Teoria dos Circuitos
e Fundamentos de Electrónica

Mestrado em Engenharia Física Tecnológica (MEFT)
Mestrado em Engenharia Biomédica (MEBiom)

Soluções da Colectânea de Problemas

1 – Teoria dos Circuitos
2 – Circuitos com Amplificadores Operacionais
3 – Circuitos com Díodos
4 – Circuitos com Transístores de Junção Bipolar

Fernando Gonçalves
Teresa Mendes de Almeida

DEEC – Área Científica de Electrónica

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PARTE 1 – Teoria dos Circuitos

1.1 **a)** $R_{18} = R_{12} + R_{34} + R_{56} + R_{78}$
b) $R_{15} = (R_{12} + R_{34}) // (R_{87} + R_{65})$
c) $R_{12} = R_{12} // (R_{34} + R_{56} + R_{78})$
d) $R_{14} = R_{12} // R_{34} // R_{56} // R_{78}$

1.2 $I_1 = 2$ A

1.3 **a)** Nós = 4; Ramos = 6
b) $I_4 = -4$ A; $V_2 = 50$ V
c) $R_1 = 4\ \Omega$; $R_2 = 6{,}25\ \Omega$

1.4 **a)** $R_1 = 19\ \Omega$; $R_2 = 2{,}22\ \Omega$
b) P = -280 W

1.5 **a)** $V_{IN} = -26$ V; $V_S = 6$ V
b) P = -320 W

1.6 $R_4 = 8{,}2\ \Omega$

1.7 **a)** $V_S = 300$ V
b) $V_S = 120$ V
c) $I_0 = 0{,}333$ A

1.8 **a)** $R_L = 6\ \Omega$
b) $I_{V1} = 0{,}625$ A

1.9 $I_X = -1{,}14$ A

1.10 **a)** $V_{OC} = -22{,}5$ V; $I_{SC} = -2{,}4$ A; $R_{TH} = 9{,}375\ \Omega$

1.11 $V_{TH} = 10$ V; $R_{TH} = 16\ \Omega$

1.12 **a)** $V_{TH} = 32$ V; $I_N = 8$ A; $R_{TH} = R_N = 4\ \Omega$
b) $V_{TH} = 48{,}571$ V; $I_N = 15$ A; $R_{TH} = R_N = 3{,}238\ \Omega$

1.13 **a)** $V_{TH} = \dfrac{R_2}{R_1 + R_2 - \alpha} V_S$; $I_N = \dfrac{V_S}{R_1}$; $R_{TH} = R_N = \dfrac{R_1 R_2}{R_1 + R_2 - \alpha}$

b) Quando $\alpha > R_1 + R_2 \Rightarrow R_{TH}$ negativa

1.14 **a)** $V_S = 5$ V; $V_1 = V_2 = 1$ V; $V_3 = 0{,}5$ V
b) $V_{TH} = 0{,}5$ V; $R_{TH} = 625\ \Omega$
c) $R_X = 625\ \Omega$

1.15 **a)** $V_{TH} = V_S \dfrac{R_3}{R_1 + R_3} + I_S \left[R_2 + (R_1 // R_3) \right]$; $R_{TH} = R_2 + (R_1 // R_3)$

b) $R_{TH} = R_L // [R_2 + (R_1 // R_3)]$; $V_{TH} = \dfrac{V_S R_L R_3 + I_S \left[R_L (R_1 R_2 + R_1 R_3 + R_2 R_3) \right]}{R_L R_1 + R_L R_3 + R_1 R_2 + R_1 R_3 + R_2 R_3}$

1.16 **a)** $V_{TH} = 2$ V; $R_{TH} = 1\ k\Omega$
b) I = 1 mA

1.17 **a)** $V_{AB} = -0{,}5$ V
b) $I_{CC} = -1$ mA
c) $I_N = -1$ mA; $R_N = 500\ \Omega$

1.18 **a)** $V_{TH} = 1$ V; $R_{TH} = 2\ k\Omega$
b) $I_N = 0{,}5$ mA; $R_N = R_{TH} = 2\ k\Omega$
c) $R_5 = 2\ k\Omega$

1.19 $V_A = V_1 = 28$ V; $V_B = 10$ V; $V_C = 20$ V
$I_{R1} = -1$ A; $I_{R2} = 3$ A; $I_{R3} = -2$ A; $I_{R4} = 5$ A; $I_{R5} = -1$ A; $I_{V1} = 4$ A

1.20 **a)** $V_X = -2{,}0909$ V; $I_Y = -4{,}364$ A
b) $V_{TH} = -2{,}333$ V; $I_N = -0{,}875$ A; $R_{TH} = R_N = 2{,}666\ \Omega$

