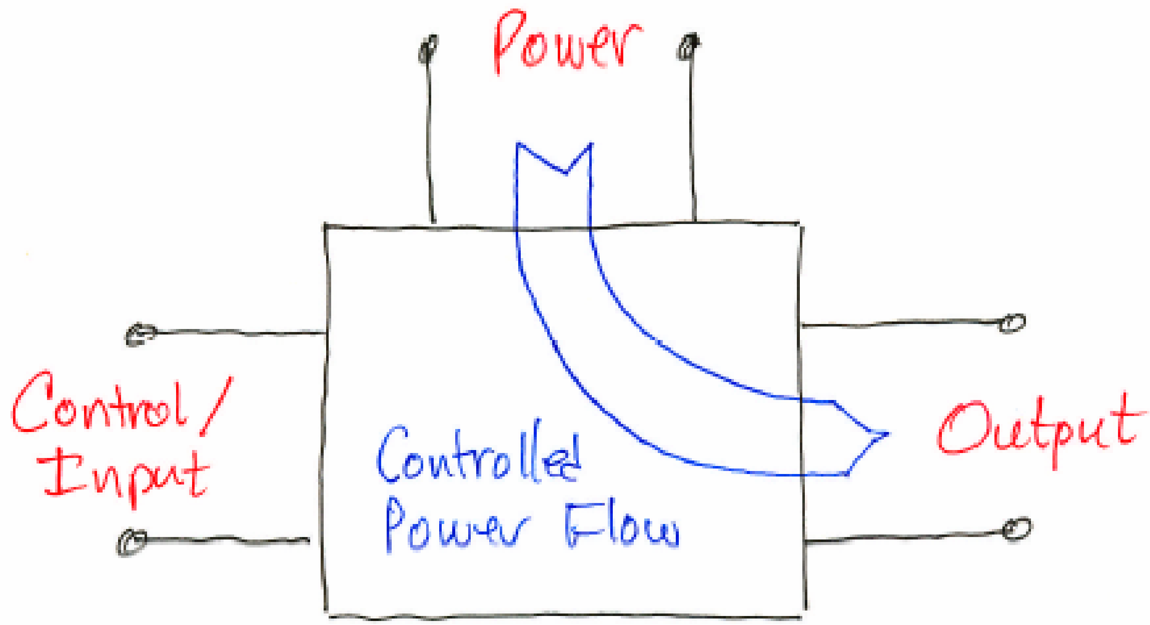
6.200 - Lecture 06

Amplifiers

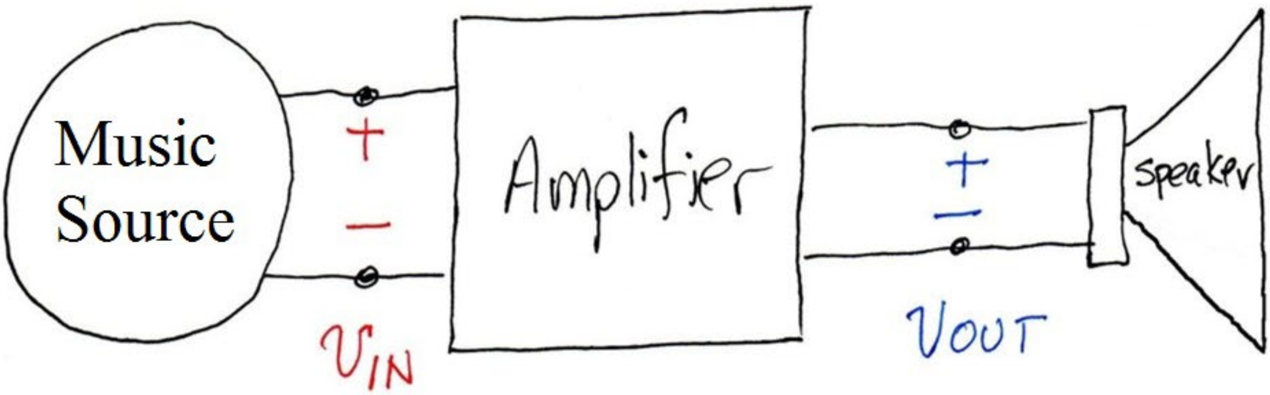
- Amplifiers
- Amplifier Modeling and Dependent Sources
- Amplifying Devices
- Amplifier Implementation

