GunnShow Tutorial

Electrical Refresher Course

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Table of Contents

I.   Introduction

The goal of this packet is to review and demonstrate concepts which are fundamental to understanding the fluid and electric aspect development process for Ts21. By the end of this packet you should have an understanding of:

- How fluid and electric network equations are constructed
- How those equations are solved
- How this process can be done automatically for simulations using the General Use Nodal Network Solver (GUNNS).
- How simulation networks are constructed by hand using C++ code, or graphically using GUNNSHOW.

You will start by working through a brief review of current, voltage, and circuit concepts. Then, armed with this knowledge you will solve a real world circuit problem, derive matrix equations, and use the equations to solve for the voltage at various points in the circuit. Next, you will see how this process can be automated using C++ code and the GUNNS software package. Afterwards, you will learn how to use a graphical network tool, GUNNSHOW, to quickly create manager files which can be run in a trick simulation environment.

II.   Current Refresher

   i.   **Objective: Refresh basic knowledge of electrical current. These skills will be used when we solve real world network problems.**

   ii. **Definitions:** (Hambley Ch1, 2008)

      a. **Electrical Current** = the time rate of flow of electrical charge through a conductor or circuit element.

      b. **Ampere (A)=** a measure of the amount of electric charge passing a point in an electric circuit per unit time with 6.241 × 10^18 electrons, or one coulomb per second.
1A = 1C/1s

      c. **Coulomb (C)**= the quantity of electricity carried in 1 second by a current of 1ampere. 1C = 1A x 1s

         i. *Confusion:* amperes can be viewed as a flow rate, coulombs as the number of particles

      d. **Khirchoff's current Law** = The net current entering a node is zero. Current into node is positive, current out of node is negative.

Suppose that charge is flowing through an element. If we keep a record of the net charge as a function of time *q(t)*, we get the electric current flowing through the element. We will assign charge flowing to the right as positive, and charge flowing left as negative.
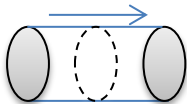
$$i(t) = \frac{dq(t)}{dt}$$

If we use a constant current of one ampere, we know that one Coulomb of charge will go through the cross section every second. Therefore, integrate to find total charge.

$$i(t) = \frac{dq(t)}{dt}$$
$$dt * i(t) = dq(t)$$
$$dq(t) = dt * i(t)$$
$$q(t) = \int_0^t i(t) * dt + q(t_0)$$

Example 2.1

A wire in a wiring harness on the International Space Station(ISS) has 2 A of current flowing through it at a constant rate. How much net charge passes through it after 5 seconds.

Example 2.2

Sketch the charge vs. time and current vs. time characteristics of a circuit element if ...
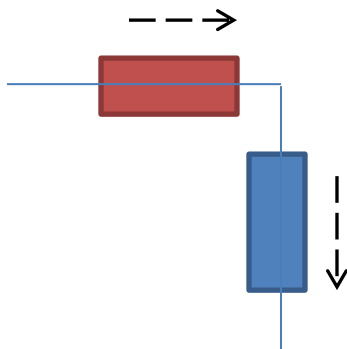
$q(t) = 0$ for $t < 0$

$q(t) = 20$ for $t = 0$

$q(t) = -2t$ for $t > 0$

Example 2.3

What can you say about the current through these two unknown elements.

III.   Voltage Refresher

1.   **Objective: Refresh basic knowledge of electrical voltage. These skills will be used when we solve a simple electric circuit.**

2.   **Definitions:** (Hambley, 2008)

(1)   **Voltage (V)** = the electrical potential difference between two points. Voltage is the energy transferred per unit of charge that flows through an element (J/C).

(2)   **Joule (J)=** the energy expended in passing an electric current of one ampere through a resistance of one ohm for one second (W*s).

(3)   **Power (W) =** the rate of energy transfer, power, is the product of voltage and current (V*I).

(4)   **Resistance (Ω)** = the resistance of a conductor is the opposition to the passage of an electric current through that conductor.

(5)   **Conductance (G) =** the inverse of resistance

(6)   **Ohms Law =** the voltage across an ideal resistor is proportional to the current I through the resistor (V = IR).

(7)   **Khirchoff's voltage law** = the algebraic sum of the voltages equal zero for any closed path in an electric circuit.

(8)   **Ohms Law =** the voltage across an ideal resistor is proportional to the current I through the resistor (V = IR).

When charge moves through circuit elements, energy can be transferred. In the case of light headlights, stored chemical energy is supplied by the socket and absorbed by the filament where it appears as heat and light. Review the analogies below between fluid and electric networks.
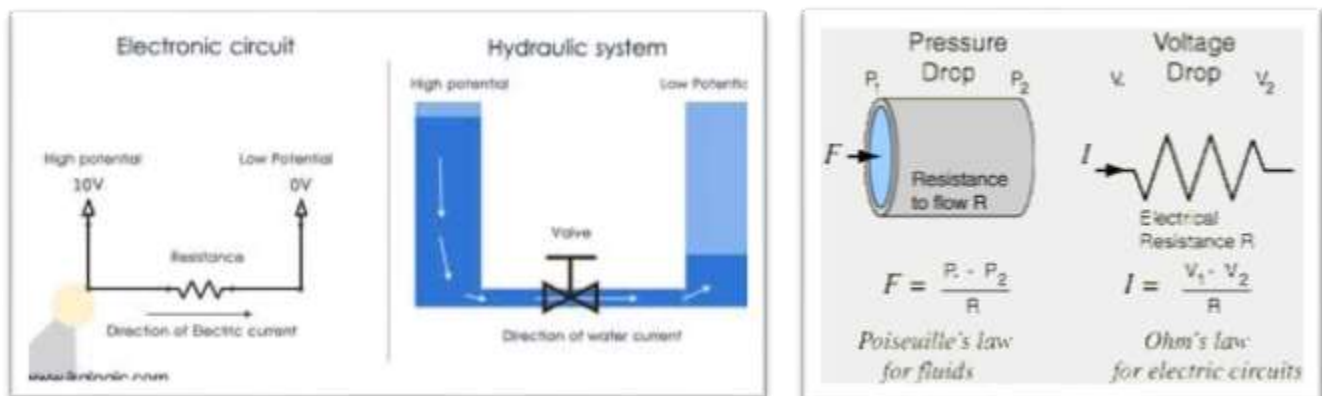
Example 3.1

Photons from sunlight hit a photovoltaic grid made from silicon semiconductors doped with phosphorous and boron. Some energy from the light is absorbed in the silicon and knocks off enough electrons to create a 124V potential difference. Calculate the current drawn by a downstream power bus which is drawing 1600W of power. What is the equivalent resistance of the bus. What is the conductance of the bus?