1.21 $V_X = 171{,}64$ V; $V_Y = -17{,}44$ V

1.22 **a)** $V_c = -60{,}87$ V
b) P = 195,65 W

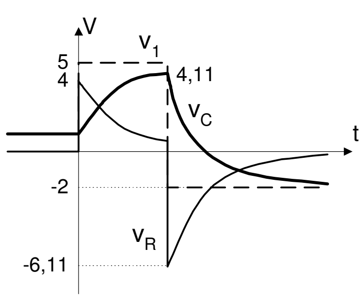
1.23 **a)** $V_1 = 6$ V; $V_2 = 4{,}23$ V; $V_3 = -8$ V; $V_4 = 8{,}84$ V
b) P = -10,6 W

1.24 **a)** t = 1 s: $v_c = 3{,}6789$ V; i = 3,6789 μA
t = 2 s: $v_c = 1{,}353$ V; i = 1,353 μA
$v_C(t) = 10e^{-t}\ \text{(V)};\ i(t) = 10e^{-t}\ (\mu\text{A})$
b) t = 693,3 ms
c) R = 621,3 kΩ

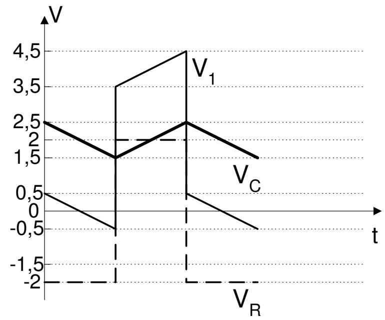
1.25 **a)** t = 0,5τ: $v_c = 3{,}94$ V; $v_R = 6{,}06$ V; i = 6,06 mA
t = τ: $v_c = 6{,}32$ V; $v_R = 3{,}68$ V; i = 3,68 mA
t = 2τ: $v_c = 8{,}64$ V; $v_R = 1{,}36$ V; i = 1,36 mA
t = 3τ: $v_c = 9{,}50$ V; $v_R = 0{,}50$ V; i = 0,50 mA
t = 4τ: $v_c = 9{,}81$ V; $v_R = 0{,}19$ V; i = 0,19 mA
t = 5τ: $v_c = 9{,}93$ V; $v_R = 0{,}07$ V; i = 0,07 mA
$v_C(t) = 10(1 - e^{-10^6 t})\ \text{(V)};\ v_R(t) = 10e^{-10^6 t}\ \text{(V)};\ i(t) = 10e^{-10^6 t}\ \text{(mA)}$
b) t = 2,1927 μs

1.26
$$v_c(t) = \begin{cases} 1 & ,t \le 0 \\ 5 - 4e^{-10^4 t} & ,\ 0 \le t \le 150\ \mu s \quad [V] \\ -2 + 6{,}11e^{-10^4 (t-t_1)} & ,\ t \ge 150\ \mu s \end{cases}$$

$$v_R(t) = \begin{cases} 0 & ,\ t \le 0 \\ 4e^{-10^4 t} & ,\ 0 \le t \le 150\ \mu s \quad [V] \\ -6{,}11e^{-10^4 (t-t_1)} & ,\ t \ge 150\ \mu s \end{cases}$$



1.27 $v_{C\,máx} = 2{,}5$ V; $v_{C\,min} = 1{,}5$ V

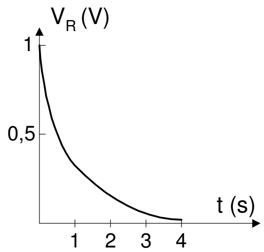


1.28 **a)** $\tau = RC = 1$ s

b) $V_C(t) = e^{-t}$ [V]

c) $V_C(1\text{ s}) = 0{,}368$ V; $V_C(4\text{ s}) = 0{,}018$ V

d) $V_R(t) = V_C(t) = e^{-t}$

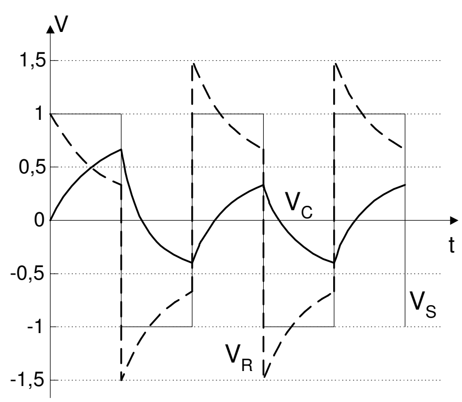


e) R >> 1 Ω ⇒ τ maior ⇒ descida mais lenta
R << 1 Ω ⇒ τ menor ⇒ descida mais rápida