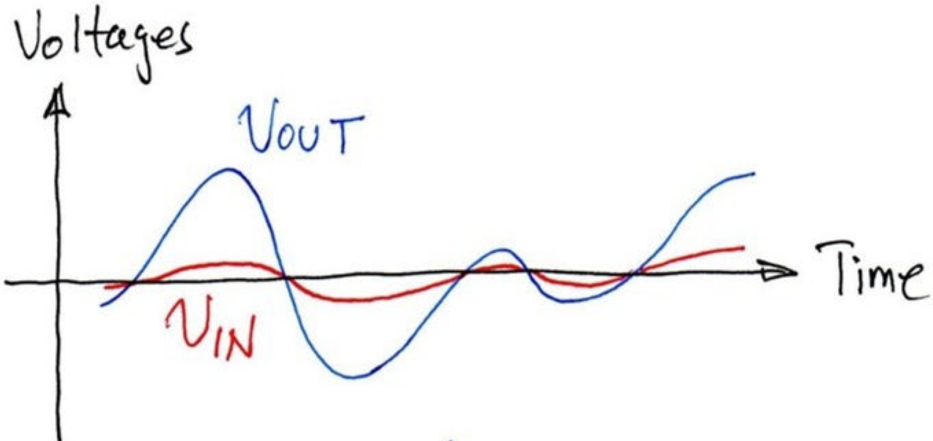
Amplifiers

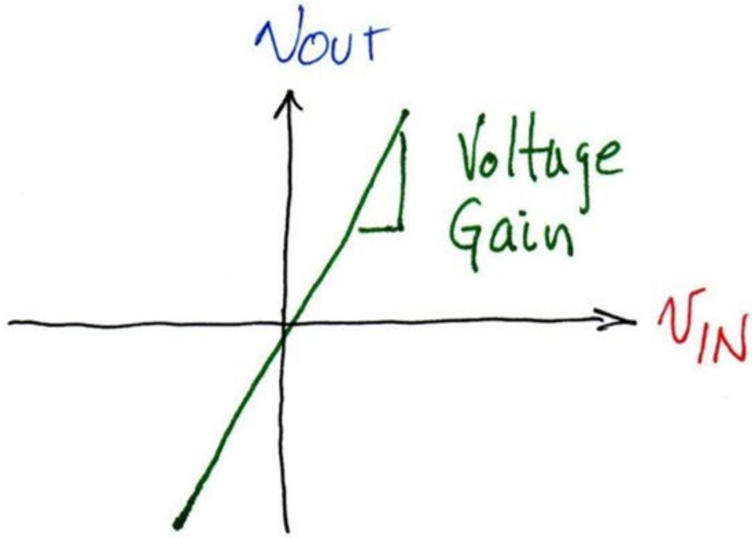


- An amplifier is a three-port device.
- Ubiquitous use to improve signal strength, improve signal-to-noise ratio, and provide power gain.
- Examples found in electronics, mechanics, pneumatics, hydraulics, economics, society ...

