

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).

Competency: **Analog oscilloscope set-up** Version:

Schematic

Given conditions

V_{signal} = Set by instructor without student's knowledge

f_{signal} = Set by instructor without student's knowledge

Parameters

Between two and five cycles of waveform displayed,
without exceeding either top or bottom edge of screen.

file 01674

Competency: Digital oscilloscope set-up	Version:
Schematic	
Given conditions	
<p>$V_{\text{signal}} =$ Set by instructor without student's knowledge</p> <p>$f_{\text{signal}} =$ 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 03305

Competency: **RMS versus peak measurements** Version:

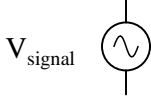
Schematic

Given conditions

V_{signal} = Set by instructor without student's knowledge

Parameters

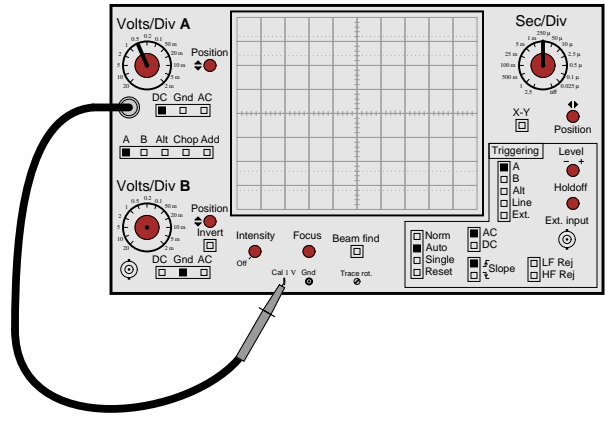
		Measured	
	$V_{\text{signal(peak)}}$		(Measured with oscilloscope)
	Predicted	Measured	
$V_{\text{signal(RMS)}}$			(Measured with true-RMS multimeter)

Competency: Measuring frequency	Version:
Schematic	
	
Given conditions	
$V_{\text{signal}} =$	
$f_{\text{signal}} =$ Set by instructor without student's knowledge	
Parameters	
Measured with oscilloscope	
t_{period} <input type="text"/>	
Measured with counter Measured with oscilloscope	
f_{signal} <input type="text"/> <input type="text"/>	

file 01660

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

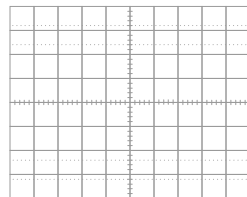
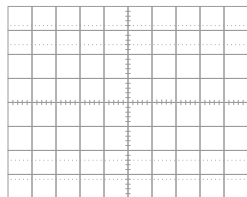
Between two and five cycles of waveform displayed, without exceeding either top or bottom edge of screen.

Measured

V_{signal}

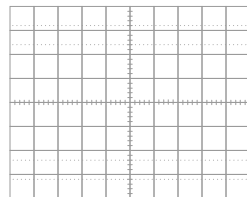
f_{signal}

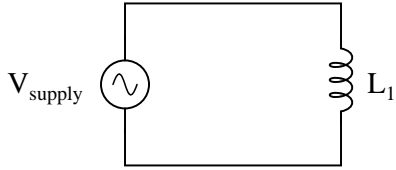
Properly compensated probe waveform

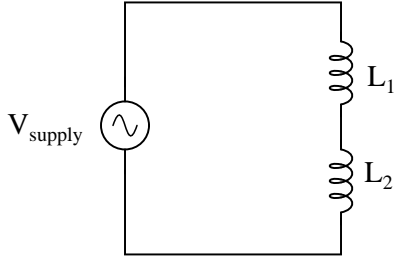


Overcompensated probe waveform

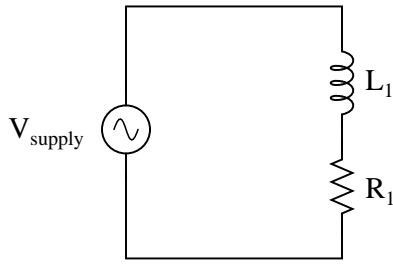
Undercompensated probe waveform



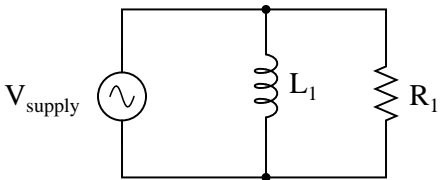
Competency: Inductive reactance and Ohm's Law for AC Version:				
Schematic				
				
Given conditions				
$V_{\text{supply}} =$	$L_1 =$			
$f_{\text{supply}} =$				
Parameters				
	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="padding: 5px;">Predicted</td> <td style="padding: 5px;">Measured</td> </tr> </table>	Predicted	Measured	
Predicted	Measured			
I_{total}	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> </tr> </table>			
V_{L1}	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> </tr> </table>			
<i>Qualitative answers only: Increase, decrease, or same</i>				
	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="padding: 5px;">Predicted</td> <td style="padding: 5px;">Measured</td> </tr> </table>	Predicted	Measured	
Predicted	Measured			
I_{total}	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="padding: 0 10px;">as frequency increases</td> </tr> </table>			as frequency increases
		as frequency increases		
I_{total}	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="padding: 0 10px;">as frequency decreases</td> </tr> </table>			as frequency decreases
		as frequency decreases		

Competency: Series AC inductive reactances	Version:	
Schematic		
		
Given conditions		
$V_{\text{supply}} =$	$L_1 =$	$L_2 =$
$f_{\text{supply}} =$		
Parameters		
X_{L1} Predicted	X_{L2} Predicted	X_{total} Predicted
<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
I_{total} Predicted	Measured	Derived ($X = V/I$)
<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>	X_{total} <input style="width: 100px; height: 20px;" type="text"/>
Analysis		
Do series inductive reactances <i>add</i> or <i>diminish</i> ?		
Fault analysis		
Suppose component <input style="width: 50px; height: 20px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____		
<input type="checkbox"/> shorted		
<i>What will happen in the circuit?</i>		

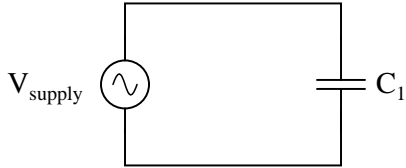
file 01655

Competency: Series LR circuit	Version:								
Schematic									
									
Given conditions									
$V_{\text{supply}} =$	$L_1 =$								
$f_{\text{supply}} =$	$R_1 =$								
Parameters									
	<table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">V_{L1} <input style="width: 80px; height: 25px;" type="text"/></td> <td style="padding: 5px;"><input style="width: 80px; height: 25px;" type="text"/></td> </tr> <tr> <td style="padding: 5px;">V_{R1} <input style="width: 80px; height: 25px;" type="text"/></td> <td style="padding: 5px;"><input style="width: 80px; height: 25px;" type="text"/></td> </tr> <tr> <td style="padding: 5px;">I_{total} <input style="width: 80px; height: 25px;" type="text"/></td> <td style="padding: 5px;"><input style="width: 80px; height: 25px;" type="text"/></td> </tr> </tbody> </table>	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"/>
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: 50px; height: 25px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted <i>What will happen in the circuit?</i>									

