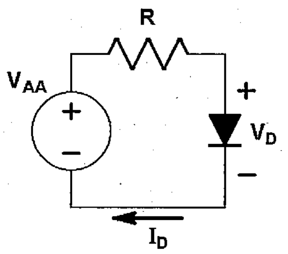
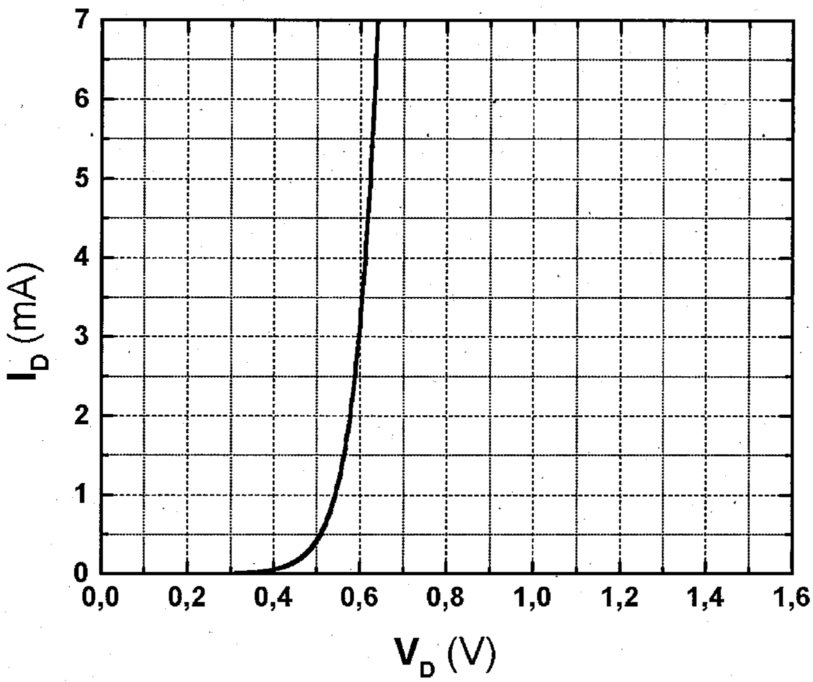
PROBLEMAS DE CIRCUITOS ELECTRÓNICOS
2º Curso de Grado en Ingeniería Informática – 17/18

TEMA 4: El diodo

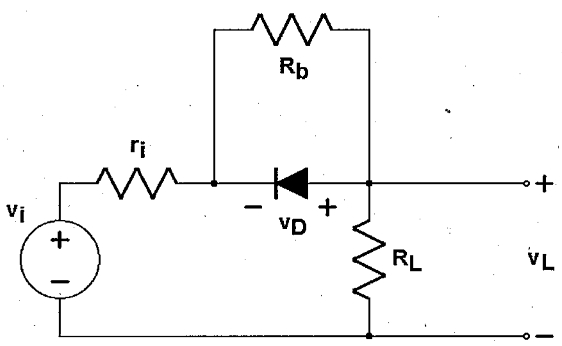
1.- En el circuito de la figura se emplea un diodo de silicio con la característica representada, siendo $V_{AA} = 5$ V y R = 1 KΩ.

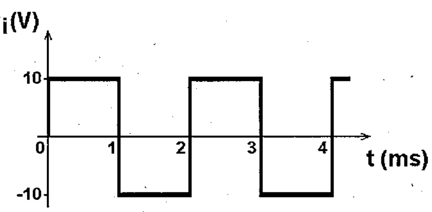
a) Determinar la corriente en el diodo y la tensión entre sus extremos.
b) ¿Cuánta potencia disipa el diodo?
c) ¿Cuál será la corriente del diodo si se cambia R a 2 KΩ? ¿Y a 5 KΩ?





2.- Para el siguiente circuito (considerando para el diodo $v_\gamma = 0.6$ V, $R_d = 0$):
a) Dibujar $v_L(t)$ si $R_b = 100$ KΩ, $r_i = R_L = 1$ KΩ y v_i es como se indica en la figura.
b) Repetir para una v_i senoidal de 1 V de *cresta* (o amplitud máxima, V_{im}).

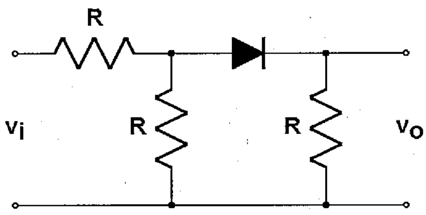




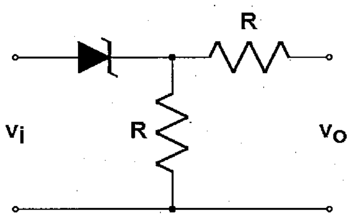
3.- Expresar la característica de transferencia de los siguientes circuitos:

a) Datos: Suponer para el diodo $V_\gamma = 0.6$ V y $r_d = 0$; R=10 Ω.

b) Datos: Suponer el zener con $V_\gamma = 0.6$ V y $r_d = 0$ en directa y $V_Z = 5$ V y $r_Z = 10$ Ω en inversa. R = 20 Ω.

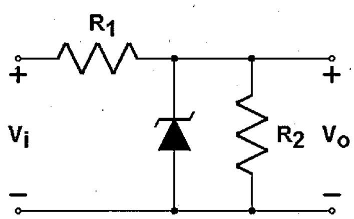


(*a*)



(*b*)

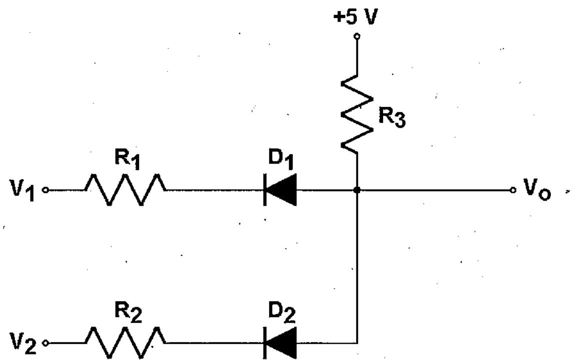
4.- En el circuito de la figura, calcular la característica de transferencia, $V_o = f(V_i)$, empleando para el diodo Zener un modelo lineal en sus diferentes regiones (V_Z, R_Z=0; V_γ, R_d=0). Expresar la dependencia funcional de todos los tramos y puntos de corte sin emplear valores numéricos, suponiendo que V_i toma valores en el todo el rango posible ($-\infty<V_i<\infty$).
Dibujar la forma de dicha función empleando los valores numéricos V_Z=10V, V_γ=0.6V y $R_1=R_2$=10KΩ.



5.- Encontrar V_o para:

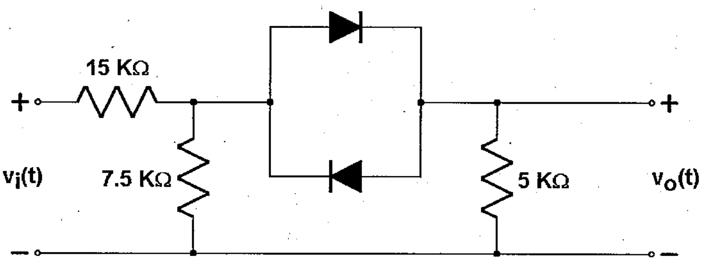
a) $V_1 = 5$ V y $V_2 = 5$ V
b) $V_1 = 5$ V y $V_2 = 0$ V
c) $V_1 = 0$ V y $V_2 = 5$ V
d) $V_1 = 0$ V y $V_2 = 0$ V

siendo: $R_3 = 18$ KΩ.
$R_1 = R_2 = 2$ KΩ.
$V_\gamma = 0.65$ V.

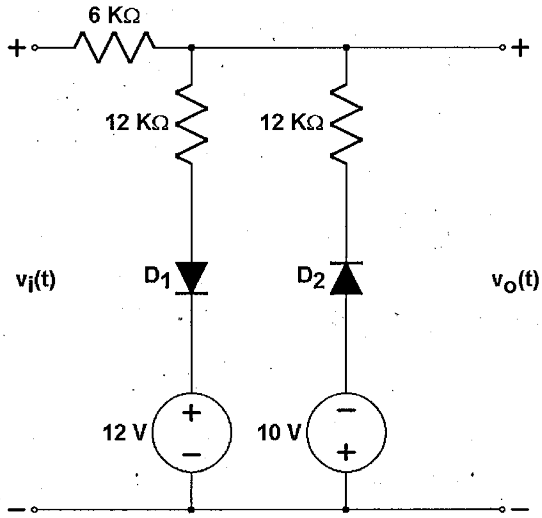


¿Qué función lógica podría realizar este circuito?

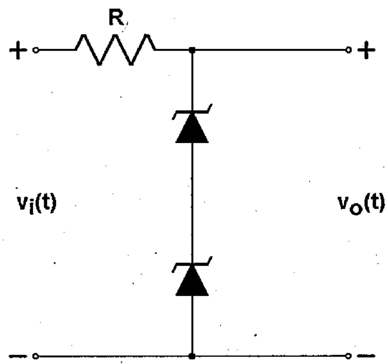
6. Trazar la característica de transferencia de tensión del circuito, suponiendo los dos diodos idénticos, siendo en ellos $V_\gamma = 0.6$ V y $r_d = 0$ Ω.



7.- Obtener la característica de transferencia de tensión del circuito asumiendo el modelo lineal de la tensión umbral para los diodos ($V_\gamma = 0.6$ V, $R_d = 0$ Ω). Esbozar un ciclo de la tensión de salida suponiendo que la tensión de entrada sea $v_i(t) = 20$ sen(ωt).



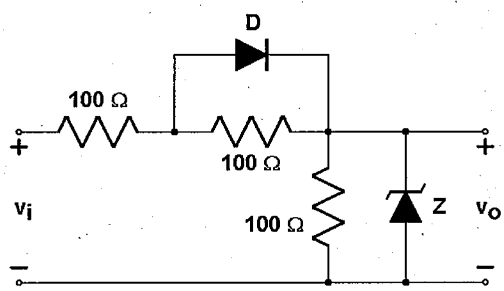
8.- Expresar la característica de transferencia del siguiente circuito, suponiendo ambos diodos zener idénticos, con $V_\gamma = 0.6$ V y $r_d = 0$ en directa y $V_Z = 3$ V y $r_Z = 10$ Ω en inversa. R = 20 Ω.



9.- En el circuito de la figura el diodo, D, tiene una tensión de ruptura infinita mientras que la del zener, Z, es: $V_Z = 5$V. La tensión umbral de conducción tanto del zener como del diodo D es: $V_\gamma = 0.6$V. Considerar que las resistencias serie asociadas a ambos diodos son despreciables.

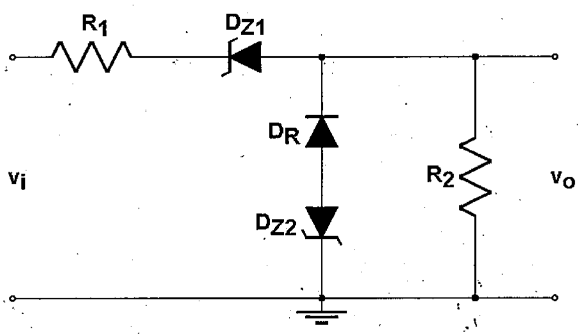
a) Encontrar la tensión de salida en función de la tensión de entrada, $v_o = f(v_i)$ para tensiones de entrada: $-15\text{V} < v_i < +15\text{V}$.

b) Dibujar esquemáticamente $v_o = f(v_i)$.



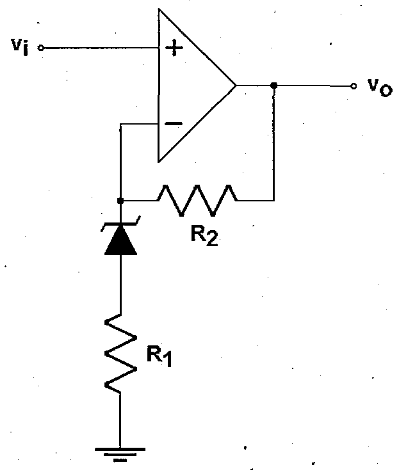
10.- Calcular la característica de transferencia de tensión del siguiente circuito. Esbozarla gráficamente indicando los valores de v_i para los que varía su pendiente, así como los valores de dicha pendiente en cada uno de los intervalos de vi así definidos.

Suponer que las resistencias de los diodos son despreciables ($R_d = R_Z = 0$), y que las tensiones Zener son iguales (de valor V_Z) y mayores que sus umbrales de conducción directa (de valor V_γ).



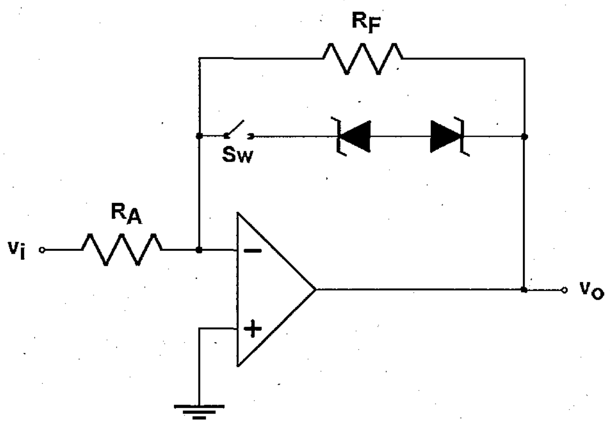
11.- Suponer que el amplificador operacional es ideal, y que el diodo zener tiene un voltaje umbral en directa de $V_\gamma = 0$ con resistencia dinámica $R_d = 0$ y un voltaje de ruptura inversa de valor V_Z ($V_Z > 0$) con resistencia despreciable $R_Z = 0$.
Suponer también que la tensión de saturación positiva del amplificador operacional es mayor que V_Z.

a) Obtener la expresión de v_o en función de v_i.
b) Esbozar la característica de transferencia si $R_2 = 2R_1$.



12.- En el circuito de la figura, $v_i = 1\text{ V}\cos(\omega t)$, $R_F = 100\text{ K}\Omega$ y $R_A = 10\text{ K}\Omega$. Además, el amplificador operacional es ideal y los diodos zener tienen una tensión de ruptura $V_Z = 5$ V y una tensión de conducción (umbral) $V_\gamma = 0.7$ V.

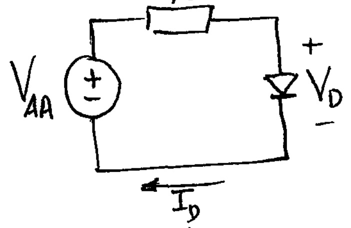
a) Calcular la tensión de salida v_o cuando el interruptor Sw está abierto.
b) Calcular la tensión de salida cuando el interruptor Sw está cerrado.



TEMA 4 : DIODOS

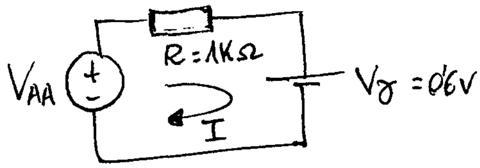
1.

$V_{AA} = 5V \qquad R = 1k\Omega$



a) observando la gráfica: $V_\gamma \approx 0'6V$

Hipótesis 1: Diodo en conducción



$V_D = V_\gamma = 0'6V$

$$I = I_D = \frac{V_{AA} - V_\gamma}{R} = \frac{5 - 0'6}{1} = 4'4\ mA > 0$$

$\Rightarrow$ Hipótesis correcta.

b) $P = V.I = 0'6 . 4'4.10^{-3} = 2'64 . 10^{-3}\ w = 2'64\ mw$

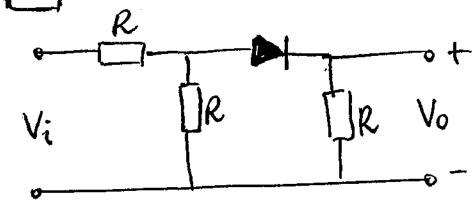
c) $I_D = I = \dfrac{V_{AA} - V_\gamma}{R} =$

$\longrightarrow I_D = \dfrac{5V - 0'6V}{2} = 2'2\ mA$

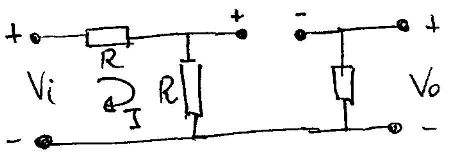
$\longrightarrow I_D = \dfrac{5V - 0'6V}{5} = 0'88\ mA$

3.

