

Performance-based assessments for AC circuit competencies

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The purpose of these assessments is for instructors to accurately measure the learning of their electronics students, in a way that melds theoretical knowledge with hands-on application. In each assessment, students are asked to predict the behavior of a circuit from a schematic diagram and component values, then they build that circuit and measure its real behavior. If the behavior matches the predictions, the student then simulates the circuit on computer and presents the three sets of values to the instructor. If not, then the student then must correct the error(s) and once again compare measurements to predictions. Grades are based on the number of attempts required before all predictions match their respective measurements.

You will notice that no component values are given in this worksheet. The *instructor* chooses component values suitable for the students' parts collections, and ideally chooses different values for each student so that no two students are analyzing and building the exact same circuit. These component values may be hand-written on the assessment sheet, printed on a separate page, or incorporated into the document by editing the graphic image.

This is the procedure I envision for managing such assessments:

1. The instructor hands out individualized assessment sheets to each student.
2. Each student predicts their circuit's behavior at their desks using pencil, paper, and calculator (if appropriate).
3. Each student builds their circuit at their desk, under such conditions that it is impossible for them to verify their predictions using test equipment. Usually this will mean the use of a multimeter only (for measuring component values), but in some cases even the use of a multimeter would not be appropriate.
4. When ready, each student brings their predictions and completed circuit up to the instructor's desk, where any necessary test equipment is already set up to operate and test the circuit. There, the student sets up their circuit and takes measurements to compare with predictions.
5. If any measurement fails to match its corresponding prediction, the student goes back to their own desk with their circuit and their predictions in hand. There, the student tries to figure out where the error is and how to correct it.
6. Students repeat these steps as many times as necessary to achieve correlation between all predictions and measurements. The instructor's task is to count the number of attempts necessary to achieve this, which will become the basis for a percentage grade.
7. (OPTIONAL) As a final verification, each student simulates the same circuit on computer, using circuit simulation software (Spice, Multisim, etc.) and presenting the results to the instructor as a final pass/fail check.

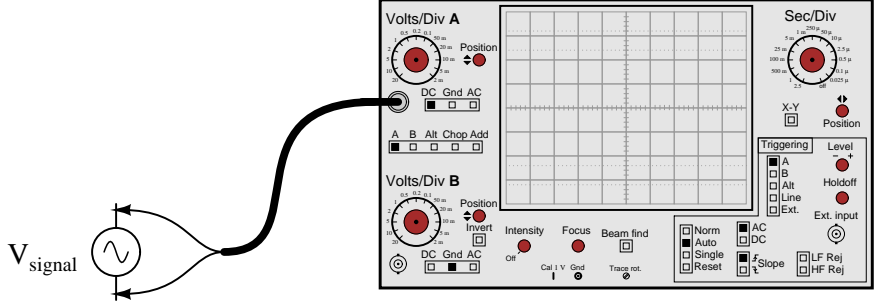
These assessments more closely mimic real-world work conditions than traditional written exams:

- Students cannot pass such assessments only knowing circuit theory or only having hands-on construction and testing skills – they must be proficient at both.
- Students do not receive the “authoritative answers” from the instructor. Rather, they learn to validate their answers through real circuit measurements.
- Just as on the job, the work isn't complete until *all errors* are corrected.
- Students must recognize and correct their own errors, rather than having someone else do it for them.
- Students must be fully prepared on exam days, bringing not only their calculator and notes, but also their tools, breadboard, and circuit components.

Instructors may elect to reveal the assessments before test day, and even use them as preparatory labwork and/or discussion questions. Remember that there is absolutely nothing wrong with “teaching to

the test” *so long as the test is valid*. Normally, it is bad to reveal test material in detail prior to test day, lest students merely memorize responses in advance. With performance-based assessments, however, there is no way to pass without truly understanding the subject(s).

Question 1

Competency: Analog oscilloscope set-up	Version:
Schematic	
	
Given conditions	
<p>V_{signal} = Set by instructor without student's knowledge</p> <p>f_{signal} = Set by instructor without student's knowledge</p>	
Parameters	
<p>Between two and five cycles of waveform displayed, without exceeding either top or bottom edge of screen.</p>	

file 01674

Answer 1

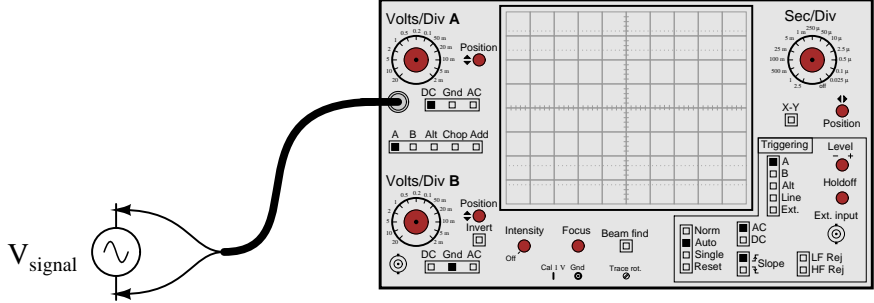
You may use circuit simulation software to set up similar oscilloscope display interpretation scenarios, for practice or for verification of what you see in this exercise.

Notes 1

Use a sine-wave function generator for the AC voltage source, and be sure set the frequency to some reasonable value (well within the capability of both the oscilloscope and counter to measure).

If this is not the first time students have done this, be sure to "mess up" the oscilloscope controls prior to them making adjustments. Students *must* learn how to quickly configure an oscilloscope's controls to display any arbitrary waveform, if they are to be proficient in using an oscilloscope as a diagnostic tool.

Question 2

Competency: Digital oscilloscope set-up	Version:
Schematic	
	
Given conditions	
<p>V_{signal} = Set by instructor without student's knowledge</p> <p>f_{signal} = Set by instructor without student's knowledge</p>	
Parameters	
<p>Between two and five cycles of waveform displayed, without exceeding either top or bottom edge of screen.</p>	

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Answer 2

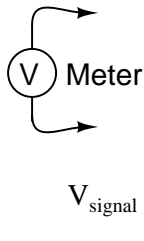
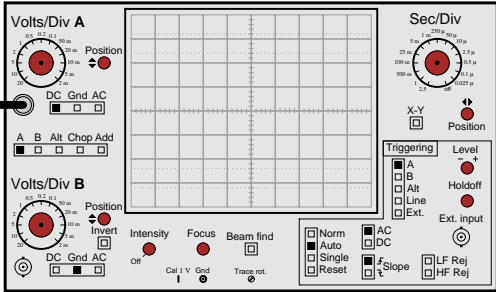
You may use circuit simulation software to set up similar oscilloscope display interpretation scenarios, for practice or for verification of what you see in this exercise.

Notes 2

Use a sine-wave function generator for the AC voltage source, and be sure set the frequency to some reasonable value (well within the capability of both the oscilloscope and counter to measure).

Some digital oscilloscopes have "auto set" controls which automatically set the vertical, horizontal, and triggering controls to "lock in" a waveform. Be sure students are learning how to set up these controls on their own rather than just pushing the "auto set" button!

Question 3

Competency: RMS versus peak measurements		Version:															
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 10px;">Schematic</div> <div style="display: flex; align-items: center; justify-content: space-around;">   </div>																	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 10px;">Given conditions</div> <p style="margin-top: 10px;">V_{signal} = Set by instructor without student's knowledge</p>																	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 10px;">Parameters</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%;"></td> <td style="width: 20%; text-align: center;">Measured</td> <td style="width: 50%;"></td> </tr> <tr> <td style="text-align: right;">$V_{\text{signal(peak)}}$</td> <td style="text-align: center;"><div style="border: 1px solid black; width: 100px; height: 30px; display: inline-block;"></div></td> <td style="text-align: left;">(Measured with oscilloscope)</td> </tr> <tr> <td></td> <td style="text-align: center;">Predicted</td> <td style="text-align: center;">Measured</td> </tr> <tr> <td style="text-align: right;">$V_{\text{signal(RMS)}}$</td> <td style="text-align: center;"><div style="border: 1px solid black; width: 100px; height: 30px; display: inline-block;"></div></td> <td style="text-align: center;"><div style="border: 1px solid black; width: 100px; height: 30px; display: inline-block;"></div></td> </tr> <tr> <td></td> <td></td> <td style="text-align: left;">(Measured with true-RMS multimeter)</td> </tr> </table>				Measured		$V_{\text{signal(peak)}}$	<div style="border: 1px solid black; width: 100px; height: 30px; display: inline-block;"></div>	(Measured with oscilloscope)		Predicted	Measured	$V_{\text{signal(RMS)}}$	<div style="border: 1px solid black; width: 100px; height: 30px; display: inline-block;"></div>	<div style="border: 1px solid black; width: 100px; height: 30px; display: inline-block;"></div>			(Measured with true-RMS multimeter)
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		(Measured with true-RMS multimeter)															

file 01693

Answer 3

You may use circuit simulation software to set up similar oscilloscope display interpretation scenarios, for practice or for verification of what you see in this exercise.


Notes 3

Use a sine-wave function generator for the AC voltage source, and be sure set the frequency to some reasonable value (well within the capability of a multimeter to measure). It is very important that students learn to convert between peak and RMS measurements for sine waves, but you might want to mix things up a bit by having them do the same with triangle waves and square waves as well! It is vital that students realize the rule of $V_{RMS} = \frac{V_{peak}}{\sqrt{2}}$ only holds for *sinusoidal* signals.

If you do choose to challenge students with non-sinusoidal waveshapes, be very sure that they do their voltmeter measurements using *true-RMS* meters! This means no analog voltmeters, which are "miscalibrated" so their inherently average-responding movements register (sinusoidal) RMS accurately. Your students must use true-RMS digital voltmeters in order for their non-sinusoidal RMS measurements to correlate with their calculations.

Incidentally, this lab exercise also works well as a demonstration of the importance of true-RMS indicating meters, comparing the indications of analog, non-true-RMS digital, and true-RMS digital on the same non-sinusoidal waveform!

Question 4

Competency: Measuring frequency	Version:
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; margin-top: 50px;"> V_{signal}  </div>	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <p style="margin-top: 20px;">$V_{\text{signal}} =$</p> <p>$f_{\text{signal}} =$ Set by instructor without student's knowledge</p>	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <div style="text-align: center; margin-top: 20px;"> <p>Measured with oscilloscope</p> <p>t_{period} <input style="width: 100px; height: 25px;" type="text"/></p> </div> <div style="display: flex; justify-content: space-around; margin-top: 20px;"> <div style="text-align: center;"> <p>Measured with counter</p> <p>f_{signal} <input style="width: 100px; height: 25px;" type="text"/></p> </div> <div style="text-align: center;"> <p>Measured with oscilloscope</p> <p><input style="width: 100px; height: 25px;" type="text"/></p> </div> </div>	

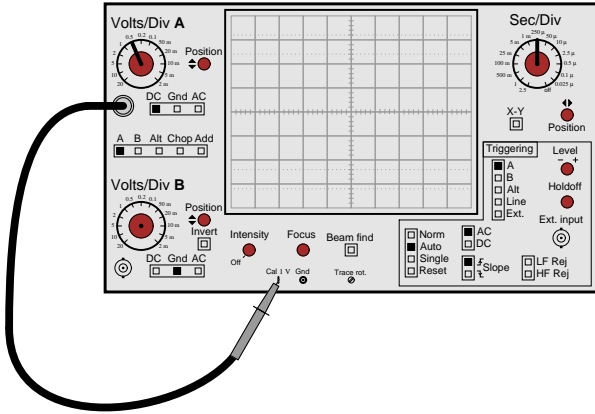
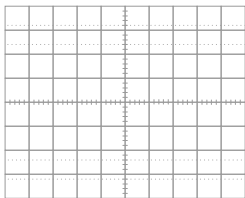
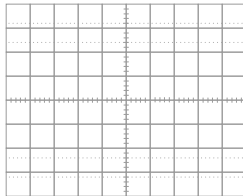
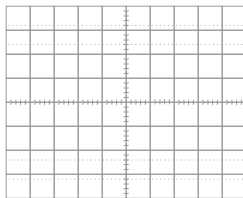
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Answer 4

You may use circuit simulation software to set up similar oscilloscope display interpretation scenarios, for practice or for verification of what you see in this exercise.

Notes 4

Use a sine-wave function generator for the AC voltage source, and be sure set the frequency to some reasonable value (well within the capability of both the oscilloscope and counter to measure).

Competency: Probe compensation adjustment		Version:	
Schematic			
			
Given conditions			
(Use the built-in square wave signal source in your oscilloscope, and use a $\times 10$ probe to measure it)			
Parameters			
Between two and five cycles of waveform displayed, without exceeding either top or bottom edge of screen.			
Measured V_{signal} <input style="width: 100px; height: 25px;" type="text"/> f_{signal} <input style="width: 100px; height: 25px;" type="text"/>	<div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;"> <p><i>Properly compensated probe waveform</i></p>  </div> <div style="text-align: center;"> <p><i>Overcompensated probe waveform</i></p>  </div> <div style="text-align: center;"> <p><i>Undercompensated probe waveform</i></p>  </div> </div>		

Answer 5

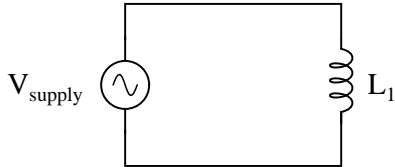
There really isn't much you can do to verify your experimental results. That's okay, though, because the results are qualitative anyway.

Notes 5

If the oscilloscope does not have its own internal square-wave signal source, use a function generator set up to output square waves at 1 volt peak-to-peak at a frequency of 1 kHz.

If this is not the first time students have done this, be sure to "mess up" the oscilloscope controls prior to them making adjustments. Students *must* learn how to quickly configure an oscilloscope's controls to display any arbitrary waveform, if they are to be proficient in using an oscilloscope as a diagnostic tool.