Amplifier


Music Source
+
−
Amplifier
+
−
speaker
VIN
VOUT


Voltages
VOUT
VIN
Time


VOUT
Voltage Gain
VIN

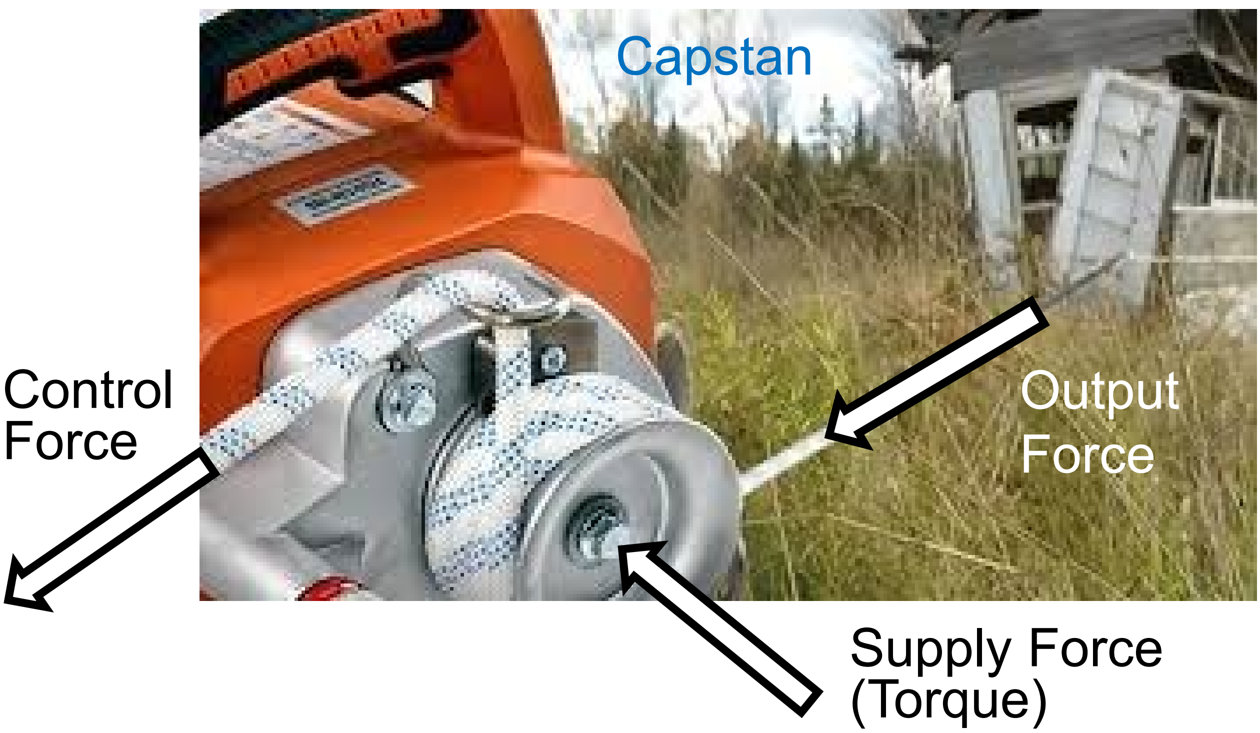
Some Amplifier Properties

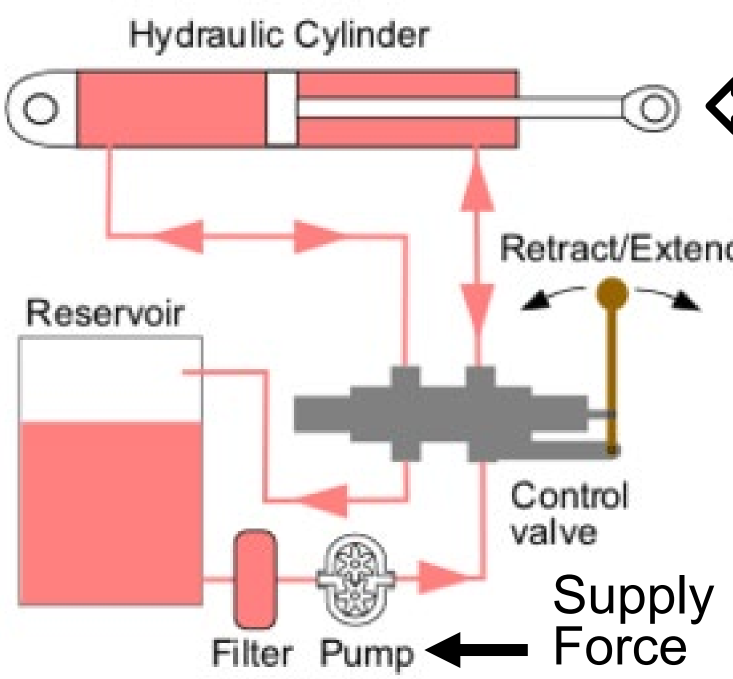
- Gain: voltage, current and power

  To be an amplifier, a device should provide power gain.

- Linearity
- Equivalence: input and output
- Bandwidth
- Dissipation
- Stability
- Noise
- Size
- Cost

