Performance-based assessments for semiconductor circuit competencies

---

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

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

This is the procedure I envision for managing such assessments:

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

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

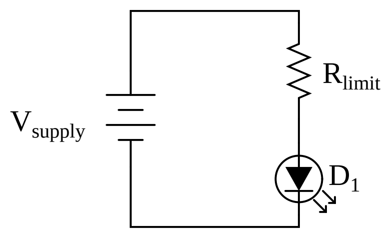
- Students cannot pass such assessments only knowing circuit theory or only having hands-on construction and testing skills – they must be proficient at both.
- Students do not receive the "authoritative answers" from the instructor. Rather, they learn to validate their answers through real circuit measurements.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

Instructors may elect to reveal the assessments before test day, and even use them as preparatory labwork and/or discussion questions. Remember that there is absolutely nothing wrong with "teaching to the test" *so long as the test is valid*. Normally, it is bad to reveal test material in detail prior to test day, lest students merely memorize responses in advance. With performance-based assessments, however, there is no way to pass without truly understanding the subject(s).

Question 1

Competency: **LED current limiting** Version:

Schematic



Given conditions

V_{supply} = $V_{forward\ (LED)}$ = $I_{forward(LED)}$ =

Parameters

	Given		Predicted	Measured
V_{supply} =		$V_{R_{limit}}$		
		V_{D1}		
		I_{D1}		

Analysis

Show how you calculated the appropriate value for R_{limit}

Draw the directions of both electron and conventional current

Fault analysis

Suppose component ☐ fails ☐ open ☐ shorted ☐ other ____________

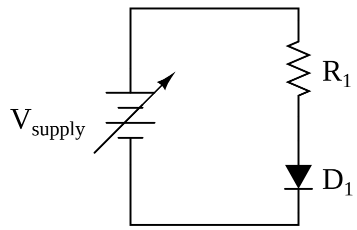
What will happen in the circuit?

file 04075

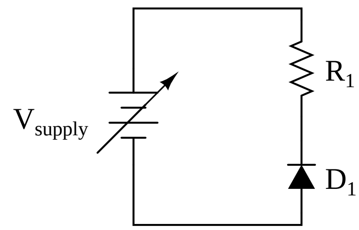
Competency: **Rectifying diode behavior** Version:

Schematic

Forward-biased



Reverse-biased



Given conditions

V_{supply} = (see multiple values given below)

R_1 =

Parameters *Forward-biased*

Given		Predicted	Measured
V_{supply} =	V_{R1}		
	V_{D1}		

Given		Predicted	Measured
V_{supply} =	V_{R1}		
	V_{D1}		

Parameters *Reverse-biased*

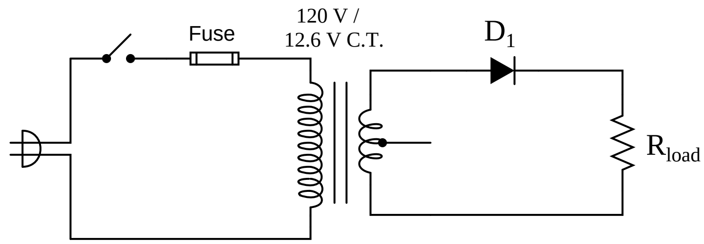
Given		Predicted	Measured
V_{supply} =	V_{R1}		
	V_{D1}		

Given		Predicted	Measured
V_{supply} =	V_{R1}		
	V_{D1}		

file 01940

Competency: **Half-wave rectifier** Version:

Schematic



Given conditions

$V_{secondary}$ = (VAC RMS) R_{load} =

Parameters

	Predicted	Measured	
$V_{load(DC)}$			(Approximate only)
V_{ripple}			
f_{ripple}			

Fault analysis

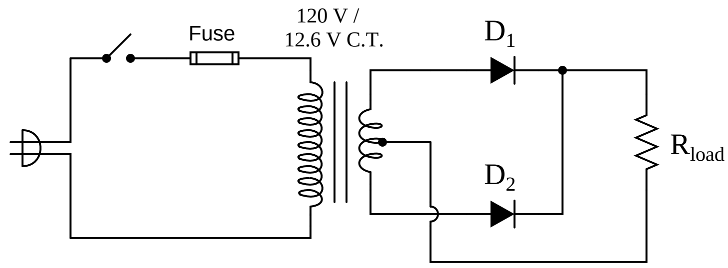
Suppose component ☐ fails ☐ open ☐ shorted ☐ other ____________

What will happen in the circuit?

file 01941

Competency: **Full-wave center-tap rectifier** Version:

Schematic



Given conditions

$V_{secondary}$ = (VAC RMS) R_{load} =

Parameters

	Predicted	Measured	
$V_{load(DC)}$			(Approximate only)
V_{ripple}			
f_{ripple}			

Fault analysis

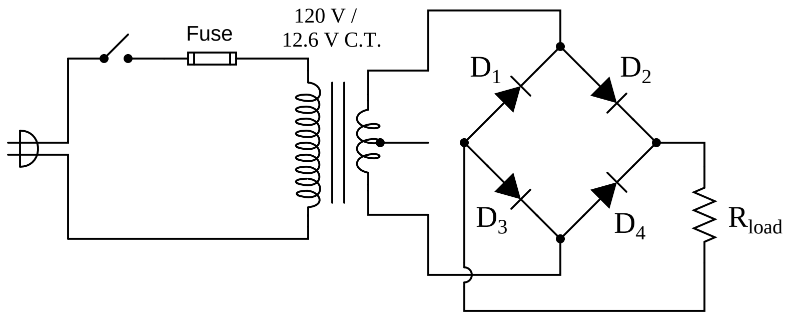
Suppose component ☐ fails ☐ open ☐ shorted ☐ other ______

What will happen in the circuit?

file 01942

Competency: **Full-wave bridge rectifier** Version:

Schematic



Given conditions

$V_{secondary}$ = (VAC RMS) R_{load} =

Parameters

	Predicted	Measured	
$V_{load(DC)}$			(Approximate only)
V_{ripple}			
f_{ripple}			

Fault analysis

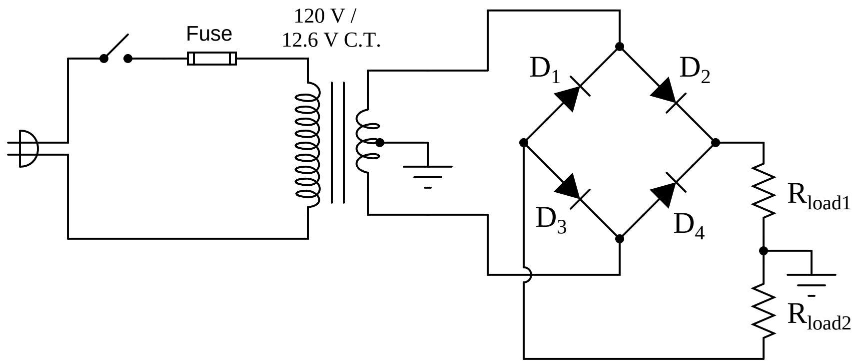
Suppose component ☐ fails ☐ open ☐ other ______ ☐ shorted

What will happen in the circuit?

file 01943

Competency: **Full-wave center-tap bridge rectifier** Version:

Schematic



Given conditions

$V_{secondary}$ = (VAC RMS) $R_{load1} = R_{load2}$ =

Parameters

	Predicted	Measured
$V_{load(DC)}$		
V_{ripple}		
f_{ripple}		

For R_{load1}

	Predicted	Measured
$V_{load(DC)}$		
V_{ripple}		
f_{ripple}		

For R_{load2}

file 01944

Competency: **Full-wave rectifier circuit** Version:

Description

Design and build a full-wave rectifier circuit of any configuration desired. It simply needs to output DC when energized by an AC source (provided by the instructor).

Given conditions

$V_{supply(AC)}$ = f_{supply} =

Schematic

Parameters

	Predicted	Measured
V_{ripple}		
f_{ripple}		

file 02296

Competency: **AC-DC power supply circuit** Version:

Description

Build a "brute force" AC-DC power supply circuit, consisting of a step-down transformer, full-wave bridge rectifier, capacitive filter, and load resistor.

Given conditions

V_{supply} = C_{filter} = R_{load} =

Schematic

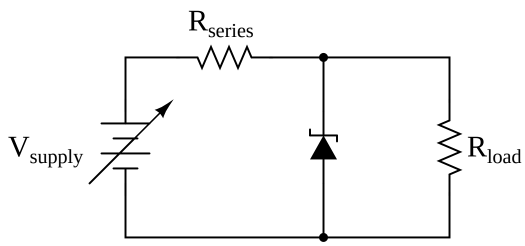
Parameters

	Predicted	Measured
$V_{out(DC)}$		
$V_{out(ripple)}$		

file 01622

Competency: **Zener diode voltage regulator** Version:

Schematic



Given conditions

R_{series} =

V_{supply} = V_{zener} =

R_{load} =

Parameters

	Predicted	Measured
V_{load} (nominal)		
V_{supply} (max)		X
V_{supply} (min)		

Fault analysis

Suppose component ______ fails ☐ open ☐ shorted ☐ other ______

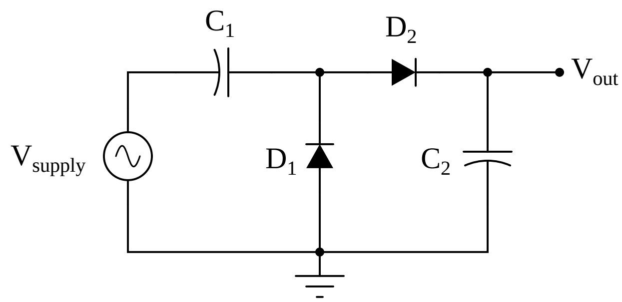
What will happen in the circuit?

The V_{supply} (min) parameter is the minimum voltage setting that V_{supply} may be adjusted to with the regulator circuit maintaining constant load voltage at R_{load}. V_{supply} (max) is the maximum voltage that V_{supply} may be adjusted to without exceeding the zener diode's power rating. V_{load} (nominal) is simply the regulated voltage output of the circuit under normal conditions.

file 01623

Competency: **Half-wave voltage doubler** Version:

Schematic



Given conditions

V_{supply} = $C_1 = C_2$ = V_F (typical) =

Parameters

	Predicted	Measured
V_{C1}		
V_{C2}		
V_{out}		

Fault analysis

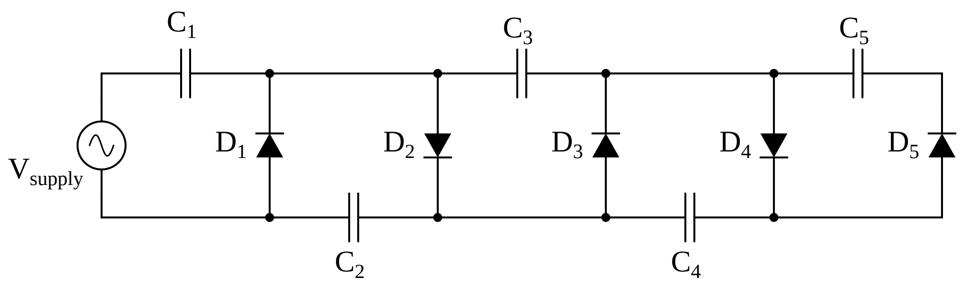
Suppose component ☐ fails ☐ open ☐ shorted ☐ other ______________

What will happen in the circuit?

file 01974

Competency: **Voltage multiplier** Version:

Schematic



Given conditions

V_{supply} =

$C_1 = C_2 = C_3 = C_4 = C_5 =$

Parameters

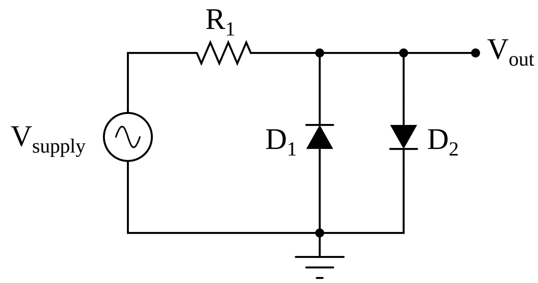
	Predicted	Measured
V_{C1}		
V_{C2}		
V_{C3}		
V_{C4}		
V_{C5}		
V_{out} (max)		

Show where to measure greatest DC output voltage

file 02012

Competency: **Diode clipper circuit** Version:

Schematic



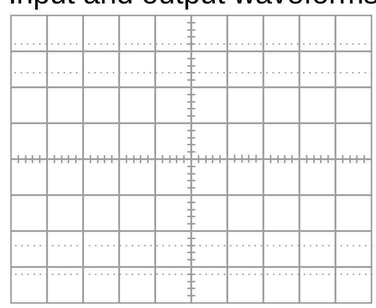
Given conditions

V_{supply} = R_1 = V_F (typical) =

Parameters

	Predicted	Measured
V_{out}		

Input and output waveforms



Fault analysis

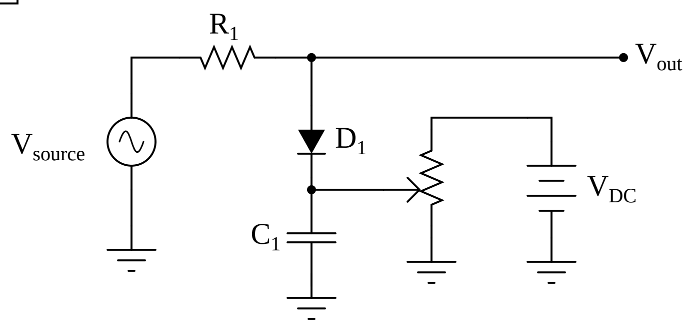
Suppose component ☐ fails ☐ open ☐ other ________ ☐ shorted

What will happen in the circuit?

file 01979

Competency: **Diode clipper circuit, adjustable** Version:

Schematic



Given conditions

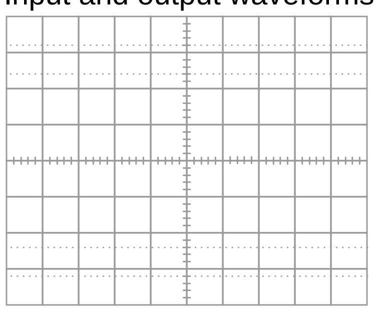
V_{source} = C_1 = R_1 = V_F (typical) =

V_{DC} =

Parameters

	Predicted	Measured	
V_{out}			(positive peak)
V_{out}			(negative peak)

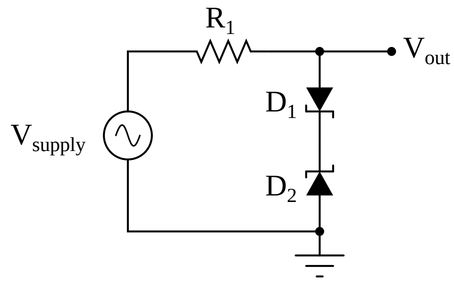
Input and output waveforms



file 01986

Competency: **Zener diode clipper circuit** Version:

Schematic



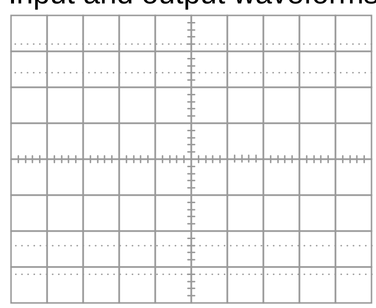
Given conditions

V_{supply} = R_1 = V_F (typical) = V_Z =

Parameters

	Predicted	Measured
V_{out}		

Input and output waveforms



Fault analysis

Suppose component [ ] fails [ ] open [ ] shorted [ ] other ____________

What will happen in the circuit?

file 01980

Competency: **BJT terminal identification** Version:

Description

Identify the terminals (emitter, base, and collector) of a bipolar junction transistor using a multimeter. Then, compare your conclusions with information from a datasheet or cross-reference book.