Example 3.2

A schematic representing the connections on a Remote Power Control Module(RPCM) from the ISS is drawn below. What can be said of the voltage at point A,B, and C?
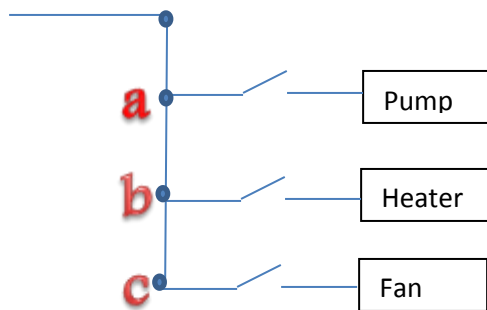
IV.   Circuits

i.   **Objective: Use voltage and current skills to show the derivation and solution to an electric circuit problem using node voltage analysis.**

ii.   **Definitions:** (Hambley, 2008)

   a.   **node-voltage analysis** = a general technique that can be applied to solve any circuit.

   b.   **Node** = a point at which two or more circuit elements are joined together.

   c.   **Ground symbol** = an electrically common reference point.

   d.   **Resistors in series** = the equivalent resistance of of n resistors in series is

   $$\text{i.   Req} = \text{R1} + \text{R2} + \text{R3} + \ldots + \text{Rn}$$

   e.   **Resistors in parallel =**

   $$\text{i.   } \frac{1}{R_{eq}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Now we will show a simple circuit and the steps taken to solve the voltages at key locations using the node voltage analysis. The first step, is to label the nodes, then assign a voltage variable to each. So given the following, we label nodes one, two, three, and a ground node for common electrical potential. Assume the voltage source is a constant 120V DC source.
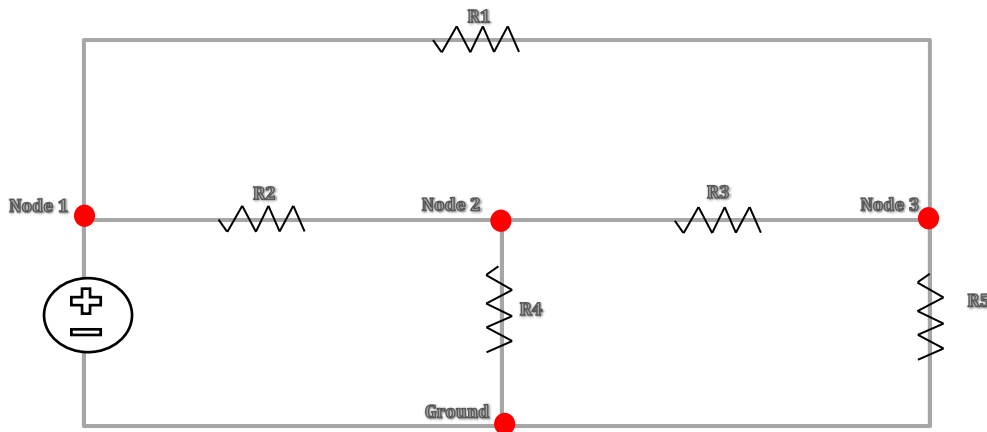
Step1: create a voltage label at each node. The label is arbitrary, but once we find the node voltages, it is quick to find the voltage across any two points using Ohm's law and Khirchoff's laws.
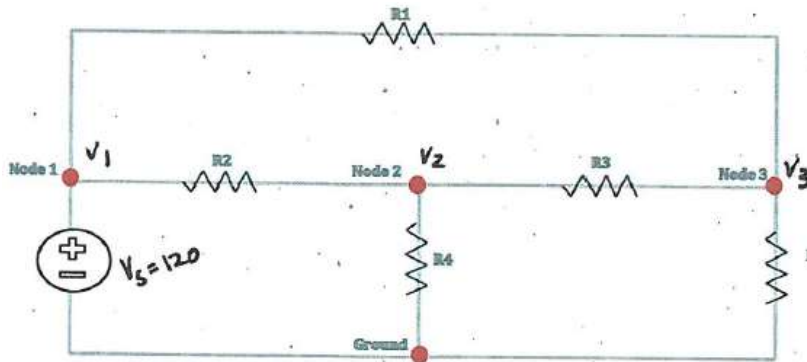
I label V_1, V_2, V_3.
Right away I can see
that $V_1 = V_s = 120V$

Ex: V_3 is the voltage
at Node 3 with respect
to our ground reference.

Step 2 : Create equations to solve for the node voltage. It is usually best to start by writing equations for the current at each of the nodes. So for example, the current at node 3 flowing out through R5 is v3/ R5. Remember, the total current into a node must equal the total current out of a node.

The direction
I choose does not have to be correct, just consistent
from Node to Node.
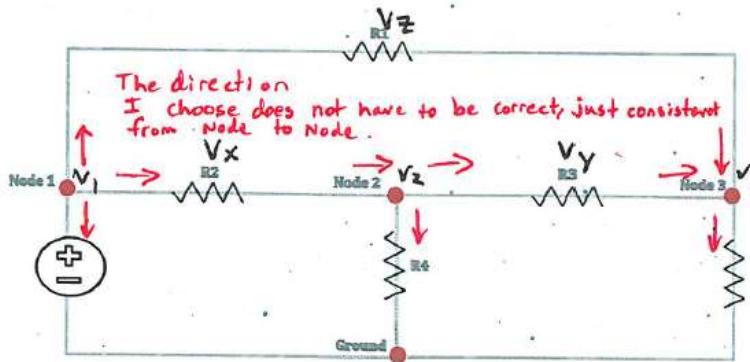
I have to arbitrarily set current directions one Node at a time. I choose $\bullet \longrightarrow$ as positive. current flows from plus to minus, so after we assign the direction, we can assign our voltage polarities.

Now do Khirchoffs law for each node.

Node 1: $\quad \dfrac{V_z}{R_1} + \dfrac{V_x}{R_2} + I_{source} = 0$

Node 2: $\quad \dfrac{-V_x}{R_2} + \dfrac{V_Y}{R_3} + \dfrac{V_z}{R_4} = 0$

Node 3: $\quad -\dfrac{V_z}{R_1} - \dfrac{V_Y}{R_3} + \dfrac{V_3}{R_5} = 0$

Step3: We have some good equations, but the variables Vx, Vy, and Vz are still unknown. To solve for them we can use Khirchoff's voltage Law and draw three loops. Remember, the voltage along any closed path is zero. After we find Vx,Vy,and Vz, we can substitute the values in. We usually can get all the equations we need to solve for the node voltage by applying Khirchoff's laws to nodes where unknown voltage appears.
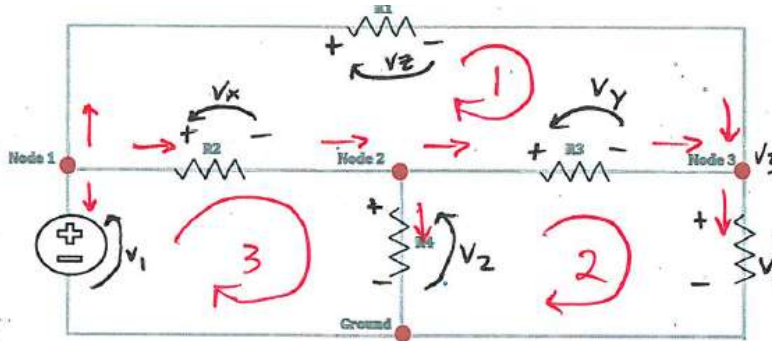
we already picked our reference directions for current, so now apply the appropriate polarities.

Travelling around the loop, we sum the voltages while remember that arrow heads for voltage point to the positive reference with my ref. dir.

