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

Lecture 1

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

More joyful circuit analysis!

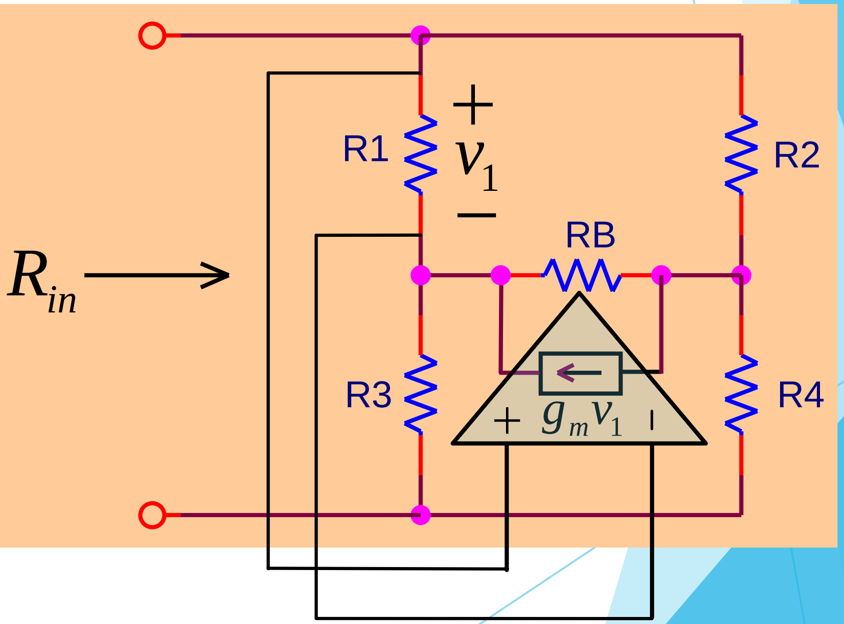
Example 1: Determine R_{in} with g_m as a parameter

STEP 1.

You have a choice of taking out g_m either as $g_m = 0$ or as $g_m \to \infty$.

Since g_m is a gain of a trans-conductance amplifier or device, it is useful first determine R_{in} by $g_m \to \infty$.

When we take out g_m by letting $g_m \to \infty$, then we obtain an ideal operational amplifier circuit in which the infinite gain of the opamp does not appear in any of the results.



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Example 1: *(cont.)*

Let $g_m \to \infty$ so that we have effectively an ideal OpAmp circuit with v_1 its differential input signal. Hence we have:

$$g_m \to \infty \Rightarrow v_1 \to 0$$

Determine now:

$$R_{in}|_{g_m \to \infty} = \left.\frac{v_T}{i_T}\right|_{g_m \to \infty}$$

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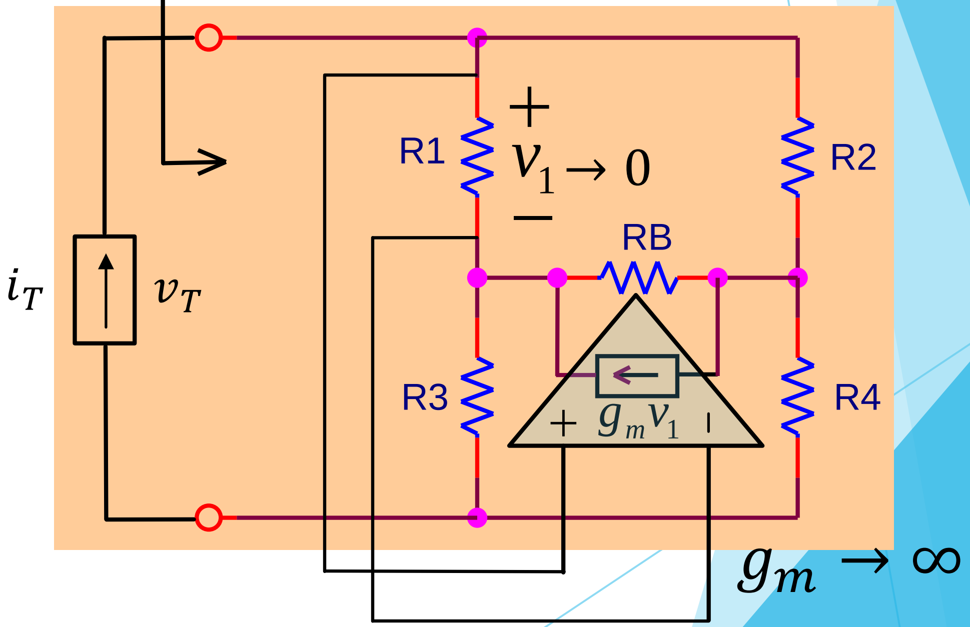

