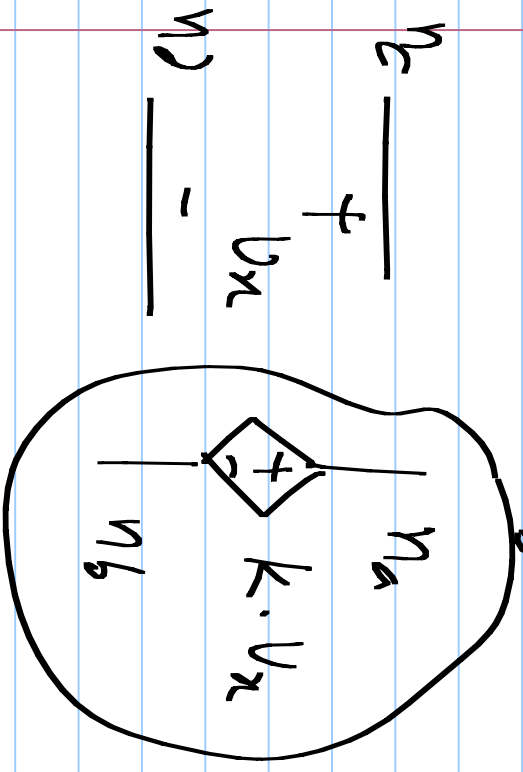


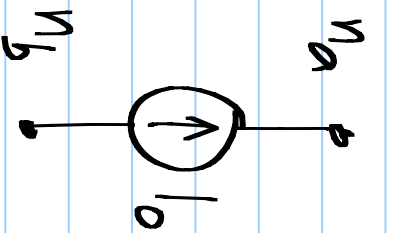
CCVS



$$i_x = \frac{V_{nc} - V_{nd}}{R}$$

$$V_{na} - V_{nb} - R_x \cdot \frac{V_{nc} - V_{nd}}{R} = 0$$

Modified nodal analysis (MNA)



