Course 1: How to solve circuits the right way – once and for all!

The Joys of Circuit Analysis

Course 1: How to solve circuits the right way – once and for all!

Based on my book:

"Fast Analytical Techniques in Electrical and Electronic Circuits"
Published by Cambridge University Press, 2002.

Course 1: How to solve circuits the right way – once and for all!

Lecture 1

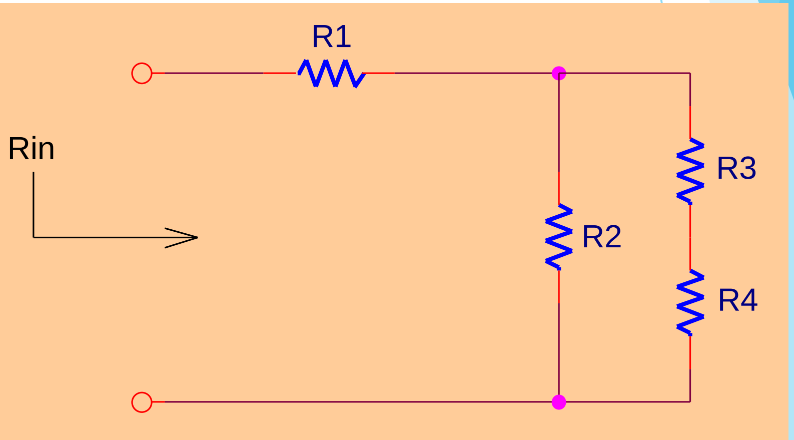
1. Meaningful and meaningless solutions to circuits.
2. Painful circuit analysis.
3. Painless and joyful circuit analysis.
4. Excruciating circuit analysis.
5. More joyful circuit analysis.
6. Dr. R.D. Middlebrook's Legacy.

Lecture 1

Meaningful and meaningless expressions

Example 1: *A Meaningful* solution to the input resistance of a very simple circuit is given by:

$$R_{in} = R_1 + R_2 \,||\, (R_3 + R_4)$$



This is a *meaningful* solution because it is an *analytical* expression in which the circuit elements are grouped together in series and parallel combinations which mirror the physical circuit.

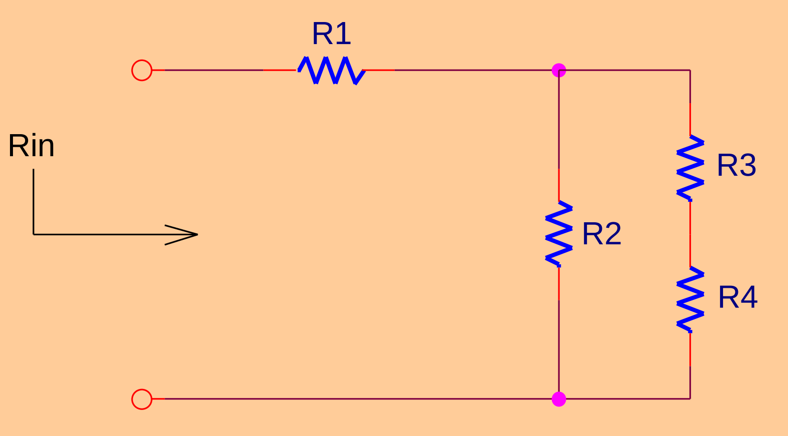
It is *meaningful* because it gives you an idea of what the circuit looks like even if you do not see the circuit.

Lecture 1

Meaningful and meaningless expressions

Example 2: *A Meaningless*, but nevertheless *correct*, solution to the input resistance of this same circuit is given by:

$$R_{in} = \frac{R_1R_2 + R_1R_3 + R_1R_4 + R_2R_3 + R_2R_4}{R_2 + R_3 + R_4}$$



It is *meaningless* because the grouping of the resistors in this expression says nothing about the structure of the circuit. If you do not see the circuit, you have no clue What is going on just by looking at the expression above!

It is *meaningless* because this expression cannot be approximated *easily* if for example $R_4 >> R_3$ or $R_4 >> R_3, R_2$.

It is *meaningless* and it is the result of *painful* circuit analysis which is the only kind of circuit analysis that you know, are learning now or, worse, teaching it to some undergraduate.

