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!

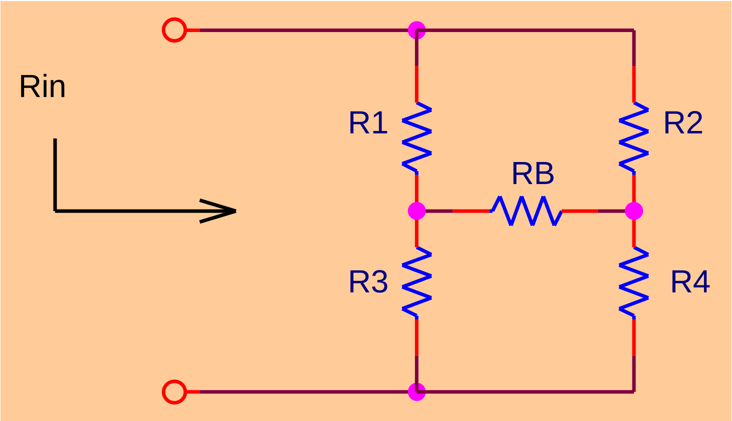
Lecture 1

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

Painless circuit analysis

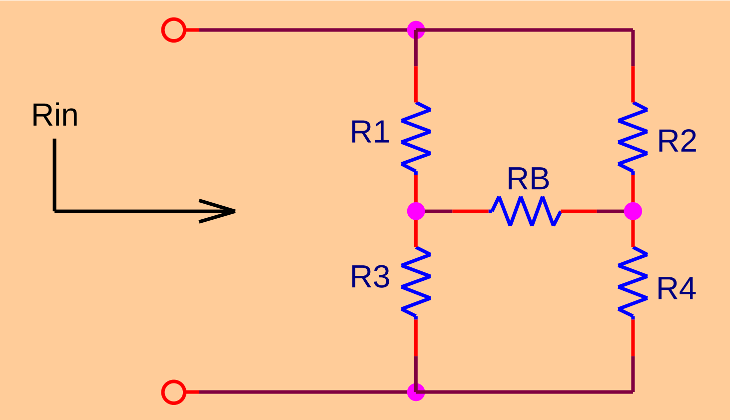
- **Multiple meaningful solutions:** Now we can see that there is a solution for each resistor!



Lecture 1

Painless circuit analysis

- **Multiple meaningful solutions:** For example if we take R_2 out, then we have the following:



$$R_{in} = R_{in}\big|_{R_2 \to \infty} \frac{1 + \dfrac{\mathscr{R}^{(2)}}{R_2}}{1 + \dfrac{R^{(2)}}{R_2}}$$

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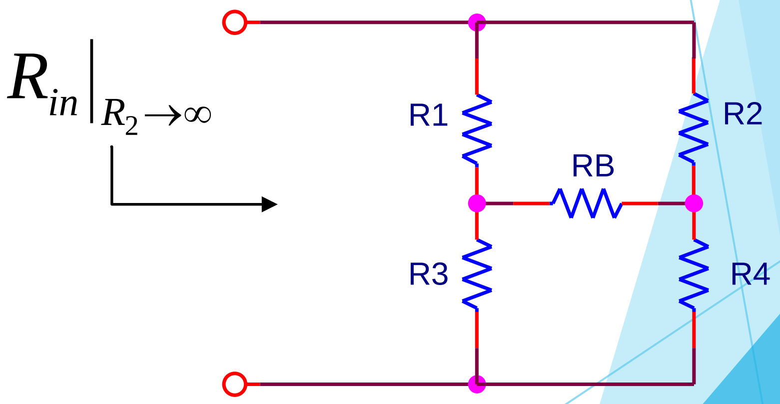
Painless circuit analysis

Example 1: Determine the input resistance with R_2 as a parameter.

