E246: Electronics & Instrumentation

Lecture 3: Review of Basic Electronics
Plan

- Source transformations
- Superposition
- Thevenin’s Theorem
- Norton’s Theorem
- Sections in textbook: 2.9-2.11
A source transformation is a procedure for transforming one source into another while retaining the terminal characteristics of the original source.
Source Transformations

- An *equivalent* circuit is one whose terminal characteristics remain identical to those of the original circuit.

- Note that equivalence implies an identical effect *at the terminals* but not within the equivalent circuits themselves.
Source Transformations

Clearly, so long as the current that passes through $R$ is the same, the two circuits are equivalent.
Source Transformations

What is the relationship between $v_s$ and $i_s$ so that the transformation is transparent to a load resistor $R$ connected between the terminals $a$ and $b$?

(a) 

(b)
a). \( v_s = iR_s + v \Rightarrow \frac{v_s}{R_s} = i + \frac{v}{R_s} \) 

b). \( i_s = i + \frac{v}{R_p} \)
Dual circuits are two circuits such that the equations describing the first circuit, with $\nu$ and $i$ interchanged and $R$ and $G$ interchanged, describe the second circuit.
Method

Set \( i_s = \frac{v_s}{R_s} \)

Set \( R_p = R_s \)

Set \( v_s = i_s R_p \)

Set \( R_s = R_p \)
Example 1:

Find the current $i$ by reducing the circuit to the right of terminals a-b to its simplest form using source transformations.
Superposition

IF

\[ i_1 \rightarrow v_1 \]
\[ i_2 \rightarrow v_2 \]

THEN

\[ i_1 + i_2 \rightarrow v_1 + v_2 \]

The **superposition principle** requires that the total effect of several causes acting simultaneously is equal to the sum of the effects of the individual causes acting one at a time.
Superposition

The principle of superposition requires that for a linear circuit consisting of linear elements and independent sources, we can determine the total response by finding the response to each independent source with all other independent sources set to zero and then summing the individual responses.
Example 2:

Find the current measured by the ammeter.
Equivalent Circuits

A circuit equivalent to another circuit exhibits identical characteristics at identical terminals.
Motivations

- Sometimes we are interested only in what happens at a pair of terminals (e.g., an appliance plugged into the wall).
- We want to know only how the voltage and current supplied at the terminals as we vary the load.
- Thevenin and Norton equivalents are circuit techniques that focus on terminal behavior.
Thevenin’s Theorem

For any circuit of resistance elements and energy sources with an identical terminal pair, the circuit can be replaced by a series combination of an ideal voltage source $v_t$ and a resistance $R_t$, where $v_t$ is the open-circuit voltage at the two terminals and $R_t$ is the ratio of the open-circuit voltage to the short-circuit current at the terminal pair.
### Thévenin Circuit Approach

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Identify circuit A and circuit B.</td>
</tr>
<tr>
<td>(b)</td>
<td>Separate circuit A from circuit B.</td>
</tr>
</tbody>
</table>

- Circuit A
- Circuit B

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>(c)</td>
<td>Replace circuit A with its Thévenin equivalent.</td>
</tr>
<tr>
<td>(d)</td>
<td>Reconnect circuit B and determine the variable of interest (e.g., current $i$).</td>
</tr>
</tbody>
</table>
A Thevenin equivalent circuit is an independent voltage source $v_t$ in series with a resistor $R_t$. 

![Thevenin Equivalent Circuit Diagram]
If the load resistance is infinitely large, then the open circuit voltage is \( v_t \);

We calculate \( v_t \) by calculating the open circuit voltage in the original circuit.
If the load resistance is zero, we have a short circuit. This must be the same as the short circuit current in the actual circuit.

We calculate $R_t$ as $R_t = \frac{v_t}{i_{sc}}$.
If the circuit contains *only independent* sources, an alternative method to find $R_t$ is to deactivate all independent sources and then calculate the resistance seen looking into the circuit at the designated pair,

Note that a voltage source is deactivated by replacing it with a short circuit; and a current source is deactivated by replacing it with a open circuit.
Thevenin Circuit with Dependent Sources

When separating a circuit containing dependent sources into two sub-circuits to make a Thevenin equivalent, the dependent source and its control voltage or current must be in the same subcircuit.
Example 1:

Find the Thevenin equivalent circuit for the following circuit.
Norton Equivalent Circuit

A Norton equivalent circuit is an independent current source $i_{sc}$ in parallel with a resistor $R_n$. 

![Norton Equivalent Circuit Diagram]
Norton’s Equivalent

- The Norton equivalent circuit is a dual of the Thevenin equivalent circuit.
- The Norton equivalent circuit is found by performing a source transformation on the Thevenin equivalent.
Norton’s Theorem

For any circuit of resistance elements and energy sources with an identical terminal pair, the circuit can be replaced by a parallel combination of an ideal current source \( i_{sc} \) and a conductance \( G_n \), where \( i_{sc} \) is the short-circuit current at the two terminals and \( G_n \) is the ratio of short-circuit current to the open-circuit voltage at the terminal pair.
A Norton equivalent circuit is an independent current source $i_{sc}$ in parallel with a resistor $R_n$. 
Steps in finding a Thevenin or Norton equivalent circuit:

- Step 1: Find the open circuit voltage $v_{oc}$, this is the voltage source ($v_t$) in Thevenin circuit;
- Step 2: Find the short circuit current $i_{sc}$, this is the current source in Norton circuit;
- Step 3: The resistance in Thevenin and Norton circuits can be found by $R = \frac{v_{oc}}{i_{sc}}$. 
There are two other techniques for deriving a Thevenin equivalent:

- If the circuit contains only independent sources, deactivate the sources and calculate the resistance as seen by looking into the circuit at the designated pair;
If the circuit contains dependent sources, deactivate all the independent sources and then apply a test voltage source or a test current source to the terminals ab;

The Thevenin/Norton resistance is the ratio of the voltage across the test source to the current delivered by the test source.
Example 1:

Find the Norton equivalent circuit.
Example 2:

Find the Norton equivalent circuit.