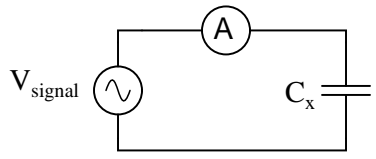
file 01665

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 style="padding-right: 10px;">I_{L1}</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="padding-right: 10px;">I_{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="padding-right: 10px;">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	I_{L1}			I_{R1}			I_{total}		
	Predicted	Measured											
I_{L1}													
I_{R1}													
I_{total}													
Calculations													
<p style="margin: 0;"> Fault analysis Suppose component fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted <i>What will happen in the circuit?</i> </p>													

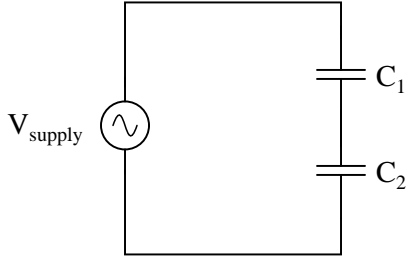
file 01816

Competency: Capacitive reactance and Ohm's Law for AC Version:				
Schematic				
				
Given conditions				
$V_{\text{supply}} =$	$C_1 =$			
$f_{\text{supply}} =$				
Parameters				
	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="padding: 5px;">Predicted</td> <td style="padding: 5px;">Measured</td> </tr> </table>	Predicted	Measured	
Predicted	Measured			
I_{total}	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> </tr> </table>			
V_{C_1}	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> </tr> </table>			
<p><i>Qualitative answers only: Increase, decrease, or same</i></p>				
	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="padding: 5px;">Predicted</td> <td style="padding: 5px;">Measured</td> </tr> </table>	Predicted	Measured	
Predicted	Measured			
I_{total}	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="padding: 0 10px;">as frequency increases</td> </tr> </table>			as frequency increases
		as frequency increases		
I_{total}	<table style="margin-left: auto; margin-right: auto;"> <tr> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="border: 1px solid black; width: 80px; height: 25px;"></td> <td style="padding: 0 10px;">as frequency decreases</td> </tr> </table>			as frequency decreases
		as frequency decreases		

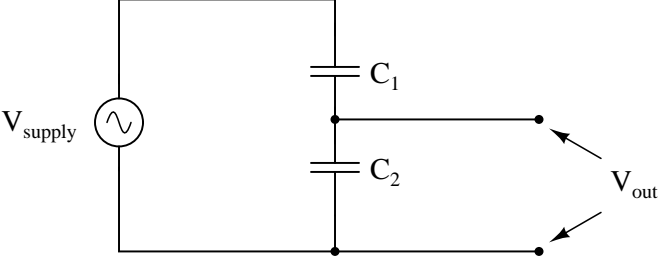
file 01617

Competency: Measuring capacitance by AC reactance	Version:
Schematic	
	
Given conditions	
$V_{\text{signal}} =$	
Parameters	
Measured	Calculated
I_C <input style="width: 80px; height: 25px;" type="text"/> at f =	$\rightarrow C_x$ <input style="width: 80px; height: 25px;" type="text"/>
I_C <input style="width: 80px; height: 25px;" type="text"/> at f =	$\rightarrow C_x$ <input style="width: 80px; height: 25px;" type="text"/>
I_C <input style="width: 80px; height: 25px;" type="text"/> at f =	$\rightarrow C_x$ <input style="width: 80px; height: 25px;" type="text"/>
C_x <input style="width: 80px; height: 25px;" type="text"/> (With C meter)	C_x <input style="width: 80px; height: 25px;" type="text"/> (Average)

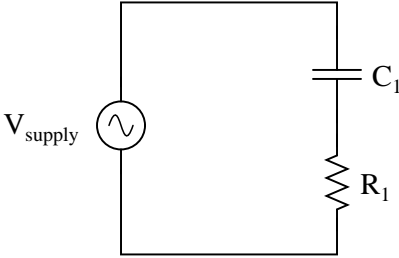
file 01920

Competency: Series AC capacitive reactances	Version:	
Schematic		
		
Given conditions		
$V_{\text{supply}} =$	$C_1 =$	$C_2 =$
$f_{\text{supply}} =$		
Parameters		
X_{C1} Predicted	X_{C2} Predicted	X_{total} Predicted
<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
I_{total} Predicted	Measured	Derived ($X = V/I$)
<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>	X_{total} <input style="width: 100px; height: 20px;" type="text"/>
Analysis		
Do series capacitive reactances <i>add</i> or <i>diminish</i> ?		
Fault analysis		
Suppose component <input style="width: 50px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____		
<input type="checkbox"/> shorted		
<i>What will happen in the circuit?</i>		

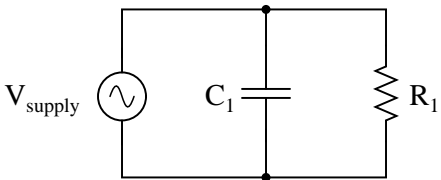
file 01656

Competency: Capacitive AC voltage divider	Version:	
Schematic		
		
Given conditions		
$V_{\text{supply}} =$	$C_1 =$	$C_2 =$
$f_{\text{supply}} =$		
Parameters		
V_{out}	Predicted	Measured
<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>	at specified frequency
<i>Qualitative answers only: Increase, decrease, or same</i>		
V_{out}	Predicted	Measured
<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>	as frequency increases
V_{out}	Predicted	Measured
<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>	as frequency decreases

[file 01662](#)

Competency: Series RC circuit	Version:								
Schematic									
									
Given conditions									
$V_{\text{supply}} =$	$C_1 =$								
$f_{\text{supply}} =$	$R_1 =$								
Parameters									
	<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%; text-align: center;">Predicted</th> <th style="width: 50%; text-align: center;">Measured</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">V_{C1} <input style="width: 80%;" type="text"/></td> <td style="padding: 5px;"><input style="width: 80%;" type="text"/></td> </tr> <tr> <td style="padding: 5px;">V_{R1} <input style="width: 80%;" type="text"/></td> <td style="padding: 5px;"><input style="width: 80%;" type="text"/></td> </tr> <tr> <td style="padding: 5px;">I_{total} <input style="width: 80%;" type="text"/></td> <td style="padding: 5px;"><input style="width: 80%;" type="text"/></td> </tr> </tbody> </table>	Predicted	Measured	V_{C1} <input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>	V_{R1} <input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>	I_{total} <input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>
Predicted	Measured								
V_{C1} <input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>								
V_{R1} <input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>								
I_{total} <input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>								
Calculations									
Fault analysis									
Suppose component <input style="width: 50px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted <i>What will happen in the circuit?</i>									

file 01664

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: 10%;"></th> <th style="width: 45%; text-align: center;">Predicted</th> <th style="width: 45%; text-align: center;">Measured</th> </tr> </thead> <tbody> <tr> <td style="text-align: right;">I_{C1}</td> <td style="border: 1px solid black; width: 45%; height: 25px;"></td> <td style="border: 1px solid black; width: 45%; height: 25px;"></td> </tr> <tr> <td style="text-align: right;">I_{R1}</td> <td style="border: 1px solid black; width: 45%; height: 25px;"></td> <td style="border: 1px solid black; width: 45%; height: 25px;"></td> </tr> <tr> <td style="text-align: right;">I_{total}</td> <td style="border: 1px solid black; width: 45%; height: 25px;"></td> <td style="border: 1px solid black; width: 45%; height: 25px;"></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 <input style="width: 40px; height: 20px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted</p> <p><i>What will happen in the circuit?</i></p>													

file 01817

Competency: **Time-domain phase shift measurement**
Version:

Schematic

Given conditions

$f_{\text{supply}} =$ $C_1 =$ $R_1 =$

Parameters

Predicted

θ

Measured

Shift (divisions)

Period (divisions)

θ

Dual oscilloscope trace

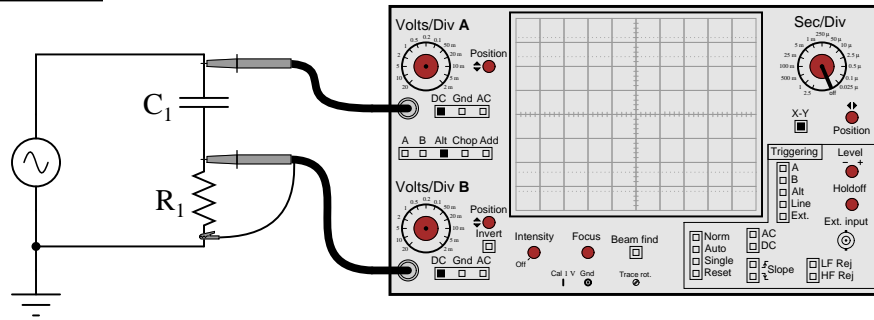
\rightarrow | | \leftarrow Period

\rightarrow | | \leftarrow Shift

file 01688

Competency: **Lissajous figures for phase shift measurement** Version:

Schematic



Given conditions

$f_{\text{supply}} =$ $C_1 =$ $R_1 =$

Parameters

Predicted

θ

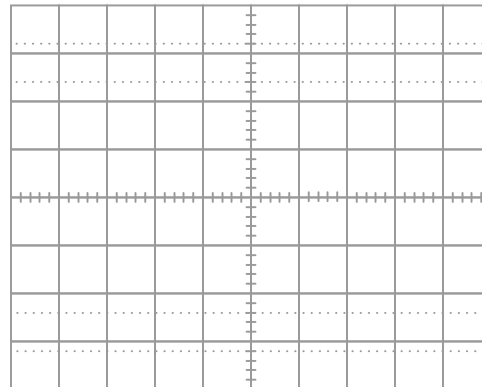
Measured

n (Divisions)

m (Divisions)

θ

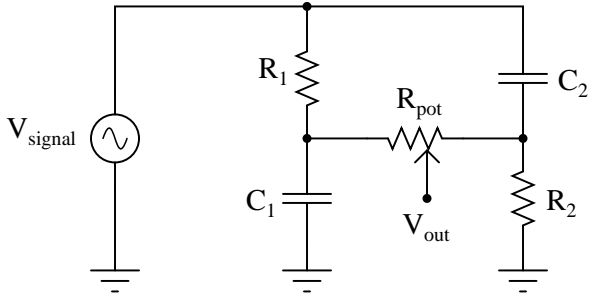
Lissajous figure (measured)



file 01676

Competency: Phase shift circuit	Version:
Description	
Build an RC circuit to produce the specified phase shift from input to output, and measure this shift with an oscilloscope.	
Given conditions	
$\theta =$	Leading <input type="checkbox"/>
	<i>(instructor checks one)</i>
$f_{\text{supply}} =$	Lagging <input type="checkbox"/>
Schematic	
Parameters	
Shift (divisions) <input style="width: 100px;" type="text"/>	Measured
Period (divisions) <input style="width: 100px;" type="text"/>	Dual oscilloscope trace
θ <input style="width: 100px;" type="text"/>	
	Predicted
	C_1 <input style="width: 100px;" type="text"/>
	R_1 <input style="width: 100px;" type="text"/>

file 02170

Competency: Variable phase shift bridge circuit		Version:				
Schematic						
						
Given conditions						
$V_{\text{signal}} =$ $f_{\text{signal}} =$	$R_1 = R_2 =$ $C_1 = C_2 =$ $R_{\text{pot}} =$	<p style="text-align: center;"><i>Recommendations</i></p> $R \approx \frac{1}{2\pi f C}$ $R_{\text{pot}} \gg R_1, R_2$				
Parameters						
$\theta_{V_{\text{out}}}$	<table border="1" style="margin: auto;"> <tr> <th style="padding: 2px;">Predicted</th> <th style="padding: 2px;">Measured</th> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> </table>	Predicted	Measured			<i>Potentiometer at full-left position</i>
Predicted	Measured					
$\theta_{V_{\text{out}}}$	<table border="1" style="margin: auto;"> <tr> <th style="padding: 2px;">Predicted</th> <th style="padding: 2px;">Measured</th> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> </table>	Predicted	Measured			<i>Potentiometer at full-right position</i>
Predicted	Measured					
V_{out}	<table border="1" style="margin: auto;"> <tr> <th style="padding: 2px;">Predicted</th> <th style="padding: 2px;">Measured</th> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> </table>	Predicted	Measured			<i>Potentiometer at full-left position</i>
Predicted	Measured					
V_{out}	<table border="1" style="margin: auto;"> <tr> <th style="padding: 2px;">Predicted</th> <th style="padding: 2px;">Measured</th> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> </table>	Predicted	Measured			<i>Potentiometer at full-right position</i>
Predicted	Measured					

file 03468

Competency: **Differential voltage measurement** Version:

Schematic

Given conditions

$V_{\text{supply}} =$ $R_1 =$ $R_2 =$ $R_3 =$

Parameters

	Predicted	Measured
V_{R2}	<input type="text"/>	<input type="text"/>

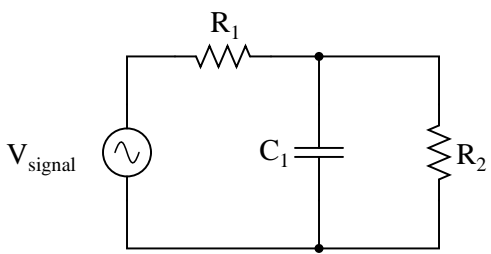
Fault analysis

Suppose component fails open other _____
 shorted

What will happen in the circuit?

