ELTR 125 (Semiconductors 2), section 1

Recommended schedule

Day 1

Topics: *The BJT as a linear amplifier, current mirrors*
Questions: *1 through 15*
Lab Exercise: *Current mirror (question 76)*

Day 2

Topics: *Common-collector BJT amplifiers, transistor amplifier biasing*
Questions: *16 through 30*
Lab Exercise: *Signal biasing/unbiasing network (question 77)*

Day 3

Topics: *Common-emitter BJT amplifiers*
Questions: *31 through 45*
Lab Exercise: *Common-collector amplifier circuit (question 78)*

Day 4

Topics: *Common-base BJT amplifiers, gain expressed in decibels*
Questions: *46 through 60*
Lab Exercise: *Common-emitter amplifier circuit (question 79)*

Day 5

Topics: *Input and output impedances of amplifier circuits*
Questions: *61 through 75*
Lab Exercise: *Common-base amplifier circuit (question 80)*

Day 6

Exam 1: *includes Amplifier with specified voltage gain performance assessment*
Lab Exercise: *Troubleshooting practice (oscillator/amplifier circuit – question 81)*

Troubleshooting practice problems

Questions: *84 through 93*

General concept practice and challenge problems

Questions: *94 through the end of the worksheet*

Impending deadlines

Troubleshooting assessment (oscillator/amplifier) due at end of ELTR125, Section 3
Question 82: Troubleshooting log
Question 83: Sample troubleshooting assessment grading criteria

Skill standards addressed by this course section

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

D Technical Skills – Discrete Solid-State Devices
D.12 Understand principles and operations of single stage amplifiers.
D.13 Fabricate and demonstrate single stage amplifiers.
D.14 Troubleshoot and repair single stage amplifiers.

B Basic and Practical Skills – Communicating on the Job
B.01 Use effective written and other communication skills. *Met by group discussion and completion of labwork.*
B.03 Employ appropriate skills for gathering and retaining information. *Met by research and preparation prior to group discussion.*
B.04 Interpret written, graphic, and oral instructions. *Met by completion of labwork.*
B.06 Use language appropriate to the situation. *Met by group discussion and in explaining completed labwork.*
B.07 Participate in meetings in a positive and constructive manner. *Met by group discussion.*
B.08 Use job-related terminology. *Met by group discussion and in explaining completed labwork.*
B.10 Document work projects, procedures, tests, and equipment failures. *Met by project construction and/or troubleshooting assessments.*
C Basic and Practical Skills – Solving Problems and Critical Thinking
C.01 Identify the problem. *Met by research and preparation prior to group discussion.*
C.03 Identify available solutions and their impact including evaluating credibility of information, and locating information. *Met by research and preparation prior to group discussion.*
C.07 Organize personal workloads. *Met by daily labwork, preparatory research, and project management.*
C.08 Participate in brainstorming sessions to generate new ideas and solve problems. *Met by group discussion.*
D Basic and Practical Skills – Reading
D.01 Read and apply various sources of technical information (e.g. manufacturer literature, codes, and regulations). *Met by research and preparation prior to group discussion.*
E Basic and Practical Skills – Proficiency in Mathematics
E.01 Determine if a solution is reasonable.
E.02 Demonstrate ability to use a simple electronic calculator.
E.05 Solve problems and [sic] make applications involving integers, fractions, decimals, percentages, and ratios using order of operations.
E.06 Translate written and/or verbal statements into mathematical expressions.
E.09 Read scale on measurement device(s) and make interpolations where appropriate. *Met by oscilloscope usage.*
E.12 Interpret and use tables, charts, maps, and/or graphs.
E.13 Identify patterns, note trends, and/or draw conclusions from tables, charts, maps, and/or graphs.
E.15 Simplify and solve algebraic expressions and formulas.
E.16 Select and use formulas appropriately.
E.17 Understand and use scientific notation.

Common areas of confusion for students

Difficult concept: *Inverting nature of common-emitter amplifier.*

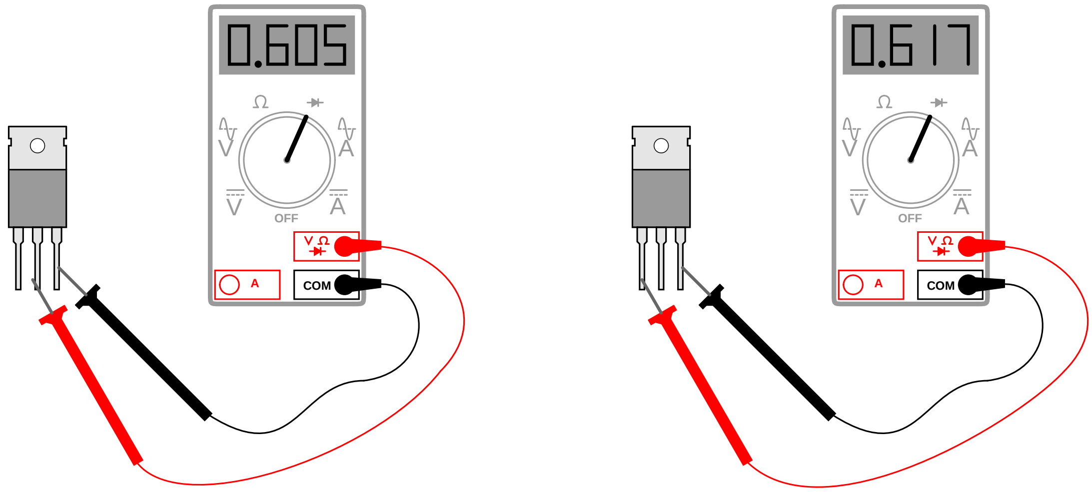
Some students find it quite difficult to grasp why the DC output voltage of a common-emitter amplifier *decreases* as the DC input voltage level increases. Step-by-step DC analysis of the circuit is the only remedy I have found to this conceptual block: getting students to carefully analyze what happens as voltages increase and decrease.

Difficult concept: *Transistor biasing.*

Transistors (at least BJTs) are unilateral, DC-only devices, which leads to a problem if we wish to use them to amplify AC signals. The way we usually get around this is to *bias* them with a DC voltage in order to "trick" them into staying in conduction through more of the AC cycle. Realizing that biasing is nothing more than a clever trick used to make a DC-only device handle AC signals is a major step in understanding how it works.

Question 1

A technician uses a multimeter's "diode check" function to identify the terminals on a BJT. There are only two places where a non-infinite reading is obtained, and they are as follows:

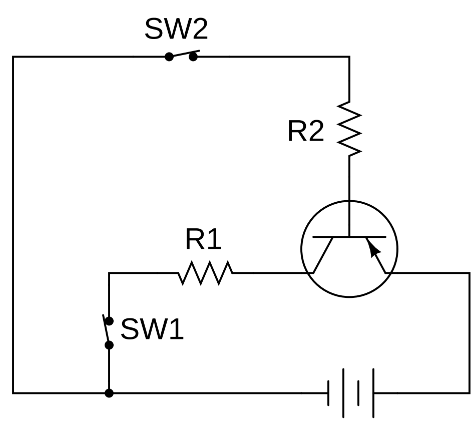


From these measurements, determine what type of BJT this is (PNP or NPN) and identify all three terminals.

file 03745

Question 2

Trace the directions of all currents in this circuit, and determine which current is larger: the current through resistor R1 or the current through resistor R2, assuming equal resistor values.



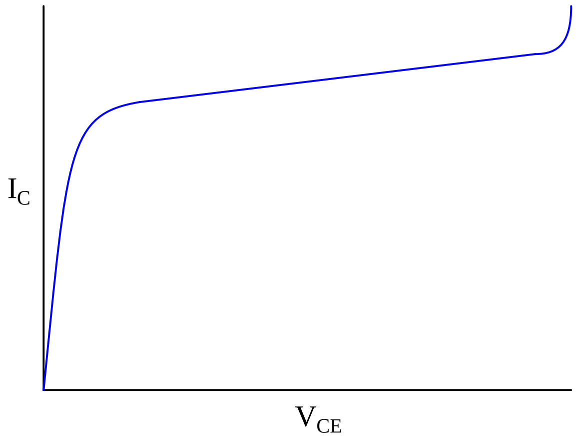
If switch SW2 were opened (and switch SW1 remained closed), what would happen to the currents through R1 and R2?

If switch SW1 were opened (and switch SW2 remained closed), what would happen to the currents through R1 and R2?

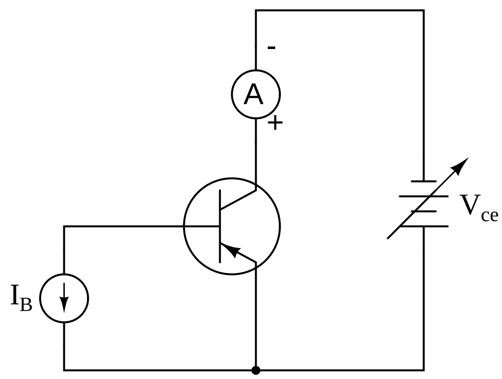
file 00522

Question 3

A very important measure of a transistor's behavior is its *characteristic curves*, a set of graphs showing collector current over a wide range of collector-emitter voltage drops, for a given amount of base current. The following plot is a typical curve for a bipolar transistor with a fixed value of base current:



A "test circuit" for collecting data to make this graph looks like this:

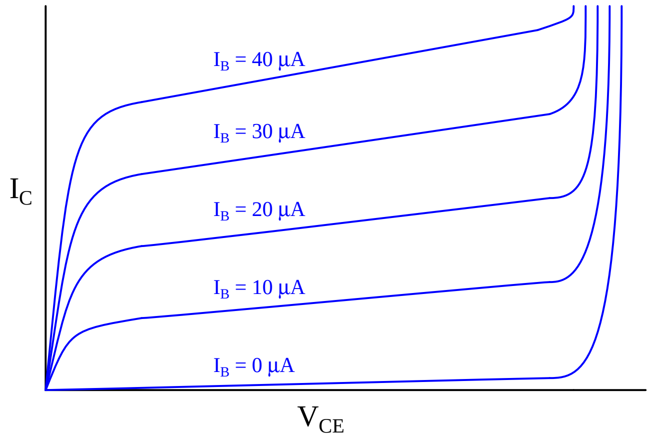


Identify three different regions on this graph: *saturation*, *active*, and *breakdown*, and explain what each of these terms mean. Also, identify which part of this curve the transistor acts most like a current-regulating device.

file 00940

Question 4

If a transistor is subjected to several different base currents, and the collector-emitter voltage (V_{CE}) "swept" through the full range for each of these base current values, data for an entire "family" of characteristic curves may be obtained and graphed:

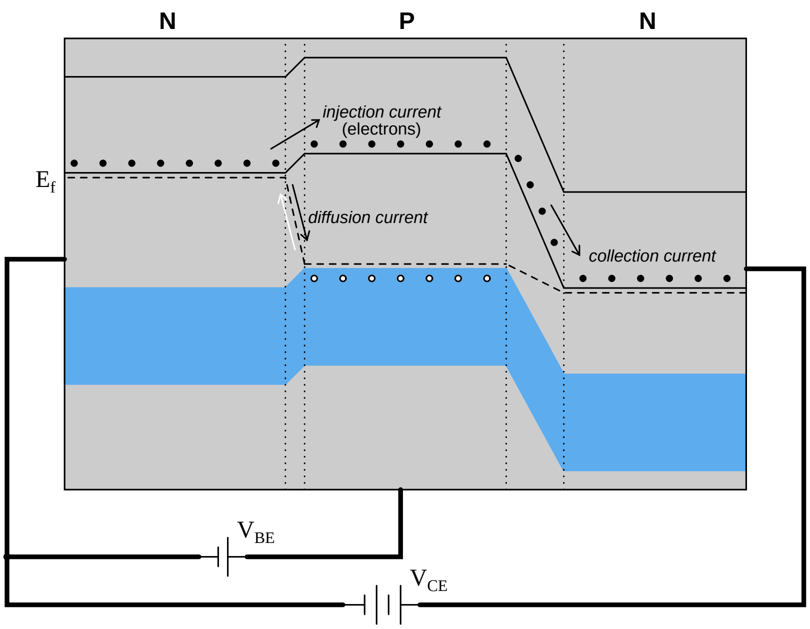


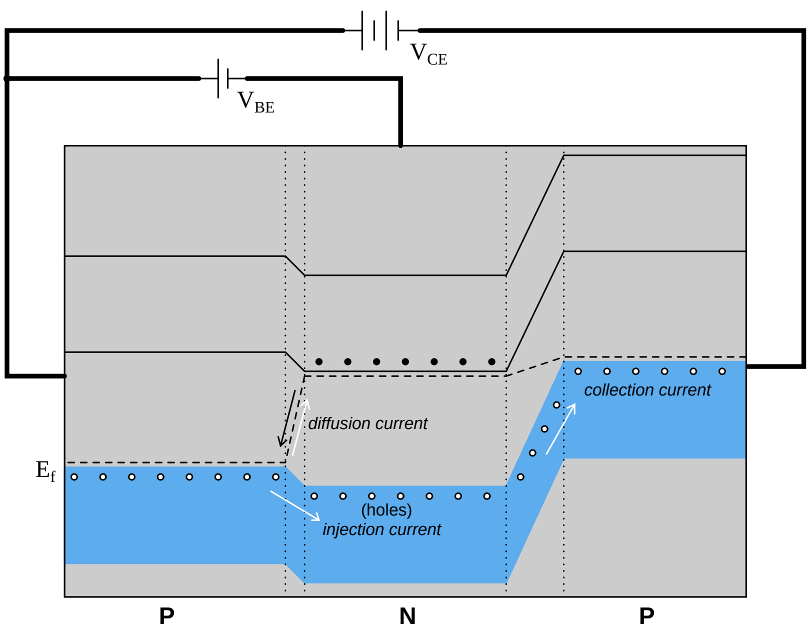
What do these characteristic curves indicate about the base current's control over collector current? How are the two currents related?

file 00941

Question 5

Conduction of an electric current through the collector terminal of a bipolar junction transistor requires that minority carriers be "injected" into the base region by a base-emitter current. Only after being injected into the base region may these charge carriers be swept toward the collector by the applied voltage between emitter and collector to constitute a collector current:





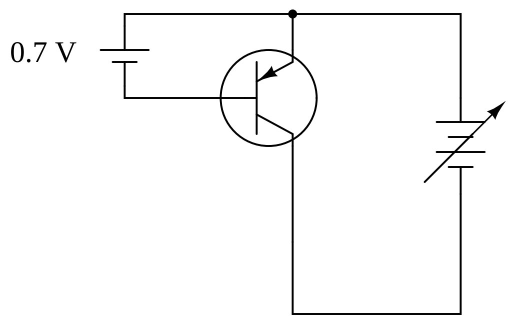
An analogy to help illustrate this is a person tossing flower petals into the air above their head, while a breeze carries the petals horizontally away from them. None of the flower petals may be "swept" away by the breeze until the person releases them into the air, and the velocity of the breeze has no bearing on how many flower petals are swept away from the person, since they must be released from the person's grip before they can go anywhere.

By referencing either the energy diagram or the flower petal analogy, explain why the collector current for a BJT is strongly influenced by the base current and only weakly influenced by the collector-to-emitter voltage.

file 02482

Question 6

Based on what you know about bipolar junction transistors, what will the collector current do (increase, decrease, or remain the same) if the variable voltage source increases in voltage? The small, fixed voltage source (0.7 volts) is just enough to make the transistor conduct, but not enough to fully saturate it.

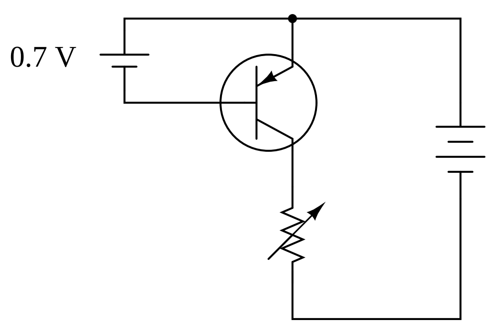


From the variable voltage source's perspective, what does the transistor circuit "look" like? It certainly does not look resistive, because a resistive circuit would increase current linearly with increases in applied voltage! If you could relate the behavior of this circuit to a common idealized electrical component, what would it be?

file 00895

Question 7

Based on what you know about bipolar junction transistors, what will the collector current do (increase, decrease, or remain the same) if the variable resistor's resistance is decreased? The small voltage source (0.7 volts) is just enough to make the transistor conduct, but not enough to fully saturate it.

