Vorpérian

Vorpérian Power Electronics Engineering

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

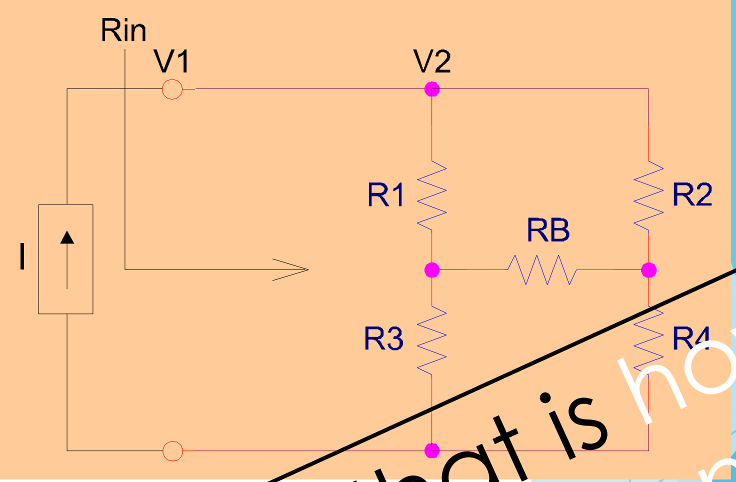
1. Meaningful and meaningless solutions to circuits.
2. Painful circuit analysis.
3. Painless and joyful circuit analysis.
4. Excruciating circuit analysis.
5. More joyful circuit analysis.
6. Dr. R.D. Middlebrooks's Legacy.

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.

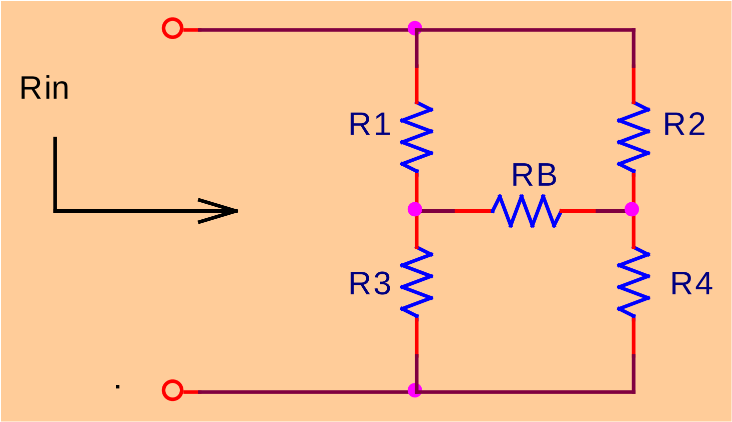
This is what I call painful analysis. It is what you learned. It is what you are learning now. It is what you are teaching.

And that is how @#it happens!!

Lecture 1

Four Steps to
Painless Analysis of a Simple Bridge Circuit

Example 1: Determine the input resistance for the bridge circuit



Lecture 1

Painless circuit analysis

STEP 1

Take out the element that is causing you pain. In the bridge circuit, the bridge resistance, R_B, is certainly one such element.

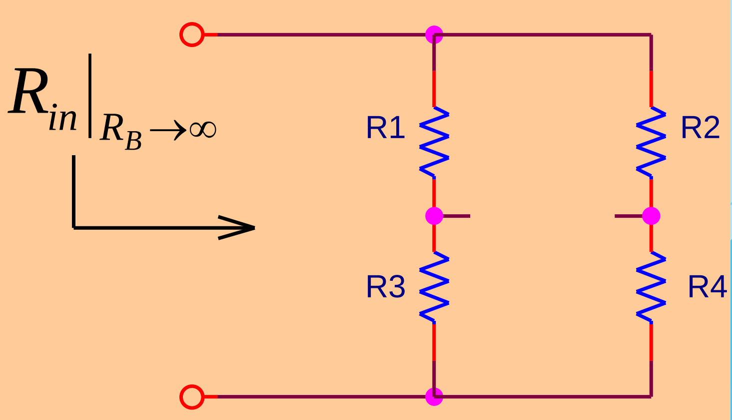
You can take out, R_B, either as an *open* or a *short*.

Let us take it out as an open.

You can now write, the input resistance right away:

$$R_{in}\Big|_{R_B\to\infty} = (R_1 + R_3)\,||\,(R_2 + R_4)$$

Partial credit answer!