Amplifiers In Other Domains



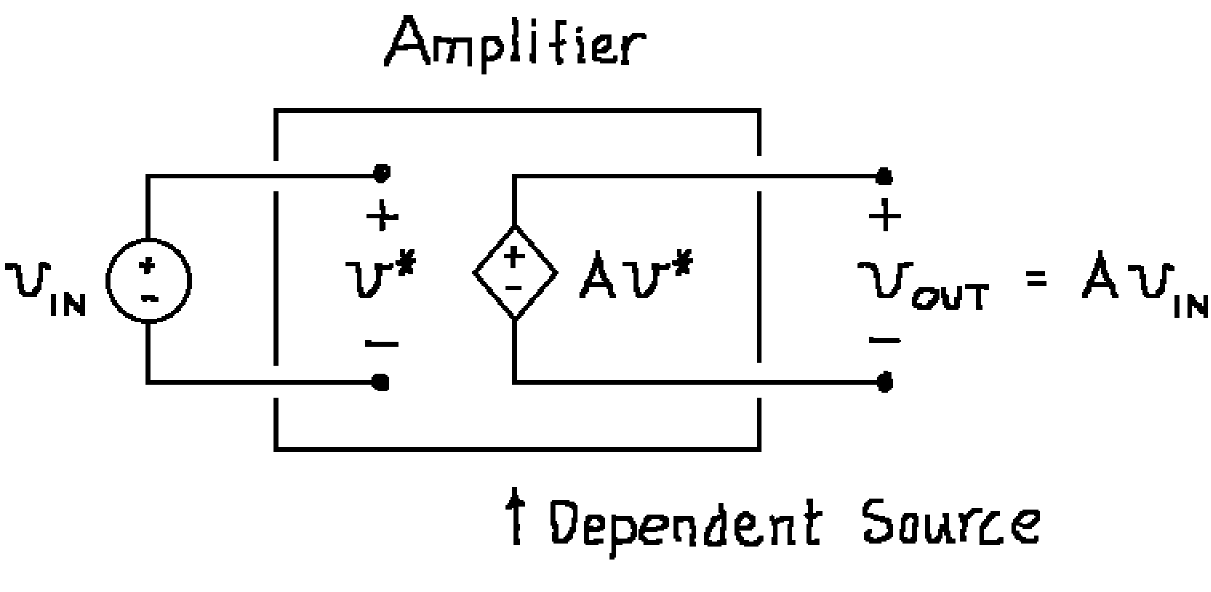


Hydraulics

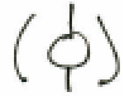
Amplifier Representation

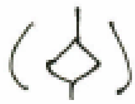
How does one represent a multi-port circuit that can provide power gain?

- With a detailed circuit diagram drawn at the device level
- Using a high-level summary device, namely a dependent source with an implied power supply for power gain

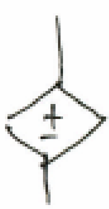


Independent & Dependent Sources

Independent Sources () are external inputs and are independent of all other signals.

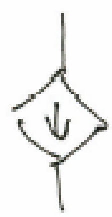
Dependent Sources () are internal sources having values that depend on other internal branch variables.