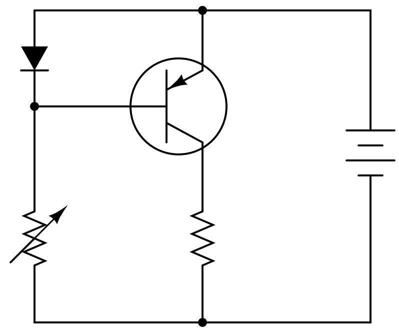


From the variable resistor's perspective, what does the rest of the transistor circuit "look" like?

file 02165

Question 8

Describe what happens to the collector current of the transistor as the variable resistor's value is changed:



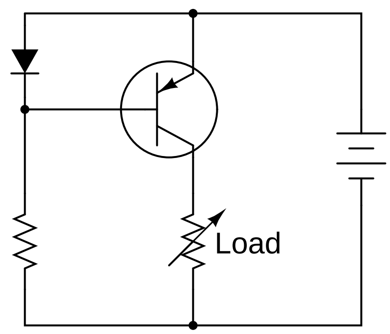
Hint: it is helpful to remember that the voltage drop across a PN junction is not exactly constant as the current through it varies. There is a nonlinear relationship between diode voltage drop (V_D) and diode current (I_D) as described by the *diode equation*:

$$I_D = I_S(e^{\left(\frac{qV_D}{NkT}\right)} - 1)$$

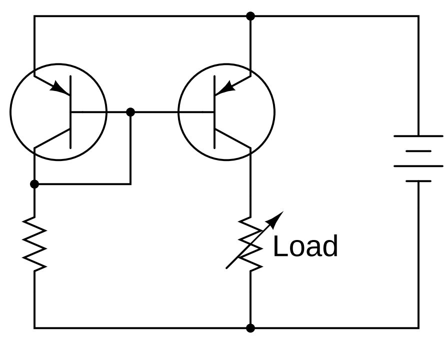
file 02166

Question 9

The circuit shown here is a simple *current mirror*. Explain what happens as the load resistance changes:



Most current mirrors are not built exactly like this. Instead of a diode, they use a transistor (identical to the other transistor) with the base and collector terminals shorted together:

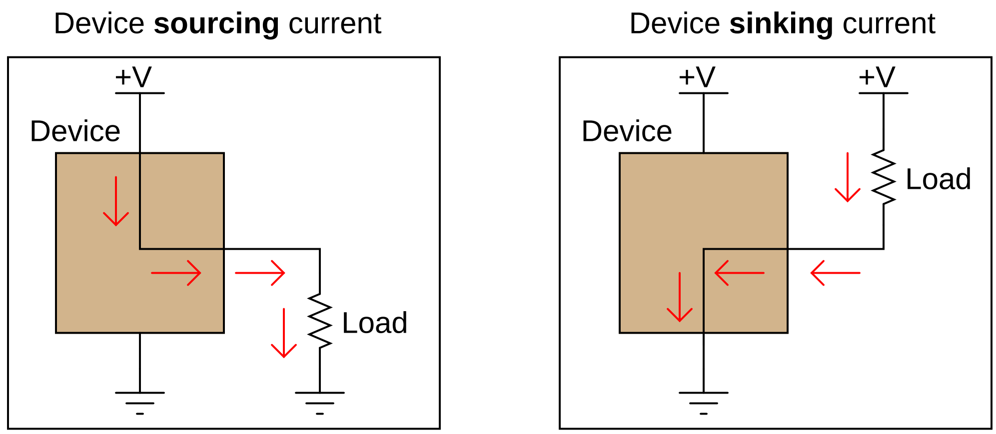


Ideally, the two transistors are built on the same substrate material, so as to always be at equal temperature. Explain why this design is preferable to the first circuit (using the diode) shown in this question.

file 00896

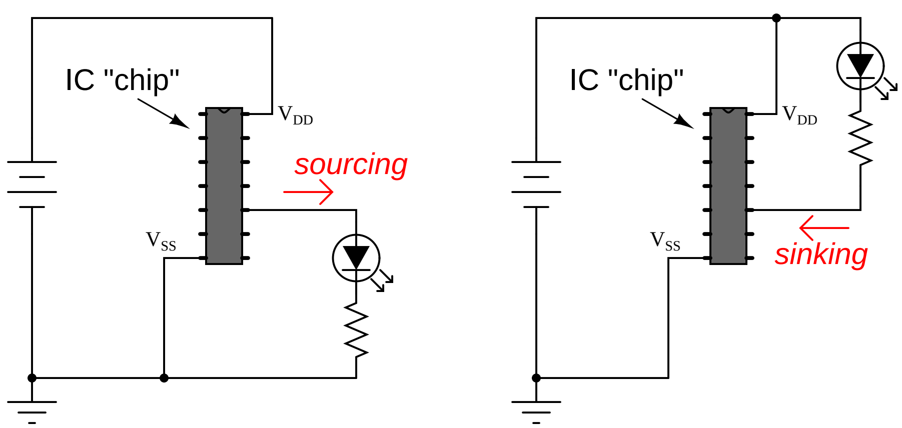
Question 10

Two terms used commonly in electronics are *sourcing* and *sinking*, in reference to the direction of electric current between an active circuit and a load:



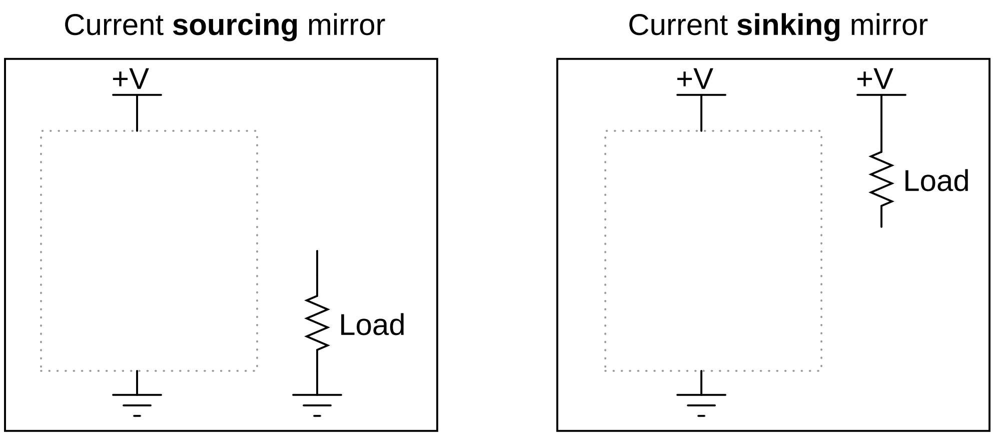
(All current directions shown in "conventional flow" notation)

A practical example of where this distinction is important is in certain integrated circuits (IC "chips") where output pins may be able to only sink current, only source current, or both sink and source current.. Take a look at these two examples, each where an integrated circuit "chip" controls power to an LED. In one instance the IC is wired to source current to the LED, and in the other instance it is wired to sink current from the LED:



If an IC is only able to do one or the other (source *or* sink current, but not both), it makes a big difference how you connect load devices to it! What makes the difference between a circuit that is able to source current versus a circuit that is able to sink current is the internal configuration of its transistors.

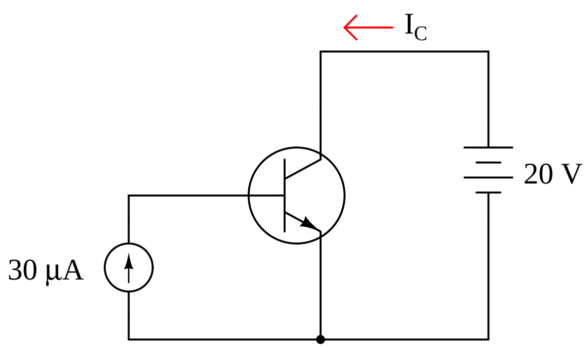
Similarly, a current mirror circuit may be built to either source current or sink current, but not do both. Draw current mirror circuits within the dotted-line boxes suitable for sourcing and sinking current to a load resistor:

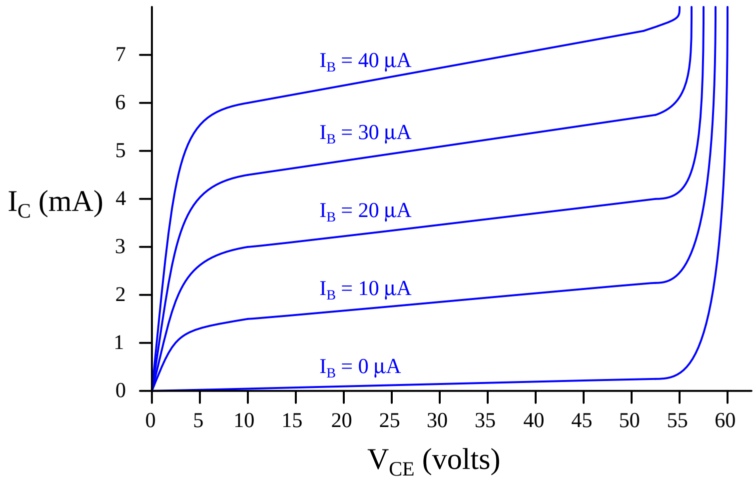


file 00897

Question 11

Determine the approximate amount of collector current for this transistor circuit, given the following characteristic curve set for the transistor:

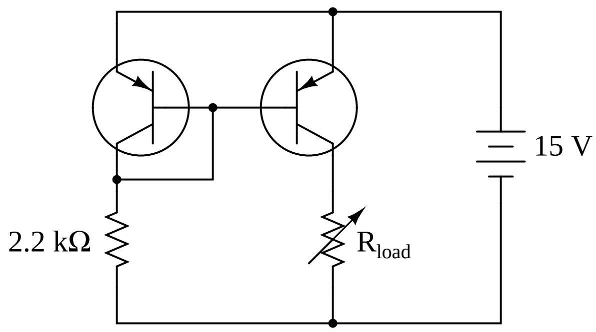




file 02435

Question 12

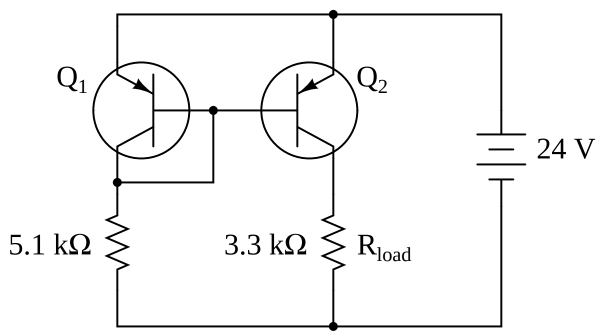
Calculate the approximate amount of current this current mirror circuit will try to maintain through R_{load}, assuming silicon transistors (0.7 volts forward base-emitter junction drop):



file 02432

Question 13

Calculate the approximate amount of current this current mirror circuit will try to maintain through R_{load}, assuming silicon transistors (0.7 volts forward base-emitter junction drop):

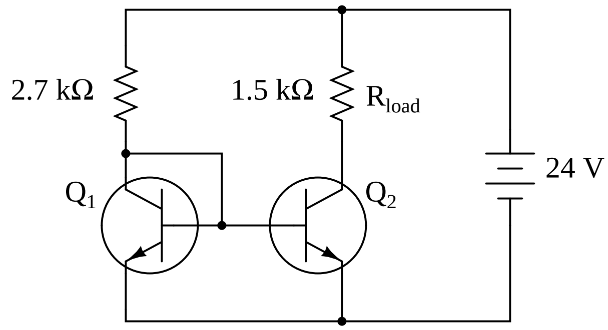


Also, calculate the approximate power dissipation of transistor Q_2.

file 02433

Question 14

Calculate the approximate amount of current this current mirror circuit will try to maintain through R_{load}, assuming silicon transistors (0.7 volts forward base-emitter junction drop):

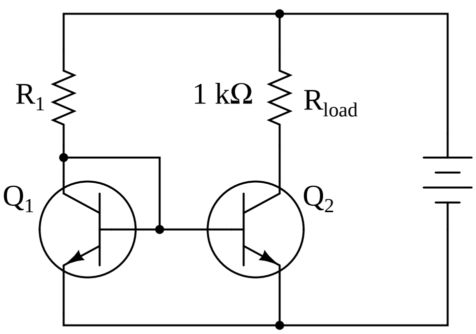


Also, calculate the approximate power dissipation of both transistors.

file 02434

Question 15

Choose a power supply voltage and resistance value for R_1 that will maintain approximately 15 mA of current through the 1 kΩ load resistor. Assume the use of a silicon transistor:

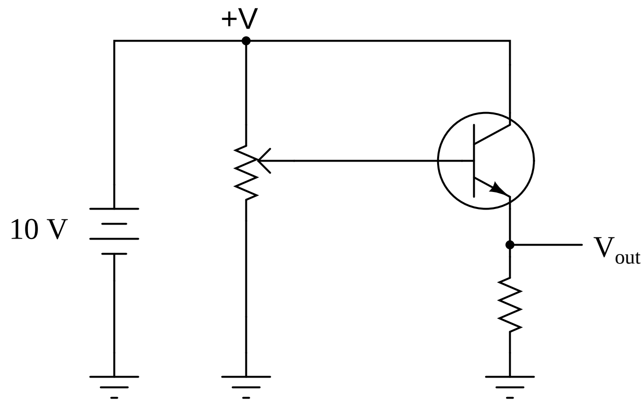


To ensure plenty of regulation range (the ability to maintain regulated current over a wide range of load resistance values), design your circuit so that at least 20 volts V_{CE} are dropped across transistor Q_2. Also, calculate the approximate power dissipation of transistor Q_2.

file 02437

Question 16

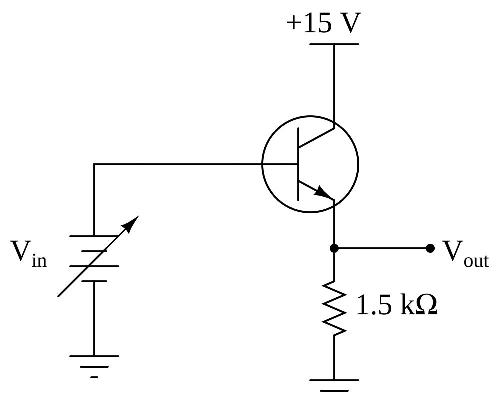
Describe what the output voltage of this transistor circuit will do (measured with reference to ground), if the potentiometer wiper begins at the full-down position (common with ground), and is slowly moved in the *upward* direction (closer to +V):



file 02220

Question 17

Complete the table of output voltages for several given values of input voltage in this common-collector amplifier circuit. Assume that the transistor is a standard silicon NPN unit, with a nominal base-emitter junction forward voltage of 0.7 volts:



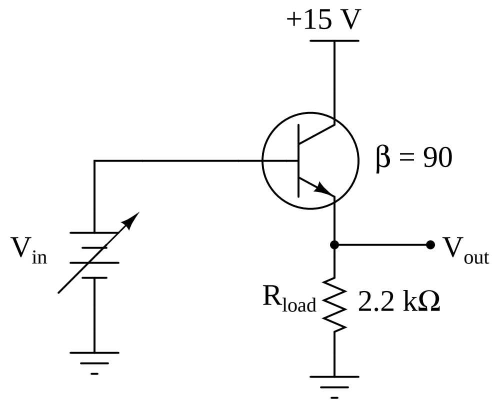
V_{in}	V_{out}
0.0 V	
0.5 V	
1.0 V	
1.5 V	
5.0 V	
7.8 V	

Based on the values you calculate, explain why the common-collector circuit configuration is often referred to as an *emitter follower*.

file 02224

Question 18

Complete the table of output voltages, output currents, and input currents for several given values of input voltage in this common-collector amplifier circuit. Assume that the transistor is a standard silicon NPN unit, with a nominal base-emitter junction forward voltage of 0.7 volts:



V_{in}	V_{out}	I_{in}	I_{out}
0.0 V			
0.4 V			
1.2 V			
3.4 V			
7.1 V			
10.8 V			

Calculate the voltage and current gains of this circuit from the numerical values in the table:

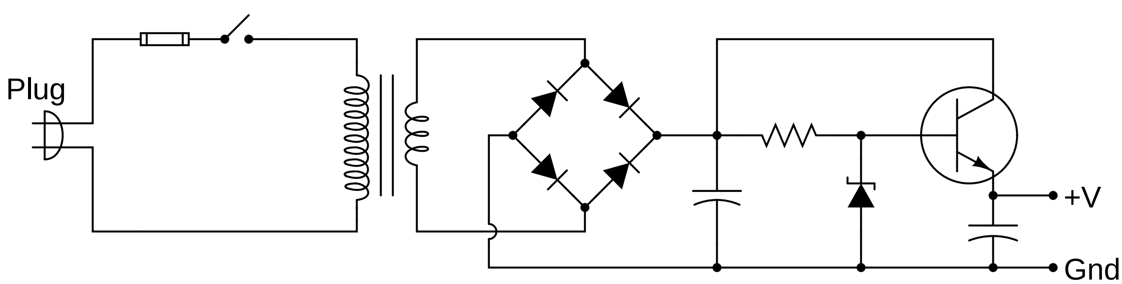
$$A_V = \frac{\Delta V_{out}}{\Delta V_{in}} =$$

$$A_I = \frac{\Delta I_{out}}{\Delta I_{in}} =$$

file 02225

Question 19

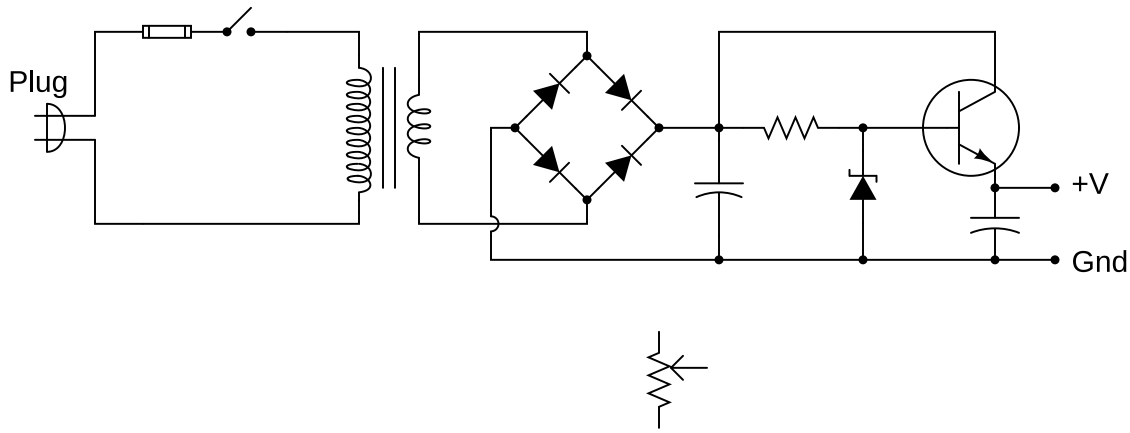
Describe the purpose of the transistor in this AC-DC power supply circuit:



file 00892

Question 20

Install a potentiometer in this circuit so that the regulated output voltage of this power supply becomes adjustable:

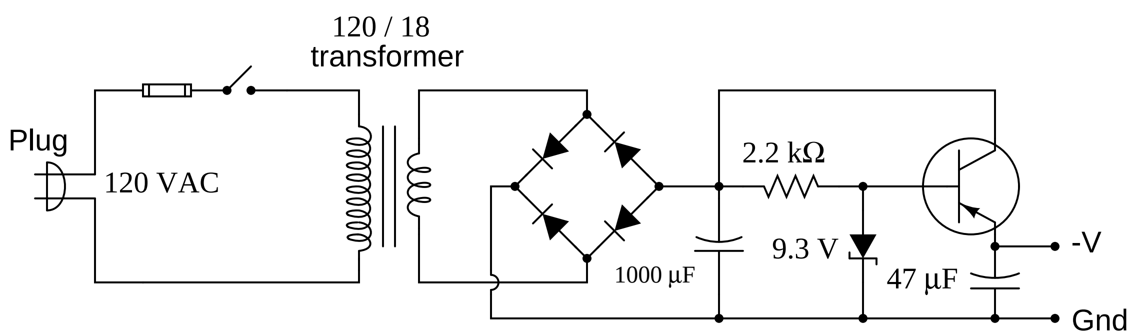


Challenge: leave the potentiometer symbol in its place, and make the necessary wire connections between it and the rest of the circuit!

