spice# and MNA

⊞— Numerical Inverse Laplace Transform

⊞— MNA WITH STAMPS

⊞— Spice

⊟— MNA Method

MNA Method

Given a linear circuit with n Nodes and m sources, solve the system

$$\mathbf{A}\cdot\mathbf{X}=\mathbf{B}$$

$$\mathbf{A}_{n+m\,n+m}=\begin{bmatrix} G_{n\cdot n} & C_{n\cdot m} \\ C_{m\cdot n} & D_{m\cdot m}\end{bmatrix}$$

G have the passive elements: the diagonal elements G(n,n) are the sum of the conductance of each element connected to the node n, and the others G(i,j) are the negative conductance of the element connected to the nodes i,j.

C have the voltage sources, where if a voltage source is connected to nodes m, n, then C(m,n) = ±1, or zero otherwise.

D is the same of B, but with dependent sorces.

$$\mathbf{X}_{n+m}=\begin{bmatrix} V\_\#N \\ I\_V\#M\end{bmatrix}$$

X have the node voltages and currents trhough voltage sources.

$$\mathbf{B}_{n+m}=\begin{bmatrix} \Sigma\left(I_X\right) \\ V_m\end{bmatrix}$$

For b, b(n) = sum of the currents through the passive elements into the node n, and b(m) = value of the independent voltage sources m.

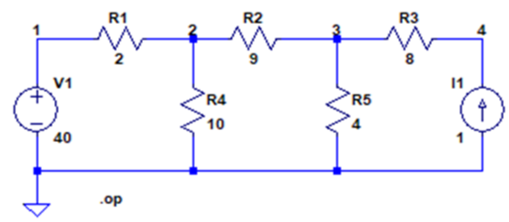
Example MNA Method

```
Vb 1 0
R1 1 2
R2 2 3
R3 3 4
R4 2 0
R5 3 0
Is 0 4
```

$\chi s := 1$

```
Vb 1 0 40
R1 1 2 2
R2 2 3 9
R3 3 4 8
R4 2 0 10
R5 3 0 4
Is 0 4 1
```

$\chi := 1$



$$G1 := \frac{1}{R1} \qquad G2 := \frac{1}{R2} \qquad G3 := \frac{1}{R3} \qquad G4 := \frac{1}{R4} \qquad G5 := \frac{1}{R5}$$

$$G := \begin{bmatrix} G1 & -G1 & 0 & 0 \\ -G1 & G1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0\end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & G2 & -G2 & 0 \\ 0 & -G2 & G2 & 0 \\ 0 & 0 & 0 & 0\end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & G3 & -G3 \\ 0 & 0 & -G3 & G3\end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & G4 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0\end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & G5 & 0 \\ 0 & 0 & 0 & 0\end{bmatrix}$$

$$D := \begin{bmatrix} 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0\end{bmatrix} \quad V_b$$

$$\mathbf{B} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ -Is \\ Vb\end{bmatrix}$$

at node 4

First V source

$$\begin{bmatrix} A & B & X & V & I \end{bmatrix} := MNA\left(\text{"}\chi s\text{"}\right)$$

$$X = \begin{bmatrix} V\_1 \\ V\_2 \\ V\_3 \\ V\_4 \\ I\_Vb\end{bmatrix}$$

$$A = \begin{bmatrix} \frac{1}{R1} & -\frac{1}{R1} & 0 & 0 & 1 \\ -\frac{1}{R1} & \frac{(R2+R4)\cdot R1+R2\cdot R4}{R1\cdot R2\cdot R4} & -\frac{1}{R2} & 0 & 0 \\ 0 & -\frac{1}{R2} & \frac{(R3+R5)\cdot R2+R3\cdot R5}{R2\cdot R3\cdot R5} & -\frac{1}{R3} & 0 \\ 0 & 0 & -\frac{1}{R3} & \frac{1}{R3} & 0 \\ 1 & 0 & 0 & 0 & 0\end{bmatrix} \qquad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ Is \\ Vb\end{bmatrix}$$

$$\text{Clear}\left(D, G, G1, G2, G3, G4, G5\right) = 1$$

Numerically: $\begin{bmatrix} A & B & X & V & I \end{bmatrix} := MNA(\text{"χ"})$

$$V = \begin{bmatrix} 40 \\ 30 \\ 12 \\ 20 \end{bmatrix} \qquad A^{-1} \cdot B = \begin{bmatrix} 40 \\ 30 \\ 12 \\ 20 \\ -5 \end{bmatrix} \qquad Spice\left(\text{"χ"}, \text{".OP"}, \begin{bmatrix} \text{"V(1)"} \\ \text{"V(2)"} \\ \text{"V(3)"} \\ \text{"V(4)"} \\ \text{"I(Vb)"} \end{bmatrix} \right) = \begin{bmatrix} 0 & 40 \\ 0 & 30 \\ 0 & 12 \\ 0 & 20 \\ 0 & -5 \end{bmatrix}$$

$$I = \begin{bmatrix} -5 \end{bmatrix}$$

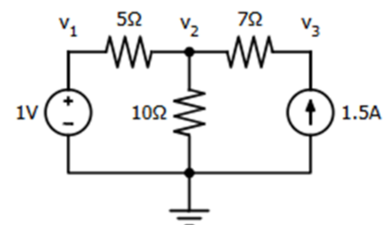
Example spice# MNA Method spice sharp also uses MNA. From:

