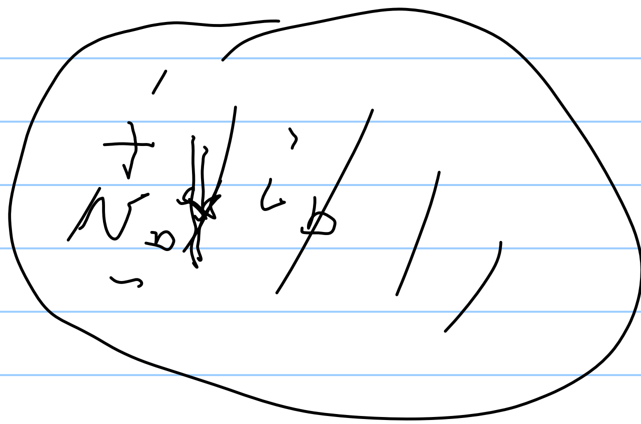
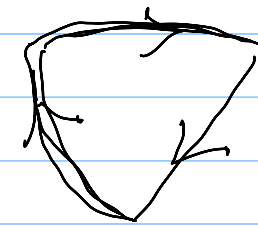


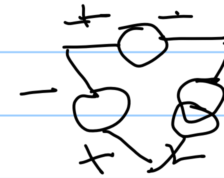
$$P_{in}(t) = v_b^T(t)\, i_b(t)$$

if finite $= 0$



$$v_b = C^T v_t \,, \quad i_b = J^T i_l$$

$$P_{in} = 0 = v_t^T C \cdot J^T i_l$$

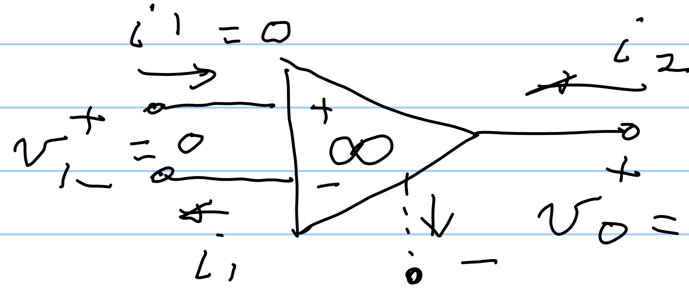


choose v_t freely by assuming there are voltage sources in the tree & the same for current sources in the links

$$\Longrightarrow \quad \underset{t \times l}{0} = C J^T$$

Tellegen's Theorem, p. 118 is $v_b^T \hat{i}_b = 0$
for the same graph
but different circuit elements

circuit without $Y_{b \times b}$: ones with ideal op-amps

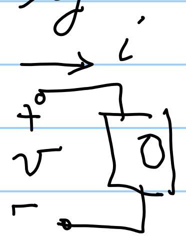


$v_0 = v_2$

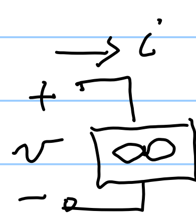
$$\begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}$$

no Y or Z matrix
if "linear" $\quad Av = Bi \Rightarrow i = Yv$

$$Y = B^{-1}A$$



nullator $\Rightarrow v = i = 0$



$\Rightarrow$ norator,
v = arbitrary } independent
i = arbitrary }

$$\begin{bmatrix} 0 \end{bmatrix}\begin{bmatrix} v \end{bmatrix} = \begin{bmatrix} 0 \end{bmatrix}\begin{bmatrix} i \end{bmatrix} \Leftarrow \text{norators}$$

$$\begin{bmatrix} 1 \\ 0 \end{bmatrix}\begin{bmatrix} v \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}\begin{bmatrix} i \end{bmatrix} \Leftarrow \text{nullators}$$

- - - - - - - general theory

$$v_b = \mathcal{C}^T v_t \qquad i_b = \mathcal{J}^T i_\ell \qquad v_b = e + v$$

$$\hat{i}_b = j + i$$

$$Av = Bi$$

or

$$Av_b = Ae + Av \Rightarrow Av = Av_b - Ae = Bi = Bi_b - Bj$$

$$Bi_b = Bj + Bi$$

or

$$A\mathcal{C}^T v_t - B\mathcal{J}^T i_\ell = Ae - Bj$$

$$\begin{bmatrix} A\mathcal{C}^T & \vdots & -B\mathcal{J}^T \end{bmatrix}\begin{bmatrix} v_t \\ i_\ell \end{bmatrix} = \begin{bmatrix} A & -B \end{bmatrix}\begin{bmatrix} e \\ j \end{bmatrix}$$

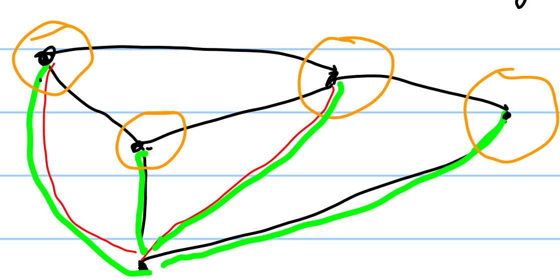
as $b = t + l$ $\quad [v_t , i_l]^T$ is a b-vector

$\Rightarrow$ b unknowns; if A & B square have
b equations

if $b\{\underbrace{[AC^T}_{t} \vdots \underbrace{-BJ^T]}_{l}$ is nonsingular we can solve the circuit $\Rightarrow$ know v_t , i_l ; $v_b = C^T v_t$, $i_b = J^T i_l$

$b = t + l$

For "nodal" analysis take a tree where all of v_t are voltages of the nodes with respect to ground



fictitious branches are open circuits. Use "nodal analysis"