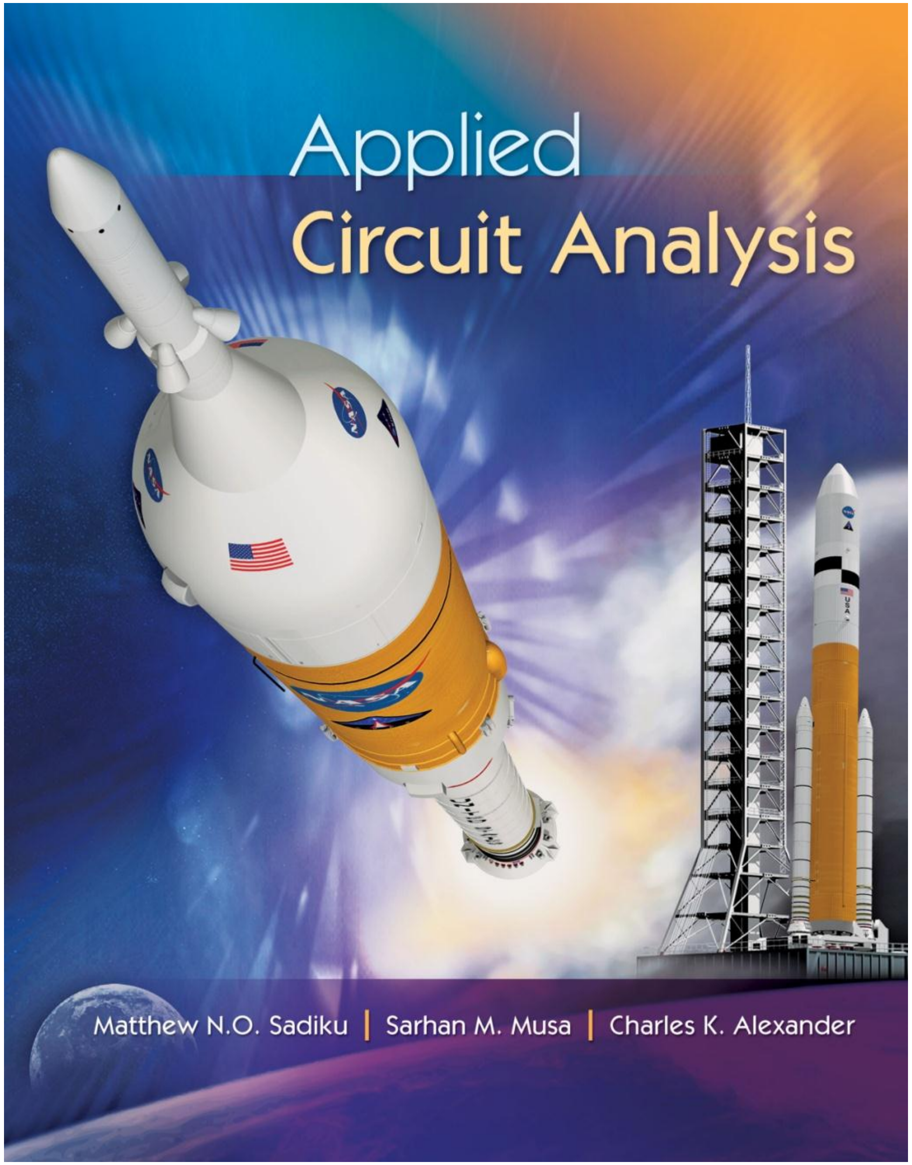


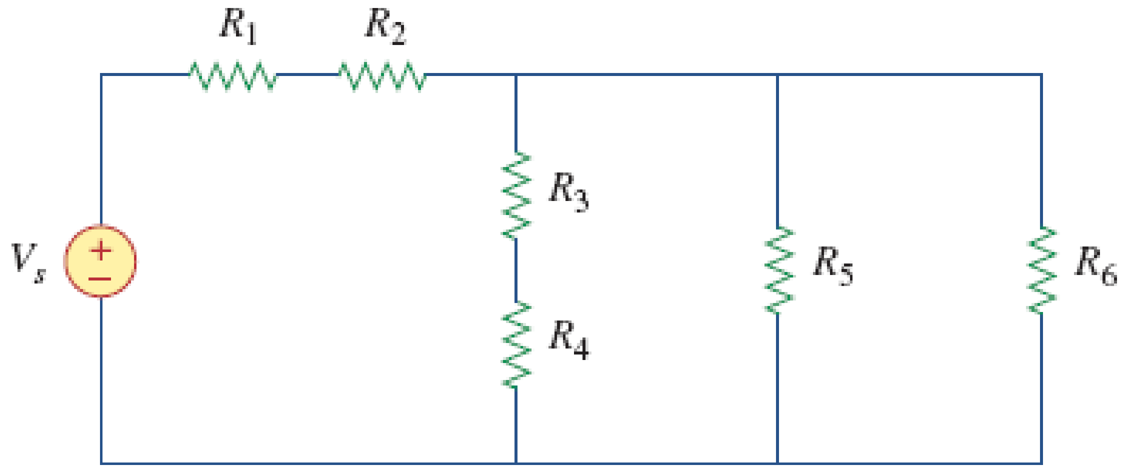
Applied Circuit Analysis
Chapter 6
Series-Parallel Circuits

Overview

- Cover circuits that combine series and parallel features.
- Ohm’s law along with both Kirchhoff’s laws will be used.
- Ladder networks will be introduced.
- Dependent sources will also be introduced.

Series-Parallel Circuits

- **Many circuits include both series and parallel circuit topologies.**
- **An example of a series-parallel circuit is shown here:**



Analysis

- Analysis always begins with identification of any regions that are purely series or parallel.