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$$R_{in}|_{g_m\to\infty} = \frac{v_T}{i_T}\bigg|_{g_m\to\infty}$$

Example 1: *(cont.)*

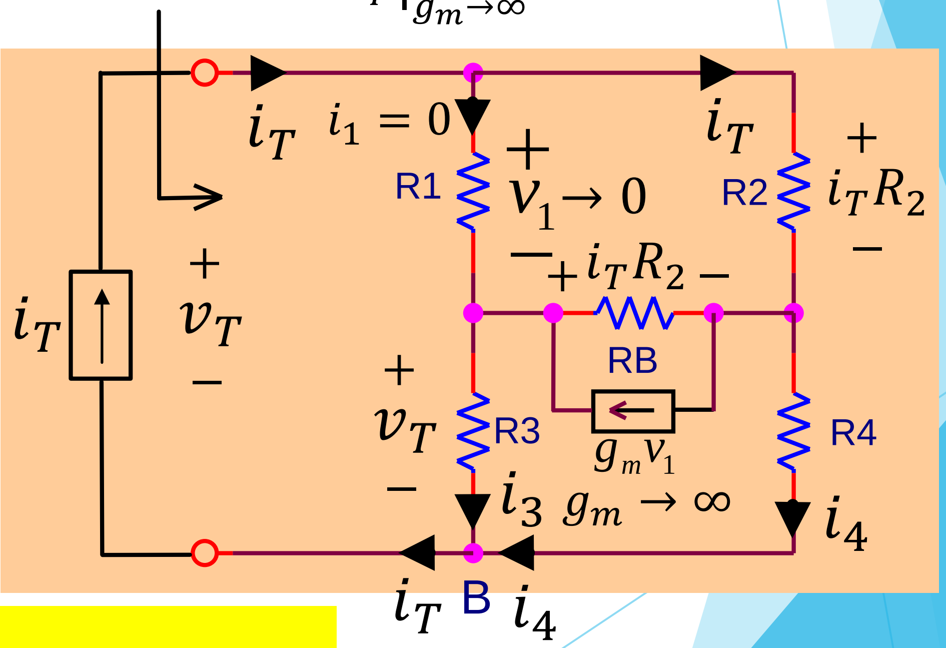
With $g_m \to \infty$ and $v_1 \to 0$ we have:

$$v_1 \to 0 \Rightarrow i_1 = \frac{v_1}{R_1} \to 0\ ,\ i_2 = i_T$$

$$v_1 \to 0 \Rightarrow v_{R_3} = v_T\ ,\ i_3 = \frac{v_T}{R_3}$$

$$v_1 \to 0 \Rightarrow v_{R_B} = i_T R_2$$

$$v_{R_4} = v_T - i_T R_2 \Rightarrow\ i_4 = \frac{v_T - i_T R_2}{R_4}$$



At node B we have:

$$i_T = \frac{v_T - i_T R_2}{R_4} + \frac{v_T}{R_3} \Rightarrow \frac{v_T}{i_T}\bigg|_{g_m\to\infty} = \left(1 + \frac{R_2}{R_4}\right) R_B \| R_3 = R_{in}|_{g_m\to\infty}$$