file 00893

Question 21

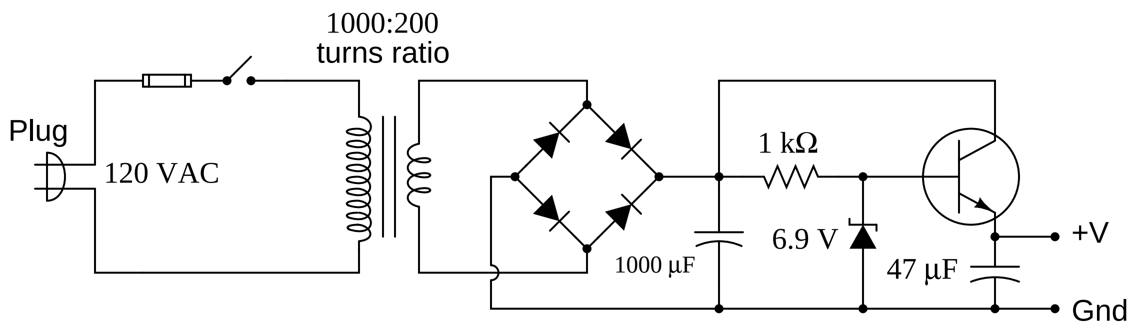
Calculate the approximate output voltage of this regulated power supply circuit and the amount of current through the zener diode under no-load conditions:



file 02440

Question 22

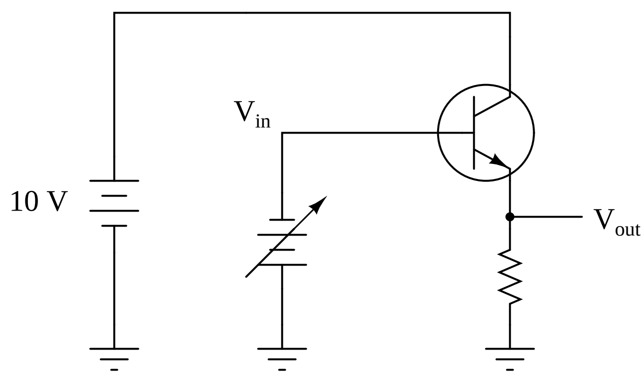
Calculate the approximate output voltage of this regulated power supply circuit, the amount of current through the zener diode, and the (unregulated) voltage across the 1000 μF capacitor, all under no-load conditions:



file 02439

Question 23

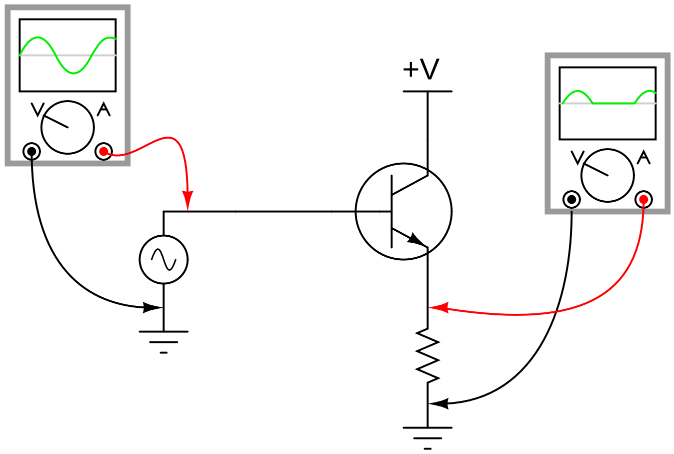
Describe what the output voltage of this transistor circuit will do (measured with reference to ground), if the input voltage ramps from 0 volts to -10 volts (measured with respect to ground):



file 02221

Question 24

If we were to apply a sinusoidal AC signal to the input of this transistor amplifier circuit, the output would definitely *not* be sinusoidal:

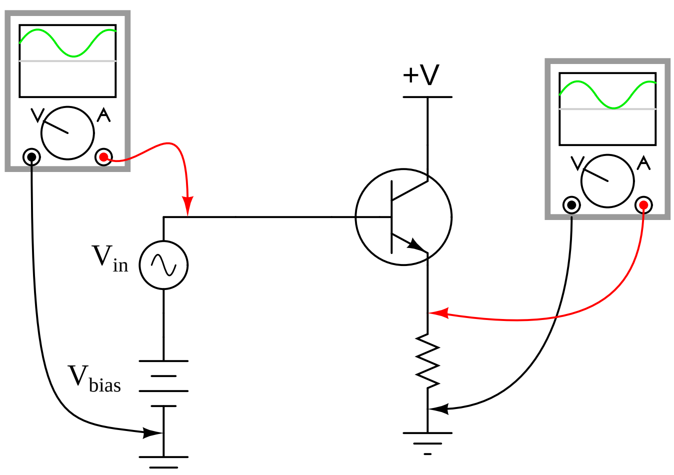


It should be apparent that only portions of the input are being reproduced at the output of this circuit. The rest of the waveform seems to be "missing," being replaced by a flat line. Explain why this transistor circuit is not able to amplify the *entire* waveform.

file 02222

Question 25

Class-A operation may be obtained from this simple transistor circuit if the input voltage (V_{in}) is "biased" with a series-connected DC voltage source:

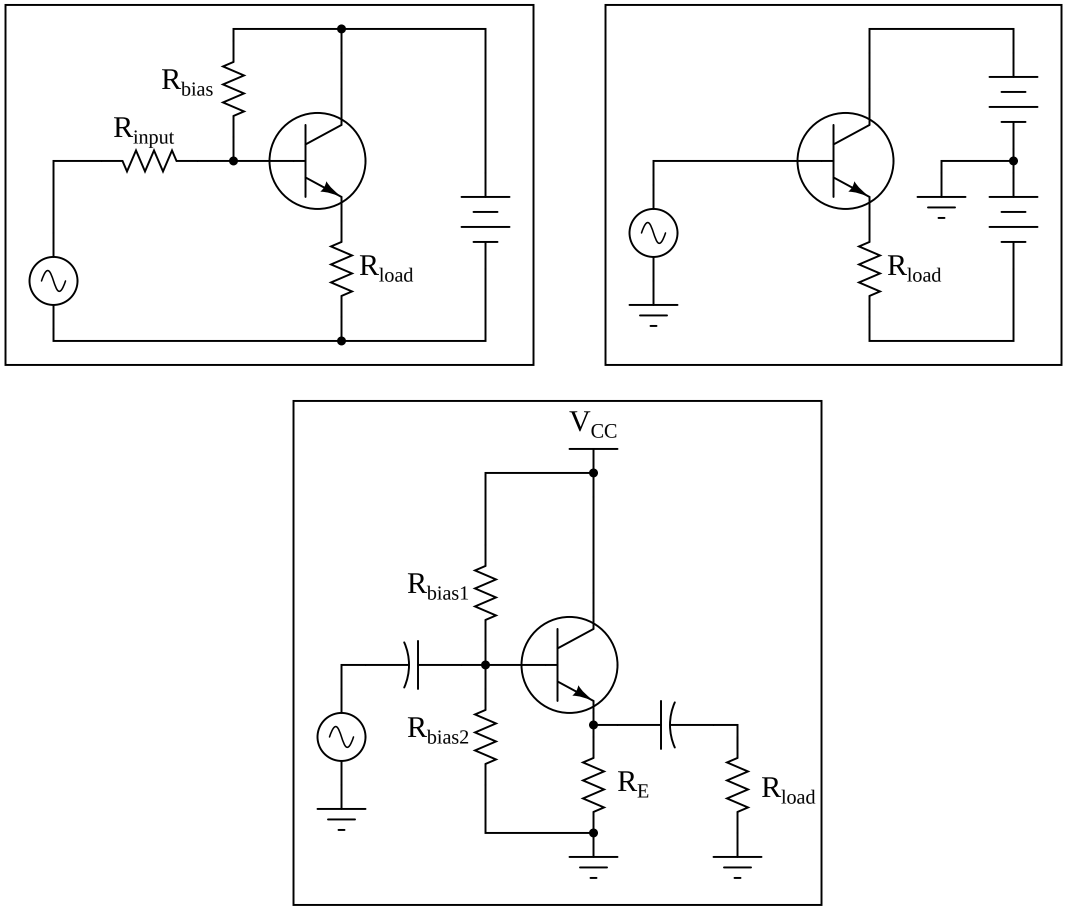


First, define what "Class A" amplifier operation is. Then, explain *why* biasing is required for this transistor to achieve it.

file 02223

Question 26

Explain how the following bias networks function:



Each one has the same basic purpose, but works in a different way to accomplish it. Describe the purpose of any biasing network in an AC signal amplifier, and comment on the different means of accomplishing this purpose employed by each of the three circuits.

Hint: imagine if the AC signal source in each circuit were turned off (replaced with a short). Explain how each biasing network maintains the transistor in a partially "on" state at all times even with no AC signal input.

file 02229

Question 27

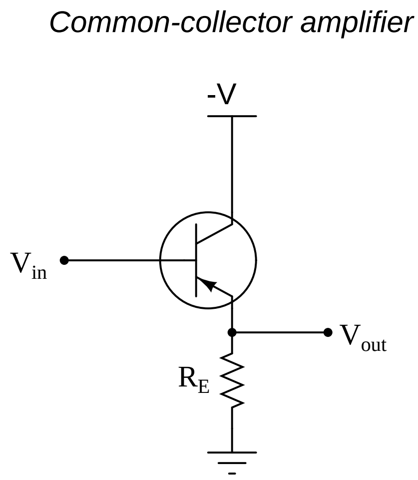
Define what a *common-collector* transistor amplifier circuit is. What distinguishes this amplifier configuration from the other single-BJT amplifier configurations, namely *common-emitter* and *common-base*?

Also, describe the typical gains (voltage and current) of this amplifier configuration, and whether it is *inverting* or *noninverting*.

file 02226

Question 28

The following schematic diagram shows a simple *common-collector* transistor amplifier circuit:



Explain why the AC voltage gain ($A_{V(AC)}$) of such an amplifier is approximately 1, using any or all of these general "rules" of transistor behavior:

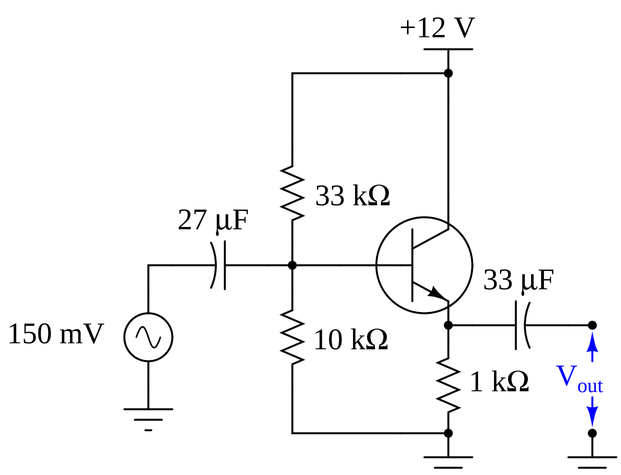
- $I_E = I_C + I_B$
- $I_E \approx I_C$
- $V_{BE} \approx 0.7$ volts
- $\beta = \frac{I_C}{I_B}$

Remember that AC voltage gain is defined as $\frac{\Delta V_{out}}{\Delta V_{in}}$.

file 01523

Question 29

Calculate the approximate amount of AC voltage output by this common-collector amplifier circuit:

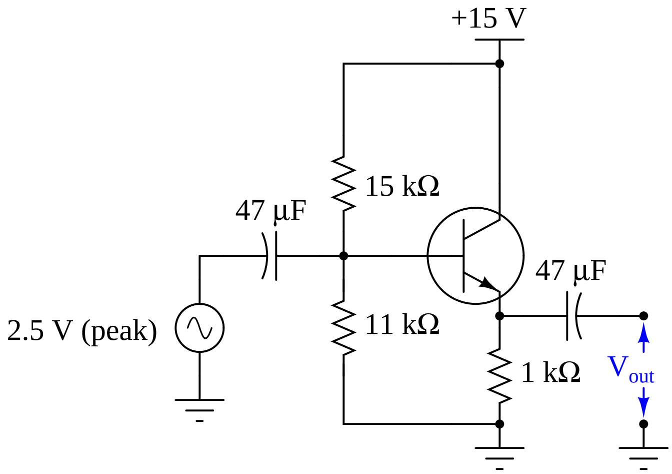


Also, explain why the reactance of each capacitor is a negligible factor in the operation of this amplifier circuit, assuming a signal frequency of 5 kHz.

file 02438

Question 30

Calculate the approximate amount of AC voltage output by this common-collector amplifier circuit:

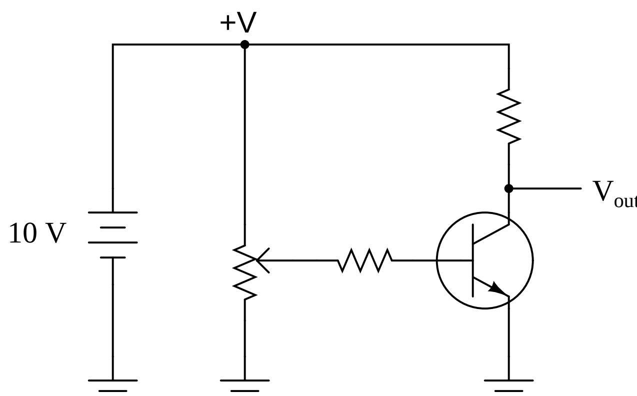


Also, determine a signal frequency value that yields less than 1 ohm of reactance for each of the two coupling capacitors.

file 02441

Question 31

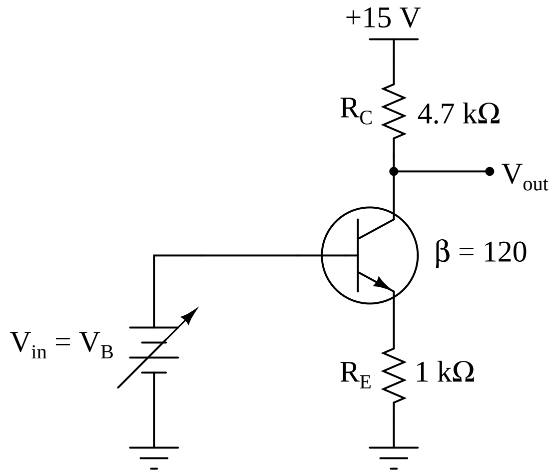
Describe what the output voltage of this transistor circuit will do (measured with reference to ground), if the potentiometer wiper begins at the full-down position (common with ground), and is slowly moved in the *upward* direction (closer to +V):



file 00822

Question 32

Complete the table of voltages and currents for several given values of input voltage in this common-emitter amplifier circuit. Assume that the transistor is a standard silicon NPN unit, with a nominal base-emitter junction forward voltage of 0.7 volts. For the last row of the table, give qualitative answers (*increase*, *decrease*, or *same*) representing what each of the quantities will do given an increasing base voltage (V_B):



V_B	V_E	I_C	V_{R_C}	V_{CE}	V_C (V_{out})
0.0 V					
0.5 V					
1.0 V					
1.5 V					
2.0 V					
2.5 V					
3.0 V					
increase					

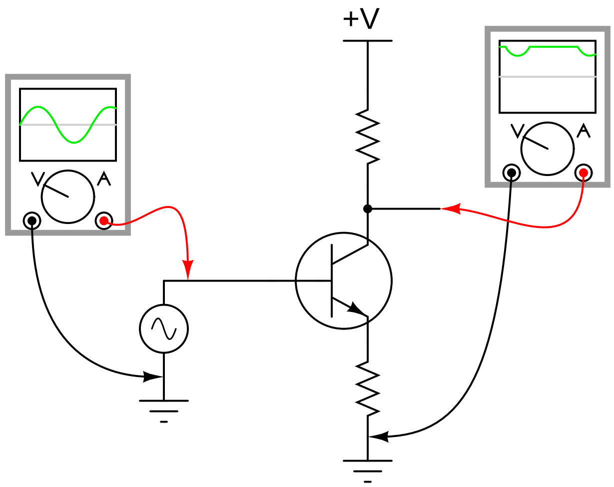
Calculate the voltage gain of this circuit from the numerical values in the table:

$$A_V = \frac{\Delta V_{out}}{\Delta V_{in}} =$$

file 02230

Question 33

If we were to apply a sinusoidal AC signal to the input of this transistor amplifier circuit, the output would definitely *not* be sinusoidal:

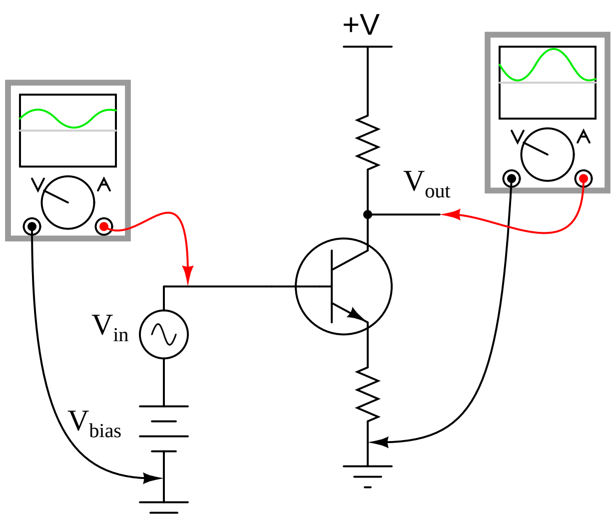


It should be apparent that only portions of the input are being amplified in this circuit. The rest of the waveform seems to be "missing" in the output, being replaced by a flat line. Explain why this transistor circuit is not able to amplify the entire waveform.

file 00746

Question 34

Class-A operation may be obtained from this simple transistor circuit if the input voltage (V_{in}) is "biased" with a series-connected DC voltage source:

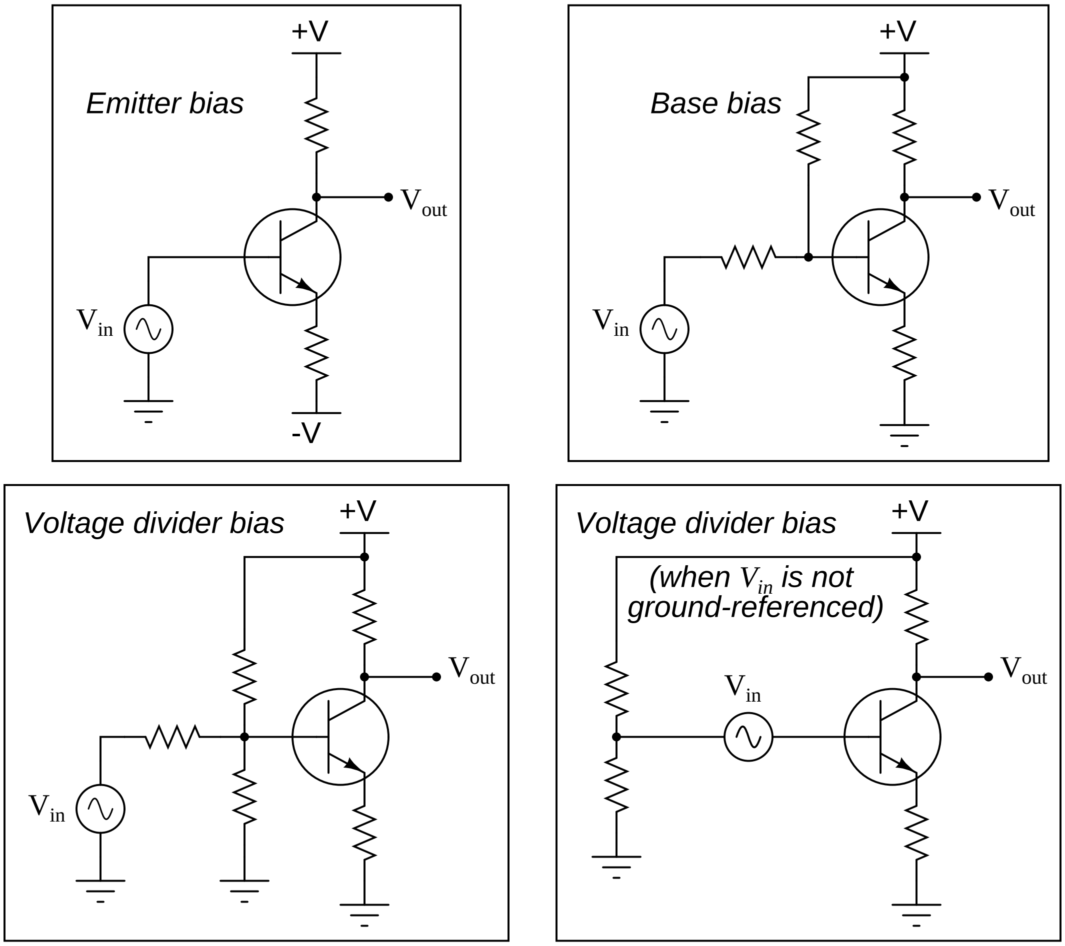


First, define what "Class A" amplifier operation is. Then, explain *why* biasing is required for this transistor to achieve it.

file 00747

Question 35

Explain how the following bias networks function:

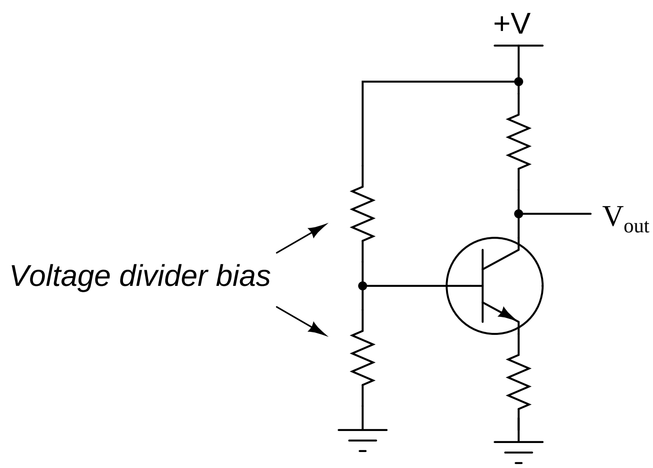


Each one has the same basic purpose, but works in a different way to accomplish it. Describe the purpose of any biasing network in an AC signal amplifier, and comment on the different means of accomplishing this purpose employed by each of the three circuits.

