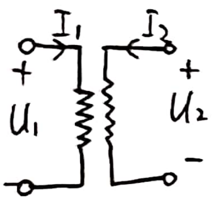
电路IB

第十章 二端口网络.

参数矩阵	开路参数矩阵Z	短路参数矩阵Y	传输参数A	混合参数H
	$\begin{bmatrix}\dot{U}_1\\ \dot{U}_2\end{bmatrix}=\begin{bmatrix}Z_{11} & Z_{12}\\ Z_{21} & Z_{22}\end{bmatrix}\begin{bmatrix}\dot{I}_1\\ \dot{I}_2\end{bmatrix}$;	$\begin{bmatrix}\dot{I}_1\\ \dot{I}_2\end{bmatrix}=\begin{bmatrix}Y_{11} & Y_{12}\\ Y_{21} & Y_{22}\end{bmatrix}\begin{bmatrix}\dot{U}_1\\ \dot{U}_2\end{bmatrix}$	$\begin{bmatrix}\dot{U}_1\\ \dot{I}_1\end{bmatrix}=\begin{bmatrix}A_{11} & A_{12}\\ A_{21} & A_{22}\end{bmatrix}\begin{bmatrix}\dot{U}_2\\ -\dot{I}_2\end{bmatrix}$	$\begin{bmatrix}\dot{U}_1\\ \dot{I}_2\end{bmatrix}=\begin{bmatrix}H_{11} & H_{12}\\ H_{21} & H_{22}\end{bmatrix}\begin{bmatrix}\dot{I}_1\\ \dot{U}_2\end{bmatrix}$
互易	$Z_{12}=Z_{21}$	$Y_{12}=Y_{21}$	$A_{11}A_{22}-A_{21}A_{12}=1$	$H_{12}=-H_{21}$
互易+对称	$+\ Z_{11}=Z_{22}$.	$+\ Y_{11}=Y_{22}$	$+\ A_{11}=A_{22}$.	$+\ H_{11}H_{22}-H_{12}H_{21}=1$

理想变压器



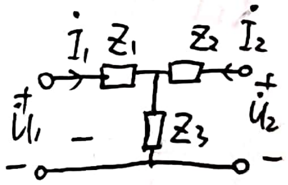
$$\begin{bmatrix}\dot{U}_1\\ \dot{I}_1\end{bmatrix}=\begin{bmatrix}n & 0\\ 0 & \frac{1}{n}\end{bmatrix}\begin{bmatrix}\dot{U}_2\\ -\dot{I}_2\end{bmatrix}$$ 互易条件

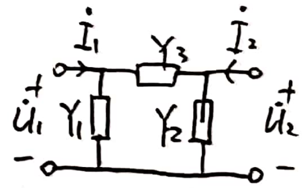
二端口等效电路

- 独立无源二端口网络,可以用最简二端口网络等效代替
- 一般二端口有四个独立参数,互易二端口可由三阻抗或导纳元件组成.

形成T形网络,Π型网络

$$Z=\begin{bmatrix}Z_1+Z_3 & Z_3\\ Z_3 & Z_2+Z_3\end{bmatrix},\quad Y=\begin{bmatrix}Y_1+Y_3 & -Y_3\\ -Y_3 & Y_2+Y_3\end{bmatrix}$$



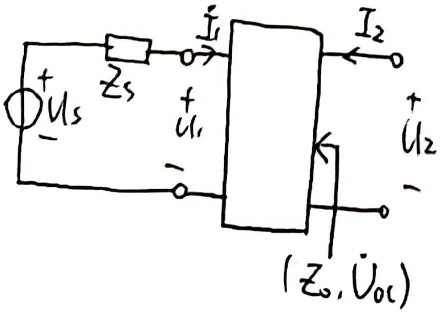


非互易网络等效(受控源)

$$\dot{U}_1=Z_{11}\dot{I}_1+Z_{12}\dot{I}_2$$ 外加电流控制的电压源

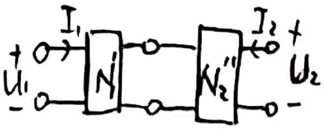
$$\dot{U}_2=Z_{12}\dot{I}_1+Z_{22}\dot{I}_2+\boxed{(Z_{21}-Z_{12})\dot{I}_1}$$