Given conditions

Part number =

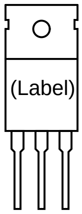
Parameters

	Measured
$V_{bias(BE)}$	
$V_{bias(BC)}$	

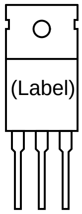
Terminal identification

(Draw your own sketch if the one shown is not appropriate)

Advertised



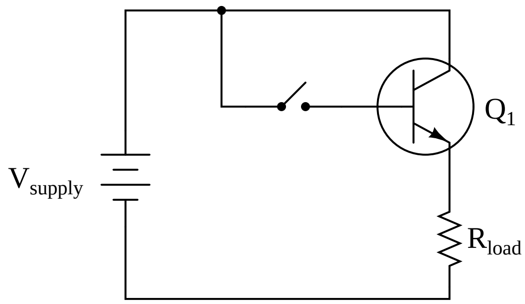
Your conclusion



file 01921

Competency: **Current-sourcing BJT switch** Version:

Schematic



Given conditions

V_{supply} = R_{load} = β =

Parameters

	Predicted	Measured		Calculated
I_{load}			β	
I_{switch}			P_{Q1}	

Fault analysis

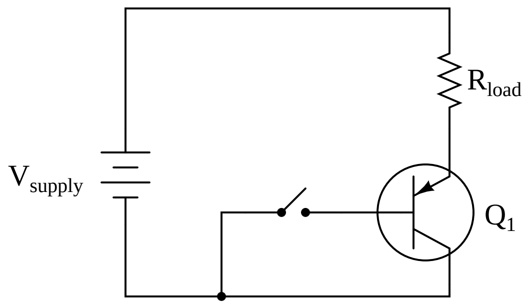
Suppose component [ ] fails ☐ open ☐ shorted ☐ other ________

What will happen in the circuit?

file 01931

Competency: **Current-sinking BJT switch** Version:

Schematic



Given conditions

V_{supply} = R_{load} = β =

Parameters

	Predicted	Measured		Calculated
I_{load}			β	
I_{switch}			P_{Q1}	

Fault analysis

Suppose component ☐ fails ☐ open ☐ other ________ ☐ shorted

What will happen in the circuit?

file 01932

Competency: **BJT switch circuit** Version:

Description

Design and build a circuit that uses a switch to turn on a bipolar junction transistor, which then turns on a DC load such as a light bulb or small electric motor. The switch must only carry enough current to activate the BJT, and must not carry the full load current.

Given conditions

V_{supply} =

Schematic

Parameters

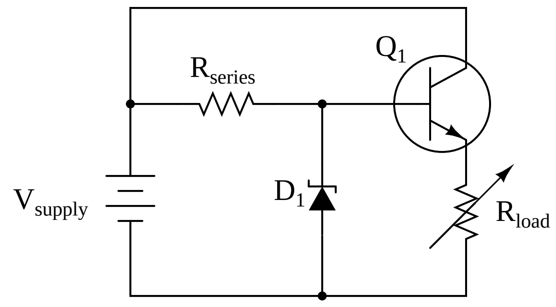
	Measured
I_{load}	
I_{switch}	

Is $I_{load} >> I_{switch}$?

file 02319

Competency: **Buffered zener diode voltage regulator** Version:

Schematic



Given conditions

V_{supply} = V_{zener} = R_{series} =

Parameters

	Predicted	Measured
V_{load} (nominal)		
R_{load} (max)		
R_{load} (min)		

While still regulating V_{load}

Be sure to calculate transistor power dissipation before loading the circuit with R_{load} (min) and measuring V_{load}, to ensure there will be no damage done to the circuit.

Fault analysis

Suppose component ______ fails ☐ open ☐ shorted ☐ other ______

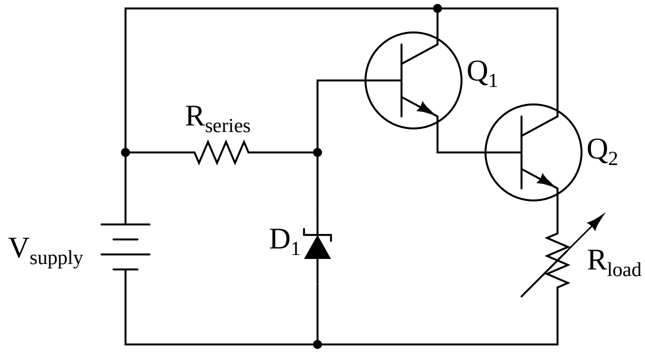
What will happen in the circuit?

The R_{load} (max) and R_{load} (min) parameters are the maximum and minimum resistance settings that R_{load} may be adjusted to with the regulator circuit maintaining constant load voltage. V_{load} (nominal) is simply the regulated voltage output of the circuit under normal conditions.

file 01945

Competency: **Darlington-buffered zener voltage regulator** Version:

Schematic



Given conditions

V_{supply} = V_{zener} = R_{series} =

Parameters

	Predicted	Measured	
V_{load} (nominal)			
R_{load} (max)			While still regulating V_{load}
R_{load} (min)			

Be sure to calculate transistor power dissipation before loading the circuit with R_{load} (min) and measuring V_{load}, to ensure there will be no damage done to the circuit.

Fault analysis

Suppose component ☐ fails ☐ open ☐ other ______ ☐ shorted

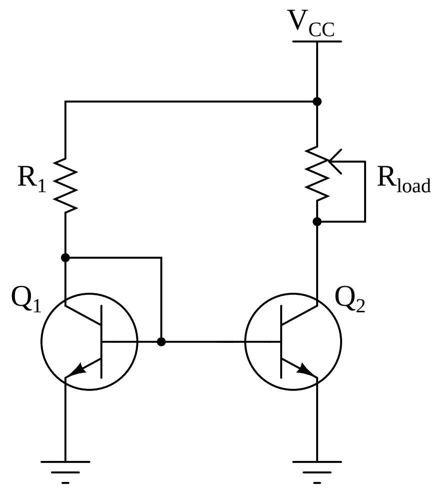
What will happen in the circuit?

The R_{load} (max) and R_{load} (min) parameters are the maximum and minimum resistance settings that R_{load} may be adjusted to with the regulator circuit maintaining constant load voltage. V_{load} (nominal) is simply the regulated voltage output of the circuit under normal conditions.

file 2010

Competency: **Current mirror** Version:

Schematic



Given conditions

V_{CC} = R_1 = R_{load} (max) =

Parameters

	Predicted	Measured	
I_{R1}			
I_{load}			(R_{load} set to mid-value)
$R_{load(max)}$			(Maximum R with I_{load} stable)
$R_{load(min)}$			(Minimum R with I_{load} stable)

Fault analysis

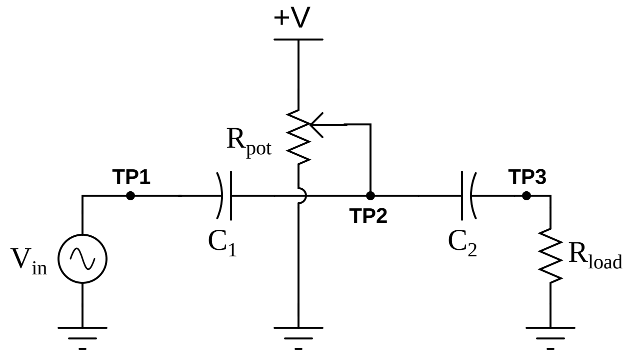
Suppose component [ ] fails ☐ open ☐ other ______ ☐ shorted

What will happen in the circuit?

file 01938

Competency: **Signal biasing/unbiasing network** Version:

Schematic



Given conditions

V_{in} =

+V =

$C_1 = C_2$ =

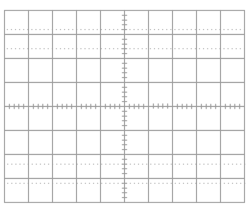
R_{load} =

R_{pot} =

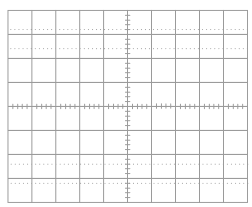
Parameters

With potentiometer set to its ___% position:

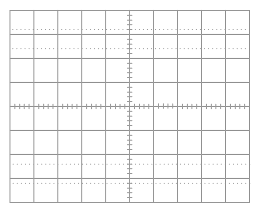
V_{TP1}



V_{TP2}



V_{TP3}



Explanation

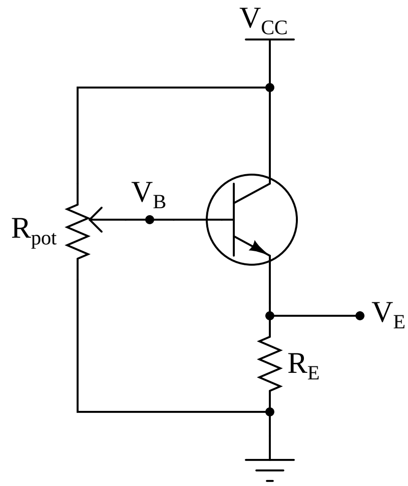
What effect, if any, does the potentiometer position have on the voltage measured at each test point?

Explain how you could measure the effects of the potentiometer's position *without* using an oscilloscope.

file 01946

Competency: **Common-collector biasing** Version:

Schematic



Given conditions

V_{CC} = R_{pot} = R_E =

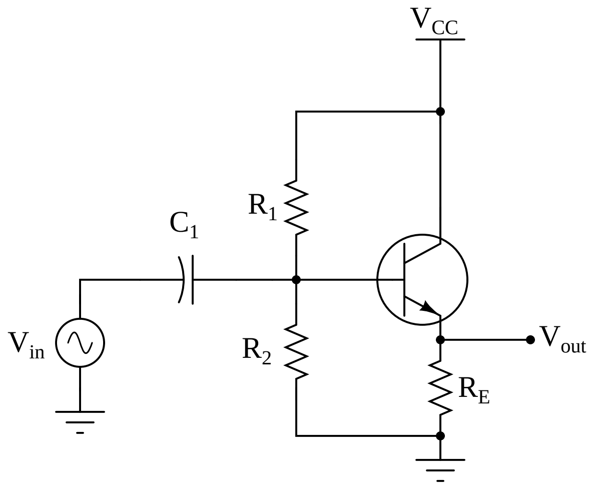
Parameters

	Predicted	Measured	R_{pot} setting
V_E			V_B = 0 volts
V_E			V_B = 25% of V_{CC}
V_E			V_B = 50% of V_{CC}
V_E			V_B = 75% of V_{CC}
V_E			$V_B = V_{CC}$

file 01977

Competency: **Common-collector class-A amplifier** Version:

Schematic



Given conditions

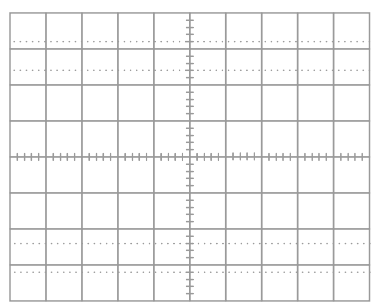
V_{in} = V_{CC} = R_E =

C_1 = R_1 = R_2 =

Parameters

	Predicted	Measured
V_B (DC)		
V_{out} (DC)		
V_{out} (AC)		
A_V		

Input and output waveforms (measured)



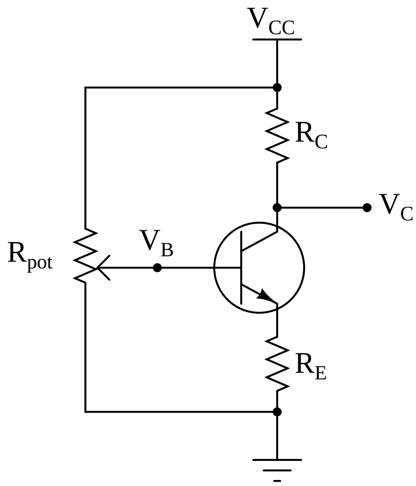
Inverting . . . ☐

or noninverting? ☐

file 01967

Competency: **Common-emitter biasing** Version:

Schematic



Given conditions

V_{CC} = R_{pot} = R_C = R_E =

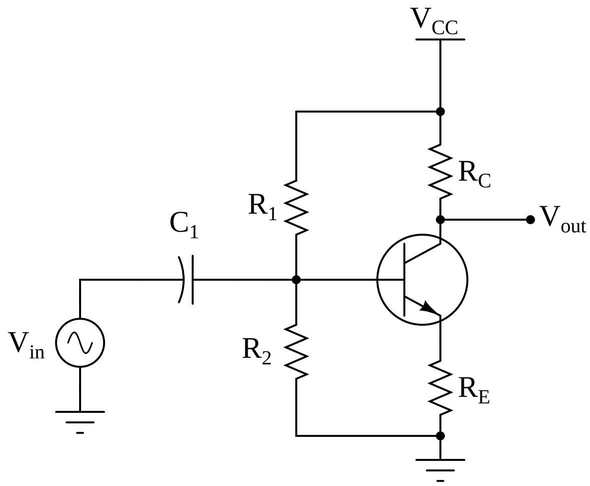
Parameters

	Predicted	Measured	R_{pot} setting
V_C			V_B = 0 volts
V_C			V_B = 25% of V_{CC}
V_C			V_B = 50% of V_{CC}
V_C			V_B = 75% of V_{CC}
V_C			V_B = V_{CC}

file 01978

Competency: **Common-emitter class-A amplifier** Version:

Schematic



Given conditions

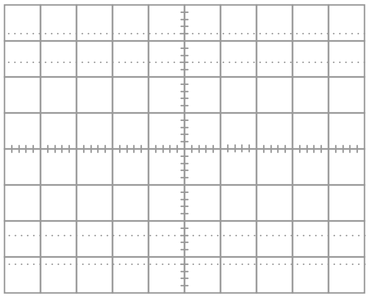
V_{in} = V_{CC} = R_C = R_E =

C_1 = R_1 = R_2 =

Parameters

	Predicted	Measured
V_B (DC)		
V_{out} (DC)		
V_{out} (AC)		
A_V		

Input and output waveforms (measured)



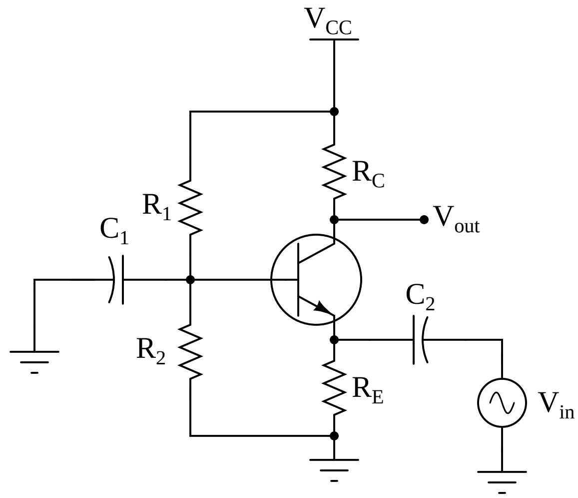
Inverting . . . ☐

or noninverting? ☐

file 01966

Competency: **Common-base class-A amplifier** Version:

Schematic



Given conditions

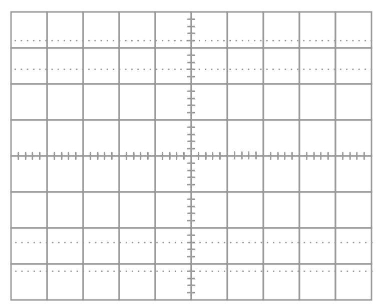
V_{in} = V_{CC} = R_C = R_E =

$C_1 = C_2$ = R_1 = R_2 =

Parameters

	Predicted	Measured
V_B (DC)		
V_{out} (DC)		
V_{out} (AC)		
A_V		

Input and output waveforms (measured)



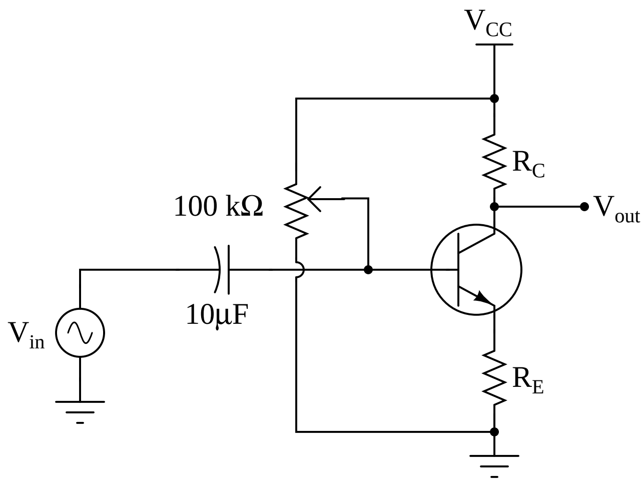
Inverting . . . ☐

or noninverting? ☐

file 01981

Competency: **Variable-bias, common-emitter BJT amp** Version:

Schematic



Given conditions

V_{in} = V_{CC} = R_C = R_E =

Parameters

	Predicted	Measured
A_V		
V_{out}		

In class-A mode

Fault analysis

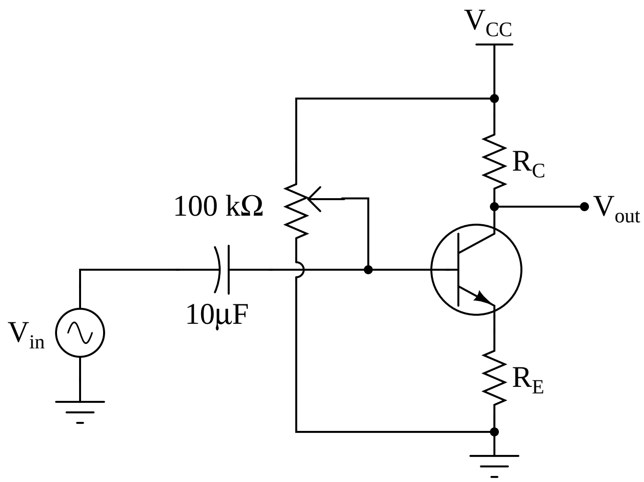
Suppose component ☐ fails ☐ open ☐ other ________ ☐ shorted

What will happen in the circuit?

file 03919

Competency: **Variable-class BJT amplifier circuit** Version:

Schematic



Given conditions

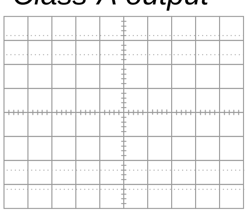
V_{in} = V_{CC} = R_C = R_E =

Parameters

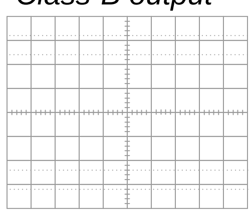
	Predicted	Measured	
A_V			*In class-A mode*
V_{out}			

Input and output voltage waveform plots

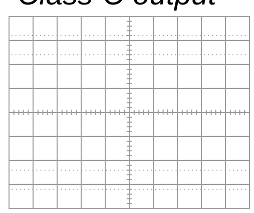
Class-A output



Class-B output



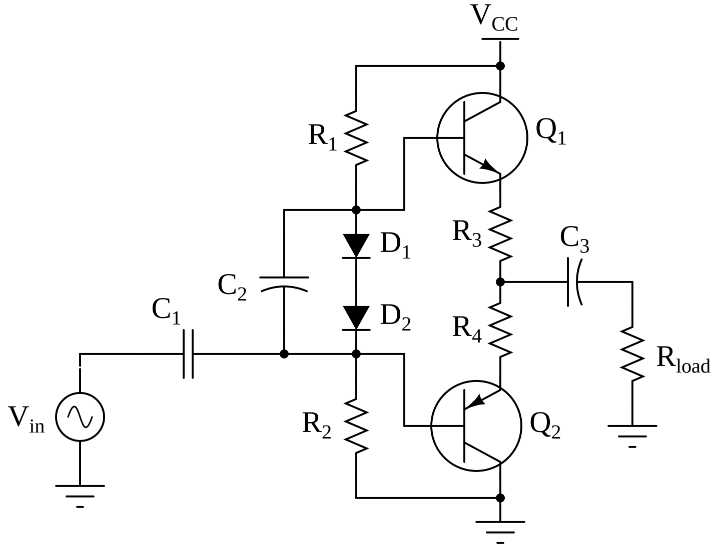
Class-C output



file 01624

Competency: **Push-pull BJT amplifier circuit** Version:

Schematic



Given conditions

V_{in} =

V_{CC} =

$R_1 = R_2$ =

$R_3 = R_4$ =

C_1 =

C_3 =

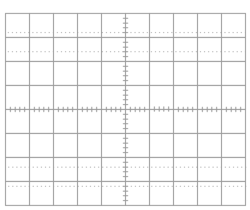
C_2 =

Parameters

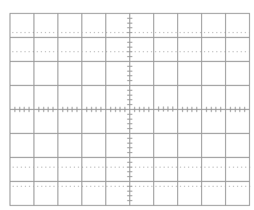
	Predicted	Measured
A_V		
V_{out}		

Draw the output waveforms with 2 diodes and with 1 diode and explain why there is more distortion in one case.

With both diodes working



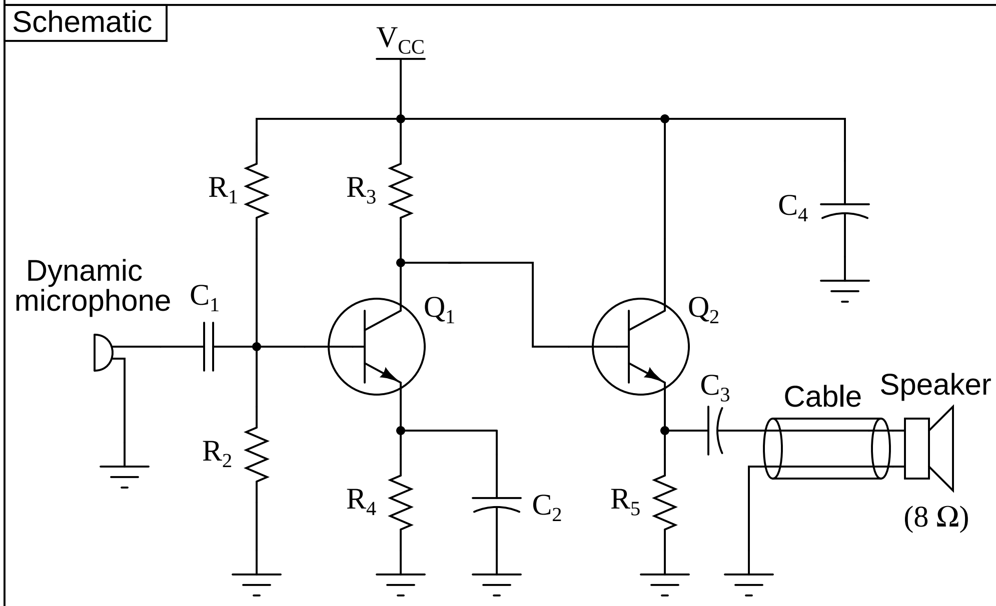
With one diode shorted



file 01994

Competency: **Audio intercom circuit** Version:

Schematic



Given component values

V_{CC} =	C_1 =	R_1 =
	C_2 =	R_2 =
	C_3 =	R_3 =
	C_4 =	R_4 =
		R_5 =

Fault analysis

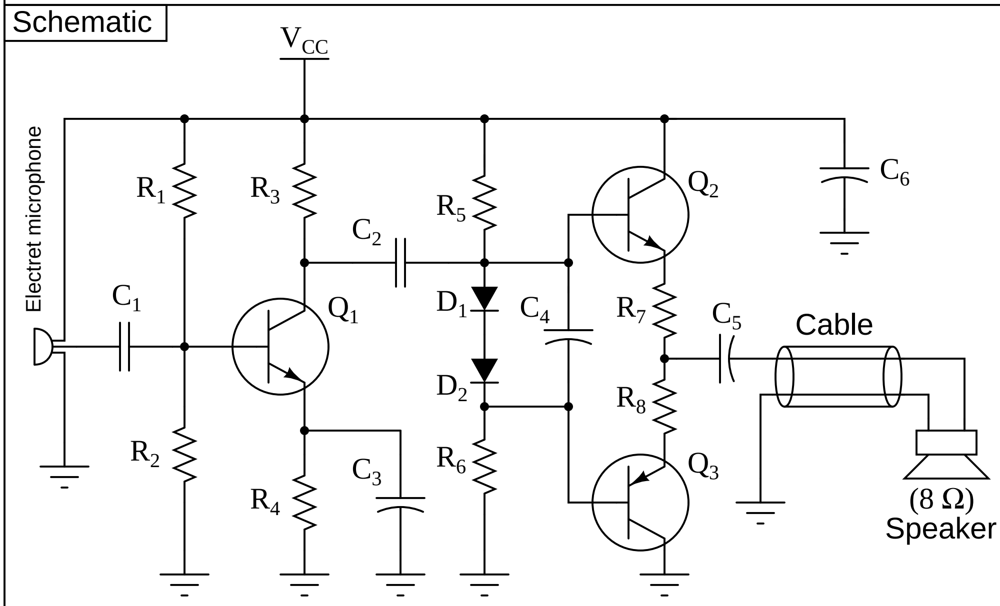
Suppose component ☐ fails ☐ open ☐ other ______________ ☐ shorted

What will happen in the circuit?

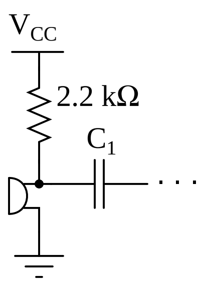
file 01937

Competency: **Audio intercom circuit, push-pull output** Version:

Schematic



Two-wire electret microphone schematic



Given component values

$C_1 = C_2 =$

$C_3 = C_4 =$

$C_5 =$

$C_6 =$

$V_{CC} =$

$R_1 =$

$R_2 =$

$R_3 =$

$R_4 =$

$R_5 = R_6 =$

$R_7 = R_8 =$

Fault analysis

Suppose component [ ] fails ☐ open ☐ shorted ☐ other ____________

What will happen in the circuit?

file 01995

Competency: **Class-A BJT amplifier w/specified gain** Version:

Description

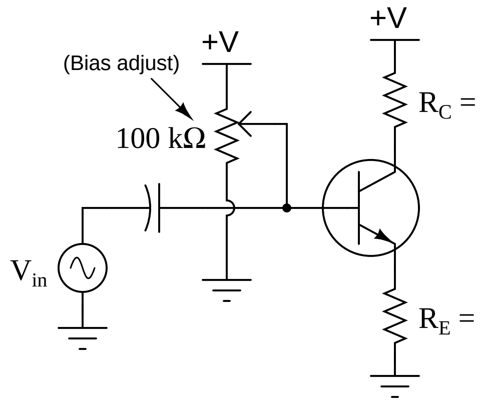
Design and build a class-A BJT amplifier circuit with a voltage gain (A_V) that is within tolerance of the gain specified.