https://spicesharp.github.io/SpiceSharp/articles/tutorials/writing_behaviors/modified_nodal_analysis.html

$$\begin{pmatrix} \frac{1}{5\Omega} & -\frac{1}{5\Omega} & 0 & 1 \\ -\frac{1}{5\Omega} & \frac{1}{5\Omega}+\frac{1}{10\Omega}+\frac{1}{7\Omega} & -\frac{1}{7\Omega} & 0 \\ 0 & -\frac{1}{7\Omega} & \frac{1}{7\Omega} & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \\ v_3 \\ i_V \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 1.5A \\ 1V \end{pmatrix}$$

```
V1 1 0 1
R1 1 2 5
R2 2 3 7
R3 2 0 10
I1 0 3 1.5
```

$χ := 1$



$\begin{bmatrix} A & B & X & V & I \end{bmatrix} := MNA(\text{"χ"})$

$$A = \begin{bmatrix} 0.2 & -0.2 & 0 & 1 \\ -0.2 & 0.44 & -0.14 & 0 \\ 0 & -0.14 & 0.14 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \qquad X = \begin{bmatrix} V\_1 \\ V\_2 \\ V\_3 \\ I\_V1 \end{bmatrix} \qquad B = \begin{bmatrix} 0 \\ 0 \\ 1.5 \\ 1 \end{bmatrix}$$

$$V = \begin{bmatrix} 1 \\ 5.67 \\ 16.17 \end{bmatrix} \qquad Spice\left(\text{"χ"}, \text{".OP"}, \begin{bmatrix} \text{"V(1)"} \\ \text{"V(2)"} \\ \text{"V(3)"} \\ \text{"I(V1)"} \end{bmatrix} \right) = \begin{bmatrix} 0 & 1 \\ 0 & 5.67 \\ 0 & 16.17 \\ 0 & 0.93 \end{bmatrix}$$

$$I = \begin{bmatrix} 0.93 \end{bmatrix}$$

Ohm's Law

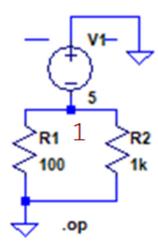
Ohm's Law

```
V1 1 0
R1 1 0
R2 1 0
```

$χs := 1$

```
V1 1 0 5
R1 1 0 100
R2 1 0 1k
```

$χ := 1$



$\begin{bmatrix} A & B & X & V & I \end{bmatrix} := MNA(\text{"χs"})$ $\quad V = \begin{bmatrix} V1 \end{bmatrix}$ $\quad I = \begin{bmatrix} -\dfrac{(R1+R2) \cdot V1}{R1 \cdot R2} \end{bmatrix}$

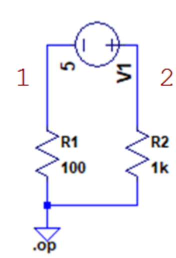
$\begin{bmatrix} A & B & X & V & I \end{bmatrix} := MNA(\text{"χ"})$ $\quad V = \begin{bmatrix} 5 \end{bmatrix}$ $\quad I = \begin{bmatrix} -0.06 \end{bmatrix}$ $\quad Spice(\text{"χ"}, \text{".OP"}, \text{"I(V1)"}) = \begin{bmatrix} 0 & -0.06 \end{bmatrix}$

```
V1 1 2
R1 1 0
R2 2 0
```

$χs := 1$

```
V1 1 2 5
R1 1 0 100
R2 2 0 1k
```

$χ := 1$



$\begin{bmatrix} A & B & X & V & I \end{bmatrix} := MNA(\text{"χs"})$

$$V = \begin{bmatrix} \dfrac{R1 \cdot V1}{R1+R2} \\ -\dfrac{R2 \cdot V1}{R1+R2} \end{bmatrix} \qquad I = \begin{bmatrix} -\dfrac{V1}{R1+R2} \end{bmatrix}$$

$\begin{bmatrix} A & B & X & V & I \end{bmatrix} := MNA(\text{"χ"})$

$$V = \begin{bmatrix} 0.45 \\ -4.55 \end{bmatrix} \qquad Spice\left(\text{"χ"}, \text{".OP"}, \begin{bmatrix} \text{"V(1)"} \\ \text{"V(2)"} \\ \text{"I(V1)"} \end{bmatrix} \right) = \begin{bmatrix} 0 & 0.45 \\ 0 & -4.55 \\ 0 & 0 \end{bmatrix}$$