STEP 1

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



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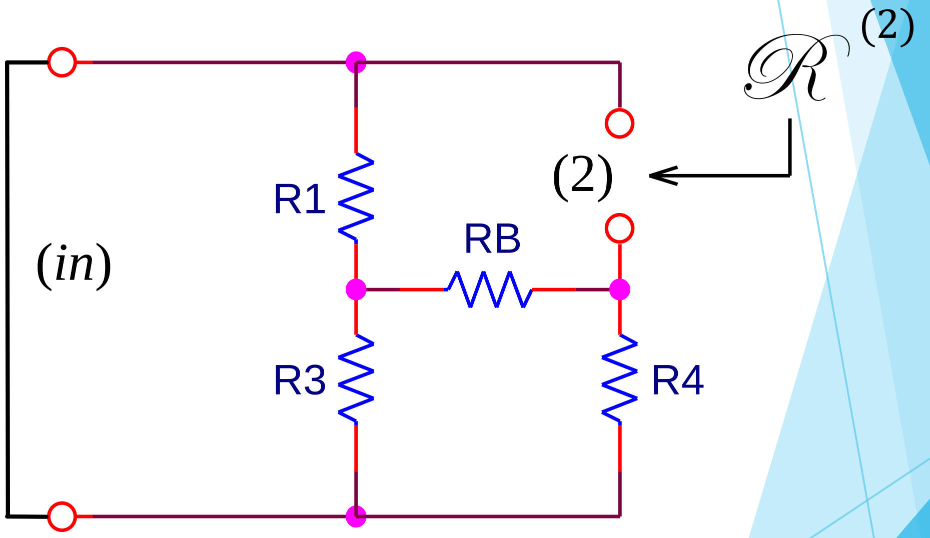
Example 1: (*cont.*)

STEP 2

$$\mathscr{R}^{(2)} = R_4 \,||\, (R_B + R_1 \,||\, R_3)$$



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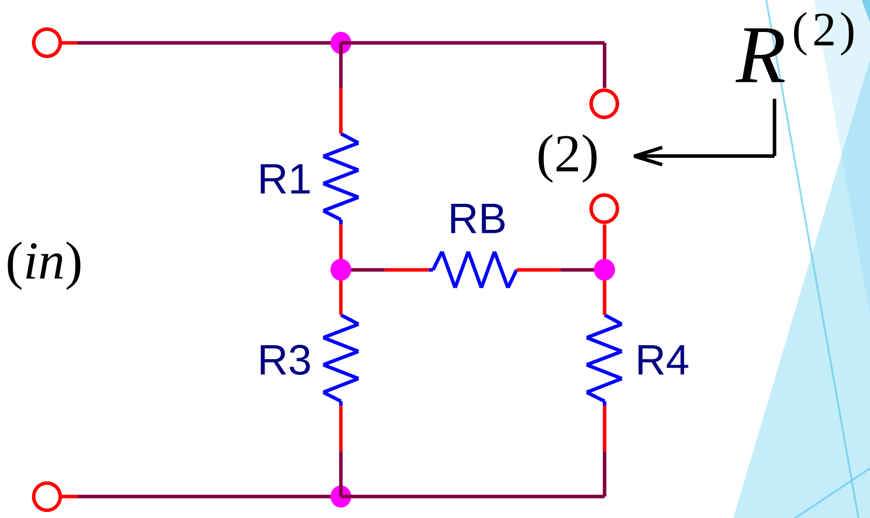
Example 1: *(cont.)*

STEP 3

$$R^{(2)} = R_1 + R_B \,||\, (R_3 + R_4)$$



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Example 1: *(cont.)*

STEP 4

Assemble the three independent calculations using the EET and obtain the input resistance:

$$R_{in} = R_{in}\Big|_{R_2\to\infty} \frac{1+\dfrac{\mathscr{R}^{(2)}}{R_2}}{1+\dfrac{R^{(2)}}{R_2}}$$

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

Painless! Isn't it?

Lecture 1

Painless circuit analysis

DISCUSSION

Five meaningful and analytical solutions are obtained using this painless circuit analysis technique.

Each solution yields the input resistance parametrized in terms of one of the chosen resistors designated as the *extra element*.

This is also known as **parameter extraction**.

The technique that you just learned is the most effective and simplest possible technique for parameter extraction.

But wait! There are five more meaningful analytical solutions that we can obtain if we choose to take out each resistor by shorting it instead of opening it. That brings the total to ten meaningful analytical solutions!

Let us see how!

Lecture 1

Painless circuit analysis

Example 2: Determine the input resistance with R_B as a parameter.