- These can be reduced to equivalent resistances and the circuit reexamined.
- At this point new series or parallel segments may be identified and treated in the same manner.

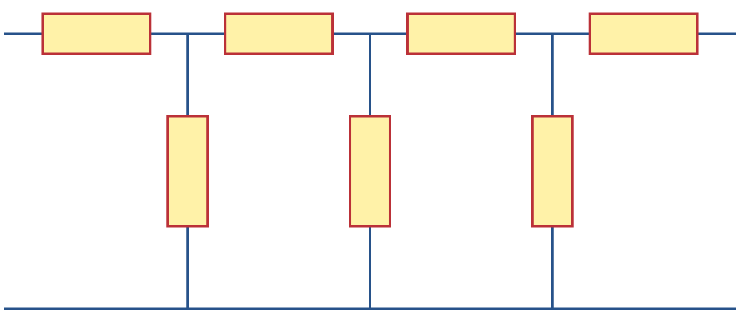
Analysis II

- If a circuit cannot be fully reduced by this method alone, then one can turn to using KVL and KCL, or Ohm's law.
- Additionally, voltage or current division may also be useful when the circuit presents such configurations.

Examples

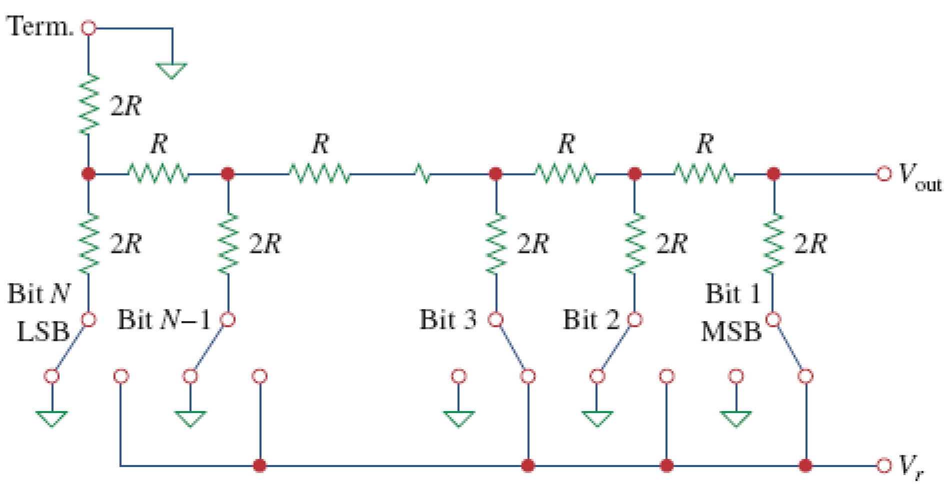
Ladder Networks

- A ladder network is a special series-parallel circuit.
- An example is shown below.
- It is often referred to as a ladder because of its shape.