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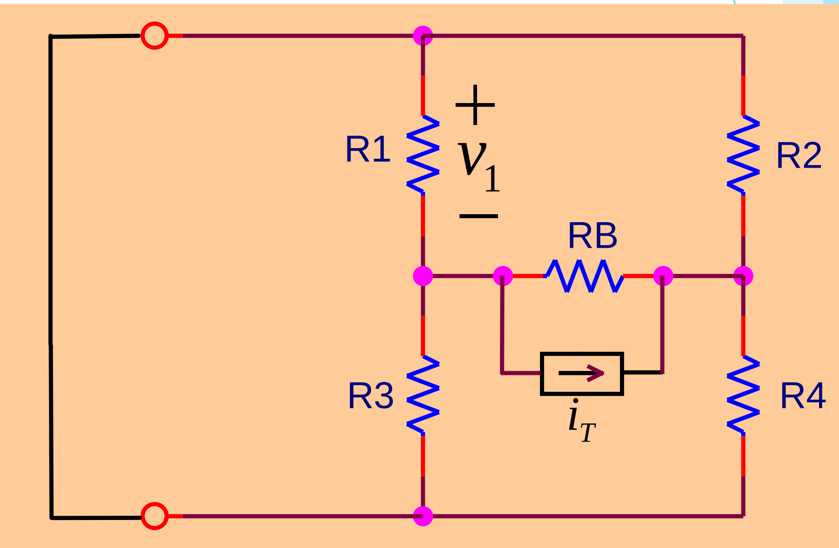
STEP 2.

Short the input port.

Replace the *dependent current* source, $g_m v_1$, with an *independent current* source, i_T , pointing in the opposite direction as shown.

Determine the *inverse* gain:

$$\overline{\mathcal{G}_m} = \frac{v_1}{i_T}$$



Again, by inspection we have:

$$\overline{\mathcal{G}_m} = \frac{v_1}{i_T} = R_3 \| R_1 \frac{R_B}{R_B + R_3 \| R_1 + R_2 \| R_4}$$

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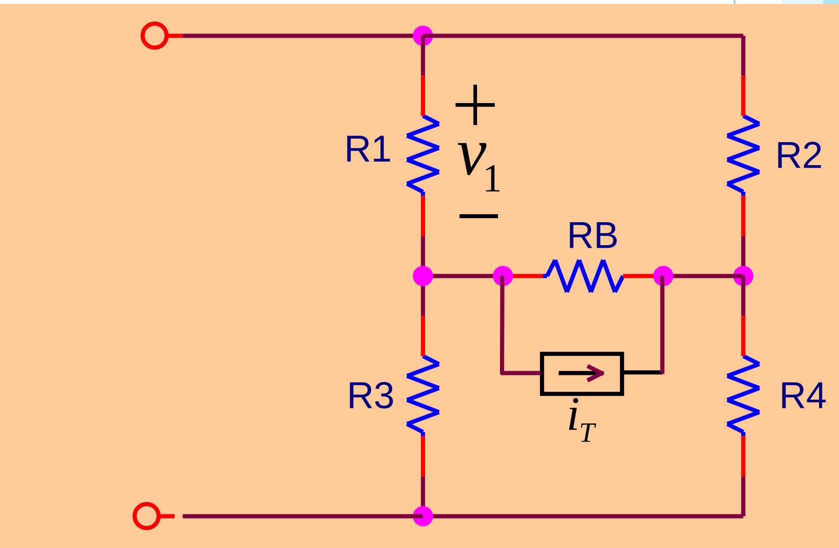
STEP 3.

Open the input port.

Replace the *dependent current* source, $g_m v_1$, with an *independent current* source, i_T , pointing in the opposite direction as shown.

Determine the *inverse* gain:

$$\overline{G_m} = \frac{v_1}{i_T}$$



By inspection we have:

$$\overline{G_m} = \frac{v_1}{i_T} = \frac{R_1}{R_1 + R_2} R_B \| (R_3 + R_4) \| (R_1 + R_2)$$

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STEP 4.

The input resistance is given by the EET as follows:

$$R_{in} = R_{in}\Big|_{g_m \to \infty} \frac{1 + \dfrac{1}{g_m \overline{\mathscr{G}}_m}}{1 + \dfrac{1}{g_m \overline{G}_m}}$$

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

And you are done!