1.29 $$V_C(t) = \begin{cases} 1-(1-V_C(t_n))e^{-(t-t_n)} & \text{quando } V_S = 1\,\text{V} \\ -1-(-1-V_C(t_n))e^{-(t-t_n)} & \text{quando } V_S = -1\,\text{V} \end{cases}$$

$$V_R(t) = \begin{cases} (1-V_C(t_n))e^{-(t-t_n)} & \text{quando } V_S = 1\,\text{V} \\ -(1+V_C(t_n))e^{-(t-t_n)} & \text{quando } V_S = -1\,\text{V} \end{cases}$$

t_n representa o tempo no início de cada troço



1.30 Para o circuito da figura (a): $Z = \dfrac{C_1 + C_2 + C_3}{j\omega C_1(C_2 + C_3)}$

Para o circuito da figura (b): $Z = j\omega\left(L_1 + \dfrac{L_2 L_3}{L_2 + L_3}\right)$

1.31 $$\left|\frac{V_{OUT}}{V_{IN}}\right| = \frac{\omega C_1 R_1}{\sqrt{(1-\omega^2 C_1 C_2 R_1 R_2)^2 + \omega^2 (C_1 R_1 + C_2 R_1 + C_2 R_2)^2}}$$

1.32 **a)** $$\frac{V_O}{V_S} = \frac{1}{1 + j\omega RC}$$

b) $$\left|\frac{V_O}{V_S}\right| = \frac{1}{\sqrt{1+\omega^2 C^2 R^2}}$$; freq = 159 Hz

1.33 **a)** $$\frac{V_O}{I_S} = \frac{j\omega LR}{R + j\omega L}$$

b) $$\left|\frac{V_O}{I_S}\right| = \frac{\omega RL}{\sqrt{R^2 + \omega^2 L^2}}$$; freq = 112,5 Hz

1.34 $$V_{ab} = \frac{j\omega C_2 R_1 R_2}{1 + j\omega C_2 (R_1 + R_2)} I_S$$

$$Z = \frac{R_2 + j\omega C_2 R_1 R_2}{1 + j\omega C_2 (R_1 + R_2)}$$

1.35 Para o circuito da figura (a): $Z = j\left[\omega L_1 - \dfrac{1}{\omega C_1}\dfrac{1-\omega^2 C_2 L_2}{1 + \dfrac{C_2}{C_1} - \omega^2 C_2 L_2}\right]$

Para o circuito da figura (b): $Z = j\left[\dfrac{\omega L_1\left(1-\omega^2 L_2 C_2\right)}{1-\omega^2 C_2 (L_1 + L_2)} - \dfrac{1}{\omega C_1}\right]$

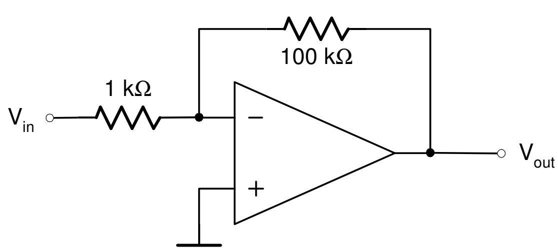
1.36 $$Z = \frac{R_1 (C_1 + C_2)}{C_1 + C_2 + j\omega C_1 C_2 R_1}$$

$$V_{ab} = \frac{R_1 C_2}{C_1 + C_2 + j\omega C_1 C_2 R_1} I_S + \frac{j\omega C_1 C_2 R_1}{C_1 + C_2 + j\omega C_1 C_2 R_1} V_S$$

PARTE 2 – Circuitos com Amplificadores Operacionais

2.1 $V_S = -1$ V

2.2



2.3 $$\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}\left(1 + \frac{R_3}{R_2} + \frac{R_3}{R_4}\right)$$

2.4 V_{o1} = -10 V; V_{out} = 12 V (tensão de saturação positiva)

2.5 **a)** $V_{out} = \frac{R_3 + R_4}{R_3} \frac{R_2}{R_1 + R_2} V_1$

b) $V_{out} = -\frac{R_4}{R_3} V_2$

c) $V_{out} = \frac{R_3 + R_4}{R_3} \frac{R_2}{R_1 + R_2} V_1 - \frac{R_4}{R_3} V_2$

d) $R_2 = 2R_1$ e $R_4 = 2R_3$

2.6 **a)** $V_{out} = -R_3 \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$

b) $V_{out} = \frac{(R_1//R_2) + R_3}{R_1//R_2} V_3$

c) $V_{out} = -R_3 \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right) + \frac{(R_1//R_2) + R_3}{R_1//R_2} V_3$

d) $R_1 = R_2 = R_3$

2.7 **a)** $V_{out} = \frac{R_3 + R_4}{R_3(R_1 + R_2)} (R_2 V_1 + R_1 V_2) - \frac{R_4}{R_3} V_3$