Question 6

Competency: Inductive reactance and Ohm's Law for AC Version:							
Schematic							
							
Given conditions							
$V_{\text{supply}} =$	$L_1 =$						
$f_{\text{supply}} =$							
Parameters							
	<table style="margin: auto;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">I_{total} <input style="width: 100px; height: 25px;" type="text"/></td> <td style="padding: 5px;"><input style="width: 100px; height: 25px;" type="text"/></td> </tr> <tr> <td style="padding: 5px;">V_{L1} <input style="width: 100px; height: 25px;" type="text"/></td> <td style="padding: 5px;"><input style="width: 100px; height: 25px;" type="text"/></td> </tr> </tbody> </table>	Predicted	Measured	I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>	V_{L1} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>
Predicted	Measured						
I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>						
V_{L1} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>						
<i>Qualitative answers only: Increase, decrease, or same</i>							
	<table style="margin: auto;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">I_{total} <input style="width: 100px; height: 25px;" type="text"/></td> <td style="padding: 5px;"><input style="width: 100px; height: 25px;" type="text"/></td> </tr> <tr> <td style="padding: 5px;">I_{total} <input style="width: 100px; height: 25px;" type="text"/></td> <td style="padding: 5px;"><input style="width: 100px; height: 25px;" type="text"/></td> </tr> </tbody> </table>	Predicted	Measured	I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>	I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>
Predicted	Measured						
I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>						
I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>						
<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="width: 40%;"></div> <div>as frequency increases</div> </div> <div style="display: flex; justify-content: space-between; align-items: center; margin-top: 10px;"> <div style="width: 40%;"></div> <div>as frequency decreases</div> </div>							

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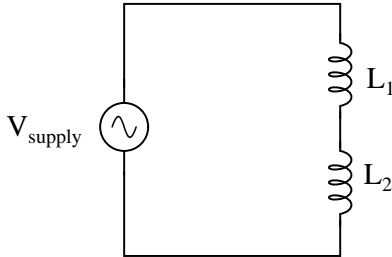
Answer 6

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 6

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify a standard inductor value.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

Competency: Series AC inductive reactances	Version:												
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; margin-top: 20px;">  </div>													
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="margin-top: 10px;"> $V_{\text{supply}} =$ $L_1 =$ $L_2 =$ $f_{\text{supply}} =$ </div>													
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <div style="margin-top: 10px;"> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%; text-align: center;">Predicted</td> <td style="width: 33%; text-align: center;">Predicted</td> <td style="width: 33%; text-align: center;">Predicted</td> </tr> <tr> <td style="text-align: center;">X_{L1} <input style="width: 80px; height: 25px;" type="text"/></td> <td style="text-align: center;">X_{L2} <input style="width: 80px; height: 25px;" type="text"/></td> <td style="text-align: center;">X_{total} <input style="width: 80px; height: 25px;" type="text"/></td> </tr> <tr> <td style="text-align: center;">Predicted</td> <td style="text-align: center;">Measured</td> <td style="text-align: center;">Derived ($X = V/I$)</td> </tr> <tr> <td style="text-align: center;">I_{total} <input style="width: 80px; height: 25px;" type="text"/></td> <td style="text-align: center;"><input style="width: 80px; height: 25px;" type="text"/></td> <td style="text-align: center;">X_{total} <input style="width: 80px; height: 25px;" type="text"/></td> </tr> </table> </div>		Predicted	Predicted	Predicted	X_{L1} <input style="width: 80px; height: 25px;" type="text"/>	X_{L2} <input style="width: 80px; height: 25px;" type="text"/>	X_{total} <input style="width: 80px; height: 25px;" type="text"/>	Predicted	Measured	Derived ($X = V/I$)	I_{total} <input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>	X_{total} <input style="width: 80px; height: 25px;" type="text"/>
Predicted	Predicted	Predicted											
X_{L1} <input style="width: 80px; height: 25px;" type="text"/>	X_{L2} <input style="width: 80px; height: 25px;" type="text"/>	X_{total} <input style="width: 80px; height: 25px;" type="text"/>											
Predicted	Measured	Derived ($X = V/I$)											
I_{total} <input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>	X_{total} <input style="width: 80px; height: 25px;" type="text"/>											
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Analysis</div> <div style="margin-top: 10px; text-align: center;"> <p>Do series inductive reactances <i>add</i> or <i>diminish</i>?</p> </div>													
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Fault analysis</div> <div style="margin-top: 10px;"> <p>Suppose component <input style="width: 60px; height: 25px;" type="text"/> fails <input style="width: 25px; height: 20px;" type="checkbox"/> open <input style="width: 25px; height: 20px;" type="checkbox"/> other _____</p> <p><input style="width: 25px; height: 20px;" type="checkbox"/> shorted</p> <p><i>What will happen in the circuit?</i></p> </div>													

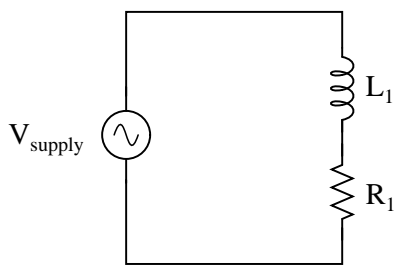
Answer 7

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 7

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard inductor values. If the inductors are not well shielded, be sure to keep them adequately separated so as to avoid mutual inductance!

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

Competency: Series LR circuit	Version:
Schematic	
	
Given conditions	
$V_{\text{supply}} =$	$L_1 =$
$f_{\text{supply}} =$	$R_1 =$
Parameters	
Predicted	Measured
V_{L1} <input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
V_{R1} <input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
I_{total} <input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
Calculations	
Fault analysis	
Suppose component <input style="width: 60px; height: 25px;" type="text"/> fails <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted </div>	
<i>What will happen in the circuit?</i>	

Answer 8

Use circuit simulation software to verify your predicted and measured parameter values.

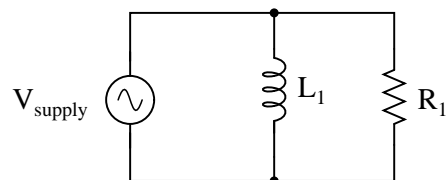
Notes 8

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard resistor and inductor values.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Question 9

Competency: Parallel LR circuit	Version:												
Schematic													
													
Given conditions													
$V_{\text{supply}} =$ $L_1 =$ $R_1 =$ $f_{\text{supply}} =$													
Parameters													
<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 35%; text-align: center;">Predicted</th> <th style="width: 35%; text-align: center;">Measured</th> </tr> </thead> <tbody> <tr> <td>I_{L1}</td> <td style="border: 1px solid black; height: 20px;"></td> <td style="border: 1px solid black; height: 20px;"></td> </tr> <tr> <td>I_{R1}</td> <td style="border: 1px solid black; height: 20px;"></td> <td style="border: 1px solid black; height: 20px;"></td> </tr> <tr> <td>I_{total}</td> <td style="border: 1px solid black; height: 20px;"></td> <td style="border: 1px solid black; height: 20px;"></td> </tr> </tbody> </table>			Predicted	Measured	I_{L1}			I_{R1}			I_{total}		
	Predicted	Measured											
I_{L1}													
I_{R1}													
I_{total}													
Calculations													
Fault analysis													
<p>Suppose component fails <input type="checkbox"/> open <input type="checkbox"/> other _____</p> <p><input type="checkbox"/> shorted</p> <p><i>What will happen in the circuit?</i></p>													

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Answer 9

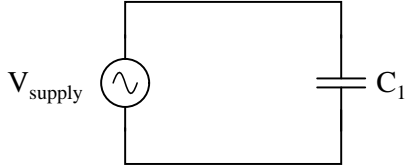
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 9

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard resistor and inductor values, and select a frequency that results in the inductor having a high Q value, so that its parasitic resistance does not become a significant factor in the calculations.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Capacitive reactance and Ohm's Law for AC Version:										
Schematic										
										
Given conditions										
$V_{\text{supply}} =$	$C_1 =$									
$f_{\text{supply}} =$										
Parameters										
Predicted	Measured									
I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>									
V_{C1} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>									
<p style="text-align: center;"><i>Qualitative answers only:</i> Increase, decrease, or same</p> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 10px; text-align: center;">Predicted</td> <td style="padding: 10px; text-align: center;">Measured</td> <td></td> </tr> <tr> <td style="padding: 10px;">I_{total} <input style="width: 100px; height: 25px;" type="text"/></td> <td style="padding: 10px;"><input style="width: 100px; height: 25px;" type="text"/></td> <td style="padding: 10px;">as frequency increases</td> </tr> <tr> <td style="padding: 10px;">I_{total} <input style="width: 100px; height: 25px;" type="text"/></td> <td style="padding: 10px;"><input style="width: 100px; height: 25px;" type="text"/></td> <td style="padding: 10px;">as frequency decreases</td> </tr> </table>		Predicted	Measured		I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>	as frequency increases	I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>	as frequency decreases
Predicted	Measured									
I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>	as frequency increases								
I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>	as frequency decreases								

file 01617

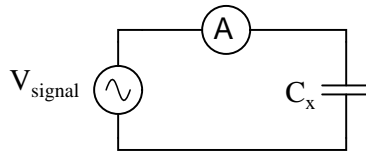
Answer 10

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 10

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify a standard capacitor value.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

Competency: Measuring capacitance by AC reactance		Version:																								
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; margin-top: 20px;">  </div>																										
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="margin-top: 20px;"> $V_{\text{signal}} =$ </div>																										
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <table style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr> <th style="text-align: center; width: 30%;">Measured</th> <th style="width: 20%;"></th> <th style="text-align: center; width: 30%;">Calculated</th> <th style="width: 20%;"></th> </tr> </thead> <tbody> <tr> <td> I_c <input style="width: 80px;" type="text"/> at $f =$ </td> <td style="text-align: center; vertical-align: middle;">\longrightarrow</td> <td> C_x <input style="width: 80px;" type="text"/> </td> <td></td> </tr> <tr> <td> I_c <input style="width: 80px;" type="text"/> at $f =$ </td> <td style="text-align: center; vertical-align: middle;">\longrightarrow</td> <td> C_x <input style="width: 80px;" type="text"/> </td> <td></td> </tr> <tr> <td> I_c <input style="width: 80px;" type="text"/> at $f =$ </td> <td style="text-align: center; vertical-align: middle;">\longrightarrow</td> <td> C_x <input style="width: 80px;" type="text"/> </td> <td></td> </tr> <tr> <td></td> <td></td> <td style="text-align: center;"> \downarrow </td> <td></td> </tr> <tr> <td> C_x <input style="width: 80px;" type="text"/> (With C meter) </td> <td></td> <td> C_x <input style="width: 80px;" type="text"/> (Average) </td> <td></td> </tr> </tbody> </table>			Measured		Calculated		I_c <input style="width: 80px;" type="text"/> at $f =$	\longrightarrow	C_x <input style="width: 80px;" type="text"/>		I_c <input style="width: 80px;" type="text"/> at $f =$	\longrightarrow	C_x <input style="width: 80px;" type="text"/>		I_c <input style="width: 80px;" type="text"/> at $f =$	\longrightarrow	C_x <input style="width: 80px;" type="text"/>				\downarrow		C_x <input style="width: 80px;" type="text"/> (With C meter)		C_x <input style="width: 80px;" type="text"/> (Average)	
Measured		Calculated																								
I_c <input style="width: 80px;" type="text"/> at $f =$	\longrightarrow	C_x <input style="width: 80px;" type="text"/>																								
I_c <input style="width: 80px;" type="text"/> at $f =$	\longrightarrow	C_x <input style="width: 80px;" type="text"/>																								
I_c <input style="width: 80px;" type="text"/> at $f =$	\longrightarrow	C_x <input style="width: 80px;" type="text"/>																								
		\downarrow																								
C_x <input style="width: 80px;" type="text"/> (With C meter)		C_x <input style="width: 80px;" type="text"/> (Average)																								

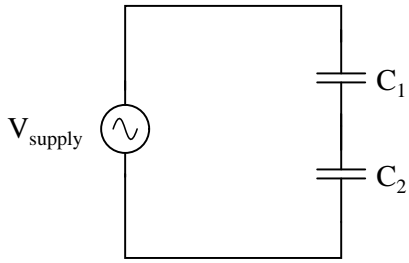
Answer 11

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 11

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify a standard capacitor value.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

Competency: Series AC capacitive reactances	Version:																		
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; margin-top: 20px;">  </div>																			
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="margin-top: 10px;"> $V_{\text{supply}} =$ $C_1 =$ $C_2 =$ $f_{\text{supply}} =$ </div>																			
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <div style="margin-top: 10px;"> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="text-align: center; width: 33%;">Predicted</td> <td style="text-align: center; width: 33%;">Predicted</td> <td style="text-align: center; width: 33%;">Predicted</td> </tr> <tr> <td style="text-align: center;">X_{C1}</td> <td style="text-align: center;">X_{C2}</td> <td style="text-align: center;">X_{total}</td> </tr> <tr> <td style="text-align: center;"><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td style="text-align: center;"><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td style="text-align: center;"><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> </tr> </table> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="text-align: center; width: 33%;">Predicted</td> <td style="text-align: center; width: 33%;">Measured</td> <td style="text-align: center; width: 33%;">Derived ($X = V/I$)</td> </tr> <tr> <td style="text-align: center;">I_{total}</td> <td></td> <td style="text-align: center;">X_{total}</td> </tr> <tr> <td style="text-align: center;"><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td style="text-align: center;"><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td style="text-align: center;"><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> </tr> </table> </div>		Predicted	Predicted	Predicted	X_{C1}	X_{C2}	X_{total}	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	Predicted	Measured	Derived ($X = V/I$)	I_{total}		X_{total}	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>
Predicted	Predicted	Predicted																	
X_{C1}	X_{C2}	X_{total}																	
<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>																	
Predicted	Measured	Derived ($X = V/I$)																	
I_{total}		X_{total}																	
<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>																	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Analysis</div> <div style="text-align: center; margin-top: 10px;"> Do series capacitive reactances <i>add</i> or <i>diminish</i>? </div>																			
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Fault analysis</div> <div style="margin-top: 10px;"> Suppose component <div style="border: 1px solid black; width: 50px; height: 25px; display: inline-block;"></div> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted <i>What will happen in the circuit?</i> </div>																			

Answer 12

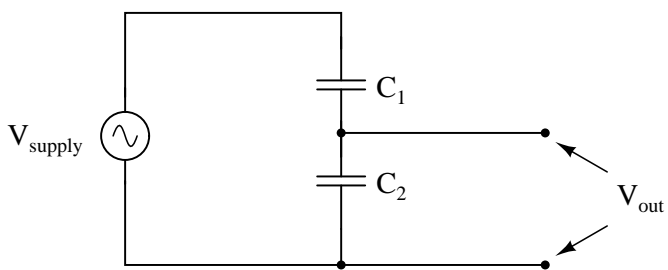
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 12

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard capacitor values.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

Students often become confused when learning about series and parallel capacitive reactances, because many think capacitors are inherently "opposite" of inductors and resistors in all respects. In other words, they first learn that *capacitance* (measured in Farads) adds in parallel and diminishes in series, and that this is just the opposite of resistance (Ohms) and inductance (Henrys), and they mistakenly carry this thinking on through capacitive *reactance* (Ohms) as well. The real lesson of this exercise is that reactances add in series, regardless of their nature.

