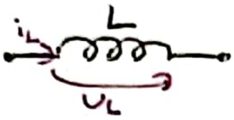
Condensador

$i_C(t) = C \frac{du_C}{dt}$

Bobina



$u_L(t) = L \frac{di_L}{dt}$

①

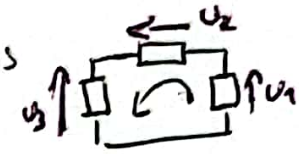
KCL:

correntes nos nós

$i_1 = i_2 + i_3$

KVL:

tensões nas malhas



$u_1 + u_2 - u_3 = 0$

Num circuito com r ramos e n nós:

KCL: n-1 eq. indep.

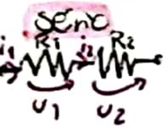
KVL: r-(n-1) eq. indep.

②

Associação Componentes

Resistências

série

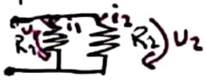


$u = u_1 + u_2$

$i = i_1 = i_2$

$R = R_1 + R_2$

paralelo



$u = u_1 = u_2$

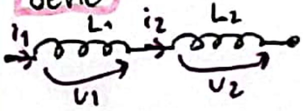
$i = i_1 + i_2$

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \Leftrightarrow R = \frac{R_1 . R_2}{R_1 + R_2}$

③

Bobinas

série

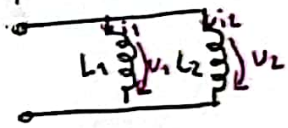


$u = u_1 + u_2$

$i = i_1 = i_2$

$L = L_1 + L_2$

paralelo



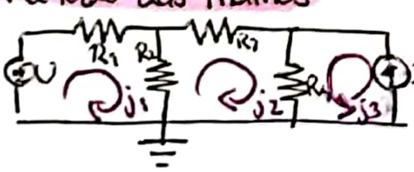
$u = u_1 = u_2$

$i = i_1 + i_2$

$L = \frac{L_1 . L_2}{L_1 + L_2}$

④

Método das malhas



$-U + R_1 j_1 + R_2(j_1 - j_2) = 0 \rightarrow$ malha 1

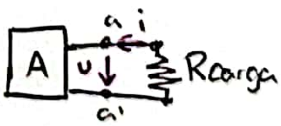
$R_2(j_2 - j_1) + R_3 j_2 + R_4(j_2 + j_3) = 0 \rightarrow$ malha 2

$j_3 = I \rightarrow$ malha 3

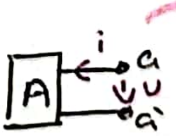
$$\begin{bmatrix} R_1+R_2 & -R_2 & 0 \\ -R_2 & R_2+R_3+R_4 & R_4 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} j_1 \\ j_2 \\ j_3 \end{bmatrix} = \begin{bmatrix} U \\ 0 \\ I \end{bmatrix}$$

⑤

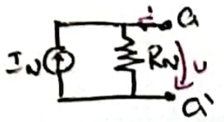
Teorema Thévenin-Norton



A → rede elétrica linear
só tem resistências, fontes de corrente e fontes de tensão



THÉVENIN

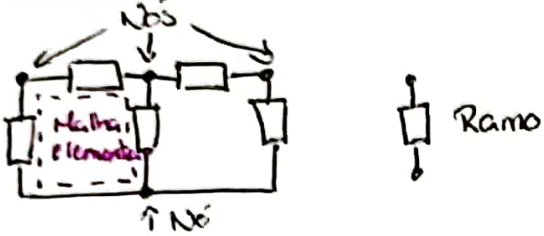


NORTON

$R_{th} = R_N$

⑥

$R = \frac{U}{I}$ $P = U \times I = RI^2$



nº nós: 4
nº ramos: 5
nº malhas elementares: 2
nº malhas: 3

Teorema Tellegen:

Soma das potências em todos os ramos de um circuito é 0

$$\sum_{k=1}^{r} P_k = 0$$

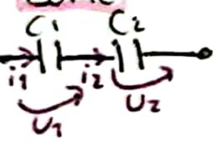
— // —

$P > 0 \Rightarrow$ recebe energia

$P < 0 \Rightarrow$ fornece energia

Condensadores

série



$U = U_1 + U_2$

$i = i_1 = i_2$

$C = \frac{C_1 C_2}{C_1 + C_2}$

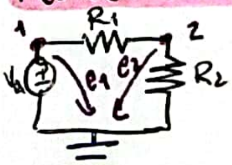
paralelo

$U = U_1 = U_2$

$i = i_1 + i_2$

$C = C_1 + C_2$

Método dos nós



KCL: $i_1 + i_2 = 0$ $e_1 = V_A$

$i_1 = \frac{e_2 - e_1}{R_1} = \frac{e_2 - V_A}{R_1}$ $i_2 = \frac{e_2 - 0}{R_2}$

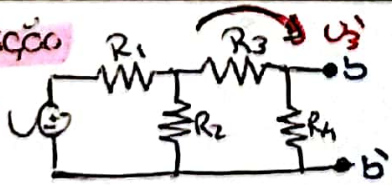
$\frac{e_2 - V_A}{R_1} + \frac{e_2}{R_2} = 0$

$\begin{bmatrix} 1 & 0 \\ 0 & G_1 + G_2 \end{bmatrix} \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} = \begin{bmatrix} V_A \\ G_1 V_A \end{bmatrix}$

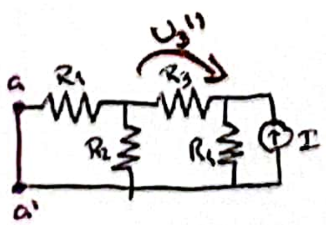
$G_1 = \frac{1}{R_1}$ $G_2 = \frac{1}{R_2}$

Teorema da sobreposição

Anula-se a fonte de corrente



Anula-se a fonte de tensão



Resposta total: $U_3 = U_3' + U_3''$

$u_g(t) = A\cos(\omega t + \alpha)$

$$U_{ef} = \sqrt{\frac{1}{T}\int_0^T u^2(t)\,dt} \Leftrightarrow U_{ef} = \frac{A}{\sqrt{2}}$$

Regime forçado sinusoidal

$x(t) = A\cos(\omega t + \varphi) \rightarrow Ae^{j\varphi} = \bar{X}$

$y(t) = B\cos(\omega t + \theta) \rightarrow Be^{j\theta}$

Impedância

$$Z = \frac{\overline{U}}{\overline{I}}$$

resistência: $Z_R = \frac{\overline{U_R}}{\overline{I_R}} = R$

tensão em avanço em relação à corrente

bobina: $Z_L = \frac{\overline{U_L}}{\overline{I_L}} = j\omega L \Leftrightarrow Z_L = \omega L e^{j\left(\frac{\pi}{2}\right)}$

condensador: $Z_C = \frac{\overline{U_C}}{\overline{I_C}} = \frac{1}{j\omega C} \Leftrightarrow Z_C = \frac{1}{\omega C} e^{-j\left(\frac{\pi}{2}\right)}$

tensão em atraso em relação à corrente

7

Regime transitório

$$i_L(t) = i_L(t)_{forçado} + i_L(t)_{livre}$$

para circuitos RL ou RC $\longrightarrow Ae^{-\frac{t}{\tau}}$

Constante de tempo

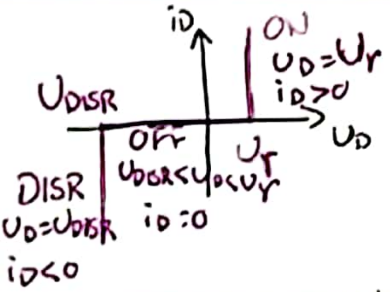
$$\tau = \frac{L}{R_{th}} \quad \text{ou} \quad \tau = CR_{th}$$