Dependent Voltage Source



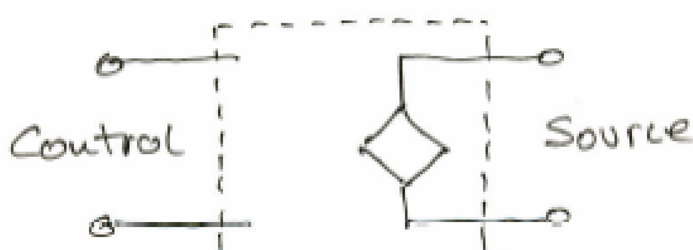
Label Indicates Dependence

Dependent Current Source

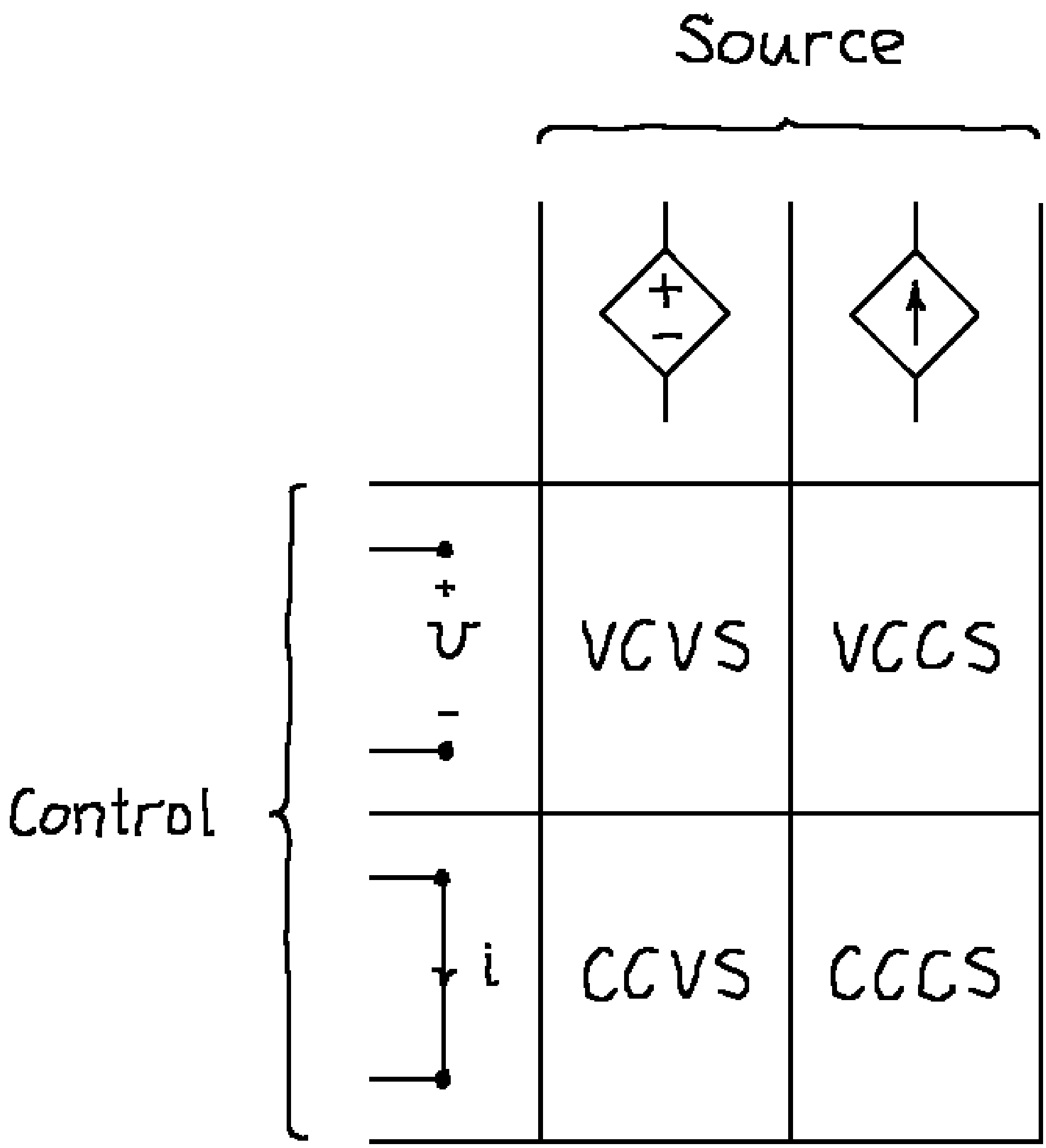


Label Indicates Dependence

Dependent sources are atleast two-port devices, and are three-port devices if they can source power.

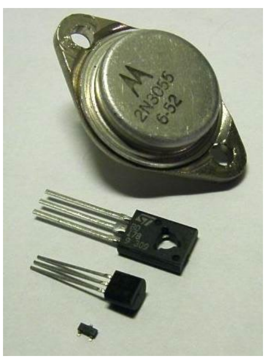


Some Dependent Sources



Dependent Source Uses

Dependent sources are used to model amplifying devices and amplifier systems.



Transistors

Vacuum Tubes

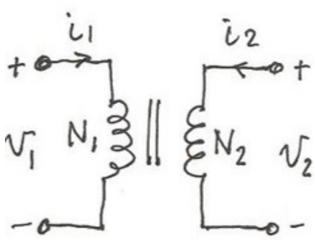
Operational Amplifiers

Amplifier Systems

Device Modeling

Dependent sources are used to model devices that sometimes connect different physical domains