You may use a potentiometer to adjust the biasing of the transistor, to make the design process easier.

Given conditions

V_{in} = $+V$ = A_V = $Tolerance_{A_V}$ =

Schematic



Parameters

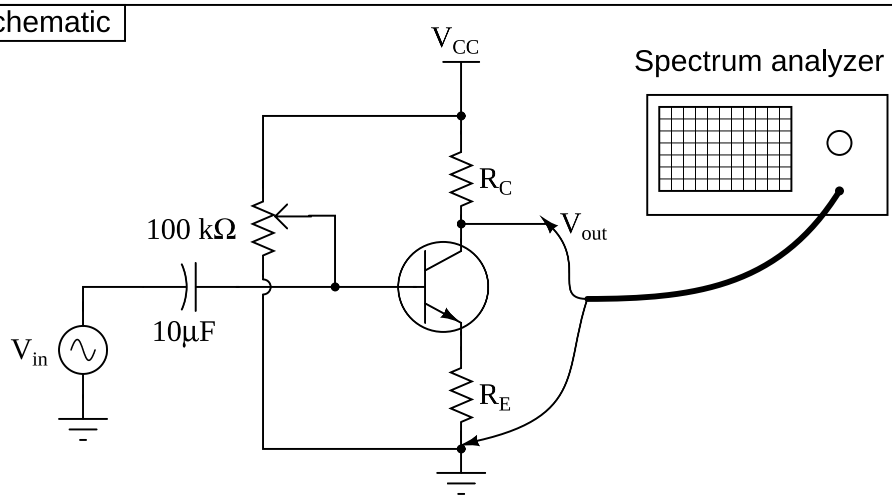
	Measured		Calculated
V_{in}		A_V	
V_{out}		$Error_{A_V}$	

$$\frac{A_{V(actual)} - A_{V(ideal)}}{A_{V(ideal)}} \times 100\%$$

file 01935

Competency: **Testing amplifier distortion** Version:

Schematic

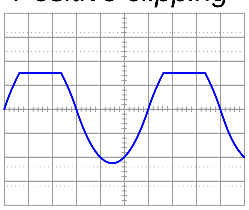


Given conditions

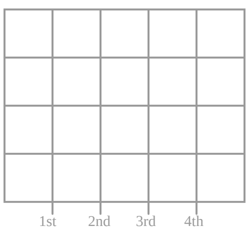
V_{in} = V_{CC} = R_C = R_E =

Parameters

Positive clipping

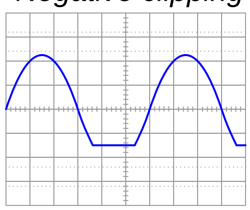


Oscilloscope trace

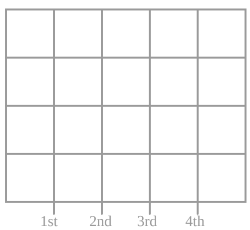


Spectrum analyzer display

Negative clipping

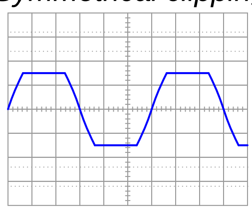


Oscilloscope trace

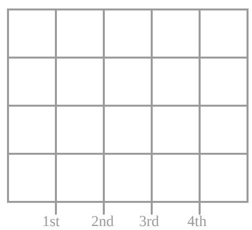


Spectrum analyzer display

Symmetrical clipping



Oscilloscope trace



Spectrum analyzer display

Analysis

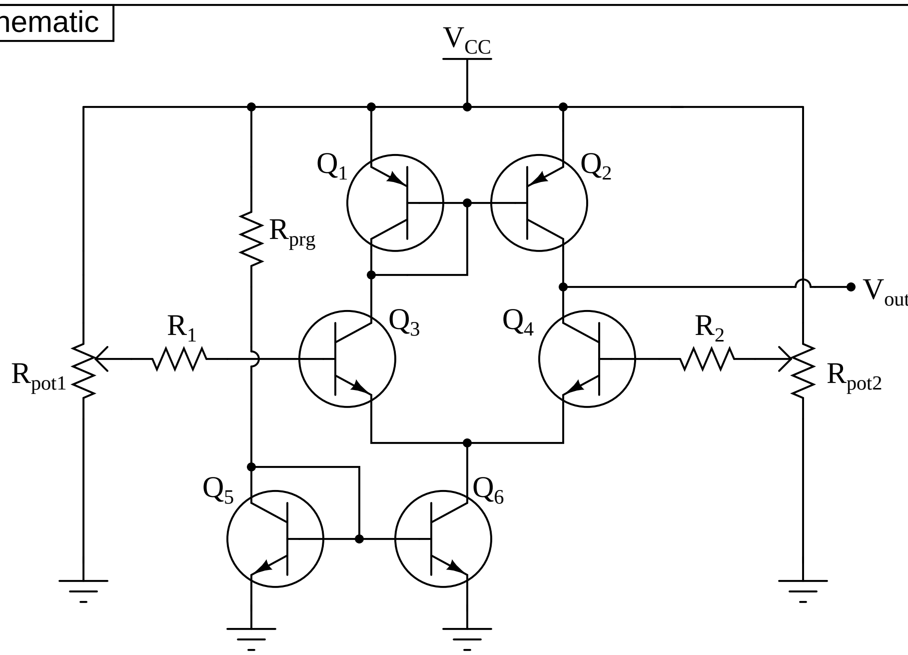
Which clipping conditions generate even harmonics?

Which clipping conditions generate odd harmonics?

file 01996

Competency: **BJT differential amplifier** Version:

Schematic



Given conditions

$R_1 = R_2 =$

$R_{prg} =$

$V_{CC} =$

$R_{pot1} = R_{pot2} =$

Parameters

	Predicted	Measured
I_C (Q_6)		

Which transistor does the inverting input belong to?

Which transistor does the non-inverting input belong to?

file 01997

Competency: **JFET terminal identification** Version:

Description

Identify the terminals (emitter, base, and collector) of a junction field-effect transistor using a multimeter. Then, compare your conclusions with information from a datasheet or cross-reference book.

Given conditions

Part number =

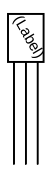
Parameters

	Measured
$V_{\text{gate-channel}}$	
V_{channel}	

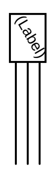
Terminal identification

(Draw your own sketch if the one shown is not appropriate)

Advertised



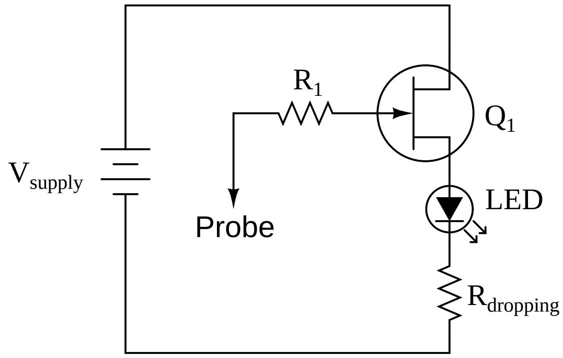
Your conclusion



file 01930

Competency: **Current-sourcing JFET switch** Version:

Schematic



Given conditions

V_{supply} = R_1 = $R_{dropping}$ =

Parameters

	Predicted	Measured		
I_{LED} (max)				

	Advertised	Measured		Calculated
$V_{GS\ (off)}$			P_{Q1}	

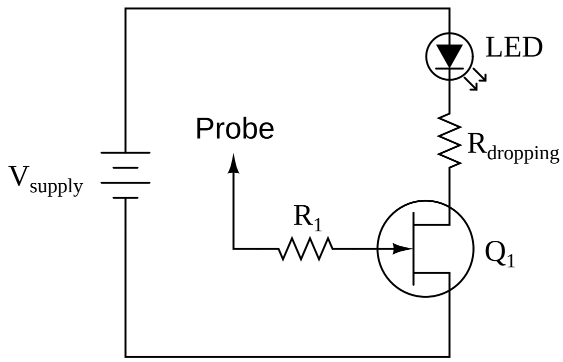
Schematic

(Draw a schematic diagram showing what is necessary to turn the transistor fully *off*)

file 01972

Competency: **Current-sinking JFET switch** Version:

Schematic



Given conditions

V_{supply} = R_1 = $R_{dropping}$ =

Parameters

	Predicted	Measured
I_{LED} (max)		

	Advertised	Measured		Calculated
$V_{GS\ (off)}$			P_{Q1}	

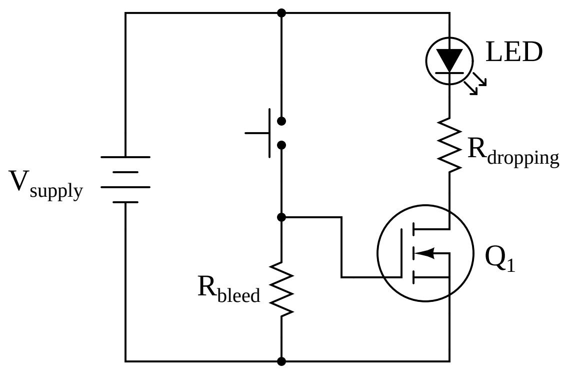
Schematic

(Draw a schematic diagram showing what is necessary to turn the transistor fully *off*)

file 01973

Competency: **Current-sinking MOSFET switch** Version:

Schematic



Given conditions

V_{supply} = R_{bleed} = $R_{dropping}$ =

Parameters

	Predicted	Measured		Calculated
I_{LED}			$R_{DS(on)}$	
I_{switch}			P_{Q1}	

Fault analysis

Suppose component ______ fails ☐ open ☐ other ______ ☐ shorted

What will happen in the circuit?

file 02425

Competency: **MOSFET switch circuit** Version:

Description

Design and build a circuit that uses a switch to turn on an E-type MOSFET, which then turns on a DC load such as a light bulb or small electric motor. The switch must carry zero current, with the transistor carrying 100% of the load current.

Given conditions

V_{supply} =

Schematic

Parameters

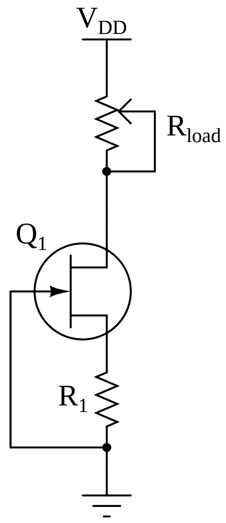
	Measured
I_{load}	
I_{switch}	

Is I_{switch} = 0 mA ?

file 02424

Competency: **JFET current regulator** Version:

Schematic



Given conditions

V_{DD} = R_1 = R_{load} (max) =

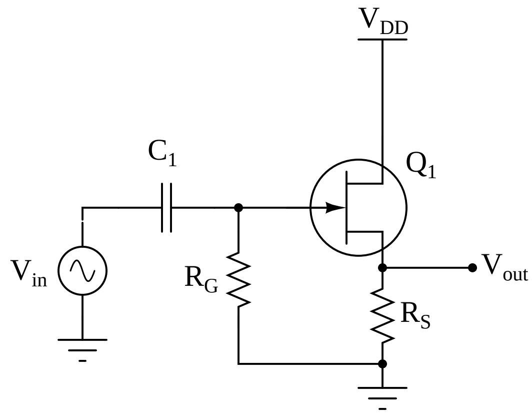
Parameters

	Predicted	Measured	
I_{R1}			
I_{load}			(R_{load} set to mid-value)
$R_{load(max)}$			(Maximum R with I_{load} stable)
$R_{load(min)}$			(Minimum R with I_{load} stable)

file 01948

Competency: **Common-drain class-A amplifier** Version:

Schematic



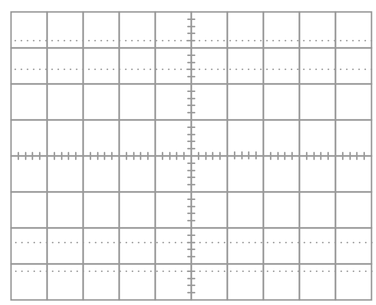
Given conditions

V_{in} = V_{DD} = R_G = R_S = C_1 =

Parameters

	Predicted	Measured
V_G (DC)		
V_{out} (AC)		
A_V		

Input and output waveforms (measured)



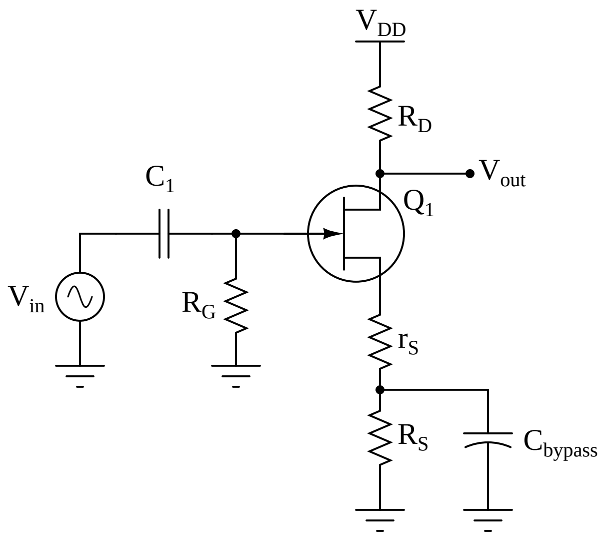
Inverting . . . ☐

or noninverting? ☐

file 01992

Competency: **Common-source class-A amplifier** Version:

Schematic



Given conditions

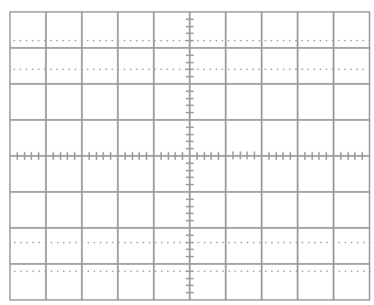
V_{in} = V_{DD} = R_G = R_D = C_1 =

r_S = R_S = C_{bypass} =

Parameters

	Predicted	Measured
V_G (DC)		
V_{out} (AC)		
A_V		

Input and output waveforms (measured)



Inverting . . . ☐

or noninverting? ☐

file 01993

Competency: **Class-A JFET amplifier w/specified phase** Version:

Description

Design and build a class-A JFET amplifier circuit
with the phase (inverting or noninverting) specified.