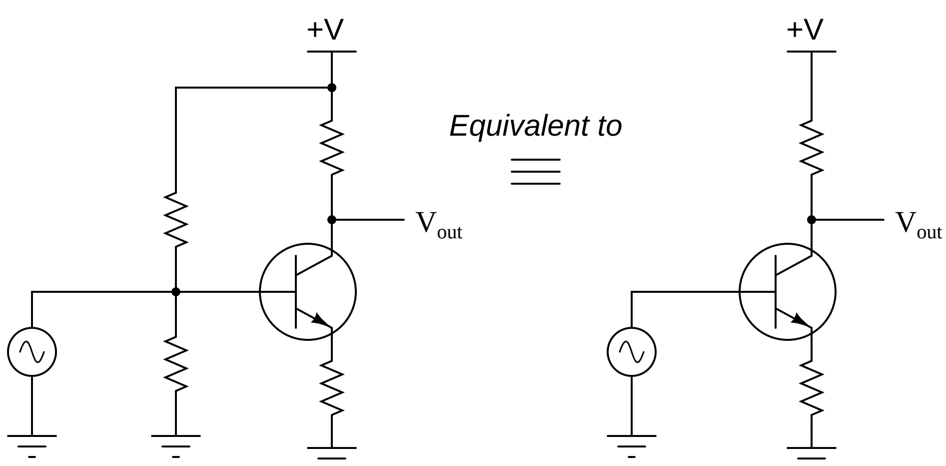
file 00749

Question 36

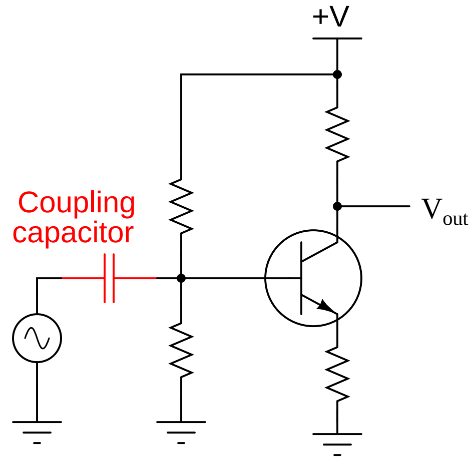
A *very* common method of providing bias voltage for transistor amplifier circuits is with a voltage divider:



However, if we were to directly connect a source of AC signal voltage to the junction between the two voltage divider resistors, the circuit would most likely function as if there were no voltage divider network in place at all:



Instead, circuit designers usually place a *coupling capacitor* between the signal source and the voltage divider junction, like this:

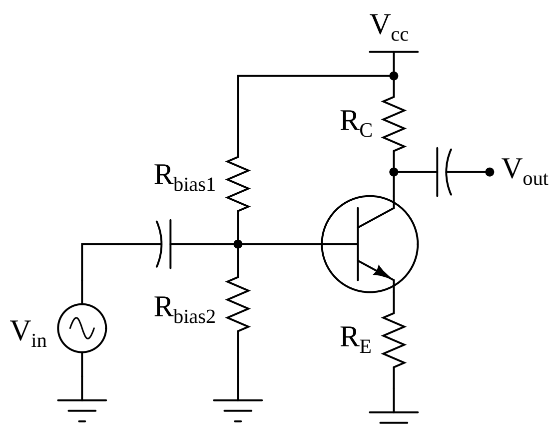


Explain why a coupling capacitor is necessary to allow the voltage divider to work in harmony with the AC signal source. Also, identify what factors would be relevant in deciding the size of this coupling capacitor.

file 01591

Question 37

Determine what would happen to the voltage gain of a common-emitter transistor amplifier circuit if the following resistance values were changed (consider one change at a time):

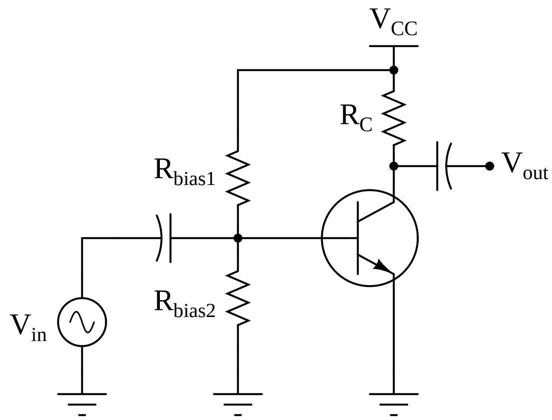


- Resistance R_C increased; A_V . . .
- Resistance R_E increased; A_V . . .
- Resistance R_{bias1} increased; A_V . . .
- Resistance R_{bias2} increased; A_V . . .

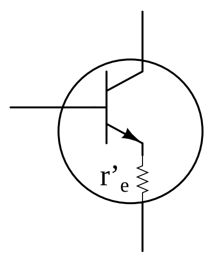
file 02231

Question 38

A student attempts to calculate the voltage gain of the following common-emitter amplifier circuit, and arrives at an incalculable value (divide-by-zero error):



According to a simple formula for approximating the voltage gain of this type of amplifier, it would indeed seem as though this circuit would have infinite voltage gain with zero emitter resistance. However, even with no emitter resistor installed in such a circuit, the transistor itself contains a small amount of resistance intrinsic to the semiconductor material, commonly symbolized as r'_e:

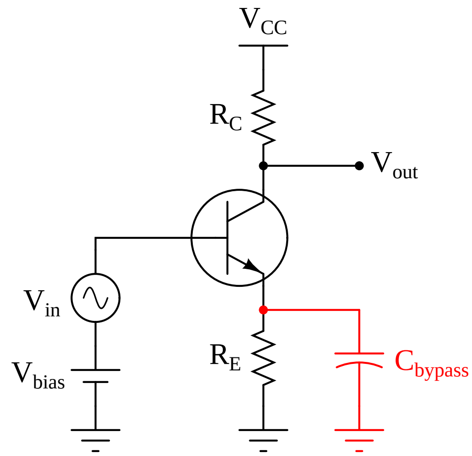


The problem is, this resistance value r'_e is far from stable. Determine some of the factors influencing the value of the transistor's intrinsic emitter resistance, and explain why a circuit such as the one first shown in this question would be very unstable (possibly resulting in the self-destruction of the transistor!).

file 02232

Question 39

A popular method of "reclaiming" some of the lost voltage gain resulting from the addition of an emitter resistor (R_E) to a common-emitter amplifier circuit is to connect a "bypass" capacitor in parallel with that resistor:



Explain why this technique works to increase the circuit's AC voltage gain, without leading to the problems associated with directly grounding the emitter.

file 00965

Question 40

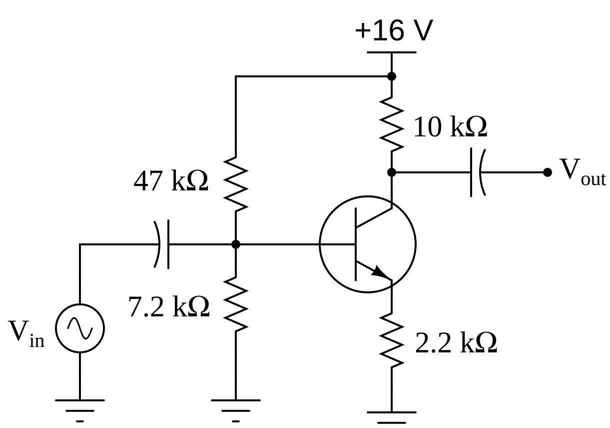
Define what a *common-emitter* transistor amplifier circuit is. What distinguishes this amplifier configuration from the other single-BJT amplifier configurations, namely *common-collector* and *common-base*?

Also, describe the typical gains (voltage and current) of this amplifier configuration, and whether it is *inverting* or *noninverting*.

file 02227

Question 41

Calculate the approximate voltage gain (A_V) for the following common-emitter amplifier circuit, and also calculate the quiescent DC voltages measured at the three terminals of the transistor with respect to ground (V_B, V_E, and V_C). Assume a silicon transistor:

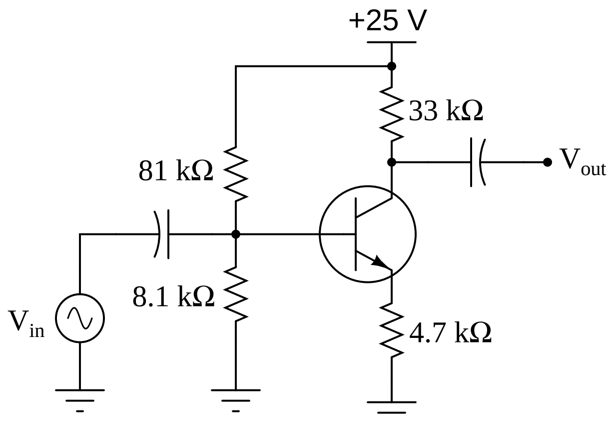


- $A_V \approx$
- $V_B \approx$
- $V_E \approx$
- $V_C \approx$

file 02442

Question 42

Calculate the approximate voltage gain (A_V) for the following common-emitter amplifier circuit, and also calculate the quiescent DC voltages measured at the three terminals of the transistor with respect to ground (V_B, V_E, and V_C). Assume a silicon transistor:

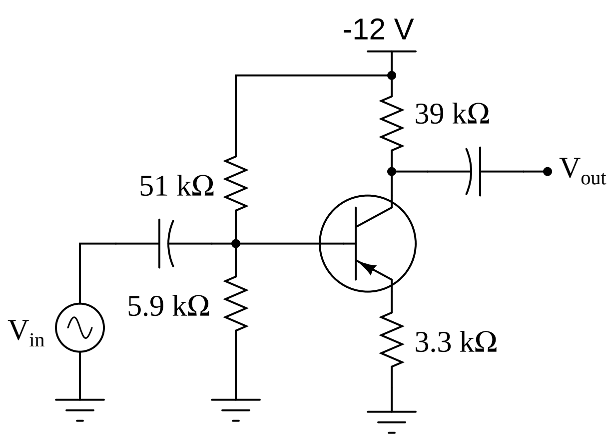


- $A_V \approx$
- $V_B \approx$
- $V_E \approx$
- $V_C \approx$

file 02443

Question 43

Calculate the approximate voltage gain (A_V) for the following common-emitter amplifier circuit, and also calculate the quiescent DC voltages measured at the three terminals of the transistor with respect to ground (V_B, V_E, and V_C). Assume a silicon transistor:

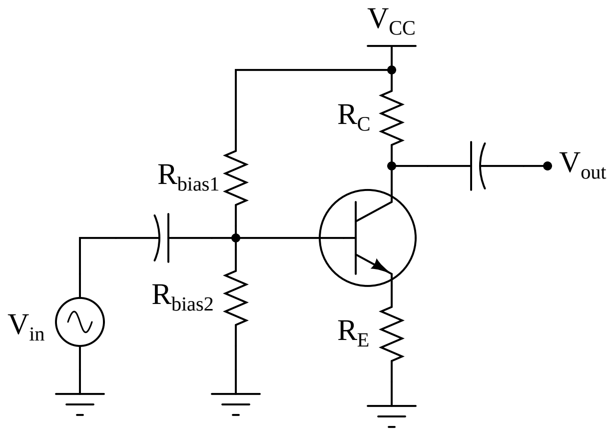


- $A_V \approx$
- $V_B \approx$
- $V_E \approx$
- $V_C \approx$

file 02444

Question 44

Choose values for the collector and emitter resistors that will yield a voltage gain of approximately 5 for the following common-emitter amplifier circuit:

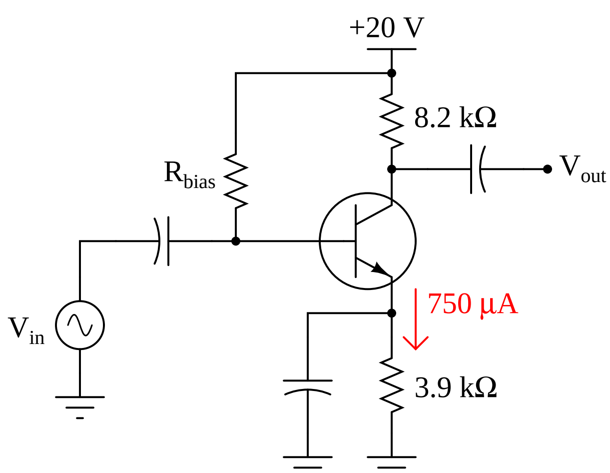


- $R_C =$
- $R_E =$

file 02445

Question 45

Calculate the approximate voltage gain (A_V) for the following bypassed common-emitter amplifier circuit, assuming a quiescent (DC) emitter current value of 750 μA. Also calculate the quiescent DC voltage measured at the transistor's collector terminal with respect to ground (V_C). Assume a silicon transistor:

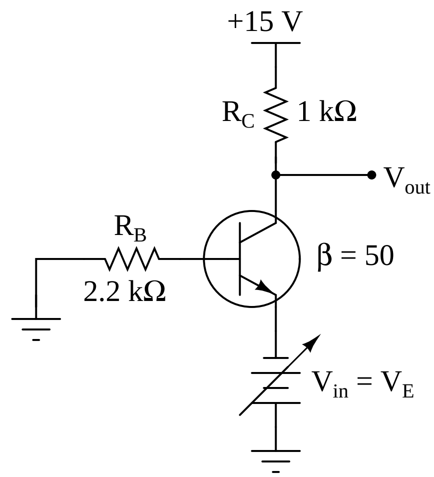


- $A_V \approx$
- $V_C \approx$

file 02446

Question 46

Complete the table of voltages and currents for several given values of input voltage in this common-base amplifier circuit. Assume that the transistor is a standard silicon NPN unit, with a nominal base-base junction forward voltage of 0.7 volts:



V_E	V_B	I_B	I_C	V_{R_C}	V_C
0.0 V					
-0.5 V					
-0.8 V					
-1.0 V					
-1.1 V					
-1.2 V					
-1.3 V					

Calculate the voltage gain of this circuit from the numerical values in the table:

$$A_V = \frac{\Delta V_{out}}{\Delta V_{in}} =$$

file 02233

Question 47

Define what a *common-base* transistor amplifier circuit is. What distinguishes this amplifier configuration from the other single-BJT amplifier configurations, namely *common-collector* and *common-emitter*?

Also, describe the typical gains (voltage and current) of this amplifier configuration, and whether it is *inverting* or *noninverting*.

file 02228

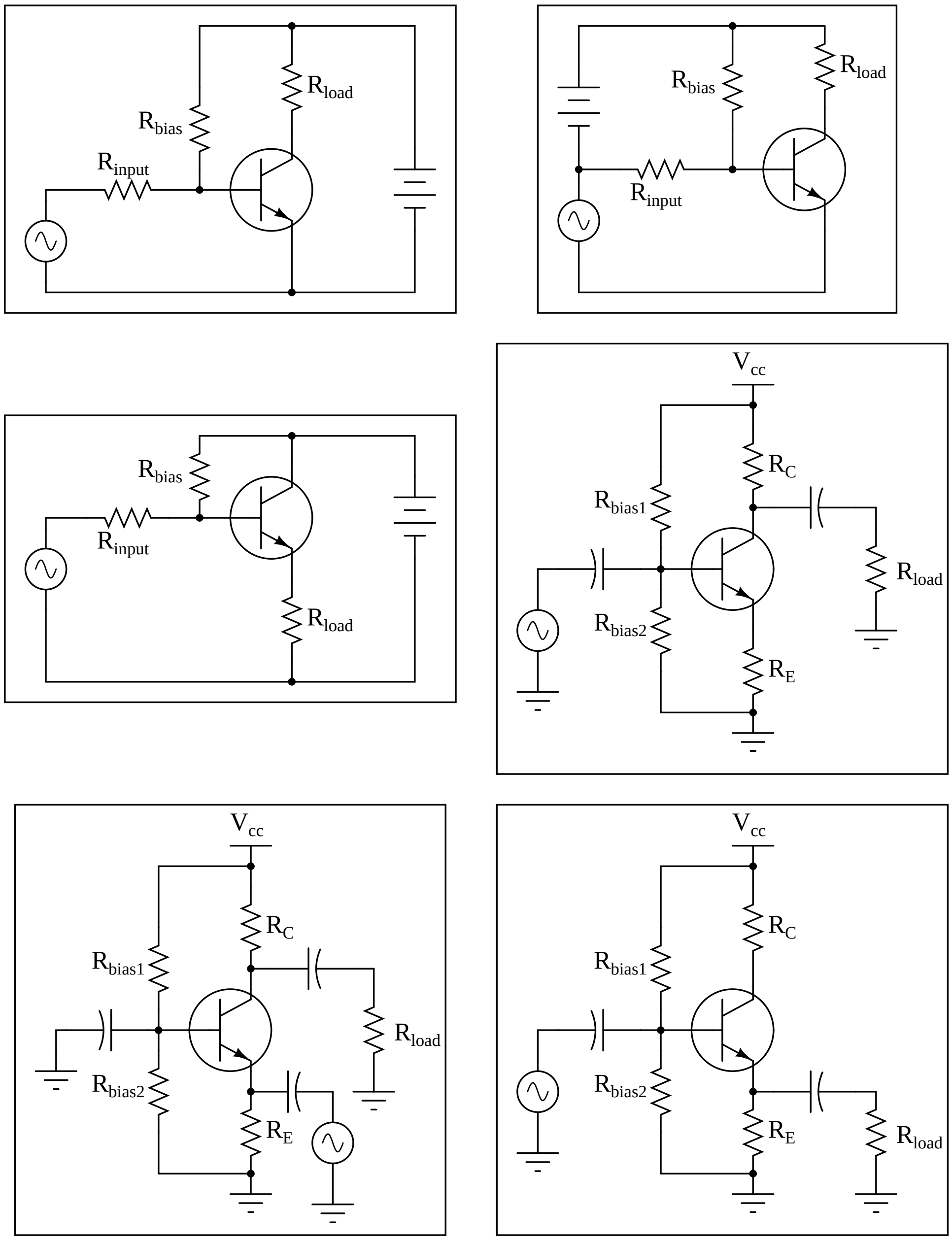
Question 48

Compared to common-collector and common-emitter amplifiers, *common-base* circuits have few practical applications. Explain why.

file 02234

Question 49

Identify the type of transistor amplifier configuration in these schematic diagrams as either *common-emitter*, *common-collector*, or *common-base*.



file 00960

Question 50

During the early development of telephone technology, a unit was invented for representing power gain (or loss) in an electrical system. It was called the *Bel*, in honor of Alexander Graham Bell, the telecommunications pioneer.