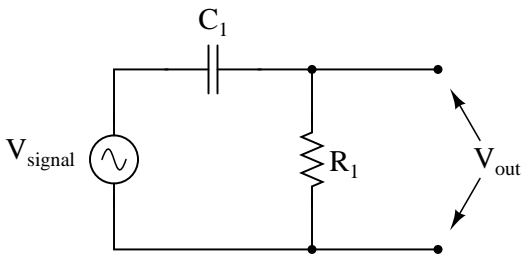
Competency: Measuring decibels	Version:			
Schematic				
Given conditions				
$V_{\text{supply}} = 1 \text{ volt RMS}$ $\phantom{V_{\text{supply}}} = 0 \text{ dBV}$				
Parameters				
V_A	Measured (V) <input style="width: 100px; height: 20px;" type="text"/>	Measured (dBV) <input style="width: 100px; height: 20px;" type="text"/>	<i>(Establishing reference voltage)</i>	
V_B	Predicted (V) <input style="width: 100px; height: 20px;" type="text"/>	Predicted (dBV) <input style="width: 100px; height: 20px;" type="text"/>	Measured (V) <input style="width: 100px; height: 20px;" type="text"/>	Measured (dBV) <input style="width: 100px; height: 20px;" type="text"/>
V_C	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
V_D	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
V_E	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>

file 03456

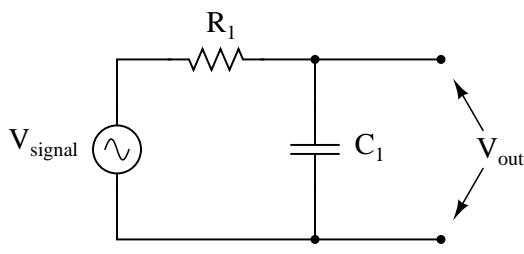
Competency: Series-parallel RC circuit	Version:		
Schematic			
			
Given conditions			
$V_{\text{signal}} =$	$C_1 =$	$R_1 =$	$R_2 =$
$f_{\text{signal}} =$			
Parameters			
	Predicted	Measured	
V_{R1}			
I_{C1}			
I_{R2}			
I_{total}			
Fault analysis			
Suppose component fails <input type="checkbox"/> open <input type="checkbox"/> other _____			
<input type="checkbox"/> shorted <i>What will happen in the circuit?</i>			

file 01659

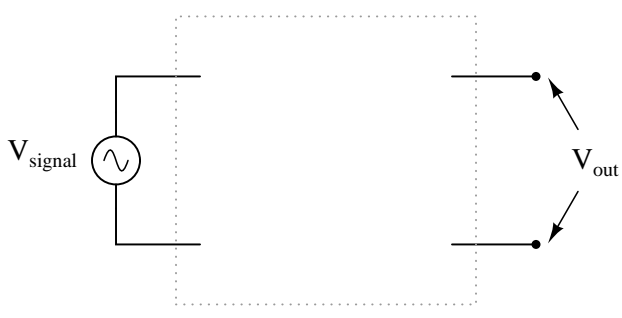
Competency: Series-parallel RC circuit	Version:	
Schematic		
Given conditions		
$V_{\text{signal}} =$	$R_1 =$	$R_2 =$
$f_{\text{signal}} =$	$C_1 =$	$C_2 =$
Parameters		
	Predicted	Measured
V_{R1}	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
V_{R2}	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
V_{C2}	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
I_{C1}	<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"/>
Fault analysis		
Suppose component <input style="width: 40px; height: 20px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted What will happen in the circuit?		

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: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
$f_{-3\text{dB}}$	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
$\theta_{-3\text{dB}}$	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
Calculations		
Fault analysis		
Suppose component <input style="width: 50px; height: 20px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted <i>What will happen in the circuit?</i>		

file 01613

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: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
$f_{-3\text{dB}}$	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
$\theta_{-3\text{dB}}$	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
Calculations		
Fault analysis		
Suppose component <input style="width: 50px; height: 20px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted <i>What will happen in the circuit?</i>		

file 01614

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	
	

file 02095

Competency: Passive twin-tee filter circuit		Version:
Schematic		
Given conditions		
$V_{\text{signal}} =$	$C_1 =$	$R_1 =$
	$C_2 =$	$R_2 =$
	$C_3 =$	$R_3 =$
Parameters		
Filter type (hp, lp, bp, bs)	Predicted <input style="width: 100px; height: 20px;" type="text"/>	Measured <input style="width: 100px; height: 20px;" type="text"/>
f_{center}	<input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
Fault analysis		
Suppose component <input style="width: 50px; height: 20px;" type="text"/> fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted What will happen in the circuit?		

file 02580

Competency: Series resonance	Version:						
Schematic							
Given conditions							
$R_1 =$	$C_1 =$	$L_1 =$					
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 style="padding: 5px;">f_{resonant}</td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> <td style="border: 1px solid black; width: 60px; height: 25px;"></td> </tr> </tbody> </table>		Predicted	Measured	f_{resonant}			
	Predicted	Measured					
f_{resonant}							
Calculations							
<p>Fault analysis</p> <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>							

file 01690

Competency: **Dampened resonant oscillations** Version:

Schematic

Given conditions

$L_1 =$ $C_1 =$

Parameters

	Predicted	Measured
f	<input type="text"/>	<input type="text"/>

Typical waveform

Captured waveform

file 01689

Competency: Measuring inductance by series resonance Version:	
Schematic	
Given conditions	
$R_1 =$	$C_1 =$
Parameters	
f_{resonant}	Measured <input style="width: 100px; height: 20px;" type="text"/>
Inferred from f_{resonant}	Measured with LCR meter
L_x <input style="width: 100px; height: 20px;" type="text"/>	<input style="width: 100px; height: 20px;" type="text"/>
Calculations	

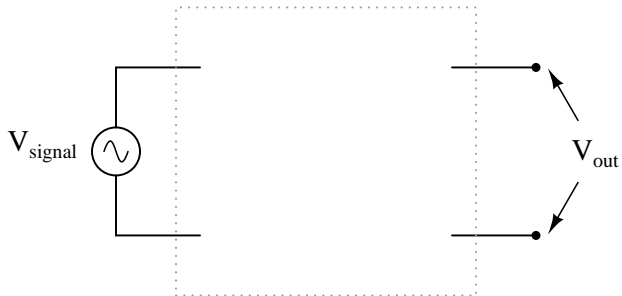
file 01691

Competency: Passive resonant filter circuit	Version:		
Schematic			
Given conditions			
$V_{\text{signal}} =$	$C_1 =$	$L_1 =$	$R_{\text{load}} =$
Parameters			
	Predicted	Measured	
Filter type (hp, lp, bp, bs)	<input style="width: 80px; height: 20px;" type="text"/>	<input style="width: 80px; height: 20px;" type="text"/>	
f_{resonant}	<input style="width: 80px; height: 20px;" type="text"/>	<input style="width: 80px; height: 20px;" type="text"/>	
θ_{resonant}	<input style="width: 80px; height: 20px;" type="text"/>	<input style="width: 80px; height: 20px;" type="text"/>	
Calculations			
Fault analysis			
Suppose component <input style="width: 40px; height: 20px;" type="text"/> fails		<input type="checkbox"/> open	<input type="checkbox"/> other _____
<i>What will happen in the circuit?</i>		<input type="checkbox"/> shorted	

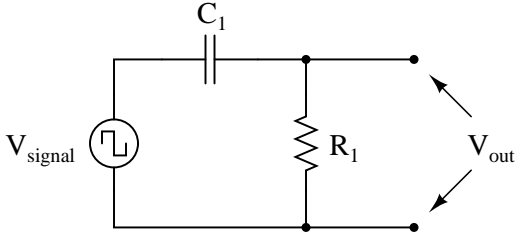
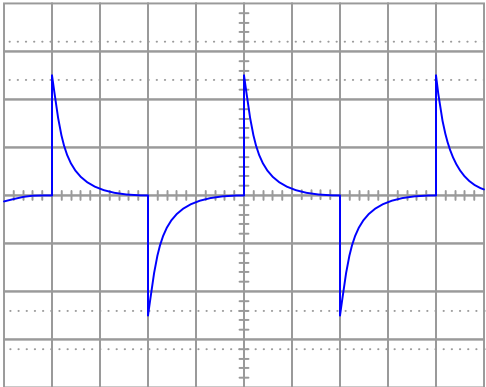
file 01615