Expresar la característica de transferencia: DATOS: $V_\gamma = 0'6V$ y $R = 10\Omega$

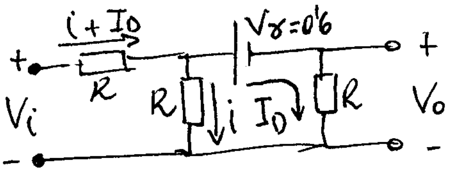


$V_o = 0$ siempre y cuando $V_D < V_\gamma$



$$V_D = V_i - I.R = V_i - \frac{V_i}{2R}R = \frac{V_i}{2} \Rightarrow V_o = 0 \text{ cuando } \frac{V_i}{2} < V_\gamma$$

$$\boxed{V_o = 0 \quad \text{cuando} \quad V_i < 2V_\gamma}$$

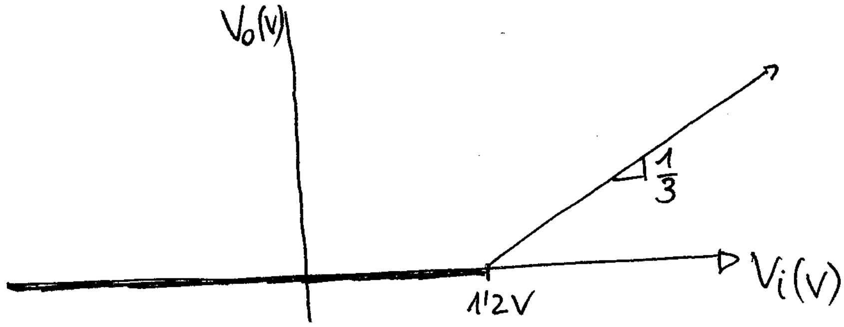


$$\begin{cases} V_i - (i + I_D)R - iR = 0 \\ iR - 0'6 - I_D R = 0 \end{cases} \Rightarrow \ldots \Rightarrow I_D = \frac{V_i - 2V_\gamma}{3R}$$

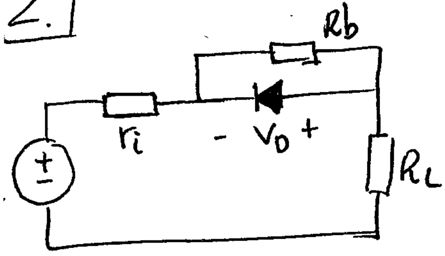
$I_D > 0 \Leftrightarrow V_i > 2V_\gamma$

$$V_o = I_D . R = \frac{V_i - 2V_\gamma}{3}$$

$$\boxed{V_o = \frac{V_i - 2V_\gamma}{3} \quad \text{cuando} \quad V_i > 2V_\gamma}$$



2.

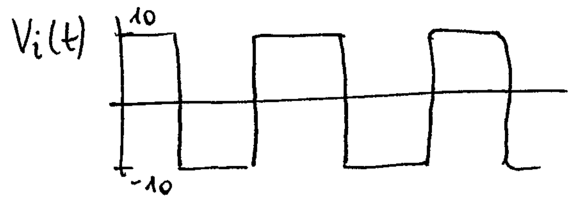


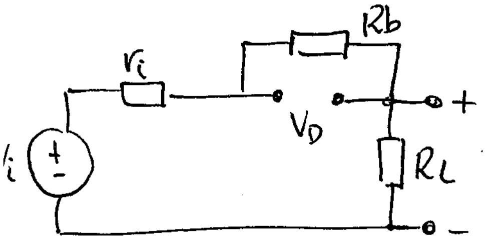
$V_\gamma = 0'6\,V$

$R_b = 100\,K\Omega$

$r_i = 1\,K\Omega$

$R_L = 1\,K\Omega$



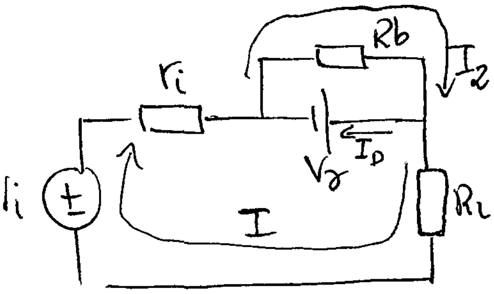


$$V_L = I.R_L = \frac{V_i}{r_i+R_b+R_L}\cdot R_L \approx \frac{V_i}{100}$$

siempre y cuando $V_D < V_\gamma$

$$V_D = -I.R_b = \frac{-V_i}{r_i+R_b+R_L}.R_b \approx -V_i$$

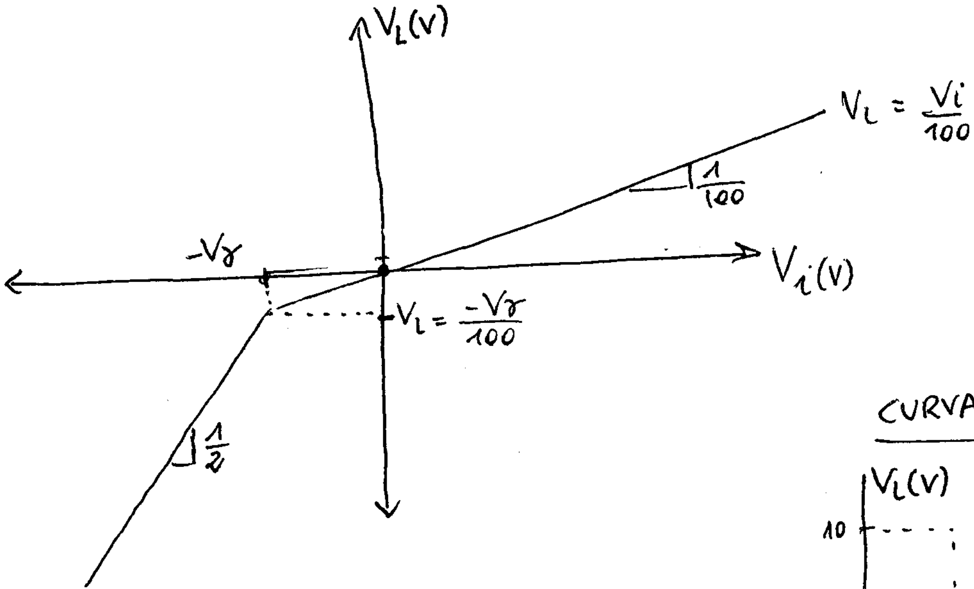
$$\boxed{V_L = \frac{V_i}{100} \quad \text{cuando} \quad V_i \geq -V_\gamma}$$



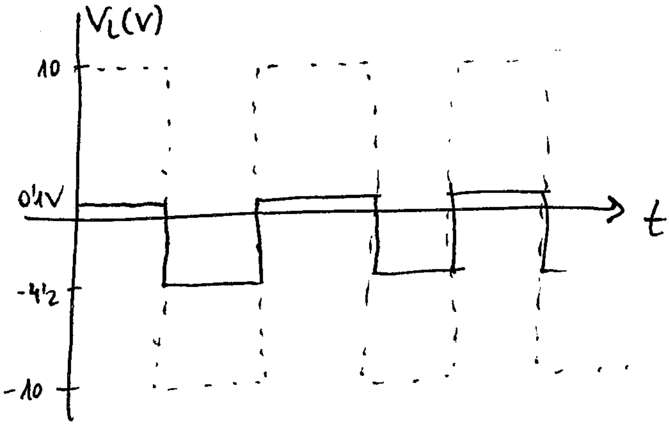
$$\begin{cases} V_L = I.R_L \\ R_L.I - V_\gamma + r_i I - V_i = 0 \end{cases} \Rightarrow V_L = R_L\frac{V_i+V_\gamma}{r_i+R_L} \Rightarrow$$

$$\Rightarrow \boxed{V_L = \frac{V_i+V_\gamma}{2} \quad \text{cuando} \quad \underbrace{V_i < -V_\gamma}_{\text{complementario a la anterior}}}$$

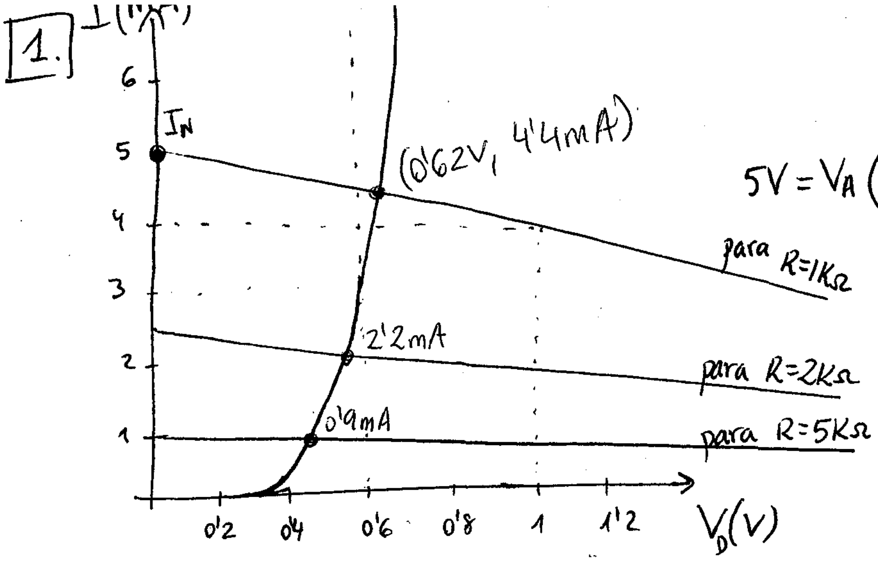
CURVA CARACTERÍSTICA

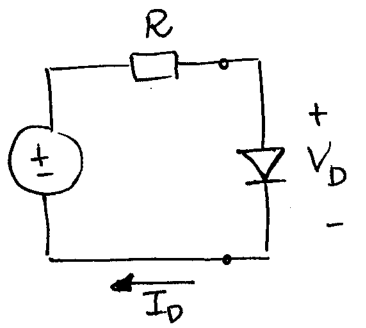


CURVA SALIDA V_L



1.





$V_{Th} = 5V$

$I_N = \frac{5V}{1K\Omega} = 5mA$ pendiente $= \frac{-1}{1K\Omega}$ ⊛

b) $P = V_D . I_D = 2'73$ mw

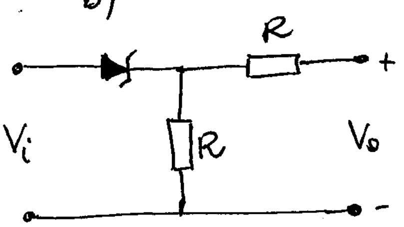
c) $I_N = \frac{5V}{2K\Omega} = 2'5mA$ pendiente $= \frac{-1}{2K\Omega}$ ⊛

$I_N = \frac{5V}{5K\Omega} = 1mA$ pendiente $= \frac{-1}{5K\Omega}$ ⊛

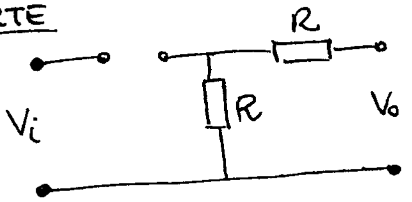
⊛ pendiente $= -(R^{-1})$ porque estamos representando I frente a V, y no V frente a I.

3. DATOS: $V_\gamma = 0'6V$; $V_Z = 5V$ y $r_Z = 10\Omega$; $R = 20\Omega$

b)

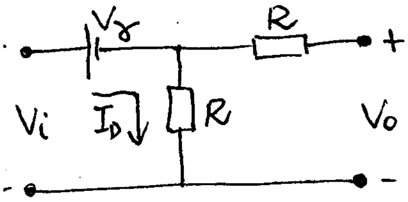


CORTE



$\boxed{V_o = 0}$ cuando $V_D = \boxed{V_i < V_\gamma}$

CONDUCCIÓN DIRECTA

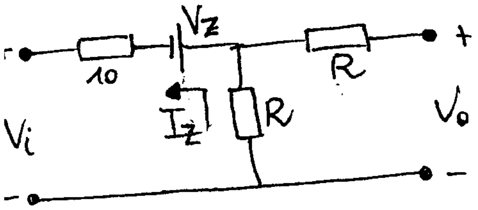


$V_i - V_\gamma - I_D R = 0 \rightarrow I_D = \frac{V_i - V_\gamma}{R}$

$V_o = I_D R = V_i - V_\gamma \rightarrow \boxed{V_o = V_i - V_\gamma}$ cuando $I_D > 0$

$\Rightarrow \frac{V_i - V_\gamma}{R} > 0 \leftrightarrow \boxed{V_i > V_\gamma}$

CONDUCCIÓN INVERSA



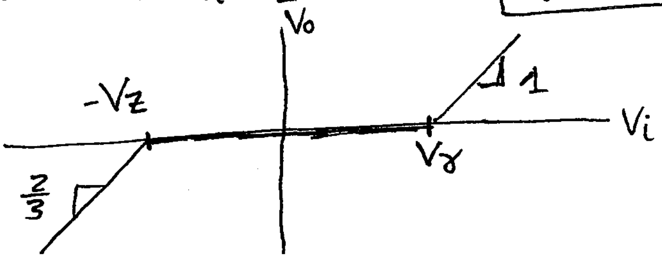
$V_i + I_Z.10 + V_Z + I_Z.20 = 0$

$V_i + I_Z(10+20) + V_Z = 0 \Rightarrow I_Z = \frac{-V_i - V_Z}{30}$

$V_o = -20 I_Z = \frac{2}{3}(V_i + V_Z) \rightarrow \boxed{V_o = \frac{2}{3}(V_i + V_Z)}$

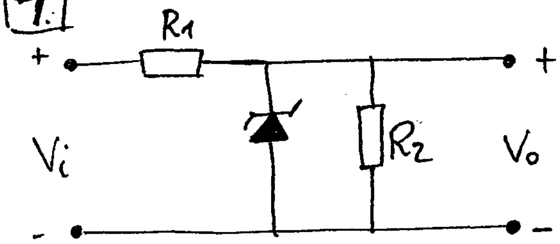
Cuando $I_Z > 0 \leftrightarrow -V_i - V_Z > 0 \rightarrow \boxed{V_i < -V_Z}$

$$V_o \begin{cases} = V_i - V_\gamma & \text{cuando } V_i > V_\gamma \\ = 0 & \text{cuando } -V_Z < V_i < V_\gamma \\ = \frac{2}{3}(V_i + V_Z) & \text{cuando } V_i < -V_Z \end{cases}$$

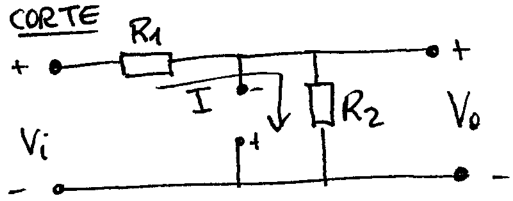


DATOS para la representación: $V_Z = 10V$, $V_\gamma = 0.6V$, $R_1 = R_2 = 10k\Omega$

4.