"Bels" relate to power gain ratios by the following equation:

$$A_{P(ratio)} = 10^{A_{P(Bels)}}$$

Given this mathematical relationship, translate these power gain figures given in units of Bels, into ratios:

- A_P = 3 B ; A_P =
- A_P = 2 B ; A_P =
- A_P = 1 B ; A_P =
- A_P = 0 B ; A_P =
- A_P = -1 B ; A_P =
- A_P = -2 B ; A_P =
- A_P = -3 B ; A_P =

file 00675

Question 51

Manipulate this equation algebraically, so that we can convert power gains expressed in units of Bels, into ratios.

$$A_{P(ratio)} = 10^{A_{P(Bels)}}$$

Then, convert the following power gains, expressed as ratios, into units of Bels:

- A_P = 250 ; A_P =
- A_P = 1275 ; A_P =
- A_P = 10 ; A_P =
- A_P = 1 ; A_P =
- A_P = 0.1 ; A_P =
- A_P = 0.025 ; A_P =
- A_P = 0.00009 ; A_P =

file 00676

Question 52

At some point in time, it was decided that the unit of the "Bel" was too large. Instead, the *deci*-Bel became the most common usage of the unit. Modify these equations to include A_P figures cast in units of decibels (dB) instead of Bels:

$$A_{P(ratio)} = 10^{A_{P(Bels)}}$$

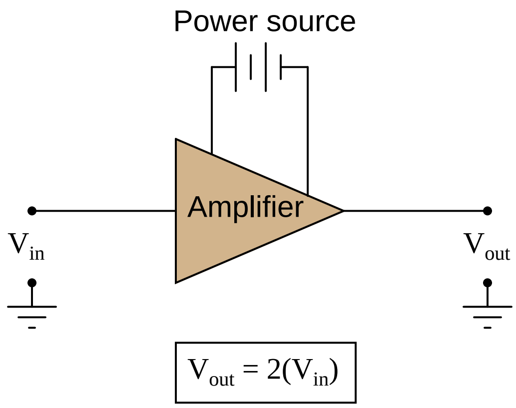
$$A_{P(Bels)} = \log A_{P(ratio)}$$

Then, calculate the decibel figures that correspond to a power gain of 2 (ratio), and a power loss of 50%, respectively.

file 00677

Question 53

Suppose an AC signal amplifier circuit has a voltage gain (ratio) of 2. That is, V_{out} is twice as large as V_{in}:

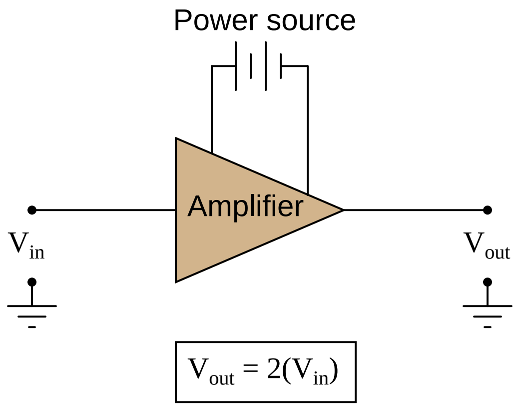


If we were to try to rate this amplifier's gain in terms of the relative *power* dissipated by a given load resistance (P_{load} when powered by V_{out}, versus P_{load} when powered by V_{in}), what ratio would we calculate? In other words, what is the ratio of power for a given load resistance, when powered by a given voltage, versus when powered by a voltage that is twice as much?

file 00826

Question 54

Suppose an AC signal amplifier circuit has a voltage gain (ratio) of 2. That is, V_{out} is twice as large as V_{in}:



If we were to try to rate this amplifier's gain in terms of the relative power dissipated by a given load resistance (P_{load} when powered by V_{out}, versus P_{load} when powered by V_{in}), what *decibel* figure would we calculate?

file 00827

Question 55

Voltage and current gains, expressed in units of decibels, may be calculated as such:

$$A_{V(dB)} = 10 \log \left(A_{V(ratio)}\right)^2$$

$$A_{I(dB)} = 10 \log \left(A_{I(ratio)}\right)^2$$

Another way of writing this equation is like this:

$$A_{V(dB)} = 20 \log A_{V(ratio)}$$

$$A_{I(dB)} = 20 \log A_{I(ratio)}$$

What law of algebra allows us to simplify a logarithmic equation in this manner?

file 00830

Question 56

Convert the following amplifier gains (either power, voltage, or current gain ratios) into gains expressed in the unit of decibels (dB):

- $A_P = 25$; $A_{P(dB)} =$
- $A_V = 10$; $A_{V(dB)} =$
- $A_I = 37$; $A_{I(dB)} =$
- $A_P = 150$; $A_{P(dB)} =$
- $A_I = 41$; $A_{I(dB)} =$
- $A_V = 3.4$; $A_{V(dB)} =$
- $A_P = 18$; $A_{P(dB)} =$
- $A_V = 100$; $A_{V(dB)} =$

file 02447

Question 57

Convert the following amplifier gains expressed in the unit of decibels (dB), to gain figures expressed as unitless ratios:

- $A_P = 5$ dB ; $A_{P(ratio)} =$
- $A_V = 23$ dB ; $A_{V(ratio)} =$
- $A_I = 20$ dB ; $A_{I(ratio)} =$
- $A_P = 2.5$ dB ; $A_{P(ratio)} =$
- $A_I = 7.4$ dB ; $A_{I(ratio)} =$
- $A_V = 45$ dB ; $A_{V(ratio)} =$
- $A_P = 12.8$ dB ; $A_{P(ratio)} =$
- $A_V = 30$ dB ; $A_{V(ratio)} =$

file 02448

Question 58

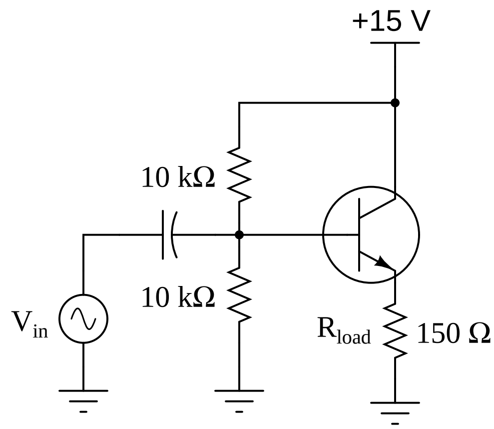
Convert the following amplifier gains between decibels and (unitless) ratios as necessary:

- $A_V = 14.1$ dB ; $A_{V(ratio)} =$
- $A_I = 202$; $A_{I(dB)} =$
- $A_P = 15$ dB ; $A_{P(ratio)} =$
- $A_I = 33$; $A_{I(dB)} =$
- $A_P = 49$ dB ; $A_{P(ratio)} =$
- $A_V = 57$; $A_{V(dB)} =$
- $A_P = 8.8$ dB ; $A_{P(ratio)} =$
- $A_V = 30$; $A_{V(dB)} =$

file 02449

Question 59

Calculate the approximate voltage gain (A_V) for the following common-collector amplifier circuit, expressing it as a ratio and as a decibel value. Also calculate the quiescent DC voltage measured across the load resistor ($V_{load(DC)}$). Assume a silicon transistor:

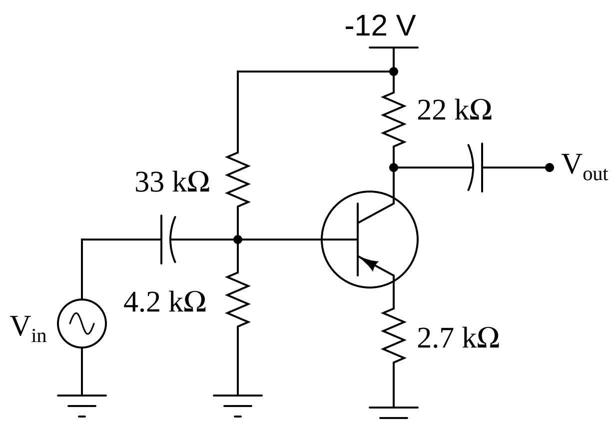


- A_V (as a ratio) $\approx$
- A_V (in decibels) $\approx$
- $V_{load(DC)} \approx$

file 02451

Question 60

Calculate the approximate voltage gain (A_V) for the following common-emitter amplifier circuit, expressing it both as a ratio and as a figure in decibels. Also calculate the quiescent DC voltages measured at the three terminals of the transistor with respect to ground (V_B, V_E, and V_C). Assume a silicon transistor:

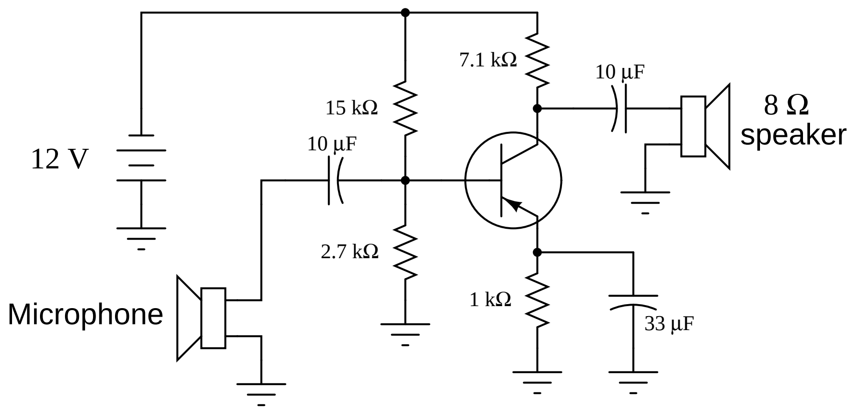


- A_V (as a ratio) $\approx$
- A_V (in decibels) $\approx$
- $V_B \approx$
- $V_E \approx$
- $V_C \approx$

file 02450

Question 61

A student builds this common-emitter amplifier so they he may amplify the audio signals from a microphone to power a speaker:



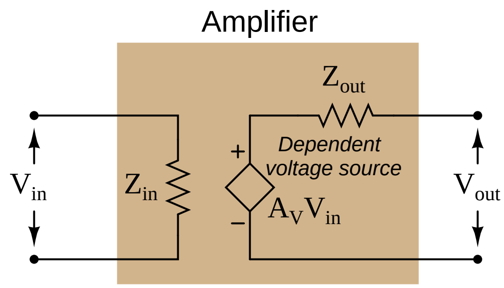
Unfortunately, the results are considerably less than expected: although some sound does come out of the speaker, it is not enough to be considered a success. Another student inspects the design and cryptically mumbles something about "poor impedance matching," leaving the first student somewhat confused.

Explain what *impedance matching* means in this context, where the mis-match might be in this circuit, and what might be done to correct it.

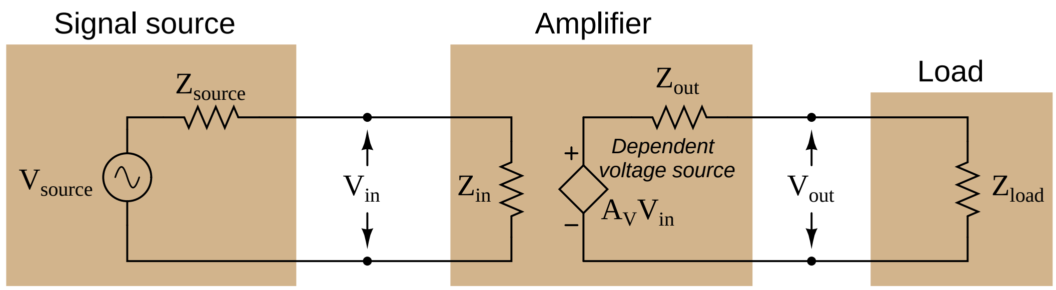
file 02235

Question 62

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



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

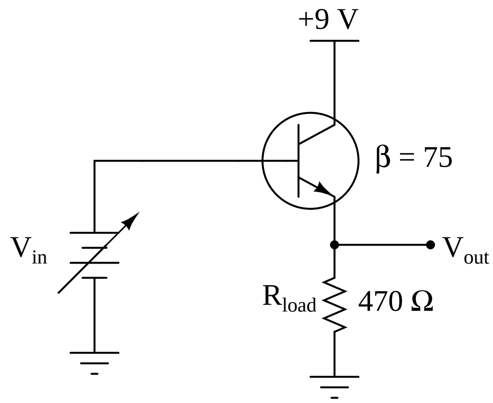


Explain why all these impedances (shown as resistors) are significant to us as we seek to apply amplifier circuits to practical applications. Which of these impedances do you suppose are typically easier for us to change, if they require changing at all?

file 02236

Question 63

Complete the table of output voltages, output currents, and input currents for several given values of input voltage in this common-collector amplifier circuit. Assume that the transistor is a standard silicon NPN unit, with a nominal base-emitter junction forward voltage of 0.7 volts:



V_{in}	V_{out}	I_{in}	I_{out}
0.8 V			
1.5 V			
3.0 V			
4.5 V			
6.0 V			
7.5 V			

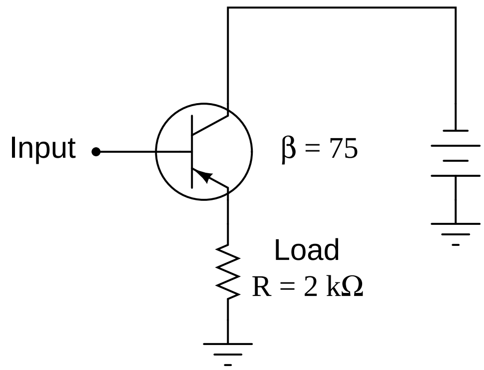
Calculate the amount of impedance "seen" by the input voltage source V_{in}, given the following definition for impedance:

$$Z_{in} = \frac{\Delta V_{in}}{\Delta I_{in}}$$

file 02237

Question 64

Calculate the approximate *input impedance* (Z_{in}) of this amplifier circuit:



Also, explain why input impedance is an important factor in amplifier circuits.
file 01179

Question 65

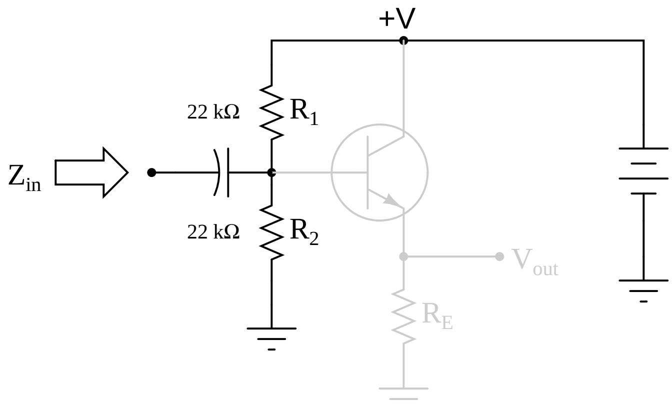
Give a step-by-step procedure for "Thévenizing" *any* circuit: finding the Thévenin equivalent voltage ($V_{Thevenin}$) and Thévenin equivalent resistance ($R_{Thevenin}$).

- Step #1:
- Step #2:

file 02456

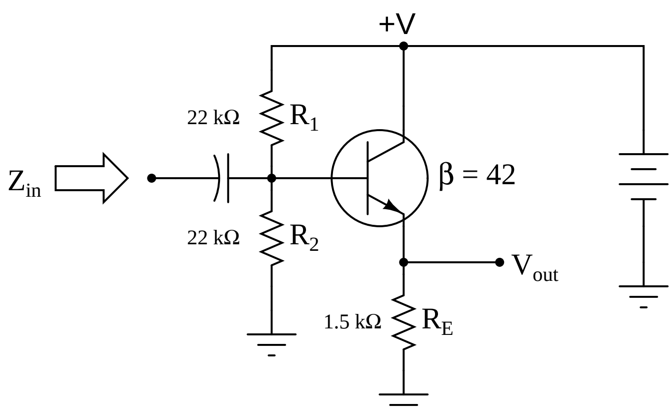
Question 66

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



Remember, what you are doing here is actually determining the Thévenin/Norton equivalent resistance as seen from the input terminal by an AC signal (consider the coupling capacitor reactance to be negligibly small).

