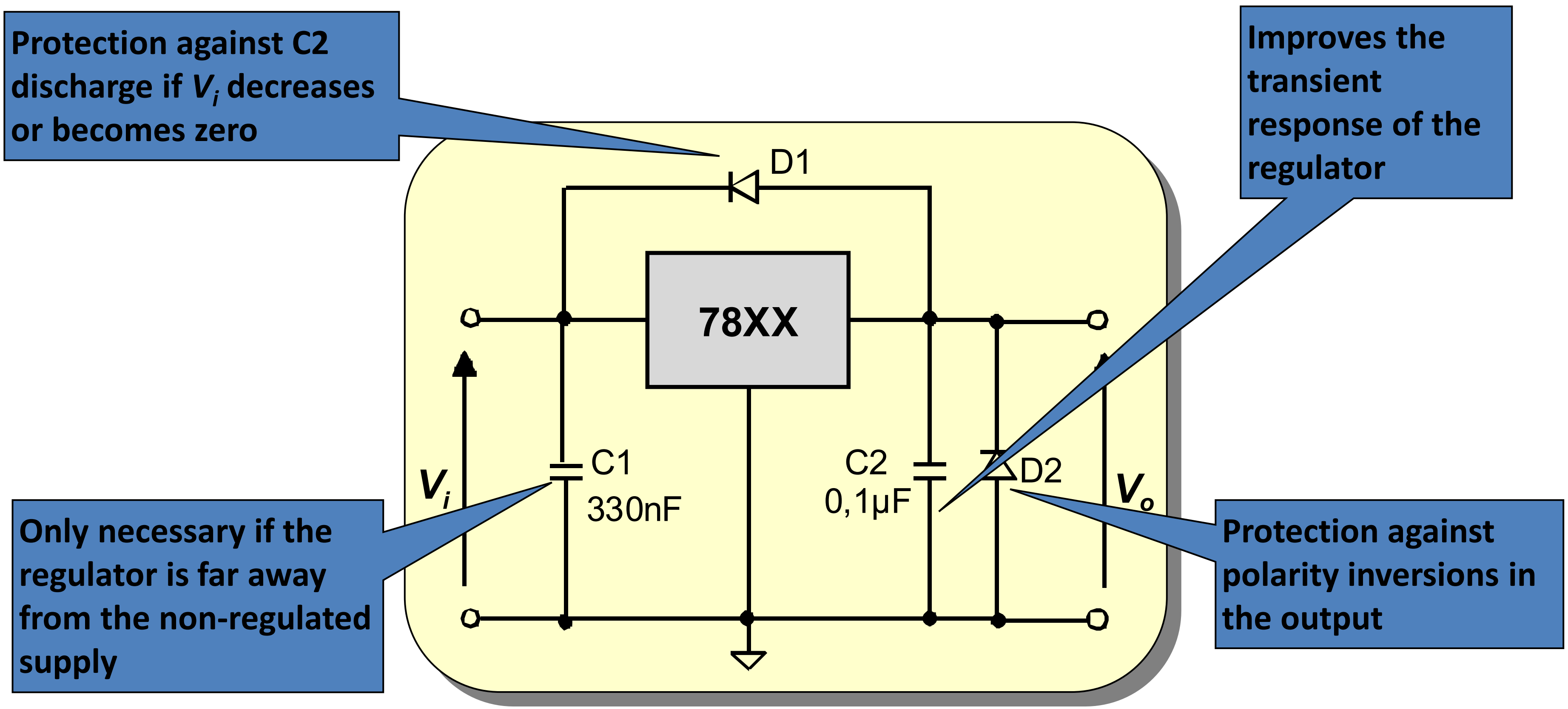
- No external element is needed.
- The input is provided by a non-stabilized voltage supply or by a DC supply.
- The input voltage must be higher than the output, at least 2 or 3V.



6. Integrated Power Supplies

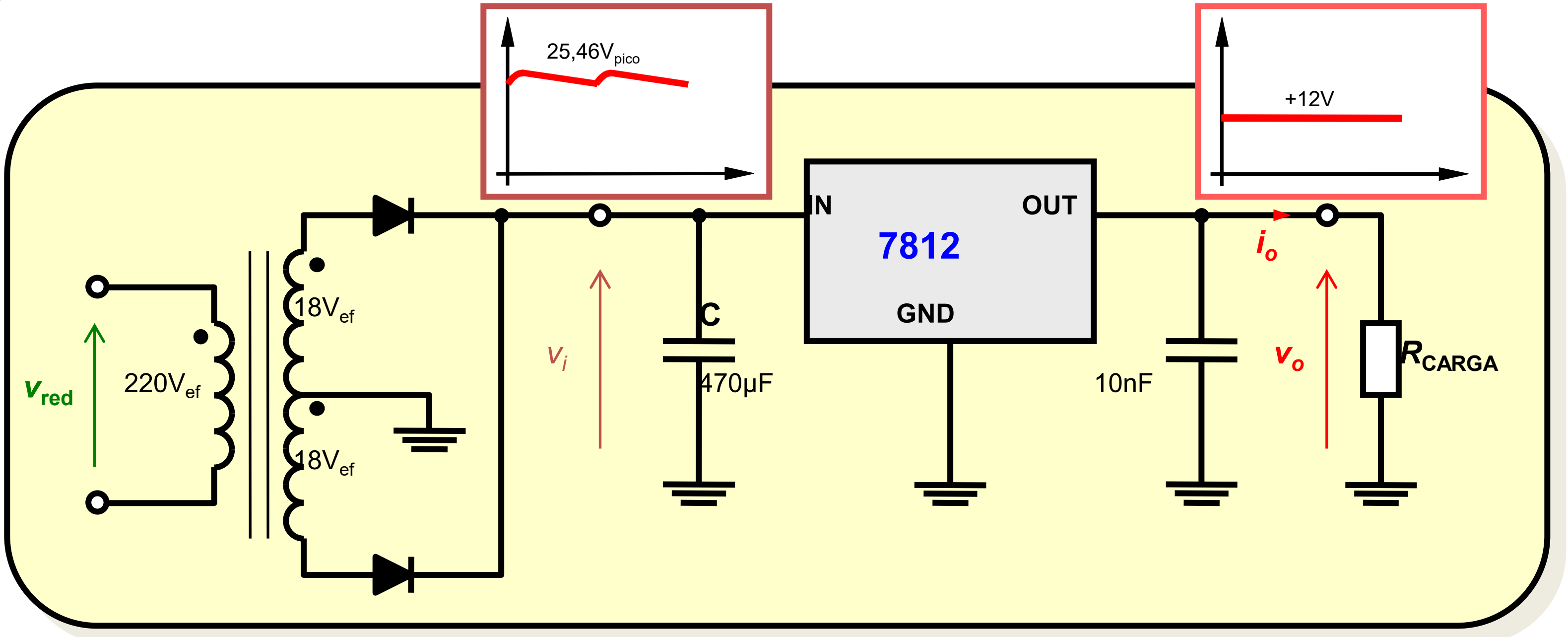
Regulators of 3 terminals. Positive.

- External elements can be added:



6. Integrated Power Supplies

Regulators of 3 terminals. Positive.



- **The selection of N2:N1 is important to minimize the power dissipation.**

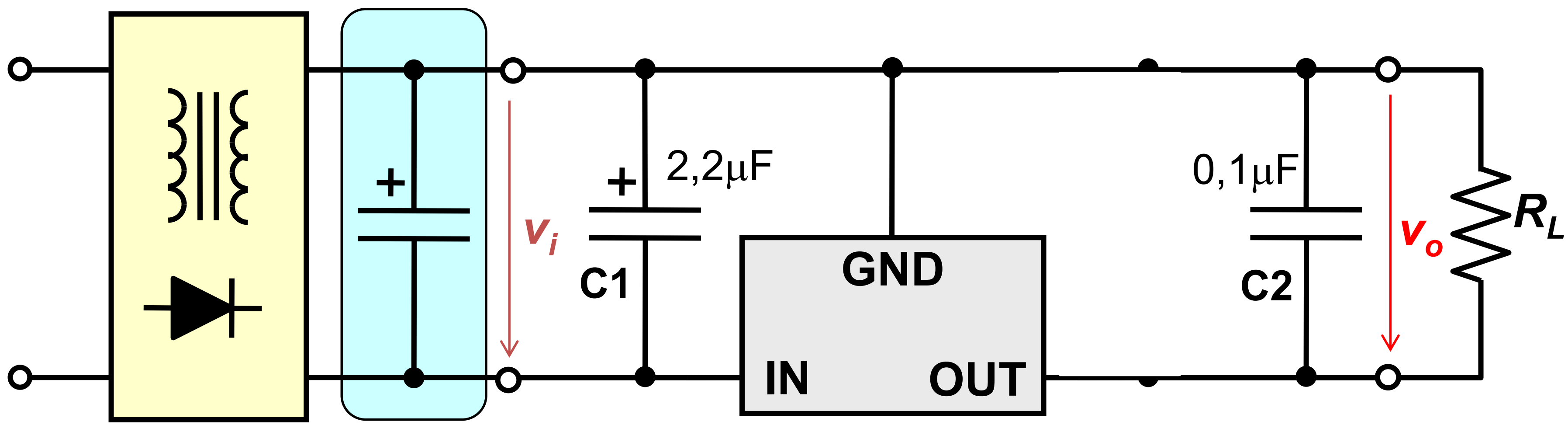
- **The capacitor *C* assures that v_i never decreases under a specific value.**
  - The discharge or output current is i_o.