$$I = \begin{bmatrix} 0 \end{bmatrix}$$

⊟ Resistive networks

Resistive networks

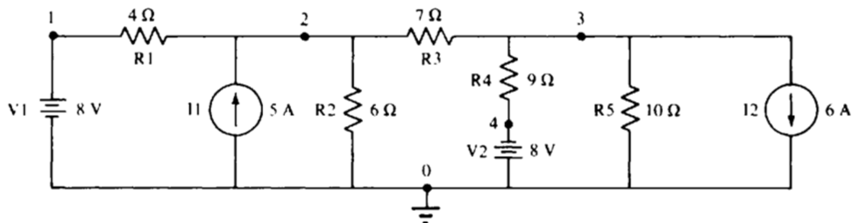


Fig. 7-1

```
V1 1 0 8
R1 1 2 4
I1 0 2 5
R2 2 0 6
R3 2 3 7
R4 3 4 9
V2 0 4 8
R5 3 0 10
I2 3 0 6
```

$\chi := 1$

$[A\ B\ X\ V\ I] := MNA(\text{"χ"})$

$V = \begin{bmatrix} 8 \\ 8.41 \\ -16.07 \\ -8 \end{bmatrix}$

$I = \begin{bmatrix} 0.1 \\ 0.9 \end{bmatrix}$

$Spice\left(\text{"χ"}, \text{".OP"}, \begin{bmatrix} \text{"V(1)"} \\ \text{"V(2)"} \\ \text{"V(3)"} \\ \text{"V(4)"} \\ \text{"I(V1)"} \\ \text{"I(V2)"} \end{bmatrix}\right) = \begin{bmatrix} 0 & 8 \\ 0 & 8.41 \\ 0 & -16.07 \\ 0 & -8 \\ 0 & 0.1 \\ 0 & 0.9 \end{bmatrix}$

⊟ RL Circuit

RL Circuit

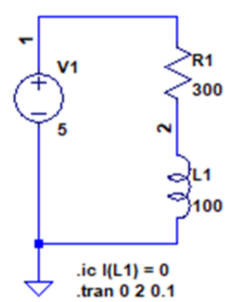
Symbolic and
Numerical analysis

```
V1 1 0
R1 1 2
L1 2 0
```

$\chi s := 1$

```
V1 1 0 5
R1 1 2 300
L1 2 0 100
```

$\chi := 1$



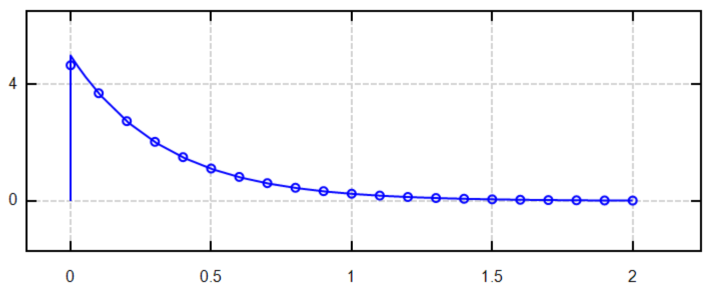
$[A\ B\ X\ V\ I] := MNA(\text{"χs"})$

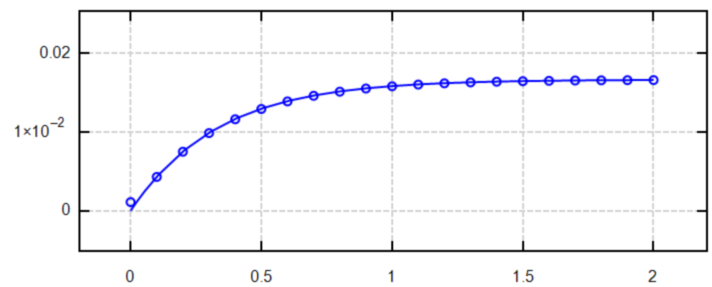
$I = \left[-\frac{V1}{R1 + s \cdot L1}\right]$

$V = \begin{bmatrix} V1 \\ \frac{V1 \cdot s \cdot L1}{R1 + s \cdot L1} \end{bmatrix}$

$[A\ B\ X\ V\ I] := MNA(\text{"χ"})$

$O := \begin{bmatrix} \text{".IC V(2) = 0"} \\ \text{".TRAN 0 2 0.1"} \end{bmatrix}$ ".IC I(L1) = 0" ?





$\left\{ \begin{matrix} Spice(\text{"χ"}, O, \text{"V(2)"}) \\ \mathcal{IL}\left(\frac{V_2}{s}, [0, 0.1..2]\right) \end{matrix} \right.$

$\left\{ \begin{matrix} Spice(\text{"χ"}, O, \text{"I(L1)"}) \\ \mathcal{IL}\left(-\frac{I_1}{s}, [0, 0.1..2]\right) \end{matrix} \right.$

⊟ RC Circuit

X 0.9m is wrong, it correct expression ?
is 900u or 900µ

RL Circuit

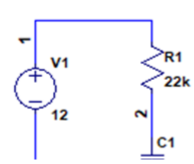
Symbolic and
Numerical analysis

```
V1 1 0
R1 1 2
C1 2 0
```

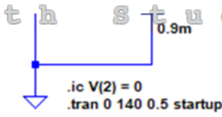
$\chi s := 1$

```
V1 1 0 12
R1 1 2 22k
C1 2 0 0.9m
```