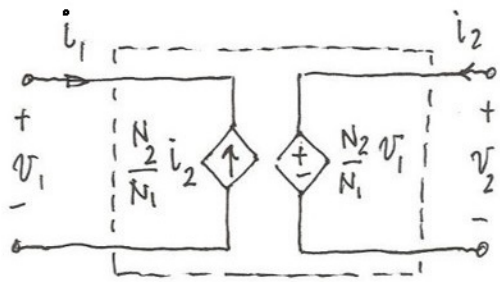
Transformer



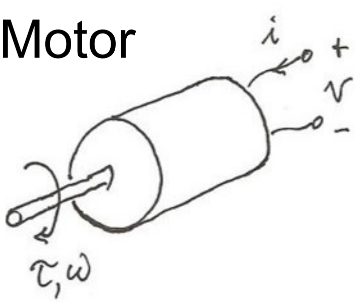
Ideal

$$\frac{v_1}{N_1} = \frac{v_2}{N_2}$$

$$N_1 i_1 + N_2 i_2 = 0$$



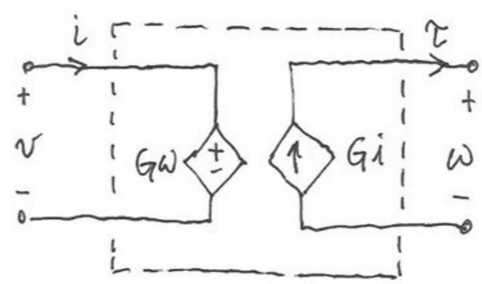
Motor



Ideal

$$v = G\omega$$

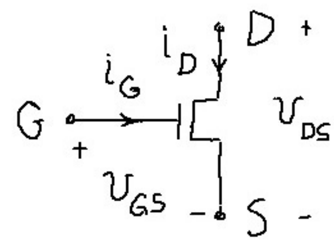
$$\tau = G i$$

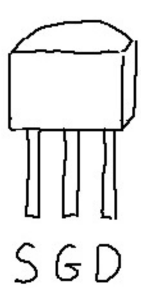


MOSFET Transistor

Idealized

$$i_G = 0$$

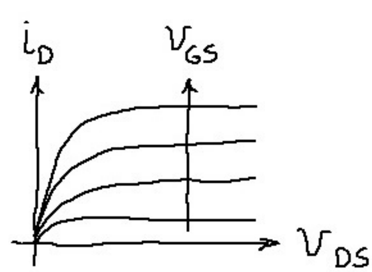


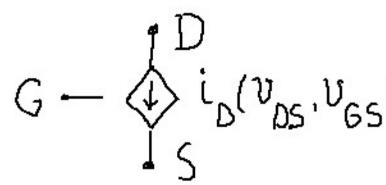


S: Source

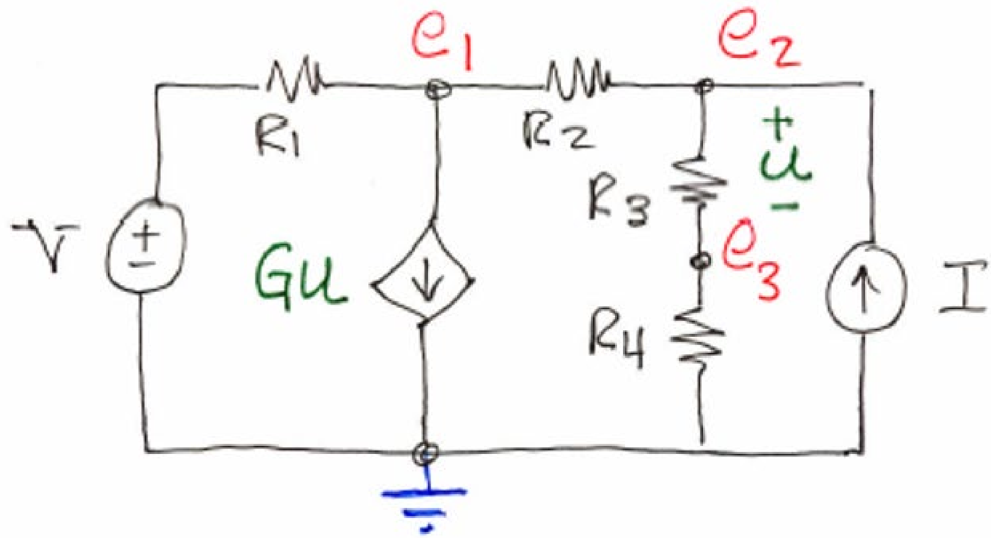
D: Drain

G: Gate





Analysis Example: Node Method



Node 1: $G_1(e_1 - V) + G(e_2 - e_3) + G_2(e_1 - e_2) = 0$

Node 2: $G_2(e_2 - e_1) + G_3(e_2 - e_3) - I = 0$