6. Integrated Power Supplies

Regulators of 3 terminals. Negative.

➢Series 79XX.

- Similar to the positive regulators 78XX.
- The capacitor in the output assures the stability.
- As in 78XX, C1 is only necessary if the regulator is far away from the filter. C3 improves the transient response.
- All capacitors associated to the regulator should be connected as near as possible from the regulator.

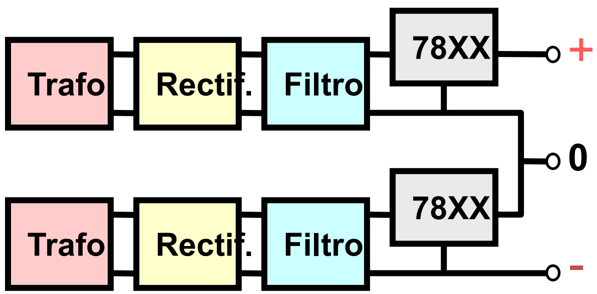


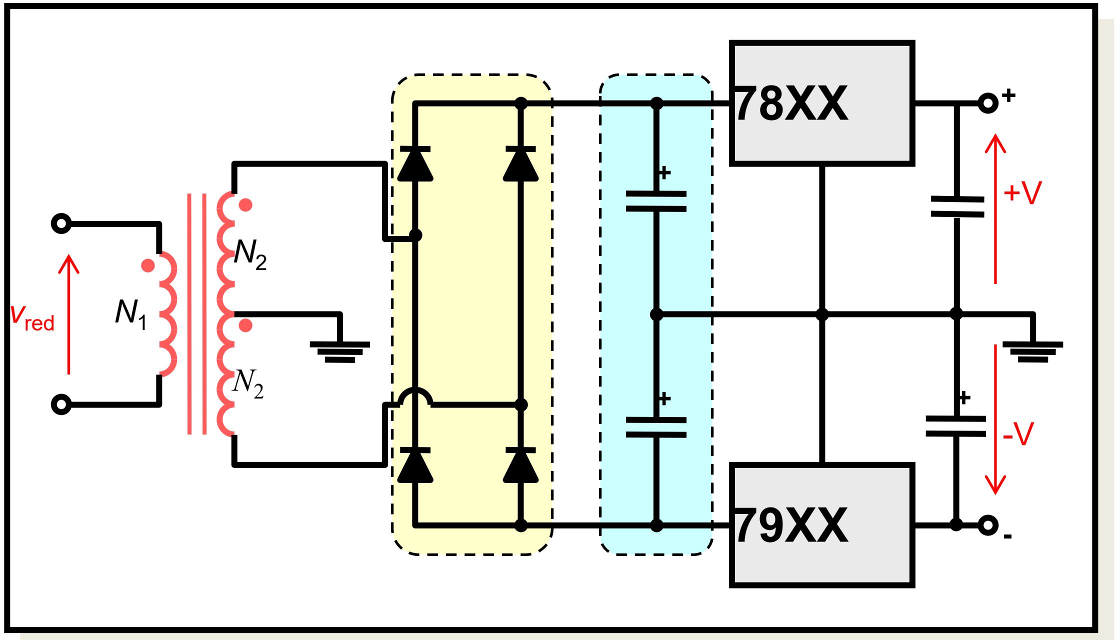
6. Integrated Power Supplies

Regulators of 3 terminals.

- **They simplify the implementation of symmetric supply sources.**

This could be achieved with 2 different 78XX, but 2 complete supply sources would be needed:

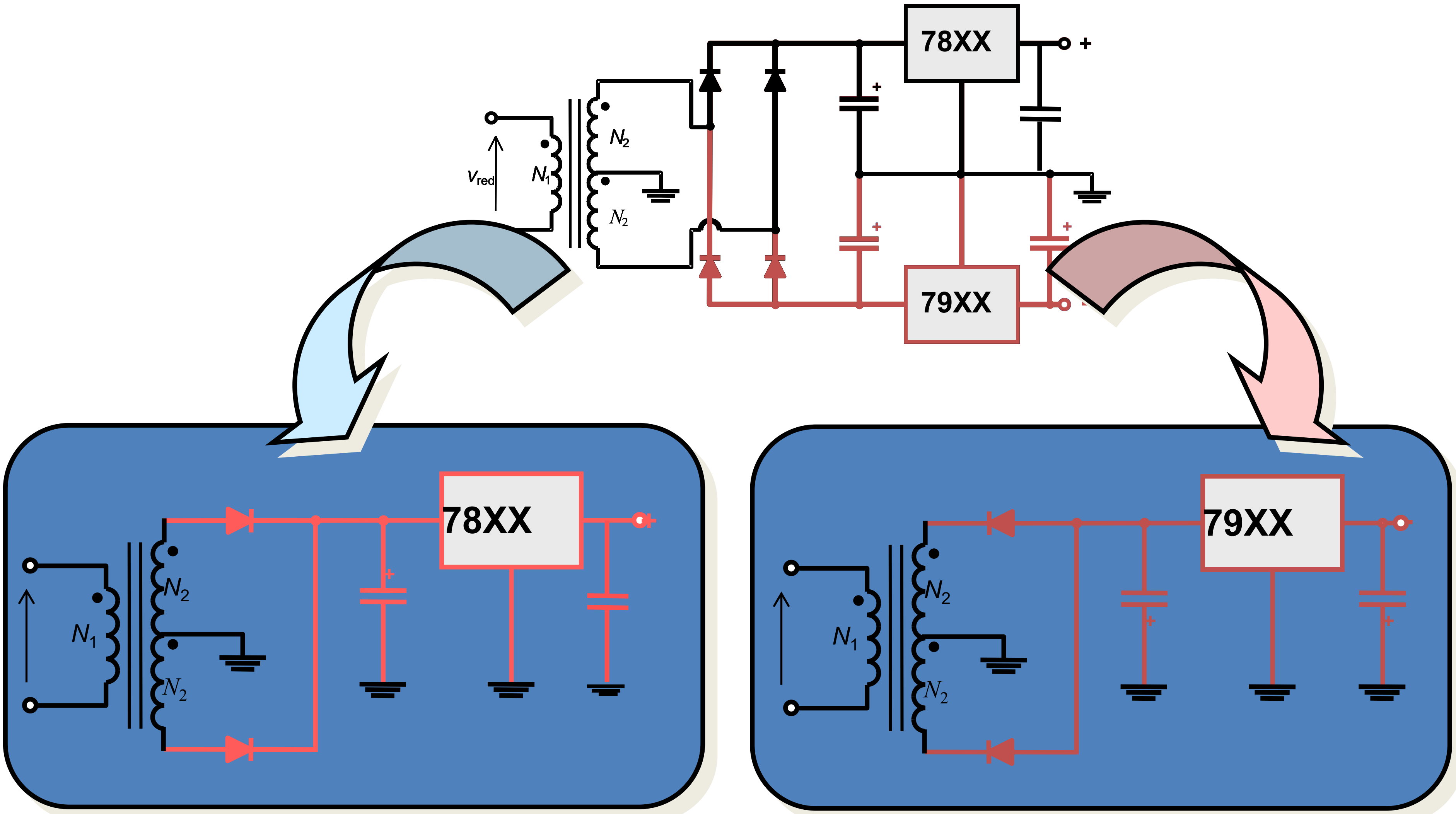




Using 79XX the design is simpler

6. Integrated Power Supplies

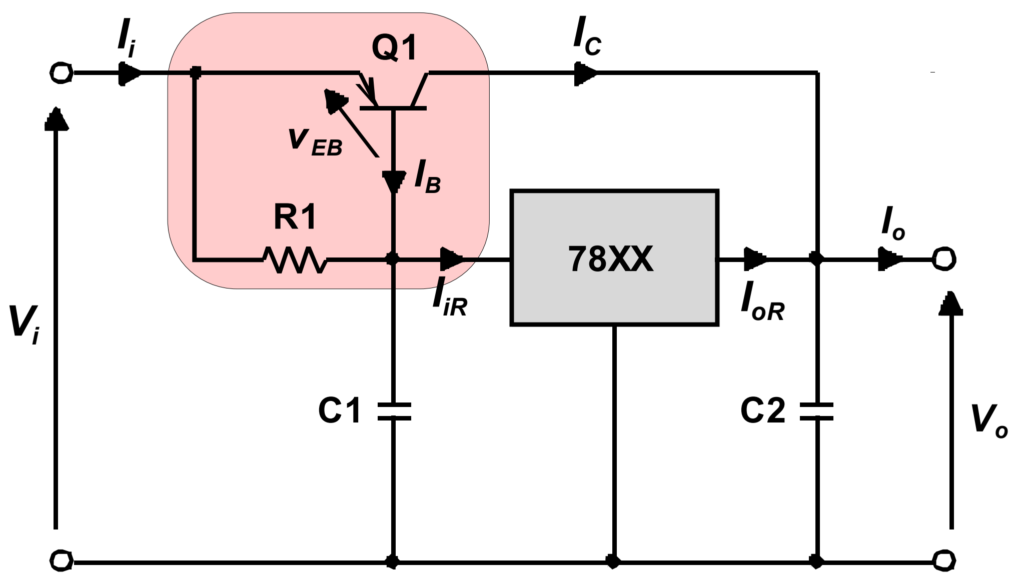
Regulators of 3 terminals.



6. Integrated Power Supplies

Regulators of 3 terminals. Increase of the output current.

- **Addition of a transistor and a resistor to increase the output current.**
  - Transistor → supports most of the current supplied to the load.
  - Regulator → assures the stability of the output voltage.
- **The minimum difference of input-output voltage increases.**
  - v_{EB} + minimum voltage drop in the regulator (2 or 3 V).



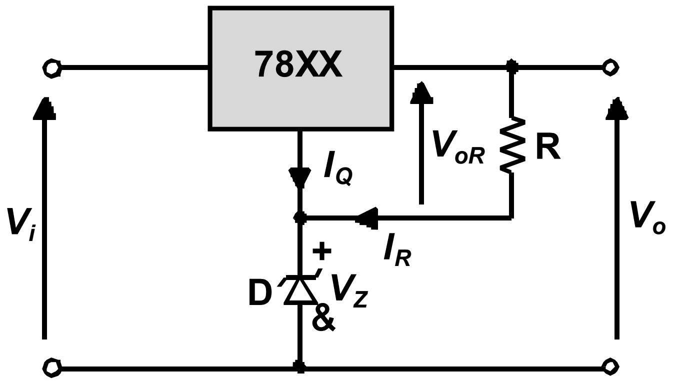
$$R_1 = \frac{v_{EB}}{I_{iR} - \frac{I_c}{\beta}}$$

$$I_o = I_{oR} + I_c$$

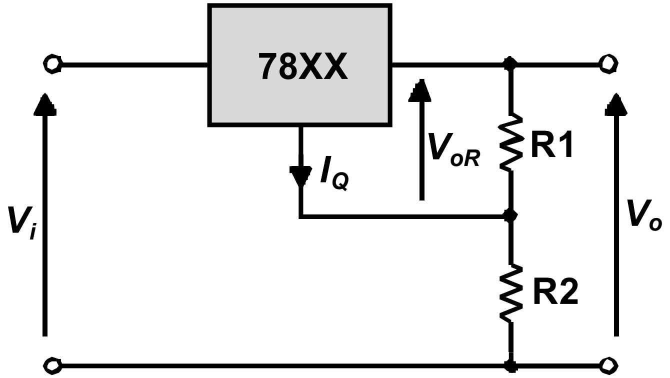
6. ntegrated Power Supplies

Regulators of 3 terminals. Increase of the output voltage.

- **With a fixed regulator a different output voltage (from the nominal one) can also be obtained.**
- **Addition of a positive voltage to the reference terminal (Gnd/Common) of the regulator.**
  - The quiescent current (8.5 mA maximum) must be assured.



$$V_o = V_{oR} + V_z$$

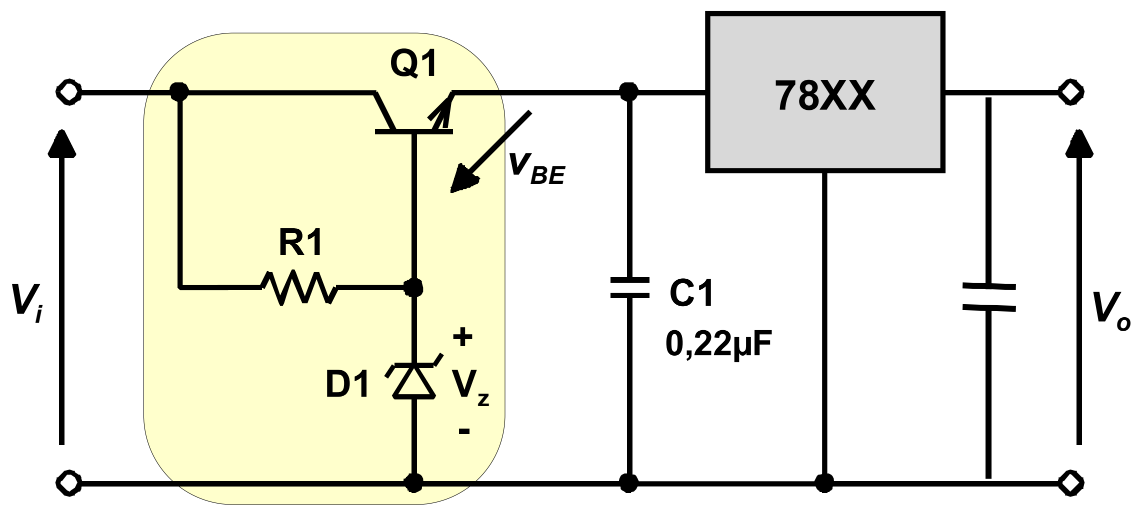


$$V_o = V_{oR}\left(1 + \frac{R_2}{R_1}\right) + I_Q \cdot R_2$$

6. Integrated Power Supplies

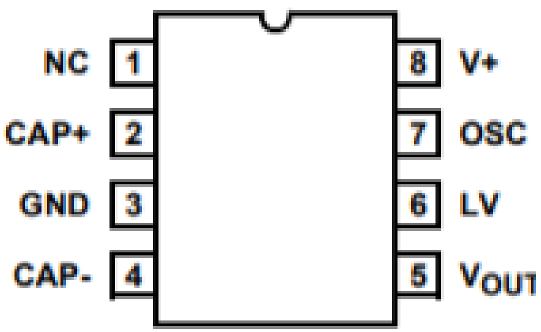
Regulators of 3 terminals. Elevated input voltages.