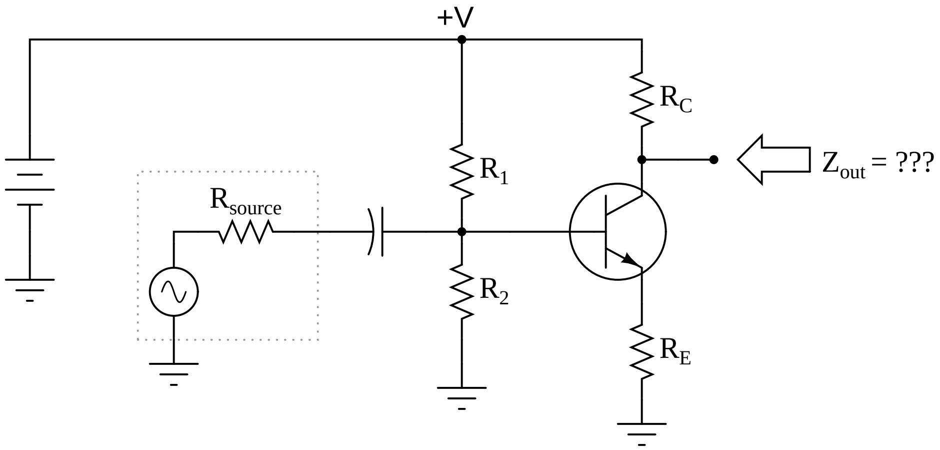
Next, calculate the input impedance of the same circuit, this time considering the presence of the transistor and emitter resistor, assuming a current gain (β or h_{fe}) of 42:



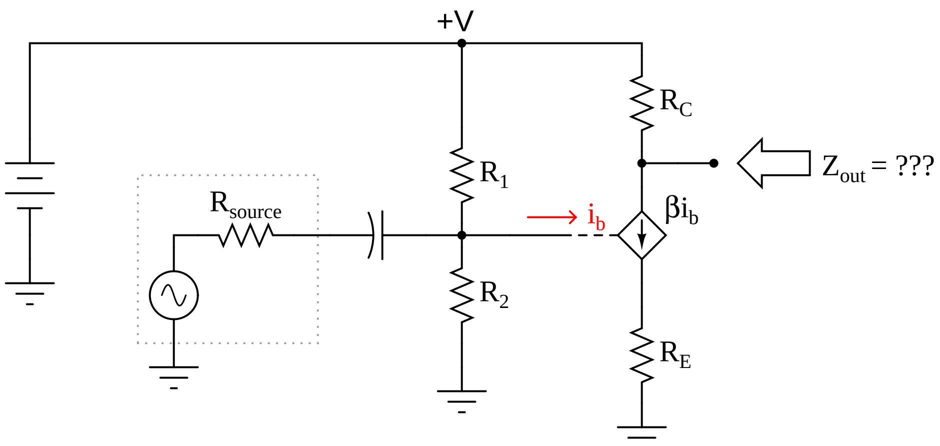
Develop an equation from the steps you take in calculating this impedance value.
file 02238

Question 67

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



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

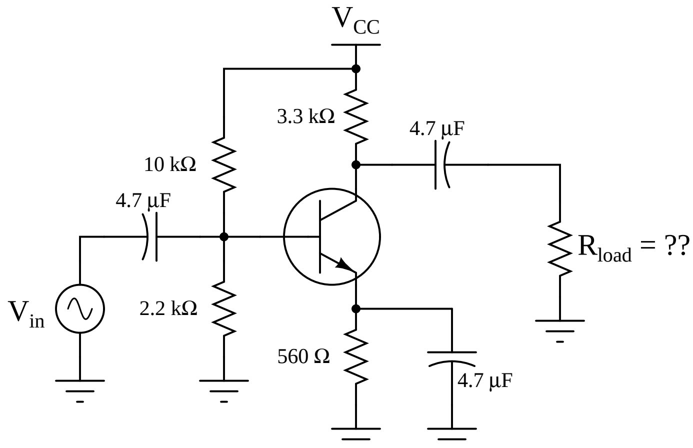


Now, apply the same steps you would use in determining the Thévenin or Norton equivalent impedance to the output of this amplifier circuit, and this will yield the amplifier's output impedance. Draw an equivalent circuit for the amplifier during this *Thévenizing/Nortonizing* process to show how the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

file 02243

Question 68

What is the ideal amount of load impedance for this amplifier circuit, so that maximum power will be delivered to it?

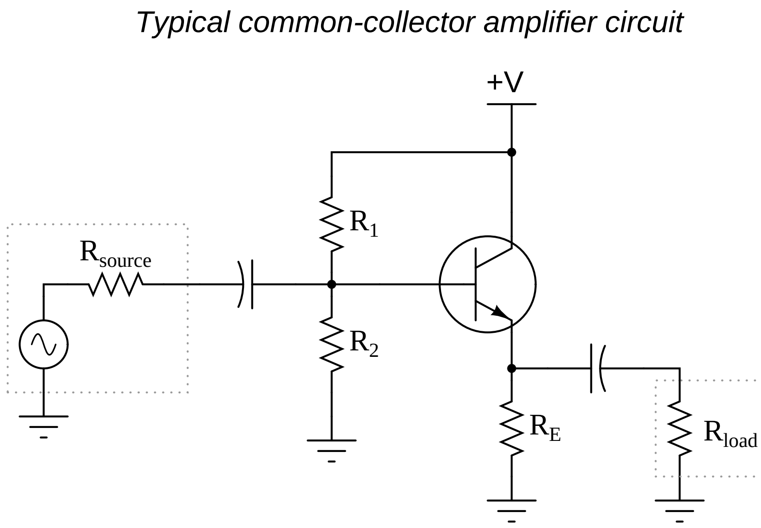


Suppose we wished to drive an 8 ohm audio speaker with this amplifier circuit. How could we better match the amplifier's impedance to the speaker's?

file 01216

Question 69

Explain each of the mathematical approximations for this typical common-collector amplifier circuit:



$$A_V \approx 1$$

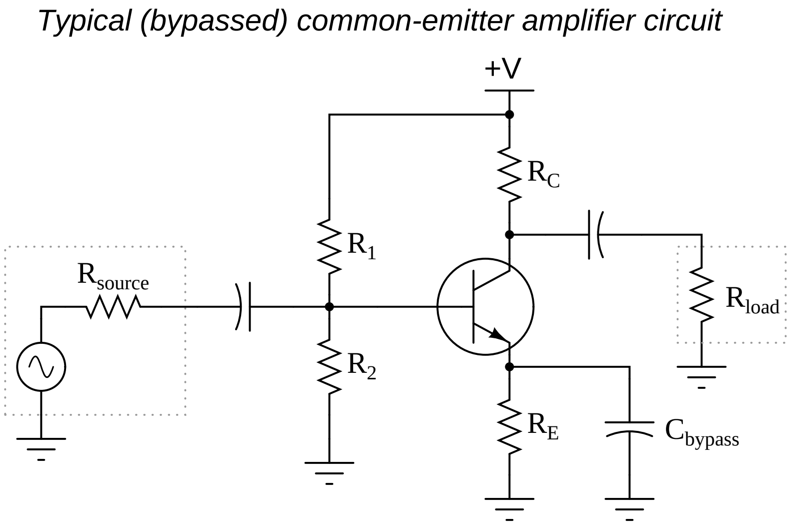
$$Z_{in} \approx R_1 \mid\mid R_2 \mid\mid (\beta + 1)[r'_e + (R_E \mid\mid R_{load})]$$

$$Z_{out} \approx R_E \mid\mid \left(r'_e + \frac{R_1 \mid\mid R_2 \mid\mid R_{source}}{\beta + 1} \right)$$

What does each term in each expression represent, and why do they relate to one another as shown?
file 02240

Question 70

Explain each of the mathematical approximations for this typical common-emitter amplifier circuit (with a bypass capacitor):



$$A_V \approx \frac{R_C \mid\mid R_{load}}{r'_e}$$

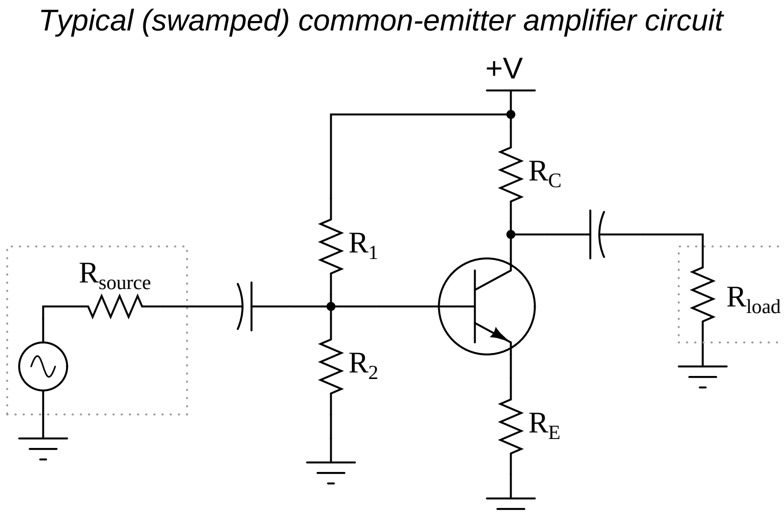
$$Z_{in} \approx R_1 \mid\mid R_2 \mid\mid (\beta + 1) r'_e$$

$$Z_{out} \approx R_C$$

What does each term in each expression represent, and why do they relate to one another as shown?
file 02241

Question 71

Explain each of the mathematical approximations for this typical common-emitter amplifier circuit (with the dynamic emitter resistance "swamped" by R_E):



$$A_V \approx \frac{R_C \ || \ R_{load}}{r'_e + R_E}$$

$$Z_{in} \approx R_1 \ || \ R_2 \ || \ (\beta + 1)(r'_e + R_E)$$

$$Z_{out} \approx R_C$$

What does each term in each expression represent, and why do they relate to one another as shown?

file 02242

Question 72

A common set of equations for calculating input and output impedances of bypassed common-emitter amplifier circuits is as follows:

$$Z_{in} \approx R_1 \ || \ R_2 \ || \ (\beta + 1)r'_e$$

$$Z_{out} \approx R_C$$

If precision is not required, we may greatly simplify the first equation by assuming the transistor to be ideal; i.e. having an infinite current gain ($\beta = \infty$). Re-write the first equation accordingly, and explain how you simplified it.

file 02454

Question 73

A common set of equations for calculating input and output impedances of common-collector amplifier circuits is as follows:

$$Z_{in} \approx R_1 \,||\, R_2 \,||\, (\beta + 1)[r'_e + (R_E \,||\, R_{load})]$$

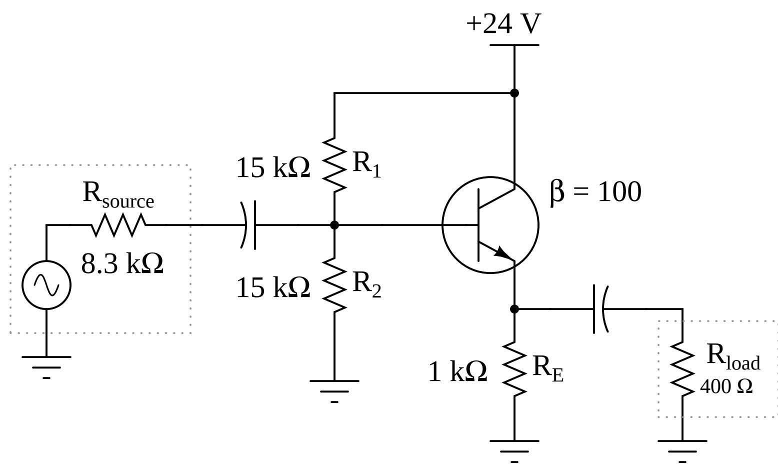
$$Z_{out} \approx R_E \,||\, \left(r'_e + \frac{R_1 \,||\, R_2 \,||\, R_{source}}{\beta + 1} \right)$$

If precision is not required, we may greatly simplify these equations by assuming the transistor to be ideal; i.e. having an infinite current gain ($\beta = \infty$). Re-write these equations accordingly, and explain how you simplified each one.

file 02453

Question 74

Approximate the following values for this common-collector amplifier circuit, assuming the use of a silicon transistor:

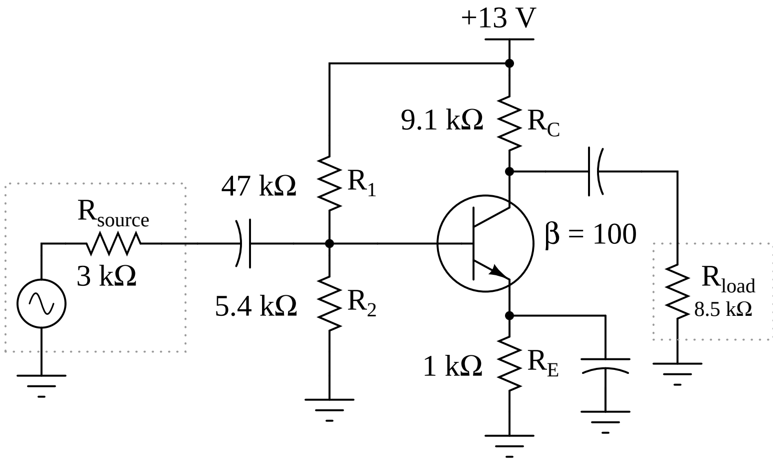


- A_V (as a ratio) $\approx$
- A_V (in decibels) $\approx$
- $Z_{in} \approx$
- $Z_{out} \approx$

file 02452

Question 75

Approximate the following values for this common-emitter amplifier circuit, assuming the use of a silicon transistor:

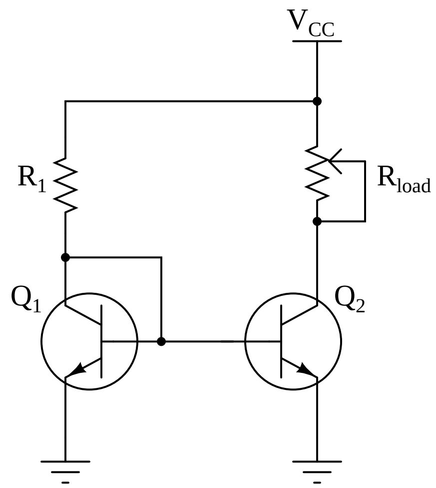


- A_V (as a ratio) $\approx$
- A_V (in decibels) $\approx$
- $Z_{in} \approx$
- $Z_{out} \approx$

file 02455

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

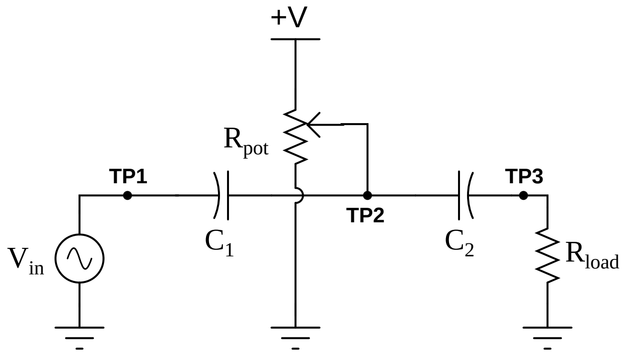
What will happen in the circuit?

file 01938

Question 77

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

Schematic



Given conditions

V_{in} =

+V =

$C_1 = C_2 =$

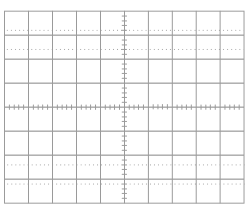
R_{load} =

R_{pot} =

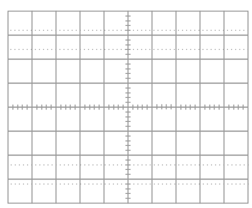
Parameters

With potentiometer set to its ___% position:

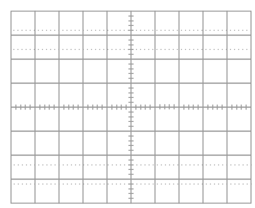
V_{TP1}



V_{TP2}



V_{TP3}



Explanation

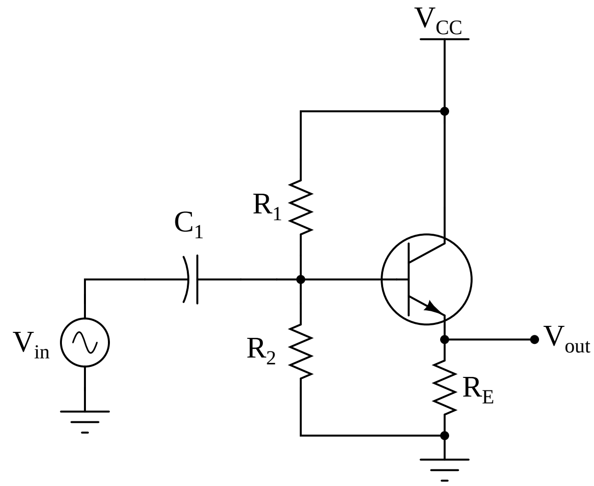
What effect, if any, does the potentiometer position have on the voltage measured at each test point?

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

file 01946

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

Schematic



Given conditions

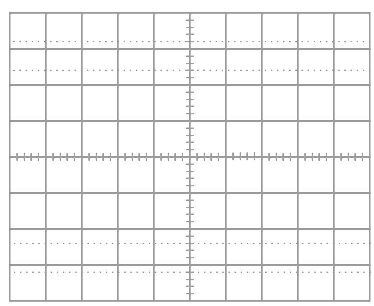
V_{in} = V_{CC} = R_E =

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)



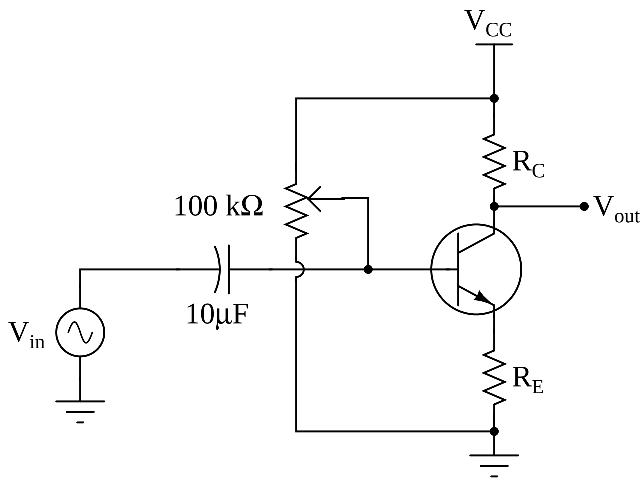
Inverting . . . ☐

or noninverting? ☐

file 01967

Competency: **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

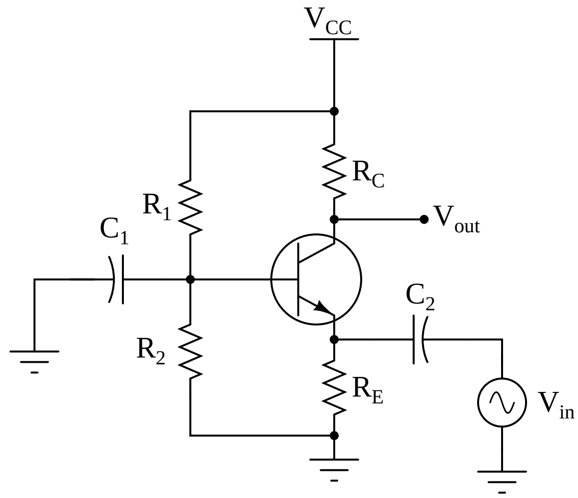
Suppose component ☐ fails ☐ open ☐ shorted ☐ other ____________

What will happen in the circuit?

file 03919

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

Schematic



Given conditions

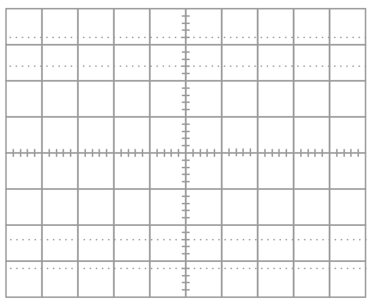
V_{in} = V_{CC} = R_C = R_E =

$C_1 = C_2$ = R_1 = R_2 =

Parameters

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

Input and output waveforms (measured)