Competency: Passive resonant filter circuit	Version:								
Schematic									
Given conditions									
$V_{\text{signal}} =$	$C_1 =$								
$L_1 =$	$R_{\text{load}} =$								
Parameters									
	<table border="1" style="margin: auto; border-collapse: collapse;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;"> <table style="border: none;"> <tr> <td style="padding: 5px;">Filter type (hp, lp, bp, bs)</td> <td style="border: 1px solid black; width: 80px; height: 20px;"></td> </tr> <tr> <td style="padding: 5px;">f_{resonant}</td> <td style="border: 1px solid black; width: 80px; height: 20px;"></td> </tr> </table> </td> <td style="border: 1px solid black; width: 80px; height: 20px;"></td> </tr> </tbody> </table>	Predicted	Measured	<table style="border: none;"> <tr> <td style="padding: 5px;">Filter type (hp, lp, bp, bs)</td> <td style="border: 1px solid black; width: 80px; height: 20px;"></td> </tr> <tr> <td style="padding: 5px;">f_{resonant}</td> <td style="border: 1px solid black; width: 80px; height: 20px;"></td> </tr> </table>	Filter type (hp, lp, bp, bs)		f_{resonant}		
Predicted	Measured								
<table style="border: none;"> <tr> <td style="padding: 5px;">Filter type (hp, lp, bp, bs)</td> <td style="border: 1px solid black; width: 80px; height: 20px;"></td> </tr> <tr> <td style="padding: 5px;">f_{resonant}</td> <td style="border: 1px solid black; width: 80px; height: 20px;"></td> </tr> </table>	Filter type (hp, lp, bp, bs)		f_{resonant}						
Filter type (hp, lp, bp, bs)									
f_{resonant}									
Calculations									
Fault analysis									
<p>Suppose component <input style="width: 40px; height: 20px;" type="text"/> 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>									

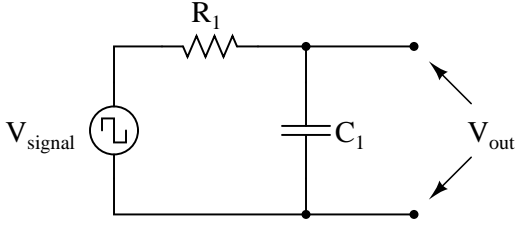
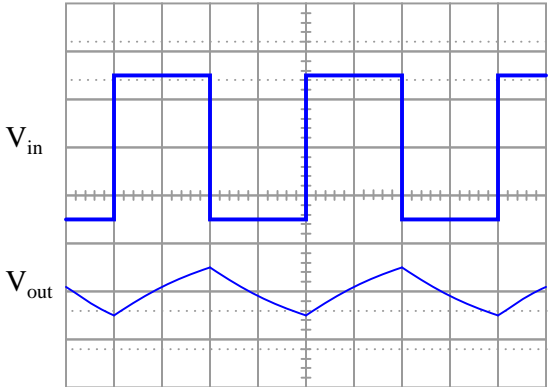
file 01658

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	
	

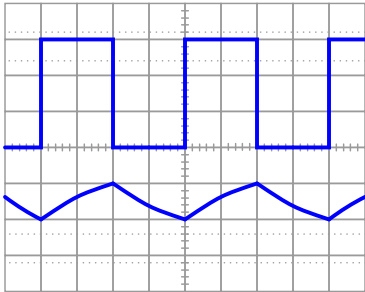
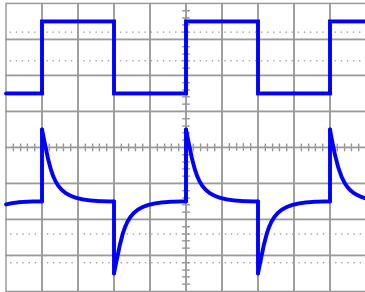
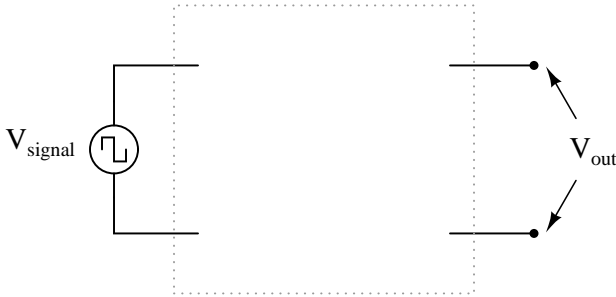
file 02097

Competency: Passive differentiator circuit	Version:
Schematic	
	
Given conditions	
$f_{\text{signal}} =$	Required V_{out} waveshape 
Parameters	
<p style="text-align: center;">Predicted</p> <p>C_1 <input style="width: 100px; height: 25px;" type="text"/></p> <p>R_1 <input style="width: 100px; height: 25px;" type="text"/></p>	
Fault analysis	
<p>Suppose component <input style="width: 50px; height: 25px;" type="text"/> 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>	

file 01686

Competency: Passive integrator circuit	Version:
Schematic	
	
Given conditions	Required waveshapes
$f_{\text{signal}} =$	
Parameters	
<p style="text-align: center;">Predicted</p> <p>C_1 <input style="width: 100px; height: 25px;" type="text"/></p> <p>R_1 <input style="width: 100px; height: 25px;" type="text"/></p>	
Fault analysis	
<p>Suppose component <input style="width: 50px; height: 25px;" type="text"/> 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>	

file 01687

Competency: Passive integrator/differentiator circuit Version:	
Description	
Build either a passive integrator or a passive differentiator circuit to produce the desired waveforms given a square-wave input.	
Given conditions	
$f_{\text{signal}} =$	
Integrator <input type="checkbox"/>	Differentiator <input type="checkbox"/>
(instructor checks one)	
	
$V_{\text{out}} = \frac{1}{3}V_{\text{in}}$	5τ in each pulse width
Schematic	
	
Parameters	
Predicted	
C_1	<input style="width: 100px; height: 20px;" type="text"/>
R_1	<input style="width: 100px; height: 20px;" type="text"/>

Competency: Tone balance control circuit	Version:																																																																																	
Schematic																																																																																		
Given conditions																																																																																		
$L_1 =$	$C_1 =$	$R_{pot1} = R_{pot2} =$																																																																																
$R_1 = R_2 =$		$Z_{headphones} =$																																																																																
(Use audio source for signal, voltage adjusted for ample volume)																																																																																		
Parameters																																																																																		
	Predicted	Measured																																																																																
Bass control	<input style="width: 80px; height: 30px;" type="text"/>	<input style="width: 80px; height: 30px;" type="text"/>																																																																																
Treble control	<input style="width: 80px; height: 30px;" type="text"/>	<input style="width: 80px; height: 30px;" type="text"/>																																																																																
(Identify which pot is which)																																																																																		
Frequency response (maximum bass, minimum treble)		Frequency response (minimum bass, maximum treble)																																																																																
V_{out}	<table border="1" style="width: 100%; height: 100%; border-collapse: collapse;"> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> </table>																																									<table border="1" style="width: 100%; height: 100%; border-collapse: collapse;"> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td><td> </td></tr> </table>																																								
	f	f																																																																																