Competency: Capacitive AC voltage divider	Version:																				
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; margin-top: 20px;">  </div>																					
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="margin-top: 10px;"> $V_{\text{supply}} =$ $C_1 =$ $C_2 =$ $f_{\text{supply}} =$ </div>																					
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <div style="margin-top: 10px;"> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;"></th> <th style="width: 20%; text-align: center;">Predicted</th> <th style="width: 20%; text-align: center;">Measured</th> <th style="width: 50%;"></th> </tr> </thead> <tbody> <tr> <td>V_{out}</td> <td style="border: 1px solid black; width: 80px; height: 30px;"></td> <td style="border: 1px solid black; width: 80px; height: 30px;"></td> <td>at specified frequency</td> </tr> <tr> <td colspan="4" style="padding-top: 20px;"> <i>Qualitative answers only:</i> <i>Increase, decrease, or same</i> </td> </tr> <tr> <td>V_{out}</td> <td style="border: 1px solid black; width: 80px; height: 30px;"></td> <td style="border: 1px solid black; width: 80px; height: 30px;"></td> <td>as frequency increases</td> </tr> <tr> <td>V_{out}</td> <td style="border: 1px solid black; width: 80px; height: 30px;"></td> <td style="border: 1px solid black; width: 80px; height: 30px;"></td> <td>as frequency decreases</td> </tr> </tbody> </table> </div>			Predicted	Measured		V_{out}			at specified frequency	<i>Qualitative answers only:</i> <i>Increase, decrease, or same</i>				V_{out}			as frequency increases	V_{out}			as frequency decreases
	Predicted	Measured																			
V_{out}			at specified frequency																		
<i>Qualitative answers only:</i> <i>Increase, decrease, or same</i>																					
V_{out}			as frequency increases																		
V_{out}			as frequency decreases																		

Answer 13

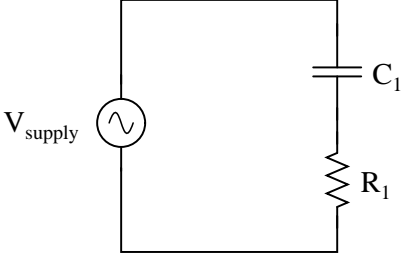
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 13

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard capacitor values.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Series RC circuit	Version:
Schematic	
	
Given conditions	
$V_{\text{supply}} =$	$C_1 =$
$f_{\text{supply}} =$	$R_1 =$
Parameters	
Predicted	Measured
V_{C1} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>
V_{R1} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>
I_{total} <input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>
Calculations	
Fault analysis	
Suppose component <input style="width: 50px; height: 25px;" type="text"/> fails <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted </div>	
<i>What will happen in the circuit?</i>	

Answer 14

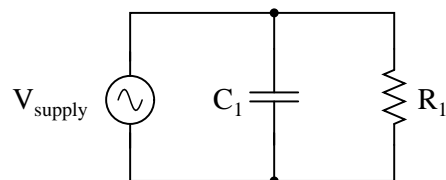
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 14

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard resistor and capacitor values.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Parallel RC circuit	Version:												
Schematic													
													
Given conditions													
$V_{\text{supply}} =$ $C_1 =$ $R_1 =$ $f_{\text{supply}} =$													
Parameters													
<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 35%; text-align: center;">Predicted</th> <th style="width: 35%; text-align: center;">Measured</th> </tr> </thead> <tbody> <tr> <td>I_{C1}</td> <td style="border: 1px solid black; height: 20px;"></td> <td style="border: 1px solid black; height: 20px;"></td> </tr> <tr> <td>I_{R1}</td> <td style="border: 1px solid black; height: 20px;"></td> <td style="border: 1px solid black; height: 20px;"></td> </tr> <tr> <td>I_{total}</td> <td style="border: 1px solid black; height: 20px;"></td> <td style="border: 1px solid black; height: 20px;"></td> </tr> </tbody> </table>			Predicted	Measured	I_{C1}			I_{R1}			I_{total}		
	Predicted	Measured											
I_{C1}													
I_{R1}													
I_{total}													
Calculations													
Fault analysis													
<p>Suppose component fails <input type="checkbox"/> open <input type="checkbox"/> other _____</p> <p><input type="checkbox"/> shorted</p> <p><i>What will happen in the circuit?</i></p>													

Answer 15

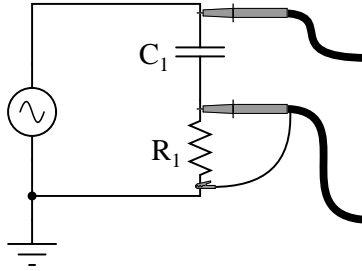
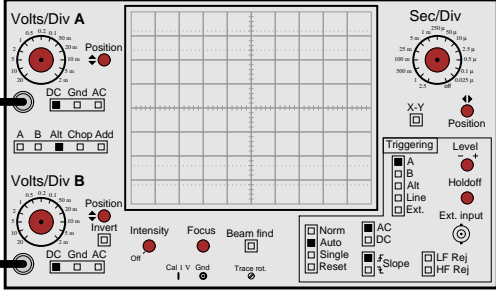
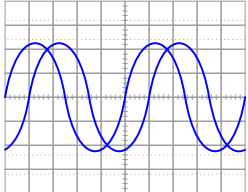
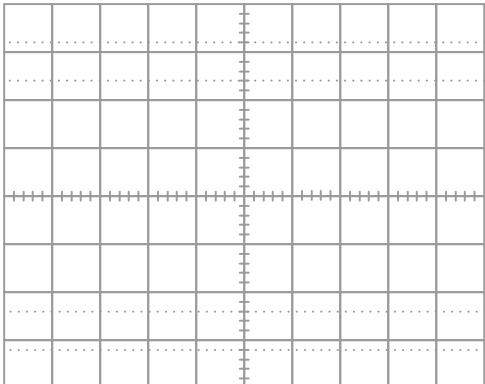
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 15

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard resistor and capacitor values.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Time-domain phase shift measurement		Version:
Schematic		
		
Given conditions		
$f_{\text{supply}} =$	$C_1 =$	$R_1 =$
Parameters		
<p style="text-align: center;">Predicted</p> <p>θ <input style="width: 100px; height: 20px;" type="text"/></p> <p style="text-align: center;">Measured</p> <p>Shift (divisions) <input style="width: 100px; height: 20px;" type="text"/></p> <p>Period (divisions) <input style="width: 100px; height: 20px;" type="text"/></p> <p style="text-align: center;">θ <input style="width: 100px; height: 20px;" type="text"/></p> <div style="text-align: center; margin-top: 10px;">  <p style="margin-top: 5px;">→ ← Period</p> <p style="margin-top: 5px;">→ ← Shift</p> </div>	<p>Dual oscilloscope trace</p> 	

file 01688

Answer 16

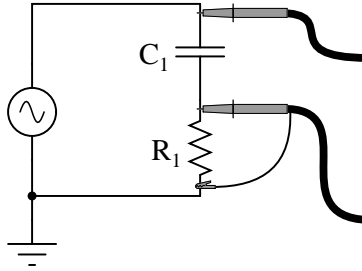
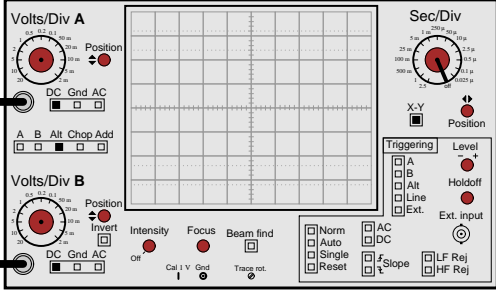
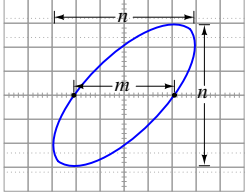
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 16

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard resistor and capacitor values.

I recommend using components that produce a phase shift of approximately 45 degrees within the low audio frequency range (less than 1 kHz). This allows most multimeters to be used for voltage measurement in conjunction with the oscilloscope.

One way for students to do this assessment is to have them predict what the sine waves will look like, based on circuit component values. They sketch the predicted waveforms on the grid provided before actually hooking up an oscilloscope, then the instructor assesses them based on the conformity of the real oscilloscope display to their prediction.

Competency: Lissajous figures for phase shift measurement		Version:
Schematic		
		
Given conditions		
$f_{\text{supply}} =$	$C_1 =$	$R_1 =$
Parameters		
<p style="text-align: center;">Predicted</p> <p>θ <input style="width: 100px; height: 30px;" type="text"/></p>	<p style="text-align: center;">Lissajous figure (measured)</p> <div style="border: 1px solid black; width: 300px; height: 150px; margin: 0 auto;"></div>	
<p style="text-align: center;">Measured</p> <p>n (Divisions) <input style="width: 100px; height: 30px;" type="text"/></p> <p>m (Divisions) <input style="width: 100px; height: 30px;" type="text"/></p> <p>θ <input style="width: 100px; height: 30px;" type="text"/></p>		

file 01676

Answer 17

Use circuit simulation software to verify your predicted and measured parameter values.

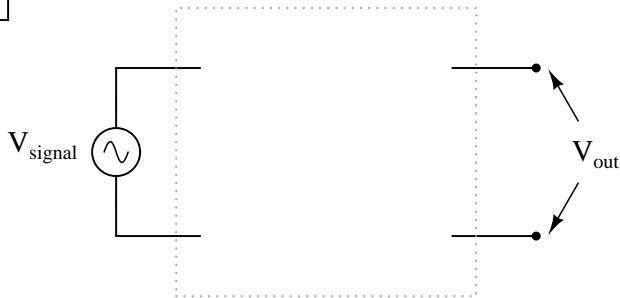
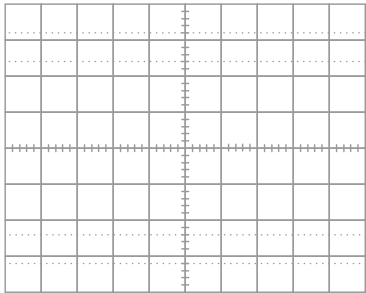
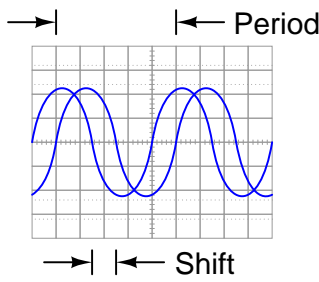
Notes 17

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard resistor and capacitor values.

I recommend using components that produce a phase shift of approximately 45 degrees within the low audio frequency range (less than 1 kHz). This allows most multimeters to be used for voltage measurement in conjunction with the oscilloscope.

Something to suggest that students do is use their oscilloscopes' *ground* position on the coupling switch, to help center the dot on the screen before they set up their Lissajous figures for phase shift measurement.

One way for students to do this assessment is to have them predict what the Lissajous figure will look like, based on circuit component values. They sketch the predicted Lissajous figure on the grid provided (working the math "backward" to arrive at n and m values before actually hooking up an oscilloscope), then the instructor assesses them based on the conformity of the real oscilloscope display to their prediction.

Competency: Phase shift circuit		Version:
<div style="border: 1px solid black; padding: 2px; display: inline-block;">Description</div>		
Build an RC circuit to produce the specified phase shift from input to output, and measure this shift with an oscilloscope.		
<div style="border: 1px solid black; padding: 2px; display: inline-block;">Given conditions</div>		
$\theta =$ $f_{\text{supply}} =$	Leading <input style="width: 40px; height: 20px;" type="text"/> <i>(instructor checks one)</i> Lagging <input style="width: 40px; height: 20px;" type="text"/>	
<div style="border: 1px solid black; padding: 2px; display: inline-block;">Schematic</div>		
		
<div style="border: 1px solid black; padding: 2px; display: inline-block;">Parameters</div>		
Shift (divisions) <input style="width: 100px; height: 30px;" type="text"/> Period (divisions) <input style="width: 100px; height: 30px;" type="text"/> θ <input style="width: 100px; height: 30px;" type="text"/>	<div style="text-align: center;">Measured</div>	<div style="text-align: center;">Dual oscilloscope trace</div> 
<div style="text-align: center;">  </div>	<div style="text-align: center;">Predicted</div> C_1 <input style="width: 100px; height: 30px;" type="text"/> R_1 <input style="width: 100px; height: 30px;" type="text"/>	

Answer 18

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 18

Here, students must choose the right type of series RC circuit configuration to provide the requested phase shift. This, of course, also involves choosing proper values for C_1 and R_1 , and being able to successfully measure phase shift with an oscilloscope.

I recommend selecting a phase shift angle (Θ) somewhere between 15° and 75° . Angles too close to 90° will result in small output voltages that are difficult to measure through the noise.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Variable phase shift bridge circuit		Version:																				
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; margin-top: 20px;"> </div>																						
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="display: flex; justify-content: space-between; align-items: flex-start; margin-top: 10px;"> <div style="width: 30%;"> $V_{\text{signal}} =$ $f_{\text{signal}} =$ </div> <div style="width: 30%;"> $R_1 = R_2 =$ $C_1 = C_2 =$ $R_{\text{pot}} =$ </div> <div style="width: 30%; text-align: right;"> <i>Recommendations</i> $R \approx \frac{1}{2\pi f C}$ $R_{\text{pot}} \gg R_1, R_2$ </div> </div>																						
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <table style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr> <th style="width: 10%;"></th> <th style="width: 15%; text-align: center;">Predicted</th> <th style="width: 15%; text-align: center;">Measured</th> <th style="width: 60%;"></th> </tr> </thead> <tbody> <tr> <td>$\theta_{V_{\text{out}}}$</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> <td><i>Potentiometer at full-left position</i></td> </tr> <tr> <td>$\theta_{V_{\text{out}}}$</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> <td><i>Potentiometer at full-right position</i></td> </tr> <tr> <td>V_{out}</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> <td><i>Potentiometer at full-left position</i></td> </tr> <tr> <td>V_{out}</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> <td><i>Potentiometer at full-right position</i></td> </tr> </tbody> </table>				Predicted	Measured		$\theta_{V_{\text{out}}}$			<i>Potentiometer at full-left position</i>	$\theta_{V_{\text{out}}}$			<i>Potentiometer at full-right position</i>	V_{out}			<i>Potentiometer at full-left position</i>	V_{out}			<i>Potentiometer at full-right position</i>
	Predicted	Measured																				
$\theta_{V_{\text{out}}}$			<i>Potentiometer at full-left position</i>																			
$\theta_{V_{\text{out}}}$			<i>Potentiometer at full-right position</i>																			
V_{out}			<i>Potentiometer at full-left position</i>																			
V_{out}			<i>Potentiometer at full-right position</i>																			

file 03468

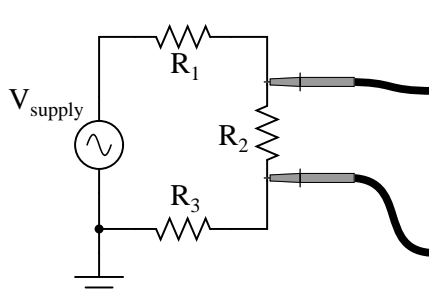
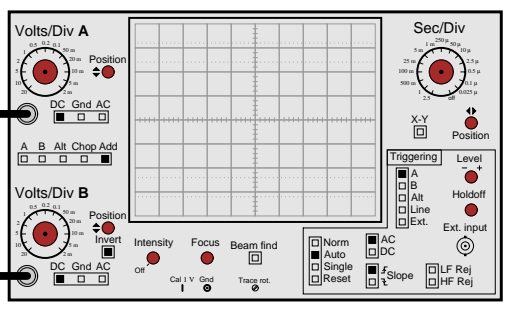
Answer 19

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 19

This is a very interesting circuit to built and test. You may build one using $1\ \mu\text{F}$ capacitors, $2.7\ \text{k}\Omega$ resistors, and a $100\ \text{k}\Omega$ potentiometer that will successfully operate on 60 Hz power-line excitation. If you prefer to use audio frequency power, try $0.047\ \mu\text{F}$ capacitors, $1\ \text{k}\Omega$ resistors, a $100\ \text{k}\Omega$ potentiometer, and 3.386 kHz for the source frequency.