Given conditions

V_{in} = +V =

☐ Inverting

☐ Noninverting

Schematic *Show all component values!*

Parameters

Does the amplifier invert the waveform or not?

file 03879

Competency: **Class-A JFET amplifier w/specified gain** Version:

Description

Design and build a class-A JFET amplifier circuit with a voltage gain (A_V) that is within tolerance of the gain specified.

Given conditions

V_{in} =   +V = A_V = Tolerance_{A_V} =

Schematic *Show all component values!*

Parameters

	Measured		Calculated
V_{in}		A_V	
V_{out}		Error_{A_V}	

$$\text{Error}_{A_V} = \frac{A_{V(actual)} - A_{V(ideal)}}{A_{V(ideal)}} \times 100\%$$

file 01936

Competency: **Class-A transistor amplifier w/specified phase**

Description

Design and build a class-A transistor amplifier circuit with the phase (inverting or noninverting) specified.

Given conditions

V_{in} =   +V =

☐ Inverting

☐ Noninverting

Schematic *Show all component values!*

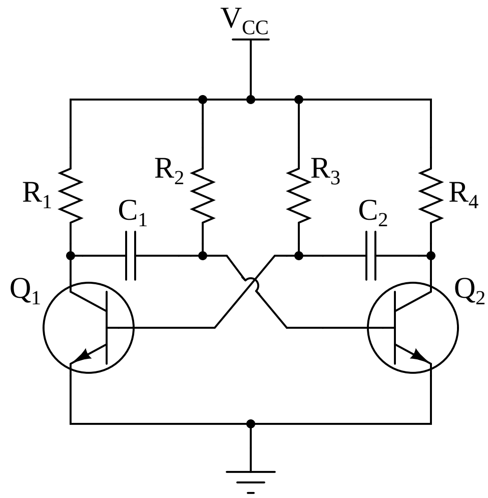
Parameters

Does the amplifier invert the waveform or not?

file 03884

Competency: **BJT multivibrator circuit, astable** Version:

Schematic



Given conditions

V_{CC} = R_1 = R_2 = C_1 =

R_4 = R_3 = C_2 =

Parameters

	Predicted	Measured	
Duty Cycle (at Q_1 collector)			Potentiometer turned fully clockwise

Fault analysis

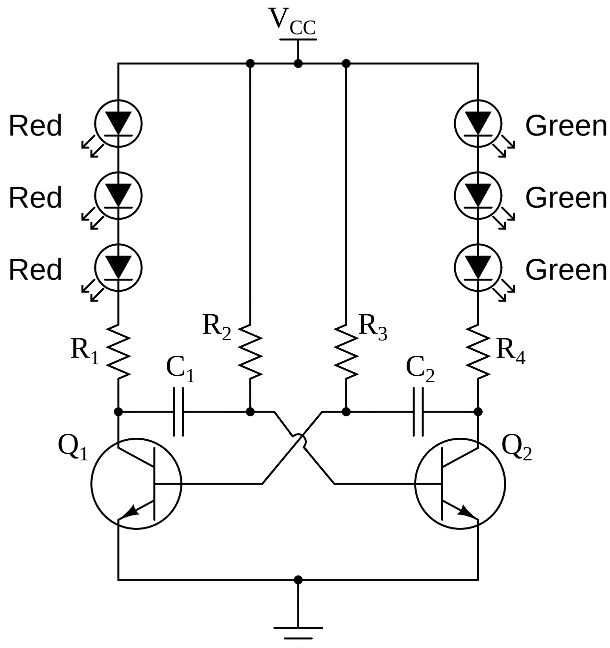
Suppose component ______ fails ☐ open ☐ shorted ☐ other ______

What will happen in the circuit?

file 01939

Competency: **BJT multivibrator circuit, astable**	Version:

Schematic



Given conditions

V_{CC} = 　　R_1 = 　　R_2 = 　　C_1 =

R_4 = 　　R_3 = 　　C_2 =

Parameters

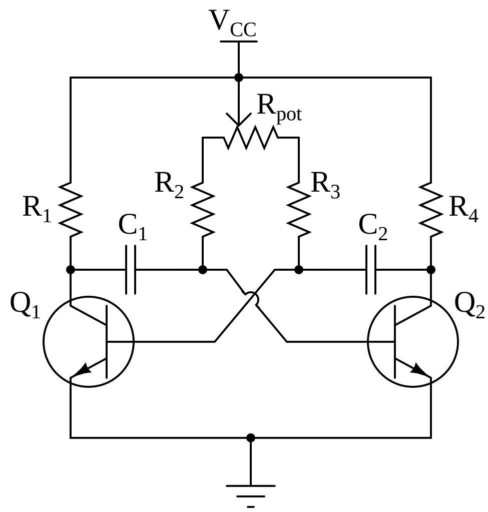
	Predicted	Measured
t_{on} (red LED)		
t_{on} (green LED)		

file 01947

Question 49

Competency: **BJT multivibrator w/ variable duty cycle** Version:

Schematic



Given conditions

V_{CC} = R_1 = R_2 = R_{pot} = C_1 =

R_4 = R_3 = C_2 =

Parameters

	Predicted	Measured	
Duty Cycle (at Q_1 collector)			Potentiometer turned fully clockwise

Fault analysis

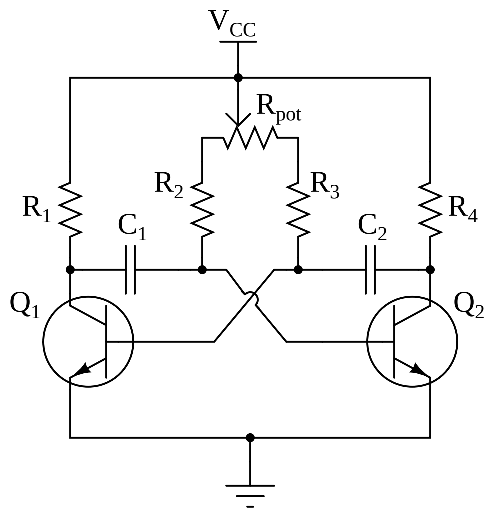
Suppose component [ ] fails ☐ open ☐ other ______ ☐ shorted

What will happen in the circuit?

file 01990

Competency: **BJT multivibrator w/ variable duty cycle** Version:

Schematic



Given conditions

V_{CC} = R_1 = R_2 = R_{pot} = C_1 =

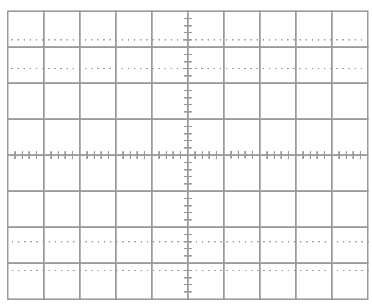
R_4 = R_3 = C_2 =

Duty cycle (D) =

Parameters

	Measured
Duty Cycle (at Q_1 collector)	

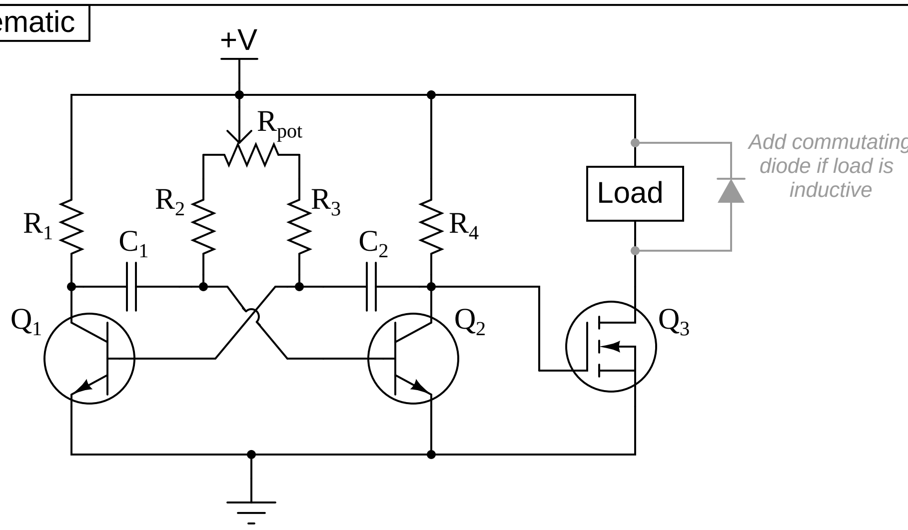
Waveform at specified *D*



file 02607

Competency: **PWM power controller, discrete** Version:

Schematic



Given conditions

+V =	R_1 =	R_2 =	R_{pot} =	C_1 =
	R_4 =	R_3 =		C_2 =

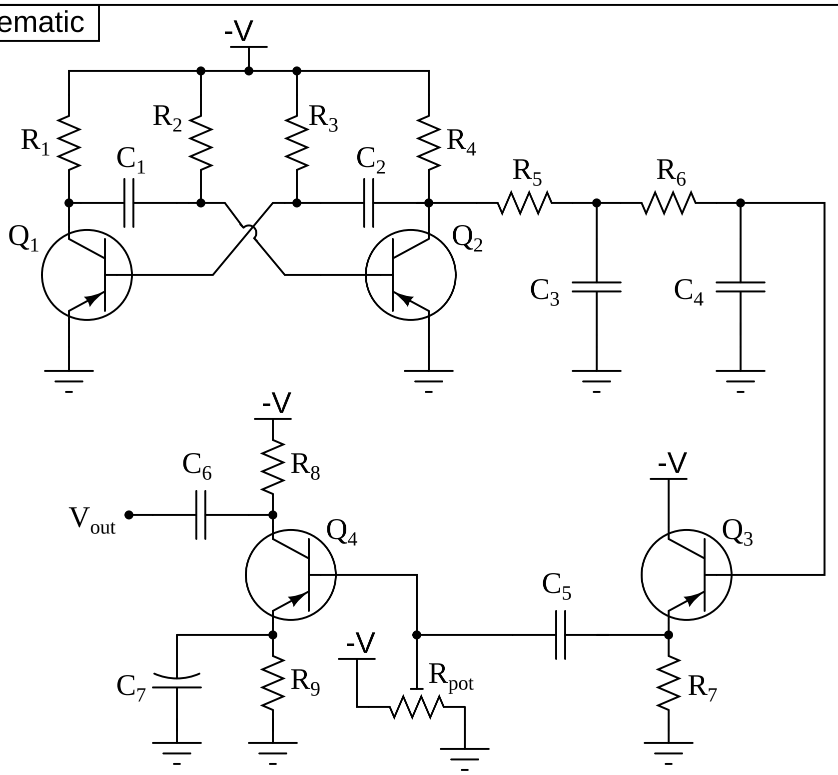
Parameters

	Predicted	Measured	
V_{load} (avg.)			Duty cycle = ____ %
V_{load} (avg.)			Duty cycle = ____ %
V_{load} (avg.)			Duty cycle = ____ %
V_{load} (avg.)			Duty cycle = ____ %

file 01991

Competency: **Oscillator/waveshaper/amplifier circuit** Version:

Schematic



Given conditions

-V =

R_1 =	R_6 =	C_1 =	C_5 =
R_2 =	R_7 =	C_2 =	C_6 =
R_3 =	R_8 =	C_3 =	C_7 =
R_4 =	R_9 =	C_4 =	
R_5 =	R_{pot} =		

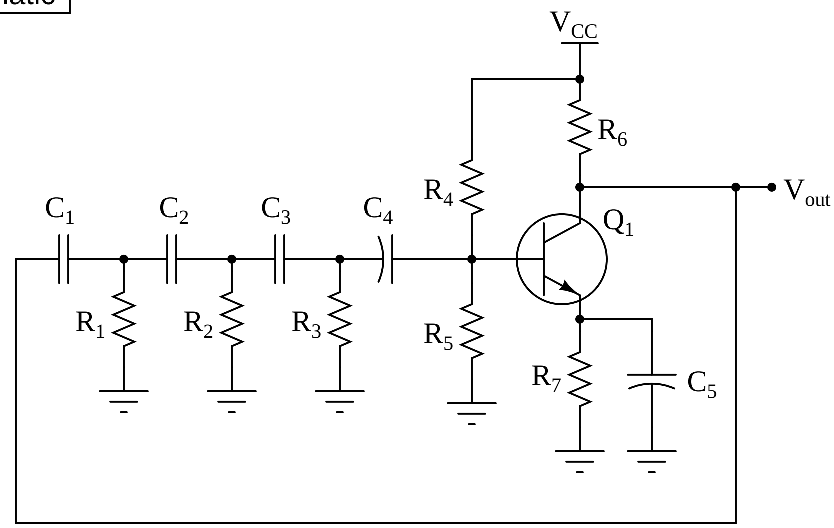
Parameters

	Predicted waveshape	Measured waveshape		Predicted waveshape	Measured waveshape
$V_{C(Q2)}$			V_{C4}		
$V_{B(Q2)}$			V_{R7}		
V_{C3}			V_{out}		

file 02507

Competency: **RC phase-shift oscillator, BJT** Version:

Schematic



Given conditions

V_{CC} = $C_1 = C_2 = C_3$ = $C_4 = C_5$ =

$R_1 = R_2 = R_3$ = R_4 = R_5 =

R_6 = R_7 =

Parameters

	Predicted	Measured
f_{out}		

Fault analysis

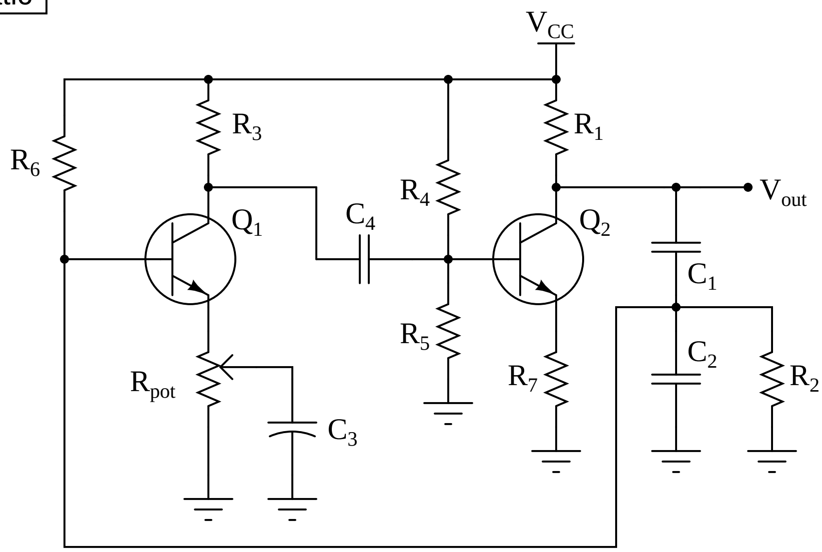
Suppose component [ ] fails [ ] open [ ] other ______ [ ] shorted