Lecture 1

Meaningful and meaningless expressions

Example 3: Approximate the *meaningful* expressions for $R_4 >> R_3$ and $R_4 >> R_3, R_2$

$$R_{in} = R_1 + R_2 \| (R_3 + R_4)$$

If $R_4 >> R_3$, then quite *obviously*, by simple arithmetic, we have:

$$R_{in} = R_1 + R_2 \| (R_3 + R_4)$$
$$\approx R_1 + R_2 \| R_4$$

If $R_4 >> R_3$ and $R_4 >> R_3, R_2$, then the smaller of two resistances in parallel dominates the parallel combination so that we have:

$$R_{in} = R_1 + R_2 \| (R_3 + R_4)$$
$$\approx R_1 + R_2 \| R_4$$
$$\approx R_1 + R_2$$

Lecture 1

Meaningful and meaningless expressions

Example 4: Approximate the *meaningless* expressions for $R_4 >> R_3$ and $R_4 >> R_3, R_2$

$$R_{in} = \frac{R_1R_2 + R_1R_3 + R_1R_4 + R_2R_3 + R_2R_4}{R_2 + R_3 + R_4}$$
$$= \frac{R_1R_2 + R_3(R_1 + R_2) + (R_1 + R_2)R_4}{R_2 + R_3 + R_4}$$
$$= \frac{R_1R_2 + (R_1 + R_2)(R_3 + R_4)}{R_2 + R_3 + R_4}$$

First, factor out $R_4 + R_3$ so that you can apply the approximation $R_4 >> R_3$

$$\approx \frac{R_1R_2 + (R_1 + R_2)(R_4)}{R_2 + R_4}$$

Apply approximation

$$= \frac{R_1(R_2 + R_4) + R_2R_4}{R_2 + R_4}$$
$$= R_1 + \frac{R_2R_4}{R_2 + R_4}$$
$$= R_1 + R_2 \| R_4$$

Do more algebra if you want to make any sense of the result!

An awful lot of algebra just to get the first approximation!!

Painful!

Lecture 1

Meaningful and meaningless expressions

Q. Where did the meaningless solution come from?

A. To be honest, for this simple circuit, *anyone* of you would have the meaningful answer right away. But, if the circuit was more complicated, then you would have had no choice but to write the nodal equations as follows:

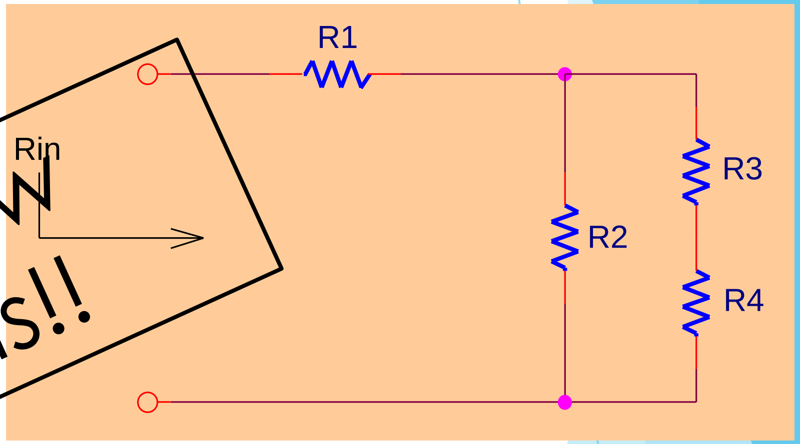
$$V_1\frac{1}{R_1}-V_2\left(\frac{1}{R_2}+\frac{1}{R_1}+\frac{1}{R_3+R_4}\right)=0$$

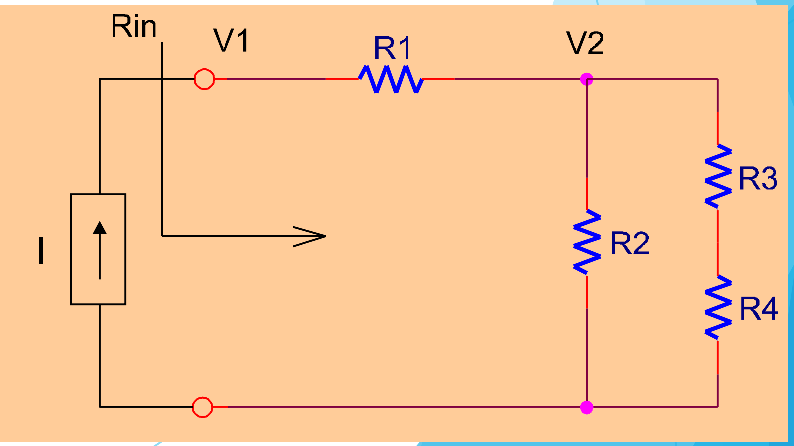
$$V_1\frac{1}{R_1}-V_2\frac{1}{R_1}=I$$

Inverting the above, we get:

$$\frac{V_1}{I}=\frac{\frac{1}{R_2}+\frac{1}{R_1}+\frac{1}{R_3+R_4}}{\begin{vmatrix}\frac{1}{R_1} & -\left(\frac{1}{R_2}+\frac{1}{R_1}+\frac{1}{R_3+R_4}\right)\\ \frac{1}{R_1} & -\frac{1}{R_1}\end{vmatrix}}=R_{in}=\frac{R_1R_3+R_1R_4+R_1R_2+R_2R_3+R_2R_4}{R_2+R_3+R_4}$$

And that is how @#it happens!!





Lecture 1

Meaningful and meaningless expressions

I am going to show you that you will never have to write another nodal or loop equation again no matter how complicated a circuit gets!

You will learn how to break a complicated circuit into a number of smaller and very simple circuits for each of which you will be able to write its input resistance, gain, or whatever appropriate characteristic just by inspection. You will then learn how to assemble the solution of the complicated circuit from the solutions of the individual simple circuits. The solution that you will get in this manner will be meaningful as you will see throughout the coming lectures.

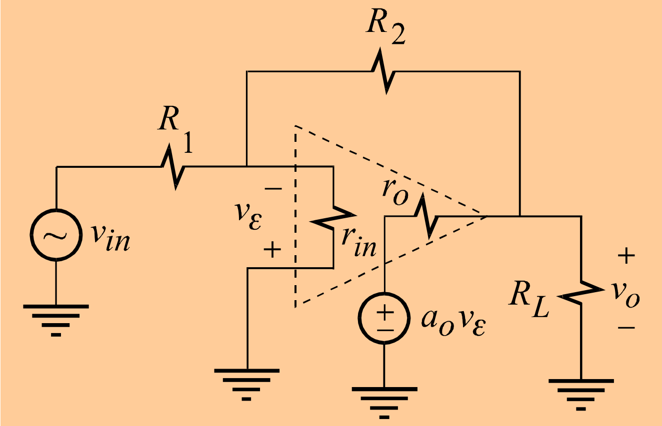
Before doing that, let us compare other types of meaningful and meaningless expressions.

Lecture 1

Meaningful and meaningless expressions

***Example 5*:** A *meaningless* expression of the voltage gain of a non-ideal inverting amplifier:

$$H = \frac{(r_o - R_2 a_o) R_L r_{in}}{R_1 r_{in}\left(r_o + R_L(1+a_o)\right) + (R_1 + r_{in})\left(R_L r_o + R_2(r_o + R_L)\right)}$$



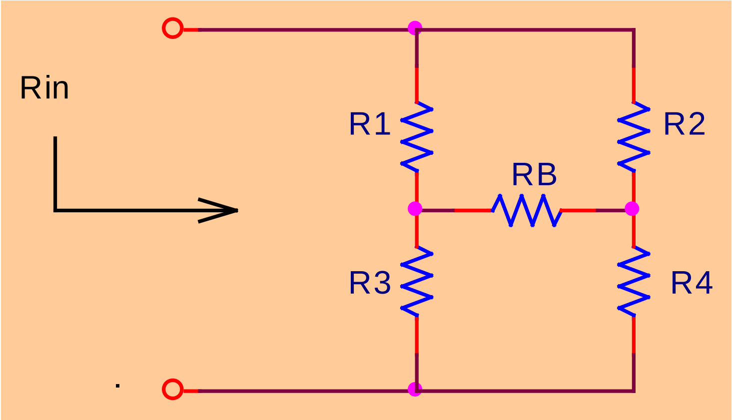
***Example 6*:** The same expression of the voltage gain above *obtained* in meaningful form:

$$H = -\frac{R_2}{R_1}\frac{1 - \dfrac{r_o}{a_o R_2}}{1 + \dfrac{1}{a_o}\left(1 + \dfrac{r_o}{R_L}\right)\left(1 + \dfrac{R_2 + R_L \| r_o}{R_1 \| r_{in}}\right)}$$

Lecture 1

Painful analysis of a simple bridge circuit

***Example 7*:** Determine the input resistance of the resistive bridge circuit shown.



R_{in} is not obvious and cannot be written easily as in the first example.