Lecture 1

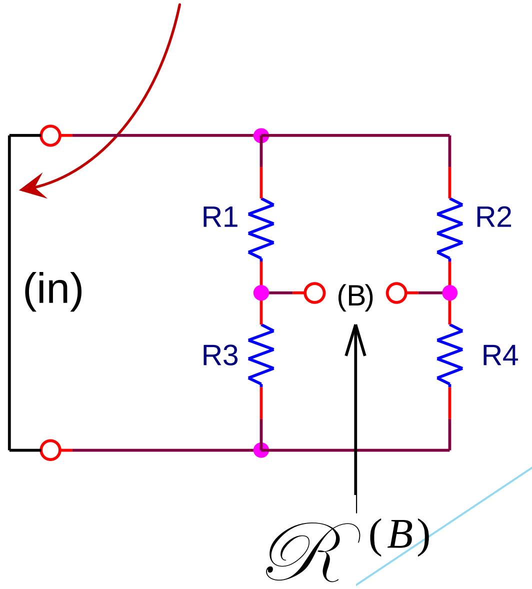
Painless circuit analysis

STEP 2

Find the resistance looking back into the bridge circuit from the same port where you took out R_B - let us call it port (B) - with the *input* port SHORT-circuited.

You can write this one right away as well:

$$\mathscr{R}^{(B)} = R_1 \,||\, R_3 + R_2 \,||\, R_4$$



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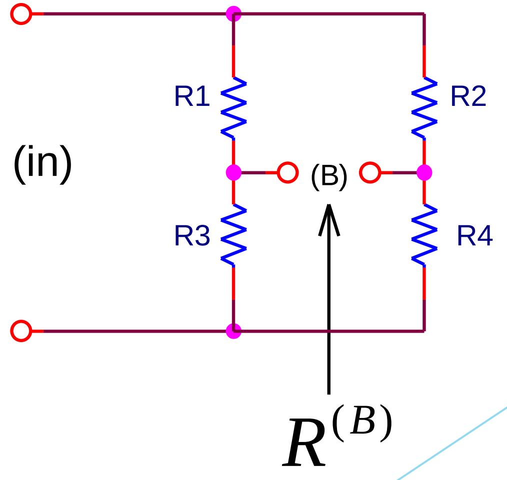
Painless circuit analysis

STEP 3

Find the resistance looking back into the bridge circuit from the same port where you took out R_B, port (B), with the *input* port OPEN-circuited.

You can write this one right away as well:

$$R^{(B)} = (R_1 + R_2) \,||\, (R_3 + R_4)$$



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Painless circuit analysis

STEP 4

Obtain the input resistance by assembling the three separate calculations according to this formula known as the Extra Element Theorem (EET):

$$R_{in} = R_{in}\big|_{R_B\to\infty} \frac{1+\dfrac{\mathscr{R}^{(B)}}{R_B}}{1+\dfrac{R^{(B)}}{R_B}}$$

$$R_{in} = (R_1+R_3)\,||\,(R_2+R_4)\frac{1+\dfrac{R_1\,||\,R_3+R_2\,||\,R_4}{R_B}}{1+\dfrac{(R_1+R_2)\,||\,(R_3+R_4)}{R_B}}$$

And that is the exact, *meaningful* answer! *Painless* – isn't it?

Lecture 1

Painless circuit analysis

DISCUSSION

- **Minimum algebra** – none in this case because all the components of the analytical solution were obtained just by looking at the circuit. This is why I call this *painless* circuit analysis.
- **Meaningful solution – approximations:** The circuit components are grouped in series and parallel combinations. This leads to very useful approximations when typical relative magnitudes of the components are known. We will show this next.
- **Meaningful solution – parametric analysis:** The analytical answer we got shows the dependence of the input resistance on the value of the bridge resistor R_B. If we wanted to study the dependence of the input resistance on any one of the other four resistors, we could have taken that one out and applied the four steps of painless analysis.
- **Multiple meaningful solutions:** One for each resistor! We will show this shortly.

Lecture 1

Painless circuit analysis

DISCUSSION

- **Robustness** – Because the answer is obtained from ***three, short and independent*** calculations rather than a ***single, long*** sequence of algebraic steps involving multiplication, substitution, subtraction and what have you.

  If you make a mistake somewhere in the ***long algebraic sequence of steps*** required of nodal analysis, then that mistake will *propagate* and *diffuse* throughout the algebra all the way to the final answer. It is like you know what hit the fan! To correct that mistake you will have to go through all the remaining steps up until the final answer!

  In contrast, if you make a mistake using this new painless method, then your mistake will remain confined to one component of the solution and will not diffuse throughout the entire analysis! To fix the error, all you need to do is fix that component only. Painless analysis is modular!