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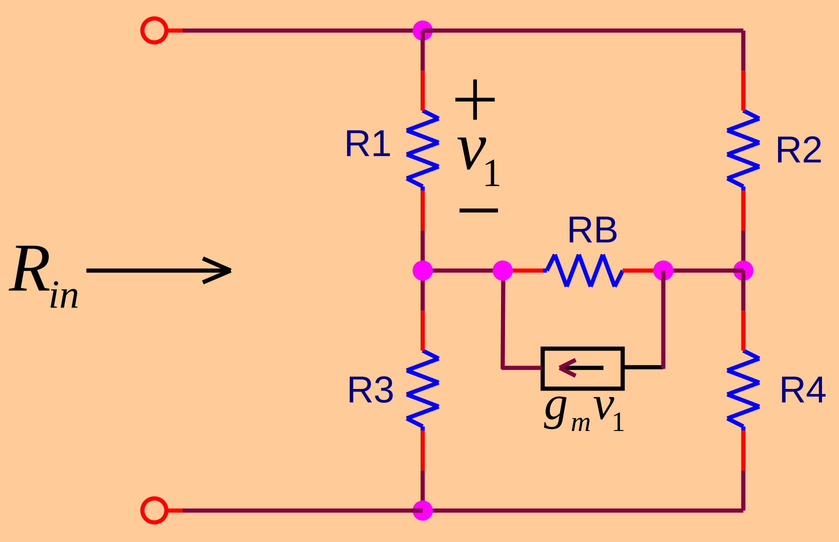
***Example 2*:** We can obtain another useful expression by letting $g_m = 0$ and applying the following form of the EET:

$$R_{in} = R_{in}\big|_{g_m \to 0} \frac{1 + g_m \overline{\mathscr{G}}_m}{1 + g_m \overline{G}_m}$$



in which $\overline{\mathscr{G}_m}$ and $\overline{G_m}$ are the same as before.

All we need to do is determine:

$$R_{in}\big|_{g_m \to 0}$$

This is the input resistance of the bridge circuit determined earlier.

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Example 2: (*cont.*)

The second meaningful expression of the input resistance is given by:

$$R_{in} = R_{in}\Big|_{g_m \to 0} \frac{1 + g_m \overline{\mathscr{G}}_m}{1 + g_m \overline{G}_m}$$

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

And you are done again!

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More joyful circuit analysis!

I hope you are convinced by now that the methods of circuit analysis that you have seen so far are better than what you have learned in school, or you are currently learning, or perhaps you are teaching.

In the rest of this course, you will learn:

1. The Extra Element Theorem for any transfer function.
2. The general derivation of the EET
3. The EET for more than one element: NEET

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Dr. R.D. Middlebrook's Legacy

Professor at Caltech from 1955 until his retirement in 1998.

While teaching and consulting in industry, he recognized that the universally adopted method of circuit analysis, which was founded on the matrix equations of linear algebra, was useless for developing a thorough understanding of complex circuits simply because the requisite algebra would run into a brick wall – algebraic paralysis as he would call it.

The matrix algebra of nodal (modified) and loop analysis is supremely well suited for numerical analysis using computers. He had no issue with that.

The problem was that a numerical result could not tell you how the gain rolled off at higher frequencies or how an unexpected resonance appeared in the voltage gain and how you could damp it out. Since, deriving analytical equations using nodal analysis, to explain the characteristics of amplifiers and other transducers was an extremely arduous task, he thought of coming up with a better technique.

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Dr. R.D. Middlebrook's Legacy

To address the problem of teaching the material more effectively, as well as do his consulting more effectively, he invented the feedback theorem and the extra element theorem.

I took his class, EE114, the first year I was at Caltech in 1979-80. It was like seeing the light for the first time! Since then, I adopted his techniques in the courses that I taught at Virginia Tech and later joined him to teach his course to industry titled Design Oriented Analysis. It was a wonderful collaboration.

He referred to his techniques as *Design Oriented Analysis Using Low Entropy Expressions*.

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Dr. R.D. Middlebrook's Legacy

With these lectures, I am passing *on my own experience* of his legacy. Most of the examples that I have used are my own spin of his material. Also included in these lectures are additional techniques that I have developed over the course of years.