Lecture 1

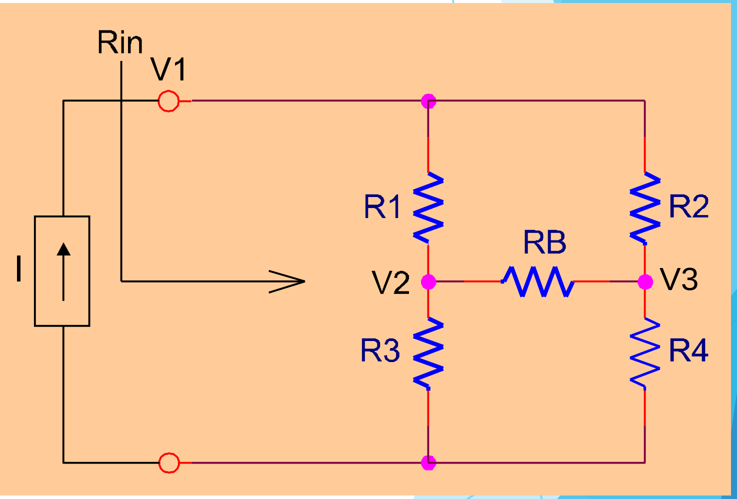
Painful analysis of a simple bridge circuit

Example 7: *(cont.)*

The nodal equations for this circuit are as follows:

$$V_1(G_1+G_2)-V_2G_1-V_3G_2=I$$
$$-V_1G_1+V_2(G_1+G_3+G_B)-V_3G_B=0$$
$$-V_1G_2-V_2G_B-V_3(G_2+G_4+G_B)=0$$

$$G_i=\frac{1}{R_i}$$



Which corresponds to the following matrix equation:

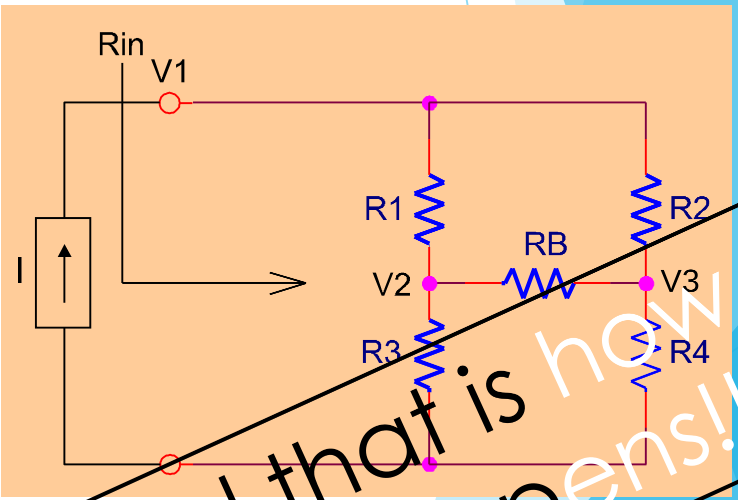
$$\begin{bmatrix} G_1+G_2 & -G_1 & -G_2 \\ -G_1 & G_1+G_3+G_B & -G_B \\ -G_2 & -G_B & G_2+G_4+G_B \end{bmatrix}\begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}=\begin{bmatrix} I \\ 0 \\ 0 \end{bmatrix}$$

Lecture 1

Painful analysis of a simple bridge circuit

Example 7: (*cont.*)

To determine the input resistance, you solve for V_1 in terms of the excitation current I using Cramer's rule:



$$R_{in} = \frac{V_1}{I} = \frac{\begin{vmatrix} G_1 + G_3 + G_B & -G_B \\ -G_B & G_2 + G_4 + G_B \end{vmatrix}}{\begin{vmatrix} G_1 + G_2 & -G_1 & -G_2 \\ -G_1 & G_1 + G_3 + G_B & -G_B \\ -G_2 & -G_B & G_2 + G_4 + G_B \end{vmatrix}}$$

So, if you are looking for a meaningful solution, like the one you got for the simpler circuit earlier, then you see that pretty much all bets are off. Expanding each of the determinants above is pretty nasty as you would guess.