CORTE



$$V_i - IR_1 - IR_2 = 0$$

$$I = \frac{V_i}{R_1+R_2}$$

$$V_o = IR_2 = \frac{V_i R_2}{R_1+R_2}$$

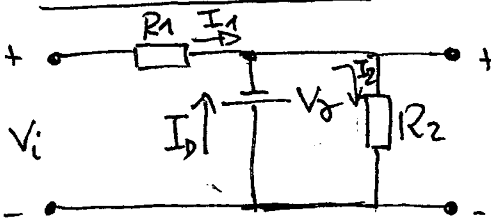
$$\boxed{V_o = \frac{V_i R_2}{R_1+R_2}}$$ cuando $V_D < V_\gamma$

$$V_D = -IR_2 = \frac{-V_i R_2}{R_1+R_2}$$

$$V_D = \frac{-V_i R_2}{R_1+R_2} < V_\gamma \rightarrow -V_i < \frac{V_\gamma(R_1+R_2)}{R_2}$$

$$\boxed{V_i > \frac{-(R_1+R_2)}{R_2} V_\gamma}$$

CONDUCCIÓN DIRECTA



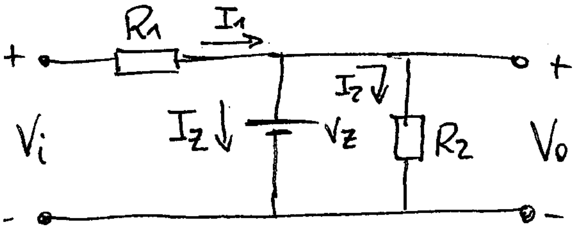
$$\boxed{V_o = -V_\gamma}$$ cuando $I_D > 0$

$$I_D = I_2 - I_1 = \frac{-V_\gamma - 0}{R_2} - \frac{V_i - (-V_\gamma)}{R_1} = \frac{-V_\gamma}{R_2} - \frac{(V_i + V_\gamma)}{R_1} = \frac{-R_1 V_\gamma - R_2(V_i+V_\gamma)}{R_1 R_2}$$

$$I_D > 0 \leftrightarrow -R_1 V_\gamma - R_2(V_i + V_\gamma) > 0 \leftrightarrow -R_2(V_i+V_\gamma) > R_1 V_\gamma \leftrightarrow$$

$$\leftrightarrow V_i + V_\gamma < \frac{-R_1 V_\gamma}{R_2} \leftrightarrow V_i < -\left(\frac{R_1}{R_2}V_\gamma + V_\gamma\right) \leftrightarrow \boxed{V_i < \frac{-V_\gamma(R_1+R_2)}{R_2}}$$

CONDUCCIÓN INVERSA

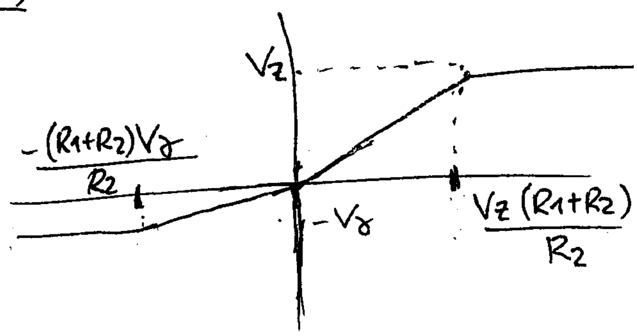


$$\boxed{V_o = V_Z}$$ cuando $I_Z > 0$

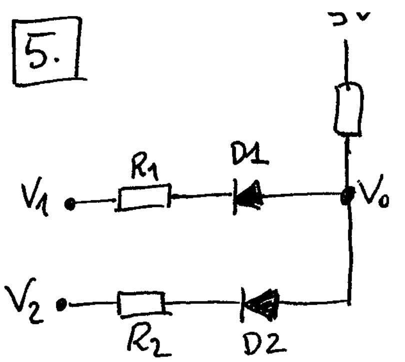
$$I_Z = I_1 - I_2 = \frac{V_i - V_Z}{R_1} - \frac{V_Z}{R_2} = \frac{R_2(V_i - V_Z) - R_1 V_Z}{R_1 R_2}$$

$$I_Z > 0 \leftrightarrow R_2 V_i - R_2 V_Z - R_1 V_Z > 0 \leftrightarrow R_2 V_i > V_Z(R_1+R_2) \leftrightarrow \boxed{V_i > \frac{V_Z(R_1+R_2)}{R_2}}$$

$$V_o \begin{cases} = \dfrac{V_i R_2}{R_1+R_2} & \text{si } \dfrac{-(R_1+R_2)V_\gamma}{R_2} < V_i < \dfrac{V_Z(R_1+R_2)}{R_2} \\ = -V_\gamma & \text{si } V_i < \dfrac{-(R_1+R_2)V_\gamma}{R_2} \\ = V_Z & \text{si } V_i > \dfrac{V_Z(R_1+R_2)}{R_2} \end{cases}$$



5.



DATOS: $R_3 = 18K\Omega$

$R_1 = R_2 = 2K\Omega$

$V_\gamma = 0'65\ V$

a) $V_1 = 5V \quad V_2 = 5V$

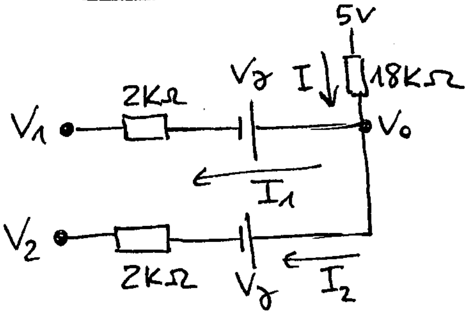
b) $V_1 = 5V \quad V_2 = 0V$

c) $V_1 = 0V \quad V_2 = 5V$

d) $V_1 = 0V \quad V_2 = 0V$

e) ¿Función lógica?

• Hipótesis 1: AMBOS CONDUCEN



$$I = I_1 + I_2$$

$$\begin{cases} I = \dfrac{5 - V_0}{18K} \\ I_1 = \dfrac{V_0 - V_\gamma - V_1}{2K} \\ I_2 = \dfrac{V_0 - V_\gamma - V_2}{2K} \end{cases}$$

$$\Rightarrow \frac{5 - V_0}{18K} = \frac{V_0 - V_\gamma - V_1}{2K} + \frac{V_0 - V_\gamma - V_2}{2K}$$

$$\Rightarrow \frac{5 - V_0}{18K} = \frac{2V_0 - 2V_\gamma - V_1 - V_2}{2K}$$

$$\Rightarrow 10K - 2KV_0 = 36KV_0 - 36KV_\gamma - 18KV_1 - 18KV_2 \Rightarrow$$

$$\Rightarrow 38KV_0 = 36KV_\gamma + 18KV_1 + 18KV_2 + 10K \Rightarrow \boxed{V_0 = \frac{18V_\gamma + 9V_1 + 9V_2 + 5}{19}}$$

Esto ocurre si y solo si $I_{D_1} > 0$ y $I_{D_2} > 0$

$$I_{D_1} = I_1 = \frac{V_0 - V_1 - 0'65}{2K} > 0 \longrightarrow \boxed{V_1 < V_0 - 0'65}$$

$$I_{D_2} = I_2 = \frac{V_0 - V_2 - 0'65}{2K} > 0 \longrightarrow \boxed{V_2 < V_0 - 0'65}$$

a) $V_1 = 5V$, $V_2 = 5V$ $\Rightarrow V_0 - 0'65 = 4'97 < V_1 \wedge 4'97 < V_2$

No se cumple

b) $V_1 = 5V$, $V_2 = 0V$ $\Rightarrow V_0 - 0'65 = 2'6 < V_1 \wedge 2'6 > 0 = V_2$

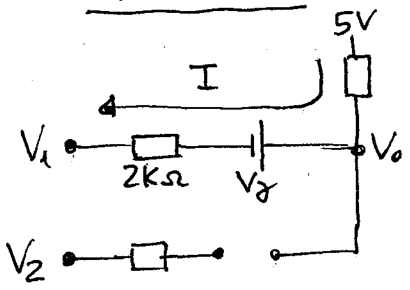
No se cumple ya que $V_0 - 0'65 < V_1$

c) Análogo al caso (b) pero ahora $V_0 - 0'65 < V_2$

d) $V_1 = 0V$, $V_2 = 0V$ $\Rightarrow V_0 - 0'65 = 0'22 > V_1 = 0 \wedge 0'22 > V_2 = 0$

Se cumple. Para el apartado (d) conducen ambos diodos.

• HIPÓTESIS 2: CONDUCE D1 y D2 CORTE



$$I = I_D = \frac{5 - V_0}{18K} = \frac{V_0 - V_\gamma - V_1}{2K}$$

$$10K - 2KV_0 = 18KV_0 - 18KV_\gamma - 18KV_1$$

$$20KV_0 = 18KV_\gamma + 18KV_1 + 10K$$

$$\boxed{V_0 = \frac{9V_\gamma + 9V_1 + 5}{10}}$$

Esto ocurre si y solo si $I_D = I > 0$ y $V_{D_2} < V_\gamma$

$I_D = I = \frac{5 - V_0}{18K} > 0 \Rightarrow \boxed{V_0 < 5}$

$V_{D_2} = V_0 - V_2 \Rightarrow \boxed{V_0 - V_2 < V_\gamma}$

a) $V_1 = 5V$, $V_2 = 5V$ $\Rightarrow V_0 = 5'585\,V \Rightarrow V_0 = 5'585 > 5$ no se cumple

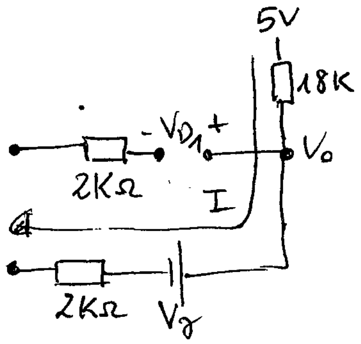
b) $V_1 = 5V$, $V_2 = 0V$ $\Rightarrow V_0 = 5'585V \Rightarrow 5'585 > 5$ no se cumple

c) $V_1 = 0V$, $V_2 = 5V$ $\Rightarrow V_0 = 1'085\,V \Rightarrow 1'085 < 5$ ✓

$V_0 - V_2 = -3'915V < V_\gamma = 0'65$ ✓

Se cumple
En el (c) D1 conduce y D2 corte

• HIPÓTESIS 3: CONDUCE D2 y D1 CORTE



$$I = I_D = \frac{5 - V_0}{18K} = \frac{V_0 - V_\gamma - V_2}{2K}$$

$$\boxed{V_0 = \frac{9V_\gamma + 9V_2 + 5}{10}}$$

Esto ocurre si y solo si $I_D = I > 0$ y $V_{D_1} < V_\gamma$

$I_D = I = \frac{5 - V_0}{18K} > 0 \Rightarrow \boxed{V_0 < 5}$

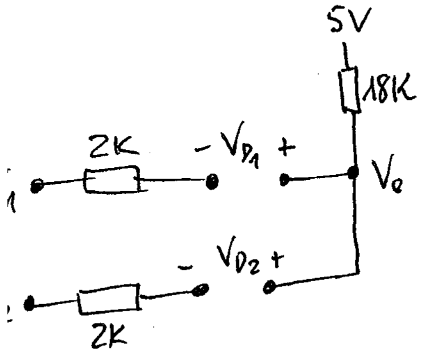
$V_{D_1} = V_0 - V_1 \Rightarrow \boxed{V_0 - V_1 < V_\gamma}$

b) $V_1 = 5V$, $V_2 = 0V$ $\Rightarrow V_0 = 1'085V \Rightarrow 1'085 < 5$ ✓

$V_0 - V_1 = -3'915 < V_\gamma = 0'65$ ✓

Se cumple
En el (b) D1 está en corte y D2 conduce.

• HIPÓTESIS 4: EN CORTE D1 y D2.



$V_o = 5V$ si y solo si $V_{D1} < V_\gamma$ y $V_{D2} < V_\gamma$

$V_{D1} = V_o - V_1 \Rightarrow \boxed{V_o - V_1 < V_\gamma}$

y

$V_{D2} = V_o - V_2 \Rightarrow \boxed{V_o - V_2 < V_\gamma}$

a) $V_1 = 5V$, $V_2 = 5V$ $\Rightarrow$ $V_o - V_1 = 0 < 0'65V$ ✓, $V_o - V_2 = 0 < 0'65V$ ✓

Se cumple. Apartado (a) no conduce ningún diodo. Están los dos en corte

e) Con $V_1 = 0V$ y $V_2 = 0V \Rightarrow V_o = 0'88V$

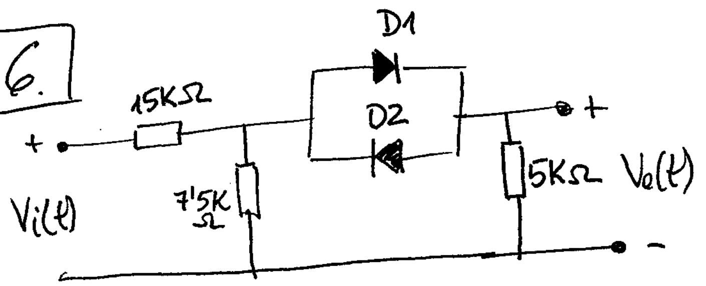
Con $V_1 = 5V$ y $V_2 = 0V \Rightarrow V_o = 1'085V$

Con $V_1 = 0V$ y $V_2 = 5V \Rightarrow V_o = 1'085V$

Con $V_1 = 5V$ y $V_2 = 5V \Rightarrow V_o = 5V$

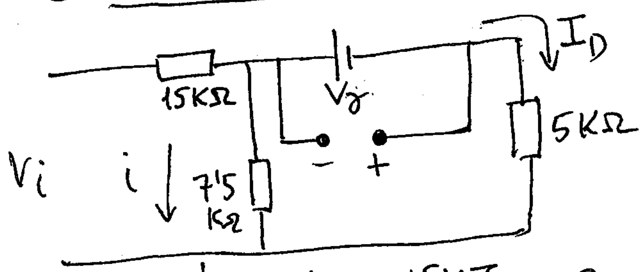
Función lógica AND

$\boxed{6.}$



$V_\gamma = 0'6V$

① D1 en conducción y D2 en corte



$V_o = I_D \cdot 5K$

$\begin{cases} V_i - 15Ki - 15KI_D - 7'5Ki = 0 \\ 7'5Ki - V_\gamma - 5KI_D = 0 \end{cases} \Rightarrow$

$\Rightarrow \begin{cases} -22'5Ki + V_i - 15KI_D = 0 \\ 7'5Ki - V_\gamma - 5KI_D = 0 \quad \times 3 \end{cases}$

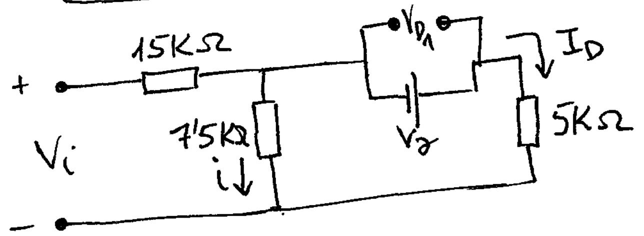
$V_i - 3V_\gamma - 30I_D = 0 \rightarrow I_D = \dfrac{V_i - 3V_\gamma}{30K}$; $V_o = \dfrac{V_i - 3V_\gamma}{30K} \cdot 5K$

$\Rightarrow \boxed{V_o = \dfrac{V_i}{6} - 0'3}$ Si:

• $I_D > 0 \Leftrightarrow V_i - 3V_\gamma > 0 \Rightarrow \boxed{V_i > 1'8}$

• $V_{D2} < V_\gamma \Leftrightarrow \boxed{-V_\gamma < V_\gamma}$ ✓ siempre se cumple para $V_\gamma = 0'6$

② D2 conduce y D1 en corte



$V_o = I_D \cdot 5K\Omega$

$$\begin{cases} 7'5Ki + V_\gamma - 5K I_D = 0 \\ V_i - 15K(i + I_D) - 7'5Ki = 0 \end{cases}$$

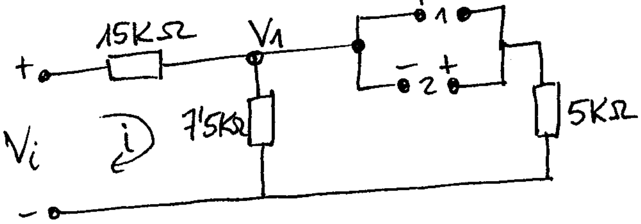
$$\Rightarrow \begin{cases} \cancel{7'5Ki} + V_\gamma - 5K I_D = 0 & \times 3 \\ \cancel{-22'5Ki} + V_i - 15K I_D = 0 \end{cases}$$

$$3V_\gamma + V_i - 30K I_D = 0 \rightarrow I_D = \frac{V_i + 3V_\gamma}{30K}$$

$\boxed{V_o = \frac{V_i}{6} + 0'3}$ Si:

- $-I_D = I_{D_2} > 0 \Rightarrow -V_i - 3V_\gamma > 0 \Rightarrow \boxed{V_i < -1'8V}$
- $V_{D_1} < V_\gamma \Rightarrow \boxed{-V_\gamma < V_\gamma}$ ✓ se cumple siempre para $V_\gamma = 0'6$ V

③ D1 y D2 en corte



$\boxed{V_o = 0}$ si $V_{\gamma_1} < V_\gamma$, $V_{\gamma_2} < V_\gamma$

$$V_1 = i \cdot 7'5K \; ; \quad i = \frac{V_i}{15K + 7'5K}$$

$$V_{D_1} = V_1 = 0'33V_i < V_\gamma \Rightarrow \boxed{V_i < 1'8}$$

$$V_{D_2} = -V_1 = -0'33V_i < V_\gamma \Rightarrow \boxed{V_i > -1'8}$$

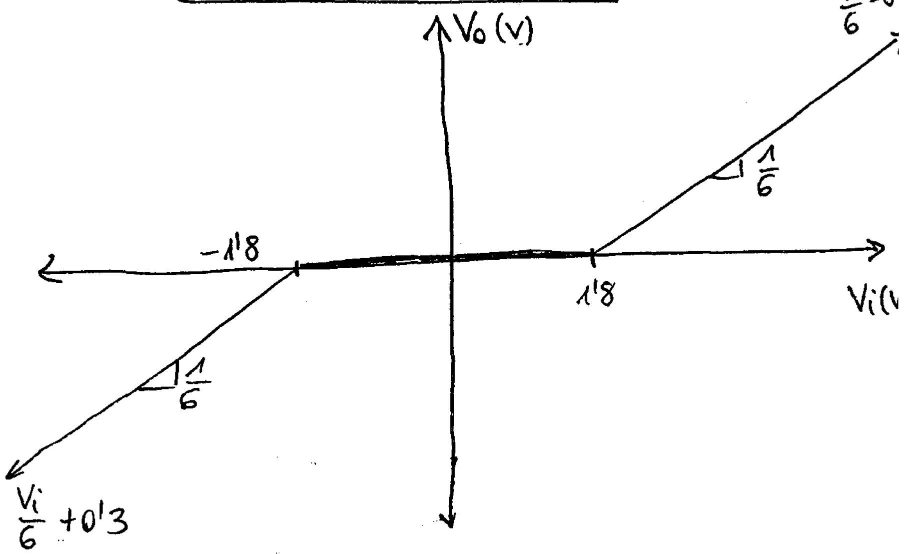
RESUMEN

$V_o = \frac{V_i}{6} - 0'3$ si $V_i > 1'8$ V

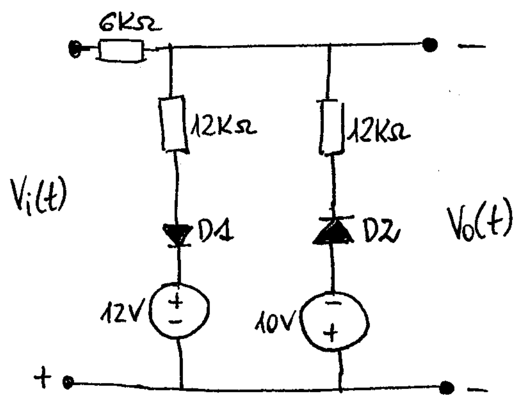
$V_o = 0$ si $-1'8 < V_i < 1'8$ V

$V_o = \frac{V_i}{6} + 0'3$ si $V_i < -1'8$ V

CURVA CARACTERÍSTICA



7.



