INST 155 (Networks and Systems), section 2

Recommended schedule

Day 1

Topics: *Superposition, Thévenin's, and Norton's theorems*
Questions: *1 through 10*
Lab Exercise: *Work on project (progress report: Question 51)*

Day 2

Topics: *DC circuit analysis using theorems*
Questions: *11 through 20*
Lab Exercise: *Work on project (progress report: Question 52)*

Day 3

Topics: *Basic trigonometry review and AC impedance calculations*
Questions: *21 through 30*
Lab Exercise: *Work on project (progress report: Question 53)*

Day 4

Topics: *Series and parallel AC circuits*
Questions: *31 through 40*
Lab Exercise: *Work on project (progress report: Question 54)*

Day 5

Topics: *RC time constants*
Questions: *41 through 50*
Lab Exercise: *Work on project (progress report: Question 55)*

Day 6

Topics: *Review*
Lab Exercise: *Work on project (progress report: Question 56)*

Day 7

Exam: ("Applied Math" exam) *includes DC network analysis performance assessment*
Project due
Question 57: Sample project grading criteria

INST 155 (Networks and Systems), section 2

Skill standards addressed by this course section

This needs to be completed!

EIA *Raising the Standard; Electronics Technician Skills for Today and Tomorrow*, June 1994

B Basic and Practical Skills – Communicating on the Job

B.01 Use effective written and other communication skills. *Met by group discussion and completion of labwork.*

B.03 Employ appropriate skills for gathering and retaining information. *Met by research and preparation prior to group discussion.*

B.04 Interpret written, graphic, and oral instructions. *Met by completion of labwork.*

B.06 Use language appropriate to the situation. *Met by group discussion and in explaining completed labwork.*

B.07 Participate in meetings in a positive and constructive manner. *Met by group discussion.*

B.08 Use job-related terminology. *Met by group discussion and in explaining completed labwork.*

B.10 Document work projects, procedures, tests, and equipment failures. *Met by project construction and/or troubleshooting assessments.*

C Basic and Practical Skills – Solving Problems and Critical Thinking

C.01 Identify the problem. *Met by research and preparation prior to group discussion.*

C.03 Identify available solutions and their impact including evaluating credibility of information, and locating information. *Met by research and preparation prior to group discussion.*

C.07 Organize personal workloads. *Met by daily labwork, preparatory research, and project management.*

C.08 Participate in brainstorming sessions to generate new ideas and solve problems. *Met by group discussion.*

D Basic and Practical Skills – Reading

D.01 Read and apply various sources of technical information (e.g. manufacturer literature, codes, and regulations). *Met by research and preparation prior to group discussion.*

E Basic and Practical Skills – Proficiency in Mathematics

E.01 Determine if a solution is reasonable.

E.02 Demonstrate ability to use a simple electronic calculator.

E.06 Translate written and/or verbal statements into mathematical expressions.

E.07 Compare, compute, and solve problems involving binary, octal, decimal, and hexadecimal numbering systems.

E.12 Interpret and use tables, charts, maps, and/or graphs.

E.13 Identify patterns, note trends, and/or draw conclusions from tables, charts, maps, and/or graphs.

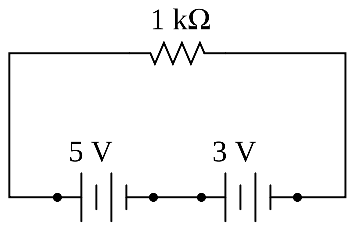
E.15 Simplify and solve algebraic expressions and formulas.

E.16 Select and use formulas appropriately.

E.18 Use properties of exponents and logarithms.

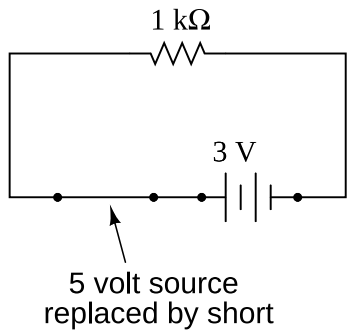
Question 1

Suppose we have a single resistor powered by two series-connected voltage sources. Each of the voltage sources is "ideal," possessing no internal resistance:

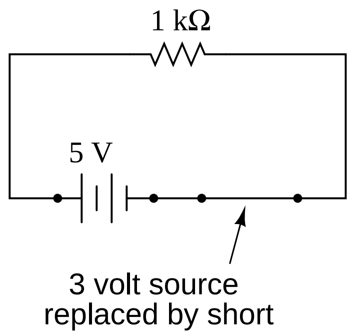


Calculate the resistor's voltage drop and current in this circuit.

Now, suppose we were to remove one voltage source from the circuit, replacing it with its internal resistance (0 Ω). Re-calculate the resistor's voltage drop and current in the resulting circuit:



Now, suppose we were to remove the other voltage source from the circuit, replacing it with its internal resistance (0 Ω). Re-calculate the resistor's voltage drop and current in the resulting circuit:



One last exercise: "superimpose" (add) the resistor voltages and superimpose (add) the resistor currents in the last two circuit examples, and compare these voltage and current figures with the calculated values of the original circuit. What do you notice?

file 00690

Answer 1

Original circuit: $E_R = 8$ volts ; $I_R = 8$ mA

With 3 volt voltage source only: $E_R = 3$ volts ; $I_R = 3$ mA

With 5 volt voltage source only: $E_R = 5$ volts ; $I_R = 5$ mA

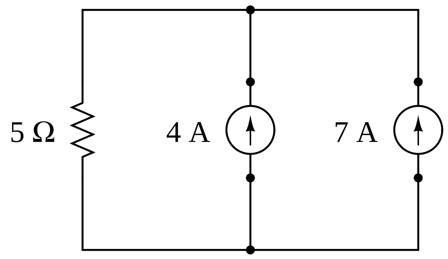
5 volts + 3 volts = 8 volts
5 mA + 3 mA = 8 mA

Notes 1

This circuit is so simple, students should not even require the use of a calculator to determine the current figures. The point of it is, to get students to see the concept of *superposition* of voltages and currents.

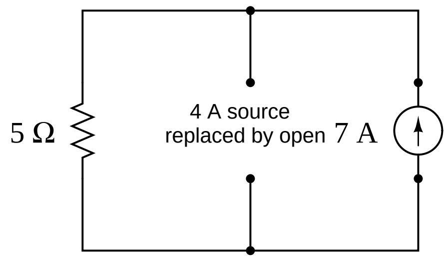
Question 2

Suppose we have a single resistor powered by two parallel-connected current sources. Each of the current sources is "ideal," possessing infinite internal resistance:

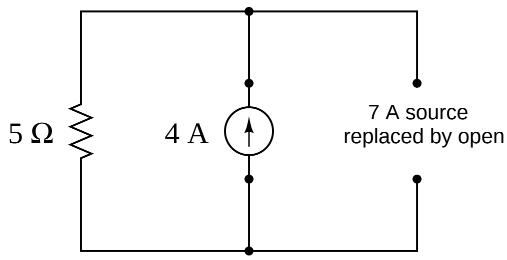


Calculate the resistor's voltage drop and current in this circuit.

Now, suppose we were to remove one current source from the circuit, replacing it with its internal resistance (∞ Ω). Re-calculate the resistor's voltage drop and current in the resulting circuit:



Now, suppose we were to remove the other current source from the circuit, replacing it with its internal resistance (∞ Ω). Re-calculate the resistor's voltage drop and current in the resulting circuit:



One last exercise: "superimpose" (add) the resistor voltages and superimpose (add) the resistor currents in the last two circuit examples, and compare these voltage and current figures with the calculated values of the original circuit. What do you notice?

file 00692

Answer 2

Original circuit: $E_R = 55$ volts ; $I_R = 11$ A

With 7 amp current source only: $E_R = 35$ volts ; $I_R = 7$ A

With 4 amp current source only: $E_R = 20$ volts ; $I_R = 4$ A

35 volts + 20 volts = 55 volts
7 A + 4 A = 11 A

Notes 2

This circuit is so simple, students should not even require the use of a calculator to determine the current figures. If students are not familiar with current sources, this question provides an excellent opportunity to review them. The main point of the question is, however, to get students to see the concept of *superposition* of voltages and currents.

Question 3

The *Superposition Theorem* is a very important concept used to analyze both DC and AC circuits. Define this theorem in your own words, and also state the necessary conditions for it to be freely applied to a circuit.

file 02036

Answer 3

There are plenty of textbook references to the Superposition Theorem and where it may be applied. I'll let you do your own research here!

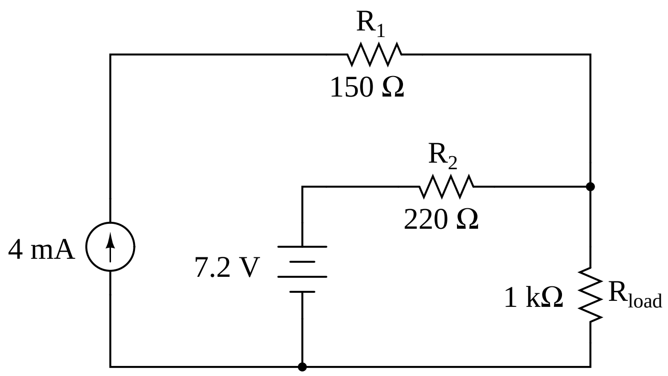
Notes 3

As the answer states, students have a multitude of resources to consult on this topic. It should not be difficult for them to ascertain what this important theorem is and how it is applied to the analysis of circuits.

Be sure students understand what the terms *linear* and *bilateral* mean with reference to circuit components and the necessary conditions for Superposition Theorem to be applied to a circuit. Point out that it is still possible to apply the Superposition Theorem to a circuit containing nonlinear or unilateral components if we do so carefully (i.e. under narrowly defined conditions).

Question 4

Explain in your own words how to apply the *Superposition Theorem* to calculate the amount of current through the load resistor in this circuit:



file 02035

Answer 4

To apply the Superposition Theorem to the analysis of R_{load}'s current, you must consider each source acting alone, then algebraically combine the results of each analysis.

$I_{load} = 6.623$ mA

Notes 4

Here is a circuit students will not be able to analyze by series-parallel analysis, since it is impossible to reduce all the resistors in it to a single equivalent resistance. It is cases like this that really showcase the power of Superposition as an analysis technique.

Question 5

The *Superposition Theorem* works nicely to calculate voltages and currents in resistor circuits. But can it be used to calculate power dissipations as well? Why or why not? Be specific with your answer.

file 00694

Answer 5

The Superposition Theorem cannot be directly used to calculate power.

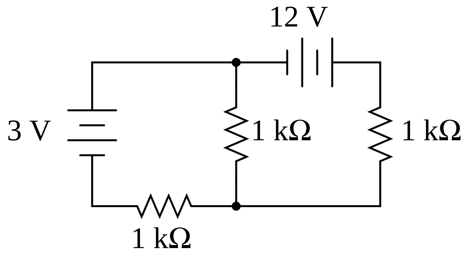
Notes 5

In order to answer this question correctly (without just looking up the answer in a book), students will have to perform a few power calculations in simple, multiple-source circuits. It may be worthwhile to work through a couple of example problems during discussion time, to illustrate the answer.

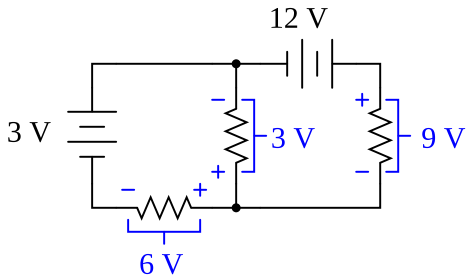
Despite the fact that resistor power dissipations cannot be superimposed to obtain the answer(s), it is still possible to use the Superposition Theorem to calculate resistor power dissipations in a multiple-source circuit. Challenge your students with the task of applying this theorem for solving power dissipations in a circuit.