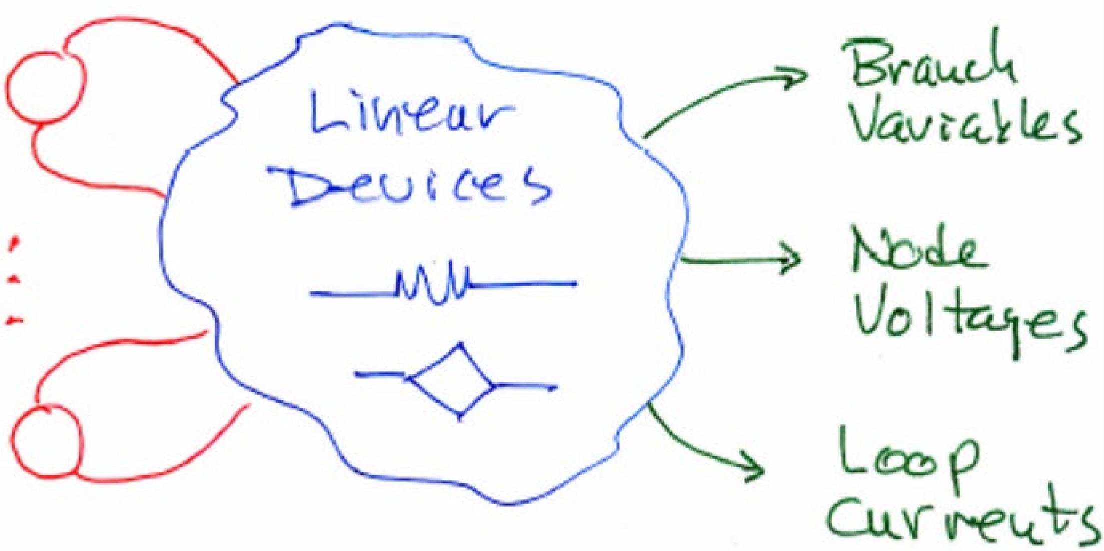
Node 3: $G_3(e_3 - e_2) + G_4(e_3) = 0$

$$\begin{bmatrix} G_1+G_2 & G-G_2 & -G \\ -G_2 & G_2+G_3 & -G_3 \\ 0 & -G_3 & G_3+G_4 \end{bmatrix} \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} G_1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V \\ I \end{bmatrix}$$

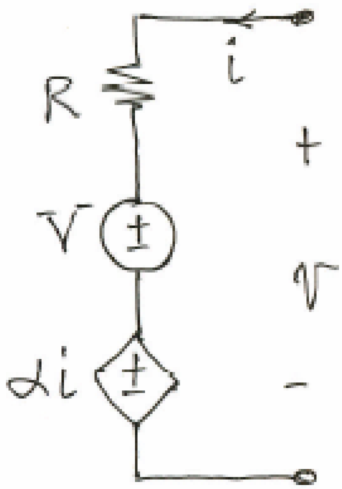
- Dependent source properties appear in coefficient matrices.
- The network remains linear if the dependent sources are linear.

Superposition

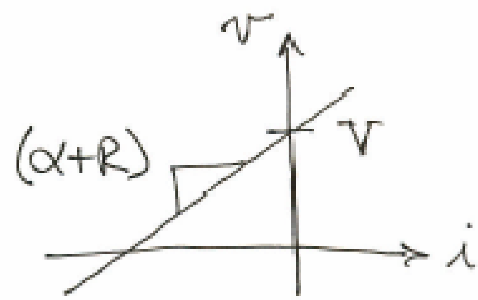
Dependent sources are part of the network/system, not part of the independent inputs. It is generally best to carry out superposition only over the independent sources.