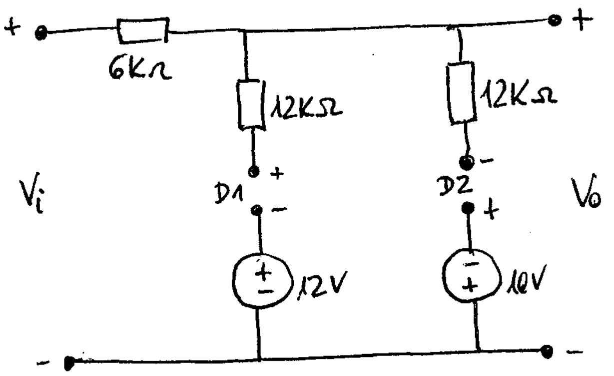
OJO: No pueden conducir los dos diodos a la vez porque:

$$V_A = 12 + 0'6 + 2RI_{D_1} > 12'6$$

$$V_A = -10 - 0'6 - 2RI_{D_2} < -10'6$$

No puede pasar esto simultáneamente.

① D1 y D2 en CORTE



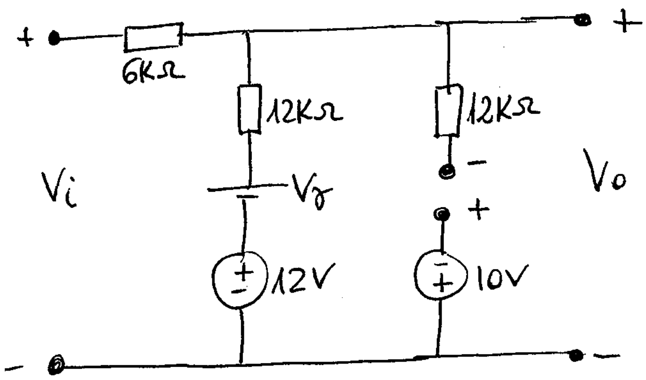
$$\boxed{V_0 = V_i}$$

Cuando:

$$V_\gamma > V_{D1} = V_i - 12 \Rightarrow \boxed{V_i < 12'6\ V}$$

$$V_\gamma > V_{D_2} = -10 - V_i \Rightarrow \boxed{V_i > -10'6\ V}$$

② D1 CONDUCCIÓN y D2 en CORTE



$$V_i = 12 + V_\gamma + 3RI_{D_1} \Rightarrow$$

$$I_{D_1} = \frac{V_i - 12'6}{3R}$$

$$\boxed{V_0 = \frac{2}{3}V_i + \frac{12'6}{3}}$$

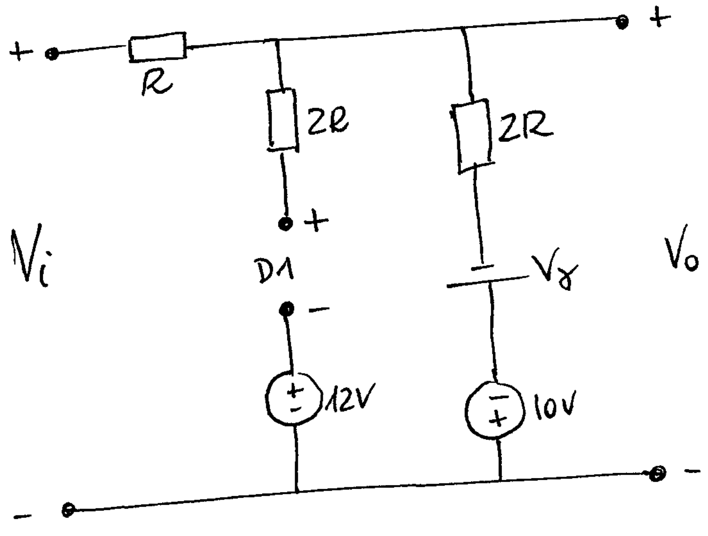
Cuando:

$$I_{D_1} > 0 \iff \boxed{V_i > 12'6\ V}$$

$$V_\gamma > V_{D_2} = -12K I_{D_1} - 12'6 + 10 \Rightarrow V_i > -4'8\ V$$

(subordinada a la condición anterior)

③ D1 en CORTE y D2 en CONDUCCIÓN



$$\begin{cases} V_i = -10 - V_\gamma - 3R\, I_{D_2} \\ V_o = -10 - V_\gamma - 2R\, I_{D_2} \end{cases} \Rightarrow$$

$$\Rightarrow I_{D_2} = \frac{-V_i - 10'6}{3R}$$

$$\boxed{V_o = \frac{2V_i - 10'6}{3}}$$

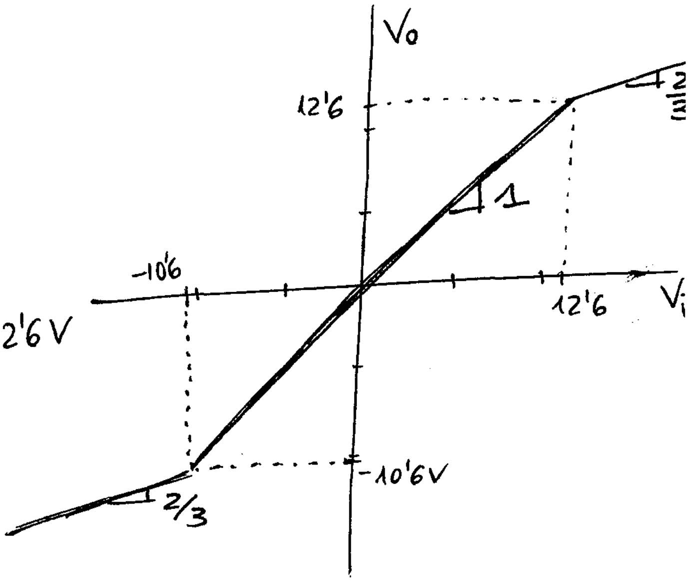
Cuando:

$I_{D_2} > 0 \iff -V_i - 10'6 < 0 \iff \boxed{V_i < -10'6\,V}$

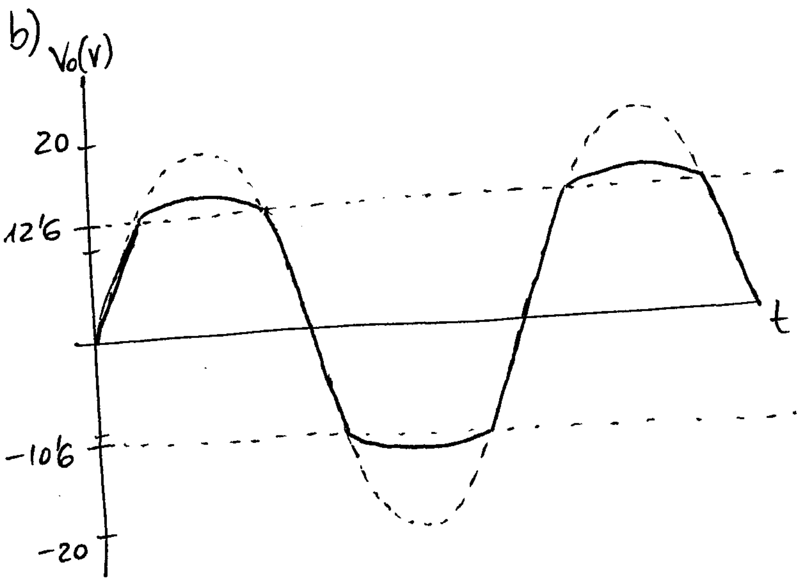
$V_{D_1} < V_\gamma \iff V_i < 24'3\,V$ (subordinada a la condición anterior)

RESUMEN

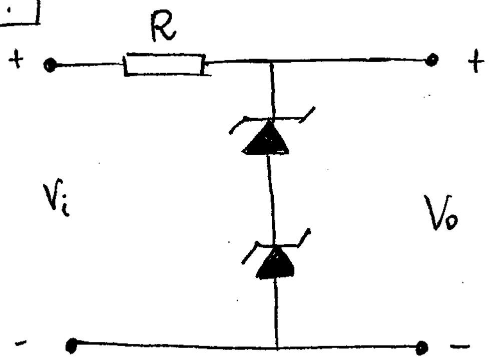
$$V_o = \begin{cases} \dfrac{2V_i - 10'6}{3} & \text{si} \quad V_i < -10'6\,V \\ V_i & \text{si} \quad -10'6\,V < V_i < 12'6\,V \\ \dfrac{2V_i + 12'6}{3} & \text{si} \quad V_i > 12'6 \end{cases}$$



b)

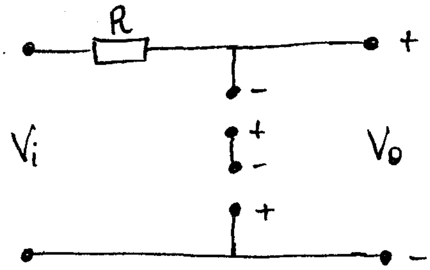


$\boxed{8.}$



Como los dos diodos se encuentran en serie, ambos tienen que estar en el mismo estado.

AMBOS EN CORTE

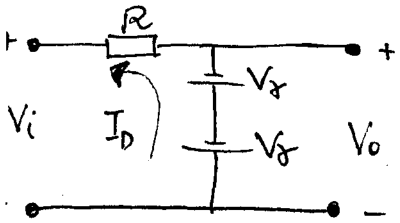


$V_0 = V_i$ cuando $V_D \leq V_\gamma$ $\quad V_D = -V_i < V_\gamma$

$\boxed{V_0 = V_i}$ cuando $\boxed{\cancel{V_i > -V_\gamma}}$

$$\boxed{-2V_\gamma < V_i < 2V_Z}$$

CONDUCCIÓN DIRECTA

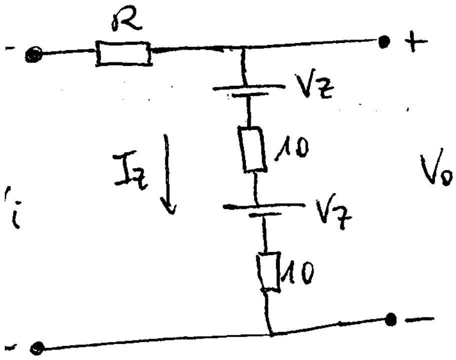


$\boxed{V_0 = -2V_\gamma}$ cuando $I_D > 0$

$$I_D = \frac{-2V_\gamma - V_i}{R} > 0 \iff -2V_\gamma - V_i > 0$$

$$\boxed{V_i < -2V_\gamma}$$

CONDUCCIÓN ZÉNER



$$V_i - I_Z R - 2V_Z - 10I_Z - 10I_Z = 0 \Rightarrow I_Z = \frac{V_i - 2V_Z}{20+R}$$

$$V_0 = 10I_Z + 2V_Z + 10I_Z = 20I_Z + 2V_Z$$

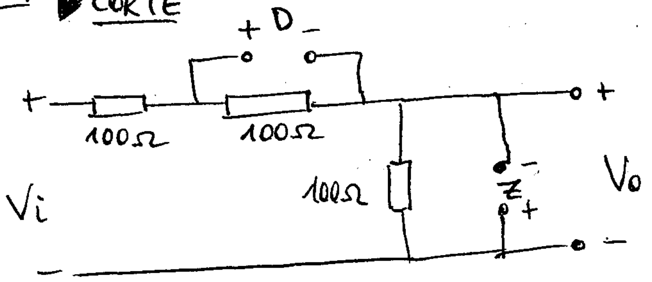
$$V_0 = \frac{20(V_i - 2V_Z)}{20+R} + 2V_Z \xrightarrow{R=20\Omega} \boxed{V_0 = \frac{V_i}{2} + V_Z}$$

cuando $I_Z > 0 \iff V_i - 2V_Z > 0 \iff \boxed{V_i > 2V_Z}$

$$V_0 = \begin{cases} = \dfrac{V_i}{2} + V_Z & \text{si } V_i > 2V_Z \\ = V_i & \text{si } -2V_\gamma < V_i < 2V_Z \\ = -2V_\gamma & \text{si } V_i < -2V_\gamma \end{cases}$$

9.