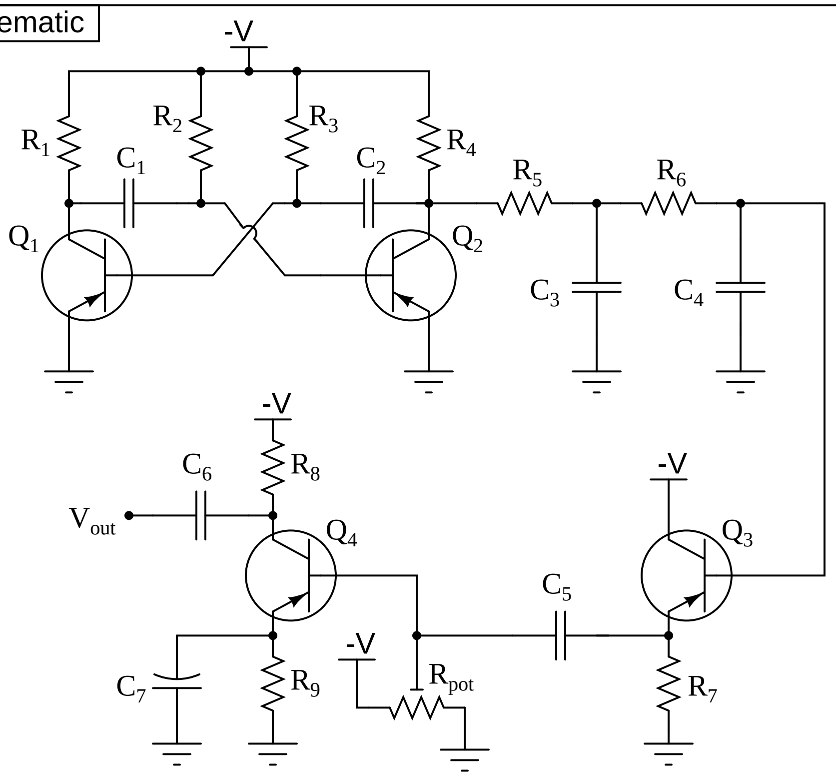
Inverting . . . ☐

or noninverting? ☐

file 01981

Competency: **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

Troubleshooting log

Actions / Measurements / Observations (i.e. *What I did and/or noticed . . .*)	**Conclusions** (i.e. *What this tells me . . .*)

file 03933

Question 83

NAME: _______________ **Troubleshooting Grading Criteria**

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

100 % *(Must meet or exceed all criteria listed)*
- A. Absolutely flawless procedure
- B. No unnecessary actions or measurements taken

90 % *(Must meet or exceed these criteria in addition to all criteria for 85% and below)*
- A. No reversals in procedure (i.e. changing mind without sufficient evidence)
- B. Every single action, measurement, and relevant observation properly documented

80 % *(Must meet or exceed these criteria in addition to all criteria for 75% and below)*
- A. No more than one unnecessary action or measurement
- B. No false conclusions or conceptual errors
- C. No missing conclusions (i.e. at least one documented conclusion for action / measurement / observation)

70 % *(Must meet or exceed these criteria in addition to all criteria for 65%)*
- A. No more than one false conclusion or conceptual error
- B. No more than one conclusion missing (i.e. an action, measurement, or relevant observation without a corresponding conclusion)

65 % *(Must meet or exceed these criteria in addition to all criteria for 60%)*
- A. No more than two false conclusions or conceptual errors
- B. No more than two unnecessary actions or measurements
- C. No more than one undocumented action, measurement, or relevant observation
- D. Proper use of all test equipment

60 % *(Must meet or exceed these criteria)*
- A. Fault accurately identified
- B. Safe procedures used at all times

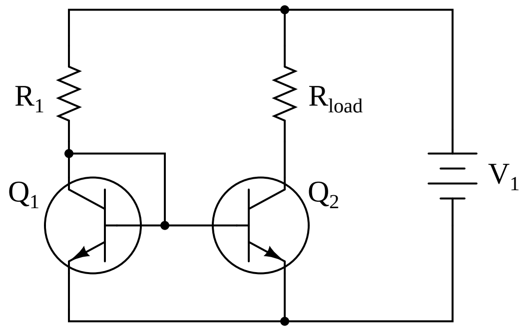
50 % *(Only applicable where students performed significant development/design work – i.e. not a proven circuit provided with all component values)*
- A. Working prototype circuit built and demonstrated

0 % *(If any of the following conditions are true)*
- A. Unsafe procedure(s) used at any point

file 03932

Question 84

Predict how all component voltages and currents in this circuit will be affected as a result of the following faults. Consider each fault independently (i.e. one at a time, no multiple faults):

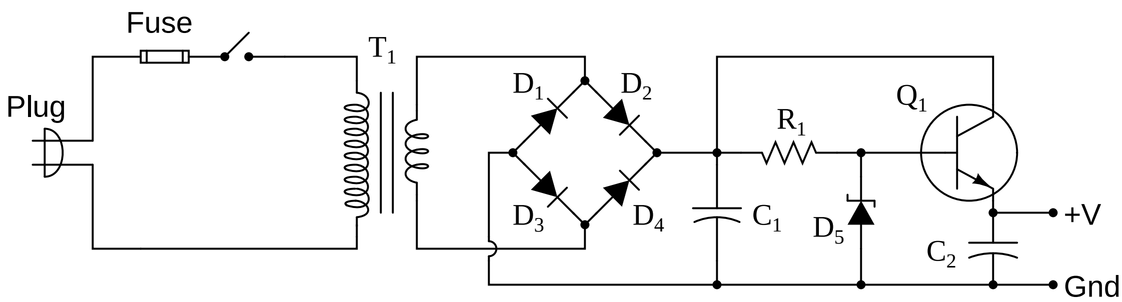


- Resistor R_1 fails open:
- Transistor Q_1 fails open, collector to emitter:
- Transistor Q_1 fails shorted, collector to emitter:
- Transistor Q_2 fails open, collector to emitter:
- Transistor Q_2 fails shorted, collector to emitter:
- Load fails shorted:

For each of these conditions, explain *why* the resulting effects will occur.
file 03735

Question 85

Predict how this power supply circuit's output voltage will be affected as a result of the following faults. Also note whether or not any other components in this circuit will become stressed as a result of each fault. Consider each fault independently (i.e. one at a time, no multiple faults):



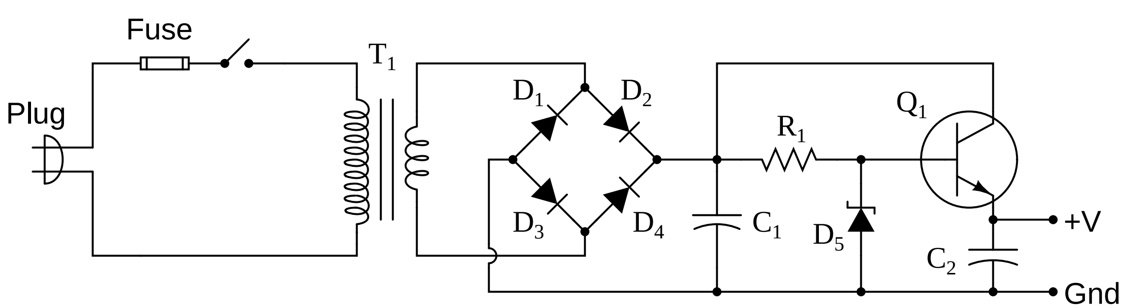
- Transformer T_1 primary winding fails shorted:
- Transformer T_1 secondary winding fails open:
- Rectifying diode D_3 fails open:
- Zener diode D_5 fails open:
- Zener diode D_5 fails shorted:
- Resistor R_1 fails open:
- Capacitor C_2 fails shorted:

For each of these conditions, explain *why* the resulting effects will occur.

file 03736

Question 86

Suppose this regulated power supply circuit used to function fine, but now has stopped outputting any DC voltage at all:



Initial diagnostic measurements show there to be full DC (unregulated) voltage across capacitor C_1, and no DC voltage between the transistor base and ground. From this data, where would you suspect the problem is?

file 03742

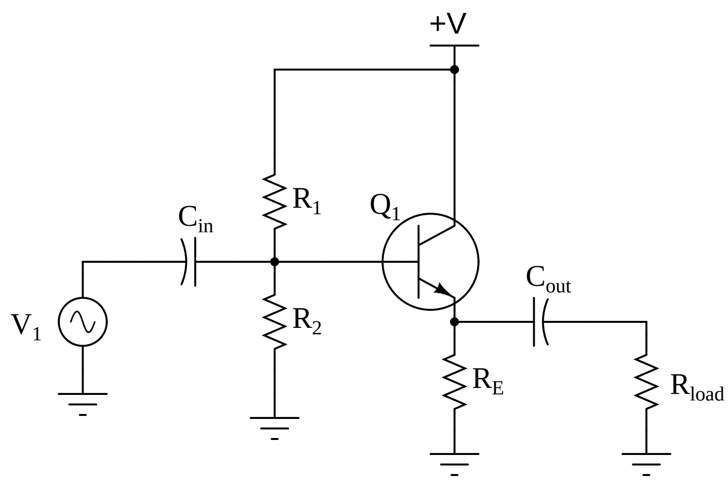
Question 87

Explain how it is possible for a fault in the biasing circuitry of a transistor amplifier to completely kill the (AC) output of that amplifier. How and why can a shift in DC bias voltage have an effect on the AC signal being amplified?

file 03741

Question 88

Predict how all transistor currents (I_B, I_C, and I_E) and the output voltage signal will be affected as a result of the following faults. Consider each fault independently (i.e. one at a time, no multiple faults):



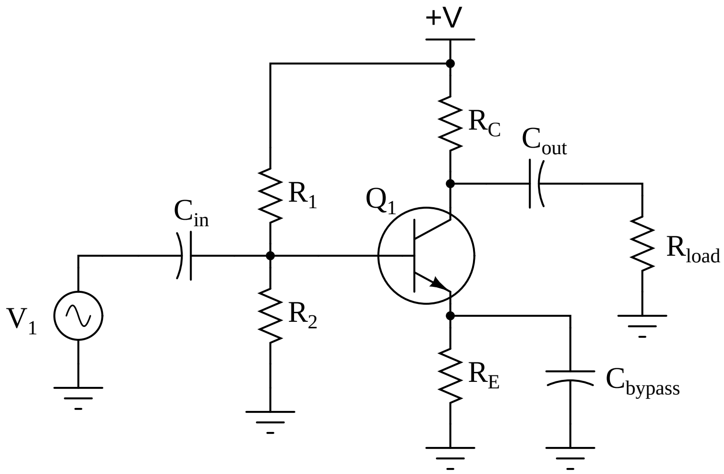
- Capacitor C_{in} fails open:
- Solder bridge (short) past resistor R_1:
- Resistor R_1 fails open:
- Resistor R_E fails open:

For each of these conditions, explain *why* the resulting effects will occur.

file 03738

Question 89

Predict how all transistor currents (I_B, I_C, and I_E) and the output voltage signal will be affected as a result of the following faults. Consider each fault independently (i.e. one at a time, no multiple faults):



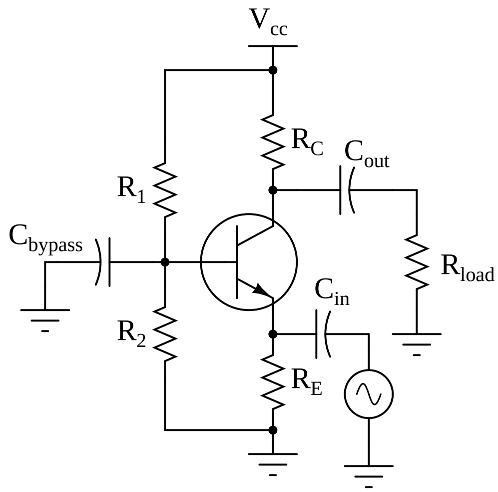
- Capacitor C_{in} fails open:
- Solder bridge (short) past resistor R_1:
- Resistor R_1 fails open:
- Resistor R_C fails open:
- Resistor R_E fails open:
- Capacitor C_{bypass} fails shorted:

For each of these conditions, explain *why* the resulting effects will occur.

file 03737

Question 90

Predict how all transistor currents (I_B, I_C, and I_E) and the output voltage signal will be affected as a result of the following faults. Consider each fault independently (i.e. one at a time, no multiple faults):

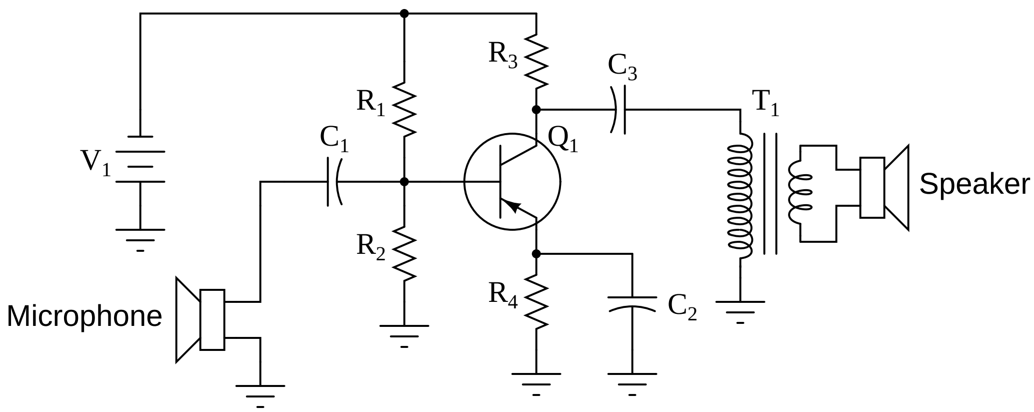


- Capacitor C_{out} fails open:
- Solder bridge (short) past resistor R_1:
- Resistor R_1 fails open:
- Resistor R_C fails open:
- Resistor R_E fails open:
- Capacitor C_{bypass} fails shorted:

For each of these conditions, explain *why* the resulting effects will occur.
file 03739

Question 91

Each of the following faults will cause this audio amplifier circuit to stop working. Determine what diagnostic voltage measurement(s) would positively identify each one of the faults.

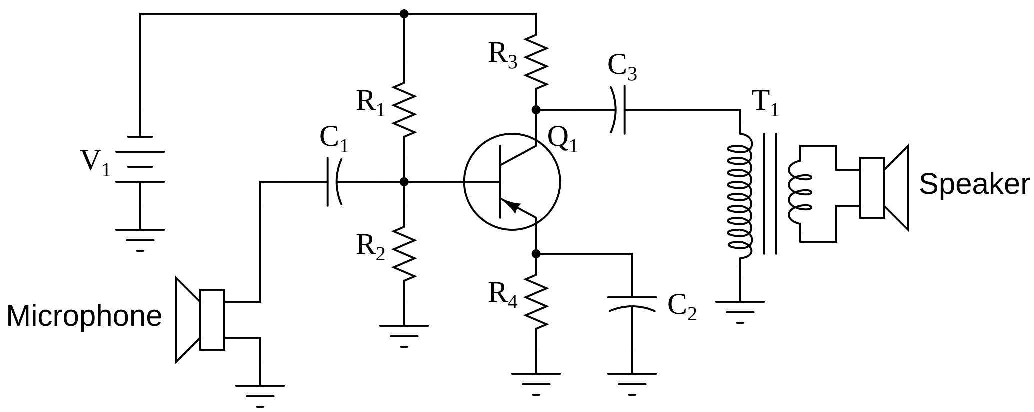


- Microphone coil fails open:
- Capacitor C_1 fails shorted:
- Resistor R_1 fails open:
- Resistor R_2 fails open:
- Capacitor C_3 fails open:
- Transformer T_1 primary winding fails open:

file 03740

Question 92

Suppose this microphone amplifier circuit used to function fine, but now has stopped outputting any sound at all:

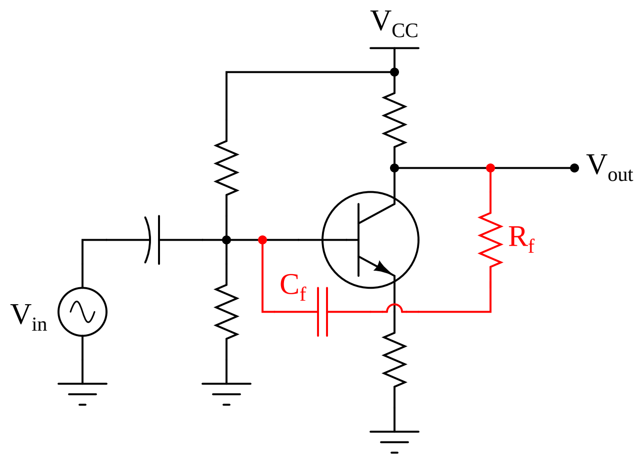


Initial diagnostic measurements show all quiescent (DC) voltages to be normal. From this data, where would you suspect the problem is, and where would you suspect the problem is *not*?

file 03743

Question 93

Sometimes a *feedback network* is purposely placed in an amplifier circuit, like the R_f-C_f combination shown in the following schematic:

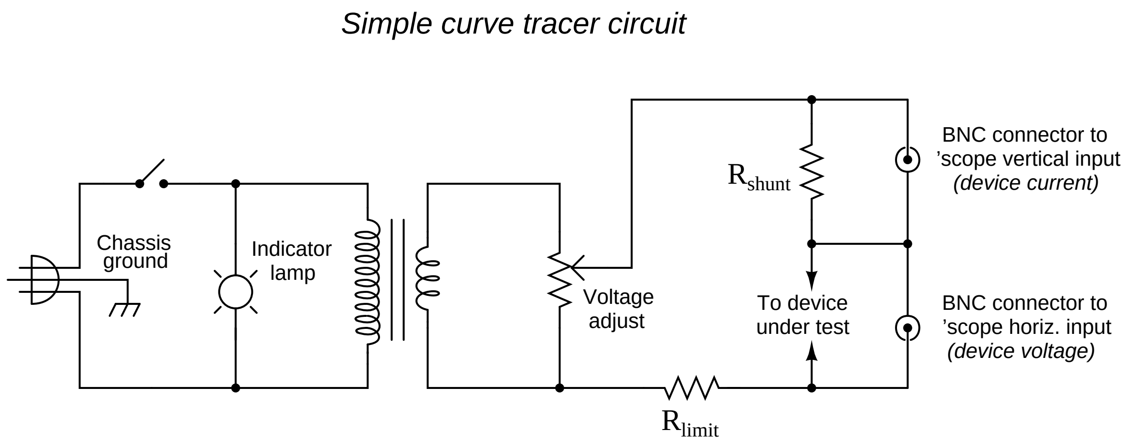


Explain what will happen to the amplifier circuit's performance if either one of the components in this feedback network fails open.

file 03744

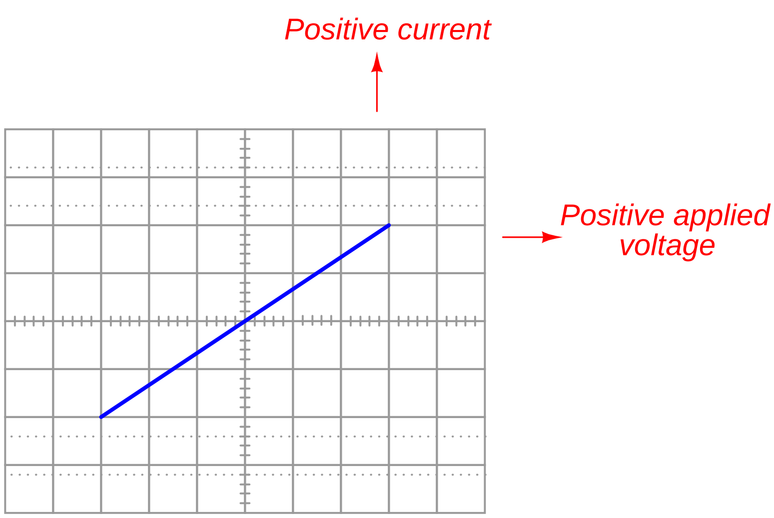
Question 94

The following schematic diagram is of a simple *curve tracer circuit*, used to plot the current/voltage characteristics of different electronic components on an oscilloscope screen:



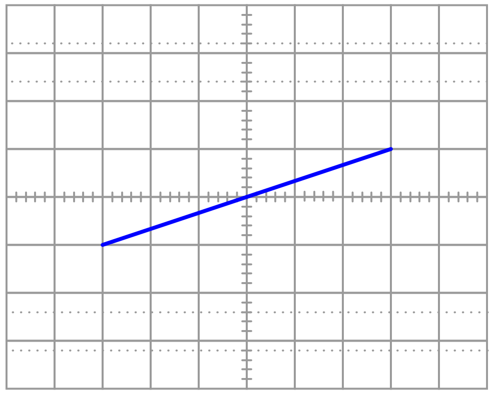
The way it works is by applying an AC voltage across the terminals of the device under test, outputting two different voltage signals to the oscilloscope. One signal, driving the horizontal axis of the oscilloscope, represents the voltage across the two terminals of the device. The other signal, driving the vertical axis of the oscilloscope, is the voltage dropped across the shunt resistor, representing current through the device. With the oscilloscope set for "X-Y" mode, the electron beam traces the device's characteristic curve.