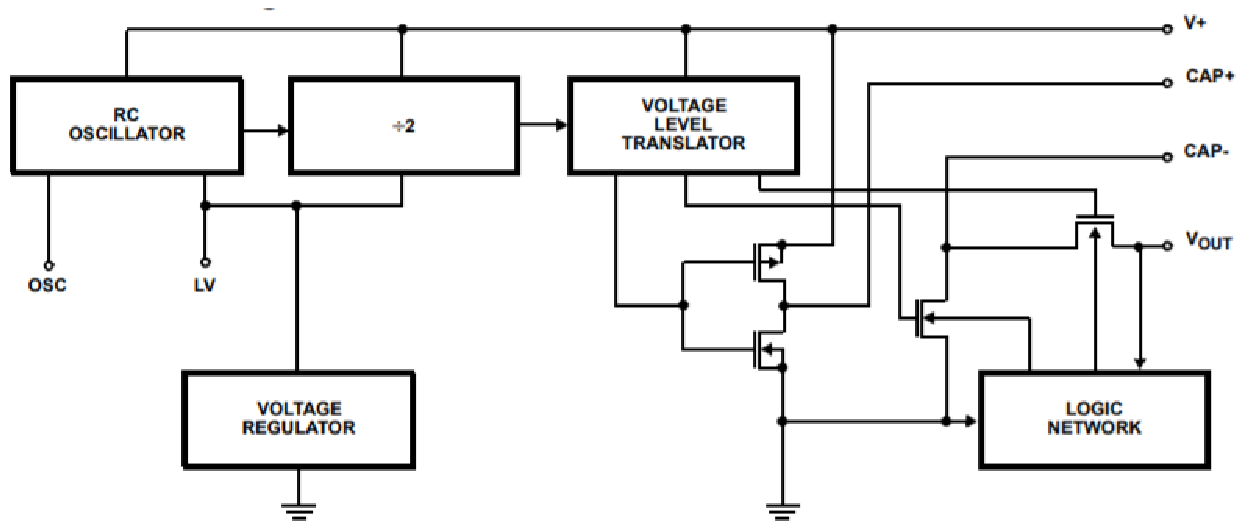
- In general, the maximum input voltage for a 78XX is 35 V (for 79XX, -35 V).
- If the input voltage is higher, a stabilizer can be connected before the regulator.
- This solution helps to dissipate less power in the regulator.



6. Integrated Power Supplies

Voltage Converters: ICL7660



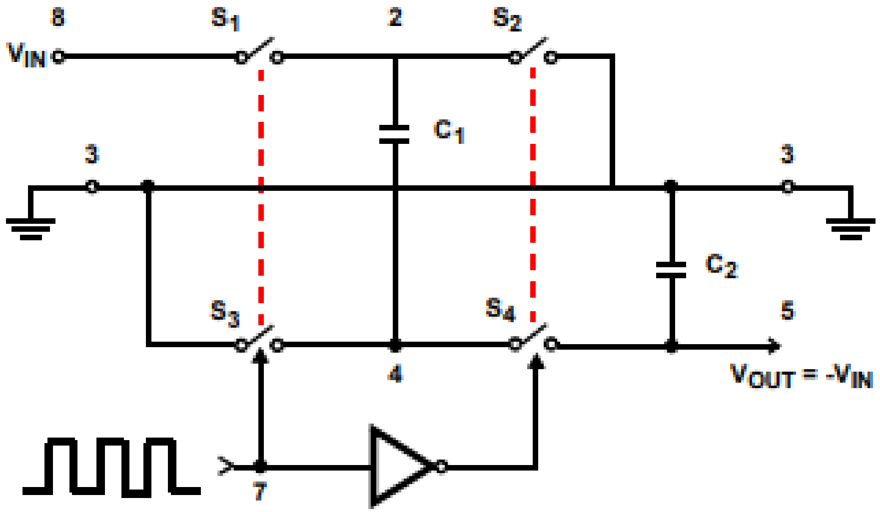


- CMOS power supply circuits
- Supply voltage conversions:

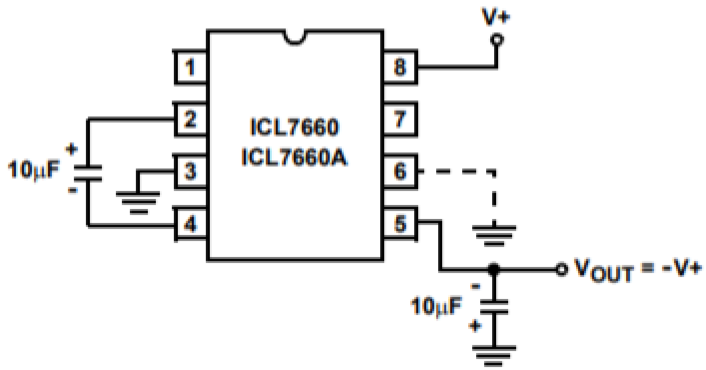
  +1.5V to +10.0V → -1.5V to -10.0V.
- Voltage doublers

6. Integrated Power Supplies

Voltage Converters: ICL7660 as negative converter



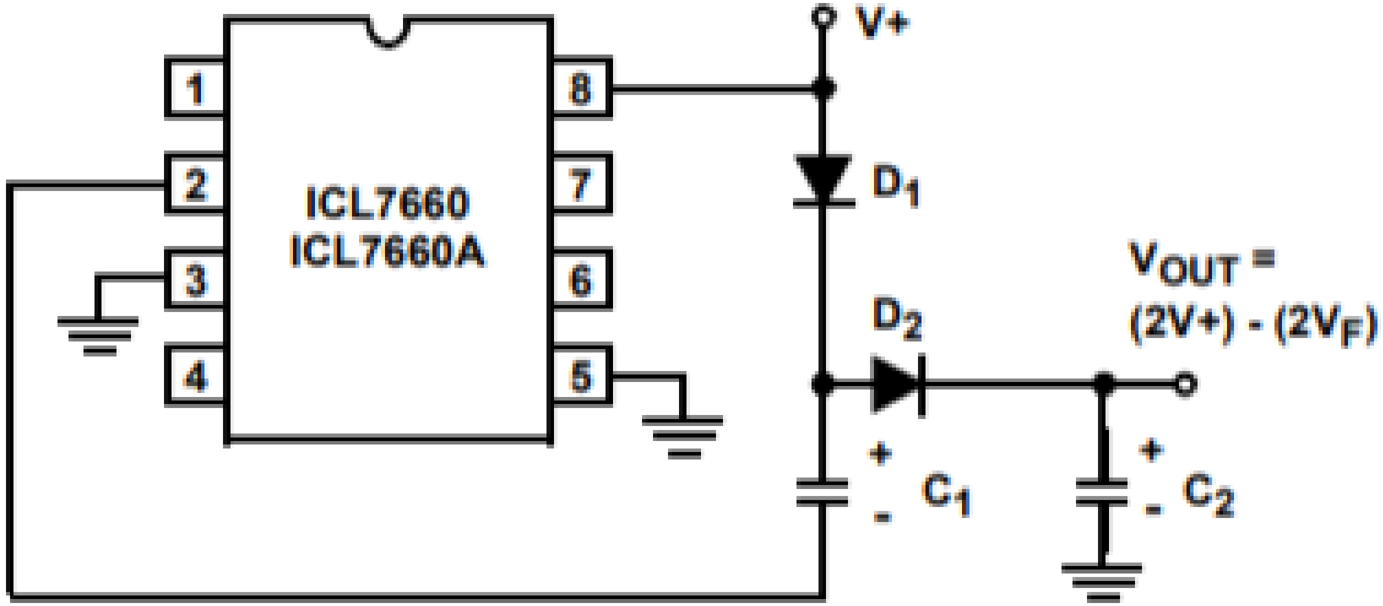
CMOS Switches:
S1, S3 charge of C1 to Vin
S2, S4 Vout=-Vin