Potência complexa

$$P_{complexa} = \frac{\overline{U} \cdot \overline{I}^*}{2}$$

$\overline{I}^*$ → conjugado

8



Análise incremental

$$g_d = \left.\frac{\partial i_D}{\partial U_D}\right|_{\substack{U_D = U_{D0} \\ i_D = I_{D0}}} \rightarrow \text{condutância incremental}$$

$$i_d = g_d u_d$$

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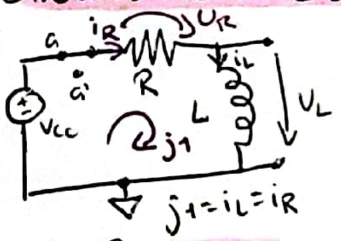
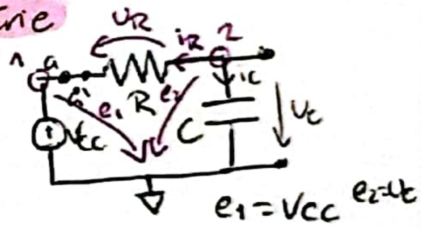
Circuitos RC e RL série



$j_1 = i_L = i_R$



$e_1 = V_{cc}$ $e_2 = U_C$

$-V_{cc} + Ri_L + U_L = 0$

$U_L = L\frac{dj_1}{dt}$

$$\frac{di_L}{dt} + \frac{R}{L} i_L = \frac{V_{cc}}{L}$$

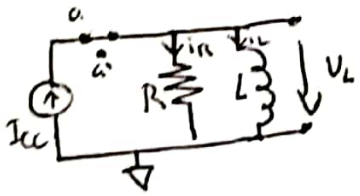
$i_C + i_R = 0 \Leftrightarrow C\frac{dU_C}{dt} + \frac{U_R}{R} = 0$

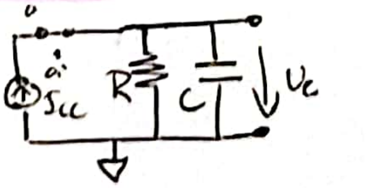
$\Leftrightarrow C\frac{de_2}{dt} + \frac{e_2 - e_1}{R} = 0 \Leftrightarrow$

$$\Leftrightarrow \frac{dU_C}{dt} + \frac{U_C}{RC} = \frac{V_{cc}}{RC}$$

10

Circuitos RC e RL paralelo





$-I_{cc} + i_L + i_R = 0 \Leftrightarrow$

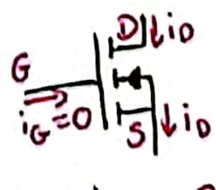
$$\Leftrightarrow \frac{di_L}{dt} + \frac{R}{L} i_L = \frac{RI_{cc}}{L}$$

$-I_{cc} + i_C + i_R = 0 \Leftrightarrow$

$$\Leftrightarrow \frac{dU_C}{dt} + \frac{U_C}{RC} = \frac{I_{cc}}{C}$$

11

TECMOS



$$i_D = \begin{cases} 0 \rightarrow \text{Corte} & \rightarrow U_{GS} < V_t \\ A\left[(U_{GS} - V_t)U_{DS} - \frac{U_{DS}^2}{2}\right] & \rightarrow U_{GS} \geq V_t \text{ e } U_{DS} < U_{GS} - V_t \\ \frac{A}{2}(U_{GS} - V_t)^2 & \rightarrow U_{GS} \geq V_t \text{ e } U_{DS} > U_{GS} - V_t \end{cases}$$

Tríodo

Saturação

12

Conversão polar->cartesiana

$$Ae^{j\varphi} = A(\cos\varphi + j\,\mathrm{sen}\,\varphi) = \underbrace{A\cos\varphi}_{a} + j\underbrace{A\,\mathrm{sen}\,\varphi}_{b}$$