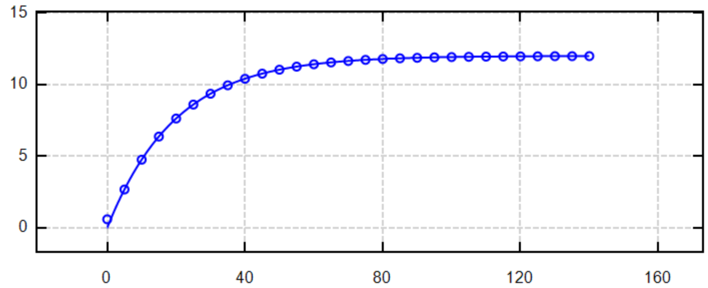
$\chi := 1$



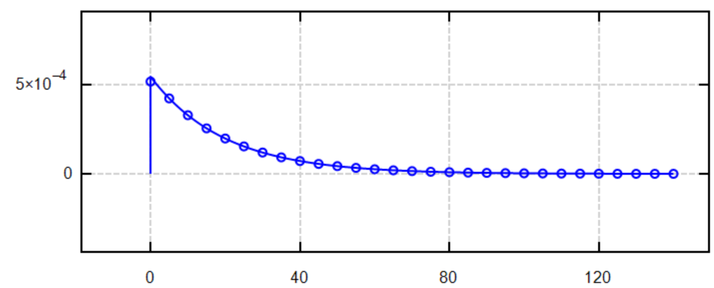
$[A\ B\ X\ V\ I] := MNA(\text{"χs"})$ $\quad I = \left[-\dfrac{s \cdot C1 \cdot V1}{1 + s \cdot C1 \cdot R1}\right]$ $\quad V = \left[\begin{matrix} V1 \\ \dfrac{V1}{1 + s \cdot C1 \cdot R1}\end{matrix}\right]$



$[A\ B\ X\ V\ I] := MNA(\text{"χ"})$ $\quad O := \left[\begin{matrix} \text{".IC V(2) = 0"} \\ \text{".TRAN 0 140 0.5"}\end{matrix}\right]$



$\begin{cases} \text{Spice}(\text{"χ"}, O, \text{"V(2)"}) \\ \mathcal{IL}\left(\dfrac{V_2}{s}, [0, 5..140]\right)\end{cases}$



$\begin{cases} \text{Spice}(\text{"χ"}, O, \text{"I(C1)"}) \\ \mathcal{IL}\left(-\dfrac{I_1}{s}, [0, 5..140]\right)\end{cases}$

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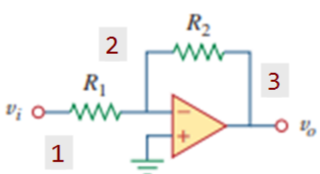
opamps

Summary of basic op amp circuits

Shorthand: $V(n) := MNA(\text{"χ"})_{4\ n}$

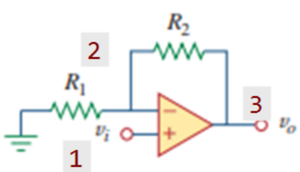


Inverter amplifier

```
V.i 1 0
R.1 1 2
R.2 2 3
O 0 3 2
```

$\chi := 1$

$V_o := V(3) = -\dfrac{V_i \cdot R_2}{R_1}$

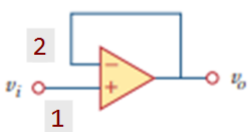


Non-inverter amplifier

```
V.i 1 0
R.1 0 2
R.2 2 3
O 1 3 2
```

$\chi := 1$

$V_o := V(3) = \dfrac{(R_1 + R_2) \cdot V_i}{R_1}$

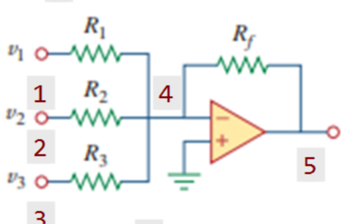


Voltage Follower

```
V 1 0 V.i
O 1 2 2
```

$\chi := 1$

$V_o := V(2) = V_i$



Summer

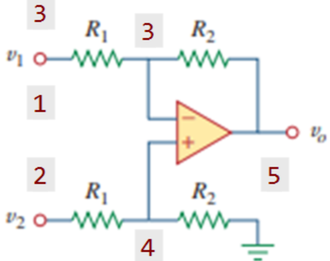
```
V 1 0 V.1
V 2 0 V.2
V 3 0 V.3
R 1 4 R.1
R 2 4 R.2
R 3 4 R.3
R 4 5 R.f
O 0 5 4
```

$\chi := 1$

$V_o := V(5) = -\dfrac{R_f \cdot \left(\left(V_1 \cdot R_2 + V_2 \cdot R_1\right) \cdot R_3 + V_3 \cdot R_2 \cdot R_1\right)}{R_3 \cdot R_2 \cdot R_1}$

or

$V_o = -\left(\dfrac{R_f}{V_1} + \dfrac{R_f}{V_2} + \dfrac{R_f}{V_3}\right)$



Difference Amplifier

```
V 1 0 V.1
V 2 0 V.2
R 1 3 R.1
R 2 4 R.2
R 3 4 R.3
R 4 5 R.f
O 0 5 4
```

$\chi := 1$

$V_o := V(5) = -\dfrac{R_f \cdot \left(V_1 \cdot R_2 + \left(R_1 + R_3\right) \cdot V_2\right)}{\left(R_1 + R_3\right) \cdot R_2}$

or

$V_o = \dfrac{R_2}{R_1} \cdot \left(V_2 - V_1\right)$

Opamp for spice#

$E(x) := 10^{x}$

```
.subckt opamp 1 2 3
G1 0 2 1 3 100k
R3 2 0 1
C3 2 0 0.001591549430919
.ends opamp
```

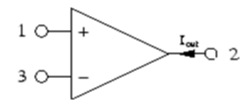
$opamp := 1$

$\_Aol := 100 \cdot E(3)$ $\_GBW := 10 \cdot E(6)$ $\dfrac{\_Aol}{2 \cdot \pi \cdot \_GBW} = 0.001591549430919$