Question 6

Note that this circuit is impossible to reduce by regular series-parallel analysis:



However, the Superposition Theorem makes it almost trivial to calculate all the voltage drops and currents:



(Currents not shown for simplicity)

Explain the procedure for applying the Superposition Theorem to this circuit.

file 01855

Answer 6

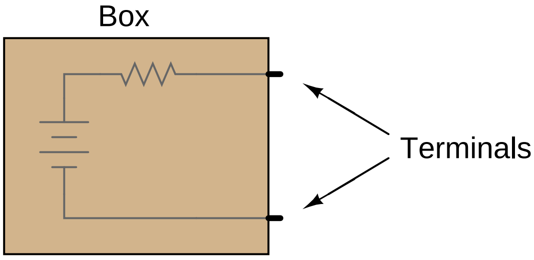
This is easy enough for you to research on your own!

Notes 6

I really enjoy covering the Superposition Theorem in class with my students. It's one of those rare analysis techniques that is intuitively obvious and yet powerful at the same time. Because the principle is so easy to learn, I highly recommend you leave this question for your students to research, and let *them* fully present the answer in class rather than you explain any of it.

Question 7

Suppose you were handed a black box with two metal terminals on one side, for attaching electrical (wire) connections. Inside this box, you were told, was a voltage source (an ideal voltage source connected in series with a resistance):



How would you experimentally determine the voltage of the ideal voltage source inside this box, and how would you experimentally determine the resistance of the series resistor? By "experimentally," I mean determine voltage and resistance using actual test equipment rather than assuming certain component values (remember, this "black box" is sealed, so you cannot look inside!).

file 01037

Answer 7

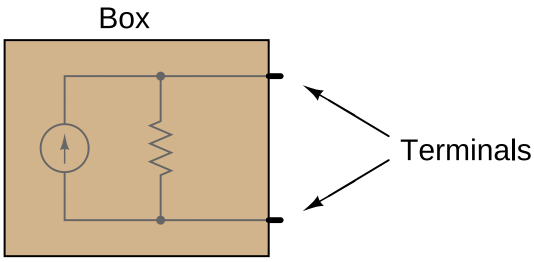
Measure the open-circuit voltage between the two terminals, and then measure the short-circuit current. The voltage source's value is measured, while the resistor's value is calculated using Ohm's Law.

Notes 7

Ask your students how they would apply this technique to an abstract circuit problem, to reduce a complex network of sources and resistances to a single voltage source and single series resistance (Thévenin equivalent).

Question 8

Suppose you were handed a black box with two metal terminals on one side, for attaching electrical (wire) connections. Inside this box, you were told, was a current source (an ideal current source connected in parallel with a resistance):



How would you experimentally determine the current of the ideal current source inside this box, and how would you experimentally determine the resistance of the parallel resistor? By "experimentally," I mean determine current and resistance using actual test equipment rather than assuming certain component values (remember, this "black box" is sealed, so you cannot look inside!).

file 01038

Answer 8

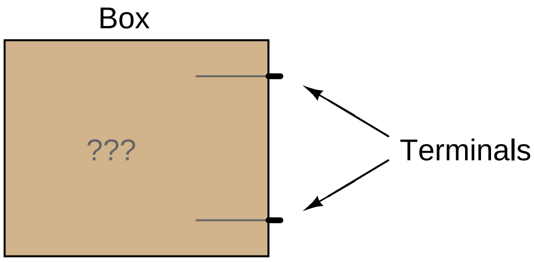
Measure the open-circuit voltage between the two terminals, and then measure the short-circuit current. The current source's value is measured, while the resistor's value is calculated using Ohm's Law.

Notes 8

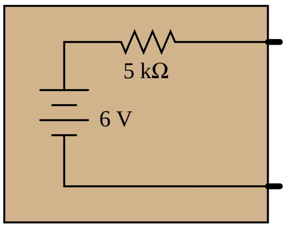
Ask your students how they would apply this technique to an abstract circuit problem, to reduce a complex network of sources and resistances to a single current source and single parallel resistance (Norton equivalent).

Question 9

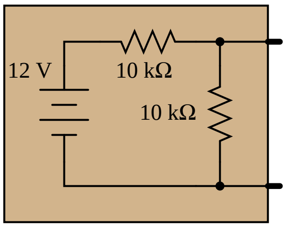
Suppose you were handed a black box with two metal terminals on one side, for attaching electrical (wire) connections. Inside this box, you were told, was a voltage source connected in series with a resistance.



Your task was to experimentally determine the values of the voltage source and the resistor inside the box, and you did just that. From your experimental data you then sketched a circuit with the following component values:



However, you later discovered that you had been tricked. Instead of containing a single voltage source and a single resistance, the circuit inside the box actually looked like this:



Demonstrate that these two different circuits are indistinguishable from the perspective of the two metal terminals, and explain what general principle this equivalence represents.

file 02020

Answer 9

A good way to demonstrate the electrical equivalence of these circuits is to calculate their responses to identical load resistor values. The equivalence you see here is an application of *Thévenin's Theorem.*

Notes 9

Ask your students to clearly state Thévenin's Theorem, and explain how it may be applied to the two-resistor circuit to obtain the one-resistor circuit.

Question 10

Give a step-by-step procedure for "Thévenizing" *any* circuit: finding the Thévenin equivalent voltage ($V_{Thevenin}$) and Thévenin equivalent resistance ($R_{Thevenin}$).

- Step #1:
- Step #2:

file 02456

Answer 10

This is easy enough for you to look up in any electronics textbook. I'll leave you to it!

Follow-up question: describe the difference in how one must consider *voltage sources* versus *current sources* when calculating the equivalent circuit's resistance ($R_{Thevenin}$) of a complex circuit containing both types of sources?

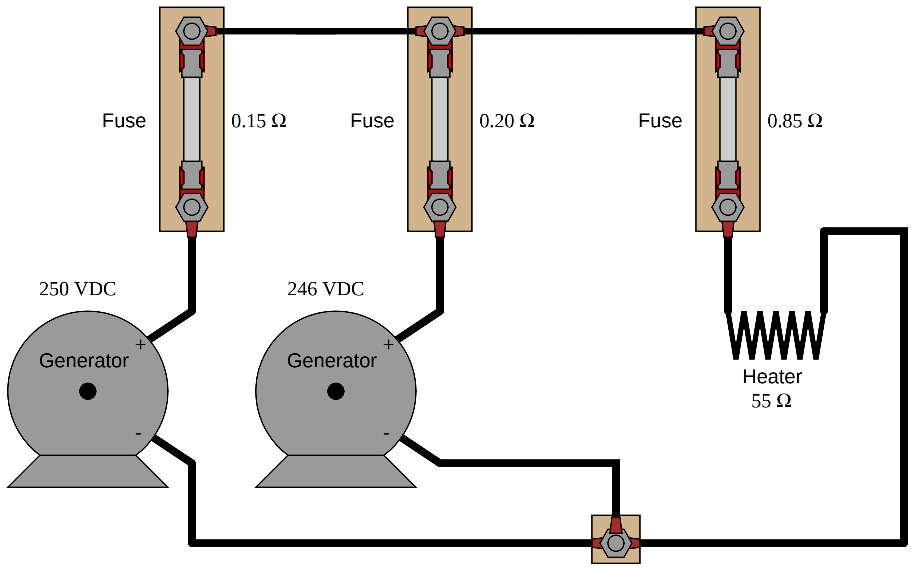
Notes 10

I really mean what I say here about looking this up in a textbook. Thévenin's Theorem is a very well-covered subject in many books, and so it is perfectly reasonable to expect students will do this research on their own and come back to class with a complete answer.

The follow-up question is very important, because some circuits (especially transistor amplifier circuits) contain *both* types of sources. Knowing how to consider each one in the process of calculating the Thévenin equivalent resistance for a circuit is very important. When performing this analysis on transistor amplifiers, the circuit often becomes much simpler than its original form with all the voltage sources shorted and current sources opened!

Question 11

Use the Superposition Theorem to calculate the amount of current going through the 55 Ω heater element. Ignore all wire and connection resistances, only considering the resistance of each fuse in addition to the heater element resistance:

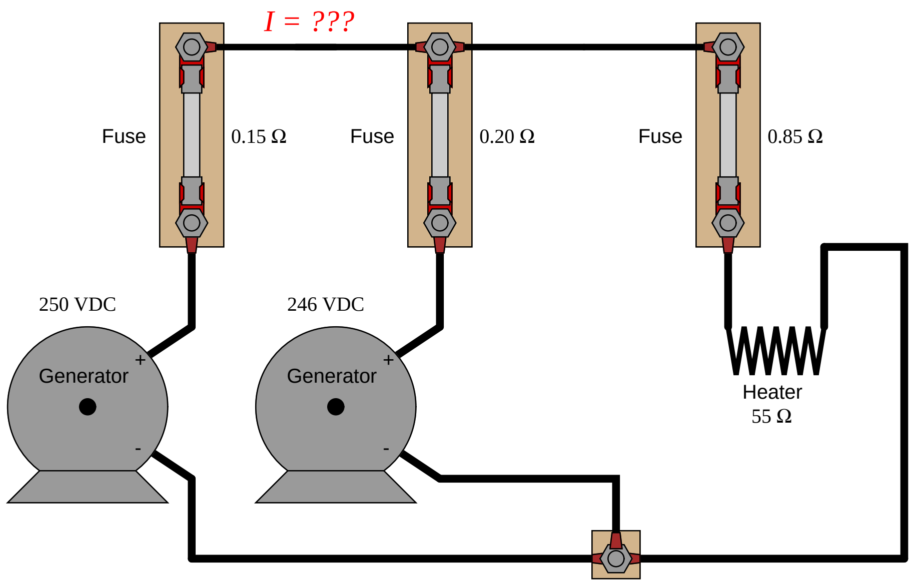


file 03129

Answer 11

$I_{heater} = 4.439$ A

Follow-up question: explain how you could use the Superposition Theorem to calculate current going through the short length of wire connecting the two generators together:

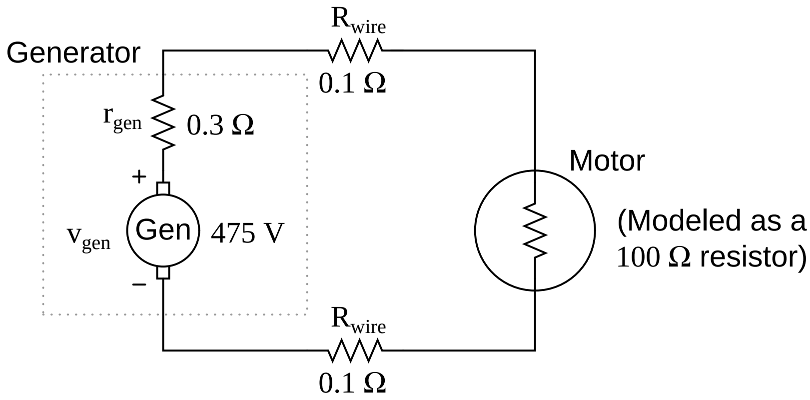


Notes 11

Though there are other methods of analysis for this circuit, it is still a good application of Superposition Theorem.

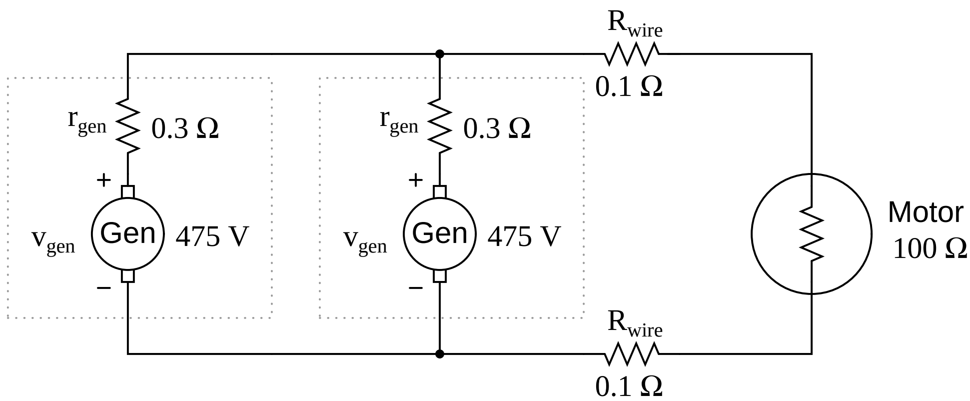
Question 12

Suppose a DC generator is powering an electric motor, which we model as a 100 Ω resistor:



Calculate the amount of current this generator will supply to the motor and the voltage measured across the motor's terminals, taking into account all the resistances shown (generator internal resistance r_{gen}, wiring resistances R_{wire}, and the motor's equivalent resistance).