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

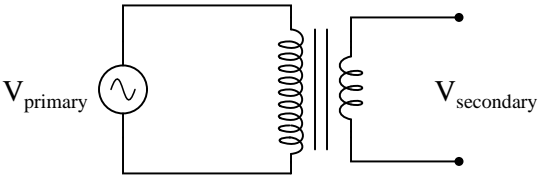
Competency: Tone balance control circuit		Version:																																																																																																				
Schematic																																																																																																						
Given conditions																																																																																																						
$L_1 =$	$C_1 =$	$R_{pot1} = R_{pot2} =$																																																																																																				
$R_1 = R_2 =$	$Z_{speaker} =$	$T_1 =$																																																																																																				
(Use audio source for signal, voltage adjusted for ample volume)																																																																																																						
Parameters																																																																																																						
	Predicted	Measured																																																																																																				
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(Identify which pot is which)																																																																																																						
Frequency response (maximum bass, minimum treble)		Frequency response (minimum bass, maximum treble)																																																																																																				
V_{out}	<table border="1" style="width: 100%; height: 100%; border-collapse: collapse;"> <tr><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td></tr> <tr><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td></tr> <tr><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td></tr> <tr><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td></tr> <tr><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td></tr> </table>																																																			<table border="1" style="width: 100%; height: 100%; border-collapse: collapse;"> <tr><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td></tr> <tr><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td></tr> <tr><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td></tr> <tr><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td></tr> <tr><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td><td style="width: 20px; height: 20px;"></td></tr> </table>																																																		
	f	f																																																																																																				

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

Competency: Noise coupling and decoupling	Version:								
Schematic									
Given conditions									
$C_{\text{decoupling}} =$	Cable length =								
Parameters									
<i>Predicted values are qualitative only (least, greatest, little bit less than . . .)</i>									
$V_{\text{noise (1b-2b)}}$	<table border="1" style="display: inline-table; border-collapse: collapse;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> </tbody> </table>	Predicted	Measured						
Predicted	Measured								
$V_{\text{noise (2b-3b)}}$	<table border="1" style="display: inline-table; border-collapse: collapse;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> </tbody> </table>	Predicted	Measured						
Predicted	Measured								
$V_{\text{noise (3b-4b)}}$	<table border="1" style="display: inline-table; border-collapse: collapse;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> </tbody> </table>	Predicted	Measured						
Predicted	Measured								
} Without $C_{\text{decoupling}}$									
$V_{\text{noise (1b-2b)}}$	<table border="1" style="display: inline-table; border-collapse: collapse;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> </tbody> </table>	Predicted	Measured						
Predicted	Measured								
$V_{\text{noise (2b-3b)}}$	<table border="1" style="display: inline-table; border-collapse: collapse;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> </tbody> </table>	Predicted	Measured						
Predicted	Measured								
$V_{\text{noise (3b-4b)}}$	<table border="1" style="display: inline-table; border-collapse: collapse;"> <thead> <tr> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> <tr> <td style="width: 60px; height: 25px;"></td> <td style="width: 60px; height: 25px;"></td> </tr> </tbody> </table>	Predicted	Measured						
Predicted	Measured								
} With $C_{\text{decoupling}}$ connected across test points									

file 01692

Competency: Transformer voltage ratio	Version:	
Schematic		
		
Given conditions		
Transformer winding (turns) ratio =		
$V_{\text{primary}} =$		
$f =$		
Parameters		
	Predicted	Measured
V_{sec}	<input type="text"/>	<input type="text"/>
Calculations		

file 03655

Competency: **Transformer voltage/current ratios** Version:

Schematic

There must be no exposed line power conductors!

Given conditions

Transformer step-down ratio =
 $V_{\text{line}} =$
 $R_{\text{load}} =$

Parameters

Procedure for ensuring no shock hazard when connecting meter:

Description (written by student)		Observed (written by instructor)	

	Predicted	Measured		Predicted	Measured
V_{pri}	<input style="width: 80%; height: 20px;" type="text"/>	<input style="width: 80%; height: 20px;" type="text"/>	V_{sec}	<input style="width: 80%; height: 20px;" type="text"/>	<input style="width: 80%; height: 20px;" type="text"/>
I_{pri}	<input style="width: 80%; height: 20px;" type="text"/>	<input style="width: 80%; height: 20px;" type="text"/>	I_{sec}	<input style="width: 80%; height: 20px;" type="text"/>	<input style="width: 80%; height: 20px;" type="text"/>

file 01675

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;">Terminal block connections 1000:8 Ω</p>																			
Given conditions																			
<p>Transformer winding (turns) ratio =</p> <p>$V_{source} =$ $R_{load} =$</p> <p>$f_{source} =$</p>																			
Parameters																			
<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 20%;">Predicted</th> <th style="width: 20%;">Measured</th> <th style="width: 15%;"></th> <th style="width: 20%;">Predicted</th> <th style="width: 20%;">Measured</th> </tr> </thead> <tbody> <tr> <td style="text-align: right;">V_{pri}</td> <td><input style="width: 80%;" type="text"/></td> <td><input style="width: 80%;" type="text"/></td> <td style="text-align: right;">V_{sec}</td> <td><input style="width: 80%;" type="text"/></td> <td><input style="width: 80%;" type="text"/></td> </tr> <tr> <td style="text-align: right;">I_{pri}</td> <td><input style="width: 80%;" type="text"/></td> <td><input style="width: 80%;" type="text"/></td> <td style="text-align: right;">I_{sec}</td> <td><input style="width: 80%;" type="text"/></td> <td><input style="width: 80%;" type="text"/></td> </tr> </tbody> </table>			Predicted	Measured		Predicted	Measured	V_{pri}	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>	V_{sec}	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>	I_{pri}	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>	I_{sec}	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>
	Predicted	Measured		Predicted	Measured														
V_{pri}	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>	V_{sec}	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>														
I_{pri}	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>	I_{sec}	<input style="width: 80%;" type="text"/>	<input style="width: 80%;" type="text"/>														
Calculations																			