An interesting thing to note about using line power is that any distortions in the excitation sine-wave will become obvious when the potentiometer wiper is turned toward the differentiating position (where Θ is positive). If listened to with an audio detector, you may even hear the change in timbre while moving the wiper from one extreme to the other. If excited by a "clean" sine-wave, however, no change in timbre should be heard because there are no harmonics present.

Competency: Differential voltage measurement		Version:				
Schematic						
						
Given conditions						
$V_{\text{supply}} =$	$R_1 =$	$R_2 =$				
$R_3 =$						
Parameters						
V_{R2}	<table border="1" style="margin: auto;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="height: 30px; width: 100px;"></td> <td style="height: 30px; width: 100px;"></td> </tr> </tbody> </table>	Predicted	Measured			
Predicted	Measured					
Fault analysis						
Suppose component fails <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted </div> <p><i>What will happen in the circuit?</i></p>						

Answer 20

The predicted value should be easy enough to figure out, given this is nothing more than a resistive voltage divider. If you are not configuring the oscilloscope properly, you will not get the correct measurement value!

Notes 20

The nature of the AC signal source is not crucial, so long as an accurate peak measurement may be obtained. I recommend specifying equal-value resistors to make the voltage drop calculation as easy as possible. The purpose of this exercise is not how to calculate voltage divider outputs, but rather how to utilize both inputs of a dual-trace oscilloscope to perform *differential* voltage measurements.

Competency: Measuring decibels		Version:																															
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; margin-top: 20px;"> </div>																																	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="margin-top: 10px;"> $V_{\text{supply}} = 1 \text{ volt RMS}$ $R_1 =$ $R_2 =$ $R_3 =$ $R_4 =$ $\quad \quad \quad = 0 \text{ dBV}$ </div>																																	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <table style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr> <th style="width: 10%;"></th> <th style="width: 20%; text-align: center;">Measured (V)</th> <th style="width: 20%; text-align: center;">Measured (dBV)</th> <th colspan="2" style="width: 50%;"></th> </tr> </thead> <tbody> <tr> <td style="text-align: right;">V_A</td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td colspan="2" style="text-align: right;"><i>(Establishing reference voltage)</i></td> </tr> <tr> <td style="text-align: right;">V_B</td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> </tr> <tr> <td style="text-align: right;">V_C</td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> </tr> <tr> <td style="text-align: right;">V_D</td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> </tr> <tr> <td style="text-align: right;">V_E</td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> <td><div style="border: 1px solid black; width: 100px; height: 25px;"></div></td> </tr> </tbody> </table>					Measured (V)	Measured (dBV)			V_A	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<i>(Establishing reference voltage)</i>		V_B	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	V_C	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	V_D	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	V_E	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>
	Measured (V)	Measured (dBV)																															
V_A	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<i>(Establishing reference voltage)</i>																														
V_B	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>																													
V_C	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>																													
V_D	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>																													
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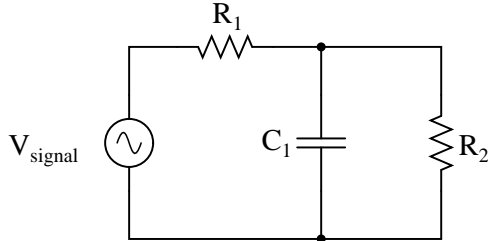
Answer 21

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 21

You will need an AC signal source of variable voltage, so that the reference voltage at test point **A** (V_A) may be precisely adjusted to 1 volt RMS. The frequency of the signal source must be within the range of the voltmeter to measure, of course. You may use a sine-wave signal generator as the source, but a step-down transformer and series potentiometer works just as well! The purpose of this exercise is not how to calculate voltage divider outputs, but rather how to utilize a dB-reading meter to measure signal strength in decibels rather than volts AC.

Most high-quality digital multimeters will measure dBV in addition to AC volts RMS. Some have a "zero" or "relative" button which acts like the "tare" button on an electronic weigh scale. With such a meter, one may set 0 dB to reference at *any* measurable level of AC voltage. Of course, this means the meter will be measuring dB instead of dBV, since the reference point is made arbitrary with the press of the "relative" button. However, this is a very useful tool for electronic signal measurements, where source strength may be set to 0 dB and then losses measured directly in -dB (relative to the source) just as easily as normal voltage measurements.

Competency: Series-parallel RC circuit	Version:															
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; margin-top: 20px;">  </div>																
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="margin-top: 10px;"> $V_{\text{signal}} =$ $C_1 =$ $R_1 =$ $R_2 =$ $f_{\text{signal}} =$ </div>																
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <table style="width: 100%; margin-top: 10px;"> <thead> <tr> <th></th> <th style="text-align: center;">Predicted</th> <th style="text-align: center;">Measured</th> </tr> </thead> <tbody> <tr> <td style="text-align: right;">V_{R1}</td> <td style="border: 1px solid black; width: 100px; height: 25px;"></td> <td style="border: 1px solid black; width: 100px; height: 25px;"></td> </tr> <tr> <td style="text-align: right;">I_{C1}</td> <td style="border: 1px solid black; width: 100px; height: 25px;"></td> <td style="border: 1px solid black; width: 100px; height: 25px;"></td> </tr> <tr> <td style="text-align: right;">I_{R2}</td> <td style="border: 1px solid black; width: 100px; height: 25px;"></td> <td style="border: 1px solid black; width: 100px; height: 25px;"></td> </tr> <tr> <td style="text-align: right;">I_{total}</td> <td style="border: 1px solid black; width: 100px; height: 25px;"></td> <td style="border: 1px solid black; width: 100px; height: 25px;"></td> </tr> </tbody> </table>			Predicted	Measured	V_{R1}			I_{C1}			I_{R2}			I_{total}		
	Predicted	Measured														
V_{R1}																
I_{C1}																
I_{R2}																
I_{total}																
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Fault analysis</div> <div style="margin-top: 10px;"> <p>Suppose component fails <input type="checkbox"/> open <input type="checkbox"/> other _____</p> <p><input type="checkbox"/> shorted</p> <p><i>What will happen in the circuit?</i></p> </div>																

Answer 22

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 22

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard resistor and capacitor values.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Series-parallel RC circuit		Version:
Schematic		
Given conditions		
$V_{\text{signal}} =$	$R_1 =$	$R_2 =$
$f_{\text{signal}} =$	$C_1 =$	$C_2 =$
Parameters		
	Predicted	Measured
V_{R1}		
V_{R2}		
V_{C2}		
I_{C1}		
I_{total}		
Fault analysis		
Suppose component fails <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted </div>		
<i>What will happen in the circuit?</i> <div style="border: 1px solid black; height: 100px; width: 100%;"></div>		

Answer 23

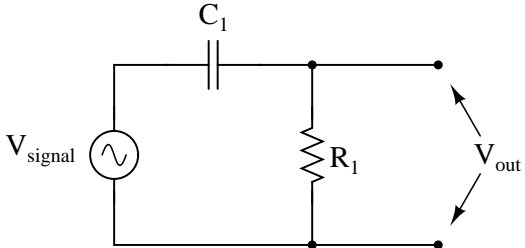
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 23

Use a sine-wave function generator for the AC voltage source. I recommend against using line-power AC because of strong harmonic frequencies which may be present (due to nonlinear loads operating on the same power circuit). Specify standard resistor and capacitor values.

If students are to use a multimeter to make their current and voltage measurements, be sure it is capable of accurate measurement at the circuit frequency! Inexpensive digital multimeters often experience difficulty measuring AC voltage and current toward the high end of the audio-frequency range.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Passive filter circuit		Version:
Schematic		
		
Given conditions		
$V_{\text{signal}} =$	$C_1 =$	$R_1 =$
Parameters		
	Predicted	Measured
Filter type (hp, lp, bp, bs)	<input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>
$f_{-3\text{dB}}$	<input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>
$\theta_{-3\text{dB}}$	<input style="width: 100px; height: 25px;" type="text"/>	<input style="width: 100px; height: 25px;" type="text"/>
Calculations		
Fault analysis		
Suppose component <input style="width: 50px; height: 25px;" type="text"/> fails <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted </div>		
<i>What will happen in the circuit?</i>		

Answer 24

Use circuit simulation software to verify your predicted and measured parameter values.

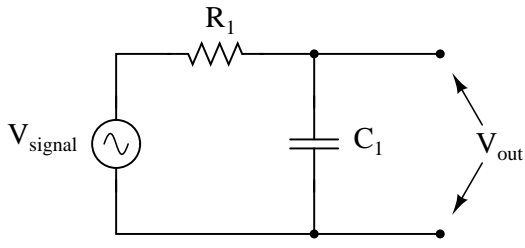
Notes 24

Use a sine-wave function generator for the AC voltage source. Specify standard resistor and capacitor values.

I recommend setting the function generator output for 1 volt, to make it easier for students to measure the point of "cutoff". You may set it at some other value, though, if you so choose (or let students set the value themselves when they test the circuit!).

I also recommend having students use an oscilloscope to measure AC voltage in a circuit such as this, because some digital multimeters have difficulty accurately measuring AC voltage much beyond line frequency range. I find it particularly helpful to set the oscilloscope to the "X-Y" mode so that it draws a thin line on the screen rather than sweeps across the screen to show an actual waveform. This makes it easier to measure peak-to-peak voltage.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Passive filter circuit		Version:
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Schematic</div>		
		
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Given conditions</div>		
$V_{\text{signal}} =$	$C_1 =$	$R_1 =$
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Parameters</div>		
	Predicted	Measured
Filter type (hp, lp, bp, bs)	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
$f_{-3\text{dB}}$	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
$\theta_{-3\text{dB}}$	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Calculations</div>		
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Fault analysis</div>		
Suppose component <input style="width: 50px; height: 25px;" type="text"/> fails <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted </div>		
<i>What will happen in the circuit?</i>		

Answer 25

Use circuit simulation software to verify your predicted and measured parameter values.

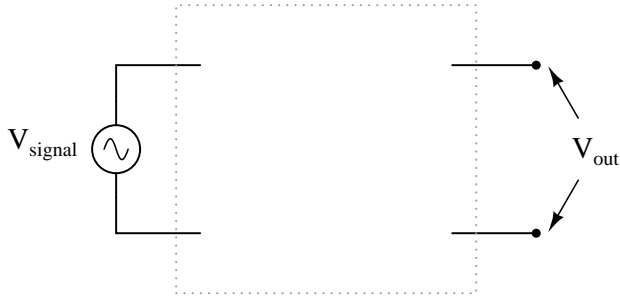
Notes 25

Use a sine-wave function generator for the AC voltage source. Specify standard resistor and capacitor values.

I recommend setting the function generator output for 1 volt, to make it easier for students to measure the point of "cutoff". You may set it at some other value, though, if you so choose (or let students set the value themselves when they test the circuit!).

I also recommend having students use an oscilloscope to measure AC voltage in a circuit such as this, because some digital multimeters have difficulty accurately measuring AC voltage much beyond line frequency range. I find it particularly helpful to set the oscilloscope to the "X-Y" mode so that it draws a thin line on the screen rather than sweeps across the screen to show an actual waveform. This makes it easier to measure peak-to-peak voltage.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Passive RC filter circuit design		Version:	
Description			
Design and build an RC filter circuit, either high pass or low pass, with the specified cutoff frequency.			
Given conditions			
<i>(instructor checks one)</i>			
$f_{-3dB} =$	High-pass	<input type="checkbox"/>	Low-pass <input type="checkbox"/>
Parameters			
	Predicted	Measured	
f_{-3dB}	<input type="text"/>	<input type="text"/>	
θ_{-3dB}	<input type="text"/>	<input type="text"/>	
Schematic			
			

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Answer 26

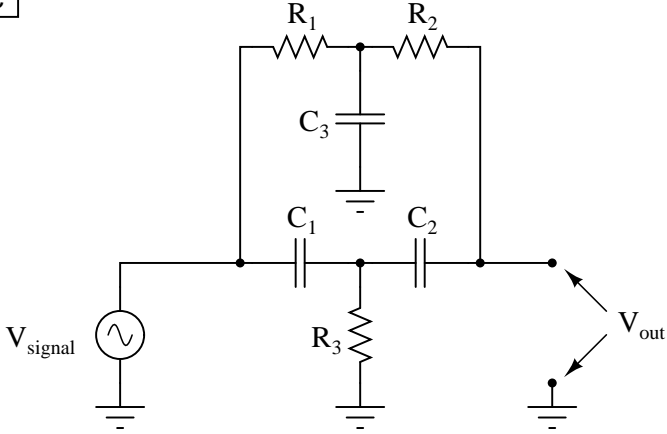
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 26

Use a sine-wave function generator for the AC voltage source. Specify a cutoff frequency within the audio range.

I recommend setting the function generator output for 1 volt, to make it easier for students to measure the point of "cutoff". You may set it at some other value, though, if you so choose (or let students set the value themselves when they test the circuit!).

I also recommend having students use an oscilloscope to measure AC voltage in a circuit such as this, because some digital multimeters have difficulty accurately measuring AC voltage much beyond line frequency range. I find it particularly helpful to set the oscilloscope to the "X-Y" mode so that it draws a thin line on the screen rather than sweeps across the screen to show an actual waveform. This makes it easier to measure peak-to-peak voltage.