What will happen in the circuit?

file 01950

Competency: **Wien bridge oscillator, BJT** Version:

Schematic



Given conditions

V_{CC} = $C_1 = C_2$ = C_3 = C_4 =

$R_1 = R_2$ = R_3 = R_4 = R_5 =

R_6 = R_7 = R_{pot} =

Parameters

	Predicted	Measured
f_{out}		

Fault analysis

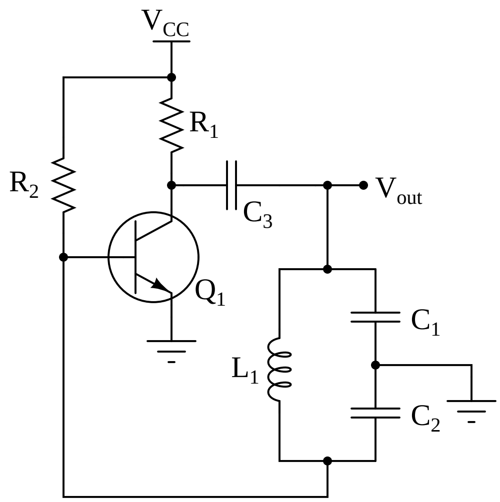
Suppose component ☐ fails ☐ open ☐ other ______ ☐ shorted

What will happen in the circuit?

file 01975

Competency: **Colpitts oscillator, BJT** Version:

Schematic



Given conditions

V_{CC} = $C_1 = C_2$ = L_1 = C_3 =

R_1 = R_2 =

Parameters

	Predicted	Measured
f_{out}		

Fault analysis

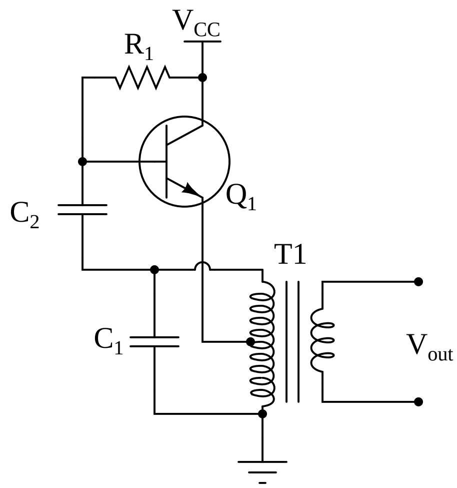
Suppose component ☐ fails ☐ open ☐ other ____________ ☐ shorted

What will happen in the circuit?

file 01952

Competency: **Hartley oscillator, series-fed BJT** Version:

Schematic



Given conditions

V_{CC} =

C_1 =

$L_{primary}$ =

R_1 =

C_2 =

Parameters

	Predicted	Measured
f_{out}		

Fault analysis

Suppose component ______ fails ☐ open ☐ other ______ ☐ shorted

What will happen in the circuit?

file 01965

Competency: **BJT oscillator w/specified frequency** Version:

Description

Design and build a BJT oscillator circuit to output a *sine-wave* AC voltage at a frequency within the specified tolerance.

Given conditions

+V = f = $Tolerance_f$ =

Schematic *Show all component values!*

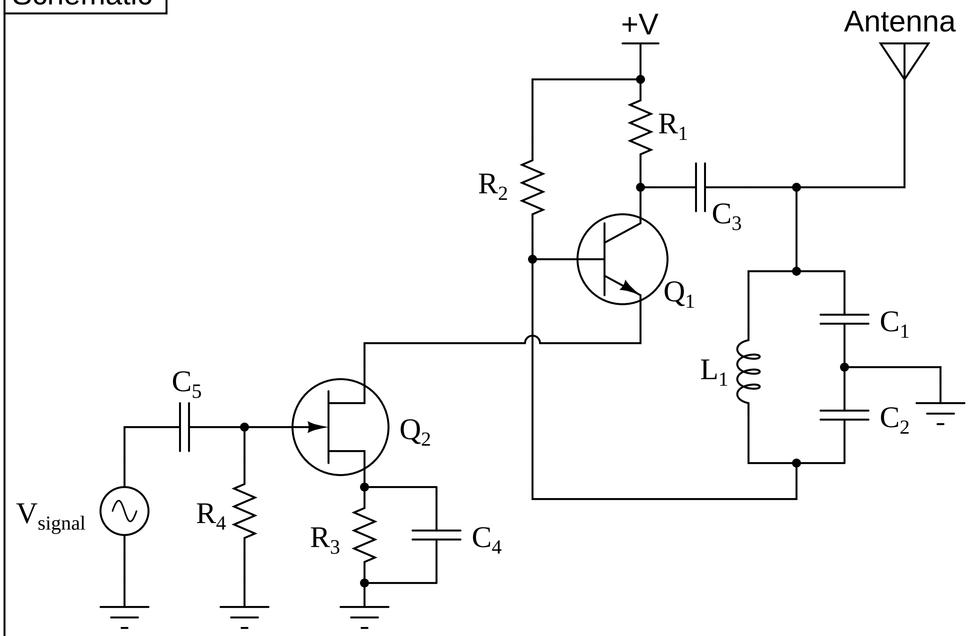
Parameters

	Measured		Calculated	
f		$Error_f$		$\frac{f_{(actual)} - f_{(ideal)}}{f_{(ideal)}} \times 100\%$

file 01949

Competency: **AM radio transmitter** Version:

Schematic



Given conditions

$+V =$ $C_1 = C_2 =$ $L_1 =$ $C_3 = C_4 = C_5 =$

$V_{signal} =$ $R_1 =$ $R_2 =$ $R_3 =$ $R_4 =$

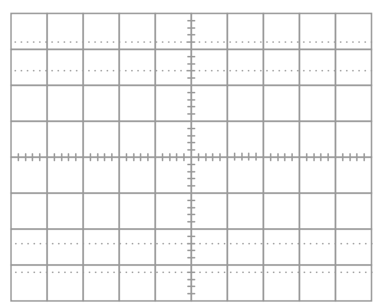
$f_{signal} =$

Parameters

	Predicted	Measured
f_{out}		

Audio signal can be heard on AM radio ☐

Oscilloscope display of modulation



file 01953

Competency: **SCR terminal identification** Version:

Description

Identify the terminals (emitter, base, and collector) of a silicon-controlled rectifier using a multimeter. Then, compare your conclusions with information from a datasheet or cross-reference book.

Given conditions

Part number =

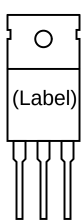
Parameters

	Measured
$V_{bias(GK)}$	

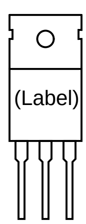
Terminal identification

(Draw your own sketch if the one shown is not appropriate)

Advertised



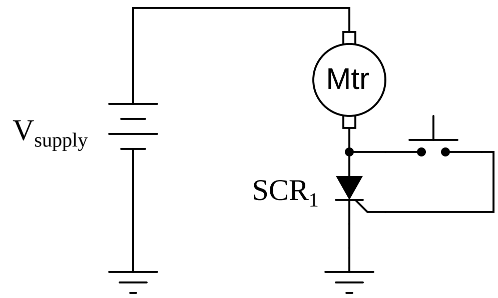
Your conclusion



file 01922

Competency: **SCR latch circuit** Version:

Schematic



Given conditions

V_{supply} =

Parameters

	Predicted	Measured
V_{motor} (on)		
I_{supply} (on)		

	Calculated
P_{SCR1}	

file 01987

Competency: **SCR latch circuit** Version:

Description

Design and build a circuit that uses a switch to turn on a Silicon-Controlled Rectifier so that it "latches" in the ON state, maintaining power to a DC load such as a lamp or small electric motor after the switch has been opened.

Given conditions

V_{supply} =

Schematic

Parameters

	Yes	No
Does the circuit *latch?*	☐	☐

file 02345

(Template)

Competency: Version:

Schematic

Given conditions

Parameters

Predicted	Measured

file 01602

Answer 1

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

Answer 2

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

Answer 3

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

Answer 4

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

Answer 5

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

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

Contrary to what you might think, the datasheet or cross-reference is not the "final authority" for checking your meter-based conclusions! I have seen datasheets and cross-reference manuals wrong more than once!

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

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

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

Contrary to what you might think, the datasheet or cross-reference is not the "final authority" for checking your meter-based conclusions! I have seen datasheets and cross-reference manuals wrong more than once!

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.

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 values.

Answer 49

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

Answer 50

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

Answer 51

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

Answer 52

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

Answer 53

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

Answer 54

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

Answer 55

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

Answer 56

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

Answer 57

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

Answer 58

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

Answer 59

Contrary to what you might think, the datasheet or cross-reference is not the ”final authority” for checking your meter-based conclusions! I have seen datasheets and cross-reference manuals wrong more than once!

Answer 60

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

Answer 61

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

Answer 62

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 1

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Have students calculate the necessary current-limiting resistor for their LEDs based on measured values of $V_{forward}$ for the LED (using a multimeter with a "diode-check" function). Let students research the typical forward current for their LED from an appropriate datasheet. Any LED should suffice for this activity.

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 2

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). I recommend using one of the 1N400X series of rectifying diodes for their low cost and ruggedness.

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 3

I recommend using 1N400X series rectifying diodes for all rectifier circuit designs. Make sure that the resistance value you specify for your load is not so low that the resistor's power dissipation is exceeded.

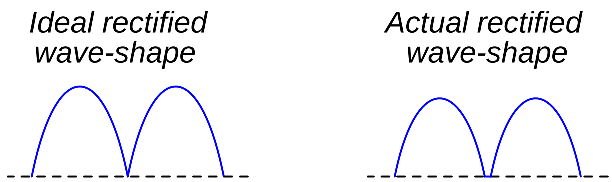
Watch out for harmonics in the power line voltage creating problems with RMS/peak voltage relationships. If this is a problem, try using a ferroresonant transformer to filter out some of the harmonic content. *Do not* try to use a sine-wave signal generator as an alternate source of AC power, because most signal generators have internal impedances that are much too high for such a task.

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.

I recommend using 1N400X series rectifying diodes for all rectifier circuit designs. Make sure that the resistance value you specify for your load is not so low that the resistor's power dissipation is exceeded.

Watch out for harmonics in the power line voltage creating problems with RMS/peak voltage relationships. If this is a problem, try using a ferroresonant transformer to filter out some of the harmonic content. *Do not* try to use a sine-wave signal generator as an alternate source of AC power, because most signal generators have internal impedances that are much too high for such a task.

It is difficult to precisely calculate the DC load voltage from a rectifier circuit such as this when the transformer secondary voltage is relatively low. The diodes' forward voltage drop essentially distorts the rectified waveform so that it is not quite the same as what you would expect a full-wave rectified waveform to be:



Accurate calculation of the actual rectified wave-shape's average voltage value requires integration of the half-sine peak over a period less than π radians, which may very well be beyond the capabilities of your students. This is why I request approximations only on this parameter.

One approximation that works fairly well is to take the AC RMS voltage (in this case, half of the secondary winding's output, since this is a center-tap design), convert it to *average* voltage (multiply by 0.9), and then subtract the forward junction voltage lost by the diode (0.7 volts typical for silicon).

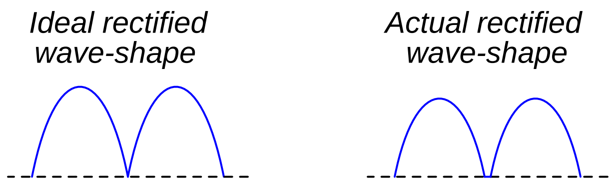
An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Notes 5

I recommend using 1N400X series rectifying diodes for all rectifier circuit designs. Make sure that the resistance value you specify for your load is not so low that the resistor's power dissipation is exceeded.

Watch out for harmonics in the power line voltage creating problems with RMS/peak voltage relationships. If this is a problem, try using a ferroresonant transformer to filter out some of the harmonic content. *Do not* try to use a sine-wave signal generator as an alternate source of AC power, because most signal generators have internal impedances that are much too high for such a task.

It is difficult to precisely calculate the DC load voltage from a rectifier circuit such as this when the transformer secondary voltage is relatively low. The diodes' forward voltage drop essentially distorts the rectified waveform so that it is not quite the same as what you would expect a full-wave rectified waveform to be:



Accurate calculation of the actual rectified wave-shape's average voltage value requires integration of the half-sine peak over a period less than π radians, which may very well be beyond the capabilities of your students. This is why I request approximations only on this parameter.

One approximation that works fairly well is to take the AC RMS voltage, convert it to *average* voltage (multiply by 0.9), and then subtract the total forward junction voltage lost by the diode (0.7 volts per diode typical for silicon, for a total of 1.4 volts).

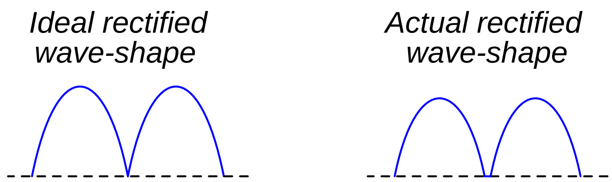
An extension of this exercise is to incorporate troubleshooting questions. Whether using this exercise as a performance assessment or simply as a concept-building lab, you might want to follow up your students' results by asking them to predict the consequences of certain circuit faults.

Notes 6

I recommend using 1N400X series rectifying diodes for all rectifier circuit designs. Make sure that the resistance value you specify for your load is not so low that the resistor's power dissipation is exceeded.