b) $R_2 = 5\ k\Omega$; $R_4 = 40\ k\Omega$

c) $R_1 = R_2$ e $R_4 = 3R_3$

2.8 **a)** $V_{out} = -\frac{R_3}{R_1} V_1 - \frac{R_3}{R_2} V_2 + \frac{R_5}{R_4 + R_5} \left(1 + \frac{R_3}{R_1//R_2} \right) V_3$

b) $R_1 = R_2 = R_3$ e $R_4 = 8R_5$

2.9 **a)** Para V_1: $V_{out} = \frac{R_3 + R}{R_3} \frac{R_2}{R_1 + R_2} V_1$

Para V_2: $V_{out} = \frac{R_3 + R}{R_3} \frac{R_1}{R_1 + R_2} V_2$

Para V_3: $V_{out} = -\frac{R}{R_3} V_3$

b) $V_{out} = \frac{R_3 + R}{R_3(R_1 + R_2)} (R_2 V_1 + R_1 V_2) - \frac{R}{R_3} V_3$

c) $R_2 = 2\ k\Omega$; $R_3 = 1\ k\Omega$

d) V_{max} = 12 V

2.10 **a)** $G_c = 0$; $G_d = 1$; RRMC = ∞

b) $G_c = 0{,}0099$; $G_d = 0{,}985$; RRMC = 99,5

c) Se R_4 sofrer um desvio equivalente ao de R_2 (-1 %) e R_3 um desvio equivalente ao de R_1 (+1 %), o ganho de modo comum volta a ser nulo.

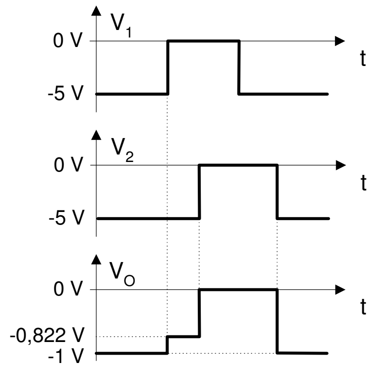
PARTE 3 – Circuitos com Díodos

3.1 **a)** $R_2 = 4\ k\Omega$

b) V_O = -0,822 V

c) V_O = 0 V

d)



3.2 **a)** V_O = -0,45 V
b) V_{TH} = -0,45 V; R_{TH} = 0,909 kΩ
c) R_2 < 612 Ω

3.3 **a)** V_O = 5 V
b) V_O = 1 V
c) V_O = 0,81 V

3.4 **a)** I_{R3} = 3,75 mA
b) V_{D2} = -7,5 V

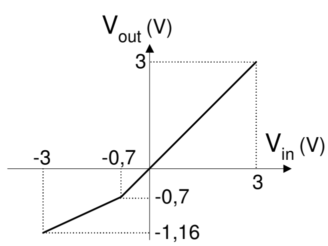
3.5 **a)** R_L < 60,63 Ω
b) R_1 > 39,84 Ω

3.6 **a)** $V_{out} = \begin{cases} 10 & \text{para } V_{in} < 10 \text{ V} \\ V_{in} & \text{para } V_{in} \geq 10 \text{ V} \end{cases}$

b) $I_{R1} = \begin{cases} 0 & \text{para } V_{in} < 10 \text{ V} \\ \dfrac{V_{in} - 10}{R_1} & \text{para } V_{in} \geq 10 \text{ V} \end{cases}$

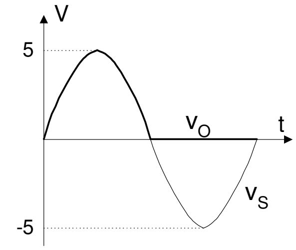
c) $V_{out} = \begin{cases} 9{,}3 & \text{para } V_{in} < 10 \text{ V} \\ V_{in} - 0{,}7 & \text{para } V_{in} \geq 10 \text{ V} \end{cases}$

3.7 **a)** $V_{out} = \begin{cases} \dfrac{V_{in} - 2{,}8}{5} & \text{para -3 V} < V_{in} \leq \text{-0,7 V} \\ V_{in} & \text{para -0,7 V} \leq V_{in} < \text{3 V} \end{cases}$

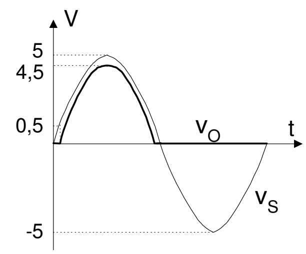


b) –286,7 V < V_{in} < 26,7 V

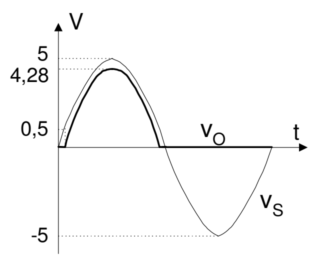
3.8 **a)**



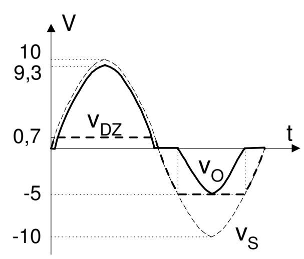
b)