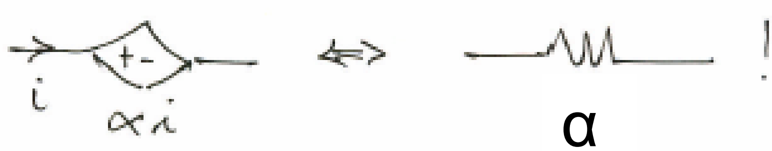
Thevenin & Norton Equivalence



$$v = \alpha i + V + Ri$$
$$= V + (\alpha + R)\, i$$

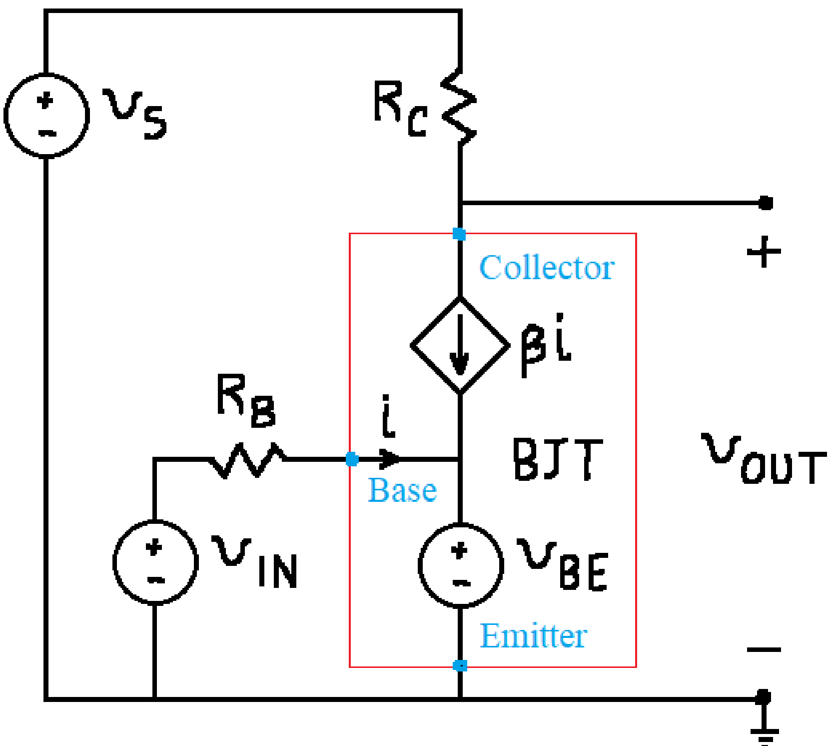


The dependent source is acting like a resistor:

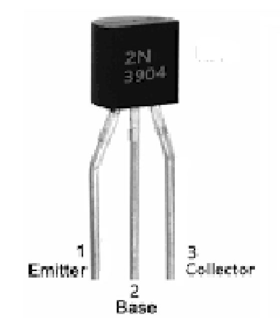


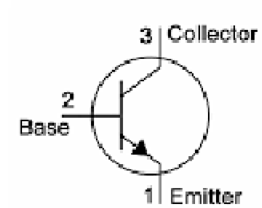
- Independent sources can only bias the i-v relation at a port.
- Dependent sources can also change the slope of the i-v relation.
- Dependent sources are part of the network, and so must be part of a Thevenin resistance calculation.

BJT Amplifier Implementation



Biolar Junction Transistor (BJT)





Approximate BJT model valid only for $i > 0$ and $v_{OUT} > v_{BE}$.

Node analysis at v_{OUT}:

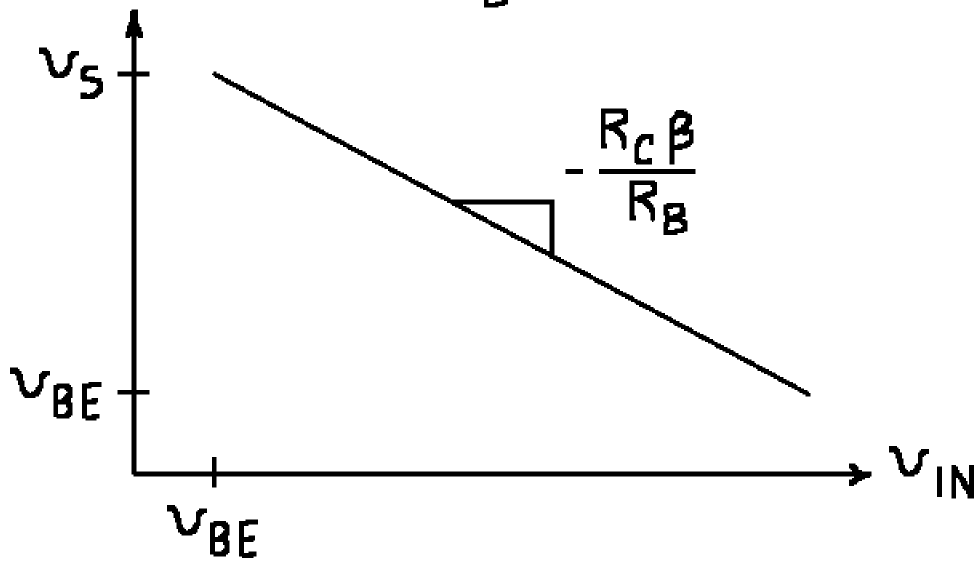
$$\frac{v_{OUT} - v_S}{R_C} + \beta \frac{v_{IN} - v_{BE}}{R_B} = 0$$

$$v_{OUT} = v_S - \frac{R_C \beta}{R_B}(v_{IN} - v_{BE})$$

BJT Amplifier Implementation

Input-Output Characteristic

$$v_{OUT} = v_S - \frac{R_C \beta}{R_B}(v_{IN} - v_{BE})$$



Thevenin Equivalent ($v_{BE} \leq v_{OUT} \leq v_S$)

- $v_{TH} = v_{OC} = v_{OUT}$
- $v_S = v_{BE} = v_{IN} = 0 \Rightarrow i = 0$ so $R_{TH} = R_C$