Watch out for harmonics in the power line voltage creating problems with RMS/peak voltage relationships. If this is a problem, try using a ferroresonant transformer to filter out some of the harmonic content. *Do not* try to use a sine-wave signal generator as an alternate source of AC power, because most signal generators have internal impedances that are much too high for such a task.

It is difficult to precisely calculate the DC load voltage from a rectifier circuit such as this when the transformer secondary voltage is relatively low. The diodes' forward voltage drop essentially distorts the rectified waveform so that it is not quite the same as what you would expect a full-wave rectified waveform to be:



Accurate calculation of the actual rectified wave-shape's average voltage value requires integration of the half-sine peak over a period less than π radians, which may very well be beyond the capabilities of your students. This is why I request approximations only on this parameter.

One approximation that works fairly well is to take the AC RMS voltage (in this case, half of the secondary winding's output, since this is a center-tap design), convert it to *average* voltage (multiply by 0.9), and then subtract the forward junction voltage lost by the diode (0.7 volts typical for silicon).

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 7

I recommend using 1N400X series rectifying diodes for all rectifier circuit designs. Make sure that the resistance value you specify for your load is not so low that the resistor's power dissipation is exceeded.

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 8

Use a Variac at the test bench to provide variable-voltage AC power for the students' power supply circuits.

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 variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard load resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.), and let the students determine the proper resistance values for their series dropping resistors.

I recommend specifying a series resistor value (R_{series}) high enough that there will little danger in damaging the zener diode due to excessive supply voltage, but also low enough so that the normal operating current of the zener diode is great enough for it to drop its rated voltage. If R_{series} is too large, the zener diode's current will be too small, resulting in lower than expected voltage drop and poorer regulation (operating near the flatter end of the characteristic curve).

Values I have used with success are as follows:

- R_{series} = 1 kΩ
- R_{load} = 10 kΩ
- V_{zener} = 5.1 volts (diode part number 1N4733)
- V_{supply} = 12 volts

Measuring the minimum supply voltage is a difficult thing to do, because students must look for a point where the output voltage begins to directly follow the input voltage (going down) instead of holding relatively stable. One interesting way to measure the rate of output voltage change is to set a DMM on the AC voltage setting, then use that to measure V_{load} as V_{supply} is decreased. While turning the voltage adjustment knob on V_{supply} at a steady rate, students will look for an increase in AC voltage (a greater rate of change) at V_{load}. Essentially, what students are looking for is the point where $\frac{dV_{load}}{dV_{supply}}$ begins to increase.

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

I've used 47 μF electrolytic capacitors and 1N4001 diodes with good success on a 10 volt AC (RMS) power supply. I recommend that students measure their own diodes to determine typical forward voltage (V_F).

Don't forget to mention the polarity sensitivity of these capacitors! Electrolytic capacitors can explode violently if reverse-connected!

Notes 11

I've used 0.47 μF capacitors and 1N4001 diodes with good success on a 10 volt AC (RMS) power supply. I recommend using low-capacity capacitors to minimize the amount of stored energy, since voltages in this circuit are potentially hazardous.

Notes 12

Any diodes will work for this, so long as the source frequency is not too high. I recommend students set the volts/division controls on both channels to the exact same range, so that the slope of the clipped wave near zero-crossing may seen to be exactly the same as the slope of the input sine wave at the same points. This makes it absolutely clear that the output waveform is nothing more than the input waveform with the tops and bottoms cut off.

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 13

Any diodes will work for this, so long as the source frequency is not too high.

I have had good success with the following values:

- V_{source} = 4 volts (peak)
- f_{source} = 3 kHz
- V_{DC} = 6 volts
- C_1 = 0.47 μF
- R_1 = 100 kΩ
- Potentiometer = 10 kΩ, linear
- D_1 = part number 1N4004 (any 1N400x diode should work)

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

Be sure to use zener diodes with reasonably low breakdown voltages, and specify the source voltage accordingly.

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

Identification of BJT terminals is a very important skill for technicians to have. Most modern multimeters have a *diode check* feature which may be used to positively identify PN junction polarities, and this is what I recommend students use for identifying BJT terminals.

To make this a really good performance assessment, you might want to take several BJT's and scratch the identifying labels off, so students cannot refer to memory for pin identification (for instance, if they remember the pin assignments of a 2N2222 because they use it so often). Label these transistors with your own numbers ("1", "2", etc.) so *you* will know which is which, but not the students!

Notes 16

Being able to design a circuit using a BJT as a switch is a valuable skill for technicians and engineers alike to have. The circuit shown in this question is not the only possibility, but it is the simplest.

Remind your students that the equation for calculating BJT power dissipation is as follows:

$$P_Q = I_C\left(V_{CE} + \frac{V_{BE}}{\beta}\right)$$

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 17

Being able to design a circuit using a BJT as a switch is a valuable skill for technicians and engineers alike to have. The circuit shown in this question is not the only possibility, but it is the simplest.

Remind your students that the equation for calculating BJT power dissipation is as follows:

$$P_Q = I_C \left(V_{CE} + \frac{V_{BE}}{\beta} \right)$$

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 18

Being able to design a circuit using a BJT as a switch is a valuable skill for technicians and engineers alike to have.

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

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts.

I highly recommend specifying a large value for R_{series} and/or a high-wattage rated transistor and variable load resistor, so that students do not dissipate excessive power at either the transistor or the load as they test for R_{load} (min). *Do not* use a decade resistance box for R_{load} unless you have made sure its power dissipation will not be exceeded under any circuit condition!

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 20

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts.

I highly recommend specifying a large value for R_{series} and/or a high-wattage rated transistor and variable load resistor, so that students do not dissipate excessive power at either the transistor or the load as they test for R_{load} (min). *Do not* use a decade resistance box for R_{load} unless you have made sure its power dissipation will not be exceeded under any circuit condition!

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 21

I recommend a 47 kΩ resistor for R_1 and a 100 kΩ potentiometer for R_{load}.

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 22

The purpose of this exercise is to get students to understand how AC signals are mixed with DC voltages ("biased") and also how these DC bias voltages are removed to leave just an AC signal. This is important to understand for the purpose of analyzing BJT amplifier circuits.

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal.

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 variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

Notes 24

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, and make sure its amplitude isn't set so high that the amplifier clips.

I have had good success using the following values:

- V_{CC} = 9 volts
- V_{in} = 1 volt RMS, audio frequency
- R_1 = 10 kΩ
- R_2 = 10 kΩ
- R_E = 27 kΩ
- C_1 = 10 µF

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 variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

Notes 26

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, and make sure its amplitude isn't set so high that the amplifier clips.

I have had good success using the following values:

- V_{CC} = 9 volts
- V_{in} = audio-frequency signal, 0.5 volt peak-to-peak
- R_1 = 220 kΩ
- R_2 = 27 kΩ
- R_C = 10 kΩ
- R_E = 1.5 kΩ
- C_1 = 10 μF

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 27

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, and make sure its amplitude isn't set so high that the amplifier clips.

The voltage gain of this amplifier configuration tends to be very high, approximately equal to $\frac{R_C}{r'_e}$. Your students will have to use fairly low input voltages to achieve class A operation with this amplifier circuit. I have had good success using the following values:

- V_{CC} = 12 volts
- V_{in} = 20 mV peak-to-peak, at 5 kHz
- R_1 = 1 kΩ
- R_2 = 4.7 kΩ
- R_C = 100 Ω
- R_E = 1 kΩ
- C_1 = 33 μF

Your students will find the actual voltage gain deviates somewhat from predicted values with this circuit, largely because it is so dependent on the value of r'_e, and that parameter tends to be unpredictable.

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 28

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, about 0.5 volts AC (peak).

Resistor values I have found practical are 10 kΩ for R_C and 2.2 kΩ for R_E. This gives a voltage gain of 4.545, and quiescent current values that are well within the range of common small-signal transistors.

An important aspect of this performance assessment is that students know what to do with the potentiometer. It is their responsibility to configure the circuit so that it operates in Class-A mode, and to explain the importance of proper biasing.

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 29

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, about 0.5 volts AC (peak).

Resistor values I have found practical are 10 kΩ for R_C and 2.2 kΩ for R_E. This gives a voltage gain of 4.545, and quiescent current values that are well within the range of common small-signal transistors.

An important aspect of this performance assessment is that students know what to do with the potentiometer. It is their responsibility to configure the circuit so that it operates in each mode (Class-A, Class-B, and Class-C).

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 30

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, and make sure its amplitude isn't set so high that the amplifier clips.

I have had good success using the following values:

- V_{CC} = 6 volts
- V_{in} = 1 volt (peak)
- $R_1 = R_2$ = 10 kΩ
- $R_3 = R_4$ = 10 Ω
- C_1 = 0.47 μF
- C_2 = 10 μF
- C_3 = 47 μF
- $D_1 = D_2$ = part number 1N4001
- Q_1 = part number 2N2222
- Q_2 = part number 2N2907

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 31

I've experienced good results using the following component values:

- V_{CC} = 12 volts
- R_1 = 220 kΩ
- R_2 = 27 kΩ
- R_3 = 10 kΩ
- R_4 = 1.5 kΩ
- R_5 = 1 kΩ
- C_1 = 0.47 µF
- C_2 = 4.7 µF
- C_3 = 33 µF
- C_4 = 47 µF
- Q_1 and Q_2 = 2N3403

Students have a lot of fun connecting long lengths of cable between the output stage and the speaker, and using this circuit to talk (one-way, simplex communication) between rooms.

One thing I've noticed some students misunderstand in their study of electronic amplifier circuits is their practical purpose. So many textbooks emphasize abstract analysis with sinusoidal voltage sources and resistive loads that some of the real applications of amplifiers may be overlooked by some students. One student of mine in particular, when building this circuit, kept asking me, "so where does the signal generator connect to this amplifier?" He was so used to seeing signal generators connected to amplifier inputs in his textbook (and lab manual!) that he never realized you could use an amplifier circuit to amplify a *real*, practical audio signal!!! An extreme example, perhaps, but real nevertheless, and illustrative of the need for practical application in labwork.

In order for students to measure the voltage gain of this amplifier, they must apply a steady, sinusoidal signal to the input. The microphone and speaker are indeed practical, but the signals produced in such a circuit are too chaotic for students to measure with simple test equipment.

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 variable-voltage, regulated power supply to supply a DC voltage safely below the maximum rating of the electret microphone (typically 10 volts). Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, and make sure its amplitude isn't set so high that the amplifier clips.

I have had good success using the following values:

- V_{CC} = 6 volts
- R_1 = 68 kΩ
- R_2 = 33 kΩ
- R_3 = 4.7 kΩ
- R_4 = 1.5 kΩ
- $R_5 = R_6$ = 10 kΩ
- $R_7 = R_8$ = 10 Ω
- $C_1 = C_2$ = 0.47 μF
- $C_3 = C_4$ = 47 μF
- C_5 = 1000 μF
- C_6 = 100 μF
- $D_1 = D_2$ = part number 1N4001
- Q_1 = part number 2N2222
- Q_2 = part number 2N2222
- Q_3 = part number 2N2907

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

Students are allowed to adjust the bias potentiometer to achieve class-A operation after calculating and inserting the resistance values R_C and R_E. However, they are not allowed to change either R_C or R_E once the circuit is powered and tested, lest they achieve the specified gain through trial-and-error!

A good percentage tolerance for gain is +/- 10%. The lower you set the target gain, the more accuracy you may expect out of your students' circuits. I usually select random values of voltage gain between 2 and 10, and I strongly recommend that students choose resistor values between 1 kΩ and 100 kΩ. Resistor values much lower than 1 kΩ lead to excessive quiescent currents, which may cause accuracy problems (r'_e drifting due to temperature effects).

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 34

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal.

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.

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

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

I suggest using ordinary (general-purpose) signal transistors in this circuit, such as the 2N2222 and 2N3403 (NPN), and the 2N2907 and 2N3906 (PNP) models, operating with a V_{CC} of 12 volts. When constructed as shown, this circuit has sufficient gain to be used as a crude operational amplifier (connect the inverting input to the output through various feedback networks).

These values have worked well for me:

- V_{CC} = 12 volts
- R_1 = 10 kΩ
- R_2 = 10 kΩ
- R_{prg} = 10 kΩ
- R_{pot1} = 10 kΩ
- R_{pot2} = 10 kΩ

I recommend instructing students to set each potentiometer near its mid-position of travel, then slightly adjusting each one to see the sharp change in output voltage as one input voltage crosses the other. If students wish to monitor each of the input voltages to check for a condition of crossing, they should measure right at the transistor base terminals, not at the potentiometer wiper terminals, so as to not incur error resulting from current through protection resistors R_1 or R_2.

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

Identification of JFET terminals is a very important skill for technicians to have. Most modern multimeters have a *diode check* feature which may be used to positively identify PN junction polarities, and this is what I recommend students use for identifying JFET terminals.

To make this a really good performance assessment, you might want to take several JFET's and scratch the identifying labels off, so students cannot refer to memory for pin identification (for instance, if they remember the pin assignments of a J309 because they use it so often). Label these transistors with your own numbers ("1", "2", etc.) so *you* will know which is which, but not the students!

Notes 37

I strongly recommend a value for R1 of 1 MΩ or more, to protect the JFET gate from overcurrent damage. The students will calculate their own dropping resistor value, based on the supply voltage and the LED ratings.

This exercise lends itself to experimentation with static electricity. The input impedance of an average JFET is so high that the LED may be made to turn on and off with just a touch of the probe wire to a charged object (such as a person).

Using only the components shown, students may not be able to get their JFETs to completely turn off. This is left for them as a challenge to figure out!

I expect students to be able to figure out how to calculate the transistor's power dissipation without being told what measurements to take!

Notes 38

I strongly recommend a value for R1 of 1 MΩ or more, to protect the JFET gate from overcurrent damage. The students will calculate their own dropping resistor value, based on the supply voltage and the LED ratings.

This exercise lends itself to experimentation with static electricity. The input impedance of an average JFET is so high that the LED may be made to turn on and off with just a touch of the probe wire to a charged object (such as a person).

Using only the components shown, students may not be able to get their JFETs to completely turn off. This is left for them as a challenge to figure out!

I expect students to be able to figure out how to calculate the transistor's power dissipation without being told what measurements to take!