CORTE



$$\boxed{V_0 = \frac{1}{3}V_i}$$

$$V_D = V_i - \frac{1}{3}V_i - \frac{1}{3}V_i = \frac{1}{3}V_i$$

$$V_D < V_\gamma \Leftrightarrow \boxed{V_i < 3V_\gamma}$$

$$V_{D_Z} = -V_0 = \frac{-1}{3}V_i$$

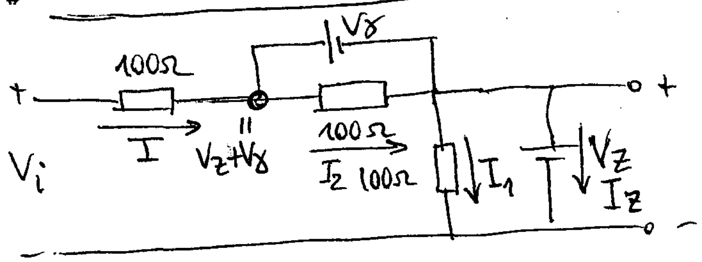
$$V_{D_Z} < V_\gamma \Leftrightarrow \frac{-1}{3}V_i < V_\gamma \Leftrightarrow \boxed{V_i > -3V_\gamma}$$

$$V_{D_Z} > -V_Z \Leftrightarrow -\frac{1}{3}V_i > -V_Z \Leftrightarrow \boxed{V_i < 3V_Z}$$

$$\boxed{-3V_\gamma < V_i < 3V_Z}$$

condición total: $\boxed{-3V_\gamma < V_i < 3V_\gamma}$

DIODO CONDUCE, ZENER INVERSA



$$\boxed{V_0 = V_Z}$$

$$I_1 = \frac{V_Z}{100} \qquad I_2 = \frac{V_\gamma}{100}$$

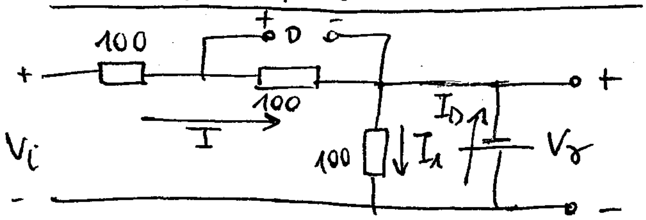
$$I = \frac{V_i - V_Z - V_\gamma}{100} \qquad I_D = I - I_2 = \frac{V_i - V_Z - 2V_\gamma}{100}$$

$$I_D > 0 \Leftrightarrow V_i - V_Z > 2V_\gamma \Leftrightarrow \boxed{V_i > 2V_\gamma + V_Z}$$

$$I_Z = I - I_1 = \frac{V_i - V_Z - V_\gamma}{100} - \frac{V_Z}{100} = \frac{V_i - V_\gamma - 2V_Z}{100}$$

$I_Z > 0 \Leftrightarrow V_i - V_\gamma - 2V_Z > 0 \Leftrightarrow \boxed{V_i > 2V_Z + V_\gamma}$ condición restrictiva

DIODO CORTE, ZENER DIRECTA



$$\boxed{V_0 = -V_\gamma}$$

$$I = \frac{V_i + V_\gamma}{200} \qquad I_1 = \frac{-V_\gamma}{100}$$

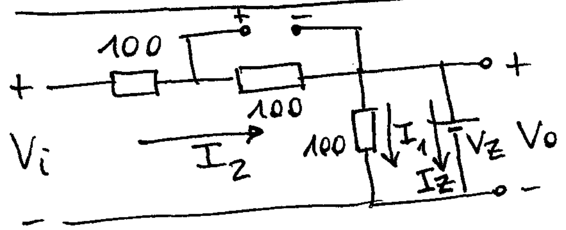
$$I_D = I_1 - I = \frac{-V_\gamma}{100} - \frac{V_i + V_\gamma}{200} = \frac{-2V_\gamma - V_i - V_\gamma}{200}$$

$$I_D > 0 \Leftrightarrow -3V_\gamma - V_i > 0 \Leftrightarrow \boxed{V_i < -3V_\gamma}$$

$$V_D = V_i - I \cdot 100 + V_\gamma = V_i - \frac{V_i + V_\gamma}{2} + V_\gamma = \frac{1}{2}V_i + \frac{1}{2}V_\gamma + V_\gamma = \frac{V_i + V_\gamma}{2} + V_\gamma$$

$V_D < V_\gamma \Leftrightarrow \frac{V_i + V_\gamma}{2} + V_\gamma < V_\gamma \Leftrightarrow \frac{V_i + V_\gamma}{2} < 0 \Leftrightarrow V_i < -V_\gamma$ no vale para nada

DIODO CORTE, ZENER INVERSA



$$\boxed{V_o = V_Z}$$

$$I_2 = \frac{V_i - V_Z}{200} \qquad I_1 = \frac{V_Z}{100}$$

$$I_Z = I_2 - I_1 = \frac{V_i - V_Z}{200} - \frac{V_Z}{100} = \frac{V_i - V_Z - 2V_Z}{200}$$

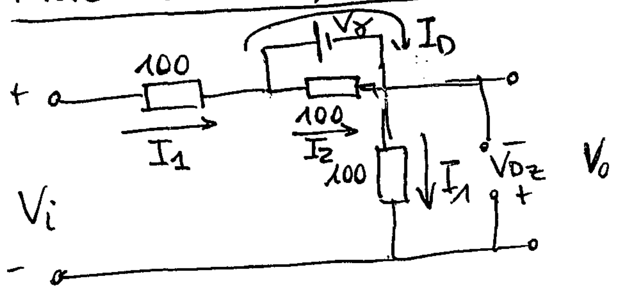
$$I_Z > 0 \iff V_i - V_Z - 2V_Z > 0 \iff V_i > 2V_Z + V_Z \iff \boxed{V_i > 3V_Z}$$

$$V_D = V_i - \frac{V_i - V_Z}{2} - V_Z < V_\gamma \iff \frac{1}{2}V_i + \frac{V_Z}{2} - V_Z < V_\gamma \iff$$

$$\iff \frac{V_i + V_Z}{2} - V_Z < V_\gamma \iff \frac{1}{2}V_i < V_\gamma + V_Z - \frac{1}{2}V_Z \iff \boxed{V_i < 2V_\gamma + V_Z}$$

No se puede dar este caso.

DIODO CONDUCE, ZENER CORTE



$$I_1 = \frac{V_i - (V_\gamma + V_o)}{100} = \frac{V_o}{100}$$

$$I_2 = \frac{V_\gamma + V_\gamma - V_o}{100} = \frac{V_\gamma}{100}$$

$$I_1 = \frac{V_i - V_\gamma - V_o}{100} = \frac{V_o}{100} \Rightarrow V_i - V_\gamma - V_o = V_o \Rightarrow \boxed{V_o = \frac{V_i - V_\gamma}{2}}$$

$$\left.\begin{aligned} I_1 &= \frac{V_i - V_\gamma}{200} \\ I_2 &= \frac{V_\gamma}{100} \end{aligned}\right\} I_D = I_1 - I_2 = \frac{V_i - V_\gamma}{200} - \frac{V_\gamma}{100} = \frac{V_i - V_\gamma - 2V_\gamma}{200}$$

$$I_D > 0 \iff V_i - 3V_\gamma > 0 \iff \boxed{V_i > 3V_\gamma}$$

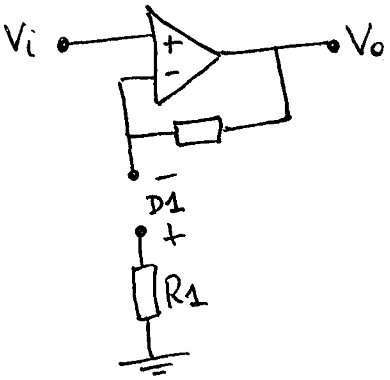
$$V_{D_Z} = -V_o < V_\gamma \iff \frac{V_\gamma - V_i}{2} < V_\gamma \iff V_\gamma - V_i < 2V_\gamma \iff -V_i < V_\gamma \iff$$

$$\iff V_i > V_\gamma$$

11.

CORTE

a)

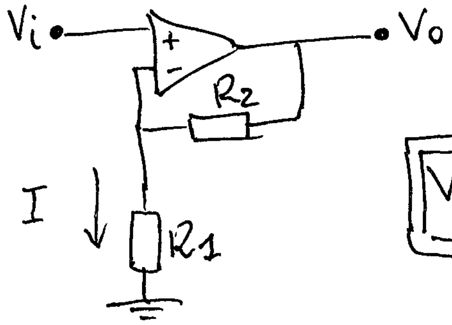


$$\boxed{V_o = V_i}$$

cuando $-V_Z < V_{D1} < V_\gamma$

cuando $-V_Z < -V_i < 0 \leftrightarrow \boxed{V_Z > V_i > 0}$

DIRECTA



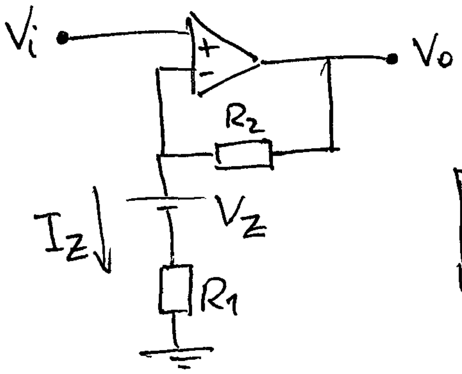
$$I_D = \frac{V_i}{R_1}$$

$$\boxed{V_o = V_i + \frac{V_i R_2}{R_1}}$$

cuando $-I > 0 \leftrightarrow -V_i > 0 \leftrightarrow$

$\leftrightarrow \boxed{V_i < 0}$

INVERSA



$$I_Z = \frac{V_i - V_Z}{R_1}$$

$$\boxed{V_o = V_i + \frac{V_i - V_Z}{R_1} \cdot R_2}$$

cuando $I_Z > 0 \leftrightarrow$

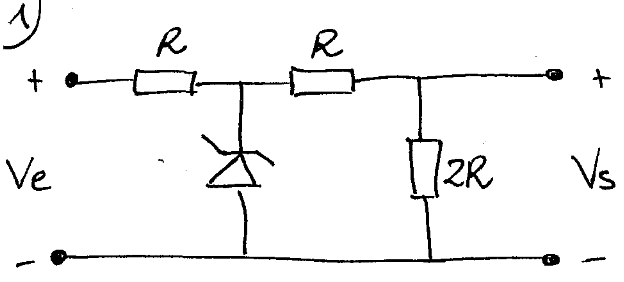
$\leftrightarrow V_i - V_Z > 0 \leftrightarrow$

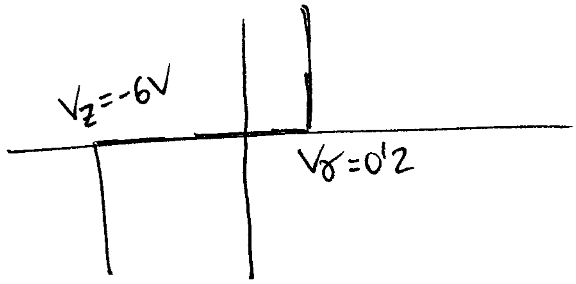
$\leftrightarrow \boxed{V_i > V_Z}$

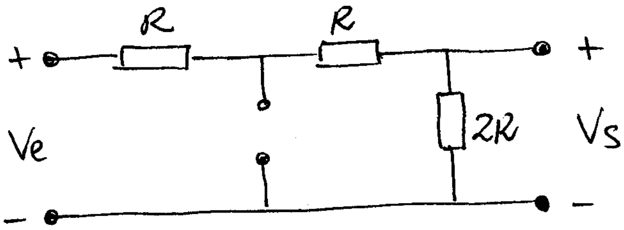
b) Fácil

EJERCICIOS EXÁMENES

1)

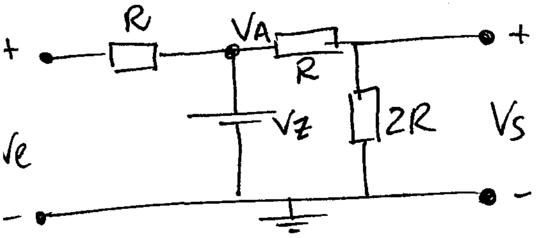






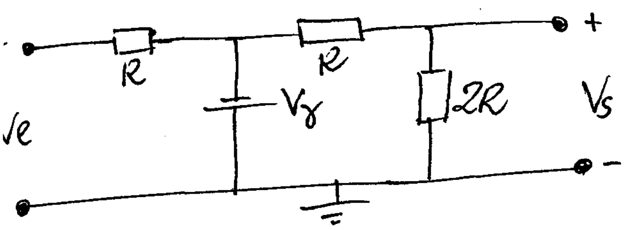
$$V_S = 2RI = 2R\,\frac{Ve}{4R} = \frac{Ve}{2}$$

$$Ve = \frac{4}{3} V_Z$$

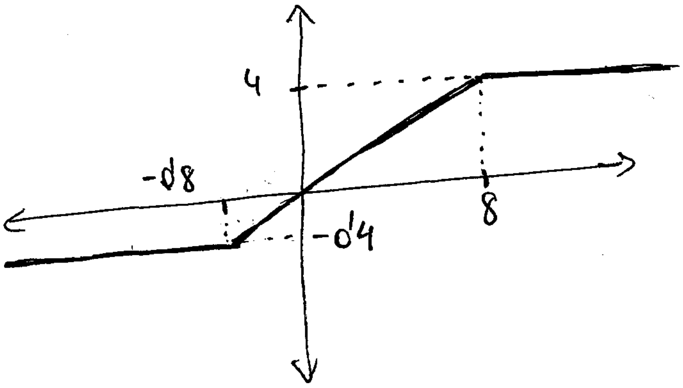


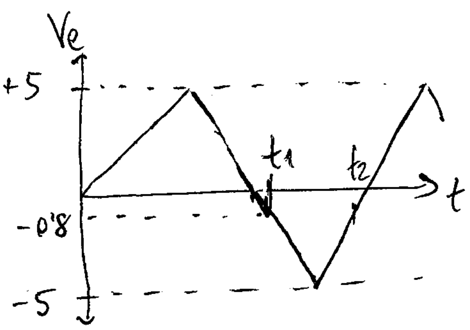
$$V_S = 2RI' = 2R\,\frac{V_Z}{3R} = \frac{2}{3} V_Z$$

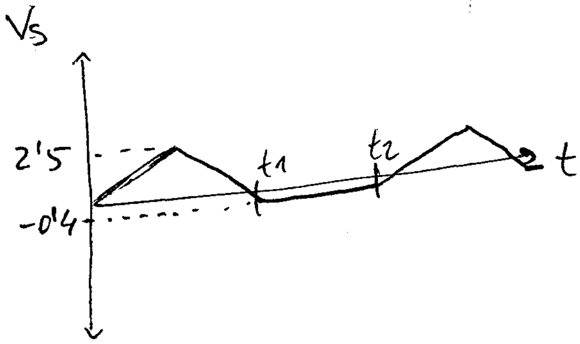
$$Ve = \frac{4}{3}(-V_\gamma) = \frac{-4}{3} V_\gamma$$



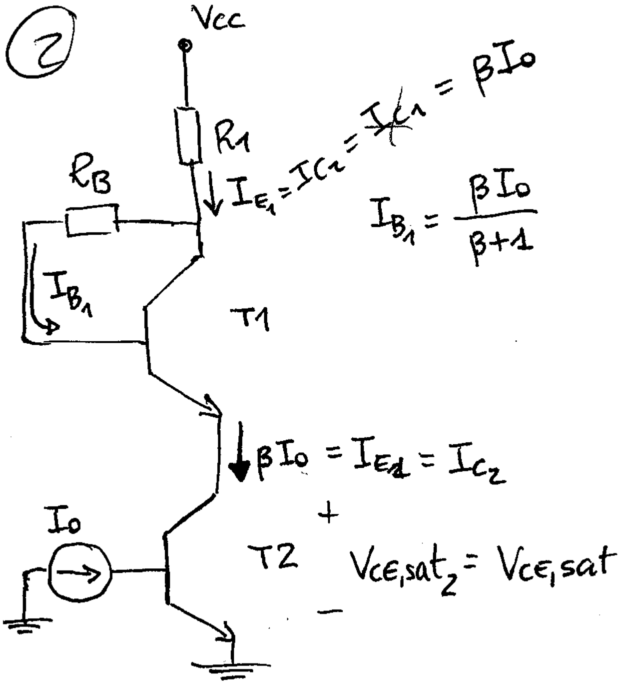
$$V_S = 2RI'' = 2R\,\frac{-V_\gamma}{3R} = \frac{-2}{3} V_\gamma$$







(2)



$$I_{B_1} = \frac{\beta I_0}{\beta+1}$$

R_1 para que I_2 entre act. y saturación

$$V_{cc} = V_{CE,sat} + V_\gamma + R_B \frac{\beta I_0}{\beta+1} + R_1 \beta I_0$$

$$\Rightarrow R_1 = \frac{V_{cc} - V_\gamma - V_{CE,sat} - R_B \frac{\beta I_0}{\beta+1}}{\beta I_0}$$

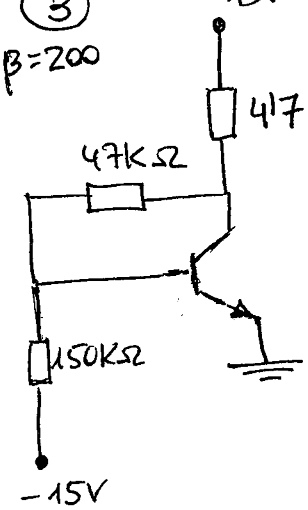
Expresiones de $V_{CE,1}$ y $V_{CE,2}$ en activa.

$$V_{CE,1} = V_\gamma + R_B \frac{\beta I_0}{\beta+1}$$

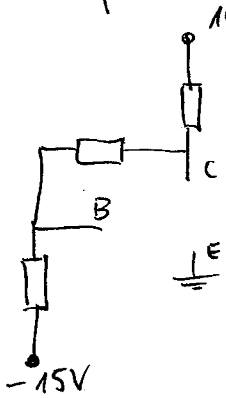
$$V_{CE,2} = V_{cc} - R_1 \beta I_0 - V_\gamma - R_B \frac{\beta I_0}{\beta+1}$$

(3)