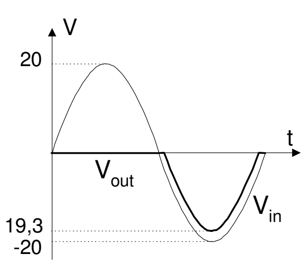
c)



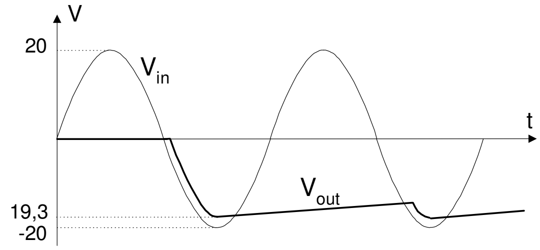
3.9



3.10 **a)** Rectificador de meia-onda negativo

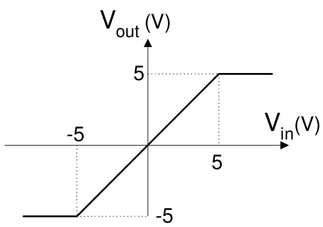


b)

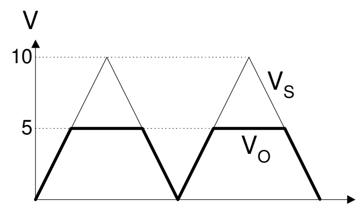


c) O condensador descarrega mais rapidamente $\Rightarrow$ maior oscilação da onda de saída

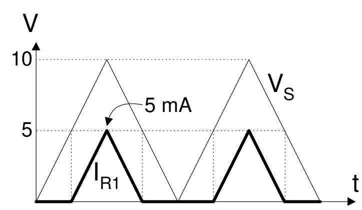
3.11



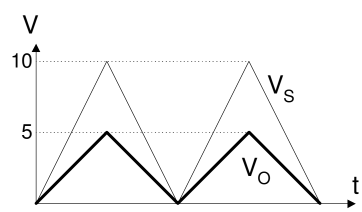
3.12 a)



b)

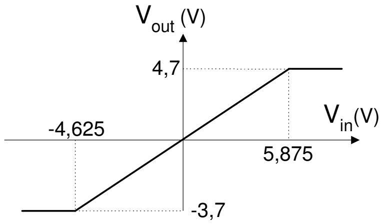


c)



3.13 a) $V_{in1} = 5{,}875$ V; $V_{in2} = -4{,}625$ V

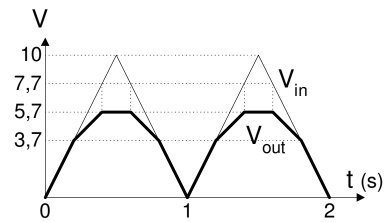
b) $$V_{out} = \begin{cases} -3{,}7 & \text{para } V_{in} < -4{,}625 \text{ V} \\ 0{,}8V_{in} & \text{para } -4{,}625 \text{ V} \le V_{in} < 5{,}875 \text{ V} \\ 4{,}7 & \text{para } V_{in} \ge 5{,}875 \text{ V} \end{cases}$$



c) I_{D1max} = 2,06 mA; I_{D2max} = 2,68 mA

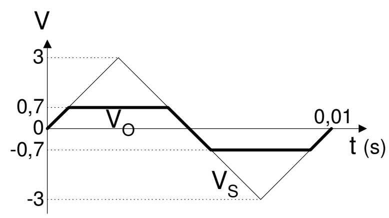
3.14 **a)** $$V_{out} = \begin{cases} V_{in} & \text{para } V_{in} < 3{,}7\text{ V} \\ 1{,}85 + \dfrac{V_{in}}{2} & \text{para } 3{,}7\text{ V} \le V_{in} < 7{,}7\text{ V} \\ 5{,}7 & \text{para } V_{in} \ge 7{,}7\text{ V} \end{cases}$$

b)