Loop 1:
$$V_z - V_y - V_x = 0$$

• We know we can substitute 3 equations with 3 unknowns,

$$V_z - (V_2 - V_3) - (V_1 - V_2) \Rightarrow \boxed{V_z = V_1 - V_3}$$

Loop 2:
$$V_y + V_3 - V_2 = 0$$

$$\boxed{V_y = V_2 - V_3}$$

Loop 3:
$$-V_3 + V_x + V_2 = 0$$

$$\boxed{V_x = V_1 - V_2}$$

Now substitute these equations back into the node eq. to get...

Node 1: $\dfrac{V_1 - V_3}{R_1} + \dfrac{V_1 - V_2}{R_2} + i_o = 0$

★ From this result, there is a shortcut we can notice.

Node 2: $\dfrac{V_2 - V_1}{R_2} + \dfrac{V_2 - V_3}{R_3} + \dfrac{V_2}{R_4} = 0$

the current flowing out of a node n to k through resistore R is simply

Node 3: $\dfrac{V_3 - V_1}{R_1} + \dfrac{V_3 - V_2}{R_3} + \dfrac{V_3}{R_5} = 0$

$$\dfrac{V_n - V_k}{R}$$

Step 4: Now that we have some equations, we can put them into standard form to solve for the missing variables. We will find that we can write these equations and solve them in matrix form using linear algebra techniques. The equations will be of the form

$$[A] * \{P\} = \{w\}$$

Where [A] is the admittance matric (admittance is conductance which is 1/R), {P} is the potential or voltage at each of the nodes we selected, and {w} is the flow rate. The admittance matrix will give us the conductance between all possible node to node combinations; essentially, it shows how easily current will flow from one node to the next. The potential matrix will give us the voltage potential at each of the nodes we selected in our example. Finally the flow matrix will give us the total current through each node.

Therefore by putting our equations in this form, while remembering that Conductance $G_1 = 1/R$, we can derive the final matrix below by inspection.

Using conductance the old equations become

Node1: $(V_1 - V_3) * G_1 + (V_1 - V_2) * G_2 + I_s = 0$

Node2: $(V_2 - V_1) * G_2 + (V_2 - V_3) * G_3 + V_2 * G_4 = 0$

Node3: $(V_3 - V_1) * G_1 + (V_3 - V_2) * G_3 + V_3 * G_5 = 0$

Expand the equations

Node1: $V_1 * G_1 - V_3 * G_1 + V_1 * G_1 - V_2 * G_2 + I_s = 0$

Node2: $V_2 * G_2 - V_1 * G_2 + V_2 * G_3 - V_3 * G_3 + V_2 * G_4 = 0$

Node3: $V_3 * G_1 - V_1 * G_1 + V_3 * G_3 - V_2 * G_3 + V_3 * G_5 = 0$

Which by inspection becomes

$$\begin{bmatrix} 2G_1 & -G_2 & -G_1 \\ -G_2 & G_2 + G_3 + G_4 & -G_3 \\ -G_1 & -G_3 & G_1 + G_3 + G_5 \end{bmatrix} * \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} -I_s \\ 0 \\ 0 \end{bmatrix}$$

Notice that this matrix is a square, positive definite matrix. In general, this type of equation can be solved using properties of the Inverse and Identity matrix. If you do not remember how to do this, use the next section as a refresher.

V. Matrix Math Refresher

i. **Objective: Refresh basic knowledge of matrix with the end goal of solving a 3x3 system of equations.**

ii. **Definitions:** (Brown 1991)

   a. **Matrix Notation** = A matrix $A_{i,j}$ has *i* rows and *j* columns. If A has four rows and 3 columns, you would describe it as a (4x3) "four by three" matrix, noting that rows are always said first.

   b. **Matrix addition =** The sum A+B of two m-by-n matrices A and B is calculated entrywise: $(A + B)_{i,j} = A_{i,j} + B_{i,j}$, where $1 \le i \le m$ and $1 \le j \le n$.

   c. **Scalar multiplication** = The scalar multiplication cA of a matrix A and a number c is given by multiplying every entry of A by c: $(cA)_{i,j} = c \cdot A_{i,j}$.

   d. **Transpose =** The transpose of an m-by-n matrix A is the n-by-m matrix AT (also denoted Atr or tA) formed by turning rows into columns and vice versa: $(A^T)_{i,j} = A_{j,i}$.

   e. **Multiplication** = an (MxN) matrix times an (NxP) matrix will give a matrix with dimensions (MxP). So, $A_{11} * B_{12} + A_{22} * B_{22}$ = Red Dot (AB_{12})
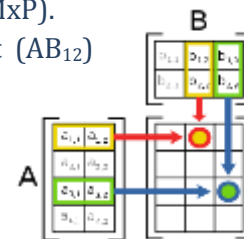
   f. **Square Matrix =** a matrix with equal number of rows and columns.

   g. **Identity Matrix** = a square matrix with ones on diagonal and zeros everywhere else.

   h. **Symmetric Matrix** = a square matrix is symmetric if $A = A^T$

   i. **Inverse Matrix** = all square matrices have matrix inverse such that $A^{-1}*A = I = A*A^{-1}$.

The information above is a brief overview to hopefully jog your memory of key terms and concepts. If you still need more review, there are many very good online tutorials on how to do matrix math.

Example 5.1

Put the system of equations below into matrix form, and then solve for the unknowns using properties of the Identity matrix, Square matrix, and the Inverse Matrix.

$$x + 2y + 2z = 5$$

$$3x - 2y + z = -6$$

$$2x + y - z = -1$$

VI. Wrapping It All Together

Okay great, we solved a network and created some equations, so why is this important? Well, it should be obvious that it would be nice if you could solve these networks automatically rather than by hand. To do that you would use a nodal network solver like GUNNS. But more importantly, how do these networks fit into day to day development on Ts21? Let's take a look at Ts21 development to see how.

Development of a vehicle simulation can be logically split into various subsystems such as thermal, electrical, fluid, and mechanical. Each subsystem would have its own system of equations. The subsystem models would solve their equations during a time step of a simulation, and then pass important information to the other subsystems to use during the next solution time step. For Ts21, two of the subsystems are the electric power subsystem (EPS), and the environmental control and life support group (ECLSS). Models from these two subsystems will often have to pass information between each other in order to operate correctly. For example, pretend that resistor R1 for the circuit in section IV is really a cabin fan model from ECLSS, and the voltage source, is a solar array model from EPS. In real life, the electric network is not static. At each point in time, we have new voltage as the solar arrays change due to the sun angle, and the Cabin Fan resistance would change depending on the speed at which it is spinning, if it is even spinning at all.

If we had computer code to model this situation, the function pseudo code may look like this. We could do incremental steps or changes to the network, and then solve the system of equations. If we do this many times a second, we have a simple and accurate simulation.

One Time step of simulation:

1. Electric model initializes to default configuration and input values..
2. Electric network solves its base solution.
3. Electric model tells the fan it is on or off based on voltage solution at node1.
4. Fan model reads the voltage at node1 to see if it can operate.
5. Since fan model has valid voltage, it initializes to speed of 3000rpms based on its own configuration data, then calculates the correct power drawn at this speed, and its new resistance.
6. Fan model tells the electric model how much power it is using and what its new resistance is.
7. Electric model reads how much power the fan is using.
8. Electric model calculates new currents and voltages based on how much power the fan is using.
9. REPEAT 3 to 7.