KCL: n_a

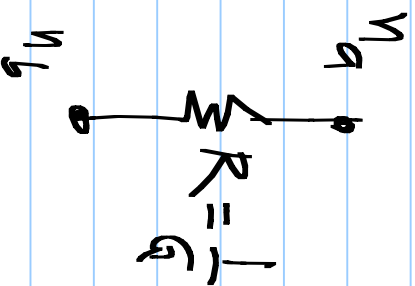
KCL: n_b

$$\begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \end{bmatrix}$$

$$\begin{bmatrix} +I_0 \\ -I_0 \end{bmatrix}$$

$$\underline{V_a} \quad \underline{V_b}$$

$$G \cdot \underline{V} = \underline{I}$$

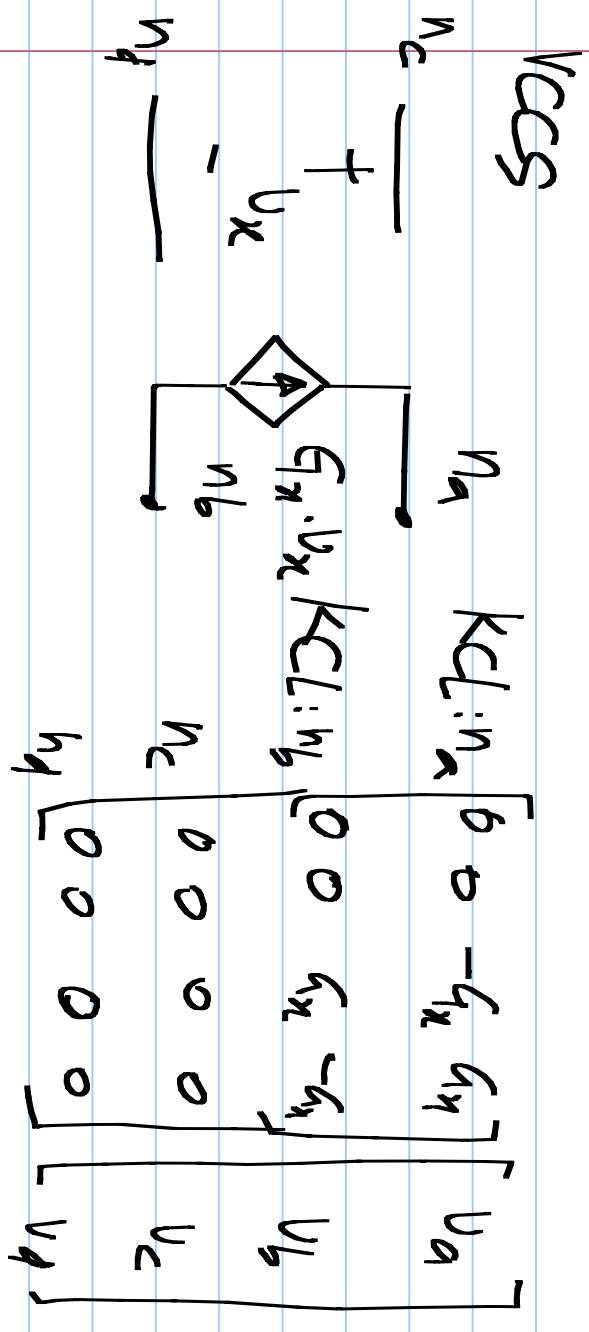
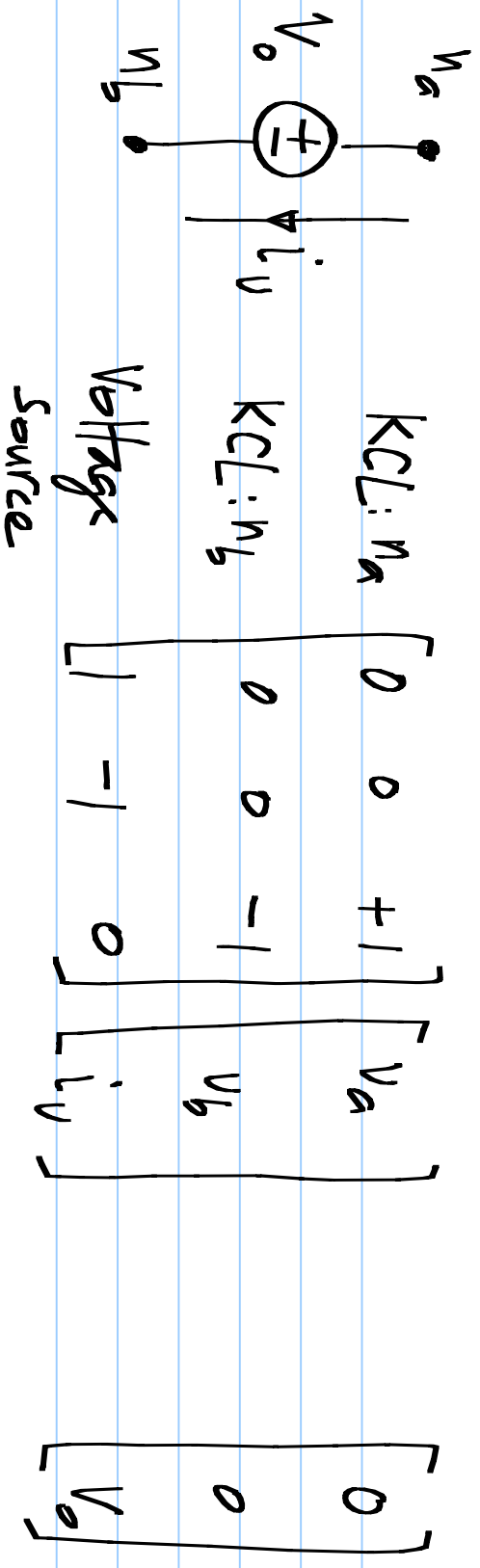


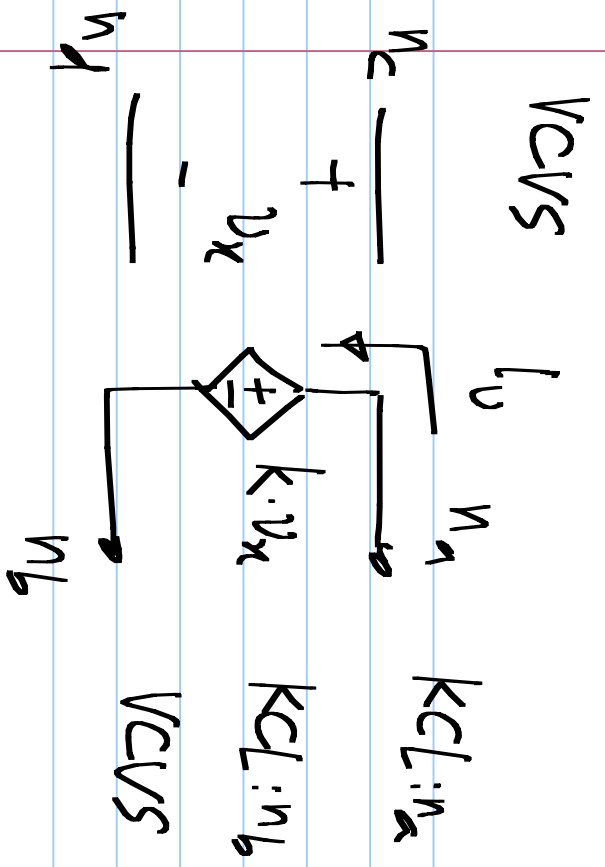
KCL: n_a

KCL: n_b

$$\begin{bmatrix} g & -g \\ -g & g \end{bmatrix} \begin{bmatrix} V_a \\ V_b \end{bmatrix}$$