Lecture 1

Painless circuit analysis

DISCUSSION

- **Approximations** – let us assume that in a certain application we have the following typical values of the resistors.

Example 2:

$$R_1, R_4 \approx 2\text{k}\Omega \qquad R_2, R_3 \approx 100\text{k}\Omega \qquad R_B \approx 300\text{k}\Omega$$

$$\frac{R_1 \| R_3 + R_2 \| R_4}{R_B} \approx \frac{4}{300}$$

$$\frac{(R_1 + R_2) \| (R_3 + R_4)}{R_B} \approx \frac{50}{300}$$

$$R_{in} = (R_1 + R_3) \| (R_2 + R_4) \frac{1 + \dfrac{R_1 \| R_3 + R_2 \| R_4}{R_B}}{1 + \dfrac{(R_1 + R_2) \| (R_3 + R_4)}{R_B}}$$

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Painless circuit analysis

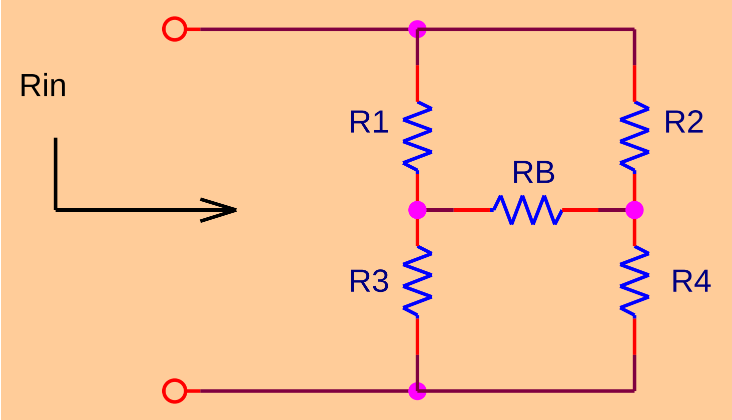
DISCUSSION

- **Approximations** – we now have the following successive approximations:

$$R_{in} \approx \frac{(R_1 + R_3)\,||\,(R_2 + R_4)}{1 + \dfrac{(R_1 + R_2)\,||\,(R_3 + R_4)}{R_B}}$$

$$\approx \frac{R_3\,||\,R_2}{1 + \dfrac{R_2\,||\,R_3}{R_B}} = \frac{1}{\dfrac{1}{R_3\,||\,R_2} + \dfrac{1}{R_B}}$$

$$= R_3\,||\,R_2\,||\,R_B$$



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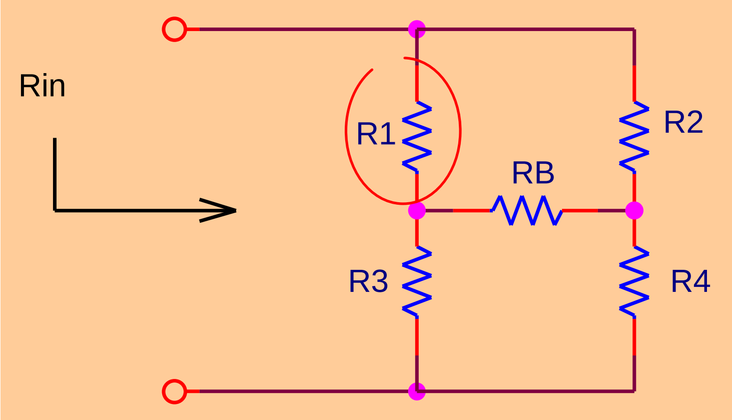
Painless circuit analysis

DISCUSSION

- **Parametric analysis** – Let us suppose that we wanted to study the dependence of the input resistance on another resistor, R_1. Since this method of analysis allows us to take out any circuit element and then reinstate in the final answer using the EET formula, we can choose the element to take out to be the one with respect to which we want to study the sensitivity of the input resistance.