As we add more variables to our simulation, such as lights, pumps, and motors to replace the other resistors, the situation becomes more difficult to solve. However, if we put our initial network into a format expected by the GUNNS nodal network solver, it will easily solve a network with more than 100 components and nodes(called links and nodes by gunns). With this many links and nodes, the simulation time step from the previous page would be a lot more complicated. You would use a simulation scheduler like TRICK to make the task feasible.

You can see why the GUNNS network is an amazing tool. However, it can still take a long time to construct a network by hand. Imagine telling computer code that resistor R1 from section IV connects to node1, node 3, and has a resistance of 20 ohms.

Imagine doing this for every electrical component and putting that information into computer code for hundreds of links and nodes. It is not impossible, but it is time consuming even for a small drawing. Plus, the circuits will only get bigger as we try to model an entire vehicle. Here is an example of what a GUNNS initialize method looks like once it is setup for the circuit in section IV.

Sample of initialization code for GUNNS network

```
///////////////////////////////////////////////////////////////////////
/// @return    void
///
/// @details   Simulation initialization task for the EpsTestCircuitElect Net
node,
///            and link objects are initialized with their config and input data
///////////////////////////////////////////////////////////////////////
EpsTestCircuitElect::initialize(const std::string& name)
{
/// - Initialize the nodes.
    EpsTestCircuitElectNodes[0].initialize(name + "Node1", 0.0);
    EpsTestCircuitElectNodes[1].initialize(name + "Node2", 0.0);
    EpsTestCircuitElectNodes[2].initialize(name + "Node3", 0.0);
    EpsTestCircuitElectNodes[3].initialize(name + "Node4 (GROUND)");
    EpsTestCircuitElectNetwork.initializeNodes(EpsTestCircuitElectNodeList);
/// - Initialize the Links.
    EpsTestCircuit.clear();
    R1.initialize(R1Config, R1Input, EpsTestElectLinks, NODE1, NODE2);
    R2.initialize(R2Config, R2Input, EpsTestCircuitElectLinks, NODE1, NODE3);
    R3.initialize(R3Config, R3Input, EpsTestCircuitElectLinks, NODE2, NODE3);
    R4.initialize(R4Config, R4Input, EpsTestCircuitElectLinks, NODE2, GROUND);
    R5.initialize(R5Config, R5Input, EpsTestCircuitElectLinks, NODE3, GROUND);
    VltgSrc.initialize(VltgSrcConfig, VltgSrcInput, EpsTestCircuitElectLinks,GROUND,NODE1);

}
```

Creates a way to store all of the nodes you care about.

Component configuration, ex: a resistor's resistance or a voltage source's voltage setpoint

Input data, ex: short circuit component or efficiency of voltage source

Component names

The nodes a link is connected to.

After the network is setup this way, GUNNS will automatically do all of the manual solution procedure that you did by hand. It would be nice if we could go from our initial drawing on section IV, and have the required code be created from it. This desired optimization is the basis of GunnShow.

GunnShow is a graphical method of creating GUNNS networks which aims to speed up network creation, documentation, and maintenance. From here on out, you will

- learn how to create the circuit from section IV using GunnShow.
- practice creating GUNNS networks in GunnShow from real vehicle schematics.

VII.   GunnShow in Practice

To make a GUNNS network, you first need to convert a real world physical problem into a meaningful combination of links and nodes which will model that problem. In section IV, we used a random circuit which consisted of only two types of electrical components: resistors and voltage sources. We will practice creating that circuit here using GunnShow. But as you go, keep in mind that there are many circuit components. Every component or link will simplify down to an object that has a conductance that is added to and affects the admittance matrix in some way. For example, a switch component has zero conductance if the switch is open, but behaves like a resistor component when the switch is closed. A diode component has conductance when current flows in one direction, but has zero conductance when the current flows opposite that direction. The decisions which go into designing and deciding to use your own GUNNS links are beyond the scope of this document, but help is available elsewhere. For now, we will use just the two initial link types, and begin creating the network from section IV in Gunnshow.
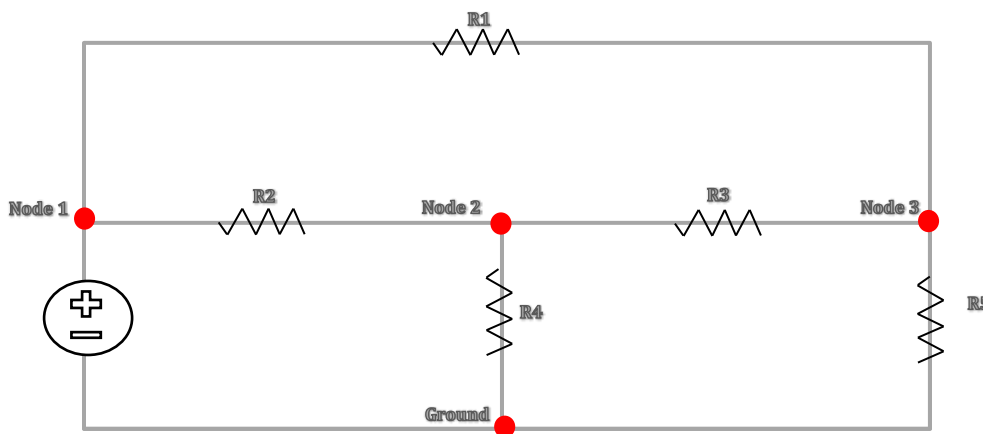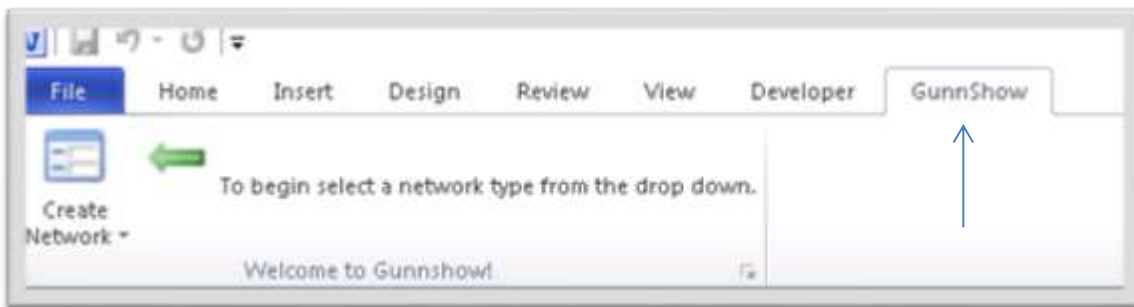

Here is the network from before. To make this in GunnShow, do the following.