$opamp := \mathrm{description}(opamp)$

nonivin

invin



Example with spice#: Inverter amplifier

```
V.i 1 0 5
R.1 1 2 10
R.2 2 3 20
X1 0 3 2 opamp
```

$\chi := 1$

$V_3 = -\dfrac{V_i \cdot R_2}{R_1}$

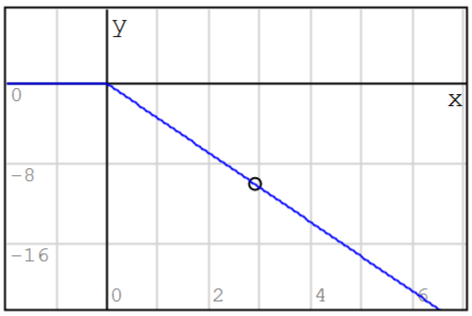
$Spice\left("\chi", \begin{bmatrix} ".OP" \\ opamp \end{bmatrix}, \begin{bmatrix} "V(1)" \\ "V(2)" \\ "V(3)" \end{bmatrix}\right) = \begin{bmatrix} 0 & 5 \\ 0 & 0 \\ 0 & -10 \end{bmatrix}$

Sweep analysis

```
V 1 0 5V
V 2 0 3V
V 3 0 4V
R 1 4 2Ω
R 2 4 8Ω
R 3 4 7Ω
R 4 5 R.f
O 0 5 4
```

$\chi := 1$

$V_o(R_f) := V(5)$ $V_o := -10\ V$ $R_f := \mathrm{roots}\left(V_o(R_f\ \Omega) = V_o, R_f\right)\ \Omega = 2.9\ \Omega$



$\begin{cases} V_o(x\ \Omega) \cdot (x > 0) \\ \mathrm{augment}(R_f, V_o, "o") \end{cases}$

Sanity check

$V := \begin{bmatrix} 5 \\ 3 \\ 4 \end{bmatrix} V$ $R := \begin{bmatrix} 2 \\ 8 \\ 7 \end{bmatrix} \Omega$

$R_f := -\dfrac{V_o}{\dfrac{V_1}{R_1} + \dfrac{V_2}{R_2} + \dfrac{V_3}{R_3}} = 2.9\ \Omega$

TODO: Sweep analysis with spice#

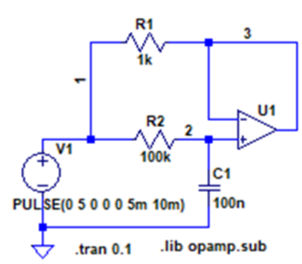
⊟— opamp: Capacitance multiplier

Capacitance multiplier

```
Vb 1 0
R1 1 3 1k
R2 1 2 100k
C1 2 0 100n
O1 2 3 3
```

$\chi := 1$

$[A\ B\ X\ V\ I] := MNA("\chi")$



Laplace transform of a pulse:

$To := 5 \cdot 10^{-3}$ $Vb := \dfrac{5}{s \cdot \left(1 + \mathrm{e}^{-To \cdot s}\right)}$

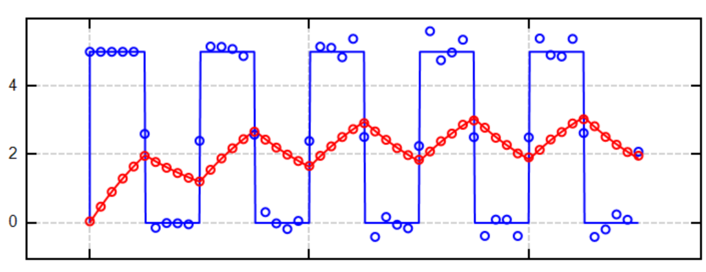
```
Vb 1 0 PULSE(0 5 0 0 0 5m 10m)
R1 1 3 1k
R2 1 2 100k
C1 2 0 100n
X1 2 3 3 opamp
```

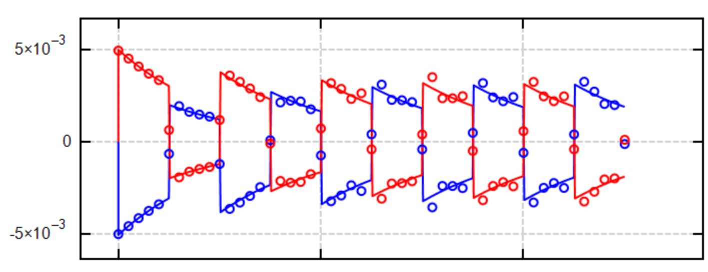
$\chi := 1$

$O := \begin{bmatrix} opamp \\ ".TRAN\ 0\ 0.05\ 0.1m" \end{bmatrix}$

$T := [0, 0.001 .. 0.05]$

$\mathrm{rows}(T) = 51$





Spice("χ", 0, "V(1)")
Spice("χ", 0, "V(2)")
$\mathcal{IL}(V_1, T)$
$\mathcal{IL}(V_2, T)$

Spice("χ", 0, "I(Vb)")
Spice("χ", 0, "I(R1)")
$\mathcal{IL}(I_1, T)$
$\mathcal{IL}(I_2, T)$