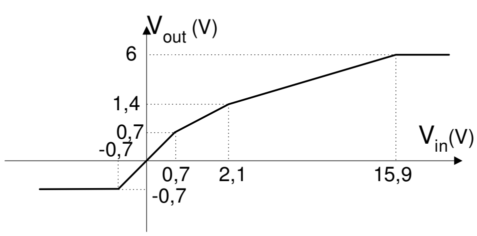
c) I_{inMax} = 4,3 mA

3.15 **a)**



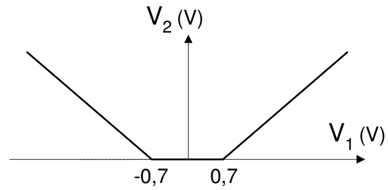
b) I_{R1max} = 1,15 mA

3.16 **a)** $$V_{out} = \begin{cases} -0{,}7 & \text{para } V_{in} < -0{,}7\text{ V} \\ V_{in} & \text{para } -0{,}7\text{ V} \le V_{in} < 0{,}7\text{ V} \\ \dfrac{V_{in}}{2} + 0{,}35 & \text{para } 0{,}7\text{ V} \le V_{in} < 2{,}1\text{ V} \\ \dfrac{V_{in}}{3} + 0{,}7 & \text{para } 2{,}1\text{ V} \le V_{in} < 15{,}9\text{ V} \\ 6 & \text{para } V_{in} \ge 15{,}9\text{ V} \end{cases}$$

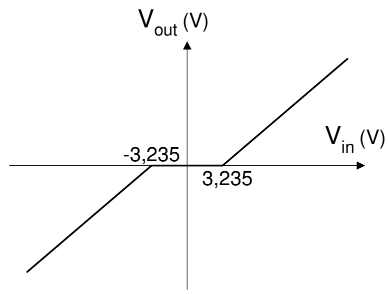


b) P_{zmax} = 144,6 mW

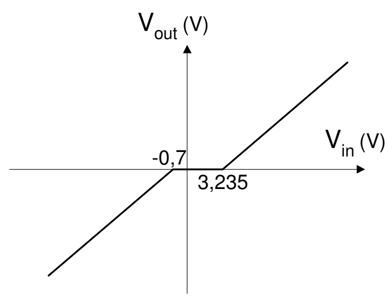
3.17 $V_2 = \begin{cases} -0{,}9\ V_1 - 0{,}63 & \text{para } V_1 < -0{,}7\ V \\ 0 & \text{para } -0{,}7\ V \le V_1 \le 0{,}7\ V \\ 0{,}9\ V_1 - 0{,}63 & \text{para } V_1 > 0{,}7\ V \end{cases}$



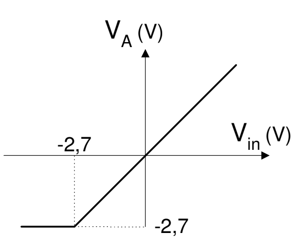
3.18 **a)** $V_{out} = \begin{cases} 0{,}9478\ V_{in} + 3{,}066 & \text{para } V_{in} < -3{,}235\ V \\ 0 & \text{para } -3{,}235\ V \le V_{in} \le 3{,}235\ V \\ 0{,}9478\ V_{in} - 3{,}066 & \text{para } V_{in} > 3{,}235\ V \end{cases}$



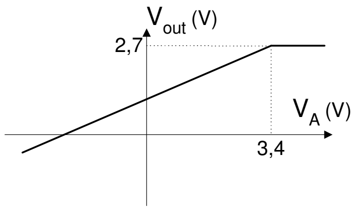
b) $V_{out} = \begin{cases} V_{in} + 0{,}7 & \text{para } V_{in} < -0{,}7\ V \\ 0 & \text{para } -0{,}7\ V \le V_{in} \le 3{,}235\ V \\ 0{,}9478\ V_{in} - 3{,}066 & \text{para } V_{in} > 3{,}235\ V \end{cases}$



3.19 **a)** $V_A = \begin{cases} -2{,}7 & \text{para } V_{in} < -2{,}7\ V \\ V_{in} & \text{para } V_{in} \ge -2{,}7\ V \end{cases}$

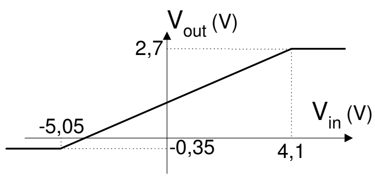


b) $V_{out} = \begin{cases} \dfrac{V_A + V_R}{2} & \text{para } V_A < 3{,}4\ V \\ 2{,}7 & \text{para } V_A \ge 3{,}4\ V \end{cases}$



c) V_{out} = 1,33 V

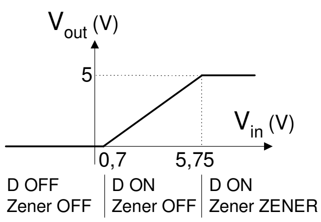
$$\textbf{d)}\ V_{out} = \begin{cases} -0{,}35 & \text{para } V_{in} < -5{,}05\text{ V} \\ \dfrac{V_{in} + 2V_R}{3} & \text{para } -5{,}05\text{ V} \le V_{in} \le 4{,}1\text{ V} \\ 2{,}7 & \text{para } V_{in} > 4{,}1\text{ V} \end{cases}$$