Competency: Passive twin-tee filter circuit		Version:									
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> 											
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%; vertical-align: top;">$V_{\text{signal}} =$</td> <td style="width: 30%; vertical-align: top;">$C_1 =$</td> <td style="width: 30%; vertical-align: top;">$R_1 =$</td> </tr> <tr> <td></td> <td style="vertical-align: top;">$C_2 =$</td> <td style="vertical-align: top;">$R_2 =$</td> </tr> <tr> <td></td> <td style="vertical-align: top;">$C_3 =$</td> <td style="vertical-align: top;">$R_3 =$</td> </tr> </table>			$V_{\text{signal}} =$	$C_1 =$	$R_1 =$		$C_2 =$	$R_2 =$		$C_3 =$	$R_3 =$
$V_{\text{signal}} =$	$C_1 =$	$R_1 =$									
	$C_2 =$	$R_2 =$									
	$C_3 =$	$R_3 =$									
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;"></th> <th style="width: 30%; text-align: center;">Predicted</th> <th style="width: 30%; text-align: center;">Measured</th> </tr> </thead> <tbody> <tr> <td>Filter type (hp, lp, bp, bs)</td> <td style="border: 1px solid black; height: 25px;"></td> <td style="border: 1px solid black; height: 25px;"></td> </tr> <tr> <td>f_{center}</td> <td style="border: 1px solid black; height: 25px;"></td> <td style="border: 1px solid black; height: 25px;"></td> </tr> </tbody> </table>				Predicted	Measured	Filter type (hp, lp, bp, bs)			f_{center}		
	Predicted	Measured									
Filter type (hp, lp, bp, bs)											
f_{center}											
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Fault analysis</div> <p>Suppose component fails <input type="checkbox"/> open <input type="checkbox"/> other _____</p> <p style="margin-left: 10px;"> shorted</p> <p><i>What will happen in the circuit?</i></p> <div style="border: 1px solid black; height: 150px; margin-top: 10px;"></div>											

Answer 27

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 27

Use a sine-wave function generator for the AC voltage source. Specify components giving a notch frequency within the audio range:

$$f_{notch} = \frac{1}{2\pi RC}$$

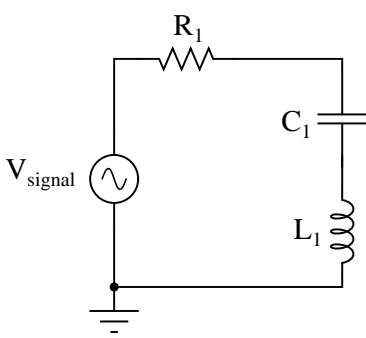
I have had good success using the following values:

- $R_1 = 10 \text{ k}\Omega$
- $R_2 = 10 \text{ k}\Omega$
- $R_3 = 5 \text{ k}\Omega$ (actually, two $10 \text{ k}\Omega$ resistors in parallel)
- $C_1 = 0.001 \text{ }\mu\text{F}$
- $C_2 = 0.001 \text{ }\mu\text{F}$
- $C_3 = 0.002 \text{ }\mu\text{F}$ (actually, two $0.001 \text{ }\mu\text{F}$ capacitors in parallel)

These component values yield a theoretical notch frequency of 16.13 kHz (the very high end of audio range), with the actual measured notch frequency for my circuit (without considering component tolerances) being 15.92 kHz.

I recommend setting the function generator output for 1 volt, to make it easier for students to measure the point of "cutoff". You may set it at some other value, though, if you so choose (or let students set the value themselves when they test the circuit!).

I also recommend having students use an oscilloscope to measure AC voltage in a circuit such as this, because some digital multimeters have difficulty accurately measuring AC voltage much beyond line frequency range. I find it particularly helpful to set the oscilloscope to the "X-Y" mode so that it draws a thin line on the screen rather than sweeps across the screen to show an actual waveform. This makes it easier to measure peak-to-peak voltage.

Competency: Series resonance		Version:
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Schematic</div>		
		
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Given conditions</div>		
$R_1 =$	$C_1 =$	$L_1 =$
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Parameters</div>		
f_{resonant}	<div style="display: inline-block; text-align: center;">Predicted</div> <div style="border: 1px solid black; width: 100px; height: 25px; margin: 5px auto;"></div>	<div style="display: inline-block; text-align: center;">Measured</div> <div style="border: 1px solid black; width: 100px; height: 25px; margin: 5px auto;"></div>
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Calculations</div>		
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Fault analysis</div>		
Suppose component fails <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted </div> <p><i>What will happen in the circuit?</i></p>		

Answer 28

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 28

Use a sine-wave function generator for the AC voltage source. Specify standard resistor, capacitor, and inductor values. I have used a small 100 mH inductor, a 0.033 μF capacitor, and 100 Ω resistor with good success. In any case I recommend keeping the resonant frequency within the mid-audio range (1 kHz to 10 kHz) to avoid problems with low inductor Q (frequency too low) and stray capacitance and inductance issues (frequency too high).

Competency: **Dampened resonant oscillations** Version:

Schematic

Given conditions

$L_1 =$ $C_1 =$

Parameters

	Predicted	Measured
f		

Typical waveform

Captured waveform

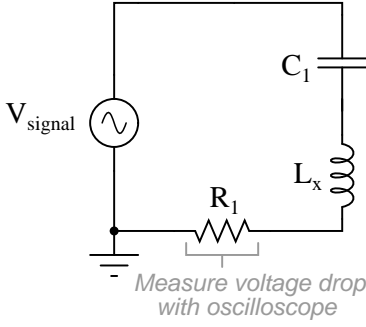
Answer 29

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 29

A digital oscilloscope capable of "capturing" the dampened oscillations will be necessary for this exercise. It will be very challenging to measuring the oscillation frequency using an analog (phosphor) oscilloscope!

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Measuring inductance by series resonance Version:	
Schematic	
	
Given conditions	
$R_1 =$	$C_1 =$
Parameters	
f_{resonant} Inferred from f_{resonant} L_x	Measured <div style="border: 1px solid black; width: 100px; height: 30px; margin: 0 auto;"></div> Measured with LCR meter <div style="border: 1px solid black; width: 100px; height: 30px; margin: 0 auto;"></div>
Calculations	

Answer 30

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 30

This is perhaps the most reliable means of measuring inductance without an impedance bridge or an LCR meter. You may wish to ask your students to explain *why* this method of measurement is so good (hint: they must explain why the inductor's intrinsic resistance has no effect on the measurement).

I prefer this particular circuit design for L measurement because series resistance does not skew the resonant point, and because the series capacitor prevents any possible DC current from "biasing" the inductor's core.

If your students own high-quality multimeters capable of measuring audio-frequency AC current and frequency, then the best way to do this is to replace the resistor R_1 with their ammeters. Otherwise, use an oscilloscope to measure (maximum) voltage dropped across R_1 .

In order to obtain good measurements using this technique, I recommend following these guidelines:

- Choose a value of R_1 low enough to give a sharp bandwidth, but not so low that the voltage signal dropped across it is "fuzzy" with noise and difficult to accurately discern the period of.
- Choose a value for C_1 as low as possible to give sharp bandwidth (thereby maximizing the $\frac{L}{C}$ ratio), without pushing the circuit's resonant frequency too close to the inductor's self-resonant frequency.
- Avoid frequencies above the audio range, lest your students measure the inductor's self-resonant point!
- Use minimal output from the signal generator, to avoid voltage and current levels that will approach core saturation in the inductor.

I've had fair results using one of the windings of a small audio output transformer (center-tapped 1000 Ω primary winding, with 8 Ω secondary winding) as the inductor, connected in series with either a 0.1 μF or a 0.47 μF metal-film capacitor, all in series with a 100 ohm resistor. For best results, of course, pre-measure the value of the capacitor rather than go by its advertised value.

I have also used a 100 mH inductor (nominal), in series with a 0.033 μF capacitor and 100 Ω resistor, with good results.

Competency: Passive resonant filter circuit		Version:	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Schematic</div>			
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Given conditions</div>			
$V_{\text{signal}} =$	$C_1 =$	$L_1 =$	$R_{\text{load}} =$
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Parameters</div>			
	Predicted	Measured	
Filter type (hp, lp, bp, bs)	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	
f_{resonant}	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	
θ_{resonant}	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Calculations</div>			
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Fault analysis</div>			
Suppose component <div style="border: 1px solid black; display: inline-block; width: 60px; height: 25px; vertical-align: middle;"></div> fails <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted </div>			
<i>What will happen in the circuit?</i>			

Answer 31

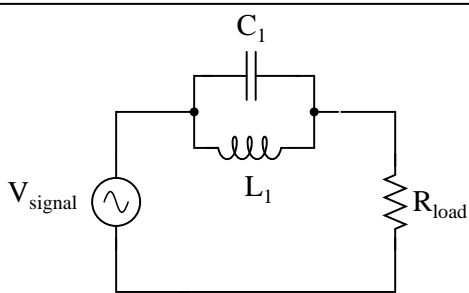
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 31

Use a sine-wave function generator for the AC voltage source. Specify standard resistor, capacitor, and inductor values. I have used a small 100 mH inductor, a 0.033 μ F capacitor, and 100 Ω resistor with good success. In any case I recommend keeping the resonant frequency within the mid-audio range (1 kHz to 10 kHz) to avoid problems with low inductor Q (frequency too low) and stray capacitance and inductance issues (frequency too high).

I also recommend having students use an oscilloscope to measure AC voltage in a circuit such as this, because some digital multimeters have difficulty accurately measuring AC voltage much beyond line frequency range. I find it particularly helpful to set the oscilloscope to the "X-Y" mode so that it draws a thin line on the screen rather than sweeps across the screen to show an actual waveform. This makes it easier to measure peak-to-peak voltage.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Passive resonant filter circuit		Version:	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Schematic</div>			
			
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Given conditions</div>			
$V_{\text{signal}} =$	$C_1 =$	$L_1 =$	$R_{\text{load}} =$
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Parameters</div>			
	Predicted	Measured	
Filter type (hp, lp, bp, bs)	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	
f_{resonant}	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Calculations</div>			
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Fault analysis</div>			
Suppose component <div style="border: 1px solid black; display: inline-block; width: 60px; height: 25px; vertical-align: middle;"></div> fails <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted </div>			
<i>What will happen in the circuit?</i>			

Answer 32

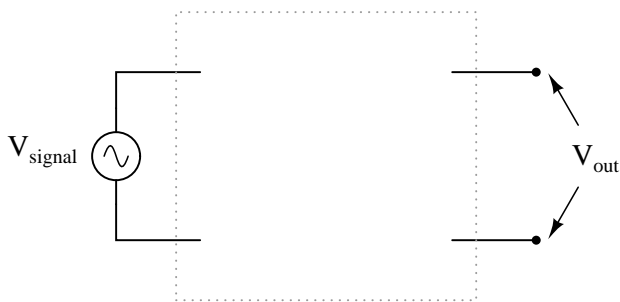
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 32

Use a sine-wave function generator for the AC voltage source. Specify standard resistor, capacitor, and inductor values. I have used a small 100 mH inductor, a 0.033 μF capacitor, and 100 Ω resistor with good success. In any case I recommend keeping the resonant frequency within the mid-audio range (1 kHz to 10 kHz) to avoid problems with low inductor Q (frequency too low) and stray capacitance and inductance issues (frequency too high).

I also recommend having students use an oscilloscope to measure AC voltage in a circuit such as this, because some digital multimeters have difficulty accurately measuring AC voltage much beyond line frequency range. I find it particularly helpful to set the oscilloscope to the "X-Y" mode so that it draws a thin line on the screen rather than sweeps across the screen to show an actual waveform. This makes it easier to measure peak-to-peak voltage.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Passive LC filter circuit design		Version:
Description		
Design and build a passive LC filter circuit with a resonant frequency specified by the instructor.		
Given conditions		
<i>(instructor checks one)</i>		
$f_r =$	Band-pass <input type="checkbox"/>	Band-stop <input type="checkbox"/>
Parameters		
	Predicted	Measured
f_r	<input type="text"/>	<input type="text"/>
Schematic		
		

Answer 33

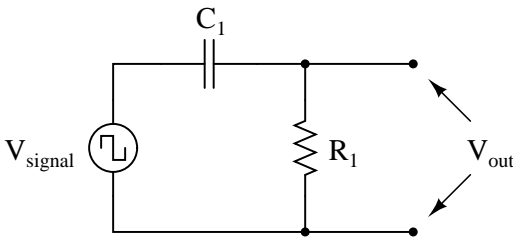
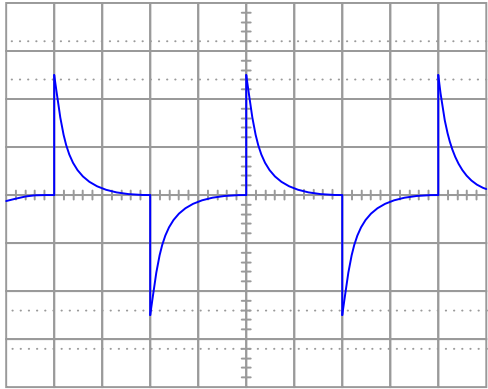
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 33

Use a sine-wave function generator for the AC voltage source. Specify a resonant frequency within the audio range.

This exercise assumes access to a variety of capacitor and/or inductor sizes, so the student may make series-parallel networks to achieve the necessary values of L and/or C . It would be wise for you (the instructor) to check your students' component kits for L and C values prior to choosing resonant frequencies for them to try to achieve.

I also recommend having students use an oscilloscope to measure AC voltage in a circuit such as this, because some digital multimeters have difficulty accurately measuring AC voltage much beyond line frequency range. I find it particularly helpful to set the oscilloscope to the "X-Y" mode so that it draws a thin line on the screen rather than sweeps across the screen to show an actual waveform. This makes it easier to measure peak-to-peak voltage.