Now suppose we connect an identical generator in parallel with the first, using connecting wire so short that we may safely discount its additional resistance:



Use the Superposition Theorem to re-calculate the motor current and motor terminal voltage, commenting on how these figures compare with the first calculation (using only one generator).

file 03130

Answer 12

With only one generator connected:

$I_{motor} = 4.726$ amps $\qquad V_{motor} = 472.6$ volts

With two generators connected:

$I_{motor} = 4.733$ amps $\qquad V_{motor} = 473.3$ volts

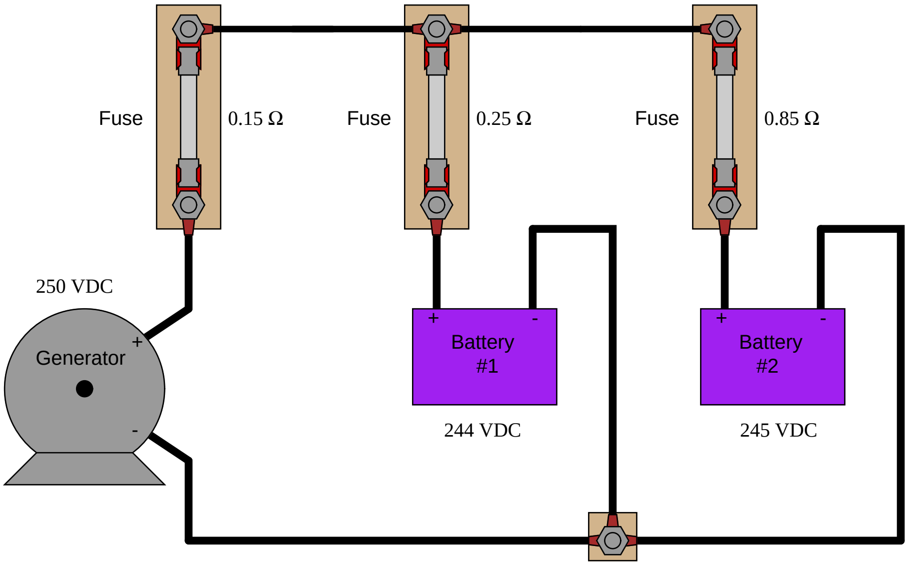
Challenge question: how much current does *each* generator supply to the circuit when there are two generators connected in parallel?

Notes 12

Some students will erroneously leap to the conclusion that another generator will send twice the current through the load (with twice the voltage drop across the motor terminals!). Such a conclusion is easy to reach if one does not fully understand the Superposition Theorem.

Question 13

Calculate the charging current through each battery, using the Superposition Theorem (ignore all wire and connection resistances – only consider the resistance of each fuse):



file 00695

Answer 13

$I_{generator} = 16.82$ A

$I_{battery1} = 13.91$ A

$I_{battery2} = 2.91$ A

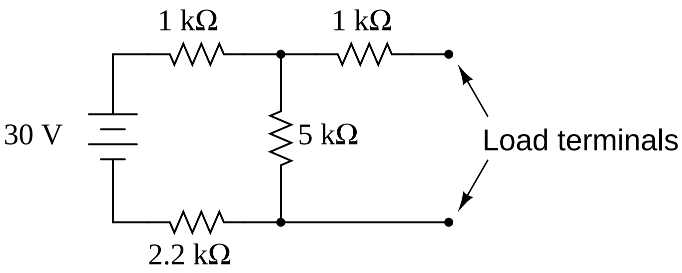
Follow-up question: identify any safety hazards that could arise as a result of excessive resistance in the fuse holders (e.g., corrosion build-up on the metal tabs where the fuse clips in to the fuse-holder).

Notes 13

Though there are other methods of analysis for this circuit, it is still a good application of Superposition Theorem.

Question 14

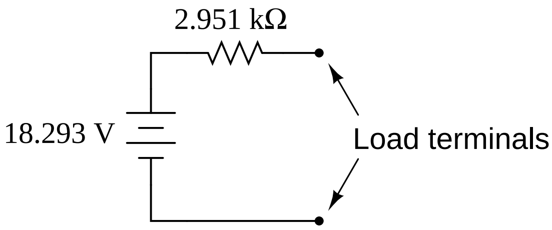
Give a step-by-step procedure for reducing this circuit to a Thévenin equivalent circuit (one voltage source in series with one resistor):



file 02021

Answer 14

I will let you research the procedure for determining Thévenin equivalent circuits, and explain it in your own words. Here is the equivalent circuit for the circuit given in the question:

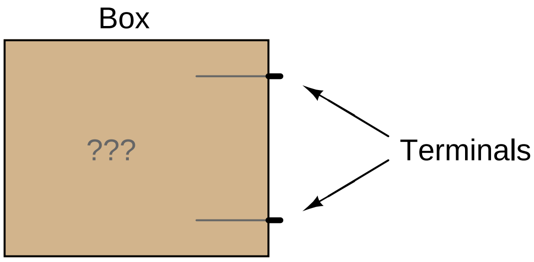


Notes 14

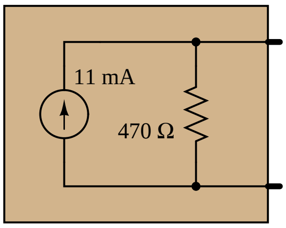
It should be easy for your students to research an algorithm (step-by-step procedure) for determining a Thévenin equivalent circuit. Let them do the work, and explain it to you and their classmates!

Question 15

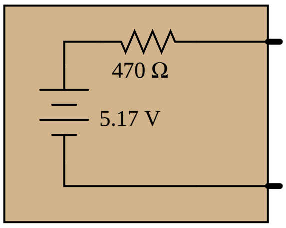
Suppose you were handed a black box with two metal terminals on one side, for attaching electrical (wire) connections. Inside this box, you were told, was a current source connected in parallel with a resistance.



Your task was to experimentally determine the values of the current source and the resistor inside the box, and you did just that. From your experimental data you then sketched a circuit with the following component values:



However, you later discovered that you had been tricked. Instead of containing a current source and a resistor, the circuit inside the box was actually a *voltage source* connected in *series* with a resistor:



Demonstrate that these two different circuits are indistinguishable from the perspective of the two metal terminals, and explain what general principle this equivalence represents.

file 02024

Answer 15

A good way to demonstrate the electrical equivalence of these circuits is to calculate their responses to identical load resistor values. The equivalence you see here proves that Thévenin and Norton equivalent circuits are interchangeable.

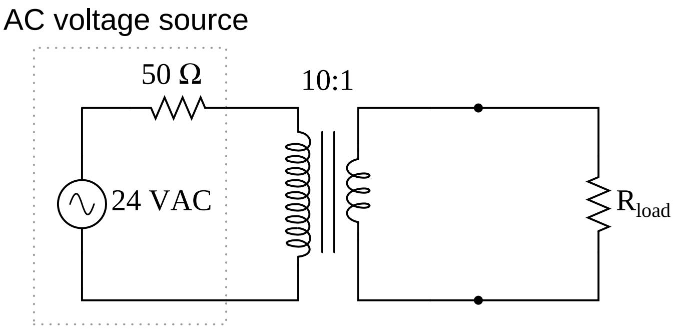
Follow-up question: give a step-by-step procedure for converting a Thévenin equivalent circuit into a Norton equivalent circuit, and visa-versa.

Notes 15

Ask your students to clearly state both Thévenin's and Norton's Theorems, and also discuss why both these theorems are important electrical analysis tools.

Question 16

An AC voltage source with an internal ("Thévenin") resistance of 50 Ω is connected to a step-down transformer with a winding ratio of 10:1. What is the equivalent source voltage and resistance, as seen from the load terminals?



file 01034

Answer 16

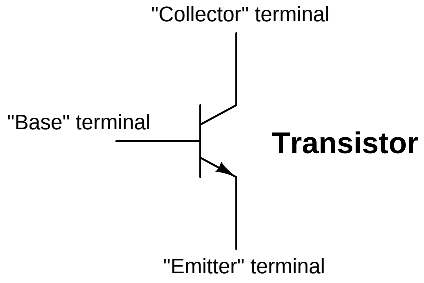
Equivalent source voltage = 2.4 VAC; equivalent source resistance = 0.5 Ω.

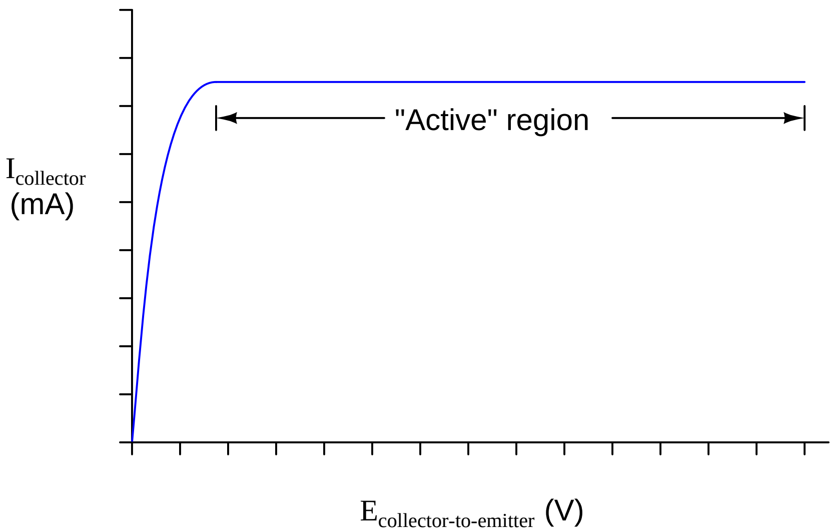
Notes 16

Ask your students to explain how they obtained the equivalent voltage and current figures for this transformer-coupled source. Is there a scenario we could imagine the source being placed in that would allow us to obtain these figures without knowing anything about transformer impedance matching?

Question 17

If we were to "model" a transistor with a standard passive component (resistor, voltage source, current source, capacitor, or inductor) for the sake of mathematically analyzing a circuit containing a transistor, what component would best represent the characteristics of the transistor within its "active" region?





file 00433

Answer 17

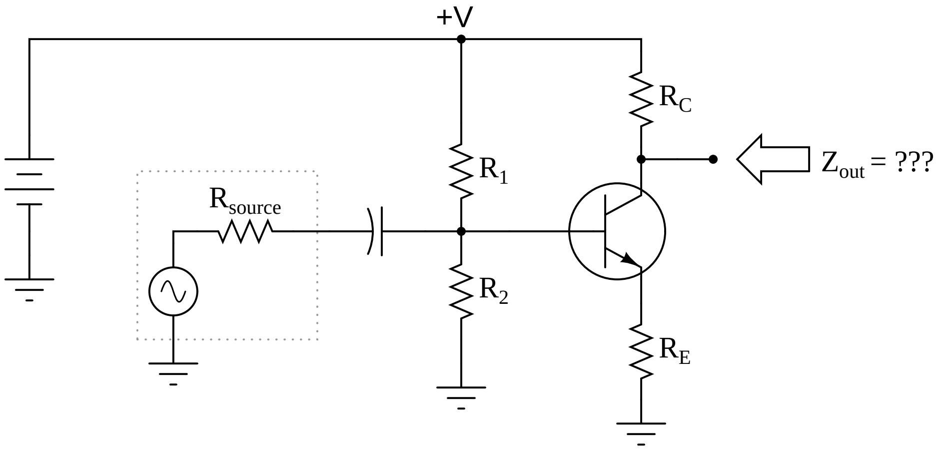
A transistor within its "active" region would be best modeled by a *current source.*

Notes 17

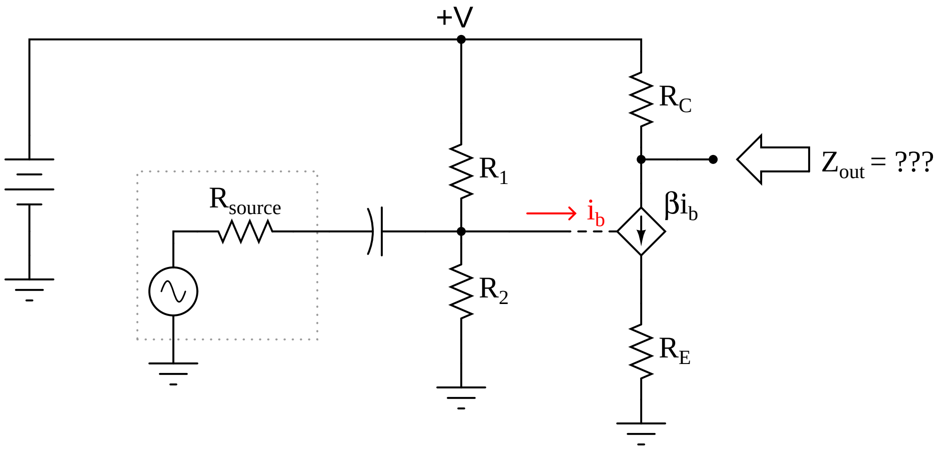
If your students are perplexed at the method of determining the answer, ask them this question: "For the transistor, what variable remains *constant* despite a wide variation in the other variable?"