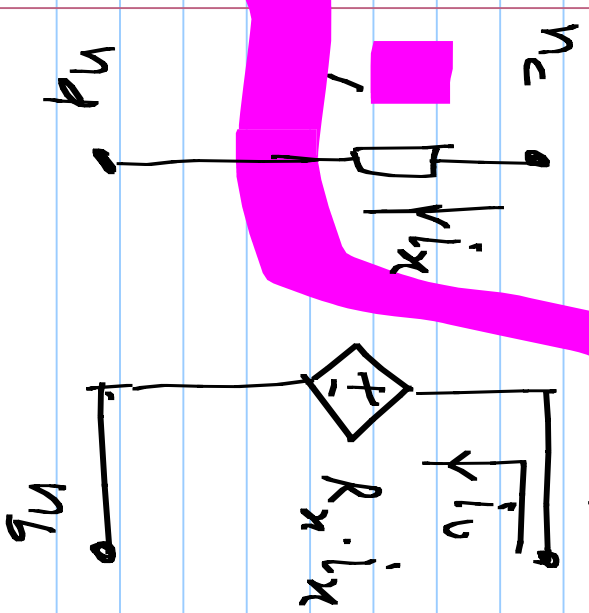
$$\begin{bmatrix} \\ \end{bmatrix}$$





$$\begin{bmatrix}
 0 & 0 & 0 & 0 & +1 \\
 0 & 0 & 0 & 0 & -1 \\
 1 & -1 & -k & +k & 0
 \end{bmatrix}
 \begin{bmatrix}
 v_a \\
 v_b \\
 v_c \\
 v_d \\
 i_u
 \end{bmatrix}
 =
 \begin{bmatrix}
 0 \\
 0 \\
 0
 \end{bmatrix}$$

CCVS



KCL: n_a

KCL: n_b

KCL: n'_a

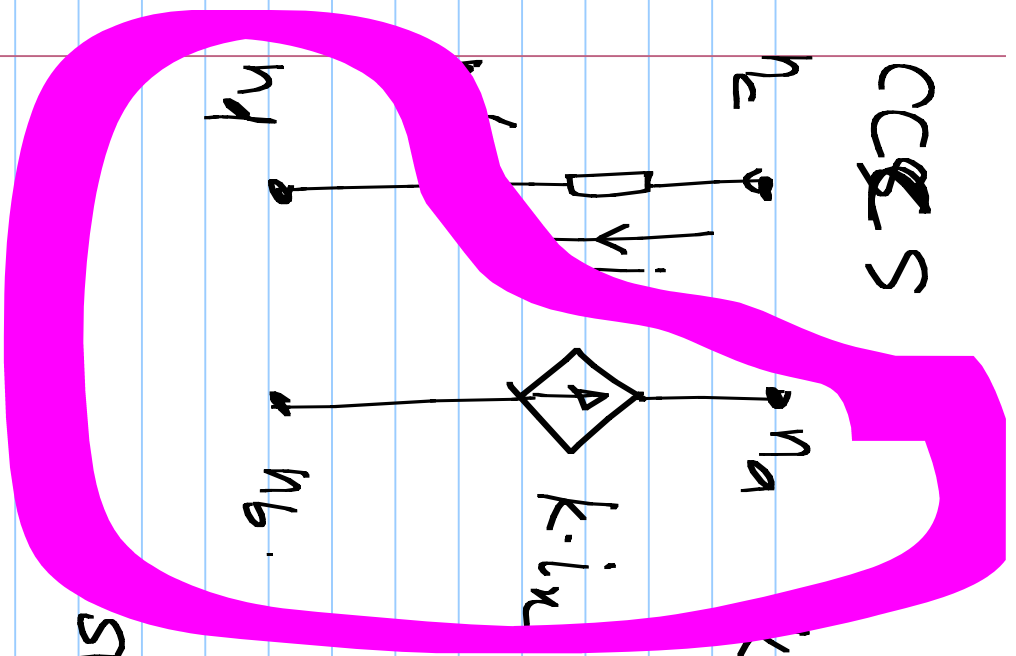
KCL: n_b

CCVS

$n'_a - n'_b$

$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 1 \\ 0 \\ -1 \end{bmatrix}$	$\begin{bmatrix} v_a \\ v_b \\ v_{i_x} \\ v_{i_x} \end{bmatrix}$
$\begin{bmatrix} 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$	$\begin{bmatrix} -1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$
$\begin{bmatrix} 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$	$\begin{bmatrix} -R_x \\ 0 \\ 0 \\ 0 \end{bmatrix}$
$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$	$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$

CCCS



Node: n_1

$$\begin{bmatrix} 0 & 0 & 0 & 0 & -k \end{bmatrix}$$

$$\begin{bmatrix} v_{n1} \end{bmatrix}$$

n_2

$$\begin{bmatrix} 0 & 0 & 0 & 0 & +k \end{bmatrix}$$

$$\begin{bmatrix} v_{n2} \end{bmatrix}$$

n_1'

$$\begin{bmatrix} 0 & 0 & 0 & 0 & +1 \end{bmatrix}$$

$$\begin{bmatrix} v_{n1'} \end{bmatrix}$$

n_2'

$$\begin{bmatrix} 0 & 0 & 0 & 0 & -1 \end{bmatrix}$$

$$\begin{bmatrix} v_{n2'} \end{bmatrix}$$

Short

$$\begin{bmatrix} 0 & 0 & 1 & -1 & 0 \end{bmatrix}$$

$$\begin{bmatrix} i_x \end{bmatrix}$$