What I call painless and joyful circuit analysis is essentially the same as what Dr. Middlebrook called Design Oriented Analysis and what I refer to as meaningful analytical solutions is the same as what Dr. Middlebrook called low-entropy solutions.

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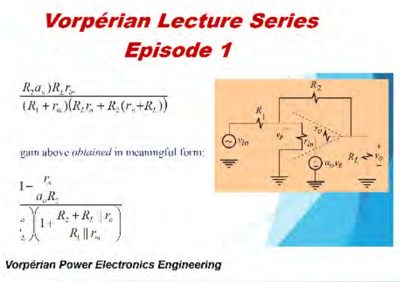
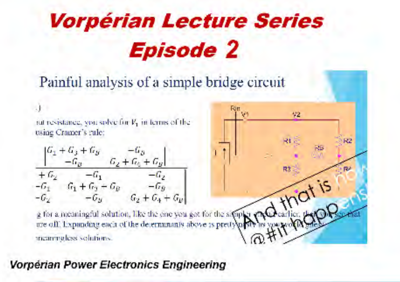
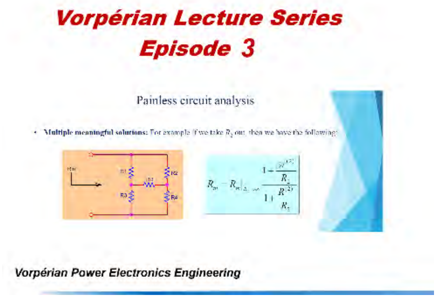
Dr. R.D. Middlebrook's Legacy

Dr. Midddlebrook passed away on April 16, 2010 in his home in San Dimas, California.

Complete Vorperian Lecture Notes







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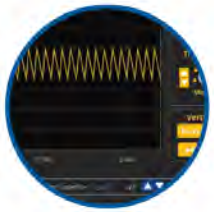

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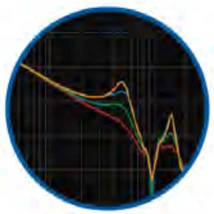

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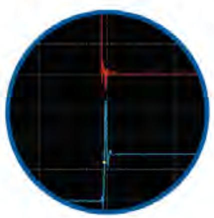

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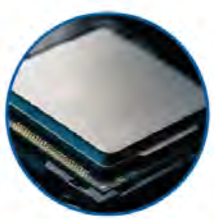

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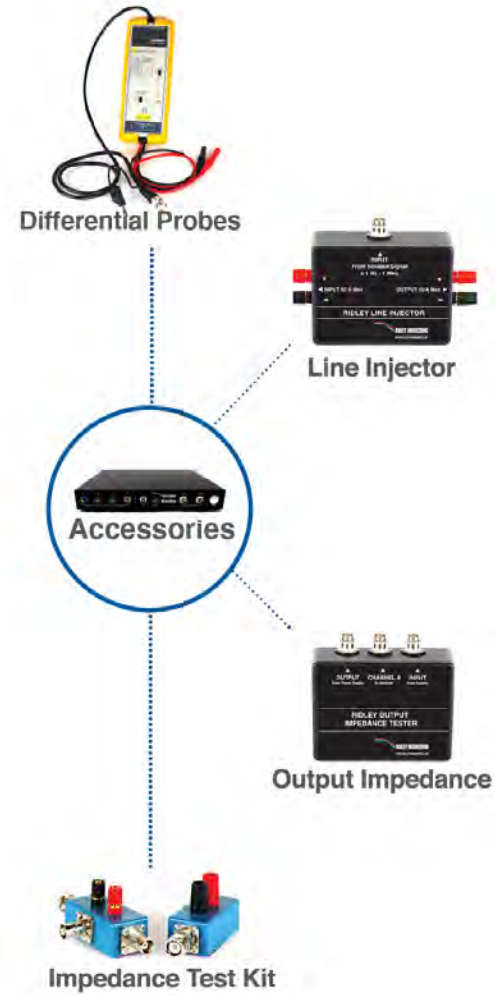

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