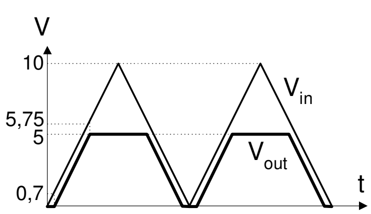
e) P_{zmax} = 9,9 mW

3.20 **a)**

$$V_{out} = \begin{cases} 0 & \text{para } V_{in} < 0{,}7\text{ V} \\ \dfrac{R_1}{R_1 + R_D}(V_{in} - 0{,}7) & \text{para } 0{,}7\text{ V} \le V_{in} \le 5{,}75\text{ V} \\ 5 & \text{para } V_{in} > 5{,}75\text{ V} \end{cases}$$



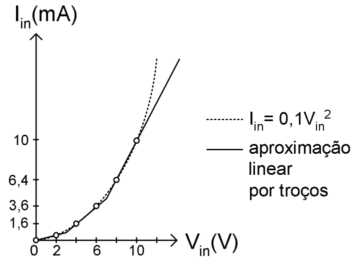
b)



c) R_1: Evita que o nó de saída fique em alta-impedância quando os díodos estão cortados
R_2: Polariza o díodo Zener

3.21 **a)** R_1 = 5 kΩ; R_2 = R_3 = 1,25 kΩ
b) Em ambos os casos o erro é de 0,3 mA

c)



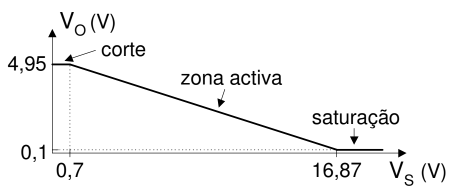
d) V_{in} = 6 V e V_{in} = 10 V

PARTE 4 – Circuitos com Transístores de Junção Bipolar

4.1 **a)** I_C = 9,2 mA
b) V_{CE} = 1,5 V

4.2 **a)** R_C = 3 kΩ; R_B = 565 kΩ
b) I_C = 0,8 mA; V_{CE} = 9,6 V

4.3



4.4 I_B = 0,1 mA; I_C = 3 mA; V_o = 2 V

4.5 I_C = 1,29 mA; V_{CE} = 13,96 V
Se R_2 estiver desligada, o transístor fica saturado

4.6 I_C = 5,64 mA; V_{CE} = -3,54 V

4.7 **a)** R_1 = 106,45 kΩ

b) $$I_C = \frac{V_{CC} - V_{BEON}}{(R_C + R_E)\frac{\beta+1}{\beta} + \frac{R_1}{\beta}} = 3{,}11\,\text{mA}$$

4.8 V_2-V_1 = -7,85 V; limites de validade: 8,05 V < V_1 < 15,5 V

4.9 **a)** I_{C1} = 501 mA; V_{CE1} = 2,5 V

b) $$I_{C1}(\text{mA}) = \begin{cases} \beta I_{in} & \text{para } I_{in} < 48\,\mu\text{A} \\ \dfrac{I_{in}}{\beta} + 24 & \text{para } I_{in} \geq 48\,\mu\text{A} \end{cases}$$

c) R_1 = 20 Ω

4.10 **a)** I_C = 277 μA (corrente I_B foi desprezada)
b) V_{CE} = 4,75 V

4.11 **a)** I_C = 758 μA
b) V_{CE} = 2,91 V
c) V_E = -0,94 V
d) V_{BC} = -2,31 V

e) O condensador evita que o ponto de funcionamento em repouso do transístor seja afectado pela tensão de entrada, V_{in}.

4.12 **a)** I_C = 2,71 mA; V_{CE} = 4,037 V
b) I_C = 2,68 mA; V_{CE} = 4,093 V
c) Redução de 50% do ganho conduziu a pequenas variações de I_C e V_{CE}

4.13 **a)** R_E = 4,95 kΩ
b) Sem R_L: R_B = 500 kΩ; Com R_L: R_B = 84 kΩ

4.14 **a)** I_C = 4 mA; V_{CE} = 2,575 V
b) R_{in} = 6,57 kΩ
c) G = 1

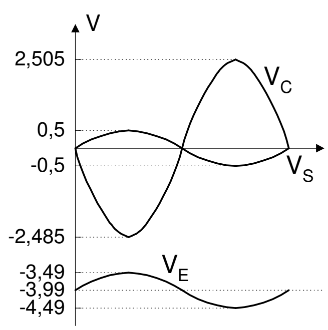
4.15 **a)** R_E = 2 kΩ
b) R_1 = 20 kΩ
c) R_C = 1,01 kΩ
d) C = 88 nF

4.16 **a)** I_E = 5 mA
b) R_2 = 255 kΩ
c) R_B = 75,5 kΩ
d) C = 1,8 nF

4.17 **a)** I_C = 406 μA; V_{CE} = 7,3 V
b) R_B = 60,6 kΩ
c) R_{in} = 35,7 kΩ
d) G = -10