DACs

- **Ladder networks are used in digital to analog converters (DACs)**
- **A special ladder used in DACs is called a R/2R latter**
- **An example is shown below**



DACs II

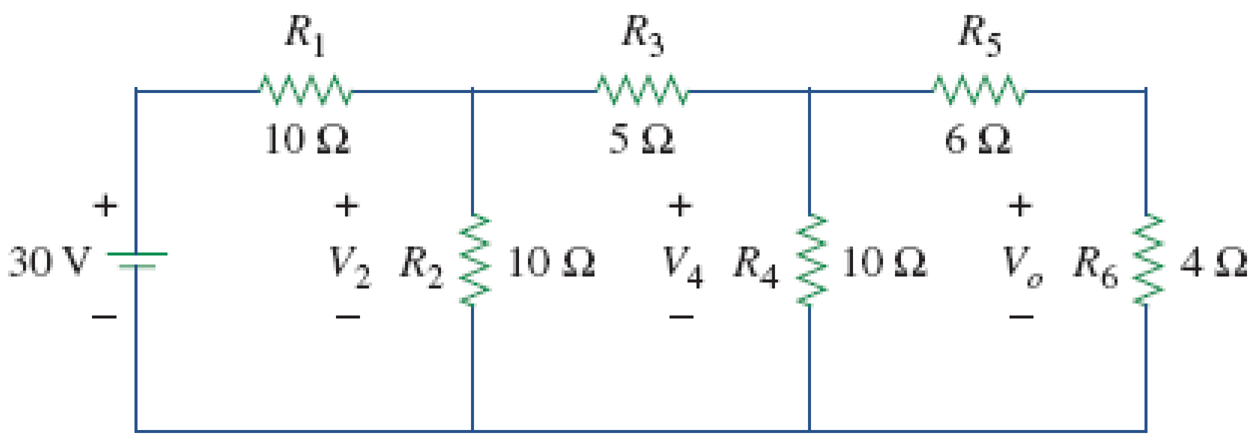
- The ladder shown works by the input of a parallel digital signal (represented by the switches in this case)
- The most significant bit (MSB) has the greatest effect on the output voltage.
- The least significant bit (LSB) has the least impact on the output, and represents the smallest change in output voltage possible.

Analyzing a ladder

- A ladder network is analyzed just like other series-parallel circuits.
- Except that the analysis usually starts by working backwards.
- This can be seen in an example:

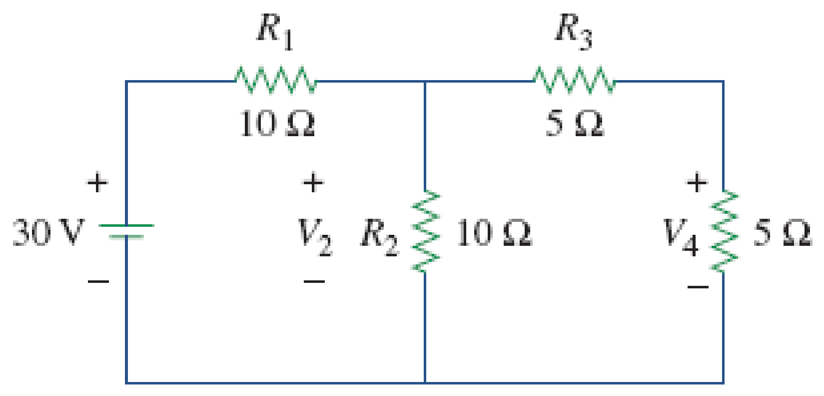
Analysis II

- Consider the circuit shown below.
- Once can see first off that R_5 and R_6 are in series, with a combined resistance of 10Ω