Question 18

Determining the output impedance of a common-emitter amplifier is impossible unless we know how to *model* the transistor in terms of components whose behavior is simple to express.



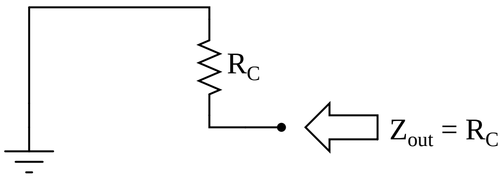
When in its active mode, a transistor operates like a *current regulator*. This is similar enough to the behavior of a *current source* that we may use a source to model the transistor's behavior for the sake of this impedance determination:



Now, apply the same steps you would use in determining the Thévenin or Norton equivalent impedance to the output of this amplifier circuit, and this will yield the amplifier's output impedance. Draw an equivalent circuit for the amplifier during this *Thévenizing/Nortonizing* process to show how the output impedance is determined.

file 02243

Answer 18



I'm leaving it up to you to explain *why* the amplifier circuit reduces to something as simple as this!

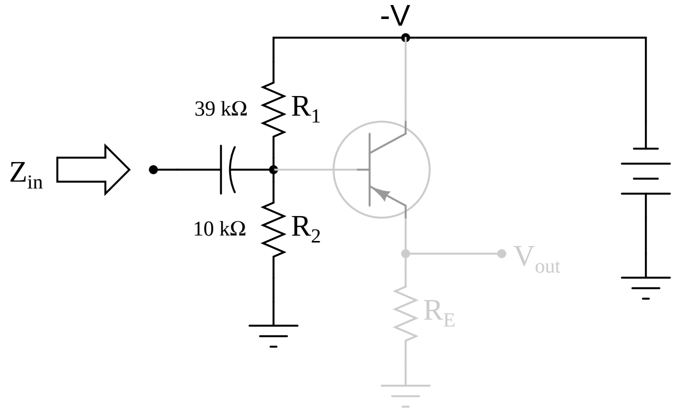
Follow-up question: what is the significance of showing the transistor as a current source using a diamond-shaped symbol rather than a circle? You should be familiar by now with circular current source symbols, but what does a diamond-shaped current source symbol specifically represent in a schematic diagram?

Notes 18

The main problem students usually have when Thévenizing or Nortonizing this circuit is what to do with the current source. They may remember that voltage sources become shorted during the impedance-determination process, but usually make the mistake of doing the exact same thing with current sources. Remind your students if necessary that *each source is to be replaced by its respective internal impedance*. For voltage sources (with zero internal impedance, ideally) it means replacing them with short circuits. For current sources (with infinite internal impedance, ideally) it means replacing them with open circuits.

Question 19

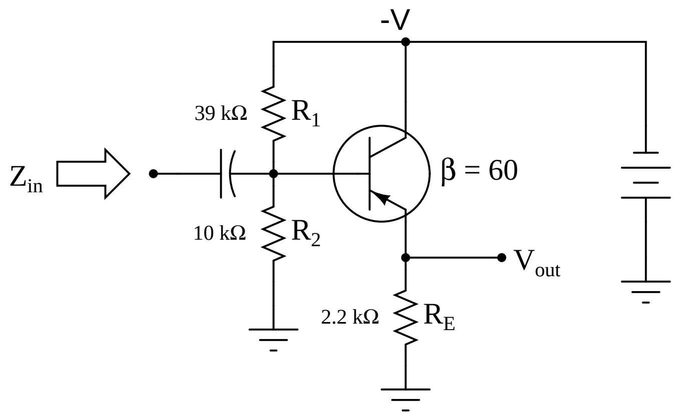
The voltage divider network employed to create a DC bias voltage for many transistor amplifier circuits has its own effect on amplifier input impedance. Without considering the presence of the transistor or the emitter resistance, calculate the impedance as "seen" from the input terminal resulting from the two resistors R_1 and R_2 in the following common-collector amplifier circuit:



Remember, what you are doing here is actually determining the Thévenin/Norton equivalent resistance as seen from the input terminal by an *AC* signal. The input coupling capacitor reactance is generally small enough to be safely ignored.

Next, calculate the input impedance of the same circuit, this time considering the presence of the transistor and emitter resistor, assuming a current gain (β or h_{fe}) of 60, and the following formula for impedance at the base resulting from β and R_E:

$$Z_B \approx (\beta + 1)R_E$$



Develop an equation from the steps you take in calculating this impedance value.

file 03127

Answer 19

Z_{in} (without considering transistor) = 7.959 kΩ

Z_{in} (complete circuit) ≈ 7.514 kΩ

$$Z_{in} \approx \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{(\beta+1)R_E}}$$

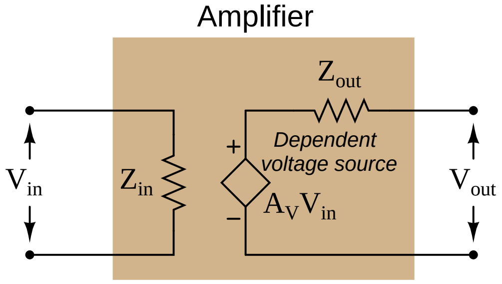
Notes 19

This question is primarily an exercise in applying Thévenin's theorem to the amplifier circuit. The most confusing point of this for most students seems to be how to regard the DC power supply. A review of Thévenin equivalent circuit procedures and calculations might be in order here.

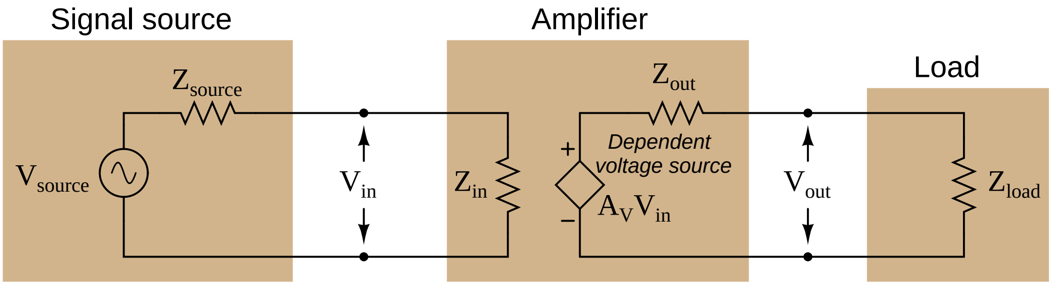
To be proper, the transistor's dynamic emitter resistance (r'_e) could also be included in this calculation, but this just makes things more complex. For this question, I wanted to keep things as simple as possible by just having students concentrate on the issue of integrating the voltage divider impedance with the transistor's base impedance. With an emitter resistor value of 1500 ohms, the dynamic emitter resistance is negligibly small anyway.

Question 20

Sometimes you will see amplifier circuits expressed as collections of *impedances* and *dependent sources*:



With this model, the amplifier appears as a load (Z_{in}) to whatever signal source its input is connected to, boosts that input voltage by the gain factor (A_V), then outputs the boosted signal through a series output impedance (Z_{out}) to whatever load is connected to the output terminals:



Explain why all these impedances (shown as resistors) are significant to us as we seek to apply amplifier circuits to practical applications. Which of these impedances do you suppose are typically easier for us to change, if they require changing at all?

file 02236

Answer 20

Z_{in} should equal Z_{source} and Z_{load} should equal Z_{out} for maximum power transfer from source to load. Typically, the values of Z_{source} and Z_{load} are fixed by the nature of the source and load devices, respectively, and the only impedances we have the freedom to alter are those within the amplifier.

Notes 20

This question has multiple purposes: to introduce students to the modeling concept of a *dependent source*, to show how an amplifier circuit may be modeled using such a dependent source, and to probe into the importance of impedances in a complete amplification *system*: source, amplifier, and load. Many interesting things to discuss here!

Question 21

Suppose you were given two components and told one was an inductor while the other was a capacitor. Both components are unmarked, and impossible to visually distinguish or identify. Explain how you could use an ohmmeter to distinguish one from the other, based on each component's response to direct current (DC).

Then, explain how you could approximately measure the value of each component using nothing more than a sine-wave signal generator and an AC meter capable only of precise AC voltage and current measurements across a wide frequency range (no direct capacitance or inductance measurement capability), and show how the reactance equation for each component (L and C) would be used in your calculations.

file 03115

Answer 21

Did you really think I would give you the answers to a question like this?

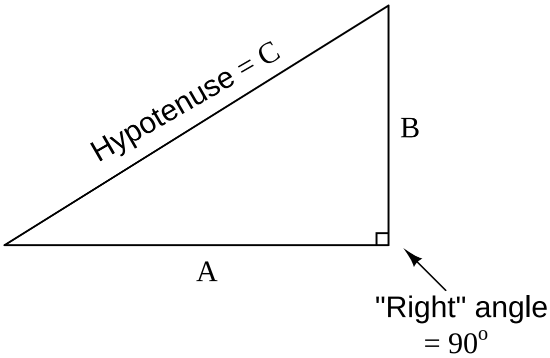
Challenge question: suppose the only test equipment you had available was a 6-volt battery and an old analog volt-milliammeter (with no resistance check function). How could you use this primitive gear to identify which component was the inductor and which was the capacitor?

Notes 21

This is an excellent opportunity to brainstorm as a group and experiment on real components. The purpose of this question is to make the reactance equations more "real" to students by having them apply the equations to a realistic scenario. The ohmmeter test is based on DC component response, which may be thought of in terms of reactance at a frequency at or near zero. The multimeter/generator test is based on AC response, and will require algebraic manipulation to convert the canonical forms of these equations to versions appropriate for calculating L and C.

Question 22

The *Pythagorean Theorem* is used to calculate the length of the hypotenuse of a right triangle given the lengths of the other two sides:



Write the standard form of the Pythagorean Theorem, and give an example of its use.
file 02102

Answer 22

I'll let you research this one on your own!

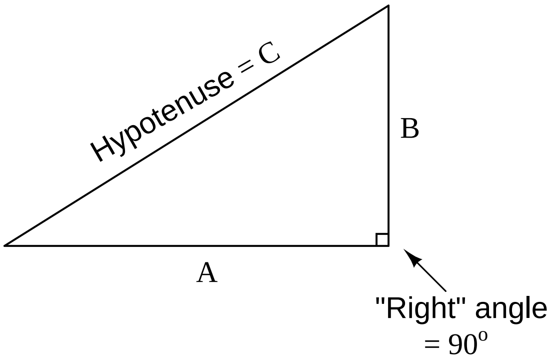
Follow-up question: identify an application in AC circuit analysis where the Pythagorean Theorem would be useful for calculating a circuit quantity such as voltage or current.