Step 1: open a Microsoft Visio application version 2010 with GunnShow installed.
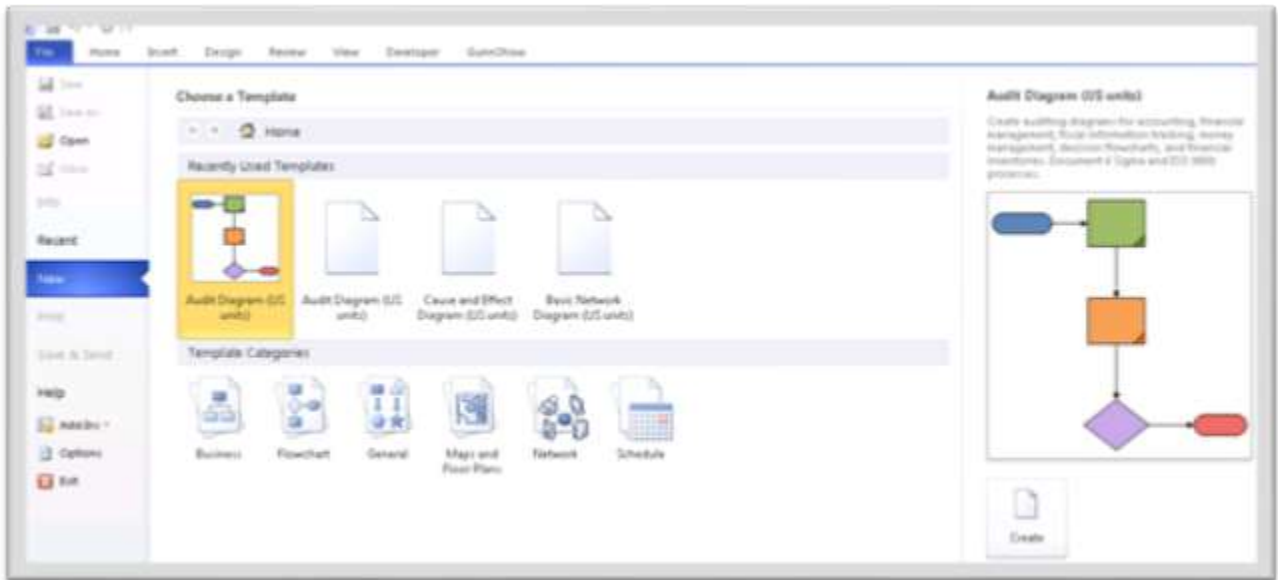
Step2: click on the GunnShow tab in the toolbar and click Create New drawing. If you cannot see the GunnShow toolbar, consult the troubleshooting area.