Simple negative converter
Pin 6 to ground only if V+ < 3.5V

6. Integrated Power Supplies

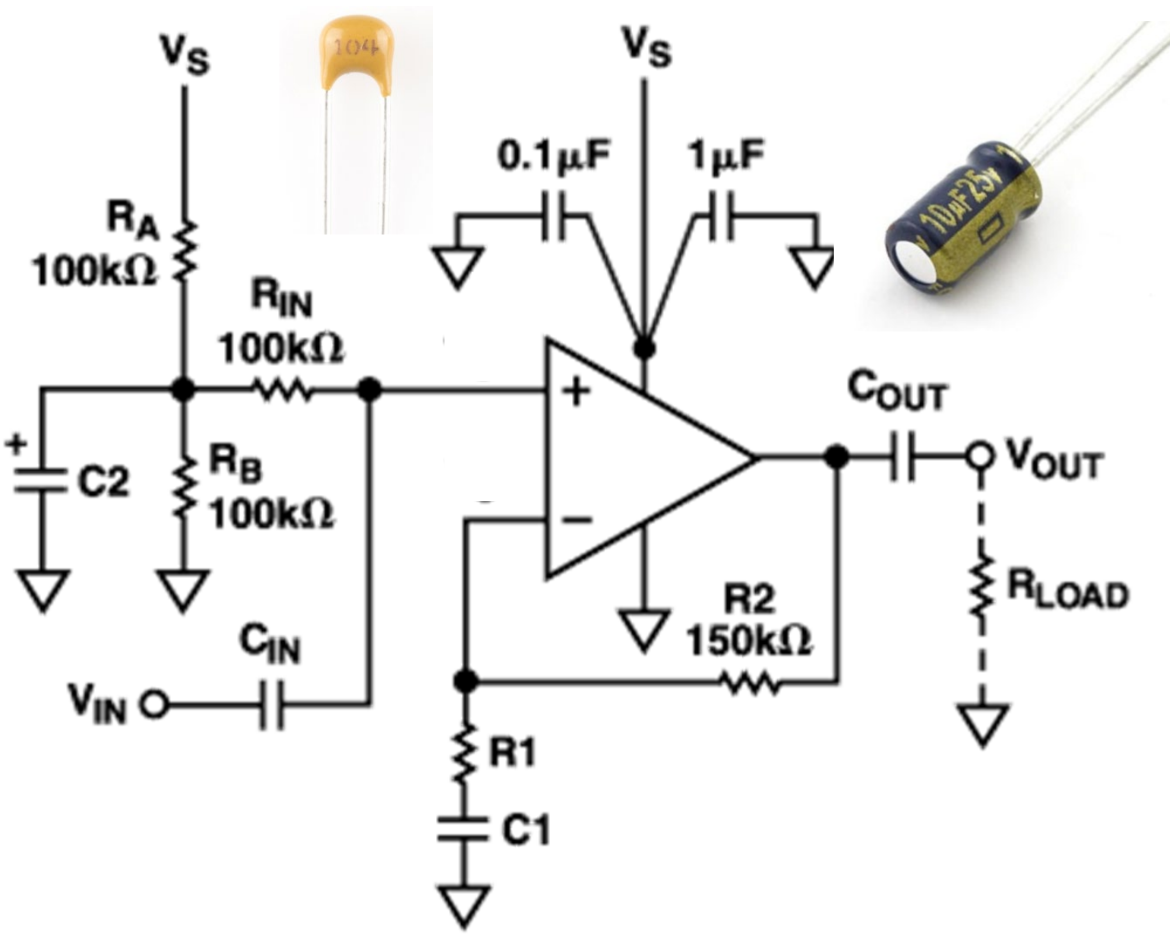
Voltage Converters: ICL7660 as voltage doubler



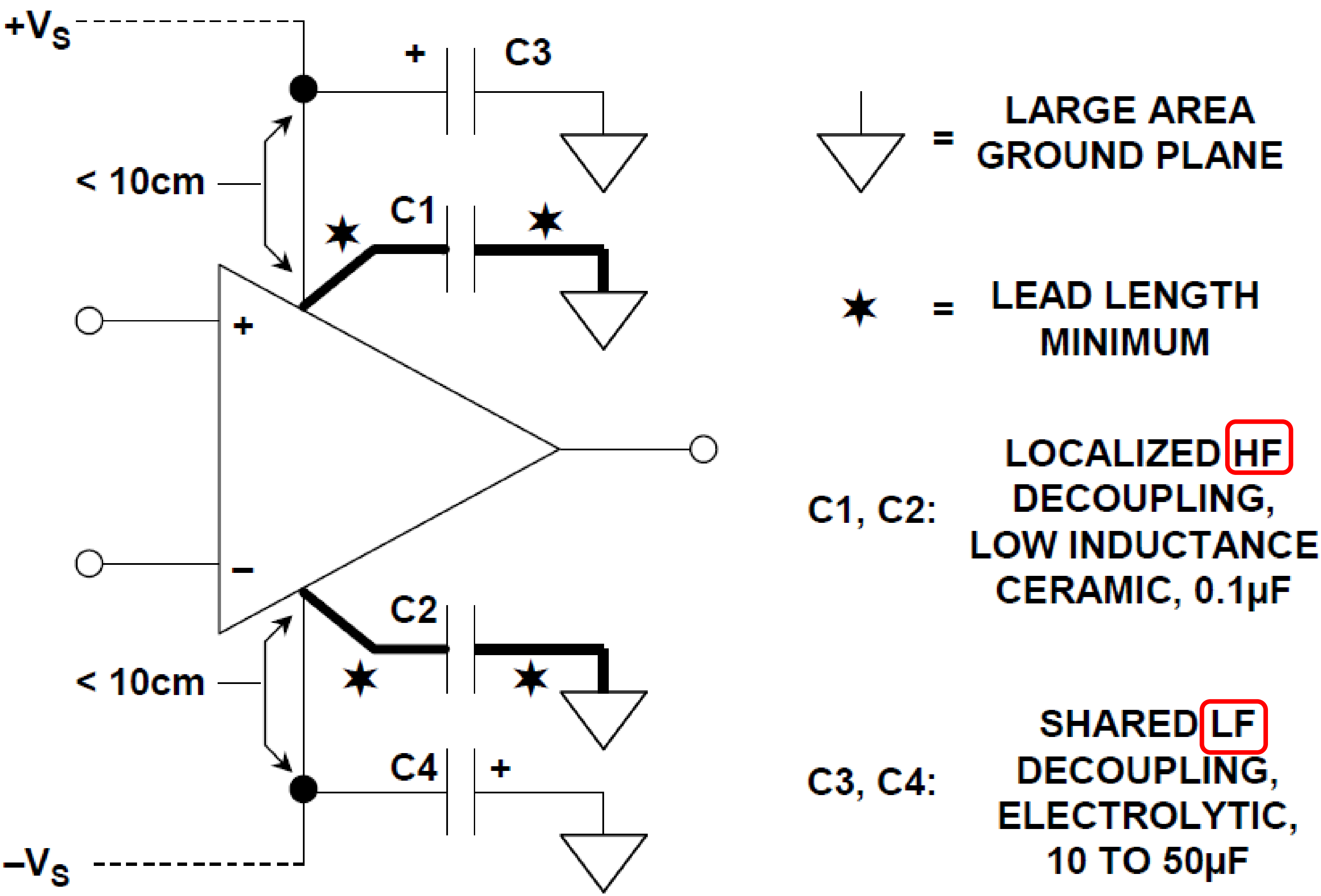
V_F forward voltage of the diode

7. Decoupling capacitors

They operate as charge reservoir (decoupling)

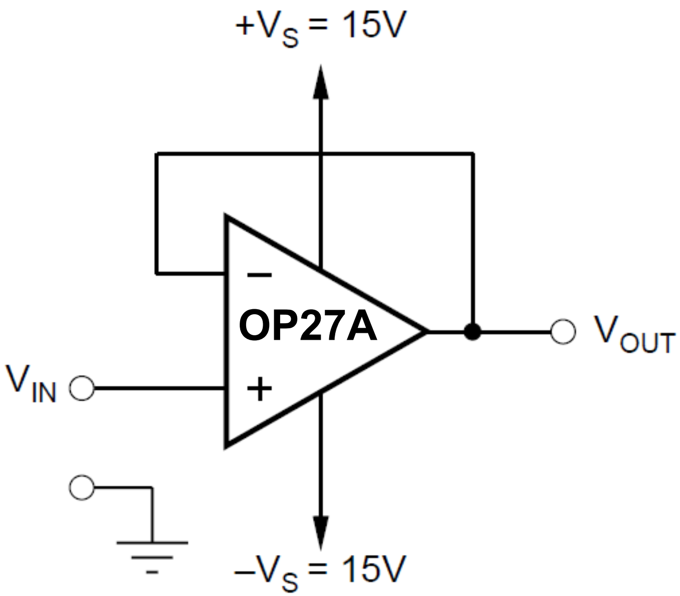


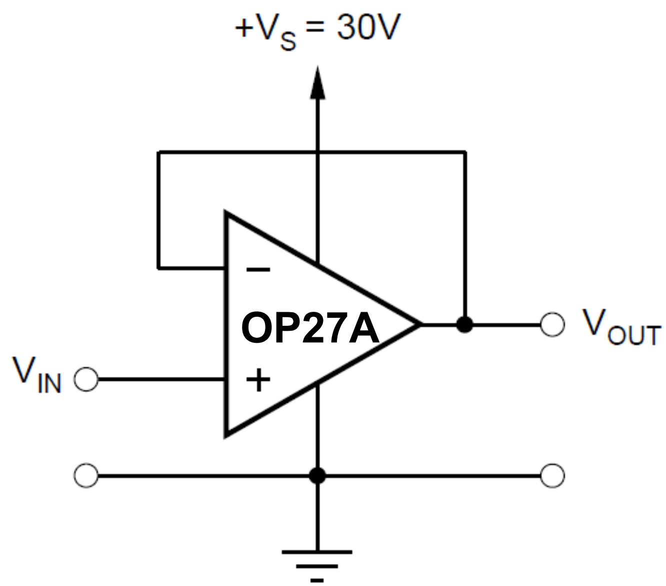
7. Decoupling capacitors



8. Non-symmetrical supply

Work out the voltage range at the output V_{OUT}





OP27 SPECIFICATIONS

ELECTRICAL CHARACTERISTICS $V_S = \pm15$ V, $T_A = 25°C$, unless otherwise noted.