Clear(Vb) = 1

opamp: DC OP Point

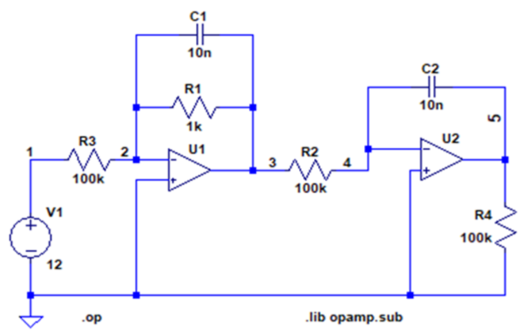
DC OP Point

```
Vb 1 0
R1 2 3
R2 3 4
R3 1 2
R4 5 0
C1 2 3
C2 4 5
O1 0 2 3
O2 0 4 5
```

$\chi s := 1$

```
Vb 1 0 12
R1 2 3 1k
R2 3 4 100k
R3 1 2 100k
R4 5 0 100k
C1 2 3 10n
C2 4 5 10n
X1 0 2 3 opamp
X2 0 4 5 opamp
```

$\chi := 1$



$$[\,R1\;\;R2\;\;R3\;\;R4\,] := \left[\frac{1}{G1}\;\;\frac{1}{G2}\;\;\frac{1}{G3}\;\;\frac{1}{G4}\right]$$

$$[\,A\;\;B\;\;X\,] := MNA(\text{"}\chi s\text{"}, \text{"ABX"}, \Sigma)$$

$$A \cdot X = B$$

$$A = \begin{bmatrix} G3 & -G3 & 0 & 0 & 0 & 1 & 0 & 0 \\ -G3 & G3+G1+s\cdot C1 & -(G1+s\cdot C1) & 0 & 0 & 0 & 1 & 0 \\ 0 & -(G1+s\cdot C1) & G2+G1+s\cdot C1 & -G2 & 0 & 0 & 0 & 0 \\ 0 & 0 & -G2 & G2+s\cdot C2 & -s\cdot C2 & 0 & 0 & 1 \\ 0 & 0 & 0 & -s\cdot C2 & G4+s\cdot C2 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \end{bmatrix} \quad X = \begin{bmatrix} V\_1 \\ V\_2 \\ V\_3 \\ V\_4 \\ V\_5 \\ I\_Vb \\ I\_O1 \\ I\_O2 \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ Vb \\ 0 \\ 0 \end{bmatrix}$$

DC Operating point (C as open circuits): ?

$$Spice\left(\text{"}\chi\text{"}, \begin{bmatrix} \text{".OP"} \\ opamp \end{bmatrix}, \begin{bmatrix} \text{"V(1)"} \\ \text{"V(2)"} \\ \text{"V(3)"} \\ \text{"I(R4)"} \\ \text{"I(Vb)"} \end{bmatrix}\right) = \begin{bmatrix} 0 & 12 \\ 0 & 1.21\cdot 10^{-9} \\ 0 & 1.2\cdot 10^{-9} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

From ltspice:

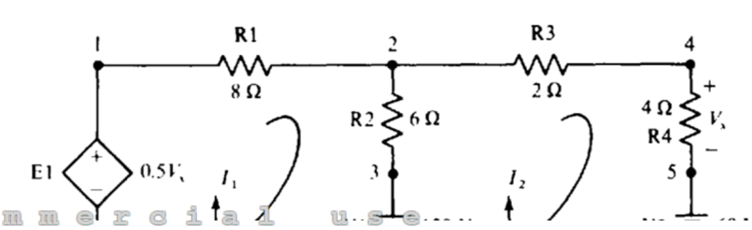
```
       --- Operating Point ---

V(1):       12       voltage
V(3):       -0.119999      voltage
V(2):       1.20119e-006      voltage
V(n001):      11999.8      voltage
V(4):       -0.119999      voltage
I(C2):       1.19999e-016      device_current
I(C1):       -1.2e-021      device_current
I(R4):       -0.119998      device_current
I(R3):       -0.00012      device_current
I(R2):       1.19999e-016      device_current
I(R1):       -0.00012      device_current
I(V1):       -0.00012      device_current
Ix(u1:3):      0.00012      subckt_current
Ix(u2:3):      -0.119998      subckt_current
```

Clear(s, Vb, R1, R2, R3, R4, C1, C2) = 1

E Source

Example

```
E1 1 0 4 5 0.5
R1 1 2 8
R2 2 3 6
V1 3 0 120
R3 2 4 2
R4 4 5 4
V2 5 0 60
```



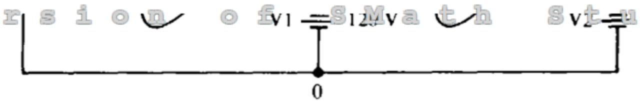


Fig. 7-4

$\chi := 1$

$O :=$ ".DC V1 120 120 0.1"

$O :=$ ".op"

$[A\ B\ X\ V\ I] := MNA(\text{"}\chi\text{"})$

? Different node convention?

$$X = \begin{bmatrix} V\_1 \\ V\_2 \\ V\_3 \\ V\_4 \\ V\_5 \\ I\_E1 \\ I\_V1 \\ I\_V2 \end{bmatrix} \quad V = \begin{bmatrix} 38.18 \\ 38.18 \\ 120 \\ 10.91 \\ 60 \end{bmatrix} \quad I = \begin{bmatrix} 25.91 \\ -13.64 \\ -12.27 \end{bmatrix}$$