STEP 1

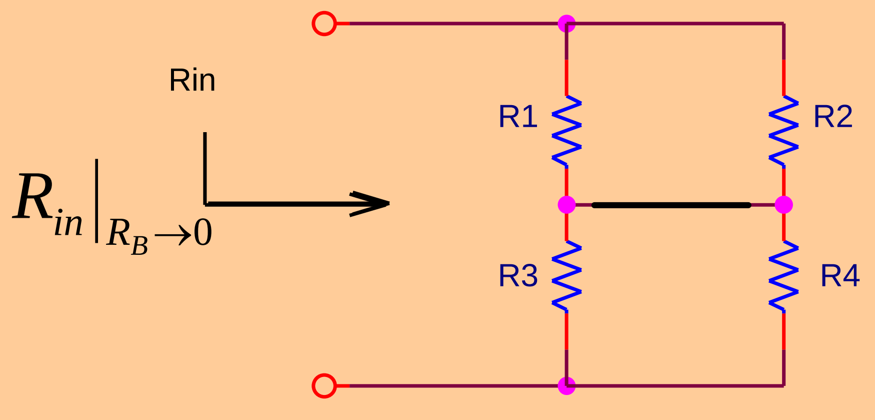
Remember you can take out R_B either as an *open* or a *short.*

Let us take it out as a short this time.

You can now write, the input resistance right away:

$$R_{in}\Big|_{R_B \to 0} = R_1 \,\|\, R_2 + R_3 \,\|\, R_4$$

Partial credit answer!



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Painless circuit analysis

Example 2: (*cont.*)

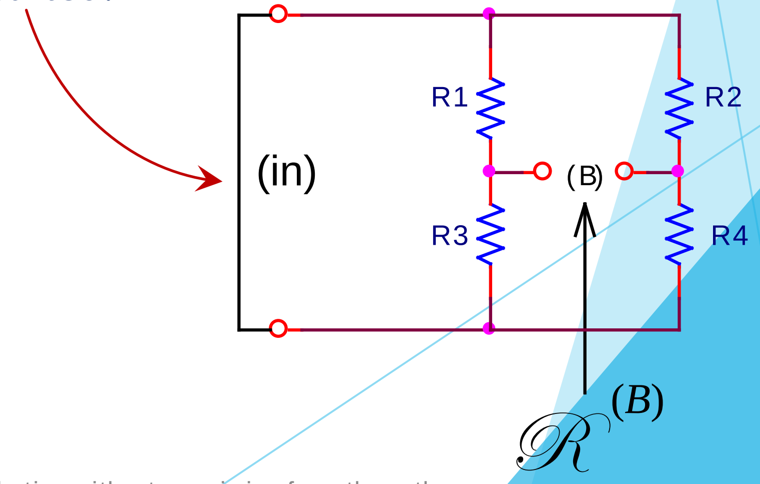
STEP 2

This step is exactly the same as before and does not depend on how you chose to take a resistor out in STEP 1. This is repeated below for convenience.

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 by inspection:

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



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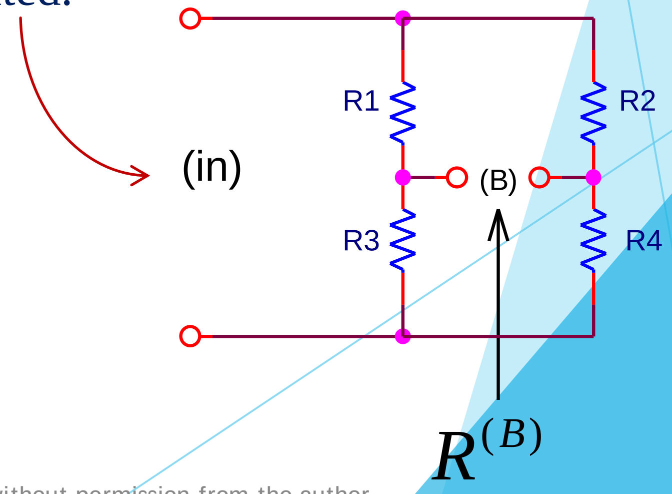
Painless circuit analysis

Example 2: *(cont.)*

STEP 3

This step is also exactly the same as before and does not depend on how you chose to take a resistor out. This is repeated below for convenience.

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 OPEN-circuited.



You can write this one by inspection:

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

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Painless circuit analysis

Example 2: (*cont.*)

STEP 4

Obtain the input resistance by assembling the three separate calculations according to this formula which is the second version given by the Extra Element Theorem (EET):

$$R_{in} = R_{in}\Big|_{R_B \to 0} \frac{1 + \dfrac{R_B}{\mathscr{R}^{(B)}}}{1 + \dfrac{R_B}{R^{(B)}}}$$

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

And here is yet another exact, *meaningful* answer! *Painless* – isn't it?