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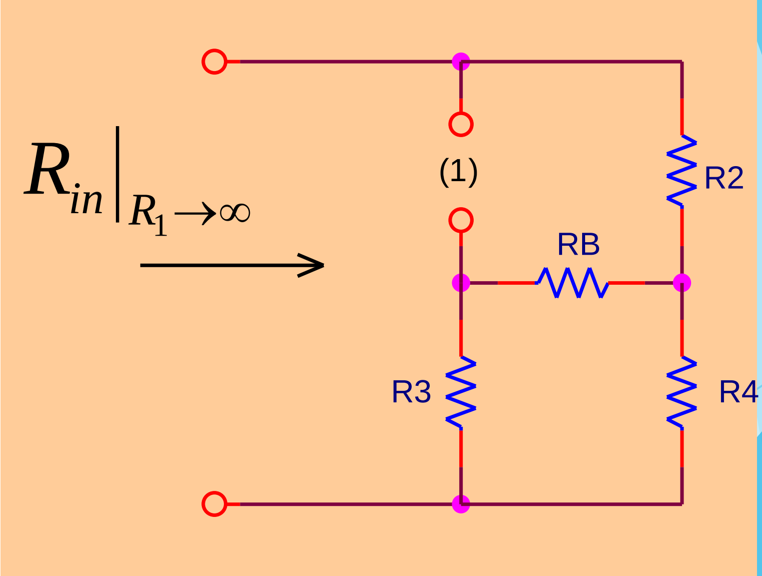
Painless circuit analysis

***Example 3*:** Determine the input resistance with R_1 as a parameter:

STEP 1

Take R_1 out as an open circuit.

$$R_{in}\Big|_{R_1\to\infty} = R_2 + R_4 \,||\, (R_B + R_3)$$



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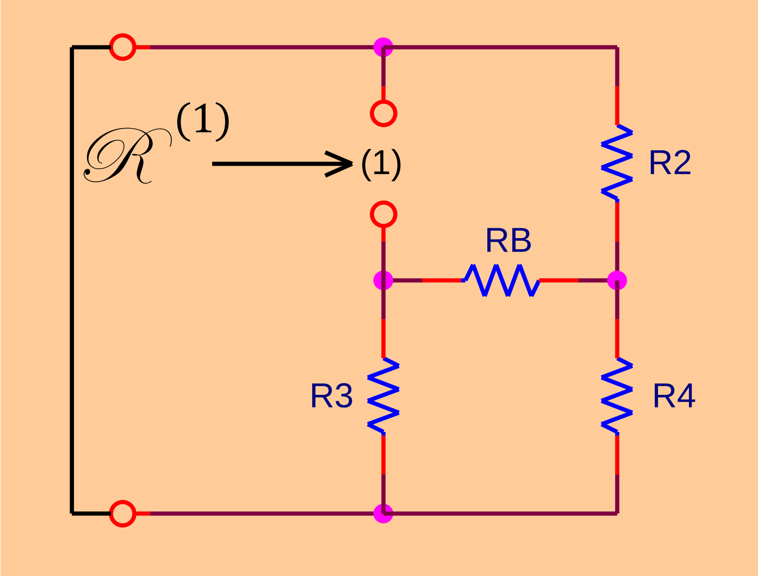
Painless circuit analysis

STEP 2

Determine the resistance looking into port (1)
with the input port SHORT.

$$\mathscr{R}^{(1)} = R_3 \,||\, (R_B + R_4 \,||\, R_2)$$



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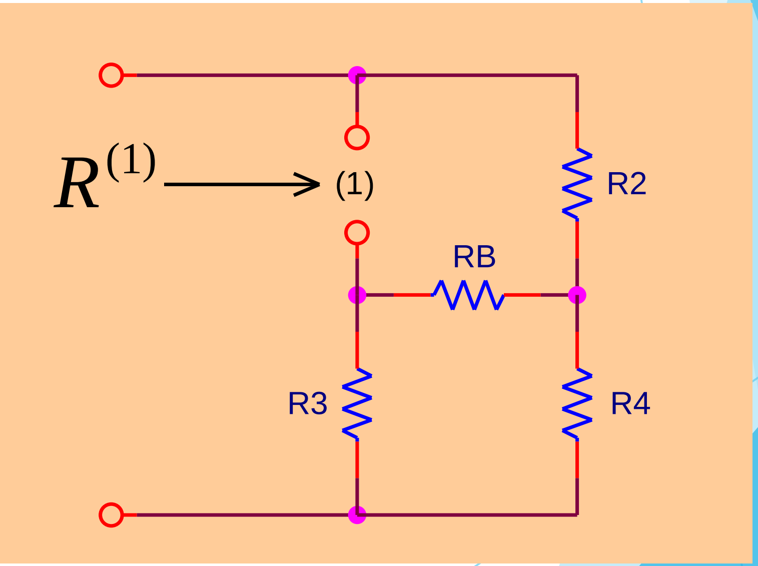
Painless circuit analysis

STEP 3

Determine the resistance looking into port (1) with the input port open.