Competency: Passive differentiator circuit		Version:
Schematic		
		
Given conditions		
$f_{\text{signal}} =$	<p>Required V_{out} waveshape</p> 	
Parameters		
<p style="text-align: center;">Predicted</p> <div style="display: flex; justify-content: space-between;"> <div style="text-align: right;">C_1</div> <div style="border: 1px solid black; width: 100px; height: 25px;"></div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="text-align: right;">R_1</div> <div style="border: 1px solid black; width: 100px; height: 25px;"></div> </div>		
Fault analysis		
<p>Suppose component fails</p> <div style="display: flex; justify-content: flex-end; align-items: center; margin-top: 5px;"> <div style="margin-right: 20px;"> <input type="checkbox"/> open <input type="checkbox"/> shorted </div> <div> <input type="checkbox"/> other _____ </div> </div> <p><i>What will happen in the circuit?</i></p>		

file 01686

Answer 34

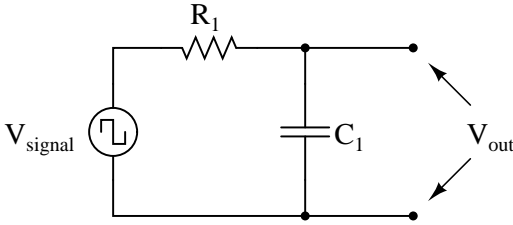
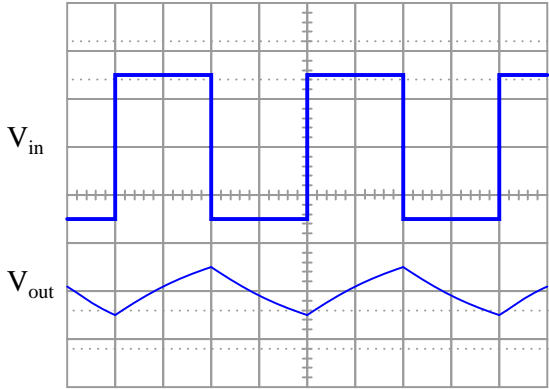
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 34

Here, students must calculate values for C_1 and R_1 that will produce the V_{out} waveshape specified in the "Given conditions" oscilloscope plot. The input signal, of course, is a square wave. Students must calculate the time constant of the circuit (τ) such that the pulse fully decays within the pulse width (half-period) of the square wave. With 5τ being the accepted standard for full charge/discharge of a time-constant circuit, this is an easy calculation.

There are many different combinations of values for C_1 and R_1 possible for any given square-wave signal frequencies. The purpose of this exercise is for students to be able to predict and select practical component values from their parts kits.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Passive integrator circuit		Version:
Schematic		
		
Given conditions		
$f_{\text{signal}} =$	Required waveshapes 	
Parameters		
<p style="text-align: center;">Predicted</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> C_1 <input style="width: 80px; height: 25px;" type="text"/> </div> <div style="text-align: center;"> R_1 <input style="width: 80px; height: 25px;" type="text"/> </div> </div>		
Fault analysis		
<p>Suppose component <input style="width: 60px; height: 25px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____</p> <p style="margin-left: 100px;"><input type="checkbox"/> shorted</p> <p><i>What will happen in the circuit?</i></p>		

Answer 35

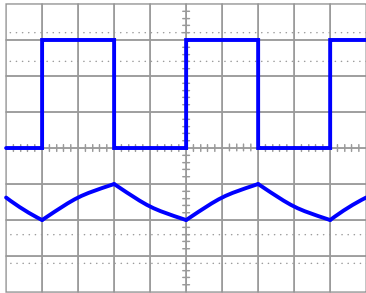
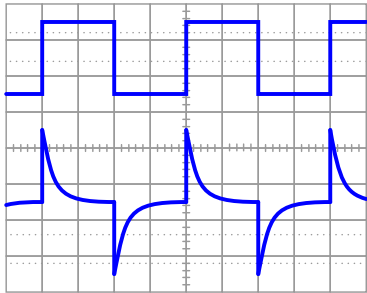
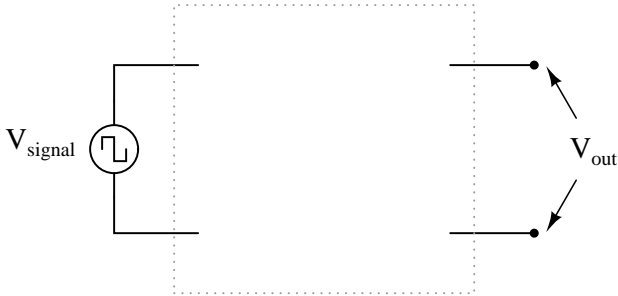
Use circuit simulation software to verify your predicted and measured parameter values.

Notes 35

Here, students must calculate values for C_1 and R_1 that will produce the V_{out} waveshape specified in the "Given conditions" oscilloscope plot. The input signal, of course, is a square wave. Students should be able to show mathematically why the time constant of the integrator (τ) must be 1.443 times the waveform's half-period ($e^{-\frac{T}{\tau}} = \frac{1}{2}$). Instructors, note: the calculations for this circuit, with $V_{out} = \frac{1}{3}V_{in}$, are exactly the same as for a 555 timer circuit, because 555 timers also cycle their capacitors' voltages at peak-to-peak values equal to one-third of the supply voltage.

There are many different combinations of values for C_1 and R_1 possible for any given square-wave signal frequencies. The purpose of this exercise is for students to be able to predict and select practical component values from their parts kits.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Passive integrator/differentiator circuit Version:	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Description</div>	
<p style="text-align: center;">Build either a passive integrator or a passive differentiator circuit to produce the desired waveforms given a square-wave input.</p>	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Given conditions</div>	
<div style="text-align: center; margin-bottom: 10px;"> $f_{\text{signal}} =$ </div> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;"> Integrator <input style="width: 30px; height: 20px;" type="checkbox"/> <i>(instructor checks one)</i> </div> <div style="text-align: center;"> Differentiator <input style="width: 30px; height: 20px;" type="checkbox"/> </div> </div> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;">  <p>$V_{\text{out}} = \frac{1}{3} V_{\text{in}}$</p> </div> <div style="text-align: center;">  <p>5τ in each pulse width</p> </div> </div>	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Schematic</div>	
	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Parameters</div>	
<div style="text-align: center; margin-bottom: 10px;">Predicted</div> <div style="display: flex; justify-content: center; gap: 20px;"> <div> C_1 <input style="width: 100px; height: 30px;" type="text"/> </div> <div> R_1 <input style="width: 100px; height: 30px;" type="text"/> </div> </div>	

Answer 36

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 36

Here, students must calculate values for C_1 and R_1 that will produce the V_{out} waveshape specified in the "Given conditions" oscilloscope plot. The input signal, of course, is a square wave.

If the chosen circuit is a differentiator, students must calculate the time constant of the circuit (τ) such that the pulse fully decays within the pulse width (half-period) of the square wave. With 5τ being the accepted standard for full charge/discharge of a time-constant circuit, this is an easy calculation.

If the chosen circuit is an integrator, students should be able to show mathematically why the time constant of the integrator (τ) must be 1.443 times the waveform's half-period ($e^{\frac{-t}{\tau}} = \frac{1}{2}$). Instructors, note: the calculations for this circuit, with $V_{out} = \frac{1}{3}V_{in}$, are exactly the same as for a 555 timer circuit, because 555 timers also cycle their capacitors' voltages at peak-to-peak values equal to one-third of the supply voltage.

There are many different combinations of values for C_1 and R_1 possible for any given square-wave signal frequencies. The purpose of this exercise is for students to be able to predict and select practical component values from their parts kits.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Tone balance control circuit		Version:											
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; padding: 20px;"> </div>													
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div>$L_1 =$</div> <div>$C_1 =$</div> <div>$R_{pot1} = R_{pot2} =$</div> </div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <div>$R_1 = R_2 =$</div> <div>$Z_{headphones} =$</div> </div> <p style="text-align: center; margin-top: 10px;">(Use audio source for signal, voltage adjusted for ample volume)</p>													
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <table style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr> <th style="width: 30%;"></th> <th style="width: 20%; text-align: center;">Predicted</th> <th style="width: 20%; text-align: center;">Measured</th> <th style="width: 30%;"></th> </tr> </thead> <tbody> <tr> <td>Bass control</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> <td rowspan="2" style="vertical-align: middle; text-align: center;">(Identify which pot is which)</td> </tr> <tr> <td>Treble control</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> </tr> </tbody> </table> <div style="display: flex; justify-content: space-around; margin-top: 20px;"> <div style="text-align: center;"> <p>Frequency response (maximum bass, minimum treble)</p> <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">V_{out}</div> <div style="border: 1px solid black; width: 200px; height: 100px; position: relative;"> <!-- Grid lines --> </div> </div> <p style="margin-top: 10px;">f</p> </div> <div style="text-align: center;"> <p>Frequency response (minimum bass, maximum treble)</p> <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">V_{out}</div> <div style="border: 1px solid black; width: 200px; height: 100px; position: relative;"> <!-- Grid lines --> </div> </div> <p style="margin-top: 10px;">f</p> </div> </div>				Predicted	Measured		Bass control			(Identify which pot is which)	Treble control		
	Predicted	Measured											
Bass control			(Identify which pot is which)										
Treble control													

Note: when testing the frequency response of the tone control circuit, you may need to replace the headphones with a non-inductive resistor of equivalent impedance, and measure V_{out} across it.

file 02022

Answer 37

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 37

A good source of audio signal is the headphone output jack of almost any radio, media player, or other portable audio device. Students like being able to do a lab exercise that directly relates to technology they're already familiar with.

The higher-impedance the headphones are, the better this circuit works, since the combination of potentiometers and mixing resistors tends to result in a relatively high output impedance. I have used cheap headphones (32 ohm) with some success, given the following component values:

- $C_1 = 0.1 \mu\text{F}$
- $L_1 = 200 \text{ mH}$ (actually two 100 mH inductors in series)
- $R_1 = R_2 = 1 \text{ k}\Omega$
- $R_{pot1} = R_{pot2} = 10 \text{ k}\Omega$

Some students with limited hearing range have difficulty detecting the changes in tone using 10 k Ω potentiometers. You may wish to use 100 k Ω potentiometers instead for added attenuation. Operating such a circuit is akin to operating a water faucet with "hot" and "cold" water valves: the two settings together determine temperature *and* flow (tone and volume, respectively, for the metaphorically challenged).

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

If you plan to use this exercise as a troubleshooting assessment, I recommend *against* inducing the following component failures, as they are difficult to detect when the signal source is music rather than a constant tone of known frequency and amplitude:

- Shorted capacitor (C_1)
- Shorted inductor (L_1)
- Shorted fixed-value resistors (R_1 or R_2)

Competency: Tone balance control circuit		Version:											
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; padding: 20px;"> </div>													
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <p style="margin: 5px 0;"> $L_1 =$ $C_1 =$ $R_{pot1} = R_{pot2} =$ $R_1 = R_2 =$ $Z_{speaker} =$ $T_1 =$ (Use audio source for signal, voltage adjusted for ample volume) </p>													
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;"></th> <th style="width: 20%; text-align: center;">Predicted</th> <th style="width: 20%; text-align: center;">Measured</th> <th style="width: 30%;"></th> </tr> </thead> <tbody> <tr> <td>Bass control</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> <td rowspan="2" style="vertical-align: middle; text-align: center;">(Identify which pot is which)</td> </tr> <tr> <td>Treble control</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> </tr> </tbody> </table> <div style="display: flex; justify-content: space-around; margin-top: 20px;"> <div style="text-align: center;"> <p>Frequency response (maximum bass, minimum treble)</p> <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">V_{out}</div> <div style="border: 1px solid black; width: 200px; height: 100px; position: relative;"> <!-- Grid lines --> </div> </div> <p style="margin-top: 10px;">f</p> </div> <div style="text-align: center;"> <p>Frequency response (minimum bass, maximum treble)</p> <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">V_{out}</div> <div style="border: 1px solid black; width: 200px; height: 100px; position: relative;"> <!-- Grid lines --> </div> </div> <p style="margin-top: 10px;">f</p> </div> </div>				Predicted	Measured		Bass control			(Identify which pot is which)	Treble control		
	Predicted	Measured											
Bass control			(Identify which pot is which)										
Treble control													

Note: when testing the frequency response of the tone control circuit, you may need to replace the transformer/speaker assembly with a non-inductive resistor of equivalent impedance, and measure V_{out} across it.

file 02023

Answer 38

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 38

A good source of audio signal is the headphone output jack of almost any radio, media player, or other portable audio device. Students like being able to do a lab exercise that directly relates to technology they're already familiar with.

I have experienced good success with the following component values:

- $C_1 = 0.1 \mu\text{F}$
- $L_1 = 200 \text{ mH}$ (actually two 100 mH inductors in series)
- $R_1 = R_2 = 1 \text{ k}\Omega$
- $T_1 = 1000:8 \text{ ohm}$ audio output transformer
- $R_{pot} = R_{pot2} = 10 \text{ k}\Omega$
- Speaker = small 8Ω unit (salvaged from an old clock radio or other inexpensive audio device)

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Noise coupling and decoupling		Version:																																
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; padding: 10px;"> <p style="text-align: center;"><i>Must be a battery!</i></p> <p style="text-align: center;">$C_{\text{decoupling}}$</p> </div>																																		
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="padding: 10px;"> $C_{\text{decoupling}} =$ Cable length = </div>																																		
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <div style="text-align: center; padding: 10px;"> <p><i>Predicted values are qualitative only (least, greatest, little bit less than . . .)</i></p> <table style="margin: auto;"> <thead> <tr> <th></th> <th>Predicted</th> <th>Measured</th> <th></th> </tr> </thead> <tbody> <tr> <td>$V_{\text{noise}} (1b-2b)$</td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> <td rowspan="3" style="vertical-align: middle; padding-left: 10px;">Without $C_{\text{decoupling}}$</td> </tr> <tr> <td>$V_{\text{noise}} (2b-3b)$</td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> </tr> <tr> <td>$V_{\text{noise}} (3b-4b)$</td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td rowspan="3" style="vertical-align: middle; padding-left: 10px;">With $C_{\text{decoupling}}$ connected across test points</td> </tr> <tr> <td>$V_{\text{noise}} (1b-2b)$</td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> </tr> <tr> <td>$V_{\text{noise}} (2b-3b)$</td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> </tr> <tr> <td>$V_{\text{noise}} (3b-4b)$</td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> <td><div style="border: 1px solid black; width: 80px; height: 30px;"></div></td> <td></td> </tr> </tbody> </table> </div>				Predicted	Measured		$V_{\text{noise}} (1b-2b)$	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	Without $C_{\text{decoupling}}$	$V_{\text{noise}} (2b-3b)$	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	$V_{\text{noise}} (3b-4b)$	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>								With $C_{\text{decoupling}}$ connected across test points	$V_{\text{noise}} (1b-2b)$	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	$V_{\text{noise}} (2b-3b)$	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	$V_{\text{noise}} (3b-4b)$	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	<div style="border: 1px solid black; width: 80px; height: 30px;"></div>	
	Predicted	Measured																																
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Answer 39

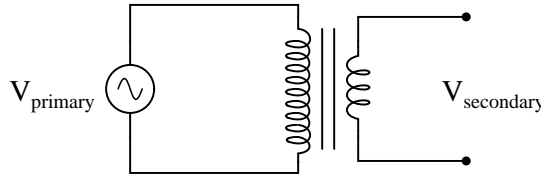
Use circuit simulation software to verify your predicted and measured parameter values, using an AC current source as the motor, and a multi-conductor transmission line as the cable. Note: this may be quite complicated to set up in simulation!