Step3: Select the type of network you want to create, fluid or electric. For this example choose electric. A default template will load. Click Save As and save the template with a new to a location of your choosing on your hard drive.
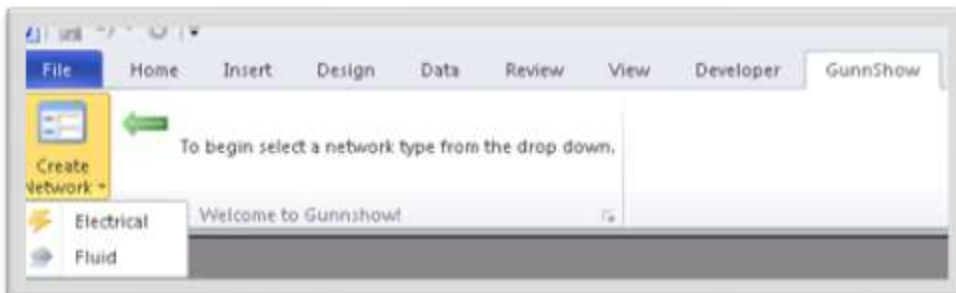
Step4: Familiarize yourself with the GunnShow toolbar. Each section or button will display a tooltip to help you with its use if you hover over it. As a broad summary, you will drag drop and connect links and nodes using the model libraries of shapes. The model libraries are Visio stencils which contain shapes for each type of link currently available to GunnShow. You use a connector tool to connect connection point from nodes to a link until you are finished drawing. When you are finished drawing, you export the network and it will automatically generate GUNNS header and source files.
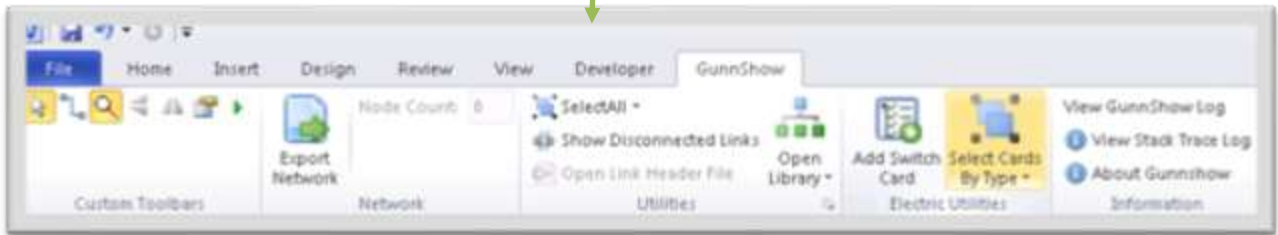
Step 5: open the electric model library. Visio has stencils, which contain many shapes. The Electrical and Fluid stencils have been preloaded with GunnShow shapes you can use.
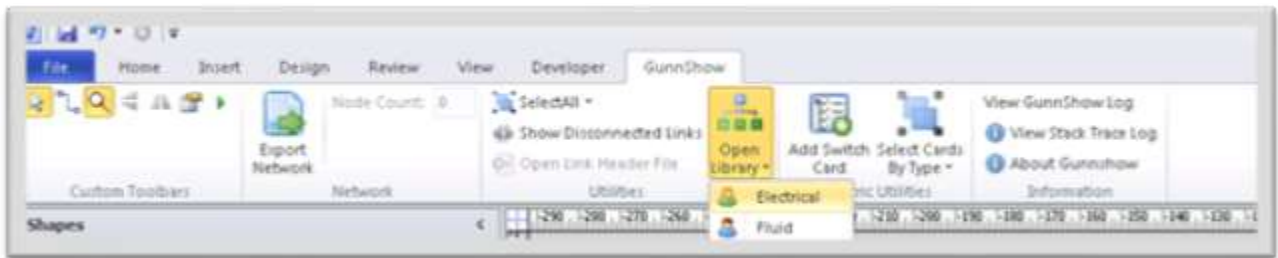
**Step 6:** At this point your page should look something similar to this.
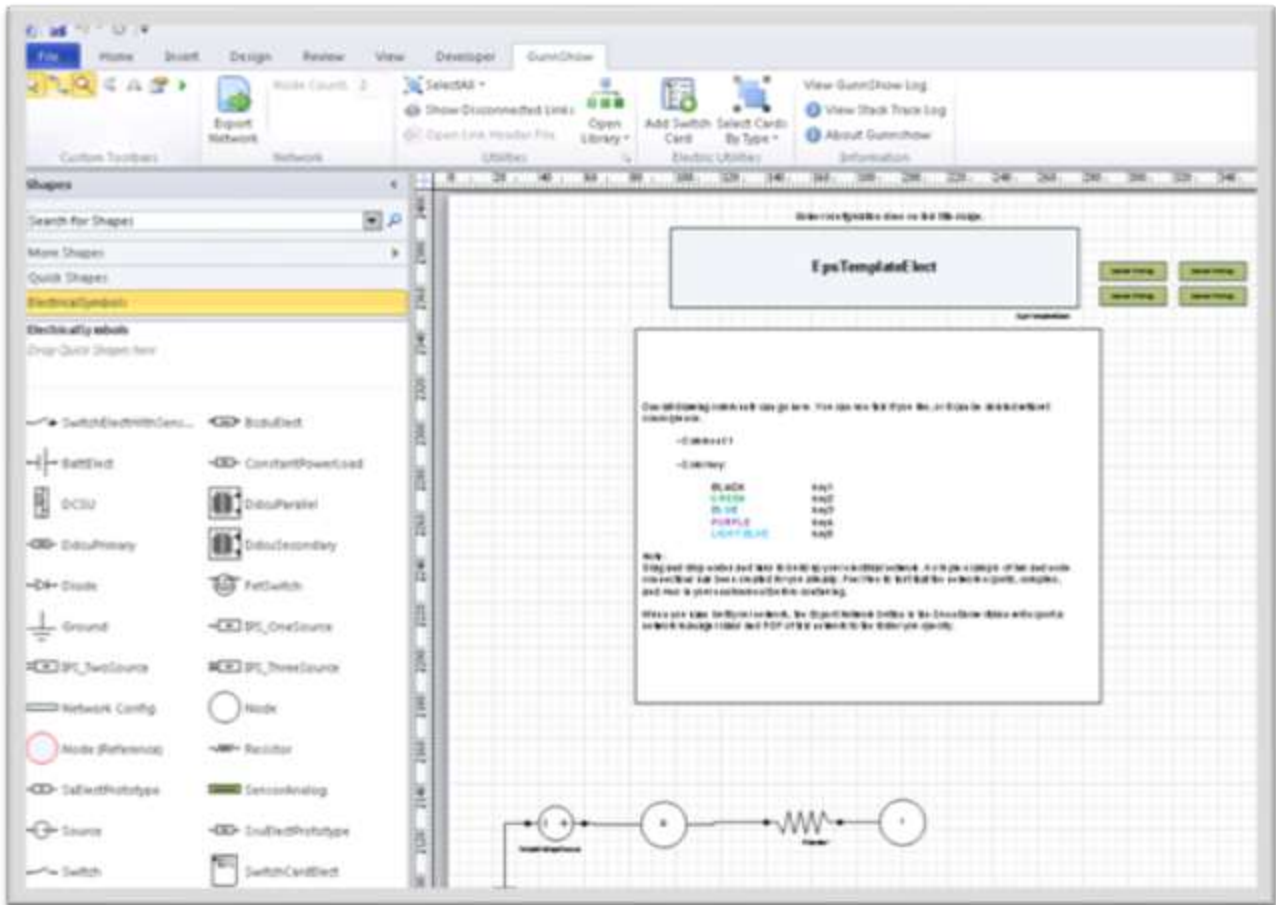
Step 7: Delete all of the shapes leaving the big blue title bar. Then, right click on the title bar and click view shape data. This will toggle a screen that shows any embedded data on a shape which you can edit.. Change the visio name to whatever you desire.
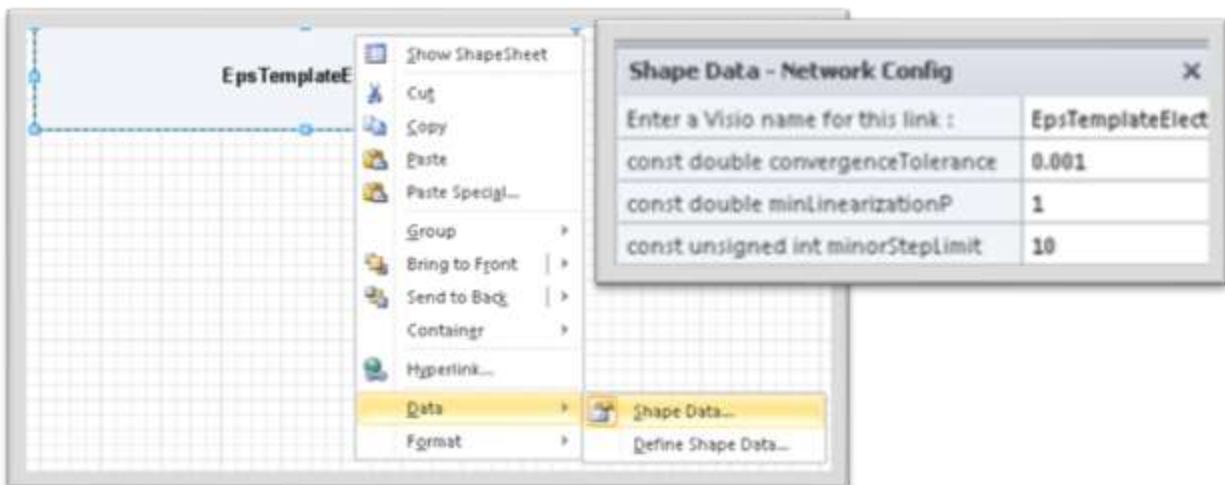
Step 8: Double click the title bar and change the text to match the name you gave in the network configuration data.
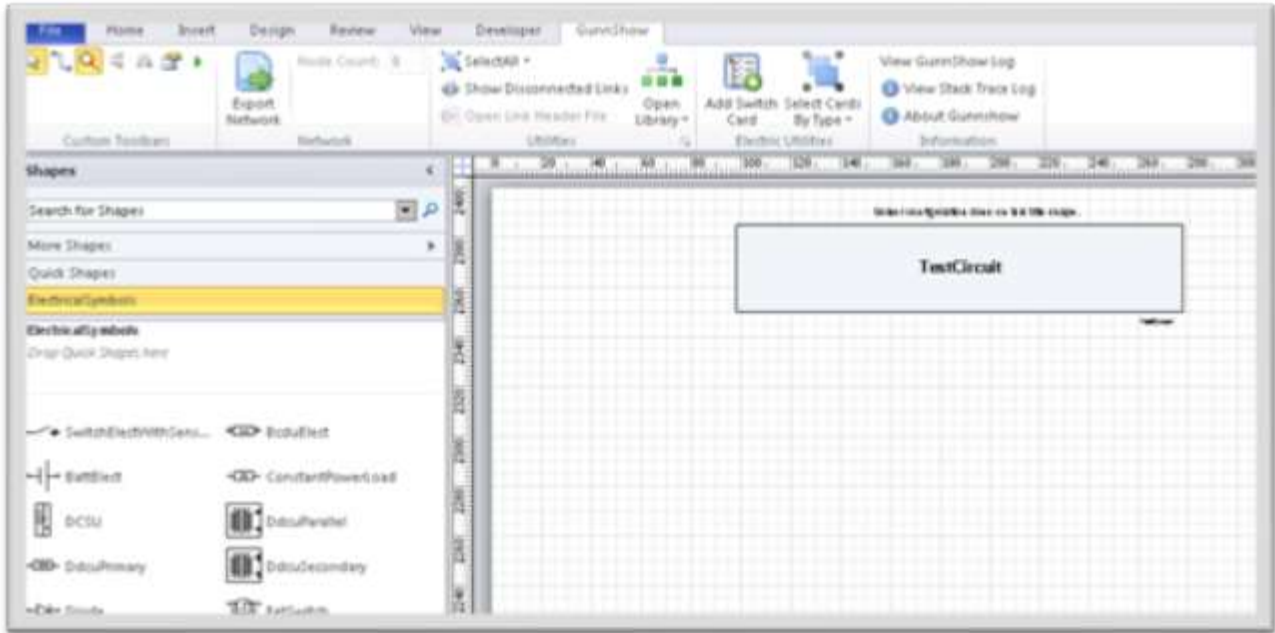