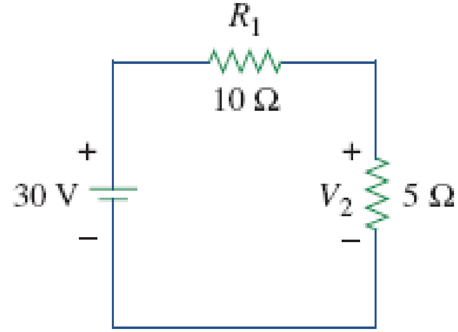
Analysis III

- This 10Ω is in parallel with R_4, giving a equivalent resistance of 5Ω
- The equivalent circuit after these steps is shown below:



Analysis IV

- The 5Ω equivalent resistance is in series with R_3, with a combined resistance of 10Ω.
- This is then in parallel with R_2, yielding an equivalent resistance of 5Ω.
- The circuit now looks like this:



Analysis V

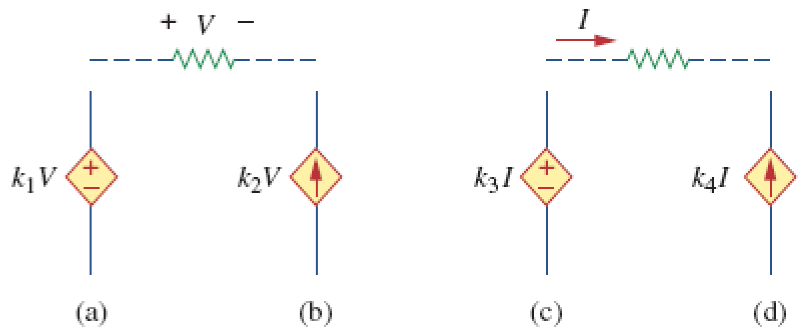
- Our goal is to get the output voltage, so we need not continue with the combination of resistances.
- At this point, one should recognize the configuration as a voltage divider.
- The problem is then worked forward, undoing the simplifications that have been made.
- Each time the voltage divider rule is applied.

Dependent Sources

- Up to this point we have analyzed circuits only with independent sources.
- These sources are unaffected by anything going on elsewhere in the circuit.
- Dependent sources on the other hand, have outputs that, as the name suggests, depend on something elsewhere in the circuit.

Dependent Sources II

- There are four types of dependent sources:
- 1. A voltage-controlled voltage source
- 2. A voltage-controlled current source
- 3. A current-controlled voltage source
- 4. A current-controlled current source).

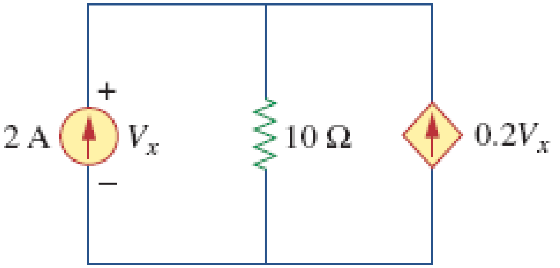


Dependent Sources III

- These sources are never inputs to a circuit.
- They instead are used to model active electronic circuit elements, such as an operational amplifier.
- The element controlling the source does not need to be close (in the circuit topology) to the source.

Dep Source Example

- Let us look at an example of a dependent source in a circuit:
- Here the dependent current source has the voltage drop across the independent current source as the input.



Dep. Source Example II

- We can see that V_x is equal to the voltage drop across the resistor.
- If we let *I* be the current passing through the resistor:

$$I = 2 + 0.2V_x$$

$$V_x = 10I = 20 + 2V_x$$

- Solving for V_x

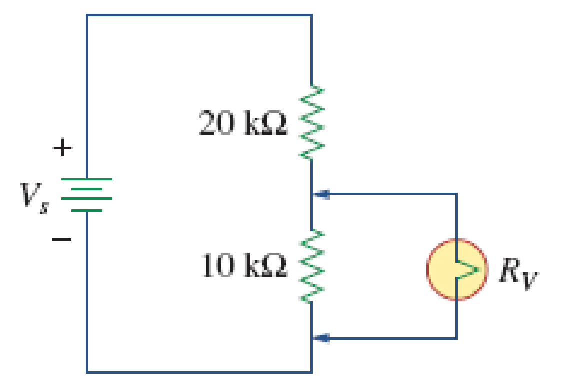
$$V_x = -20V$$

Loading Effects

- We would like to think that the act of taking a measurement has no impact on what we measure.
- In ideal circumstances that would be true, but in reality, we must be aware of the effect attaching a measuring instrument to a circuit has.
- This effect on the circuit is called *loading*.

