Amplifiers:

• But first, continuation of previous lecture

• Amplifiers

• Amplifier Modeling and Dependent Sources

• Amplifying Devices

• Amplifier Implementation
Thevenin & Norton Equivalence

Linear Network

\[ U = \sum_{n} \alpha_n V_n + \sum_{m} \beta_m I_m + R_{TH} i \]

Superposition

Open Circuit (\( i = 0 \))

\[ U_{TH} = \sum_{n} \alpha_n V_n + \sum_{m} \beta_m I_m \]

Short Circuit (\( V = 0 \))

\[ I_N = \frac{U_{TH}}{R_{TH}} \]

Thevenin

Norton
THEVENIN / NORTON EXAMPLE

Open-circuit voltage = 6 V via voltage divider \( \Rightarrow \ V_{TH} = 6 \text{ V} \)

\[ R_{TH} \Rightarrow \]

\[ I_N = \frac{V_{TH}}{R_{TH}} = 2 \text{ A} \]
Battery Example

Open-Circuit Voltage

\[ V_B = 1.5 \, \text{V} \]

Short-Circuit Current

\[ i_B = -1 \, \text{A} \]

Thevenin Equivalent
4 – Lecture Summary

- Two-terminal devices: $V, I, R$
- KCL and KVL
- Brute-force analysis
- Node analysis
- Parallel and series reductions
- Voltage and current dividers
- Superposition
- Thevenin and Norton equivalence
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 ...
Some Amplifier Properties

Gain: Voltage, Current, Power
Equivalence: Input, Output
Bandwidth
Noise
Stability
Dissipation
Load Dependence
Amplifier Example

[Diagram showing a music source connected to an amplifier and then to a speaker]

[Graph showing voltages over time with labels V_{IN} and V_{OUT}]

[Graph showing voltage gain as a function of input voltage]
Independent & Dependent Sources

**Independent Sources** ($\Phi$) are external inputs and are independent of all other signals.

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

**Dependent Voltage Source**
- Label: Indicates Dependence
- Symbol: $\pm$

**Dependent Current Source**
- Label: Indicates Dependence
- Symbol: $\downarrow$

Dependent sources are at least two-port devices, and are three-port devices if they can source power.
Dependent Source Uses

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

Transistors  Vacuum Tubes

Operational Amplifiers  Amplifier Systems
Dependent Source Uses

Dependent sources are used to model connections between different physical domains

Transformer

\[
\frac{V_1}{N_1} = \frac{V_2}{N_2}
\]

\[
N_1i_1 + N_2i_2 = 0
\]

Motor

\[
V = G \omega
\]

\[
I = G_i
\]

Toaster

\[
\dot{Q} = Ri^2
\]
Network Example (Node Method)

Node 1: \[ G_1(e_1 - V) + G(e_2 - e_3) + G_3(e_1 - e_2) = 0 \]
Node 2: \[ G_2(e_2 - e_1) + G_3(e_2 - e_3) - I = 0 \]
Node 3: \[ G_3(e_3 - e_2) + G_4(e_3) = 0 \]

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

- 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. Carry out superposition only over the independent sources.

![Diagram showing linear system and linear devices with branch variables, node voltages, and loop currents.](image)
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.
Amplifier Implementation

\[ \frac{V_{out} - V_s}{R} + G \cdot V_{in} = 0 \]

\[ V_{out} = V_s - R \cdot G \cdot V_{in} \]

\[ V_{out} \]

Power Input \hspace{1cm} \text{Output}

Therevin Equivalent:

\[ V_{out} \leftrightarrow V_s - R \cdot G \cdot V_{in} \]
Dependent Source Power

Voltage = $V_s - RG \cdot V_{in}$

Current = $G \cdot V_{in}$

Power In = Voltage $\cdot$ Current

![Graph showing voltage and current relationships with negative power output indicated.]

Dependent Source:

Control

Voltage

Power Out

Current