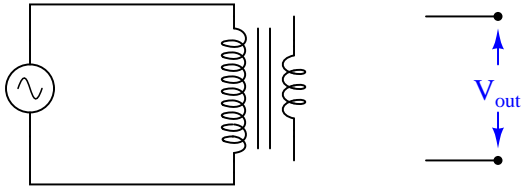
file 02122

Competency: Auto-transformers	Version:												
Description													
Connect a step-down power transformer in the "buck" auto-transformer configuration, and use it to power a low-resistance load. <i>There must be no exposed line power conductors!</i>													
Given conditions													
$V_{\text{supply}} =$	$R_{\text{load}} =$ Transformer step-down ratio =												
Parameters													
	<table><thead><tr><th></th><th>Predicted</th><th>Measured</th></tr></thead><tbody><tr><td>I_{supply}</td><td><input type="text"/></td><td><input type="text"/></td></tr><tr><td>V_{load}</td><td><input type="text"/></td><td><input type="text"/></td></tr><tr><td>I_{load}</td><td><input type="text"/></td><td><input type="text"/></td></tr></tbody></table>		Predicted	Measured	I_{supply}	<input type="text"/>	<input type="text"/>	V_{load}	<input type="text"/>	<input type="text"/>	I_{load}	<input type="text"/>	<input type="text"/>
	Predicted	Measured											
I_{supply}	<input type="text"/>	<input type="text"/>											
V_{load}	<input type="text"/>	<input type="text"/>											
I_{load}	<input type="text"/>	<input type="text"/>											

file 01611

Competency: Auto-transformers	Version:												
Description													
Connect a step-down power transformer in the "boost" auto-transformer configuration, and use it to power a low-resistance load. <i>There must be no exposed line power conductors!</i>													
Given conditions													
$V_{\text{supply}} =$	$R_{\text{load}} =$ Transformer step-down ratio =												
Parameters													
	<table><thead><tr><th></th><th>Predicted</th><th>Measured</th></tr></thead><tbody><tr><td>I_{supply}</td><td><input type="text"/></td><td><input type="text"/></td></tr><tr><td>V_{load}</td><td><input type="text"/></td><td><input type="text"/></td></tr><tr><td>I_{load}</td><td><input type="text"/></td><td><input type="text"/></td></tr></tbody></table>		Predicted	Measured	I_{supply}	<input type="text"/>	<input type="text"/>	V_{load}	<input type="text"/>	<input type="text"/>	I_{load}	<input type="text"/>	<input type="text"/>
	Predicted	Measured											
I_{supply}	<input type="text"/>	<input type="text"/>											
V_{load}	<input type="text"/>	<input type="text"/>											
I_{load}	<input type="text"/>	<input type="text"/>											

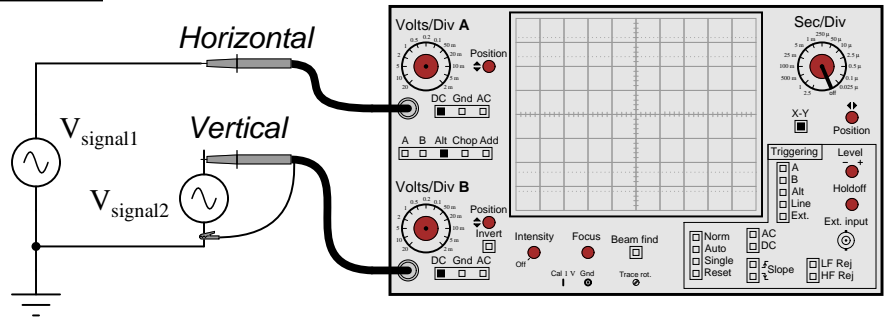
file 01612

Competency: Auto-transformers	Version:						
<div data-bbox="310 212 472 254" style="border: 1px solid black; padding: 2px;">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 data-bbox="310 495 542 537" style="border: 1px solid black; padding: 2px;">Given conditions</div> <p style="text-align: center;">$V_{\text{supply}} =$</p> <p style="text-align: center;">Transformer step-down ratio =</p> <div style="display: flex; justify-content: space-around;"> <div data-bbox="927 554 1073 611">Boost <input type="checkbox"/></div> <div data-bbox="927 646 1073 703">Buck <input type="checkbox"/></div> </div>							
<div data-bbox="310 779 477 821" style="border: 1px solid black; padding: 2px;">Schematic</div> <div style="text-align: center;">  </div> <p style="text-align: center;">(Be sure to note the transformer's polarity using dot convention)</p>							
<div data-bbox="310 1163 488 1205" style="border: 1px solid black; padding: 2px;">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="text-align: center;"><input style="width: 80%; height: 20px;" type="text"/></td> <td style="text-align: center;"><input style="width: 80%; height: 20px;" type="text"/></td> </tr> </tbody> </table>			Predicted	Measured	V_{output}	<input style="width: 80%; height: 20px;" type="text"/>	<input style="width: 80%; height: 20px;" type="text"/>
	Predicted	Measured					
V_{output}	<input style="width: 80%; height: 20px;" type="text"/>	<input style="width: 80%; height: 20px;" type="text"/>					

file 02131

Competency: **Lissajous figures for frequency ratio measurement** Version:

Schematic

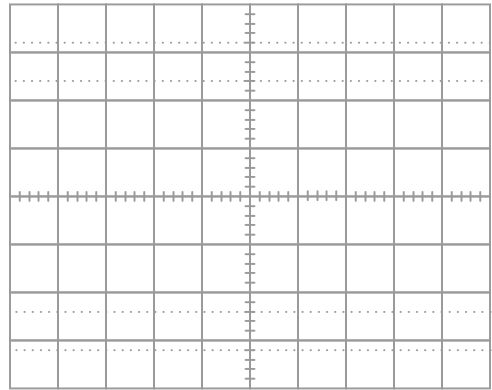


Given conditions

(Voltage specified by instructor, frequencies set by student)

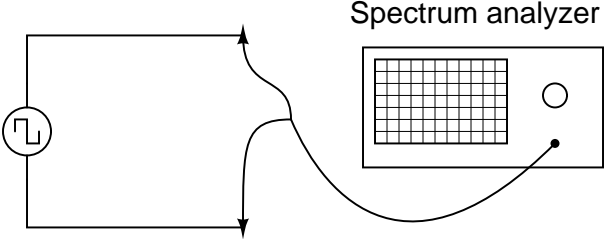
V_{signal1} and $V_{\text{signal2}} =$

Lissajous figure

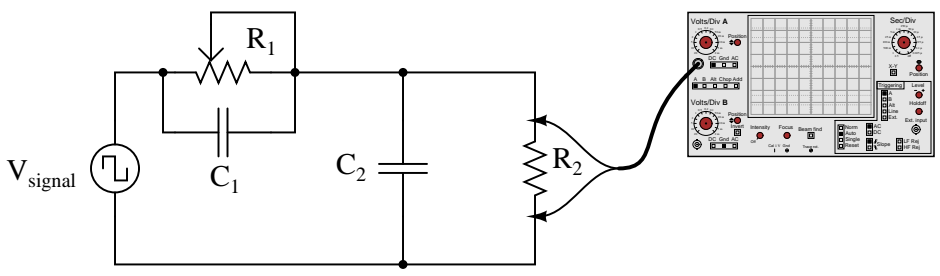


Parameters

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

Competency: Fourier analysis of a square wave	Version:	
Schematic		
		
Given conditions		
$V_{\text{supply}} =$	Duty cycle = 50%	
$f_{\text{fundamental}} =$		
Parameters		
	Predicted	Measured
1st "overtone" amplitude	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
1st "overtone" frequency	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
2nd "overtone" amplitude	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
2nd "overtone" frequency	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
3rd "overtone" amplitude	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>
3rd "overtone" frequency	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>

[file 01684](#)

Competency: Balanced attenuator circuit	Version:						
Schematic							
							
Given conditions							
$V_{\text{signal}} =$	$R_2 =$						
$f_{\text{signal}} =$	$C_1 =$						
	$C_2 =$						
Parameters							
<table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th style="padding: 5px;"></th> <th style="padding: 5px;">Predicted</th> <th style="padding: 5px;">Measured</th> </tr> </thead> <tbody> <tr> <td style="padding: 10px; text-align: center;">R_1</td> <td style="width: 60px; height: 20px;"></td> <td style="width: 60px; height: 20px;"></td> </tr> </tbody> </table>		Predicted	Measured	R_1			
	Predicted	Measured					
R_1							
(necessary to achieve undistorted square-wave output)							
Fault analysis							
Suppose component fails <input type="checkbox"/> open <input type="checkbox"/> other _____ <input type="checkbox"/> shorted What will happen in the circuit?							