Step 9: Place all the correct shapes onto the page. Use the select all tool to select resistors, and then give them all a 0.1 conductance value. When multiple shapes are selected, data that the shapes have in common is displayed in the shape data window. Editing a field applies the change to all shapes.
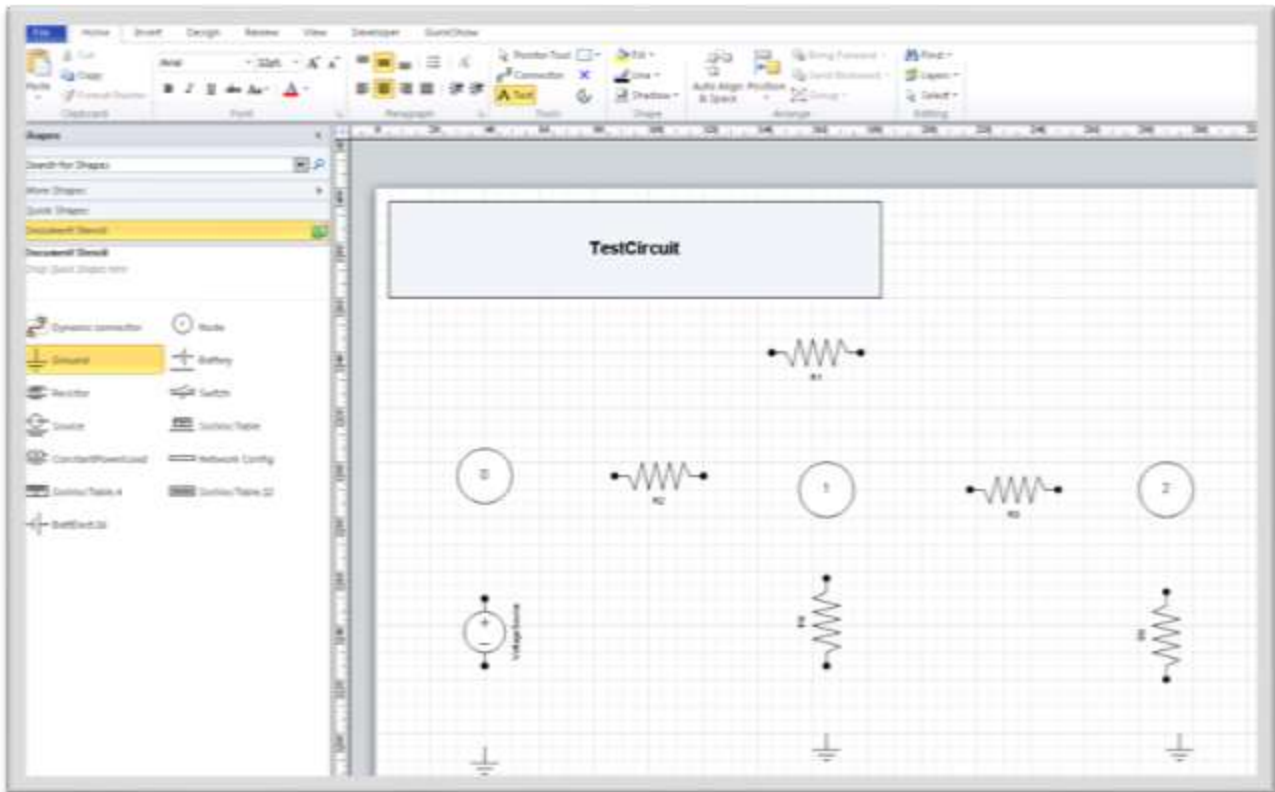
Step 10: Click on the Home tab, and then select the connector tool. This tool is used to associate two shapes to each other by connecting them together. You will connect shapes together using any of the "x" connection points. Starting at one "x", left click and drag to another "x" on a different shape. When your mouse pointer is over a connection point, a small red box will appear. When this happens let go of the left click and the shapes will be connected.