$\beta = 200$



▶ Suponemos corte

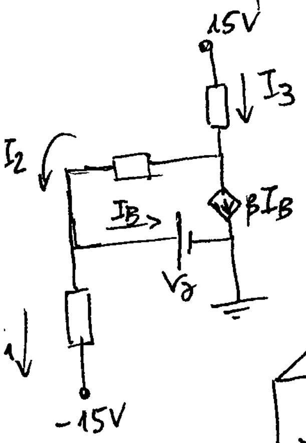


$$I = \frac{30V}{201'7K\Omega} = 1'49 \cdot 10^{-6} A$$

$V_{BE} = V_B = -15 + 15K \cdot I = 7'3\,V$

lo que es mayor que la tensión umbral $7'3V < 0'7$

▶ Suponemos activa

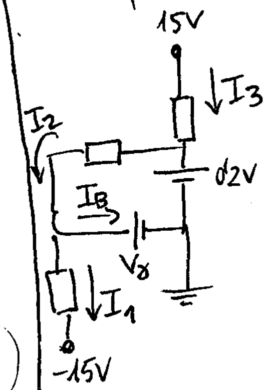


$$\begin{cases} 0'7 + 47K I_2 + 4'7 I_3 = 15V \\ I_3 = I_2 + \beta I_B \\ I_2 = I_1 + I_B \\ I_1 = \dfrac{V_\gamma - (-15)}{150K\Omega} = 105\mu A \end{cases}$$

$\rightarrow I_B = 8'94\mu A \rightarrow I_C = \beta I_B = 1'79 mA$

$\rightarrow I_2 = 114\mu A \rightarrow V_{CE} = V_\gamma + 47K I_2 = 6'05V > 0'2V$

▶ Suponemos saturación



$I_1 = 105\mu A$

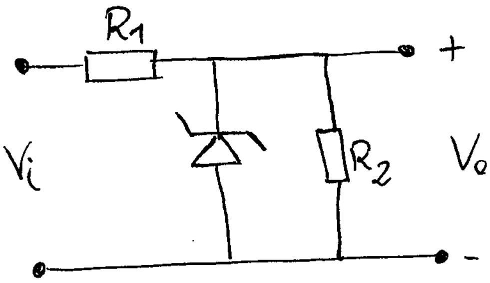
$I_2 = \frac{0'2 - 0'7}{47K} = -10'6\mu A$

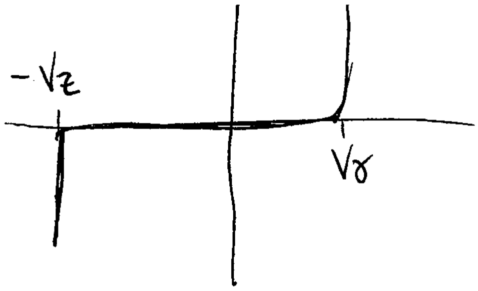
$I_B = I_2 - I_1 =$

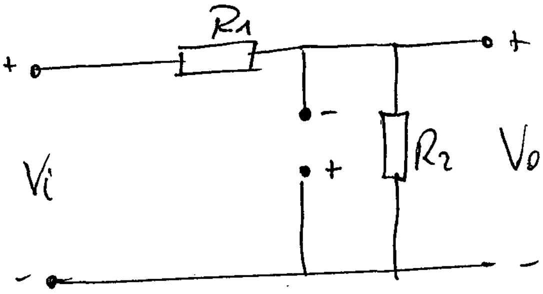
$= -115'6\,\mu A$

sale de la base → no es coherente con el modelo de transistor.

4.







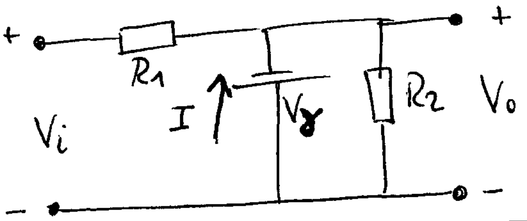
$$\boxed{V_0 = V_i \frac{R_2}{R_1+R_2}}$$

cuando

$$V_\gamma > V_D = -V_0 = -V_i \frac{R_2}{R_1+R_2} \Rightarrow$$

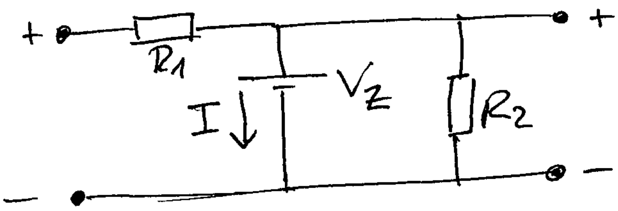
$$\Rightarrow \boxed{V_i > -\frac{R_1+R_2}{R_2} V_\gamma}$$

$$\text{y} \quad -V_z < V_D = -V_0 = -V_i \frac{R_2}{R_1+R_2} \Rightarrow \boxed{V_i > \frac{R_1+R_2}{R_2} V_z}$$



$$\boxed{V_0 = -V_\gamma}$$

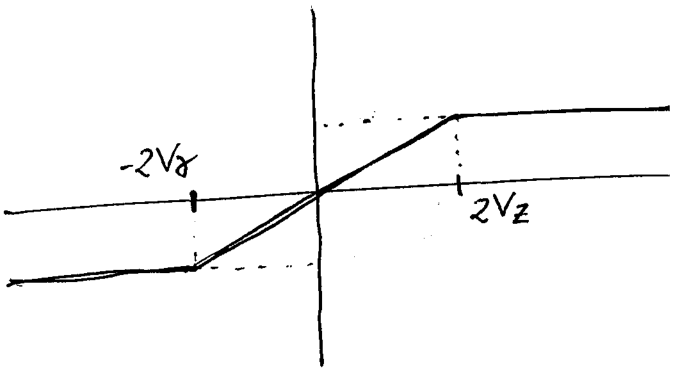
Cuando: $\boxed{V_i < -\frac{R_1+R_2}{R_2} V_\gamma}$ $\quad I > 0$



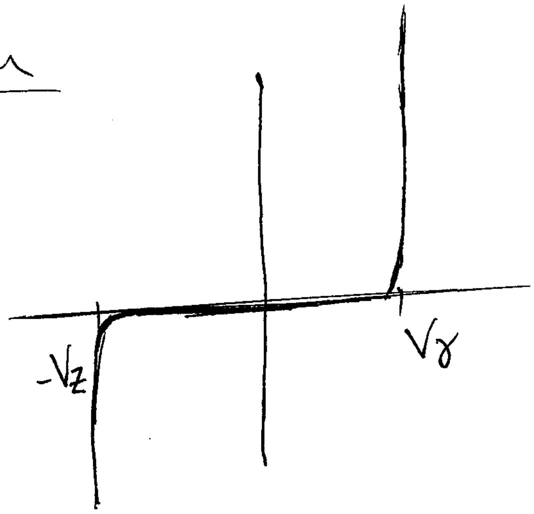
$$\boxed{V_0 = V_z}$$

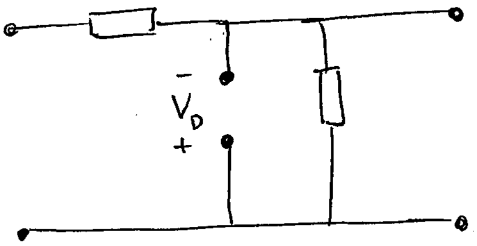
Cuando:

$I > 0 \longleftrightarrow$ $\boxed{V_i > \frac{R_1+R_2}{R_2} V_\gamma}$



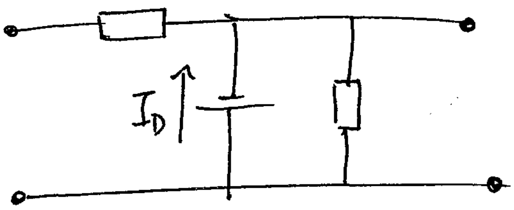
Resumen





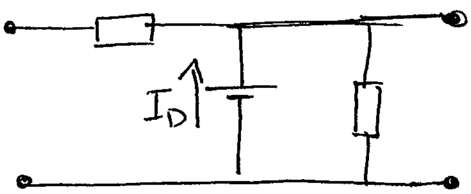
Condición:

$$-V_Z < V_D < V_\gamma$$



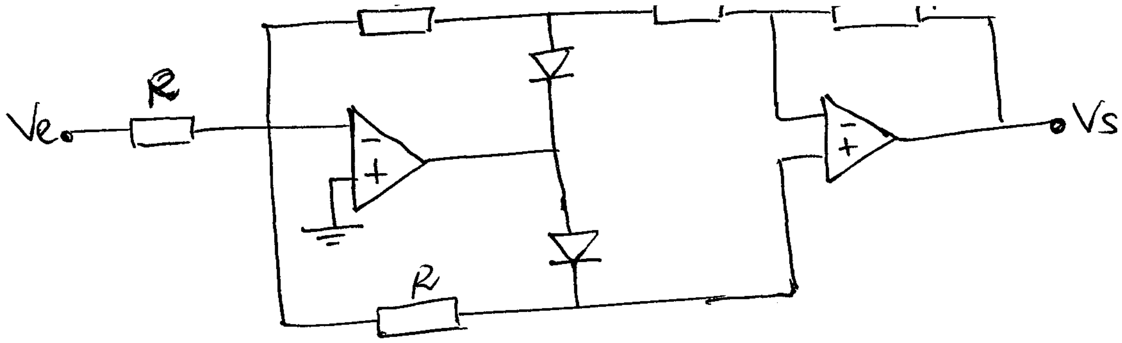
Condición:

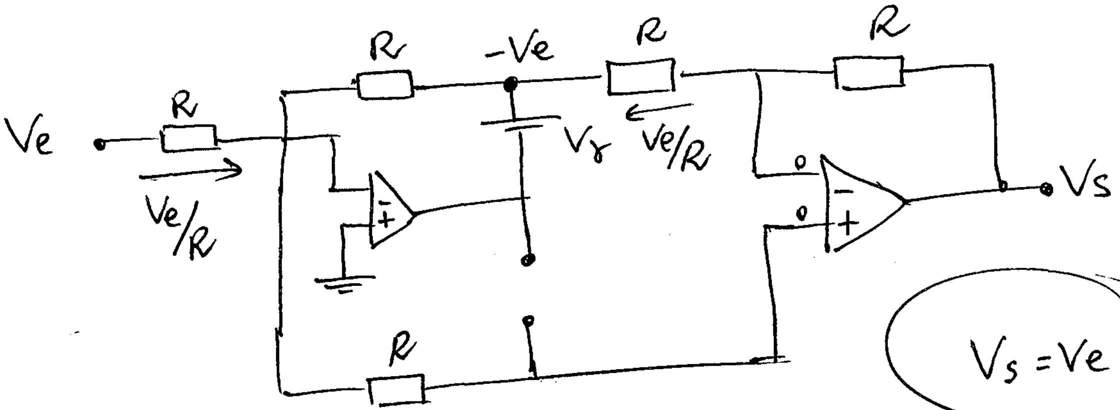
$I_D > 0$



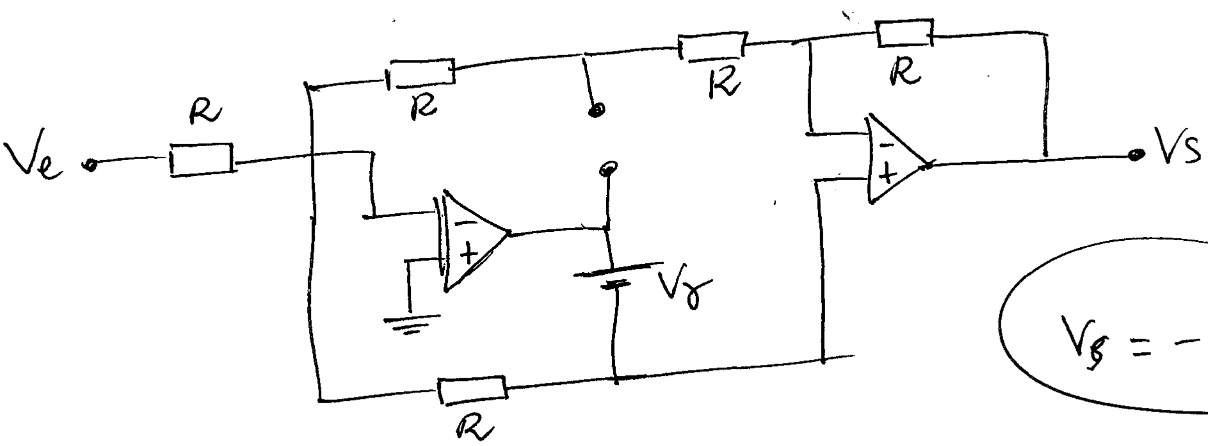
Condición

$I_D < 0$

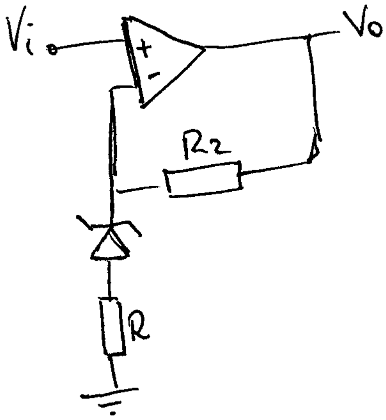




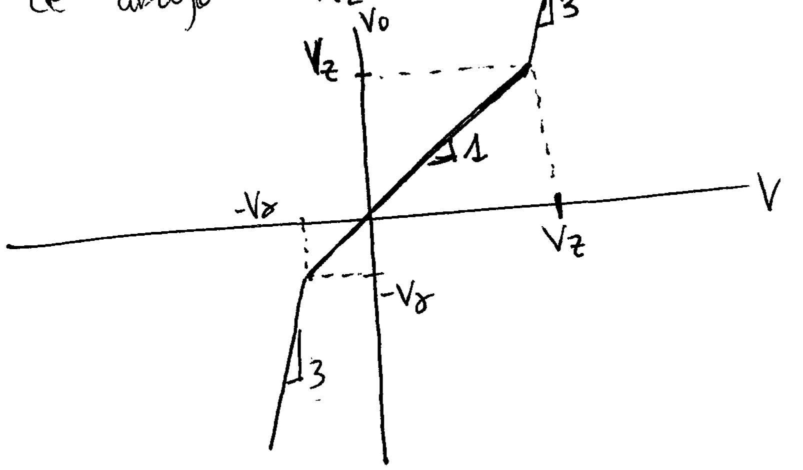
$V_s = V_e$

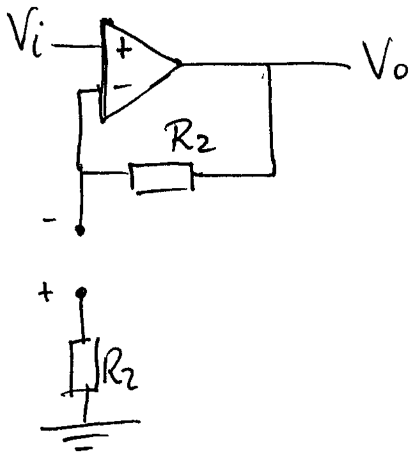


$V_s = -V_e$

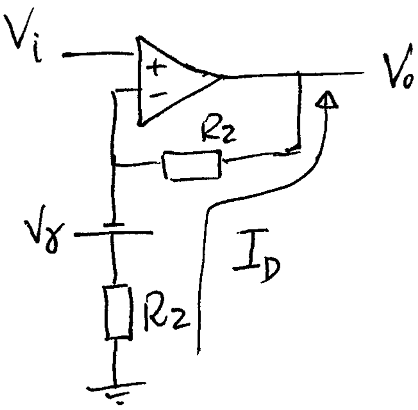


b) Apartado después de realizar los cálcu
de abajo $R_2 = 2R_1$





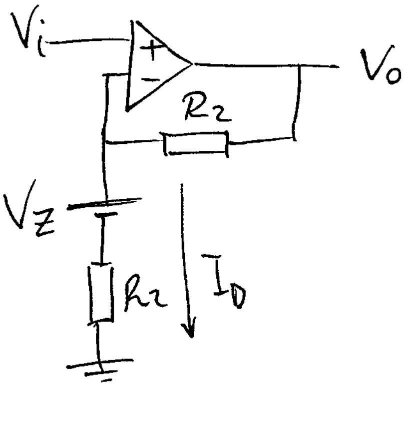
$\boxed{V_o = V_i}$ cuando: $\begin{cases} V_i > -V_\gamma \\ V_i < V_Z \end{cases}$



$$\left.\begin{array}{l} V_o = -V_\gamma - (R_1+R_2)I_D \\ I_D = \dfrac{-V_i - V_\gamma}{R_1} \end{array}\right\} V_o = V_i\left(\frac{R_1+R_2}{R_1}\right) + V_\gamma \frac{R_2}{R_1}$$

cuando:

$I_D > 0 \iff V_i < -V_\gamma$



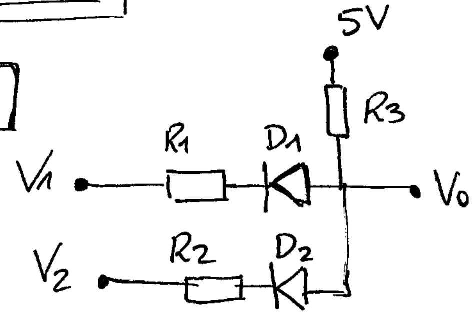
$$\left.\begin{array}{l} V_o = V_Z - (R_1+R_2)I_D \\ I_D = \dfrac{-(V_i - V_Z)}{R_1} \end{array}\right\} V_o = \left(\frac{R_1+R_2}{R_1}\right)V_i - V_Z\frac{R_2}{R_1}$$

Cuando

$I_D < 0 \iff V_i > V_Z$

HOJA 4 (hechos en clase)

5.



a) $V_1 = 5V$

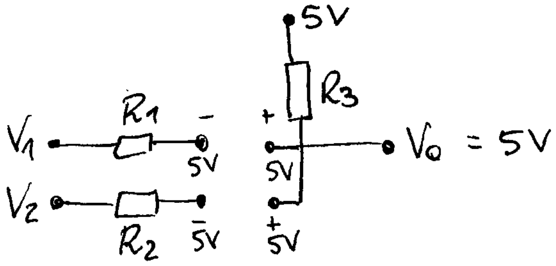
$V_2 = 5V$

$R_1 = 2K\Omega$

$R_2 = 2K\Omega$

$R_3 = 18K\Omega$

Por cuestiones de simetría, los dos diodos se encuentran en el mismo estado. Suponemos que no conducen.