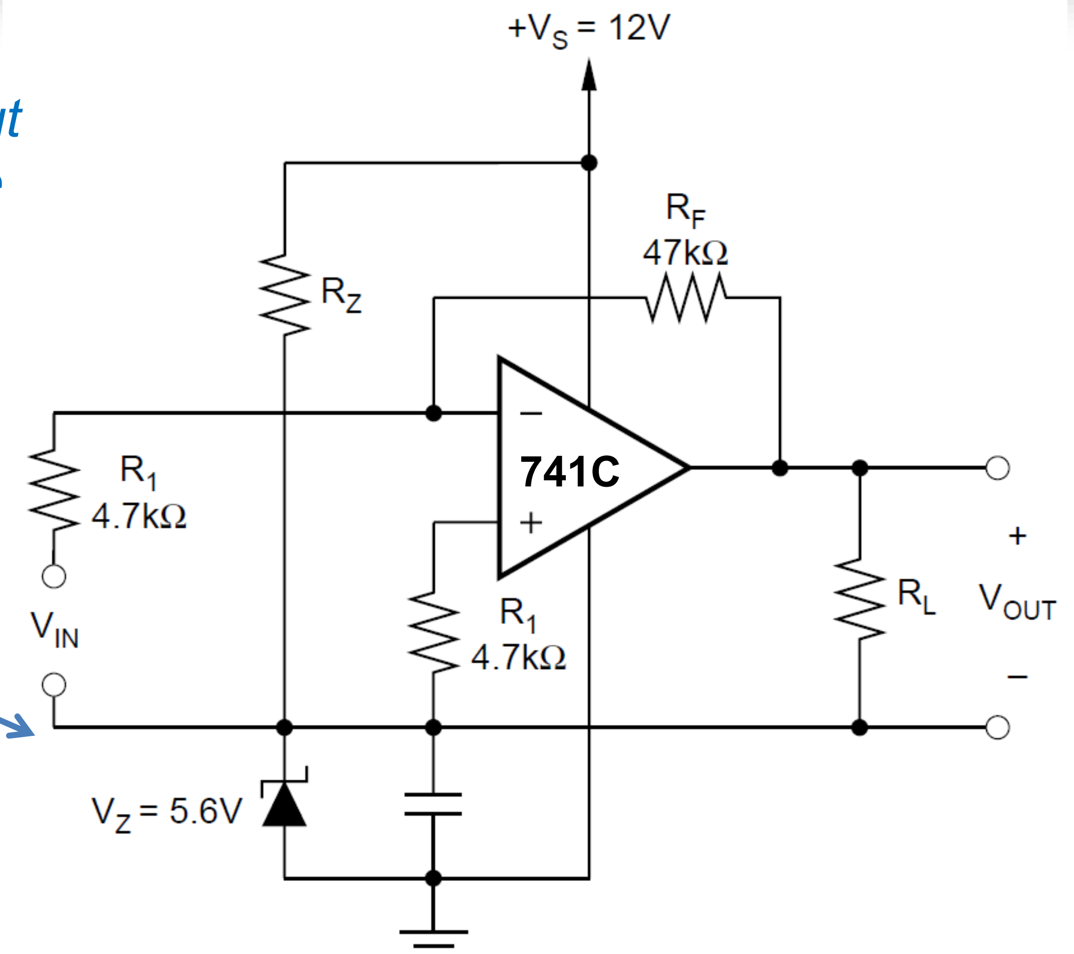
Data Sheet

			OP27A/OP27E			OP27G			
Parameter	**Symbol**	**Test Conditions**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Unit**
OUTPUT VOLTAGE SWING	V_O	$R_L \geq 2$ kΩ	±12.0	±13.8		±11.5	±13.5		V
		$R_L \geq 600$ Ω	±10.0	±11.5		±10.0	±11.5		V

8. Non-symmetrical supply

Work out the symmetrical input voltage range can process the circuit (typically).
R_L=100 kΩ
Work out the range for V_{OUT}

(floating ground)



Electrical Characteristics, LM741C

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Output voltage swing	V_S = ±15 V	R_L ≥ 10 kΩ	±12	±14		V
		R_L ≥ 2 kΩ	±10	±13		

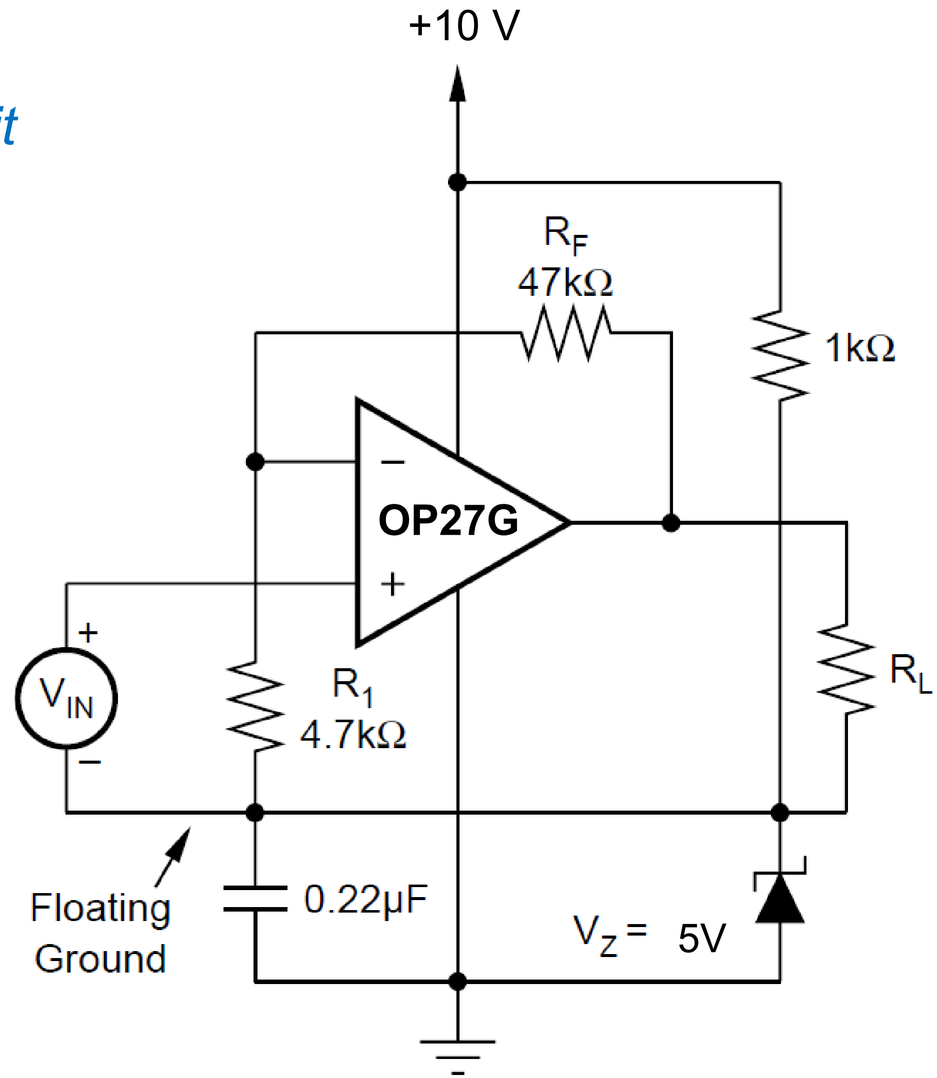
8. Non-symmetrical supply

Work out the symmetrical input voltage range can process the circuit (typically).