Lecture 1

Painless circuit analysis

DISCUSSION

Q. How do we chose whether to take an element out as a short or open?

A. You are free to do either. But if you want to chose wisely, here are some guidelines:

1. Check both cases first and see which results in the simplest circuit in Step 1.

2. If you are doing parametric analysis for a particular resistor and you happen to know that the value of that resistor is typically much larger than any one of the other resistors, then take it out as an open because the answer in Step 1 dominates the solution and you want that to appear first. The rest of the answer then comes in just as a correction factor to the dominant behavior of the circuit. Likewise, if the value of the resistor is small take it out as a short.

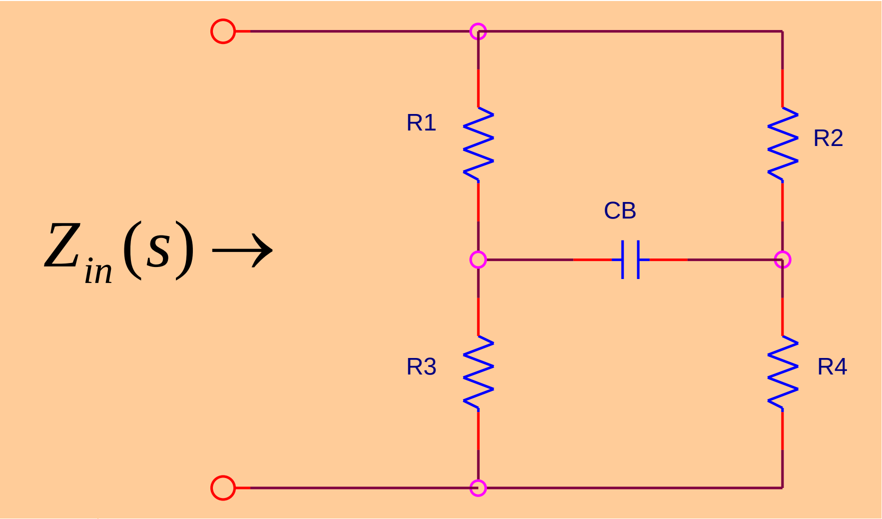
3. When the element is a capacitor or an inductor, then the choice is driven by whether you want the answer in Step 1 to be the low-frequency, high-frequency or mid-band response.

Lecture 1

Painless circuit analysis

Four steps to

Painless analysis of a *reactive* bridge circuit



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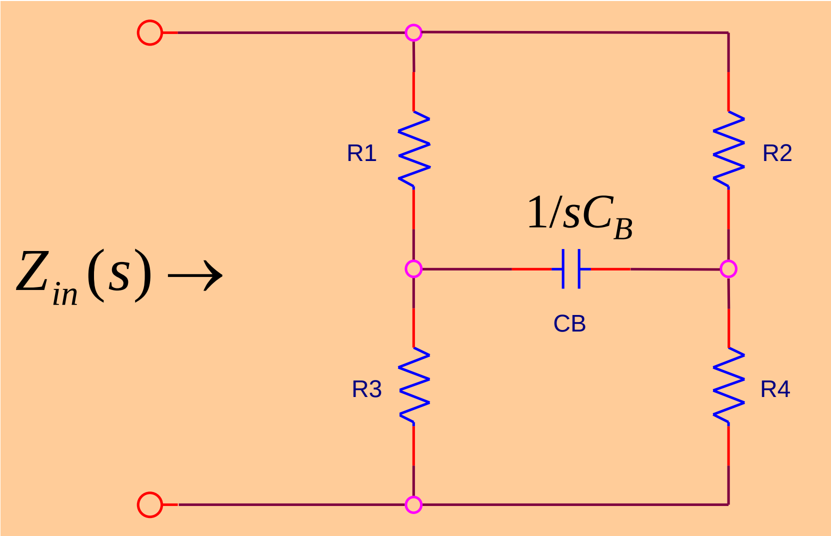
The first thing we see is that the bridge element is a capacitive reactance rather than a simple resistance:

$$R_B \longrightarrow 1/sC_B = Z_B(s)$$



You will now see how to analyze a circuit with reactive elements by only analyzing resistive circuits!