Voltmeter Loading

- Voltmeters ideally have infinite resistance, but in reality they have resistances typically in the range of 10's of MΩ.
- Connecting the voltmeter to a circuit element puts this resistance in parallel with it.

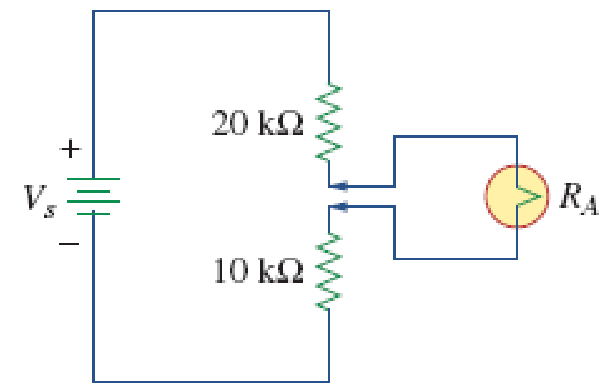


Voltmeter Loading II

- Adding a voltmeter in parallel will have the effect of reducing the effective resistance of the circuit element being measured.
- We know that this means the measured voltage will be less than what actually drops across the element normally.
- We also know that the effect will be greater for high resistances.

Ammeter Loading

- An ideal ammeter has zero resistance.
- Ammeters are inserted in series with the branch to be measured.
- Connecting an ammeter in series adds resistance to the branch.



Ammeter Loading II

- In the case of the ammeter, the effect is to increase the overall resistance of the branch it is inserted into.
- If the branch resistance is large, the effect is small.
- But if the branch resistance is small, then the ammeter can have a noticeable effect on the current, reducing it from the actual value.

Calculating Error

- **The percentage error introduced by adding the instrument into the circuit can be calculated as:**

$$\text{Error}(\%) = \frac{\text{Ideal value - Measured value}}{\text{Ideal value}}$$

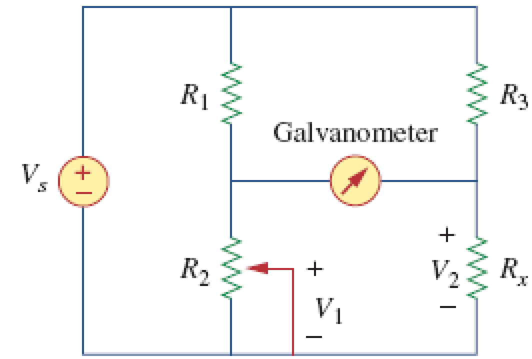
- **Where the ideal value is what we would get if no instrument had been added.**
- **Generally, an error of less than 5% is acceptable.**

Application: Wheatstone Bridge

- Although an ohmmeter provides the simplest way to measure resistance, more accurate measurements may be obtained by using a Wheatstone bridge.
- The Wheatstone bridge is best suited for measuring resistances in the range of 1Ω to 1MΩ.
- The bridge uses three known values for resistance to measure an unknown.

Wheatstone Bridge

- **The unknown resistor is R_x. That plus R_3 make up a voltage divider.**
- **R_1 and R_2 make up another divider.**
- **A galvanometer which is very sensitive to current flow is placed between the dividers.**



Wheatstone Bridge II

- If the bridge is "out of balance", then the voltages on the two dividers are not the same and the galvanometer does not read zero.
- Another way to see that is that the ratios of the two resistors in each divider are not equal.
- Adjusting the value of R_2 until the reading is zero brings the bridge into balance.

Wheatstone Bridge III

- When the bridge is balanced, the voltages on the two dividers is the same:

$$V_1 = \frac{R_2}{R_1 + R_2} V = V_2 = \frac{R_x}{R_3 + R_x} V$$

- From this we can see that the unknown resistance is:

$$R_x = \frac{R_3}{R_1} R_x$$

Unbalanced Mode

- The bridge can also be operated when unbalanced.
- This is often employed for resistive sensors, where the degree of unbalance indicates the value of the quantity being measured.
- The bridge may also be used to measure capacitance and inductance.