file 01661

Competency: **Power factor correction for AC motor** Version:

Schematic

Given conditions

Volts/div =

Sec/div =

$R_{shunt} =$

Voltage/current display on scope

Parameters

	(Without C_1) Measured	(With C_1 connected) Measured
θ	<input type="text"/>	<input type="text"/>
I_{total}	<input type="text"/>	<input type="text"/>
Predicted		
C_1	<input type="text"/> To correct P.F. to a value of unity	

Competency: Characteristic cable impedance		Version:	
Schematic			
<p style="text-align: center;"><i>← Long length of cable →</i></p>			
Given conditions			
$f_{\text{supply}} =$	$R_1 =$	$R_{\text{pot(max)}} =$	
Velocity factor =			
Parameters			
	Predicted	Measured	Measured
Length of cable	<input style="width: 80px; height: 25px;" type="text"/>	<input style="width: 80px; height: 25px;" type="text"/>	Z_0 <input style="width: 80px; height: 25px;" 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

(Template)

Competency:	Version:
Schematic	
Given conditions	
Parameters	
Predicted	Measured
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>

file 01602

Answers

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.

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.

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.

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.

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.

Answer 6

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

Answer 7

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

Answer 8

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

Answer 9

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

Answer 10

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

Answer 11

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

Answer 12

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

Answer 13

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

Answer 14

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

Answer 15

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

Answer 16

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

Answer 17

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

Answer 18

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

Answer 19

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

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!

Answer 21

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

Answer 22

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

Answer 23

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

Answer 24

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

Answer 25

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

Answer 26

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

Answer 27

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

Answer 28

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

Answer 29

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

Answer 30

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

Answer 31

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

Answer 32

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

Answer 33

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

Answer 34

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

Answer 35

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

Answer 36

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

Answer 37

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

Answer 38

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

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!

Answer 40

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

Answer 41

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

Answer 42

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

Answer 43

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

Answer 44

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

Answer 45

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

Answer 46

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

Answer 47

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

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.

Answer 49

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

Answer 50

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

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

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.

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!

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!

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).

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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 $0.033 \text{ }\mu\text{F}$ capacitor, and $100 \text{ }\Omega$ 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).

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.

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.

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.

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.

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.

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.

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 69.3% of the waveform's half-period. 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.

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 69.3% of the waveform's half-period. 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.

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)

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 8 Ω 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.

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.

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.

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.

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.

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.

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).

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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.

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).

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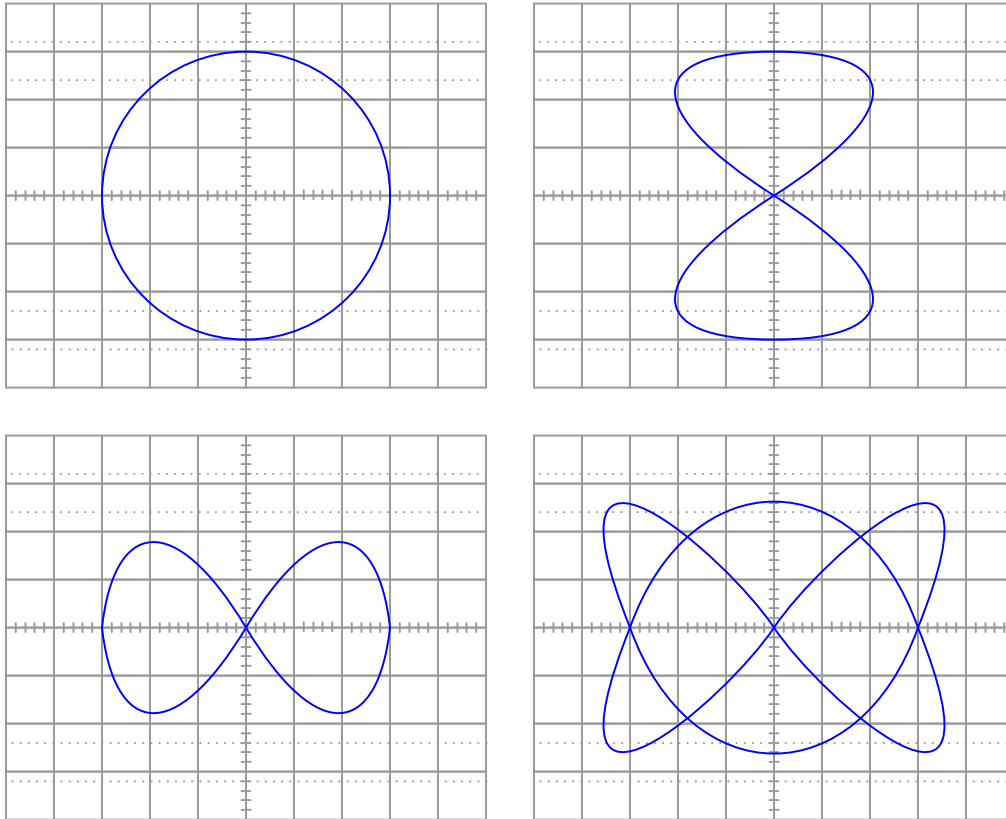
Note that there may very well be a shock hazard associated with this circuit! Be sure to take this into consideration when specifying load resistor values. You may also want to use low supply voltage levels (turn the Variac *way* down).

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.

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:



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.

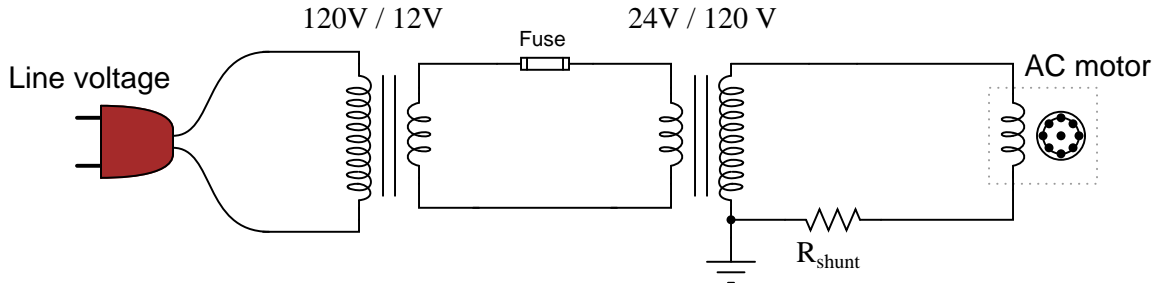
Use a square-wave function generator for the AC voltage source. I have built this circuit using resistances of approximately $4.7\text{ k}\Omega$ and capacitances of approximately $0.1\ \mu\text{F}$, and achieved good results with a square-wave (fundamental) frequency of about 300 Hz. Of course, the 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.

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.

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.

Notes 51

Any relevant notes for the assessment activity go here.