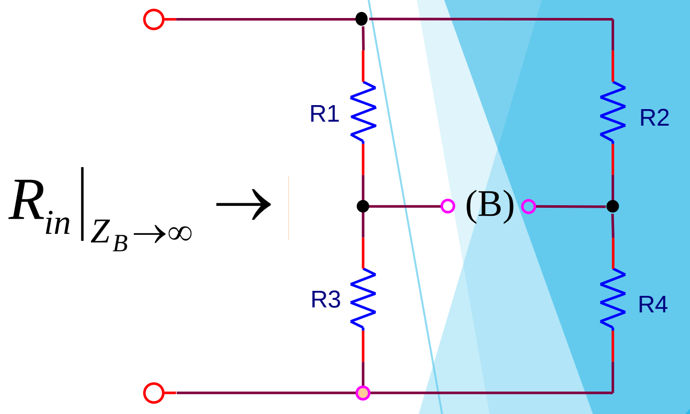
Lecture 1

Painless circuit analysis

Example 3: Determine the input impedance $Z_{in}(s)$ of the bridge circuit.

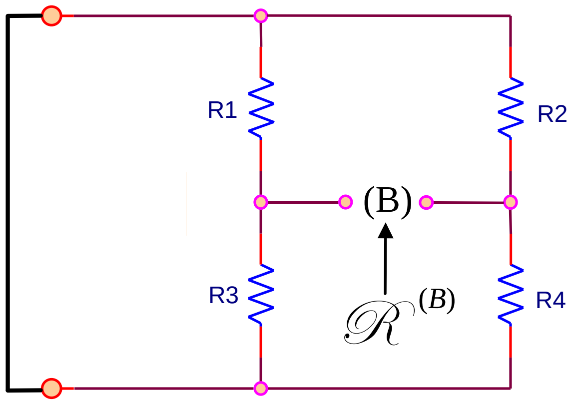
STEP 1

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



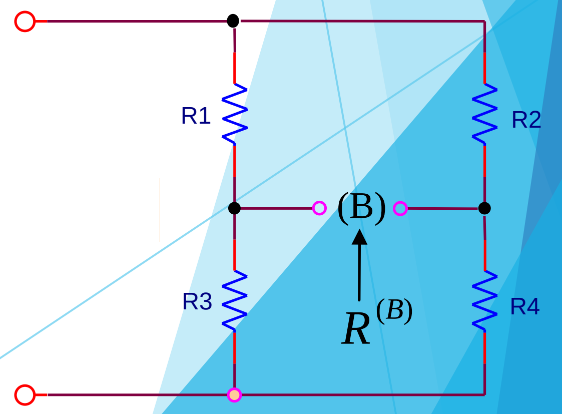
STEP 2

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



STEP 3

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



Lecture 1

Painless circuit analysis

STEP 4

$$Z_{in}(s) = Z_{in}\Big|_{Z_B\to\infty} \frac{1+\frac{\mathscr{R}^{(B)}}{Z_B}}{1+\frac{R^{(B)}}{Z_B}}$$

$$Z_{in} = (R_1+R_3)\,||\,(R_2+R_4)\frac{1+\frac{R_1\,||\,R_3+R_2\,||\,R_4}{Z_B}}{1+\frac{(R_1+R_2)\,||\,(R_3+R_4)}{Z_B}}$$

$$Z_B = \frac{1}{sC_B}$$

$$Z_{in}(s) = (R_1+R_3)\,||\,(R_2+R_4)\frac{1+sC_B(R_1\,||\,R_3+R_2\,||\,R_4)}{1+sC_B(R_1+R_2)\,||\,(R_3+R_4)}$$

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DISCUSSION

We can, and should, put $Z_{in}(s)$ in pole, zero and low-frequency asymptote form:

$$Z_{in}(s) = R_0 \frac{1+\dfrac{s}{\omega_z}}{1+\dfrac{s}{\omega_p}}$$

Where:

$$\underbrace{R_0 = (R_1 + R_3) \| (R_2 + R_4)}_{} \qquad \underbrace{\omega_z = \frac{1}{C_B (R_1 \| R_3 + R_2 \| R_4)}}_{} \qquad \underbrace{\omega_p = \frac{1}{C_B (R_1 + R_2) \| (R_3 + R_4)}}_{}$$

Low-frequency asymptote. This is the value of the input impedance at zero frequency or the capacitor open!.