Se cumplen las condiciones para diodos que no conducen

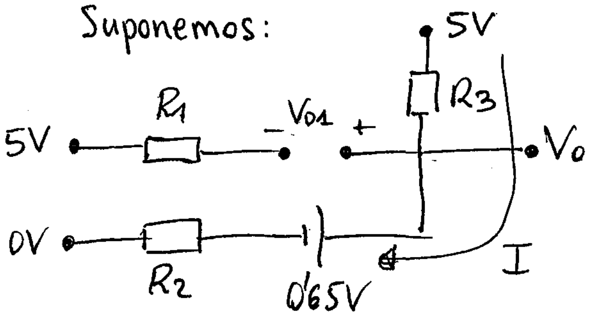
$V_D < V_\gamma = 0'65V$

En este caso $5-5=0 < 0'65$

$\boxed{V_0 = 5V}$

b) Ahora $V_1 = 5V$ y $V_2 = 0V$ $\quad R_1 = R_2 = 2K\Omega$ y $R_3 = 18K\Omega$

Suponemos:



$$V_0 = 5 - IR_3 = 5 - R_3 \cdot \frac{5-0'65}{R_2+R_3} = 1'085$$

Comprobación:

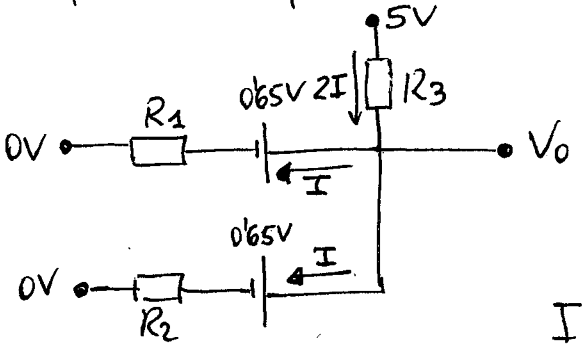
$$0 < I_{D_2} = I = \frac{5-0'65}{R_2+R_3} > 0$$

$$\underbrace{V_0 - 5}_{= -0'31} > V_{D_1} < V_\gamma = 0'65V$$

Se cumplen $\boxed{V_0 = 1'085V}$

c) Ahora $V_1 = V_2 = 0V$

Suponemos que circulan los dos:



$$\left\{\begin{array}{l} V_0 = 5 - 2I.R_3 \\ V_0 = 0'65 + R_2 I \end{array}\right. \Rightarrow \boxed{V_0 = 0'87\ V}$$

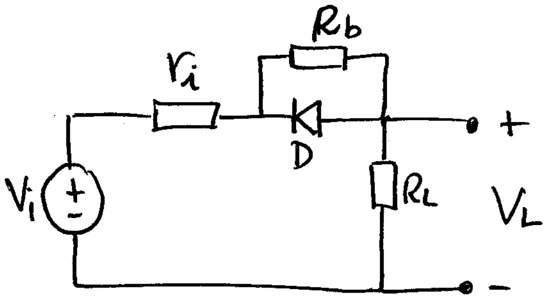
$$I = \frac{V_0 - 0'65}{R_1} = \frac{V_0 - 0'65}{R_2} > 0 \quad \text{se cumple}$$

$$\boxed{V_0 = 0'87V}$$

d) ¿Función lógica?

5	5	$V_0 = 5V$	Función <u>AND</u>.
0 5	5 0	$V_0 = 1'085V$	
0	0	$V_0 = 0'87V$	

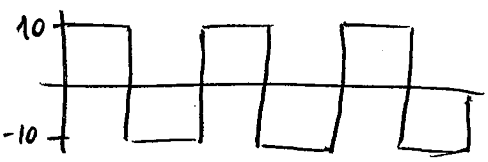
$\boxed{2.}$

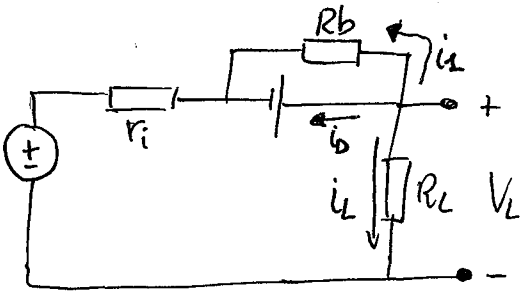


$R_b = 100K\Omega$

$r_i = 1K\Omega$

$R_L = 1K\Omega$



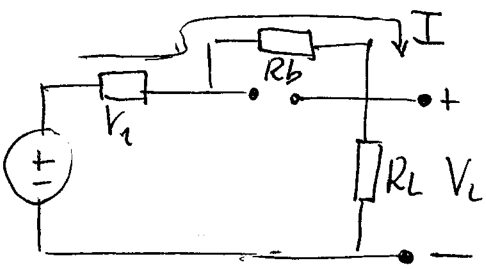


$$\left.\begin{array}{l} V_L = R_L . i_L \\ R_L i_L - V_\gamma + r_i i_L - V_i = 0 \end{array}\right\} V_L = R_L \frac{V_i + V_\gamma}{r_i + R_L} = \frac{V_i + V_\gamma}{2}$$

$V_L = \frac{V_i + V_\gamma}{2}$ siempre y cuando $I_D > 0$

$$I_D = -i_1 - i_L = -\frac{V_\gamma}{R_b} - \frac{V_i + V_\gamma}{r_i + R_L} > 0 \Leftrightarrow \cdots \Leftrightarrow -(V_i + V_\gamma) >$$

$$\Leftrightarrow V_i < -V_\gamma \Rightarrow \boxed{V_L = \frac{V_i + V_\gamma}{2} \text{ cuando } V_i < -V_\gamma}$$



$$V_L = R_L . I = R_L . \frac{V_i}{r_i + R_L + R_b} \approx \frac{V_i}{100}$$

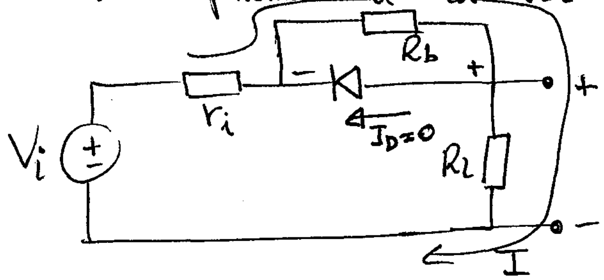
$V_L \approx \frac{V_i}{100}$ siempre y cuando $V_D < V_\gamma$

$$V_D = -IR_b = \frac{-V_i R_b}{R_L + r_i + R_b} \approx -V_i$$

error de 2%

$$\boxed{V_L \approx \frac{V_i}{100} \quad \text{cuando} \quad V_i > -V_\gamma}$$

Si imponemos a la vez que $I_D = 0$ y $V_D = V_\gamma$:

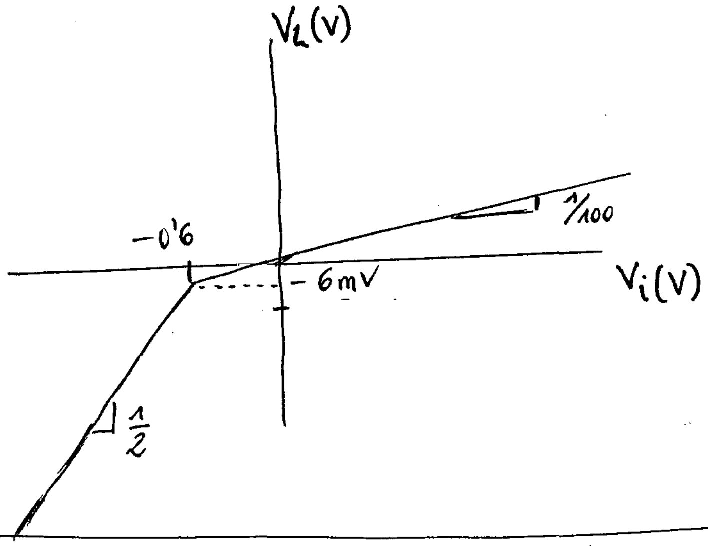


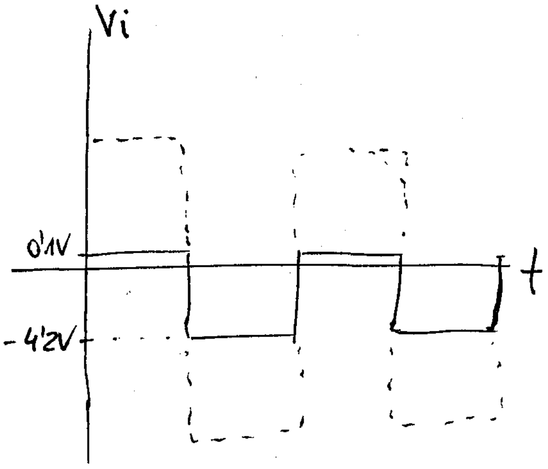
$$V_i = I(R_b + R_L + r_i)$$

$$R_b \cdot I = -V_\gamma$$

$$V_i = -V_\gamma - \frac{V_\gamma}{400} - \frac{V_\gamma}{100} \approx -V_\gamma$$

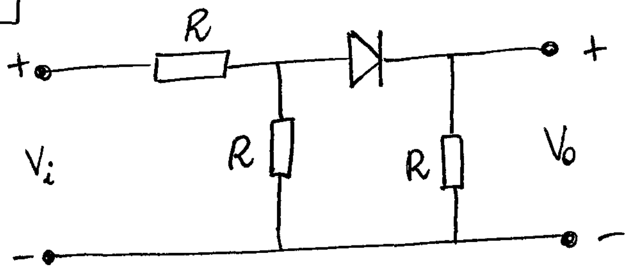
Este: $V_i \approx -V_\gamma$ sería el <u>punto de cambio de comportamien</u>

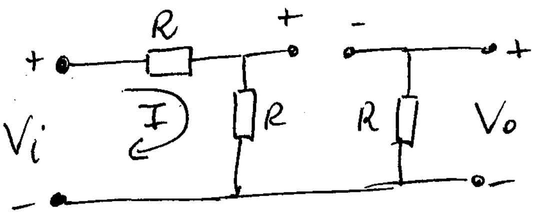




3.

$R = 10\,\Omega$

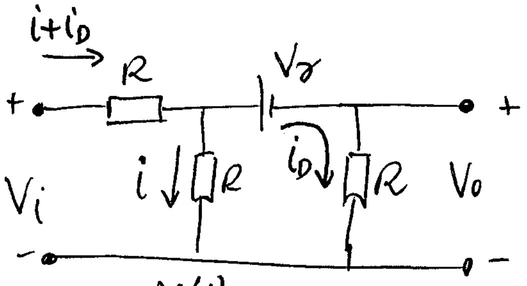




$V_o = 0$ siempre y cuando $V_D < V_\gamma$

$$V_D = V_i - IR = V_i - \frac{V_i}{2R} R = \frac{V_i}{2}$$

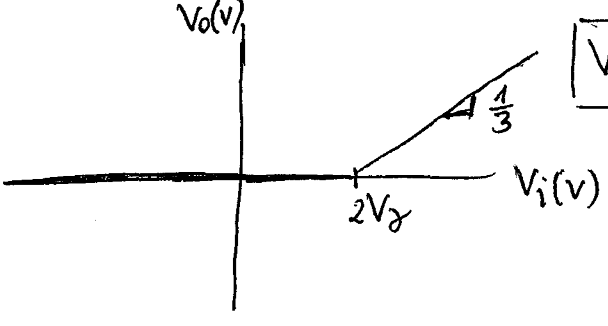
$$\boxed{V_o = 0 \quad \text{cuando} \quad V_i < 2V_\gamma}$$



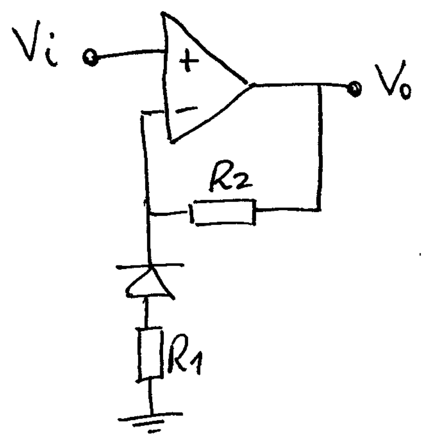
$$\left.\begin{array}{l} V_i - iR - i_D R - iR = 0 \\ iR - V_\gamma - i_D R = 0 \end{array}\right\} \Rightarrow i_D = \frac{V_i - 2V_\gamma}{3R}$$

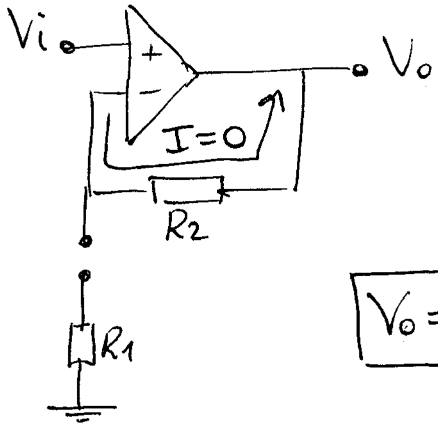
$$V_o = i_D \cdot R = \frac{V_i - 2V_\gamma}{3}$$

$$\boxed{V_o = \frac{V_i - 2V_\gamma}{3} \quad \text{cuando} \quad V_i > 2V_\gamma}$$



[11.] (CON DIODO NORMAL)