Notes 22

The Pythagorean Theorem is easy enough for students to find on their own that you should not need to show them. A memorable illustration of this theorem are the side lengths of a so-called *3-4-5* triangle. Don't be surprised if this is the example many students choose to give.

Question 23

The *Pythagorean Theorem* is used to calculate the length of the hypotenuse of a right triangle given the lengths of the other two sides:



Manipulate the standard form of the Pythagorean Theorem to produce a version that solves for the length of A given B and C, and also write a version of the equation that solves for the length of B given A and C.

file 03114

Answer 23

Standard form of the Pythagorean Theorem:

$$C = \sqrt{A^2 + B^2}$$

Solving for A:

$$A = \sqrt{C^2 - B^2}$$

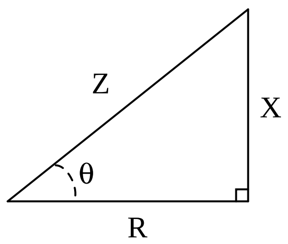
Solving for B:

$$B = \sqrt{C^2 - A^2}$$

Notes 23

The Pythagorean Theorem is easy enough for students to find on their own that you should not need to show them. A memorable illustration of this theorem are the side lengths of a so-called *3-4-5* triangle. Don't be surprised if this is the example many students choose to give.

Question 24



Identify which trigonometric functions (sine, cosine, or tangent) are represented by each of the following ratios, with reference to the angle labeled with the Greek letter "Theta" (Θ):

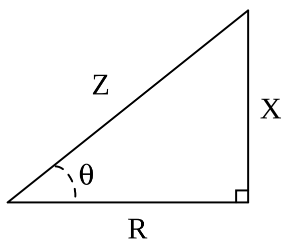
$$\frac{X}{R} =$$

$$\frac{X}{Z} =$$

$$\frac{R}{Z} =$$

file 02084

Answer 24



$$\frac{X}{R} = \tan \Theta = \frac{\text{Opposite}}{\text{Adjacent}}$$

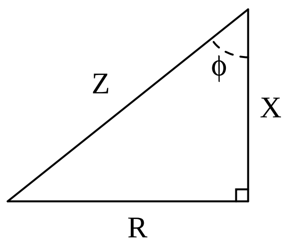
$$\frac{X}{Z} = \sin \Theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$\frac{R}{Z} = \cos \Theta = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

Notes 24

Ask your students to explain what the words "hypotenuse", "opposite", and "adjacent" refer to in a right triangle.

Question 25



Identify which trigonometric functions (sine, cosine, or tangent) are represented by each of the following ratios, with reference to the angle labeled with the Greek letter "Phi" (ϕ):

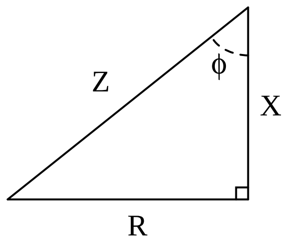
$$\frac{R}{X} =$$

$$\frac{X}{Z} =$$

$$\frac{R}{Z} =$$

file 03113

Answer 25



$$\frac{R}{X} = \tan\phi = \frac{\text{Opposite}}{\text{Adjacent}}$$

$$\frac{X}{Z} = \cos\phi = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

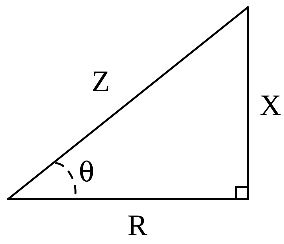
$$\frac{R}{Z} = \sin\phi = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

Notes 25

Ask your students to explain what the words "hypotenuse", "opposite", and "adjacent" refer to in a right triangle.

Question 26

Trigonometric functions such as *sine*, *cosine*, and *tangent* are useful for determining the ratio of right-triangle side lengths given the value of an angle. However, they are not very useful for doing the reverse: calculating an angle given the lengths of two sides.



Suppose we wished to know the value of angle Θ, and we happened to know the values of Z and R in this impedance triangle. We could write the following equation, but in its present form we could not solve for Θ:

$$\cos\Theta = \frac{R}{Z}$$

The only way we can algebraically isolate the angle Θ in this equation is if we have some way to "undo" the cosine function. Once we know what function will "undo" cosine, we can apply it to both sides of the equation and have Θ by itself on the left-hand side.

There is a class of trigonometric functions known as *inverse* or *"arc"* functions which will do just that: "undo" a regular trigonometric function so as to leave the angle by itself. Explain how we could apply an "arc-function" to the equation shown above to isolate Θ.

file 02086

Answer 26

$$\cos\Theta = \frac{R}{Z} \qquad \text{Original equation}$$

. . . applying the "arc-cosine" function to both sides . . .

$$\arccos\left(\cos\Theta\right) = \arccos\left(\frac{R}{Z}\right)$$

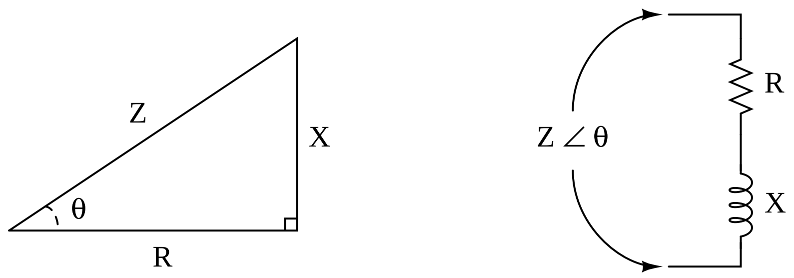
$$\Theta = \arccos\left(\frac{R}{Z}\right)$$

Notes 26

I like to show the purpose of trigonometric arcfunctions in this manner, using the cardinal rule of algebraic manipulation (do the same thing to both sides of an equation) that students are familiar with by now. This helps eliminate the mystery of arcfunctions for students new to trigonometry.

Question 27

The *impedance triangle* is often used to graphically relate Z, R, and X in a series circuit:

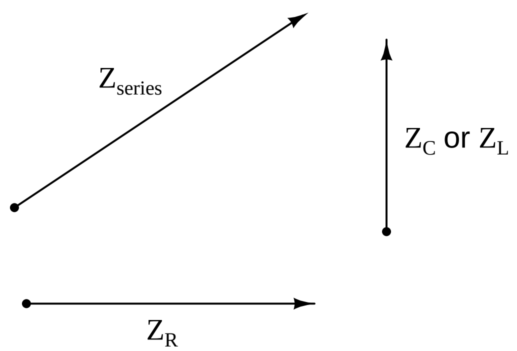


Unfortunately, many students do not grasp the significance of this triangle, but rather memorize it as a "trick" used to calculate one of the three variables given the other two. Explain *why* a right triangle is an appropriate form to relate these variables, and what each side of the triangle actually represents.

file 02076

Answer 27

Each side of the impedance triangle is actually a *phasor* (a vector representing impedance with magnitude and direction):



Since the phasor for resistive impedance (Z_R) has an angle of zero degrees and the phasor for reactive impedance (Z_C or Z_L) either has an angle of +90 or -90 degrees, the *phasor sum* representing total series impedance will form the hypotenuse of a right triangle when the first to phasors are added (tip-to-tail).

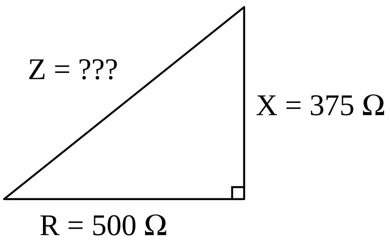
Follow-up question: as a review, explain why resistive impedance phasors always have an angle of zero degrees, and why reactive impedance phasors always have angles of either +90 degrees or -90 degrees.

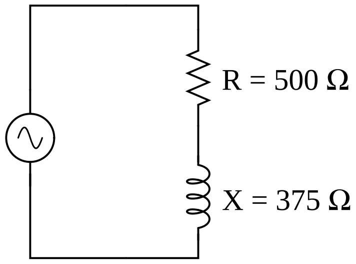
Notes 27

The question is sufficiently open-ended that many students may not realize exactly what is being asked until they read the answer. This is okay, as it is difficult to phrase the question in a more specific manner without giving away the answer!

Question 28

Use the "impedance triangle" to calculate the impedance of this series combination of resistance (R) and inductive reactance (X):





Explain what equation(s) you use to calculate Z.

file 02081

Answer 28

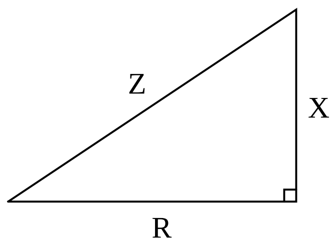
$Z = 625\ \Omega$, as calculated by the Pythagorean Theorem.

Notes 28

Be sure to have students show you the form of the Pythagorean Theorem, rather than showing them yourself, since it is so easy for students to research on their own.

Question 29

Students studying AC electrical theory become familiar with the *impedance triangle* very soon in their studies:



What these students might not ordinarily discover is that this triangle is also useful for calculating electrical quantities other than impedance. The purpose of this question is to get you to discover some of the triangle's other uses.

Fundamentally, this right triangle represents *phasor addition*, where two electrical quantities at right angles to each other (resistive versus reactive) are added together. In series AC circuits, it makes sense to use the impedance triangle to represent how resistance (R) and reactance (X) combine to form a total impedance (Z), since resistance and reactance are special forms of impedance themselves, and we know that impedances *add* in series.

List all of the electrical quantities you can think of that add (in series or in parallel) and then show how similar triangles may be drawn to relate those quantities together in AC circuits.

file 02077

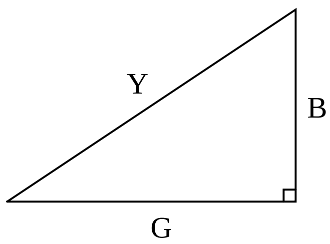
Answer 29

Electrical quantities that add:

- Series impedances
- Series voltages
- Parallel admittances
- Parallel currents
- Power dissipations

I will show you one graphical example of how a triangle may relate to electrical quantities other than series impedances:

Admittances add in parallel



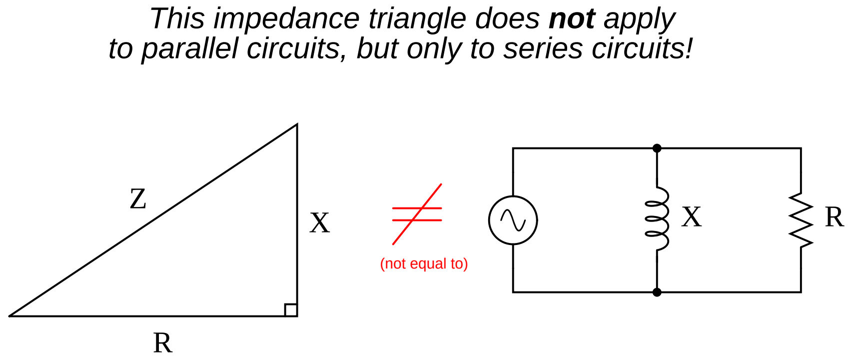
Notes 29

It is very important for students to understand that the triangle only works as an analysis tool when applied to quantities that *add*. Many times I have seen students try to apply the Z-R-X impedance triangle to parallel circuits and fail because *parallel impedances do not add*. The purpose of this question is to force students to think about where the triangle is applicable to AC circuit analysis, and not just to use it blindly.

The power triangle is an interesting application of trigonometry applied to electric circuits. You may not want to discuss power with your students in great detail if they are just beginning to study voltage and current in AC circuits, because power is a sufficiently confusing subject on its own.

Question 30

Explain why the "impedance triangle" is *not* proper to use for relating total impedance, resistance, and reactance in parallel circuits as it is for series circuits:



file 02078

Answer 30

Impedances do not add in parallel.

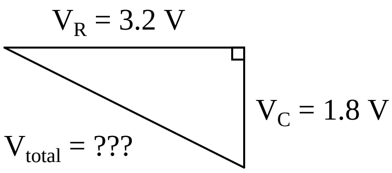
Follow-up question: what kind of a triangle *could* be properly applied to a parallel AC circuit, and why?