This is how you get meaningless solutions.

This is what I call painful analysis. It is what you learned. It is what you are learning now. It is what you are teaching.

And that is how @#it happens!!

Lecture 1

You need therapy to alleviate this pain

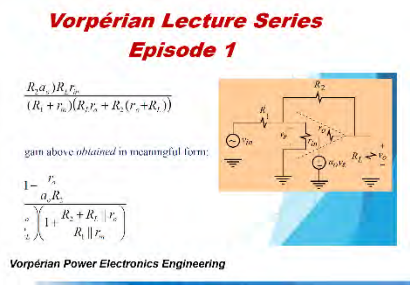
You need painless circuit analysis

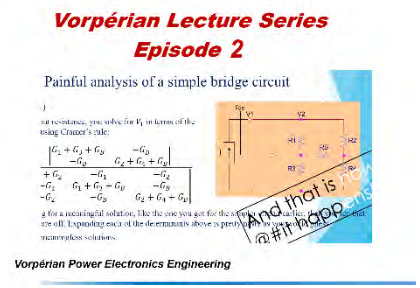
You need to learn about the joys of circuit analysis

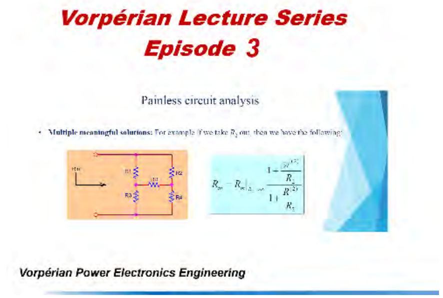
You need to listen to what I have to say in the next example

You need to listen to all my lectures

Complete Vorperian Lecture Notes







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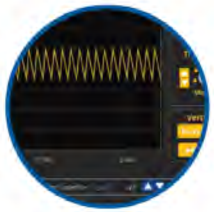

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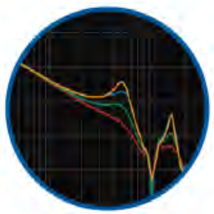

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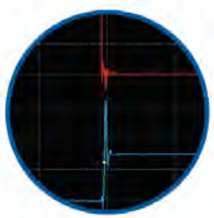

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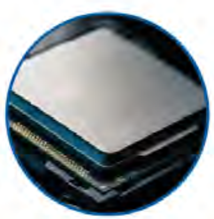

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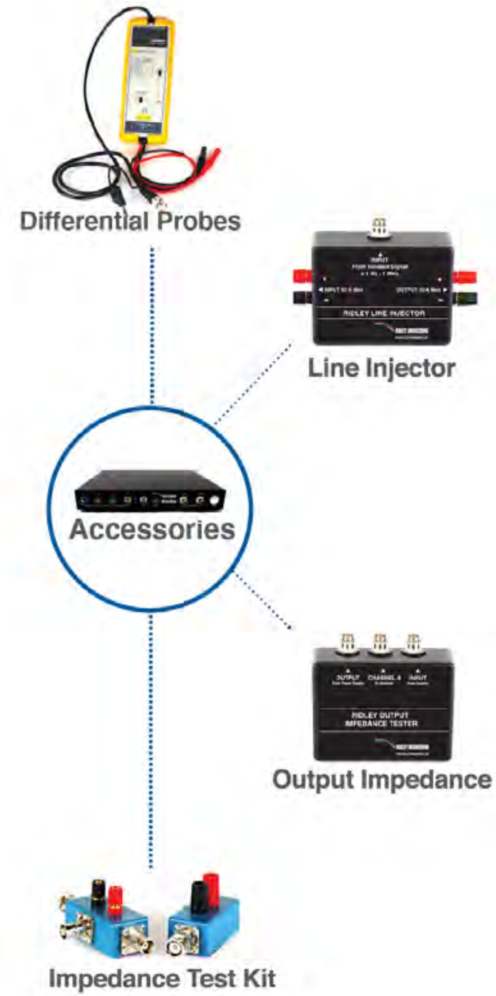

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