R_L=100 kΩ

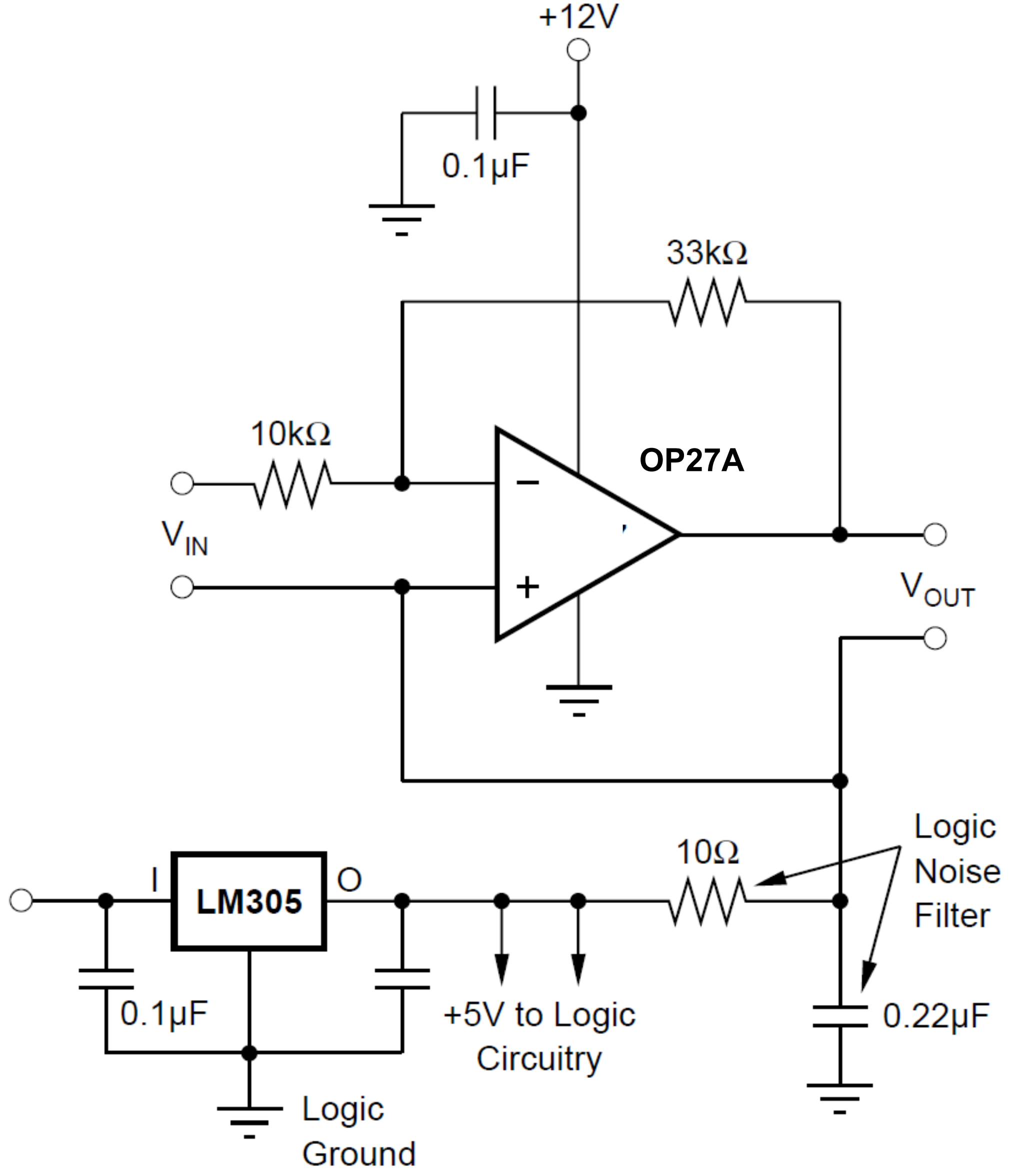
Work out the range for V_{OUT}

Work out the current in the zener diode



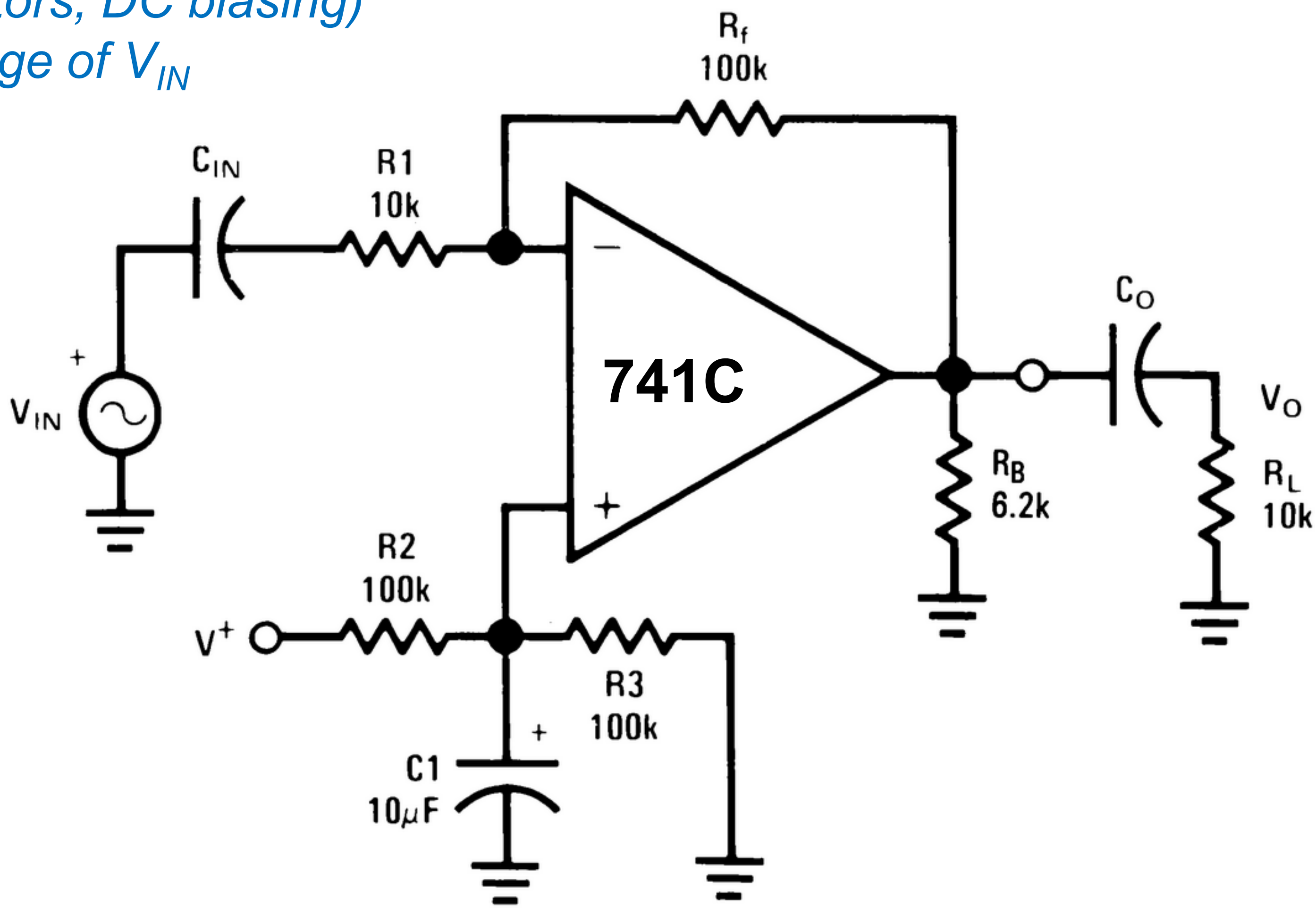
8. Non-symmetrical supply

Estimate the gain of the system (V_{OUT}/V_{IN}) and the maximum range at the input (typical values)