Notes 39

The longer the cable, the better the coupling between the motor conductors and the other conductors. I have found that this exercise is practical with just a few feet of four-wire telephone cable.

It is very important to use a battery for this exercise, and not an AC-DC power supply. The filter capacitors in an AC-DC power supply naturally decouple the motor's noise voltage, making it difficult to measure any at all!

Noise voltage should be measured with an oscilloscope set to AC input coupling, and recorded as peak-to-peak volts.

Competency: Transformer voltage ratio	Version:						
Schematic							
							
Given conditions							
Transformer winding (turns) ratio = $V_{\text{primary}} =$ $f =$							
Parameters							
<table style="width: 100%; border-collapse: collapse;"><thead><tr><th style="width: 10%;"></th><th style="width: 40%; text-align: center;">Predicted</th><th style="width: 40%; text-align: center;">Measured</th></tr></thead><tbody><tr><td style="vertical-align: middle;">V_{sec}</td><td style="border: 1px solid black; height: 30px; width: 100%;"></td><td style="border: 1px solid black; height: 30px; width: 100%;"></td></tr></tbody></table>			Predicted	Measured	V_{sec}		
	Predicted	Measured					
V_{sec}							
Calculations							

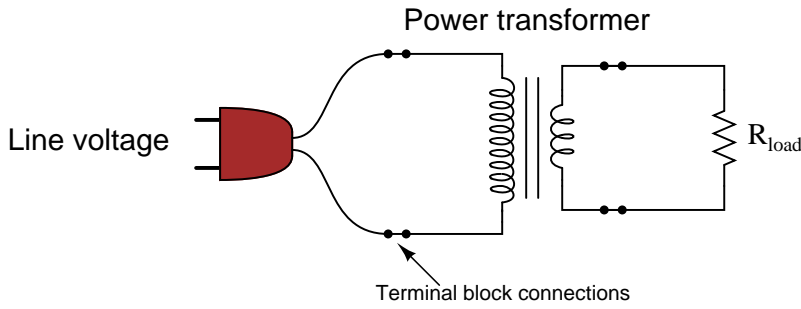
Answer 40

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 40

You may use an audio frequency impedance matching (1000:8 ohms) transformer or a step-down power transformer for this exercise. In either case, students need to know or figure out the turns ratio before proceeding with the experiment. If you are using an audio transformer, use a sine-wave signal generator for the voltage source, but avoid frequencies below 1kHz. If you are using a power transformer, use a Variac to provide adjustable primary voltage.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Transformer voltage/current ratios		Version:	
Schematic			
 <p style="margin-top: 10px;"><i>There must be no exposed line power conductors!</i></p>			
Given conditions			
Transformer step-down ratio = $V_{\text{line}} =$ $R_{\text{load}} =$			
Parameters			
<i>Procedure for ensuring no shock hazard when connecting meter:</i>			
Description (written by student)		Observed (written by instructor)	
Predicted	Measured	Predicted	Measured
V_{pri}		V_{sec}	
I_{pri}		I_{sec}	

file 01675

Answer 41

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 41

Use line-frequency power transformers for this exercise, with load resistor values low enough to "swamp" the primary winding's excitation current, so that the primary/secondary current ratio is realistic. Choosing a resistor value low enough to load the transformer near 100 % rated secondary current is a good start. Be careful that your load resistor can handle the power dissipation!

It might be a good idea for students to take careful measurements of primary and secondary voltage in an *unloaded* condition in order to calculate the actual winding turns ratio of their transformer. Knowing this precise ratio will be helpful to them later on when they use their transformers in other performance assessment activities, so their predictions will more closely match their actual measurements.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Transformer voltage/current ratios		Version:			
Schematic					
<p style="text-align: center;">Audio transformer</p> <p style="text-align: center;">V_{source} R_{load}</p> <p style="text-align: center;">$1000:8 \Omega$</p> <p style="text-align: center;">Terminal block connections</p>					
Given conditions					
Transformer winding (turns) ratio = $V_{\text{source}} =$ $R_{\text{load}} =$ $f_{\text{source}} =$					
Parameters					
	Predicted	Measured		Predicted	Measured
V_{pri}	<input style="width: 80px; height: 30px;" type="text"/>	<input style="width: 80px; height: 30px;" type="text"/>		V_{sec}	<input style="width: 80px; height: 30px;" type="text"/>
I_{pri}	<input style="width: 80px; height: 30px;" type="text"/>	<input style="width: 80px; height: 30px;" type="text"/>		I_{sec}	<input style="width: 80px; height: 30px;" type="text"/>
Calculations					

Answer 42

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 42

Use an audio frequency impedance matching (1000:8 ohms) transformer for this exercise, using a load resistance great enough not to overload the signal generator powering it. I recommend using a 100 k Ω resistor for the load. With the audio transformer's impedance ratio, this should appear as an 800 Ω load to the signal generator. Avoid frequencies below 1 kHz – power line frequency is much too low for this type of transformer.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Auto-transformers	Version:												
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Description</div> <p style="text-align: center; margin-top: 20px;">Connect a step-down power transformer in the "buck" auto-transformer configuration, and use it to power a low-resistance load.</p> <p style="text-align: center; margin-top: 20px;"><i>There must be no exposed line power conductors!</i></p>													
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Given conditions</div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"><div>$V_{\text{supply}} =$</div><div>$R_{\text{load}} =$</div><div>Transformer step-down ratio =</div></div>													
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	Predicted	Measured											
I_{supply}	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>											
V_{load}	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>											
I_{load}	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>											

file 01611

Answer 43

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 43

The *real* challenge in this assessment is for students to determine their transformers' "polarities" before connecting them to the AC voltage source! For this, they should have access to a small battery and a DC voltmeter (at their desks).

You may use a Variac at the test bench to provide variable-voltage AC power for the students' transformer circuits. I recommend specifying load resistance values low enough that the load current completely "swamps" the transformer's magnetization current. This may mean using wire-wound power resistors instead of $\frac{1}{4}$ watt carbon composition resistors.

Note that there may very well be a shock hazard associated with this circuit, as the output voltage is not far below the line voltage! Be sure to take this into consideration when specifying load resistor values. You may also want to use low supply voltage levels (turn the Variac *way* down).

In lieu of using a line-powered transformer, you may also do this exercise with a signal generator and an audio-frequency transformer. The principles are the same, and the safety hazard will be vastly reduced. If using a 1000:8 ohm transformer, the winding turns ratio is approximately 11.18 to 1.

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Auto-transformers	Version:												
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Description</div> <p style="text-align: center; margin-top: 20px;">Connect a step-down power transformer in the "boost" auto-transformer configuration, and use it to power a low-resistance load.</p> <p style="text-align: center; margin-top: 20px;"><i>There must be no exposed line power conductors!</i></p>													
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Given conditions</div> <div style="display: flex; justify-content: space-around; margin-top: 10px;"><div>$V_{\text{supply}} =$</div><div>$R_{\text{load}} =$</div><div>Transformer step-down ratio =</div></div>													
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px;">Parameters</div> <table style="width: 100%; margin-top: 10px;"><thead><tr><th></th><th style="text-align: center;">Predicted</th><th style="text-align: center;">Measured</th></tr></thead><tbody><tr><td style="text-align: right;">I_{supply}</td><td style="border: 1px solid black; width: 100px; height: 30px;"></td><td style="border: 1px solid black; width: 100px; height: 30px;"></td></tr><tr><td style="text-align: right;">V_{load}</td><td style="border: 1px solid black; width: 100px; height: 30px;"></td><td style="border: 1px solid black; width: 100px; height: 30px;"></td></tr><tr><td style="text-align: right;">I_{load}</td><td style="border: 1px solid black; width: 100px; height: 30px;"></td><td style="border: 1px solid black; width: 100px; height: 30px;"></td></tr></tbody></table>			Predicted	Measured	I_{supply}			V_{load}			I_{load}		
	Predicted	Measured											
I_{supply}													
V_{load}													
I_{load}													

Answer 44

Use circuit simulation software to verify your predicted and measured parameter values.

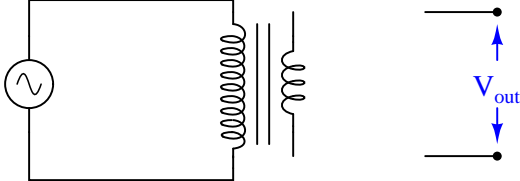
Notes 44

The *real* challenge in this assessment is for students to determine their transformers' "polarities" before connecting them to the AC voltage source! For this, they should have access to a small battery and a DC voltmeter (at their desks).

You may use a Variac at the test bench to provide variable-voltage AC power for the students' transformer circuits. I recommend specifying load resistance values low enough that the load current completely "swamps" the transformer's magnetization current. This may mean using wire-wound power resistors instead of $\frac{1}{4}$ watt carbon composition resistors.

Note that there may very well be a shock hazard associated with this circuit, as you are "boosting" the supply voltage! Be sure to take this into consideration when specifying load resistor values. You may also want to use low supply voltage levels (turn the Variac *way* down).

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Auto-transformers	Version:						
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">Description</div> <p style="text-align: center;">Connect a step-down transformer as an auto-transformer, to either boost or buck the input voltage.</p> <p style="text-align: center;"><i>There must be no exposed line power conductors!</i></p>							
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">Given conditions</div> <div style="display: flex; justify-content: space-between; align-items: flex-start;"> <div style="width: 45%;"> $V_{\text{supply}} =$ Transformer step-down ratio = </div> <div style="width: 50%;"> Boost <input style="width: 30px; height: 20px;" type="checkbox"/> Buck <input style="width: 30px; height: 20px;" type="checkbox"/> </div> </div>							
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; margin: 10px 0;">  </div> <p style="text-align: center;">(Be sure to note the transformer's polarity using dot convention)</p>							
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">Parameters</div> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 35%; text-align: center;">Predicted</th> <th style="width: 35%; text-align: center;">Measured</th> </tr> </thead> <tbody> <tr> <td style="vertical-align: middle;">V_{output}</td> <td style="border: 1px solid black; height: 25px; width: 100%;"></td> <td style="border: 1px solid black; height: 25px; width: 100%;"></td> </tr> </tbody> </table>			Predicted	Measured	V_{output}		
	Predicted	Measured					
V_{output}							

Answer 45

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 45

The *real* challenge in this assessment is for students to determine their transformers' "polarities" before connecting them to the AC voltage source! For this, they should have access to a small battery and a DC voltmeter (at their desks).

You may use a Variac at the test bench to provide variable-voltage AC power for the students' transformer circuits. I recommend specifying load resistance values low enough that the load current completely "swamps" the transformer's magnetization current. This may mean using wire-wound power resistors instead of $\frac{1}{4}$ watt carbon composition resistors.

Note that there may very well be a shock hazard associated with this circuit! Be sure to take this into consideration when specifying load resistor values. You may also want to use low supply voltage levels (turn the Variac *way* down).

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Lissajous figures for frequency ratio measurement
Version:

Schematic

Given conditions

(Voltage specified by instructor, frequencies set by student)

V_{signal1} and $V_{\text{signal2}} =$

Lissajous figure

Parameters

	Predicted	Measured
$\frac{f_{\text{signal2}}}{f_{\text{signal1}}}$	<input type="text"/>	<input type="text"/>

file 01679

Answer 46

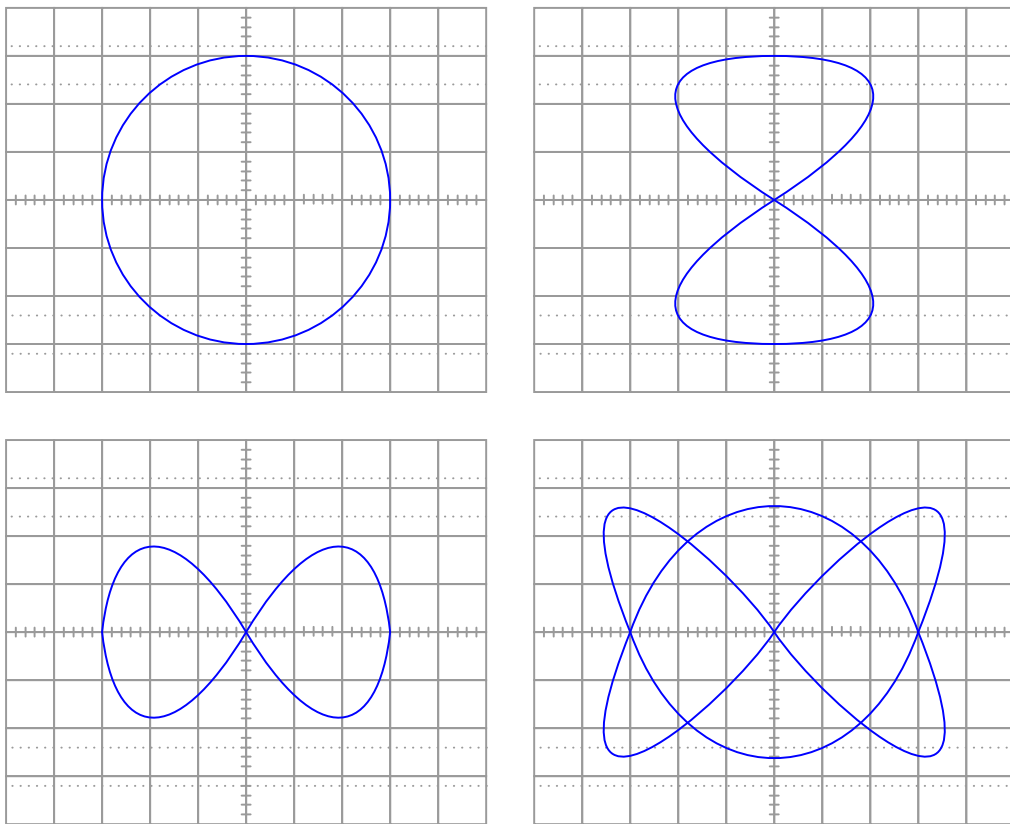
Use circuit simulation software to verify your predicted and measured parameter values.

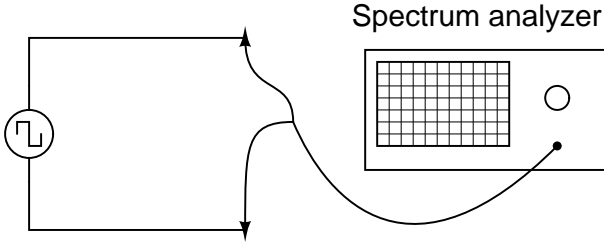
Notes 46

Lissajous figures are very informative if one understands how to interpret them. The purpose of this exercise is for students to learn exactly how to do that, in the context of measuring frequency (ratios). Please use sinusoidal AC sources (variable-frequency signal generators) for this exercise.