二端口网络与电源负载联接,(含源阻抗戴维南电路)



$$\dot{U}_{oc}=\frac{\dot{U}_s}{A_{21}Z_s+A_{11}}\qquad Z_0=\frac{\dot{U}_2}{\dot{I}_2}\Big|_{U_s=0}=\frac{A_{22}Z_s+A_{12}}{A_{21}Z_s+A_{11}}$$

二端口互联（级联）



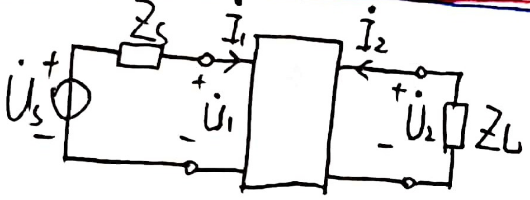
$$\boxed{A = A' \cdot A''}$$

串 $Z = Z' + Z''$

并 $Y = Y' + Y''$

输入/输出阻抗

输入 $Z_i = \dfrac{\dot{U}_1}{\dot{I}_1} = \boxed{\dfrac{A_{11}Z_L + A_{12}}{A_{21}Z_L + A_{22}}}$ 输出 $Z_o = \dfrac{\dot{U}_2}{\dot{I}_2} = \boxed{\dfrac{A_{22}Z_S + A_{12}}{A_{21}Z_S + A_{11}}}$



特性阻抗 二端口与负载、电源匹配连接

要求 $Z_o = Z_L$ $Z_S = Z_i$ $\Rightarrow$ $Z_{C1} = Z_i = Z_S = \sqrt{\dfrac{A_{11}A_{12}}{A_{21}A_{22}}}$ 输入端口特性阻抗

$Z_{C2} = Z_o = Z_L = \sqrt{\dfrac{A_{22}A_{12}}{A_{11}A_{21}}}$ 输出端口特性阻抗

二端口对称 $\Rightarrow$ $A_{11} = A_{22}$ $\Rightarrow$ $Z_{C1} = Z_{C2} = \sqrt{\dfrac{A_{12}}{A_{21}}}$ $\Rightarrow$ $Z_L = Z_C = Z_{\varphi} = \sqrt{\dfrac{A_{12}}{A_{21}}}$

$\dot{U}_1 = (A_{11} + \sqrt{A_{12}A_{21}})\dot{U}_2$ $\dot{I}_1 = (A_{11} + \sqrt{A_{12} \cdot A_{21}})(-\dot{I}_2)$

传输系数 $T = \ln(A_{11} + \sqrt{A_{12}A_{21}}) = \alpha + \beta j$

$\alpha = \ln\left(\dfrac{U_1}{U_2}\right) = \ln\left(\dfrac{I_1}{I_2}\right)$ 衰减系数，$\beta = \psi_{u1} - \psi_{u2} = \psi_{i1} - \psi_{i2}$ 相位系数