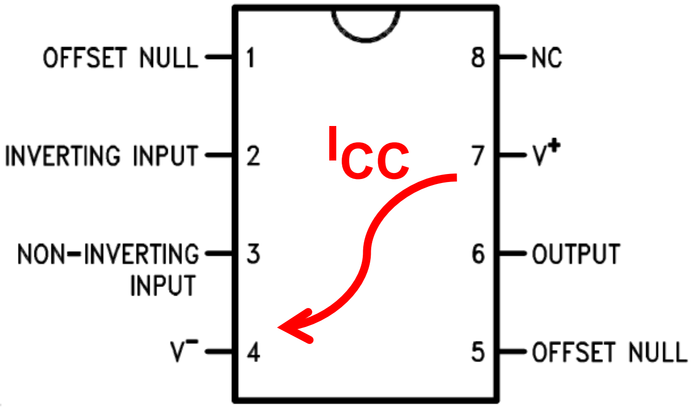


8. Non-symmetrical supply

The OA supply is +15 V, work out the voltage at the output of the OA.
What is the role of C_{IN}, C1 and C_O?
(coupling capacitors, DC biasing)
Work out the range of V_{IN}



9. Consumption estimation



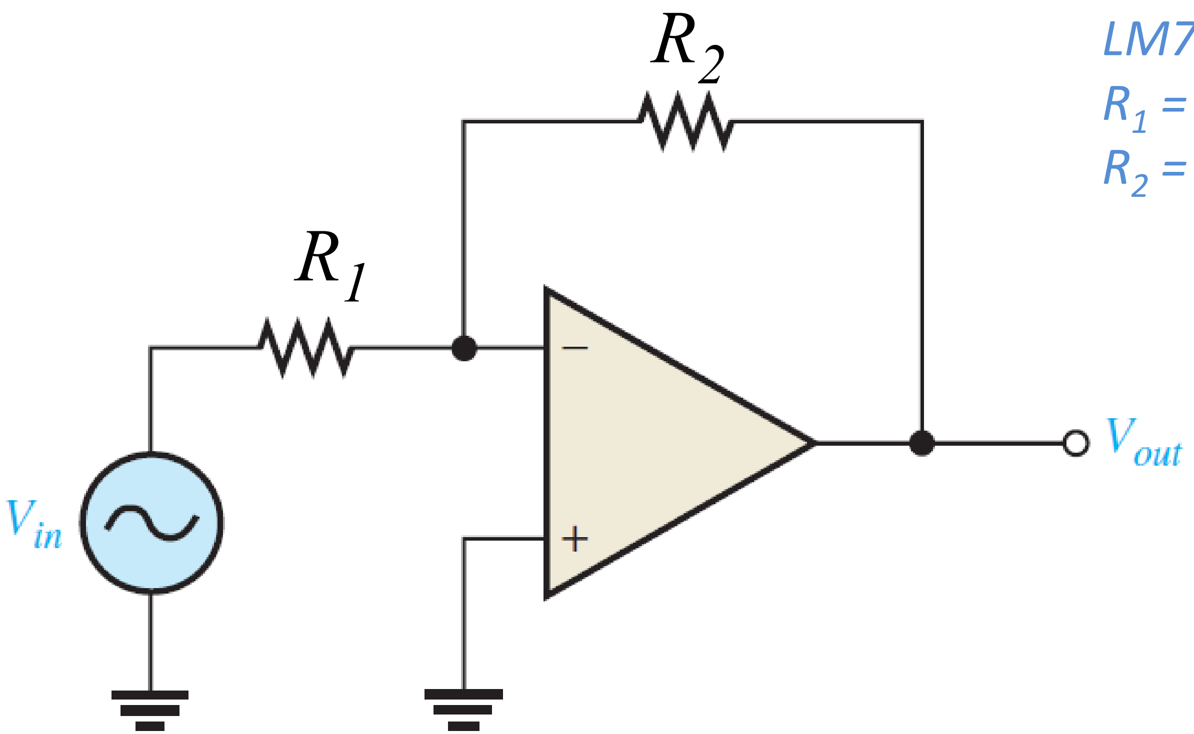
Absolute Maximum Ratings

		MIN	MAX	UNIT
Supply voltage	LM741, LM741A		±22	V
	LM741C		±18	
Power dissipation (4)			500	mW

Electrical Characteristics, LM741C

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Supply current	T_A = 25°C		1.7	2.8	mA
Power consumption	V_S = ±15 V, T_A = 25°C		50	85	mW

9. Consumption estimation



LM741C

$R_1 = 1\ k\Omega$

$R_2 = 5\ k\Omega$

Estimate the current supplied by each supply source when the OA is supplied with ±15 V and Vin = +2 V

Estimate the power dissipated by the OA. Is the maximum power exceeded?

Repeat the calculations when the supply is +30 V and Vin = −2 V

9. Consumption estimation

If the input voltage Ve varies between ±1 V, estimate:

1) Maximum current consumption (provided by the supply source)

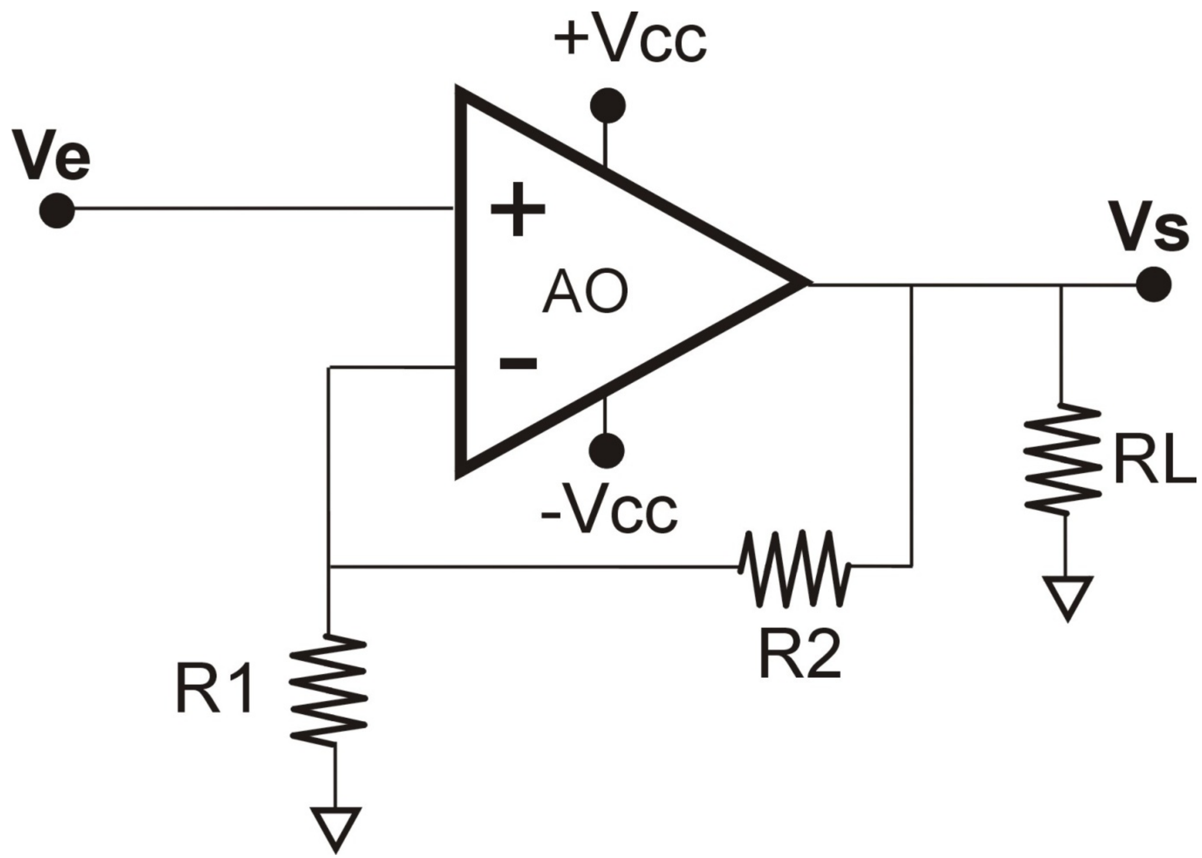
2) Maximum power dissipated by the OA. Check that the maximum power is not exceeded.

AO 741C (±15 V)

R1 = 1 kΩ

R2 = 9 kΩ

RL = 5 kΩ



9. Consumption estimation

If the input voltage Ve = –2 V, estimate:

1) Maximum current consumption (provided by the supply source)

2) Maximum power dissipated by the OA. Check that the maximum power is not exceeded.

3) Check that the balance of dissipated powers and provided by all the components of the circuit.

AO 741C (+30 V)

R1 = 2.2 kΩ

R2 = 11 kΩ