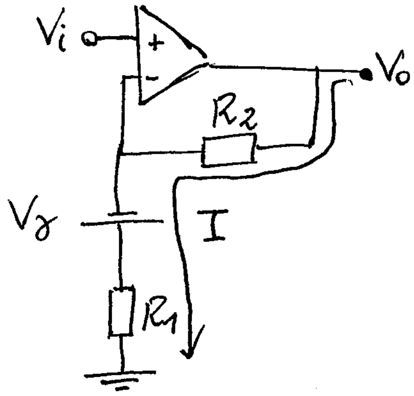




$V_o = V_i$ siempre y cuando $V_D < V_\gamma$

$V_D = -V_i < V_\gamma$

$$\boxed{V_o = V_i \text{ cuando } V_i > V_\gamma}$$



$$V_o = -V_\gamma + IR_1 + IR_2 = -V_\gamma + \frac{(R_1+R_2)(V_i+V_\gamma)}{R_1}$$

$$i = \frac{V_i+V_\gamma}{R_2} = \frac{V_i+V_\gamma}{R_1}$$

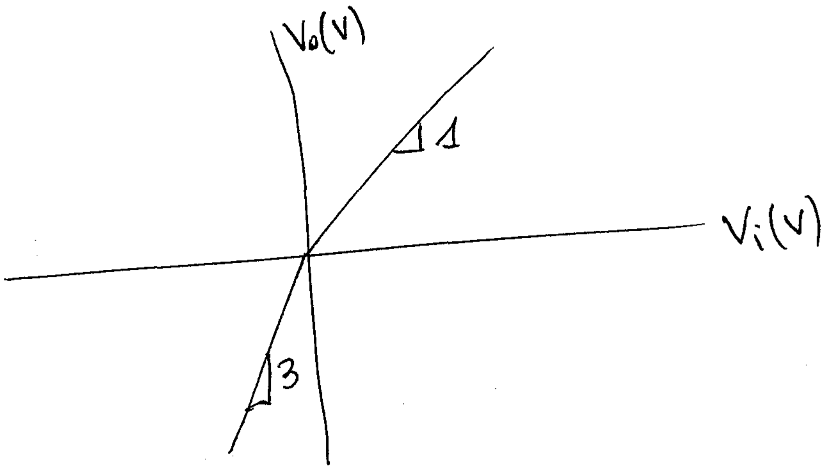
$$i_D = -i = -\frac{V_i+V_\gamma}{R_1} > 0 \longrightarrow -(V_i+V_\gamma) > 0 \Rightarrow$$

$$\Rightarrow -V_i > V_\gamma \Rightarrow V_i < -V_\gamma$$

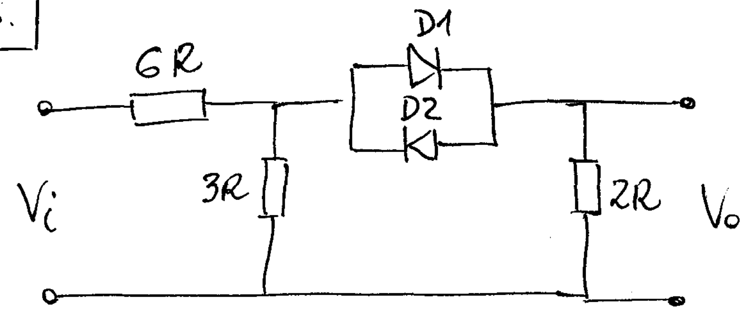
b) si $R_2 = 2R_1$ y $V_\gamma = 0$

$V_o = V_i$ cuando $V_i > 0$ (diodo no conduce)

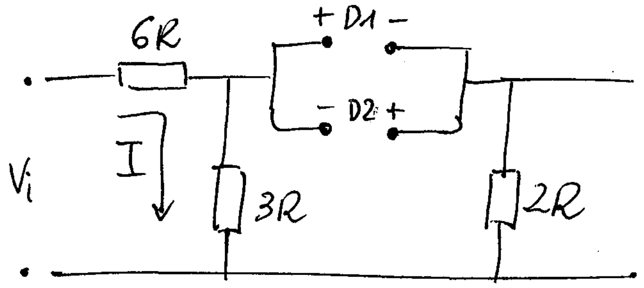
$V_o = -V_\gamma + 3V_\gamma + 3V_i = 3V_i + 2V_\gamma = 3V_i$ cuando $V_i < 0$ (diodo conduce)



$\boxed{6.}$



H1: D1 en corte



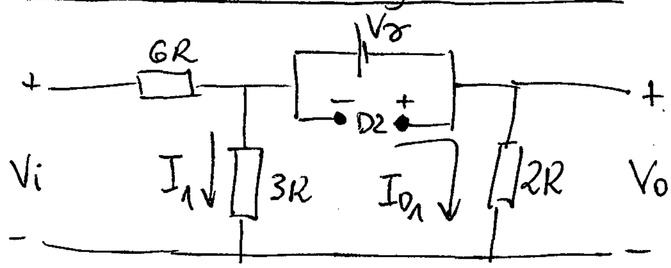
$$\boxed{V_o = 0} \quad \text{cuando} \begin{cases} V_{D1} < V_\gamma \\ V_{D2} < V_\gamma \end{cases}$$

$$V_{D1} = \frac{1}{3}V_i \Rightarrow V_i < 3V_\gamma$$

$$\boxed{-3V_\gamma < V_i < 3V_\gamma}$$

$$V_{D2} = -\frac{1}{3}V_i \Rightarrow V_i > -3V_\gamma$$

H2: D1 conducción y D2 corte



$$\begin{cases} V_i = 3RI_1 + 6R(I_1 + I_{D1}) \\ 3RI_1 - V_\gamma - 2RI_{D1} = 0 \end{cases} \Rightarrow$$

$$\Rightarrow I_{D1} = \frac{V_i - 3V_\gamma}{12R}$$

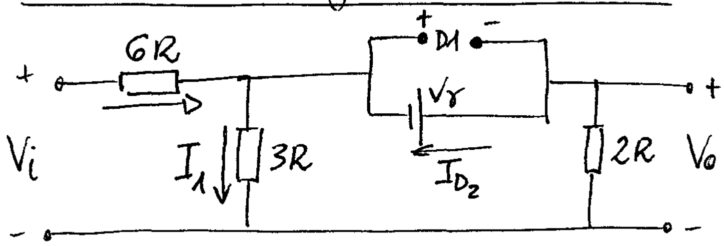
$$\boxed{V_o = 2RI_{D1} = \frac{V_i}{6} - \frac{V_\gamma}{2}}$$

cuando $I_{D1} > 0 \Rightarrow V_i - 3V_\gamma > 0 \Rightarrow \boxed{V_i > 3V_\gamma}$

y

cuando $V_{D2} < V_\gamma \Rightarrow V_\gamma > V_{D2} = -V_\gamma$

H3 : D1 corte y D2 conducción



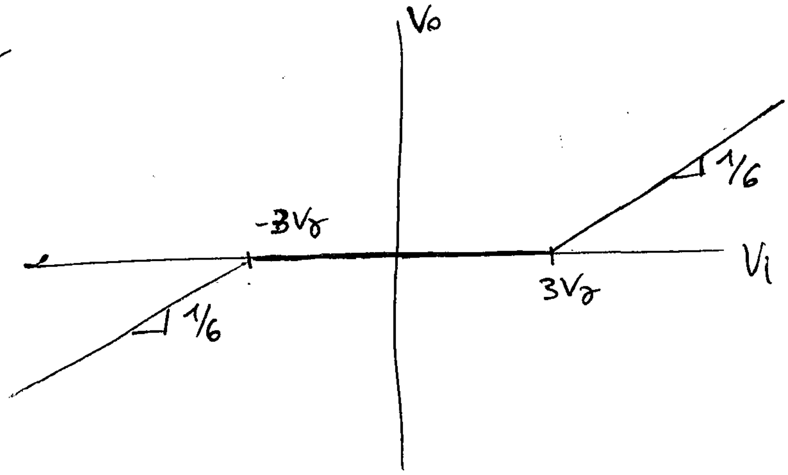
$$\begin{cases} V_i = 3RI_1 + 6R(I_1 - I_{D_2}) \\ 3RI_1 + V_\gamma + 2RI_{D_2} = 0 \end{cases} \Rightarrow$$

$$\Rightarrow I_{D_2} = -\frac{V_i + 3V_\gamma}{12R} \qquad \boxed{V_o = \frac{V_i}{6} + \frac{V_\gamma}{2}}$$

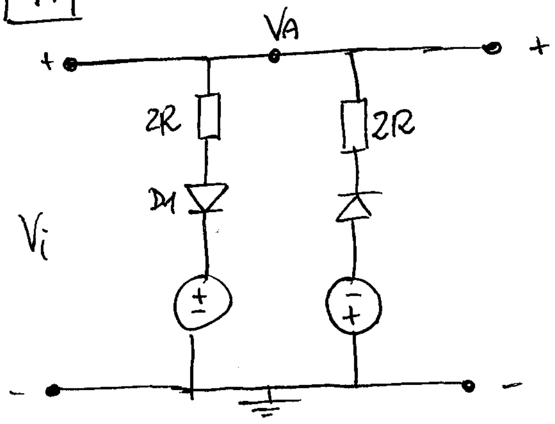
cuando $I_{D_2} > 0 \Rightarrow -V_i - 3V_\gamma > 0 \Rightarrow \boxed{V_i < -3V_\gamma}$

y

cuando $V_{D_1} < V_\gamma \Rightarrow -V_\gamma < V_\gamma$



$\boxed{7.}$



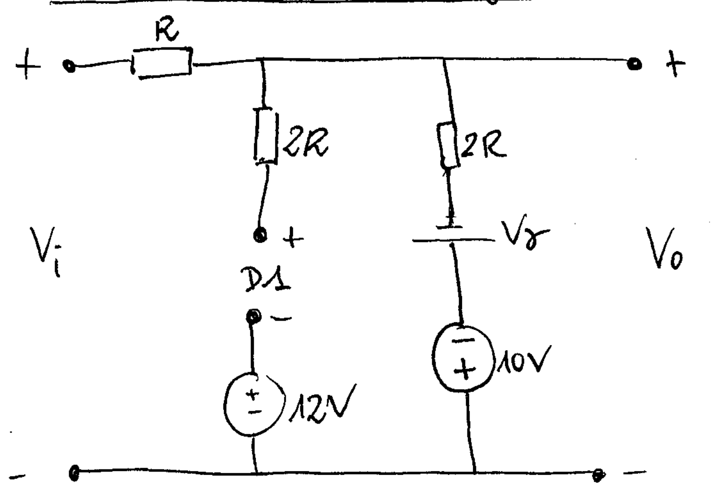
OJO: no pueden conducir los dos diodos a la vez porque:

$$V_A = 12 + 0'6 + 2RI_{D1} > 12'6$$

$$V_A = -10 - 0'6 - 2RI_{D_2} < -10'6$$

V_A no puede ser esto simultáneamente.

H3: D1 en corte y D2 en conducción



$$\begin{cases} V_i = -10 - V_\gamma - 3RI_{D_2} \\ V_o = -10 - V_\gamma - 2RI_{D_2} \end{cases} \Rightarrow$$

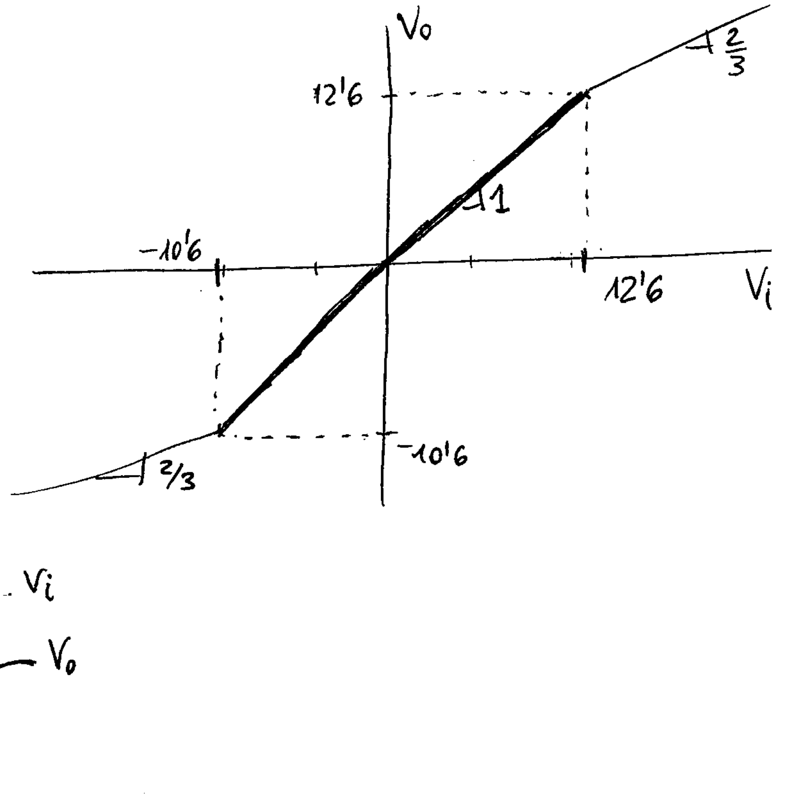
$$\Rightarrow I_{D_2} = \frac{-V_i - 10'6}{3R}$$

$$\Rightarrow \boxed{V_o = \frac{2V_i - 10'6}{3}}$$

Cuando:

$I_{D_2} > 0 \Leftrightarrow -V_i - 10'6 < 0 \Leftrightarrow \boxed{V_i < -10'6\ V}$

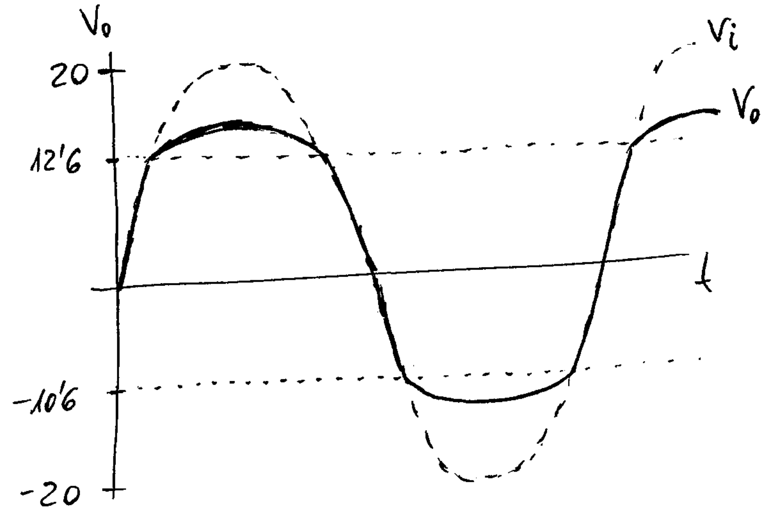
$V_{D_1} < V_\gamma \Leftrightarrow V_i < 24'3\ V$ (subordinada a la anterior)



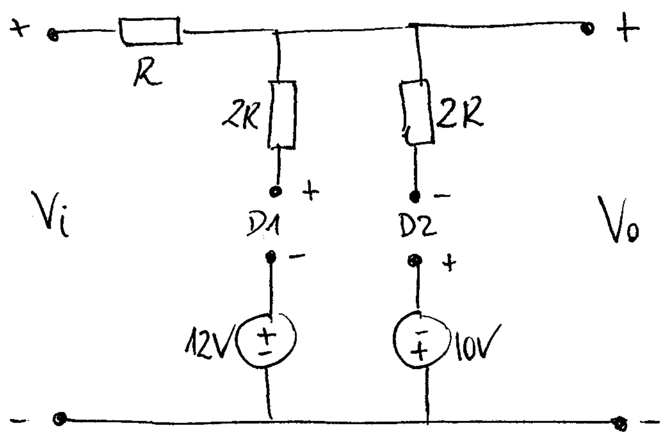
RESUMEN

$$V_o = \begin{cases} \frac{2V_i - 10'6}{3} & \text{si} \quad V_i < -10'6 \\ V_i & \text{si} \quad -10'6 < V_i < 12'6 \\ \frac{2V_i + 12'6}{3} & \text{si} \quad V_i > 12'6 \end{cases}$$

b)



H1: D1 y D2 en corte



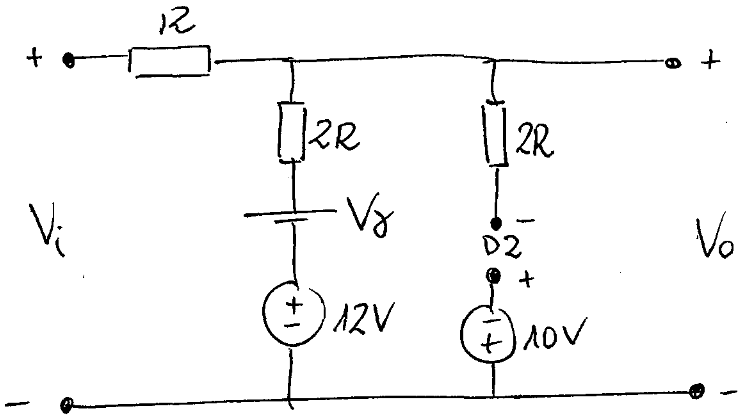
$$\boxed{V_o = V_i}$$

cuando:

$V_\gamma > V_{D1} = V_i - 12 \Rightarrow \boxed{V_i < 12'6V}$

$V_\gamma > V_{D2} = -10 - V_i \Rightarrow \boxed{V_i > -10'6V}$

H2: D1 conducción y D2 en corte



$V_i = 12 + V_\gamma + 3R\, I_{D1} \Rightarrow$

$\Rightarrow I_{D1} = \dfrac{V_i - 12'6}{3R}$

$$\boxed{V_o = \frac{2V_i + 12'6}{3}}$$

Cuando:

$I_{D1} > 0 \Rightarrow \boxed{V_i > 12'6V}$

$V_\gamma > V_{D2} = -10 - V_i \Rightarrow V_i > -22'V$ (subordinada a la anterior)