$$R^{(1)} = R_2 + R_B \parallel (R_4 + R_3)$$



Lecture 1

Painless circuit analysis

STEP 4

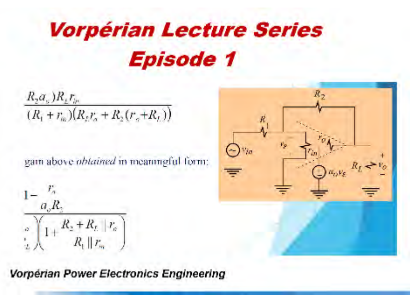
Obtain the input resistance by assembling the three separate calculations according to this formula known as the Extra Element Theorem (EET):

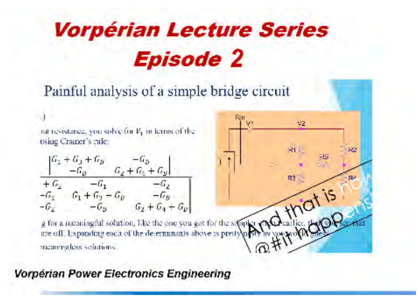
$$R_{in} = R_{in}\Big|_{R_1\to\infty} \frac{1+\dfrac{\mathscr{R}^{(1)}}{R_1}}{1+\dfrac{R^{(1)}}{R_1}}$$

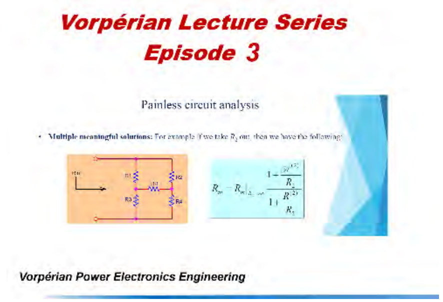
$$R_{in} = \left(R_2 + R_4 \parallel (R_B + R_3)\right) \frac{1+\dfrac{R_3 \parallel (R_B + R_4 \parallel R_2)}{R_1}}{1+\dfrac{R_2 + R_B \parallel (R_4 + R_3)}{R_1}}$$

This is a second meaningful solution obtained with painless analysis which shows the dependence of the input resistance on R_1.

Complete Vorperian Lecture Notes







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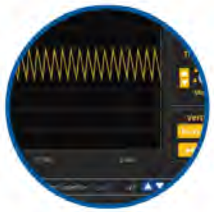

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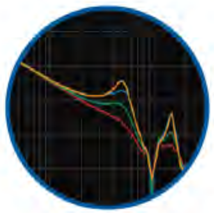

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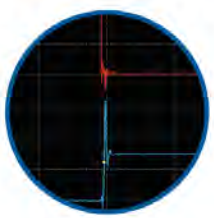

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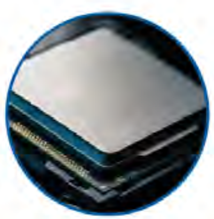

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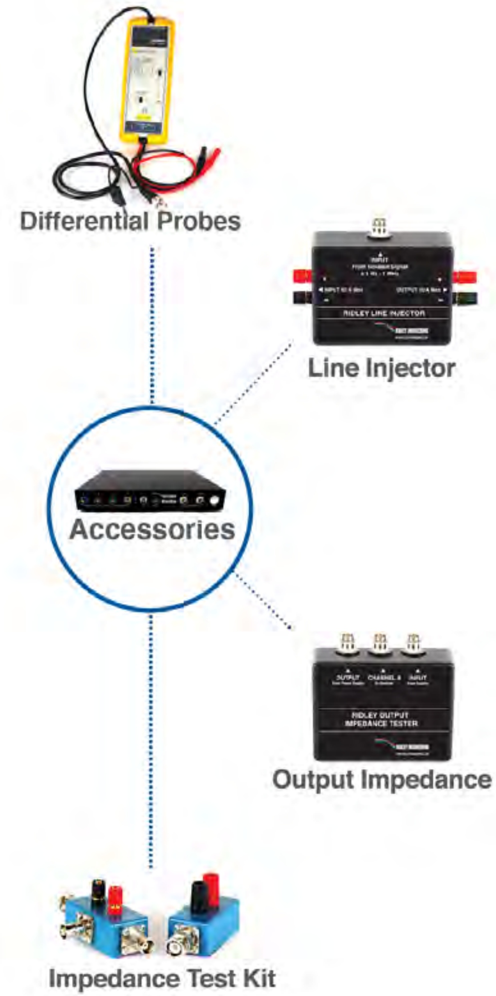

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