$Spice(\text{"}\chi\text{"}, O, \text{"V(1)"}) = [0\ 2]$

$Spice(\text{"}\chi\text{"}, O, \text{"V(2)"}) = [0\ 66]$

$Spice(\text{"}\chi\text{"}, O, \text{"V(4)"}) = [0\ 64]$

$Spice(\text{"}\chi\text{"}, O, \text{"I(R1)"}) = [0\ -8]$

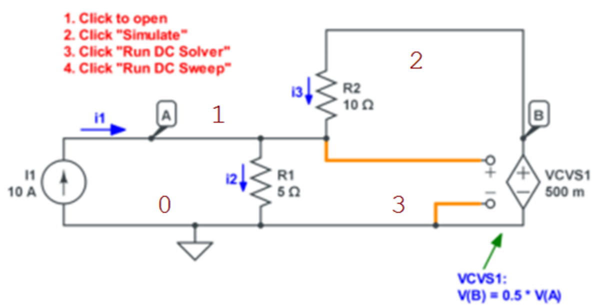
$Spice(\text{"}\chi\text{"}, O, \text{"I(R4)"}) = [0\ 1]$

SMath determinant can't handle units: $MInverse(A\#\#) := maple(inverse(A\#\#))$

⊟— Controled Sources with Feedback

Controled Sources with Feedback

ht




```
R 0 1 5Ω
R 1 2 10Ω
I 0 1 10A
E 1 2 0 0 0.5
```

$\chi := 1$

```
R1 0 1 5
R2 1 2 10
I1 0 1 10
E2 2 1 0 0 0.5
```

$\chi' := 1$

$[A\ B\ X\ V\ I] := MNA(\text{"}\chi\text{"})$

?

$$V = \begin{bmatrix} 40 \\ 20 \end{bmatrix} V \qquad Spice\left(\text{"}\chi'\text{"}, \text{".OP"}, \begin{bmatrix} \text{"V(1)"} \\ \text{"V(2)"} \\ \text{"I(R1)"} \end{bmatrix}\right) = \begin{bmatrix} 0 & 50 \\ 0 & 50 \\ 0 & -10 \end{bmatrix}$$

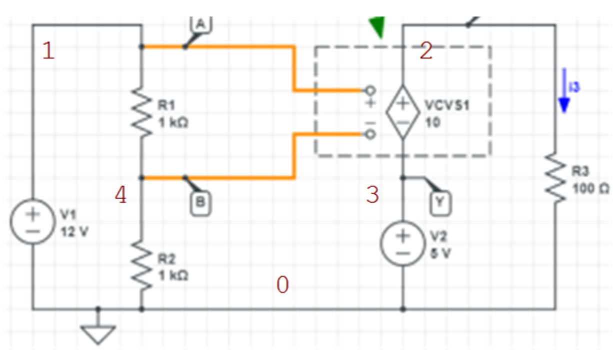
$I = [-2]\ A$

⊟— E: VCVS

Voltage Controled Voltage Source (VCVS)

ht

ht




```
V1 1 0 12V
V2 3 0 5V
R  1 4 1kΩ
R  0 4 1kΩ
R  0 2 100Ω
E  1 2 3 4 10
```

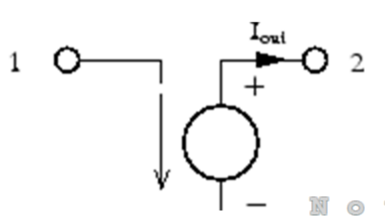
$\chi := 1$

```
V1 1 0 12
V2 3 0 5
R1  1 4 1k
R2  0 4 1k
R3  0 2 100
E1  1 2 3 4 10
```

$\chi' := 1$

$[A\ B\ X\ V\ I] := MNA(\text{"}\chi\text{"})$

?



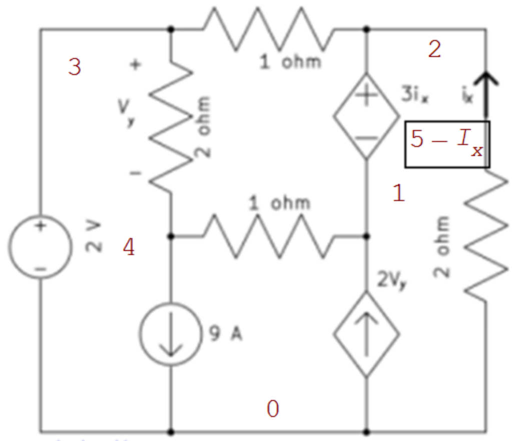
$$V = \begin{bmatrix} 12 \\ 65 \\ 5 \\ 6 \end{bmatrix} V \qquad Spice\left(\text{"}\chi'\text{"}, \text{".OP"}, \begin{bmatrix} \text{"V(1)"} \\ \text{"V(2)"} \\ \text{"V(3)"} \\ \text{"V(4)"} \\ \text{"I(R1)"} \end{bmatrix}\right) = \begin{bmatrix} 0 & 12 \\ 0 & 22 \\ 0 & 5 \\ 0 & 6 \\ 0 & 0.01 \end{bmatrix}$$