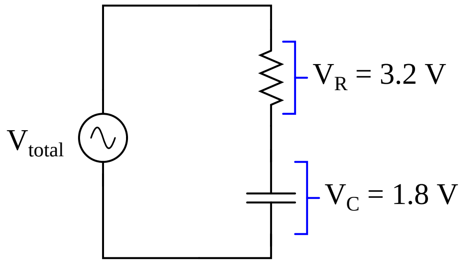
Notes 30

Trying to apply the Z-R-X triangle directly to parallel AC circuits is a common mistake many new students make. Key to knowing when and how to use triangles to graphically depict AC quantities is understanding *why* the triangle works as an analysis tool and *what* its sides represent.

Question 31

Use a triangle to calculate the total voltage of the source for this series RC circuit, given the voltage drop across each component:





Explain what equation(s) you use to calculate V_{total}, as well as why we must geometrically add these voltages together.

file 02107

Answer 31

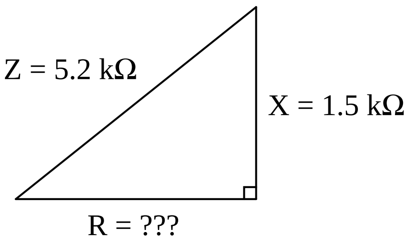
$V_{total} = 3.672$ volts, as calculated by the Pythagorean Theorem

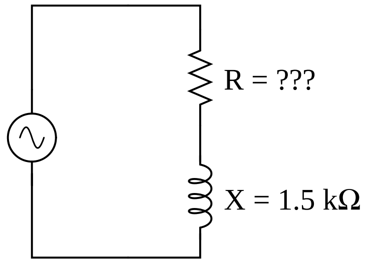
Notes 31

Be sure to have students show you the form of the Pythagorean Theorem, rather than showing them yourself, since it is so easy for students to research on their own.

Question 32

Use the "impedance triangle" to calculate the necessary resistance of this series combination of resistance (R) and inductive reactance (X) to produce the desired total impedance of 5.2 kΩ:





Explain what equation(s) you use to calculate R, and the algebra necessary to achieve this result from a more common formula.

file 02082

Answer 32

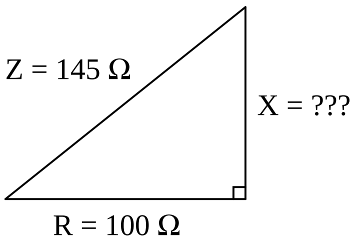
$R = 4.979$ kΩ, as calculated by an algebraically manipulated version of the Pythagorean Theorem.

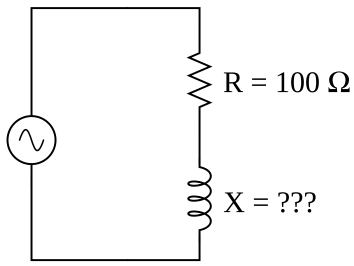
Notes 32

Be sure to have students show you the form of the Pythagorean Theorem, rather than showing them yourself, since it is so easy for students to research on their own.

Question 33

Use the "impedance triangle" to calculate the necessary reactance of this series combination of resistance (R) and inductive reactance (X) to produce the desired total impedance of 145 Ω:





Explain what equation(s) you use to calculate X, and the algebra necessary to achieve this result from a more common formula.

file 02083

Answer 33

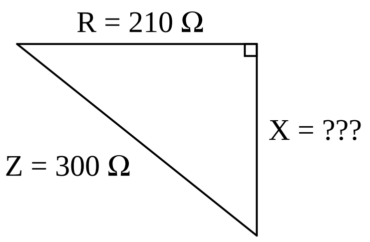
$X = 105\ \Omega$, as calculated by an algebraically manipulated version of the Pythagorean Theorem.

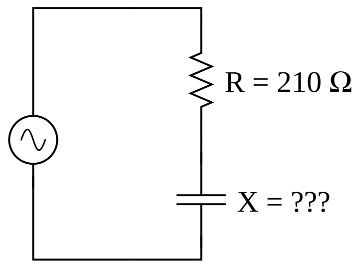
Notes 33

Be sure to have students show you the form of the Pythagorean Theorem, rather than showing them yourself, since it is so easy for students to research on their own.

Question 34

Use the "impedance triangle" to calculate the necessary reactance of this series combination of resistance (R) and capacitive reactance (X) to produce the desired total impedance of 300 Ω:





Explain what equation(s) you use to calculate X, and the algebra necessary to achieve this result from a more common formula.

file 02092

Answer 34

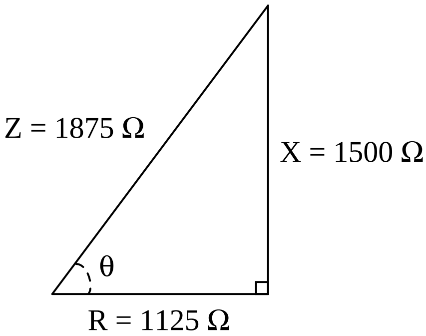
$X = 214.2$ Ω, as calculated by an algebraically manipulated version of the Pythagorean Theorem.

Notes 34

Be sure to have students show you the form of the Pythagorean Theorem, rather than showing them yourself, since it is so easy for students to research on their own.

Question 35

A series AC circuit contains 1125 ohms of resistance and 1500 ohms of reactance for a total circuit impedance of 1875 ohms. This may be represented graphically in the form of an impedance triangle:



Since all side lengths on this triangle are known, there is no need to apply the Pythagorean Theorem. However, we may still calculate the two non-perpendicular angles in this triangle using "inverse" trigonometric functions, which are sometimes called *arc*functions.

Identify which arc-function should be used to calculate the angle Θ given the following pairs of sides:

$$R \text{ and } Z$$

$$X \text{ and } R$$

$$X \text{ and } Z$$

Show how three different trigonometric arcfunctions may be used to calculate the same angle Θ.

file 02085

Answer 35

$$\arccos \frac{R}{Z} = 53.13^o$$

$$\arctan \frac{X}{R} = 53.13^o$$

$$\arcsin \frac{X}{Z} = 53.13^o$$

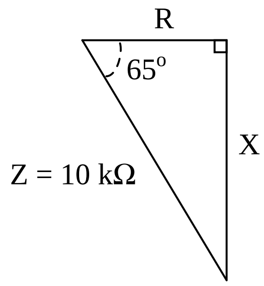
Challenge question: identify three *more* arcfunctions which could be used to calculate the same angle Θ.

Notes 35

Some hand calculators identify arc-trig functions by the letter "A" prepending each trigonometric abbreviation (e.g. "ASIN" or "ATAN"). Other hand calculators use the inverse function notation of a -1 exponent, which is *not* actually an exponent at all (e.g. $\sin^{-1}$ or $\tan^{-1}$). Be sure to discuss function notation on your students' calculators, so they know what to invoke when solving problems such as this.

Question 36

A series AC circuit exhibits a total impedance of 10 kΩ, with a phase shift of 65 degrees between voltage and current. Drawn in an impedance triangle, it looks like this:



We know that the *sine* function relates the sides X and Z of this impedance triangle with the 65 degree angle, because the sine of an angle is the ratio of *opposite* to *hypotenuse*, with X being opposite the 65 degree angle. Therefore, we know we can set up the following equation relating these quantities together:

$$\sin 65^o = \frac{X}{Z}$$

Solve this equation for the value of X, in ohms.

file 02088

Answer 36

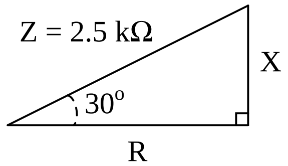
$X = 9.063$ kΩ

Notes 36

Ask your students to show you their algebraic manipulation(s) in setting up the equation for evaluation.

Question 37

A series AC circuit exhibits a total impedance of 2.5 kΩ, with a phase shift of 30 degrees between voltage and current. Drawn in an impedance triangle, it looks like this:



Use the appropriate trigonometric functions to calculate the equivalent values of R and X in this series circuit.

file 02087

Answer 37

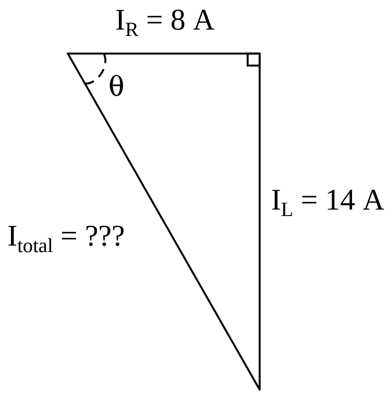
$R = 2.165$ kΩ
$X = 1.25$ kΩ

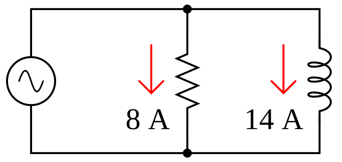
Notes 37

There are a few different ways one could solve for R and X in this trigonometry problem. This would be a good opportunity to have your students present problem-solving strategies on the board in front of class so everyone gets an opportunity to see multiple techniques.

Question 38

A parallel AC circuit draws 8 amps of current through a purely resistive branch and 14 amps of current through a purely inductive branch:





Calculate the total current and the angle Θ of the total current, explaining your trigonometric method(s) of solution.

file 02089

Answer 38

I_{total} = 16.12 amps

$\Theta = 60.26^o$ (negative, if you wish to represent the angle according to the standard coordinate system for phasors).

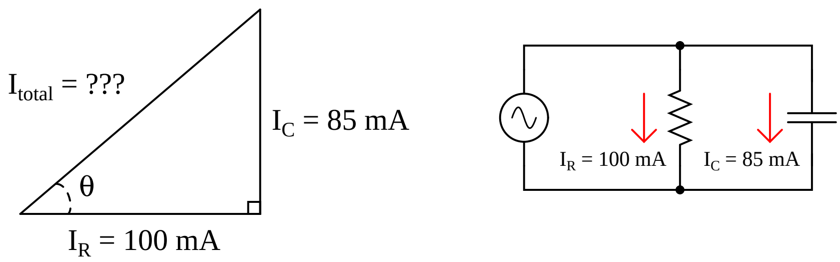
Follow-up question: in calculating Θ, it is recommended to use the arctangent function instead of either the arcsine or arc-cosine functions. The reason for doing this is accuracy: less possibility of compounded error, due to either rounding and/or calculator-related (keystroke) errors. Explain why the use of the arctangent function to calculate Θ incurs less chance of error than either of the other two arcfunctions.

Notes 38

The follow-up question illustrates an important principle in many different disciplines: avoidance of unnecessary risk by choosing calculation techniques using given quantities instead of derived quantities. This is a good topic to discuss with your students, so make sure you do so.

Question 39

A parallel AC circuit draws 100 mA of current through a purely resistive branch and 85 mA of current through a purely capacitive branch:



Calculate the total current and the angle Θ of the total current, explaining your trigonometric method(s) of solution.

file 02091

Answer 39

$I_{total} = 131.2$ mA

$\Theta = 40.36^o$

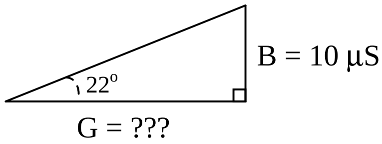
Follow-up question: in calculating Θ, it is recommended to use the arctangent function instead of either the arcsine or arc-cosine functions. The reason for doing this is accuracy: less possibility of compounded error, due to either rounding and/or calculator-related (keystroke) errors. Explain why the use of the arctangent function to calculate Θ incurs less chance of error than either of the other two arcfunctions.

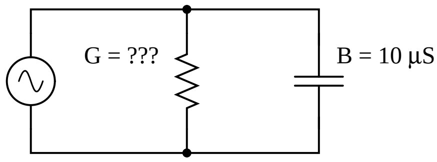
Notes 39

The follow-up question illustrates an important principle in many different disciplines: avoidance of unnecessary risk by choosing calculation techniques using given quantities instead of derived quantities. This is a good topic to discuss with your students, so make sure you do so.