Notes 39

I recommend a value for R1 of 1 MΩ or more, to show that the bleed resistor need not be very conductive to do its job well. The students will calculate their own dropping resistor value, based on the supply voltage and the LED ratings.

Students predict the LED current (approximately 20 mA) and the switch current (0 mA), and then calculate the transistor's "on" channel resistance and power dissipation after taking additional measurements. I expect students to be able to figure out how to calculate both these parameters without being told what measurements to take!

Notes 40

Being able to design a circuit using a MOSFET as a switch is a valuable skill for technicians and engineers alike to have.

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

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 a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, and make sure its amplitude isn't set so high that the amplifier clips.

I have had good success using the following values:

- V_{DD} = 9 volts
- V_{in} = 1 volt (peak), f = 2 kHz
- R_G = 100 kΩ
- R_S = 10 kΩ
- C_1 = 0.47 μF

Please note that the quiescent output voltage is impossible to precisely predict, as it depends on the particular characteristics of the JFET used (I_D versus V_{GS}). The fact that this circuit uses self-biasing instead of voltage divider biasing makes the situation worse. Predicting quiescent gate voltage, however should be extremely easy (0 volts) if one understands how JFETs function.

An interesting parameter to explore in this circuit is the effect of the source resistor value on voltage gain. The theoretical voltage gain of a simple common-drain amplifier circuit is unity (1), but this may be approximated only with relatively large load resistor (R_S) values. Try substituting a 1 kΩ or less resistor for R_S, and notice what happens to the gain. Then, have your students explain why this happens!

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

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, and make sure its amplitude isn't set so high that the amplifier clips.

I have had good success using the following values:

- V_{DD} = 12 volts
- V_{in} = 0.5 volt (peak-to-peak), f = 2 kHz
- R_G = 100 kΩ
- r_S = 2.2 kΩ
- R_S = 10 kΩ
- R_D = 10 kΩ
- C_1 = 0.47 μF
- C_{bypass} = 10 μF

Please note that the quiescent output voltage is impossible to precisely predict, as it depends on the particular characteristics of the JFET used (I_D versus V_{GS}). The fact that this circuit uses self-biasing instead of voltage divider biasing makes the situation worse. Predicting quiescent gate voltage, however should be extremely easy (0 volts) if one understands how JFETs function.

All quiescent circuit values depend on V_{DD}, so if things aren't biased the way you would like, simply adjust the power supply voltage to suit.

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

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, and make sure its amplitude isn't set so high that the amplifier clips.

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

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, and make sure its amplitude isn't set so high that the amplifier clips at the specified gain.

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 46

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.). Use a sine-wave function generator to supply an audio-frequency input signal, and make sure its amplitude isn't set so high that the amplifier clips.

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 47

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

This circuit produces nice, sharp-edged square wave signals at the transistor collector terminals when resistors R_1 and R_4 are substantially smaller than resistors R_2 and R_3. This way, R_2 and R_3 dominate the capacitors' charging times, making calculation of duty cycle much more accurate. Component values I've used with success are 1 kΩ for R_1 and R_4, 100 kΩ for R_2 and R_3, and 0.1 μF for C_1 and C_2.

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 48

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

This circuit produces nice, sharp-edged square wave signals at the transistor collector terminals when resistors R_1 and R_4 are substantially smaller than resistors R_2 and R_3. This way, R_2 and R_3 dominate the capacitors' charging times, making calculation of duty cycle much more accurate. Component values I've used with success are 470 Ω for R_1 and R_2, 270 kΩ for R_2 and R_3, 4.7 μF for C_1 and C_2, and 6 to 14 volts for V_{CC}. The frequency of this circuit *does* vary with supply voltage, so don't expect perfect agreement between predicted and measured values.

By the way, this circuit works very well for holiday flashing lights – decorate your lab room accordingly with student-built light flashers!

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 49

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

This circuit produces nice, sharp-edged square wave signals at the transistor collector terminals when resistors R_1 and R_4 are substantially smaller than the combined resistance of resistors R_2 and R_3 and the respective potentiometer section resistances. This way, R_{pot}, R_2, and R_3 dominate the capacitors' charging times, making calculation of duty cycle much more accurate. Component values I've used with success are 1 kΩ for R_1 and R_2, 10 kΩ for R_2 and R_3, 100 kΩ for R_{pot}, and 0.001 μF for C_1 and C_2.

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 50

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

This circuit produces nice, sharp-edged square wave signals at the transistor collector terminals when resistors R_1 and R_4 are substantially smaller than the combined resistance of resistors R_2 and R_3 and the respective potentiometer section resistances. This way, R_{pot}, R_2, and R_3 dominate the capacitors' charging times, making calculation of duty cycle much more accurate. Component values I've used with success are 1 kΩ for R_1 and R_2, 10 kΩ for R_2 and R_3, 100 kΩ for R_{pot}, and 0.001 μF for C_1 and C_2.

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.

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

This circuit produces nice, sharp-edged square wave signals at the transistor collector terminals when resistors R_1 and R_4 are substantially smaller than the combined resistance of resistors R_2 and R_3 and the respective potentiometer section resistances. This way, R_{pot}, R_2, and R_3 dominate the capacitors' charging times, making calculation of duty cycle much more accurate. Component values I've used with success are 1 kΩ for R_1 and R_4, 10 kΩ for R_2 and R_3, 100 kΩ for R_{pot}, and 0.001 μF for C_1 and C_2. In my prototype circuit, I used 2N2222 bipolar transistors and an IRF510 power MOSFET.

Although small DC motors work well as demonstrative loads, their counter-EMF may wreak havoc with measurements of average load voltage. Purely resistive loads work best when comparing measured average load voltage against predicted average load voltage. Also, motors and other inductive loads may cause the MOSFET to switch incorrectly (or not switch at all!) unless a commutating diode is installed to limit the voltage induced by the collapsing magnetic field every time the transistor turns off.

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 52

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

This circuit demonstrates the use of passive integrators to convert a square wave into a pseudo-sine wave output. The multivibrator portion produces nice, sharp-edged square wave signals at the transistor collector terminals when resistors R_1 and R_4 are substantially smaller than resistors R_2 and R_3. Component values I've used with success are 1 kΩ for R_1 and R_4, 100 kΩ for R_2 and R_3, and 0.001 μF for C_1 and C_2.

Resistors R_5 and R_6, along with capacitors C_3 and C_4, form a dual passive integrator network to re-shape the square-wave output of the multivibrator into a pseudo-sine wave. These components' values must be chosen according to the multivibrator frequency, so that the integration is realistic without the attenuation being excessive. Integrator component values that have worked well for the multivibrator components previously specified are 10 kΩ for R_5 and R_6, and 0.1 μF for C_3 and C_4.

Transistor Q_3 is just an emitter follower, placed there to give the amplifier section a high input impedance. Q_3's emitter resistor value is not critical. I have used a 1 kΩ resistor for R_7 with good success.

The last transistor (Q_4) is for voltage amplification. A "trimmer" style potentiometer (10 kΩ recommended for R_{pot}) provides easy adjustment of biasing for different supply voltages. Using the potentiometer, I have operated this circuit on supply voltages ranging from -6 volts to -27 volts. Use a bypass capacitor (C_7) large enough that its reactance at the operating frequency is negligible (less than 1 ohm is good), such as 33 μF. Resistor values I've used with success are 10 kΩ for R_8 and 4.7 kΩ for R_9. Coupling capacitor values are not terribly important, so long as they present minimal reactance at the operating frequency. I have used 0.47 μF for both C_5 and C_6 with good success.

You may find that the relatively high operating frequency of this circuit complicates matters with regard to parasitic capacitances. The fast rise and fall times of the strong square wave tend to couple easily to the sine-wave portions of the circuit, especially when the sine wave signal is so severely attenuated by the double integrators. One solution to this dilemma is to lower the operating frequency of the circuit, allowing a lower cutoff frequency for the double integrator (two-pole lowpass filter) section which in turn will improve the signal-to-noise ratio throughout. If you wish to try this, you may use these suggested component values:

- R_1 = 1 kΩ
- R_2 = 100 kΩ
- R_3 = 100 kΩ
- R_4 = 1 kΩ
- R_5 = 100 kΩ
- R_6 = 100 kΩ
- R_7 = 1 kΩ
- R_8 = 10 kΩ
- R_9 = 4.7 kΩ
- R_{pot} = 10 kΩ
- C_1 = 0.047 μF
- C_2 = 0.047 μF
- C_3 = 0.1 μF
- C_4 = 0.047 μF
- C_5 = 1 μF
- C_6 = 1 μF
- C_7 = 33 μF

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 53

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

I have had relatively good success with the following values:

- V_{CC} = 9 volts (from battery)
- C_1 through C_3 = 0.001 µF
- C_4 and C_5 = 4.7 µF
- R_1 through R_3 = 10 kΩ
- R_4 = 270 kΩ
- R_5 = 50 kΩ (two 100 kΩ resistors in parallel)
- R_6 = 12 kΩ (you might want to make this resistor variable so students can experiment with A_V)
- R_7 = 1 kΩ
- Q_1 = part number 2N3403

One of the problems with the RC phase-shift oscillator circuit design is the loading of the phase-shift network by the transistor's biasing network (R_4 and R_5), which will offset the predicted oscillation frequency from what you might expect from the RC network alone. While it is possible to account for all the factors in this circuit, it is not a simple task for students just beginning to understand how the circuit is supposed to work.

I have also noticed that the frequency of this circuit is significantly reduced by the capacitance of any test leads connected to it. Beware of oscilloscope probe cables – the capacitance they add to the circuit will offset the oscillation frequency!

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 54

Use a variable-voltage, regulated power supply to supply any amount of DC voltage below 30 volts. Specify standard resistor values, all between 1 kΩ and 100 kΩ (1k5, 2k2, 2k7, 3k3, 4k7, 5k1, 6k8, 10k, 22k, 33k, 39k 47k, 68k, etc.).

R_{pot} serves the purpose of providing variable AC gain in the first amplifier stage to meet the Barkhausen criterion.

I have had good success with the following values:

- V_{CC} = 12 volts
- C_1 and C_2 = 0.001 µF
- C_3 = 47 µF
- C_4 = 0.47 µF
- R_1 and R_2 = 4.7 kΩ
- R_3 = 4.7 kΩ
- R_4 = 39 kΩ
- R_5 = 22 kΩ
- R_6 = 27 kΩ
- R_7 = 3.3 kΩ
- R_{pot} = 10 kΩ, linear
- Q_1 and Q_2 = part number 2N2222

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 55

I have had great success with the following values:

- V_{CC} = 7 to 24 volts
- C_1 and C_2 = 0.22 μF
- C_3 = 0.47 μF
- L_1 = 100 μH (ferrite core RF choke)
- R_1 = 22 kΩ
- R_2 = 1.5 MΩ
- Q_1 = part number 2N3403

With these component values, the output waveform was quite clean and the frequency was very close to predicted:

$$f_{out} = \frac{1}{2\pi\sqrt{\frac{LC_1C_2}{C_1+C_2}}}$$

You might want to quiz your students on the purpose of resistor R_2, since it usually only has to be present at power-up to initiate oscillation!

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 56

I have had success with the following values:

- V_{CC} = 12 to 24 volts
- C_1 = 0.47 μF
- C_2 = 0.47 μF
- T_1 = 1000:8 Ω audio matching transformer (used as center-tap inductor)
- R_1 = 1.5 MΩ
- Q_1 = part number 2N3403

Capacitors C_1 and C_2 need not be equal value, since they serve entirely different purposes: C_1 is the tank circuit capacitance, while C_2 is merely a coupling capacitor. I just happened to be blessed with an abundance of 0.47 μF capacitors when I prototyped this circuit, so I chose that value for both capacitors!

With these component values, the output waveform I measured was not very sinusoidal, but at least it was oscillating. The harmonic output of a Hartley oscillator is substantially greater than a Colpitts, primary because the two capacitors in the Colpitts design act as decoupling capacitances, shunting high-order harmonic signals to ground.

Of course, in order to predict the frequency of oscillation in this Hartley oscillator circuit, you must know the inductance of the audio transformer's primary winding!

You might want to quiz your students on the purpose of resistor R_1, since it usually only has to be present at power-up to initiate oscillation!

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 57

Students are free to choose any oscillator design that meets the criteria: sinusoidal output at a specified frequency.

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 58

I have had great success with the following values:

- +V = 7 to 24 volts
- C_1 and C_2 = 0.001 μF
- C_3, C_4, and C_5 = 0.47 μF
- L_1 = 100 μH (ferrite core RF choke)
- R_1 = 22 kΩ
- R_2 = 1.5 MΩ
- R_3 = 6.8 kΩ
- R_4 = 100 kΩ
- Q_1 = part number 2N3403
- Q_2 = part number MPF 102

With these component values, the carrier waveform was quite clean and the frequency was almost exactly 700 kHz:

$$f_{out} = \frac{1}{2\pi\sqrt{\frac{LC_1C_2}{C_1+C_2}}}$$

Modulation isn't that great, due to the crude nature of the circuit, but it is certainly good enough to hear over an appropriately tuned AM radio. Setting V_{signal} and f_{signal} is a matter of experimentation, to achieve the desired degree of modulation and tone pitch.

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 59

Identification of SCR terminals is a very important skill for technicians to have. Most modern multimeters have a *diode check* feature which may be used to positively identify PN junction polarities, and this is what I recommend students use for identifying SCR terminals.

This exercise may be made even more interesting if students must differentiate between SCR's with sensitive gates versus SCR's without sensitive gates!

To make this a really good performance assessment, you might want to take several SCR's and scratch the identifying labels off, so students cannot refer to memory for pin identification. Label these thyristors with your own numbers ("1", "2", etc.) so *you* will know which is which, but not the students!

Notes 60

I have had good success using 12 volts DC for the supply voltage, an MCR8SN silicon-controlled rectifier, and a small brushless DC fan motor (80 mA running current) as the load. The MCR8SN is a "sensitive gate" SCR, which makes it easy to demonstrate static triggering (just *touch* the gate terminal with your finger to start the motor!). Some SCR's may be difficult to keep latched with low-current loads, so be sure to prototype your SCR/load combination before assigning part numbers to your students!

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 61

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 62

Any relevant notes for the assessment activity go here.