Zero

Pole

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Painless circuit analysis

DISCUSSION

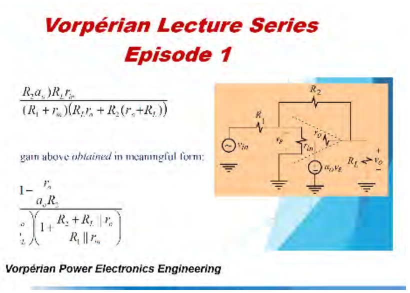
Once again, you realize that you just completed the analysis of a reactive bridge circuit by analyzing three purely resistive circuits by inspection and assembling the answer in meaningful pole, zero, and low-frequency asymptote form!

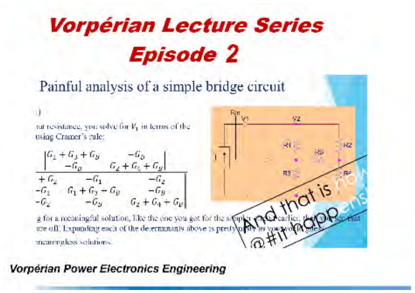
This is just a demo with one reactive element for an impedance looking into a port of a network (driving point impedance.)

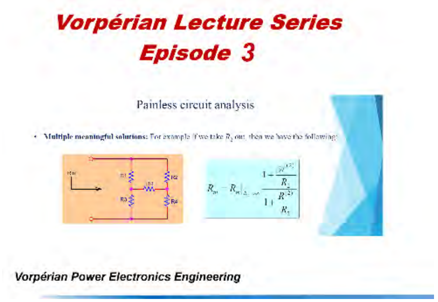
I will show you in later lectures how to do this for *any* transfer function of a circuit with *any* number of reactive elements

This is why I call this *painless* and joyful circuit analysis.

Complete Vorperian Lecture Notes







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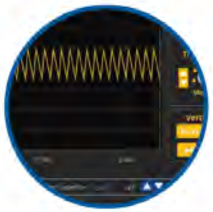

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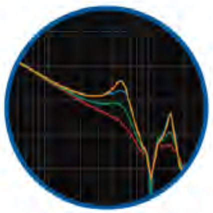

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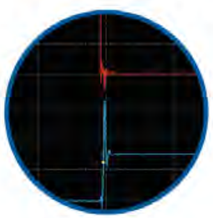

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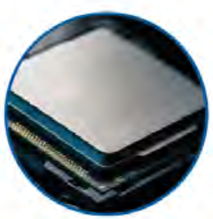

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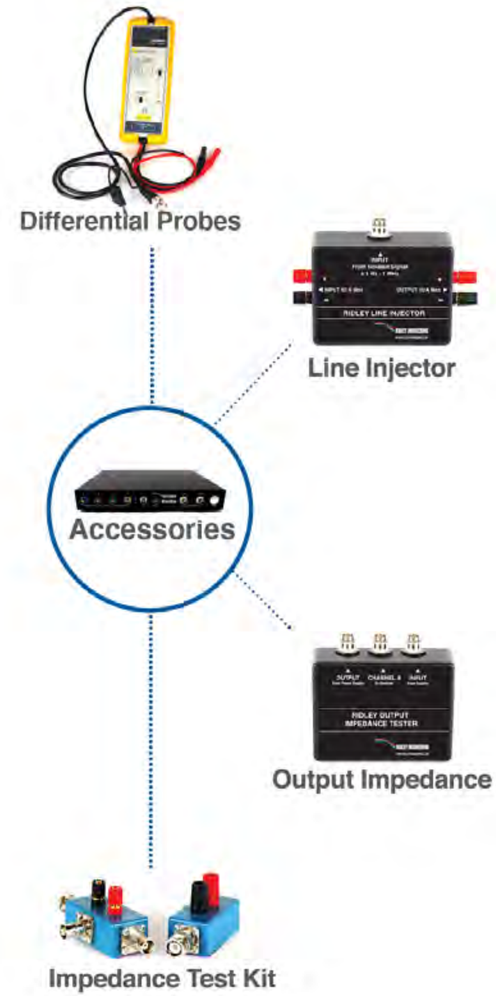

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