Question 40

A parallel RC circuit has 10 μS of susceptance (B). How much conductance (G) is necessary to give the circuit a (total) phase angle of 22 degrees?





file 02090

Answer 40

$G = 24.75\ \mu$S

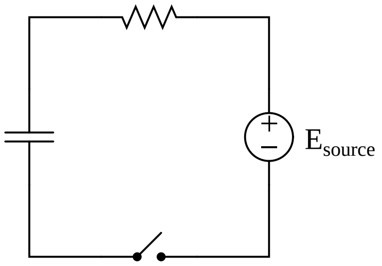
Follow-up question: how much resistance is this, in ohms?

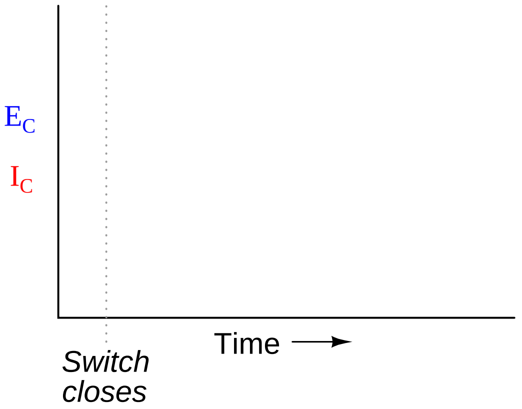
Notes 40

Ask your students to explain their method(s) of solution, including any ways to double-check the correctness of the answer.

Question 41

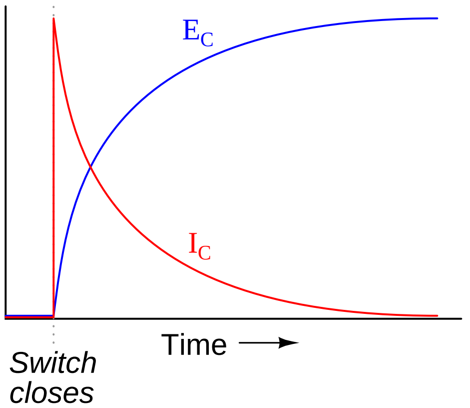
Graph both the capacitor voltage (E_C) and the capacitor current (I_C) over time as the switch is closed in this circuit. Assume the capacitor begins in a complete uncharged state (0 volts):





file 00434

Answer 41

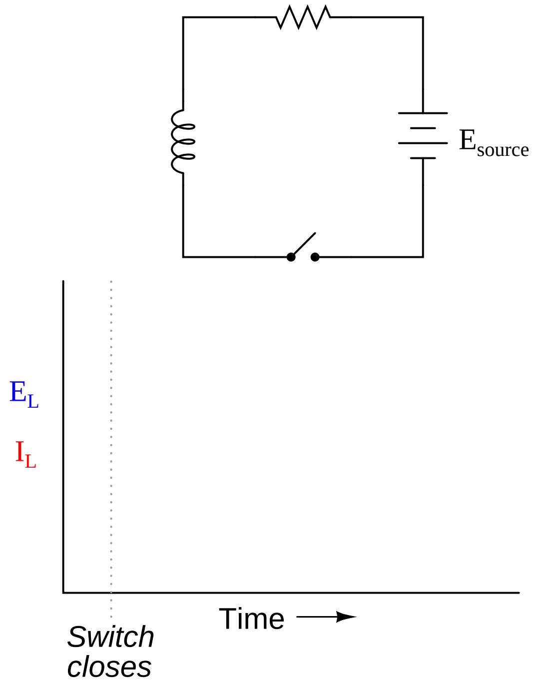


Notes 41

Have your students explain why the voltage and current curves are shaped as they are.

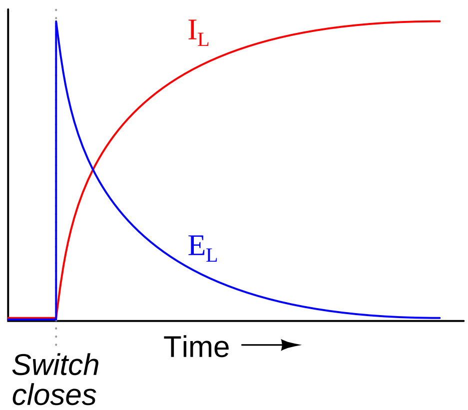
Question 42

Graph both the inductor voltage (E_L) and the inductor current (I_L) over time as the switch is closed in this circuit:



file 00435

Answer 42



Notes 42

Have your students explain why the voltage and current curves are shaped as they are.

Question 43

An electronic service technician prepares to work on a high-voltage power supply circuit containing one large capacitor. On the side of this capacitor are the following specifications:

$$3000 \text{ WVDC} \quad 0.75\mu\text{F}$$

Obviously this device poses a certain amount of danger, even with the AC line power secured (lock-out/tag-out). Discharging this capacitor by directly shorting its terminals with a screwdriver or some other piece of metal might be dangerous due to the quantity of the stored charge. What needs to be done is to discharge this capacitor at a modest rate.

The technician realizes that she can discharge the capacitor at any rate desired by connecting a resistor in parallel with it (holding the resistor with electrically-insulated pliers, of course, to avoid having to touch either terminal). What size resistor should she use, if she wants to discharge the capacitor to less than 1% charge in 15 seconds? State your answer using the standard 4-band resistor color code (tolerance = +/- 10%).

file 01525

Answer 43

Yellow, Black, Green, Silver (assuming 5 time constants' worth of time: just less than 1% charge). Yellow, Orange, Green, Silver for a discharge down to 1% in 15 seconds.

Notes 43

In order to answer this question, students must not only be able to calculate time constants for a simple RC circuit, but they must also remember the resistor color code so as to choose the right size based on color. A very practical problem, and important for safety reasons too!

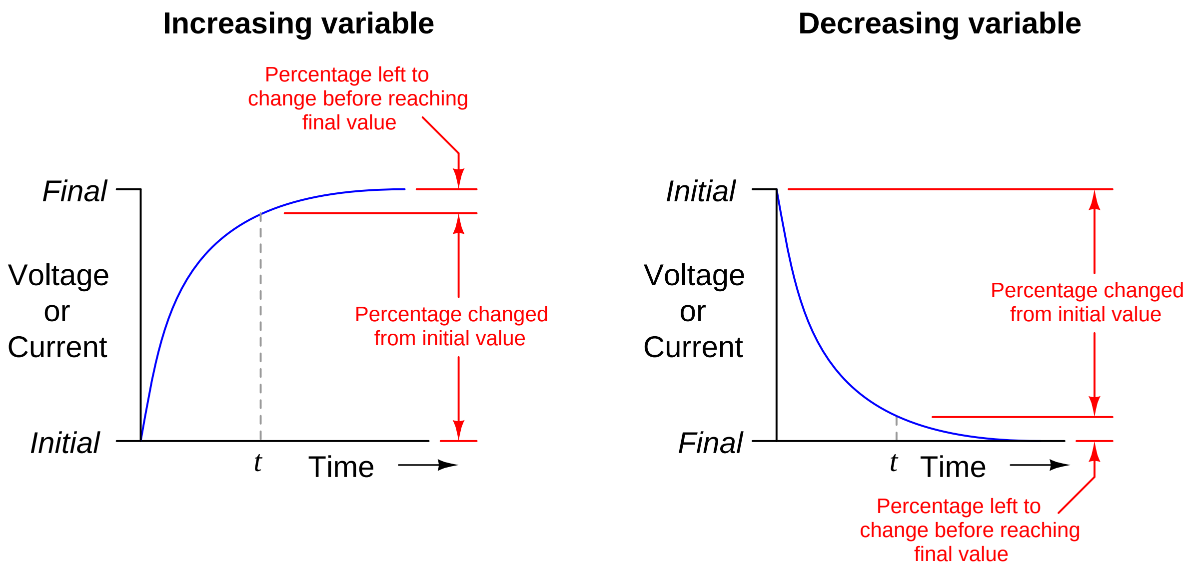
Question 44

The following two expressions are frequently used to calculate values of changing variables (voltage and current) in RC and LR timing circuits:

$$e^{-\frac{t}{\tau}} \qquad \text{or} \qquad 1 - e^{-\frac{t}{\tau}}$$

One of these expressions describes the percentage that a changing value in an RC or LR circuit *has gone* from the starting time. The other expression describes how far that same variable *has left to go* before it reaches its ultimate value (at $t = \infty$).

The question is, which expression represents which quantity? This is often a point of confusion, because students have a tendency to try to correlate these expressions to the quantities by rote memorization. Does the expression $e^{-\frac{t}{\tau}}$ represent the amount a variable has changed, or how far it has left to go until it stabilizes? What about the other expression $1 - e^{-\frac{t}{\tau}}$? More importantly, *how can we figure this out so we don't have to rely on memory?*



file 03117

Answer 44

Here is a hint: set x to zero and evaluate each equation.

Notes 44

It is very important for students to understand what this expression means and how it works, lest they rely solely on memorization to use it in their calculations. As I always tell my students, rote memorization *will* fail you! If a student does not comprehend why the expression works as it does, they will be helpless to retain it as an effective "tool" for performing calculations in the future.

Question 45

What value of resistor would need to be connected in series with a 33 μF capacitor in order to provide a *time constant* (τ) of 10 seconds? Express your answer in the form of a five-band precision resistor color code (with a tolerance of +/- 0.1%).

file 00436

Answer 45

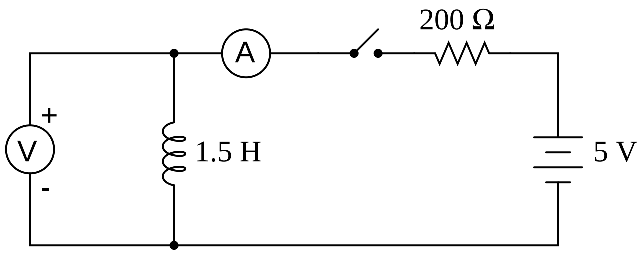
Org, Blk, Org, Org, Vio

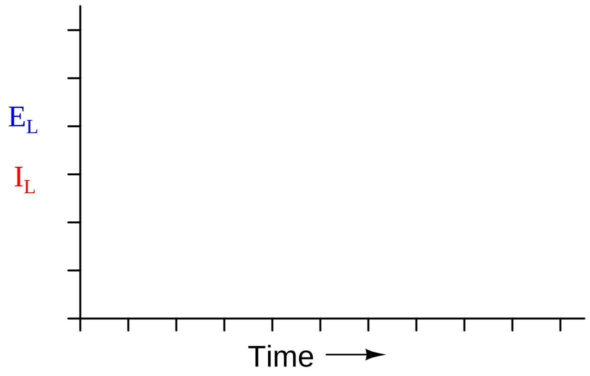
Notes 45

In order for students to answer this question, they must research the RC time constant equation and review the 5-band resistor color code.

Question 46

Plot the inductor voltage and the inductor current over time after the switch closes in this circuit, for at least 4 time constants' worth of time:

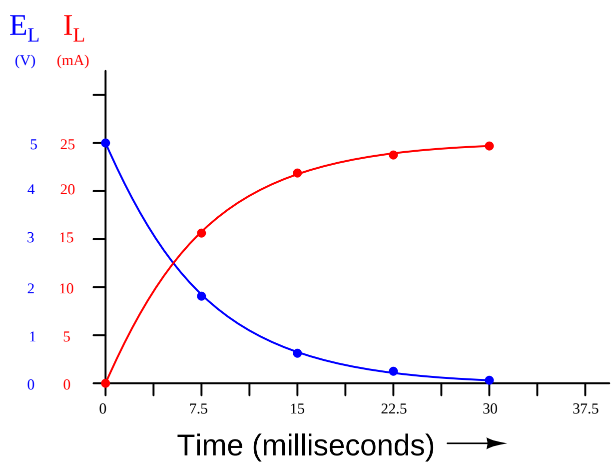




Be sure to label the axes of your graph!

file 01806

Answer 46



Notes 46

I intentionally left the graph unscaled in the problem, so that students might determine their own scales to plot the points in. The scaling shown in the answer is obviously not ideal, as the graphs have reached their terminal values (for all practical purposes) well before the horizontal axis is complete.

Question 47

Calculate the current through a 250 mH inductor after "charging" through a series-connected resistor with 100 Ω of resistance for 6 milliseconds, powered by a 12 volt battery. Assume that the inductor is perfect, with no internal resistance.