图论与网络方程

基本割集 → 单树枝割集　决定了独立的KCL方程　连支电流为一组独立变量

基本回路 → 单连支回路　决定独立KVL方程　全部支路电压中，树枝电压为一组独立变量

关联矩阵A

(表示节点，支路联结关系)，n节点 b支路线图，行对应(n-1)节点，列对应支路，

$$a_{ij} = \begin{cases} 1 & \text{支路j从节点i联出} \\ -1 \\ 0 \end{cases}$$

大小为 $(n-1)\times b$

以n节点参考，支路电压 $U=[U_1,U_2,\cdots U_b]^T$，$U_n=[U_{n1}\cdots U_{n(n-1)}]^T$

KCL: $AI=0$　　KVL: $A^TU_n=U$

基本回路矩阵B

(表示基本回路，支路包含关系) 行基本回路，列对应支路

$$b_{ij} = \begin{cases} 1 & \text{包含，方向相同} \\ -1 \\ 0 \end{cases}$$

大小 $b_l \times b$

KCL: $B^TI_l=I$　　KVL: $BU=0$

$I_t = B_t^T I_l$　　$U_l = -B_t U_t$

基本割集矩阵C

(表示基本割集与支路的包含关系) 行基本割集，列对应支路

$$C_{ij} = \begin{cases} 1 & \text{基本割集i包含j，方向相同} \\ -1 \\ 0 \end{cases}$$

KCL: $CI=0$，　KVL: $C^TU_T=U$　树枝电压列矢量

$I_t = -C_l I_l$　　$U_l = C_l^T U_t$

$AI = AB^T I_l = 0 \quad BU = BC^T U_t = 0$

$\Rightarrow AB^T = 0 \quad BA^T = 0 \quad / \quad BC^T = 0, \ CB^T = 0$

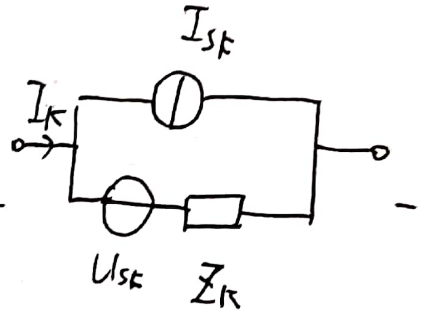
$CI = CB^T I_l = 0 \Rightarrow B_t = -C_l^T$

网络矩阵关系.

$AB^T = 0 \ / \ A^T B = 0, \quad BC^T = 0, \quad CB^T = 0$

BC 若出现单位阵，$BC^T = 0 \quad B_t = -C_l^T$

广义支路及其方程矩阵形式.



$U = ZI - ZI_s + U_s$

$$\begin{bmatrix} U_1 \\ \vdots \\ U_b \end{bmatrix} = \begin{bmatrix} Z_1 & & \\ & \ddots & \\ & & Z_b \end{bmatrix} \begin{bmatrix} I_1 \\ \vdots \\ I_b \end{bmatrix} - \begin{bmatrix} Z_1 & & \\ & \ddots & \\ & & Z_b \end{bmatrix} \begin{bmatrix} I_{s1} \\ \vdots \\ I_{sb} \end{bmatrix} + \begin{bmatrix} U_{s1} \\ \vdots \\ U_{sb} \end{bmatrix}$$

$Z_k \neq 0$ 时，存在逆矩阵 Z^{-1}，$Y = Z^{-1}$

$I = YU - YU_s + I_s$

电路方程矩阵形式

节点电压方程 $\quad AI = 0 \Rightarrow AYA^T U_n = AYU_s - AI_s$

回路电流方程 $\quad BU = 0 \Rightarrow BZB^T I_l = BZI_s - BU_s$

广义割集分析法 待求 U_t. $\quad$ 广义节点分析法

$CYC^T U_t = CYU_s - CI_s \quad\quad Y_t$

状态方程 $\quad \dot{X} = AX + BV \quad\quad X = [u_{c1} \cdots i_{L1} \cdots]^T$.

列写单电容树支割集KCL方程、单电感连支回路KVL方程

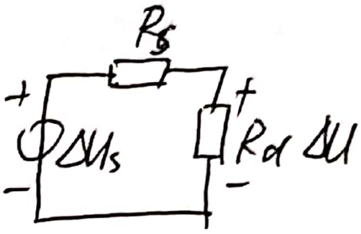
非线性电阻电路

流控、压控型非线性电阻 （自变量）+单调型

分段线性分析法 / 折线法

小信号分析

直流确定工作点，动态电导→动态电阻→小信号叠加



第七章 均匀传输线

一次参数 R_0 L_0 G_0 C_0

均匀线方程 $\begin{cases} -\dfrac{\partial u}{\partial x} = R_0 i + L_0 \dfrac{\partial i}{\partial t} \\ -\dfrac{\partial i}{\partial x} = G_0 u + C_0 \dfrac{\partial u}{\partial t} \end{cases}$

传播常数 $\gamma = \alpha + j\beta = \sqrt{(R_0 + j\omega L_0)(G_0 + j\omega C_0)}$

特性/波阻抗 $Z_c = \dfrac{Z_0}{\gamma} = \sqrt{\dfrac{R_0 + j\omega L_0}{G_0 + j\omega C_0}}$

$$\begin{bmatrix} \dot{U}(x) \\ \dot{I}(x) \end{bmatrix} = \begin{bmatrix} \cosh\gamma x & -Z_c \sinh\gamma x \\ -\frac{1}{Z_c}\sinh\gamma x & \cosh\gamma x \end{bmatrix} \begin{bmatrix} \dot{U}_1 \\ \dot{I}_1 \end{bmatrix}$$

$$\begin{bmatrix} \dot{U}(x) \\ \dot{I}(x) \end{bmatrix} = \begin{bmatrix} \cosh\gamma x' & Z_c \sinh\gamma x' \\ \frac{1}{Z_c}\sinh\gamma x' & \cosh\gamma x' \end{bmatrix} \begin{bmatrix} \dot{U}_2 \\ \dot{I}_2 \end{bmatrix}$$