$\left[\begin{matrix}"I(R2)"\\ "I(R3)"\end{matrix}\right]$ $\left[\begin{matrix}0 & -0.01\\ 0 & -0.22\end{matrix}\right]$

$X_{[5..7]}=\left[\begin{matrix}I\_V1\\ I\_V2\\ I\_E\end{matrix}\right]$ $|A|=0\ S$ $I=\left[\begin{matrix}-6\\ -650\\ 650\end{matrix}\right] mA$

G: CCCS

Current Controled Current Source (CCCS)



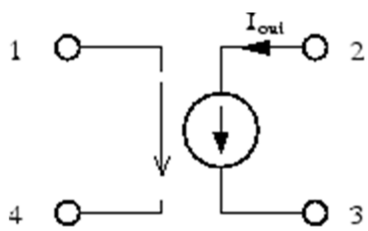
htt

```
I 4 0 9A
V 3 0 2V
R 1 4 1Ω
R 3 4 2Ω
R 2 3 1Ω
R 0 5 2Ω
Hx 5 2 1 2 3Ω
Gy 3 0 1 4 2S
```

$\chi:=1$

$[A\ B\ X\ V\ I]:=MNA("\chi")$

$V=\left[\begin{matrix}5\\ 2\\ 2\\ -2\\ 2\end{matrix}\right] V$ $I=\left[\begin{matrix}-2\\ -1\\ 1\\ 8\end{matrix}\right] A$

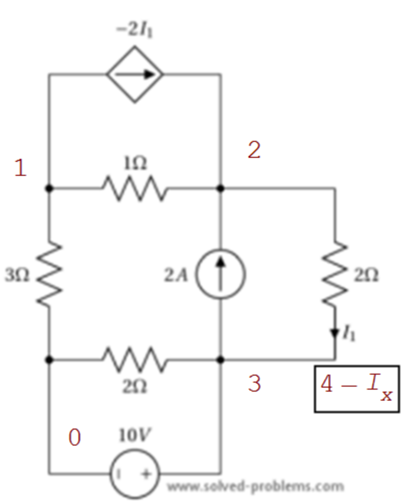


$X_{[6..9]}=\left[\begin{matrix}I\_V\\ Iin\_Hx\\ Iout\_Hx\\ I\_Gy\end{matrix}\right]$

$|A|=4.25\ S$

F: CCCS

Current Controled Current Source (CCCS)

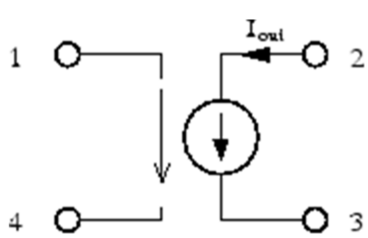



```
I 3 2 2A
V 3 0 10V
R 0 3 2Ω
R 0 1 3Ω
R 2 4 2Ω
R 1 2 1Ω
Fx 4 1 2 3 -2
```

$\chi:=1$

$[A\ B\ X\ V\ I]:=MNA("\chi")$

$V=\left[\begin{matrix}6.75\\ 9.5\\ 10\\ 10\end{matrix}\right] V$ $I=\left[\begin{matrix}-7.25\\ 0.5\end{matrix}\right] A$



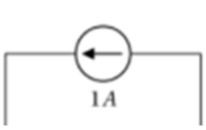
$X=\left[\begin{matrix}V\_1\\ V\_2\\ V\_3\\ V\_4\\ I\_V\\ I\_Fx\end{matrix}\right]$

LOS VOLTAJES ESTÁN BIEN, CHEKAR LAS CORRIENTES.

$\frac{|A|}{S^2}=-0.67$

H: CCVS

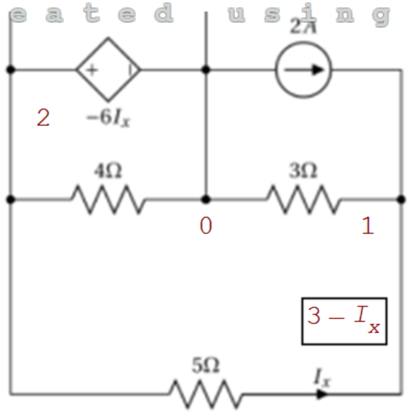
Current Controled Voltage Source (CCVS)




```
I 0 2 1A
I 0 1 2A
R 0 2 4Ω
R 0 1 3Ω
```

$[A\ B\ X\ V\ I]:=MNA("\chi")$

$\left[\begin{matrix}4.71\end{matrix}\right]$ $=\left[\begin{matrix}-0.43\end{matrix}\right]$

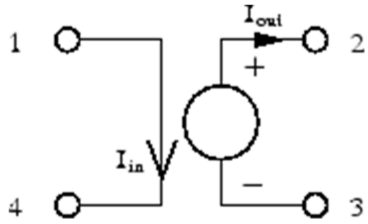



```
R 2 3 5Ω
H 3 2 0 1 -6Ω
```

$V = \begin{bmatrix} 2.57 \\ 4.71 \end{bmatrix}$ V

$\begin{bmatrix} -0.79 \end{bmatrix}$ A

$\chi := 1$



$X = \begin{bmatrix} V\_1 \\ V\_2 \\ V\_3 \\ Iin\_H \\ Iout\_H \end{bmatrix}$

Alvaro

appVersion(4) = "1.2.9018.0"