Also, express this amount of time (6 milliseconds) in terms of how many *time constants* have elapsed.

file 00453

Answer 47

$I_L = 109.11$ mA @ $t = 6$ milliseconds

6 ms = 2.4 time constants (2.4τ)

Notes 47

Here, students must choose which equation to use for the calculation, calculate the time constant for the circuit, and put all the variables in the right place to obtain the correct answer. Discuss all these steps with your students, allowing them to explain how they approached the question.

Question 48

Calculate the amount of time it takes for a 10 μF capacitor to discharge from 18 volts to 7 volts if its ultimate (final) voltage when fully discharged will be 0 volts, and it is discharging through a 22 kΩ resistor.

file 02941

Answer 48

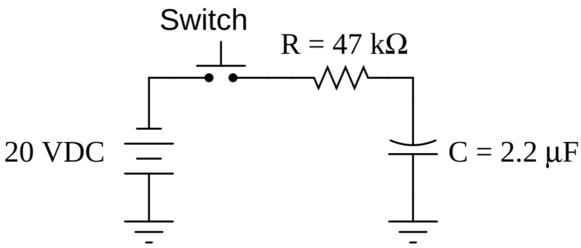
0.208 seconds

Notes 48

In order for students to solve this problem, they must algebraically manipulate the "normal" time-constant formula to solve for time instead of solving for voltage.

Question 49

Determine the amount of time needed after switch closure for the capacitor voltage (V_C) to reach the specified levels:



V_C	Time
0 volts	
-5 volts	
-10 volts	
-15 volts	
-19 volts	

Trace the direction of current in the circuit while the capacitor is charging, and be sure to denote whether you are using electron or conventional flow notation.

Note: the voltages are specified as negative quantities because they are negative with respect to (positive) ground in this particular circuit.

file 03118

Answer 49

V_C	Time
0 volts	0 ms
-5 volts	29.75 ms
-10 volts	71.67 ms
-15 volts	143.3 ms
-19 volts	309.8 ms

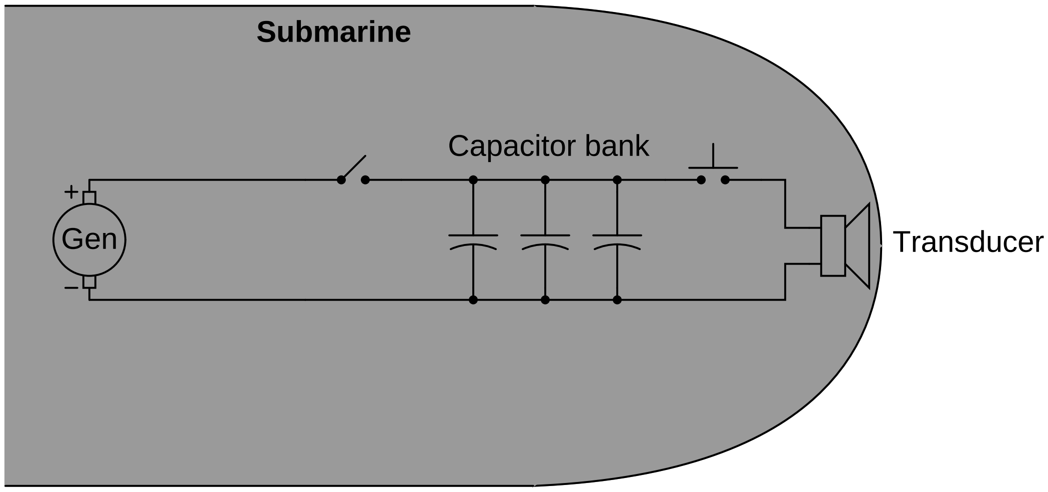
While the capacitor is charging, electron flow moves clockwise and conventional flow moves counterclockwise.

Notes 49

Ask your students to show how they algebraically solved the standard time constant equation for t using logarithms.

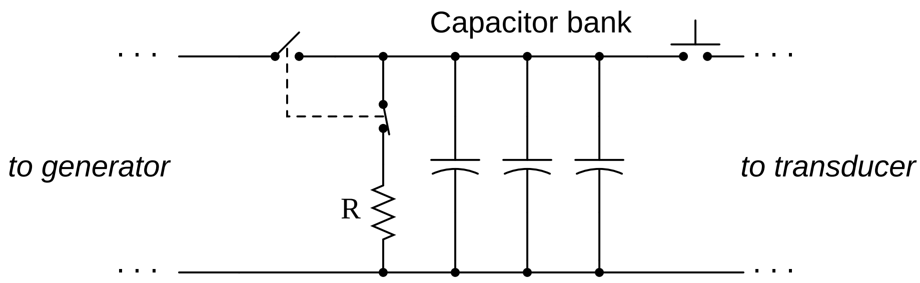
Question 50

A submarine sonar system uses a "bank" of parallel-connected capacitors to store the electrical energy needed to send brief, powerful pulses of current to a transducer (a "speaker" of sorts). This generates powerful sound waves in the water, which are then used for echo-location. The capacitor bank relieves the electrical generators and power distribution wiring aboard the submarine from having to be rated for huge surge currents. The generator trickle-charges the capacitor bank, and then the capacitor bank quickly dumps its store of energy to the transducer when needed:



As you might well imagine, such a capacitor bank can be lethal, as the voltages involved are quite high and the surge current capacity is enormous. Even when the DC generator is disconnected (using the "toggle" disconnect switch shown in the schematic), the capacitors may hold their lethal charge for many days.

To help decreases the safety risk for technical personnel working on this system, a "discharge" switch is connected in parallel with the capacitor bank to automatically provide a path for discharge current whenever the generator disconnect switch is opened:



Suppose the capacitor bank consists of forty 1500 μF capacitors connected in parallel (I know the schematic only shows three, but . . .), and the discharge resistor is 10 kΩ in size. Calculate the amount of time it takes for the capacitor bank to discharge to 10 percent of its original voltage and the amount of time it takes to discharge to 1 percent of its original voltage once the disconnect switch opens and the discharge switch closes.

file 03119

Answer 50

Time to reach 10% $\approx$ 23 minutes

Time to reach 1% $\approx$ 46 minutes

Follow-up question: without using the time constant formula again, calculate how long it will take to discharge to 0.1% of its original voltage. How about 0.01%?

Notes 50

The follow-up question illustrates an important mathematical principle regarding logarithmic decay functions: for every passing of a fixed time interval, the system decays by the same *factor*. This is most clearly (and popularly) seen in the concept of *half-life* for radioactive substances, but it is also seen here for RC (or LR) circuits.

Project progress report (1 day)
Date:
Description of progress made on this day

file 03995

Answer 51

Be sure to note *everything* accomplished for each day, so your instructor has a complete record of your progress.

Notes 51

The purpose of this report form is to familiarize students with the concept of time management as it relates to project completion. Too many students have a tendency to do little or nothing until just before their project is due. By assigning a grade value for progress made each day, you help them learn time management skills and also help them complete their projects sooner (and better!).

Project progress report (1 day)
Date:
Description of progress made on this day

file 03995

Answer 52

Be sure to note *everything* accomplished for each day, so your instructor has a complete record of your progress.

Notes 52

The purpose of this report form is to familiarize students with the concept of time management as it relates to project completion. Too many students have a tendency to do little or nothing until just before their project is due. By assigning a grade value for progress made each day, you help them learn time management skills and also help them complete their projects sooner (and better!).

Question 53

Project progress report (1 day)
Date:
Description of progress made on this day

file 03995

Answer 53

Be sure to note *everything* accomplished for each day, so your instructor has a complete record of your progress.

Notes 53

The purpose of this report form is to familiarize students with the concept of time management as it relates to project completion. Too many students have a tendency to do little or nothing until just before their project is due. By assigning a grade value for progress made each day, you help them learn time management skills and also help them complete their projects sooner (and better!).

Question 54

Project progress report (1 day)
Date:
Description of progress made on this day

file 03995

Answer 54

Be sure to note *everything* accomplished for each day, so your instructor has a complete record of your progress.

Notes 54

The purpose of this report form is to familiarize students with the concept of time management as it relates to project completion. Too many students have a tendency to do little or nothing until just before their project is due. By assigning a grade value for progress made each day, you help them learn time management skills and also help them complete their projects sooner (and better!).

Question 55

Project progress report (1 day)
Date:
Description of progress made on this day

file 03995

Answer 55

Be sure to note *everything* accomplished for each day, so your instructor has a complete record of your progress.

Notes 55

The purpose of this report form is to familiarize students with the concept of time management as it relates to project completion. Too many students have a tendency to do little or nothing until just before their project is due. By assigning a grade value for progress made each day, you help them learn time management skills and also help them complete their projects sooner (and better!).

Question 56

Project progress report (1 day)
Date:
Description of progress made on this day

file 03995

Answer 56

Be sure to note *everything* accomplished for each day, so your instructor has a complete record of your progress.

Notes 56

The purpose of this report form is to familiarize students with the concept of time management as it relates to project completion. Too many students have a tendency to do little or nothing until just before their project is due. By assigning a grade value for progress made each day, you help them learn time management skills and also help them complete their projects sooner (and better!).

Question 57

NAME: ________________ **Project Grading Criteria** PROJECT: ________________

You will receive the highest score for which *all* criteria are met.

100 % *(Must meet or exceed all criteria listed)*

A. Impeccable craftsmanship, comparable to that of a professional assembly
B. No spelling or grammatical errors anywhere in *any* document, upon first submission to instructor

95 % *(Must meet or exceed these criteria in addition to all criteria for 90% and below)*

A. Technical explanation sufficiently detailed to teach from, inclusive of every component (supersedes 75.B)
B. Itemized parts list complete with part numbers, manufacturers, and (equivalent) prices for *all* components, including recycled components and parts kit components (supersedes 90.A)

90 % *(Must meet or exceed these criteria in addition to all criteria for 85% and below)*

A. Itemized parts list complete with prices of components purchased for the project, plus total price
B. No spelling or grammatical errors anywhere in *any* document upon final submission

85 % *(Must meet or exceed these criteria in addition to all criteria for 80% and below)*

A. "User's guide" to project function (in addition to 75.B)
B. Troubleshooting log describing all obstacles overcome during development and construction

80 % *(Must meet or exceed these criteria in addition to all criteria for 75% and below)*

A. All controls (switches, knobs, etc.) clearly and neatly labeled
B. All documentation created on computer, not hand-written (including the schematic diagram)

75 % *(Must meet or exceed these criteria in addition to all criteria for 70% and below)*

A. Stranded wire used wherever wires are subject to vibration or bending
B. Basic technical explanation of all major circuit sections
C. Deadline met for working prototype of circuit (Date/Time = __________ / __________)

70 % *(Must meet or exceed these criteria in addition to all criteria for 65%)*

A. All wire connections sound (solder joints, wire-wrap, terminal strips, and lugs are all connected properly)
B. No use of glue where a fastener would be more appropriate
C. Deadline met for submission of fully-functional project (Date/Time = __________ / __________) – supersedes 75.C if final project submitted by that (earlier) deadline

65 % *(Must meet or exceed these criteria in addition to all criteria for 60%)*

A. Project fully functional
B. All components securely fastened so nothing is "loose" inside the enclosure
C. Schematic diagram of circuit

60 % *(Must meet or exceed these criteria in addition to being safe and legal)*

A. Project minimally functional, with all components located inside an enclosure (if applicable)
B. Passes final safety inspection (proper case grounding, line power fusing, power cords strain-relieved)

0 % *(If any of the following conditions are true)*

A. Fails final safety inspection (improper grounding, fusing, and/or power cord strain relieving)
B. Intended project function poses a safety hazard
C. Project function violates any law, ordinance, or school policy

file 03173

Answer 57

Be sure you meet with your instructor if you have any questions about what is expected for your project!

Notes 57

The purpose of this assessment rubric is to act as a sort of "contract" between you (the instructor) and your student. This way, the expectations are all clearly known in advance, which goes a long way toward disarming problems later when it is time to grade.