$a + jb$

Conversão cartesiana->polar

$$|a+jb| = \sqrt{a^2+b^2} - A$$
$$\phi_{a+jb} = \arctan\frac{b}{a} - \varphi$$
$> Ae^{j\varphi}$

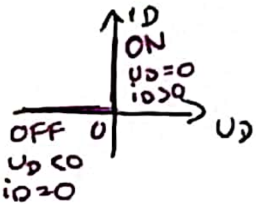
$$\frac{\overline{U_c}}{\overline{U_I}} = \frac{1}{1+j\frac{\omega}{\omega_t}} \Rightarrow \left|\frac{\overline{U_c}}{\overline{U_I}}\right| = \frac{1}{\sqrt{1+\left(\frac{\omega}{\omega_t}\right)^2}} \qquad \varphi = -\arctan\left(\frac{\omega}{\omega_t}\right)$$

Díodo

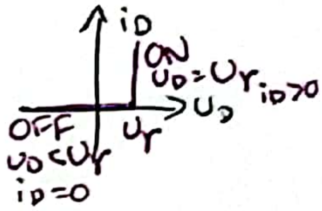
$$i_D = I_S\left(e^{\frac{U_D}{\eta U_T}} - 1\right) \qquad U_T = \frac{KT}{q}$$

$$i_D = \begin{cases} KU_D^2 & , U_D \geq 0V \\ 0 & , U_D < 0V \end{cases}$$

ideal



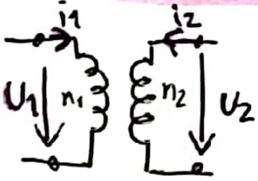
real



$$r_d = \frac{1}{g_d} \Leftrightarrow r_d = \frac{\eta U_T}{(I_D+I_S)}$$

sabendo que
$$i_D = I_S\left(e^{\frac{U_D}{\eta U_T}} - 1\right)$$

Transformadores



$$n_1 i_1 + n_2 i_2 = 0$$
$$\frac{U_1}{n_1} = \frac{U_2}{n_2}$$

Solução geral = solução regime livre + solução regime forçado

regime transitório

$$\frac{dx_e}{dt} + \frac{x_e}{\tau} = 0$$
$$\Downarrow$$
$$x_e(t) = Be^{-\frac{t-t_1}{\tau}}$$

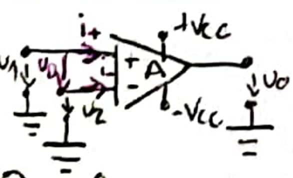
B depende da condição inicial

$V_{cc} \Rightarrow$ solução forçada

$$\left(\frac{dx}{dt} = 0\right)$$
$$\frac{x_f}{\tau} = a\,V_{cc}$$
$$\Downarrow$$
$$x_f(t) = a\tau\, V_{cc}$$

Quando o circuito não tem fontes de tensão ou corrente usamos o regime livre

Amplificador

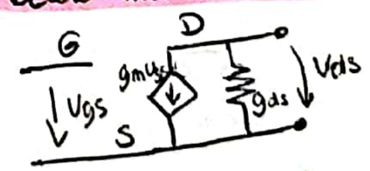


$$\begin{cases} i_- = i_+ = 0A \\ A = \infty \Rightarrow U_D = 0V \end{cases}$$

$$U_0 = AU_D \Leftrightarrow U_0 = A(U_1 - U_2)$$

Para funcionar na zona linear deve haver realimentação negativa $-V_{cc} \leq U_D \leq V_{cc}$

Modelo Incremental



Saturação	Não-Saturação
$g_m = A(U_{GS} - V_t)$	$g_m = A\,U_{DS}$
$g_{ds} = 0S$	$g_{ds} = A(U_{GS} - V_t - U_{DS})$