- Multiple lines can be connected to the same connection point on a Node
- Links must only have one connector line per connection point
- Be careful to watch for disconnected links (broken connections).
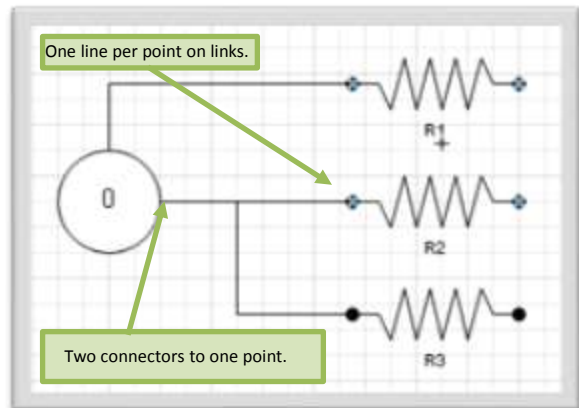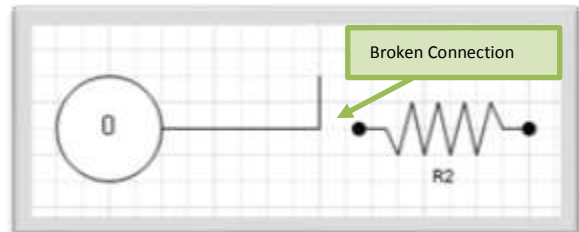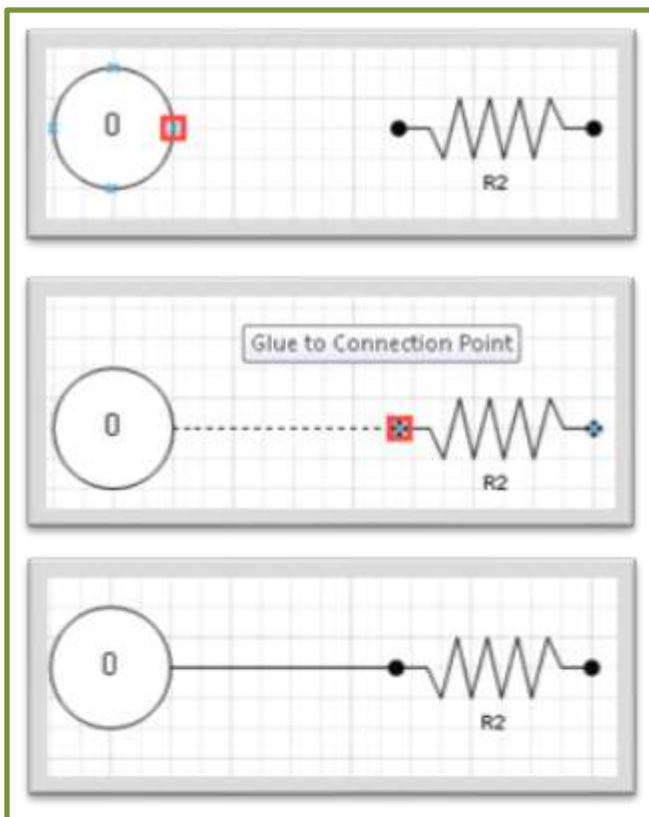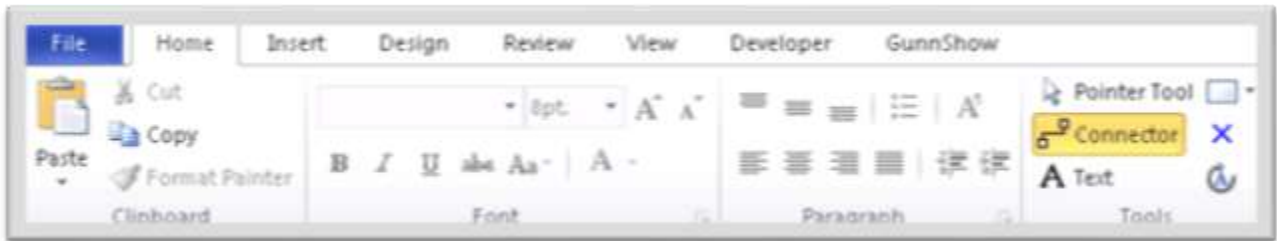
Step 11: Your drawing should look like this when it is all connected. Note that there can be many ground shapes. The ground shape references the common electrical potential. You could have drawn one ground shape, and connected the three lines to it, or you can do three ground shapes. Either method accomplishes the same thing.
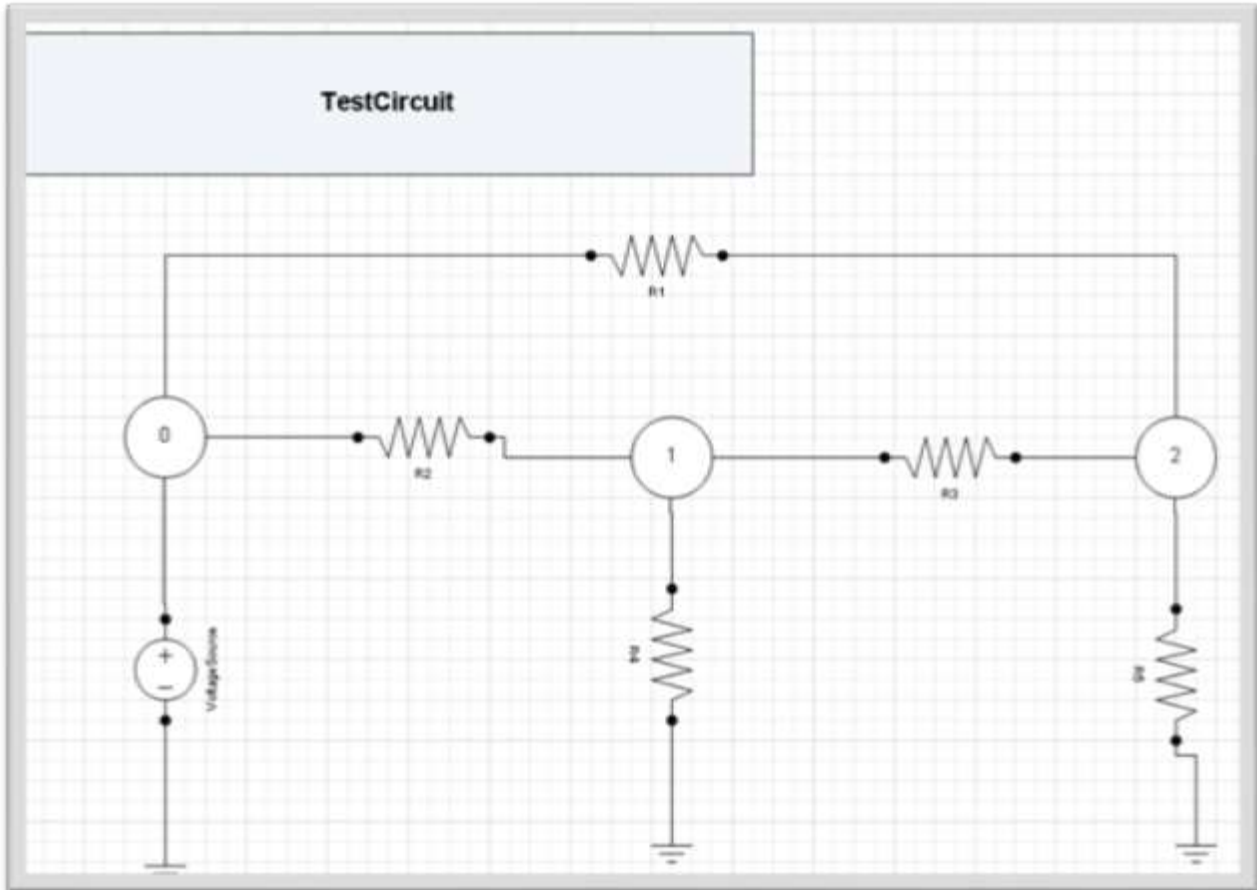
Step 12: Now we are almost finished. In the GunnShow tab, click the Export Network button and choose a path. The default path is the location that you saved the drawing to. This button will take your drawing, and generate the appropriate GUNNS manager files. If you have an error during export, see the troubleshooting appendix for help.
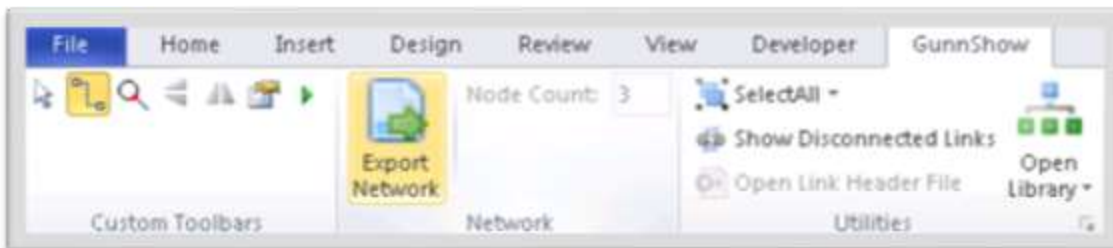
VIII. Conclusion

At this point, you have covered the basic steps you need to work with GunnShow. Go explore the two manager generated files. After completing tutorials for Trick and GUNNS, you should know what to do with them. You can find more information in the GunnShow documentation for help with

- Working with specific shapes
- Working with fluid drawings
- Troubleshooting GunnShow networks
- Integrating GUNNS header files with a TRICK simulation
- GunnShow advanced topics.

IX.   References

1. Hambley, Allan R. "1. Introduction." Electrical Engineering: Principles and Applications. 4th ed. Upper Saddle River: Pearson, 2008. 3-46. Print.

2. Hambley, Allan R. "2. Resistive Circuits." Electrical Engineering: Principles and Applications. 4th ed. Upper Saddle River: Pearson, 2008. 47-90. Print.

3. Brown 1991, Chapter I.1. Alternative references for this book include Lang 1987b and Greub 1975