输入特性阻抗 $Z_i = \dfrac{\dot{U}_1}{\dot{I}_1} = Z_c \dfrac{Z_L \cosh\gamma l + Z_c \sinh\gamma l}{Z_L \sinh\gamma l + Z_c \cosh\gamma l}$

$Z_{i0} = \dfrac{Z_c}{\tan\gamma l}$ $\quad Z_{is} = Z_c \tan\gamma l$

均匀线上行波

相速 $v_p = \frac{dx}{dt} = \frac{\omega}{\beta} = \lambda f$

瞬时值 $u^+(x,t) = \sqrt{2}U' e^{-\alpha t}\cos(\omega t - \beta x + \psi')$

$\lambda = v_p \cdot T = \frac{\omega}{\beta}\cdot\frac{2\pi}{\omega} = \frac{2\pi}{\beta}$

终端反射系数 $N_2 = \frac{Z_L - Z_C}{Z_L + Z_C}$　　$Z_L = Z_C$ 时 $N_2 = 0$，负载与传输线匹配

$Z_L \to \infty$　$N_2 = 1$ 全反射

始端反射系数　$N_1 = \frac{R_1 - Z_C}{R_1 + Z_C}$.　　R_1 始端电阻

自然功率

终端匹配时，$Z_L = Z_C$，线路任一点电压电流之比均为 Z_C。

终端负载吸收功率称自然功率 $P_2 = U_2 I_2 \cos\varphi_c = U_2 I_2 \cos\varphi_c = U_1 I_1 e^{-2\alpha l}\cos\varphi_c$

输入功率 $P_1 = U_1 I_1 \cos\varphi_c$　　$\eta = \frac{P_2}{P_1} = e^{-2\alpha l}$

无损线，驻波

$R_0 = G_0 = 0$ 线路无损，称无损耗线。

$$\gamma = \sqrt{j\omega L_0 \cdot j\omega C_0} = j\omega\sqrt{L_0 C_0} = j\beta = j\frac{2\pi}{\lambda} \Rightarrow \alpha = 0,\ \beta = \omega\sqrt{L_0 C_0}$$

无损线行波传输不衰减。 $Z_C = \sqrt{\frac{L_0}{C_0}}$

$\cosh\gamma x = \cos\beta x$　　$\sinh\gamma x = j\sin\beta x$

$$\begin{bmatrix}\dot U\\ \dot I\end{bmatrix} = \begin{bmatrix}\cos\beta x & -jZ_C\sin\beta x\\ -j\frac{1}{Z_C}\sin\beta x & \cos\beta x\end{bmatrix}\begin{bmatrix}\dot U_1\\ \dot I_1\end{bmatrix}$$

$$\begin{bmatrix}\dot U\\ \dot I\end{bmatrix} = \begin{bmatrix}\cos\beta x & jZ_C\sin\beta x\\ j\frac{1}{Z_C}\sin\beta x & \cos\beta x\end{bmatrix}\begin{bmatrix}\dot U_2\\ \dot I_2\end{bmatrix}$$

输入阻抗 $Z_i(x') = Z_C\frac{Z_L\cos\beta x' + jZ_C\sin\beta x'}{jZ_L\sin\beta x' + Z_C\cos\beta x'}$

$x' = \frac{\lambda}{4}$　　$Z_i = \frac{Z_C^2}{Z_L}$　阻抗变换

驻波.

形成条件：终端开路，短路，接纯电抗负载，

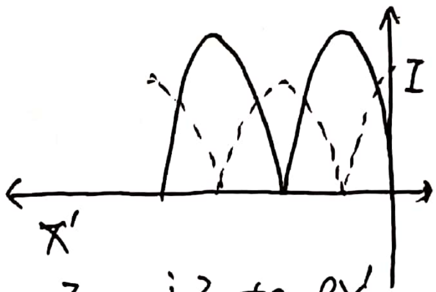
①行波沿线不衰减，$\alpha=0$，无损线 ②$|N_2|=1$.

终端开路.

$Z_i(x')=-jZ_c\cot\beta x'$

$l<\frac{\lambda}{4}$ 且终端开路，相当于电容.