The instructor will determine the voltage of the two sources (set the same), and also will graphically specify the Lissajous figure by drawing the desired figure on the oscilloscope screen illustration. The student's task is to figure out what frequency ratio will generate this pattern on the oscilloscope screen, and set the signal generators to that ratio (one set to 1 kHz, the other to the appropriate frequency). This works best if the student can only see the signal generator controls and frequency counter displays, and only the instructor can see the oscilloscope display.

Here are some sample Lissajous figures to draw for your students to duplicate:



Competency: Fourier analysis of a square wave		Version:																					
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; padding: 20px;">  <p style="margin: 0;">Spectrum analyzer</p> </div>																							
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="padding: 10px;"> <div style="display: flex; justify-content: space-between; margin-bottom: 10px;"> <div>$V_{\text{supply}} =$</div> <div>Duty cycle = 50%</div> </div> <div> <div>$f_{\text{fundamental}} =$</div> </div> </div>																							
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;"></th> <th style="width: 35%; text-align: center;">Predicted</th> <th style="width: 35%; text-align: center;">Measured</th> </tr> </thead> <tbody> <tr> <td>1st "overtone" amplitude</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> </tr> <tr> <td>1st "overtone" frequency</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> </tr> <tr> <td>2nd "overtone" amplitude</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> </tr> <tr> <td>2nd "overtone" frequency</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> </tr> <tr> <td>3rd "overtone" amplitude</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> </tr> <tr> <td>3rd "overtone" frequency</td> <td style="border: 1px solid black; height: 30px;"></td> <td style="border: 1px solid black; height: 30px;"></td> </tr> </tbody> </table>				Predicted	Measured	1st "overtone" amplitude			1st "overtone" frequency			2nd "overtone" amplitude			2nd "overtone" frequency			3rd "overtone" amplitude			3rd "overtone" frequency		
	Predicted	Measured																					
1st "overtone" amplitude																							
1st "overtone" frequency																							
2nd "overtone" amplitude																							
2nd "overtone" frequency																							
3rd "overtone" amplitude																							
3rd "overtone" frequency																							

file 01684

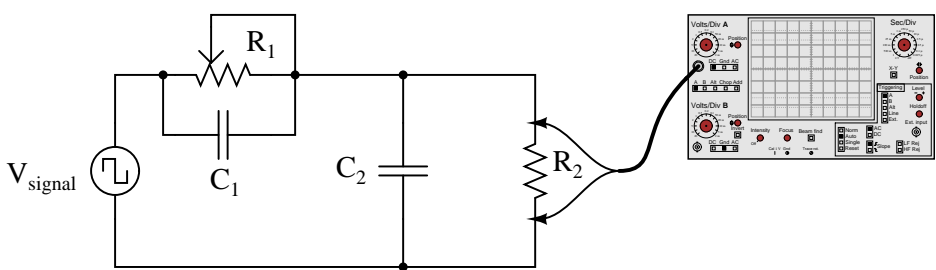

Answer 47

Use circuit simulation software to verify your predicted and measured parameter values.

Notes 47

By the word *overtone*, I imply the musical concept: the successive harmonics appearing in this particular non-sinusoidal waveform. If I were to say "1st harmonic," "2nd harmonic," and "3rd harmonic," this would specifically refer to $f_{\text{fundamental}}$, $2f_{\text{fundamental}}$, and $3f_{\text{fundamental}}$, respectively. The first of these would be given, the second nonexistent in a square wave with 50% duty cycle, leaving only the third as something to actually predict and measure. By "overtones," I mean the first, second, and third frequencies greater than the fundamental frequency found in a square wave, that happen to be harmonics of the fundamental.

If you lack a spectrum analyzer in your lab, fear not! There are free software packages in existence allowing you to use the audio input of a personal computer's sound card as a (limited) spectrum analyzer and oscilloscope! You may find some of these packages by searching on the Internet. One that I've used (2002) successfully in my own class is called WinScope.

Competency: Balanced attenuator circuit		Version:				
Schematic						
						
Given conditions						
$V_{\text{signal}} =$ $f_{\text{signal}} =$	$R_2 =$ $C_1 =$	$C_2 =$				
Parameters						
R_1  (necessary to achieve undistorted square-wave output)	<table border="1" style="margin: auto;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="height: 30px; width: 100px;"></td> <td style="height: 30px; width: 100px;"></td> </tr> </tbody> </table>	Predicted	Measured			
Predicted	Measured					
Fault analysis						
Suppose component fails <div style="display: inline-block; vertical-align: middle; margin-left: 10px;"> <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted </div> <p><i>What will happen in the circuit?</i></p>						

file 01661

Answer 48

Use circuit simulation software to verify your predicted and measured parameter waveforms.

Note: this circuit works on the same basic principle as the compensation adjustment on high-quality oscilloscope probes, except that here the resistor is variable and not the capacitor.

Notes 48

Use a square-wave function generator for the AC voltage source. I have built this circuit using resistances of approximately $4.7\text{ k}\Omega$ and capacitances of approximately $0.1\text{ }\mu\text{F}$, and achieved good results with a square-wave (fundamental) frequency of about 300 Hz . Of course, the R_1 resistance calculation is more challenging if the two capacitor values are unequal!

Incidentally, this circuit may be used to comparatively measure reactive components such as capacitors and inductors, since the square wave signal will be faithfully reproduced only when the $\frac{R_1}{R_2}$ ratio equals the $\frac{X_{C1}}{X_{C2}}$ or $\frac{X_{L1}}{X_{L2}}$ ratio. To be honest, the idea was not mine. I found it in an old book, the *Electronics Manual for Radio Engineers*, by Vin Zeluff and John Markus, first edition (1949), page 427. Apparently, the inventor of this ingenious impedance measurement technique was an employee of Allen B. DuMont Lab., Inc. named Peter S. Christaldi, who obtained a patent for the technique on October 15, 1946 (patent number 2,409,419 for those who are interested).

An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Competency: Power factor correction for AC motor Version:																	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Schematic</div> <div style="text-align: center; padding: 10px;"> <p style="color: red; font-size: small;">Oscilloscope channel 2 here (x10 probe recommended)</p> <p style="color: red; font-size: small;">Oscilloscope ground here</p> <p style="color: red; font-size: small;">Oscilloscope channel 1 here</p> </div>																	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Given conditions</div> <div style="display: flex; justify-content: space-between; align-items: flex-start; padding: 10px;"> <div style="width: 40%;"> <p>Volts/div =</p> <p>Sec/div =</p> <p>$R_{shunt} =$</p> </div> <div style="width: 55%; text-align: center;"> <p>Voltage/current display on scope</p> </div> </div>																	
<div style="border: 1px solid black; display: inline-block; padding: 2px 5px; margin-bottom: 5px;">Parameters</div> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;"></th> <th style="width: 45%; text-align: center;">(Without C_1) Measured</th> <th style="width: 45%; text-align: center;">(With C_1 connected) Measured</th> </tr> </thead> <tbody> <tr> <td style="text-align: right; padding-right: 10px;">θ</td> <td style="border: 1px solid black; height: 30px; width: 100%;"></td> <td style="border: 1px solid black; height: 30px; width: 100%;"></td> </tr> <tr> <td style="text-align: right; padding-right: 10px;">I_{total}</td> <td style="border: 1px solid black; height: 30px; width: 100%;"></td> <td style="border: 1px solid black; height: 30px; width: 100%;"></td> </tr> <tr> <td style="text-align: right; padding-right: 10px;">Predicted</td> <td colspan="2"></td> </tr> <tr> <td style="text-align: right; padding-right: 10px;">C_1</td> <td style="border: 1px solid black; height: 30px; width: 100%;"></td> <td style="text-align: center; vertical-align: middle;">To correct P.F. to a value of unity</td> </tr> </tbody> </table>				(Without C_1) Measured	(With C_1 connected) Measured	θ			I_{total}			Predicted			C_1		To correct P.F. to a value of unity
	(Without C_1) Measured	(With C_1 connected) Measured															
θ																	
I_{total}																	
Predicted																	
C_1		To correct P.F. to a value of unity															

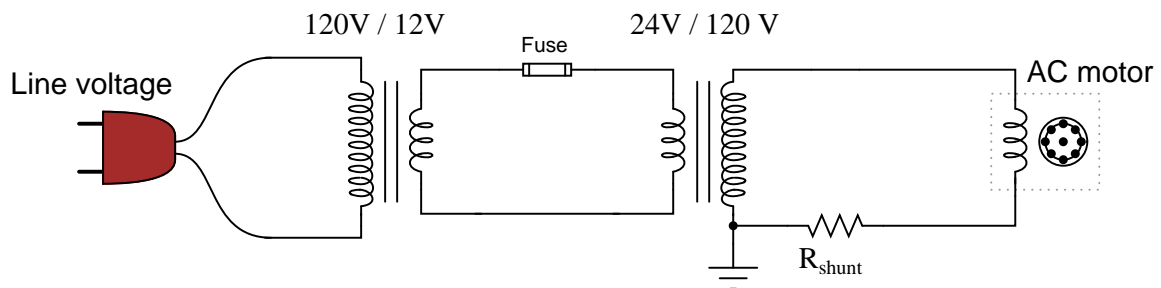
Answer 49

The meter measurements you take will constitute the "final word" for validating your predictions.

Notes 49

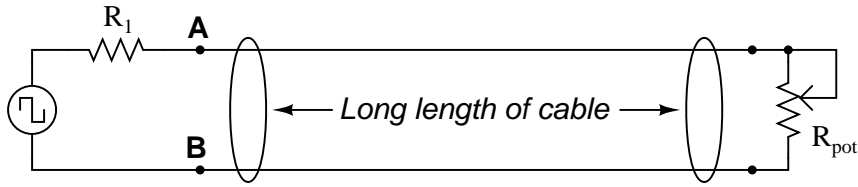
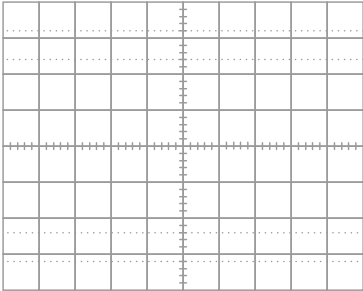
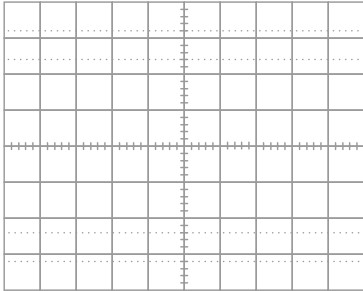
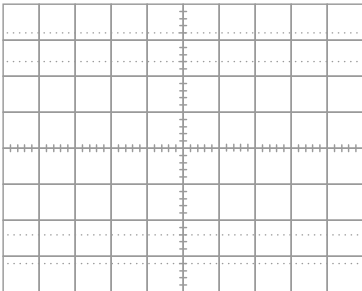
When presenting this as a performance assessment for a group of students, you will need to show the voltage/current waveforms as part of the "given" conditions. A good way to do this is to use a PC-based oscilloscope to measure the waveforms, and then display the image using a video projector.

I have found that small synchronous AC motors such as those used in clock mechanisms and in some appliances (microwave oven carousels, for example) will run satisfactorily at 24 volts AC. Small shaded-pole motors such as those used in household bathroom fans and household appliances (microwave oven cooling fans, for example) may be operated in a relatively safe manner from low-voltage AC power by stepping the voltage up through a power transformer connected directly to the motor. Use a "step down" power transformer operating in reverse (as a step-up unit), with the higher voltage wires connected and taped to the motor so that the only "loose" wire connections are on the low-voltage side. Here is a power supply circuit I recommend for the task:



This circuit ensures the motor only receives about 60 volts, reducing shock hazard somewhat and allowing the use of capacitors rated for 100 volts (a common mylar capacitor rating). The smaller the motor, the less capacitance will be required to correct for power factor. Remind your students that the capacitors used in this exercise must be *non-polarized*, since they must operate on AC and not DC!

A shunt resistor value of 1 ohm is recommended, but not absolutely required. You just need a low-value resistor that will provide a ready point of measurement for current (with the oscilloscope) without imposing too much series resistance in the motor circuit.

Competency: Characteristic cable impedance		Version:	
Schematic			
			
Given conditions			
$f_{\text{supply}} =$	$R_1 =$	$R_{\text{pot(max)}} =$	
Velocity factor =			
Parameters			
	Predicted	Measured	Measured
Length of cable	<input style="width: 100px; height: 30px;" type="text"/>	<input style="width: 100px; height: 30px;" type="text"/>	Z_0 <input style="width: 100px; height: 30px;" type="text"/>
V_{AB} waveform with R_{pot} set too low		V_{AB} waveform with R_{pot} set too high	
			
V_{AB} waveform with $R_{\text{pot}} = Z_0$ 			

file 01915

Answer 50

The oscilloscope display will conclusively show when $R_{pot} = Z_0$.

Notes 50

This is a very simple yet effective exercise in demonstrating the effects of reflections in cables where the termination resistance (R_{pot}) is unequal to the cable's characteristic impedance (Z_0). It is also an easy way to measure Z_0 , by adjusting R_{pot} until a match is shown by an undistorted square-wave between points **A** and **B**.

I've used ordinary "zip cord" type speaker wire for this experiment. You can also use household extension cords or lengths of coaxial cable if you prefer. Coax has the benefit of already being rated for a specified impedance, unlike the other cable types listed. A length of 100 feet works well to produce time delays easily measurable with inexpensive oscilloscopes.

The purpose of resistor R_1 is to "swamp" the square-wave signal generator's own Thévenin impedance, so it does not become a significant factor in the system. The maximum resistance of rheostat R_{pot} is really not that critical. I've easily achieved a match on speaker cable with $Z_0 \approx 136\Omega$ using a 10 k Ω potentiometer for R_{pot} . A 1 k Ω potentiometer would probably be best.

If you wish your students to be able to accurately predict the length of their cable from the waveshapes displayed by the oscilloscope, you need to determine the cable's velocity factor beforehand, and write that value in the "Given conditions" section. Otherwise, you could have students infer velocity factor from cable length and oscilloscope measurements.

(Template)

Competency:	Version:
Schematic	
Given conditions	
Parameters	
Predicted	Measured
<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>
<div style="border: 1px solid black; width: 100px; height: 25px;"></div>	<div style="border: 1px solid black; width: 100px; height: 25px;"></div>

file 01602

Answer 51

Here, you would indicate where or how to obtain answers for the requested parameters, but not actually give the figures. My stock answer here is “use circuit simulation software” (Spice, Multisim, etc.).

Notes 51

Any relevant notes for the assessment activity go here.