4.18 **a)** R_1 = 83,2 kΩ; R_2 = 16,8 kΩ; R_C = 2,196 kΩ
b) R_{in} = 8,66 kΩ; R_{out} = 113 Ω
c) G = -7,22
d) R_1 = 61,6 kΩ; R_2 = 38,4 kΩ; R_C = R_E = 1,24 kΩ

4.19 **a)** R_2 = 5,023 kΩ; R_C = 2,495 kΩ
b) $v_E(t) = -3{,}99 + 0{,}5 \sin(\omega t)$
$v_C(t) = 0{,}01 - 2{,}495 \sin(\omega t)$
$v_c(t)$ e $v_e(t)$ estão em oposição de fase ($\Delta\phi = 180^o$)

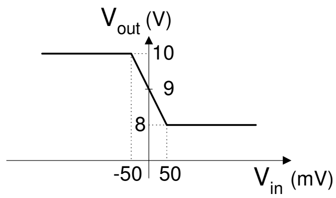


4.20 I_{C2} = 1,3 mA

4.21 R_1 = 1,38 kΩ; R_2 = 0,92 kΩ

4.22 **a)** $I_{C2} = I_{C3}$ = 1 mA
b) P_{RC1} = 2,7 mW; P_{RC2} = 5 mW; P_{RC3} = 10 mW

4.23 **a)** $$V_{out} = \begin{cases} 10 & \text{para } V_{in} < -50\text{ mV} \\ V_{CC} - R_{C1}\left(\dfrac{V_{in}}{2r_E} + \dfrac{I_{EE}}{2}\right) & \text{para } -50\text{ mV} \le V_{in} \le 50\text{ mV} \\ 8 & \text{para } V_{in} > 50\text{ mV} \end{cases}$$

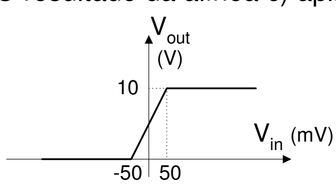


b) $G_d = -20$
c) $G_c = -0{,}0005$
d) RRMC = 40.000

4.24 **a)** $I_{C1} = I_{C2} = 1$ mA; $r_E = 25\ \Omega$
b) $G_c = 0$
c) $G_d = 100$

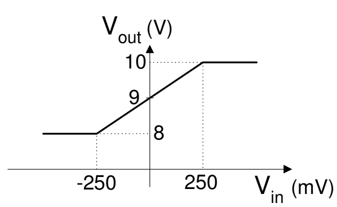
d) $$V_{out} = \begin{cases} 0 & \text{para } V_{in} < -50\text{ mV} \\ V_{CC} - R_{C2}\left(\dfrac{I_{EE}}{2} - \dfrac{V_{in}}{2r_E}\right) & \text{para } -50\text{ mV} \le V_{in} \le 50\text{ mV} \\ V_{CC} & \text{para } V_{in} > 50\text{ mV} \end{cases}$$

O resultado da alínea c) aplica-se para $V_{in} \in$ [-50 mV; 50 mV]



4.25 **a)**

$$V_{out} = \begin{cases} V_{CC} - R_{C2}I_{EE} = 8 & \text{para } V_{in} < -(r_E + R_E)I_{EE} \\ V_{CC} - R_{C2}\left(\dfrac{I_{EE}}{2} - \dfrac{V_{in}}{2(r_E + R_E)}\right) & \text{para } -(r_E + R_E)I_{EE} \le V_{in} \le (r_E + R_E)I_{EE} \\ V_{CC} = 10 & \text{para } V_{in} > (r_E + R_E)I_{EE} \end{cases}$$



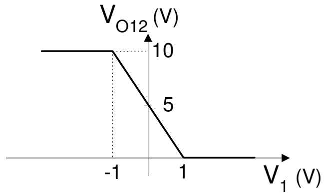
$(r_E+R_E)I_{EE} = 250$ mV

b) $G_d = 4$
c) $G_c = -0{,}0005$
d) A anulação de R_{E1} e R_{E2} provoca uma diminuição da zona de funcionamento linear do par diferencial (zona com declive $\neq 0$). Com R_{E1} e R_{E2} essa região tinha uma largura de $2(r_E+R_E)I_{EE}$=0,5 V, passando a ter uma largura de $2r_EI_{EE}$=0,1 V se R_{E1} e R_{E2} forem anuladas.

4.26 **a)** $G_c = -0{,}001$
b) $G_d = -20$
c) RRMC = 20.000

4.27 **a)** $V_X = -1{,}156$ V

b) $V_{O12} = R_{C2}\left(\frac{I_{EE}}{2} - \frac{V_1}{2R_E}\right) = 5 - 5V_1$



c) $G_d = -5$

d)