短路



$Z_i=jZ_c\tan\beta x'$

$l<\frac{\lambda}{4}$，终端短路，相当于电感

纯电抗负载.

$N_2=\dfrac{jX-Z_c}{jX+Z_c}$ $|N_2|=1$

电感可用短路无损线等效，电容可用开路无损线等效.

集中参数等效.

$$\begin{bmatrix}\dot U_1\\ \dot I_1\end{bmatrix}=\begin{bmatrix}\cosh\gamma l & Z_c\sinh\gamma l\\ \sinh\gamma l/Z_c & \cosh\gamma l\end{bmatrix}\begin{bmatrix}\dot U_2\\ \dot I_2\end{bmatrix}$$ 转为 Z、Y 参数 进行，T. Π 等效

无损均匀线通解

电流 电压

↓ ↓

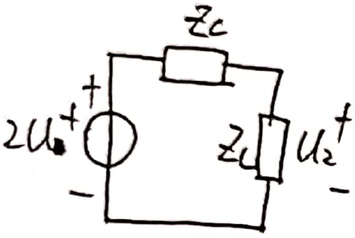
磁场 电场

终端反射

$$N_2 = \frac{Z_L - Z_C}{Z_L + Z_C} \qquad N_1 = \frac{Z_1 - Z_C}{Z_1 + Z_C}.$$

多次反射，电压叠加，电流正向叠加，反向削减.

彼得生法则 一般负载，确定终端电压，电流.



$$u_2 = 2u^+ - Z_C i_2$$

磁路

磁通 $\Phi = \oint_S B\,ds$　　$H = \frac{B}{\mu}$　μ—磁导率.

闭合面磁通 $\sum \Phi_k = 0$.

磁位差定律 $\sum U_{mj} = \sum N_k i_k = \sum F_{mk}$. —磁通势 $\sum i$.

$\int_a^b H \cdot dl$，磁位差

磁阻

$U_m = Hl$

$\Phi = BS$

$\Rightarrow R_m = \frac{U_m}{\Phi} = \frac{l}{\mu S} = \frac{1}{\Lambda}$ （单位：H^{-1}）

气隙截面修正式 $S = (a+\delta)(b+\delta)$

恒定磁通磁路计算

(1)分段 (2)计算各段截面尺寸及长度(气隙)

(3)计算磁感应强度 (4) $B \to H$ 气隙可以 $H=\frac{B_\delta}{\mu_0}$

(5)计算磁位差 $\sum U_m = \sum Hl + H_\delta \delta$ (6)磁通势计算

正弦电压作用下铁心磁路磁通 $\dot{\Phi}_m = -j\frac{\dot{U}}{4.44fN}$

$\dot{U} = j4.44fN\dot{\Phi}_m$

功率损耗 $P_{h0} = \sigma_h f B_m^n$ (系数) . $B_m < 1T$, n取1.6, $B_m > 1T$, n取2.

涡流损耗 $P_{e0} = \frac{\pi^2}{6} f^2 B_m^2 d^2 \gamma$ (电导率) 单位体积

B为0.75T, 1T, 1.5T, f=50HZ 时比损耗

记为 $P_{7.5/50}$ $P_{10/50}$ $P_{15/50}$

$P_{Fe0} = P_{10/50} B_m^n \left(\frac{f}{50HZ}\right)^{1.3}$ $B_m < 1T$, n取1.6, $B_m > 1T$, n取2

每千克

正弦磁通磁路计算

$Z_m = \frac{N\dot{I}}{\dot{\Phi}_m/\sqrt{2}} = R_m + jX_m$ 磁阻, 磁抗 → 耗能

无功量 I_q

已知 $\Phi_m \xrightarrow{\Phi_m = B_m S} B_m \xrightarrow{磁曲} H_m \xrightarrow{NI_m = H_m l} I_m$

若未饱和 $I_q = \frac{I_m}{\sqrt{2}}$, 饱和 $I_q = \frac{I_m}{\sqrt{2}\xi}$

有功量 I_p

得铁耗 $I_p = \frac{P_{Fe}}{U} = \frac{P_{Fe}}{4.44fN\Phi_m}$

励磁电流

$I = \sqrt{I_p^2 + I_q^2}$ $\theta = 90° - \varphi = \arctan\frac{I_p}{I_q}$

不计电阻和漏磁 $L = \frac{N^2}{R_m/\xi}$