For example, a simple resistor would generate this oscilloscope display:



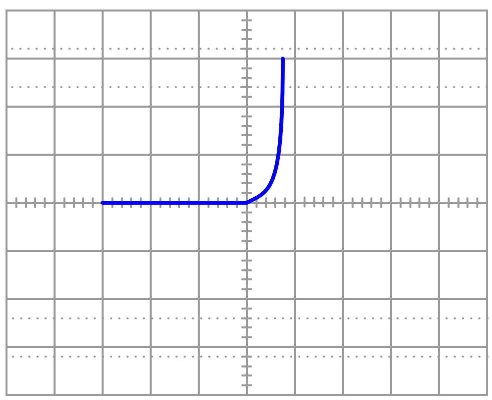
A resistor of greater value (more ohms of resistance) would generate a characteristic plot with a shallower slope, representing less current for the same amount of applied voltage:

Higher-valued resistor



Curve tracer circuits find their real value in testing semiconductor components, whose voltage/current behaviors are nonlinear. Take for instance this characteristic curve for an ordinary rectifying diode:

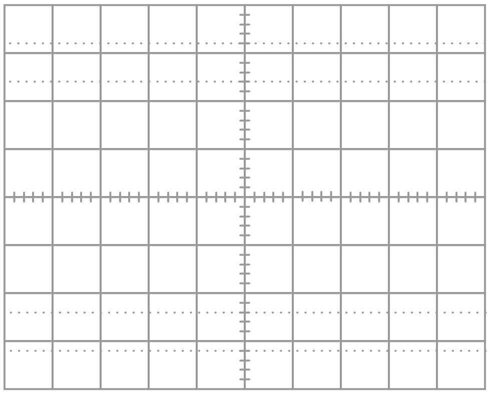
Rectifying diode curve



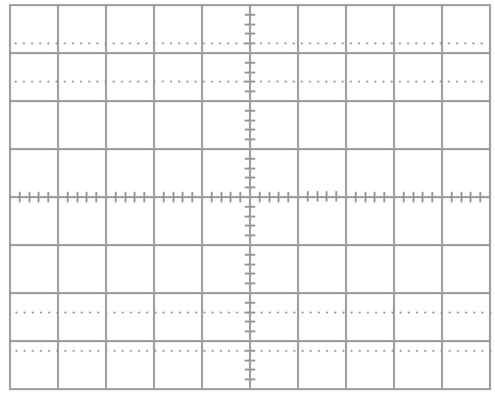
The trace is flat everywhere left of center where the applied voltage is negative, indicating no diode current when it is reverse-biased. To the right of center, though, the trace bends sharply upward, indicating exponential diode current with increasing applied voltage (forward-biased) just as the "diode equation" predicts.

On the following grids, plot the characteristic curve for a diode that is failed shorted, and also for one that is failed open:

Diode failed shorted



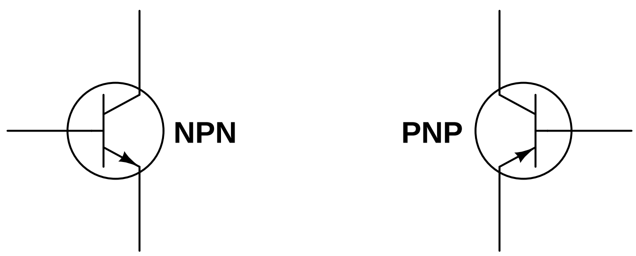
Diode failed open



file 02431

Question 95

Bipolar junction transistor (BJT) function is usually considered in terms of currents: a relatively small current through one of the transistor's terminals exerts control over a much larger current. Draw the directions of all currents for these two transistors (one NPN and one PNP), clearly identifying which of the currents is *doing* the control, and which of the currents is *being* controlled:



file 02037

Question 96

The "beta" ratio (β) of a bipolar junction transistor, sometimes alternatively referred to as h_{FE}, is a very important device parameter. In essence, it describes the amplifying power of the transistor. Give a mathematical definition for this parameter, and provide some typical values from transistor datasheets.

file 02038

Question 97

Explain why a bipolar junction transistor tends to regulate collector current over a wide range of collector-to-emitter voltage drops when its base current is constant. What happens internally that makes the BJT's collector current relatively independent of collector-to-emitter voltage and strongly dependent on base current?

file 02163

Question 98

Many technical references will tell you that bipolar junction transistors (BJTs) are *current-controlled* devices: collector current is controlled by base current. This concept is reinforced by the notion of "beta" (β), the ratio between collector current and base current:

$$\beta = \frac{I_C}{I_B}$$

Students learning about bipolar transistors are often confused when they encounter datasheet specifications for transistor β ratios. Far from being a constant parameter, the "beta" ratio of a transistor may vary significantly over its operating range, in some cases exceeding an order of magnitude (ten times)!

Explain how this fact agrees or disagrees with the notion of BJTs being "current-controlled" devices. If collector current really is a direct function of base current, then why would the constant of proportionality between the two (β) change so much?

file 02164

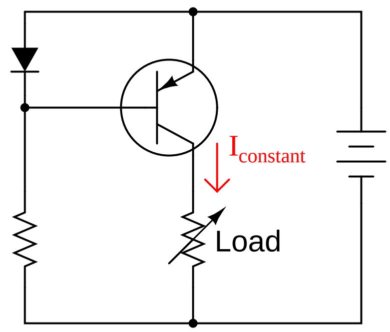
Question 99

A common term used in semiconductor circuit engineering is *small signal analysis*. What, exactly, is "small signal" analysis, and how does it contrast with *large signal analysis*?

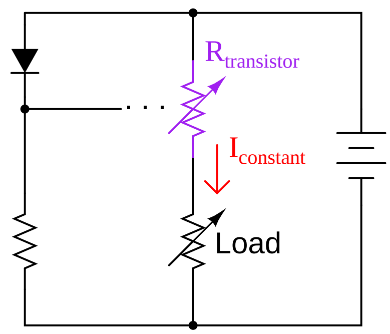
file 01680

Question 100

The purpose of a *current mirror* circuit is to maintain constant current through a load despite changes in that load's resistance:



If we were to crudely model the transistor's behavior as an automatically-varied rheostat – constantly adjusting resistance as necessary to keep load current constant – how would you describe this rheostat's response to changes in load resistance?

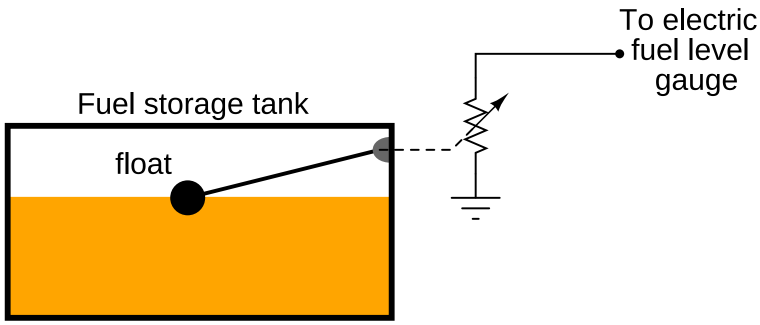


In other words, as R_{load} increases, what does $R_{transistor}$ do – increase resistance, decrease resistance, or remain the same resistance it was before? How does the changing value of $R_{transistor}$ affect total circuit resistance?

file 02656

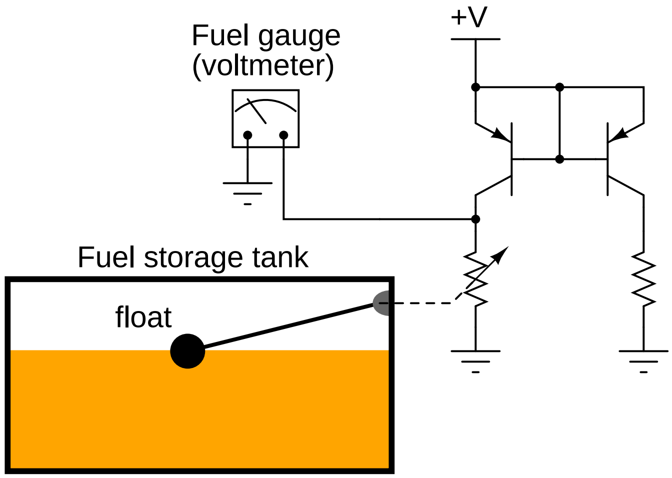
Question 101

Many different types of sensors work on the principle of a variable resistance representing a different physical quantity. One such sensor is the common fuel level sensor used in automotive, marine, and industrial fuel storage applications:



As the fuel level in the tank changes, the float position will change, changing the sensor's resistance. This resistance change is detected by an electric gauge (a special type of meter), which then provides visual indication of fuel level in the tank.

We must have some accurate way of measuring electrical resistance in order for this scheme to work. One common technique for doing this is to pass a constant current through the sensor resistance and then measure the voltage dropped across it. Since current mirror circuits function as current regulators, and therefore may be used as current sources if supplied with an external voltage, we could use a current mirror to force constant current through the fuel level sensor:



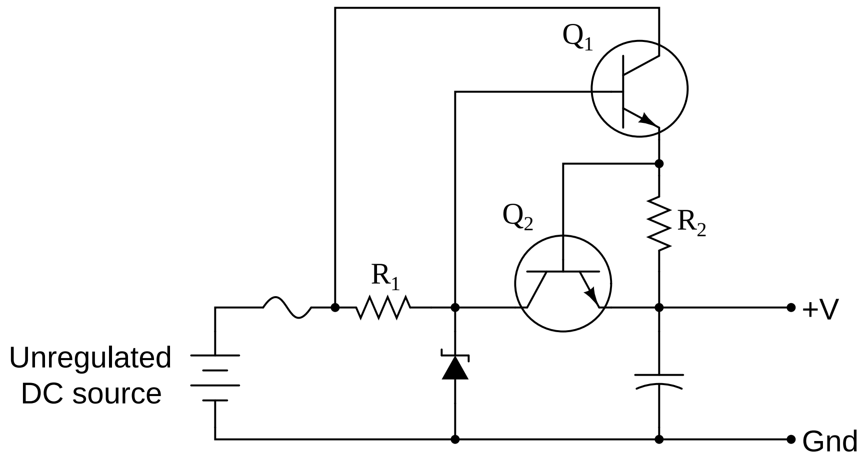
One problem with the circuit shown is that the sensor current will change as the supply voltage (+V) changes. This may be important to us, because the DC system voltage on an automobile may not be very stable, and this could lead to inaccuracies in fuel level measurement.

Figure out a way we could use a zener diode to stabilize the voltage in this current mirror circuit so that supply voltage changes would have minimal effect on the amount of current through the variable-resistance sensor.

file 02508

Question 102

A very useful feature for a regulated voltage source is an electronic *current limit*: a circuit that limits the amount of current deliverable to a load, so as to avoid needless fuse-blowing. The combination of transistor Q2 and resistor R2 provides just this feature for the following voltage regulator circuit:

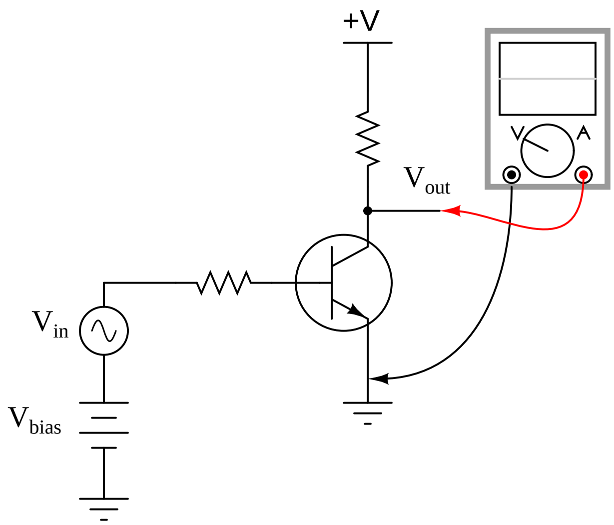


Describe how transistor Q2 limits the current sourced to a direct short-circuit across the load terminals.

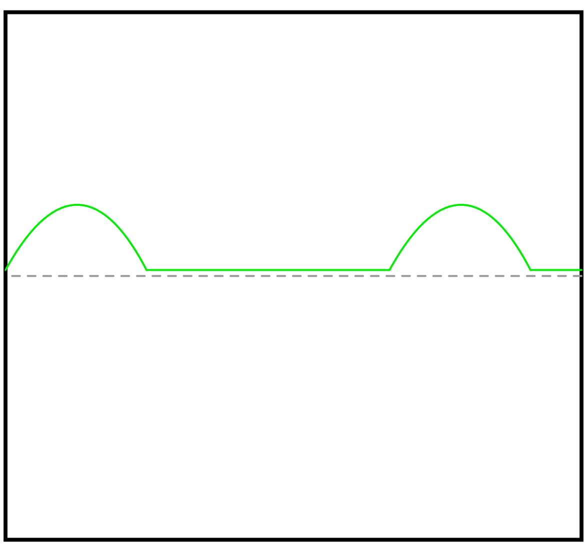
file 00894

Question 103

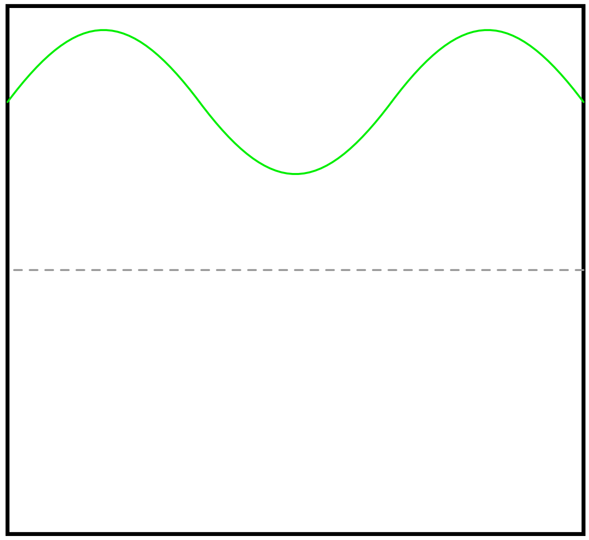
A student builds the following circuit and connects an oscilloscope to its output:



The waveform shown on the oscilloscope display looks like this:



Definitely not Class-A operation! Suspecting a problem with the input waveform, the student disconnects the oscilloscope probe from the amplifier output and moves it over to the amplifier input terminal. There, the following waveform is seen:



How can this amplifier circuit be producing such a distorted output waveform with such a clean input waveform? Explain your answer.

file 00748

Question 104

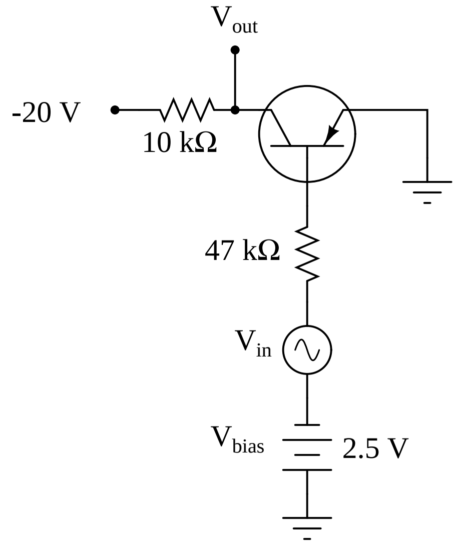
Suppose you were building a Class-A transistor amplifier for audio frequency use, but did not have an oscilloscope available to check the output waveform for the presence of "clipping" caused by improper biasing. You do, however, have a pair of audio headphones you may use to listen to the signals.

Explain how you would use a pair of headphones to check for the presence of severe distortion in a waveform.

file 00751

Question 105

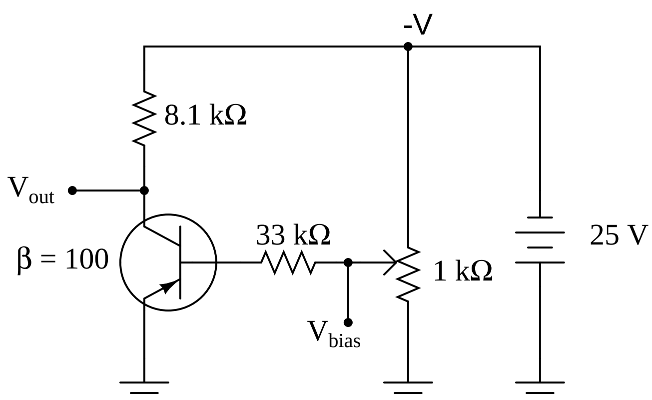
Calculate the approximate quiescent (DC) base current for this transistor circuit, assuming an AC input voltage of 0 volts, and a silicon transistor:



file 00823

Question 106

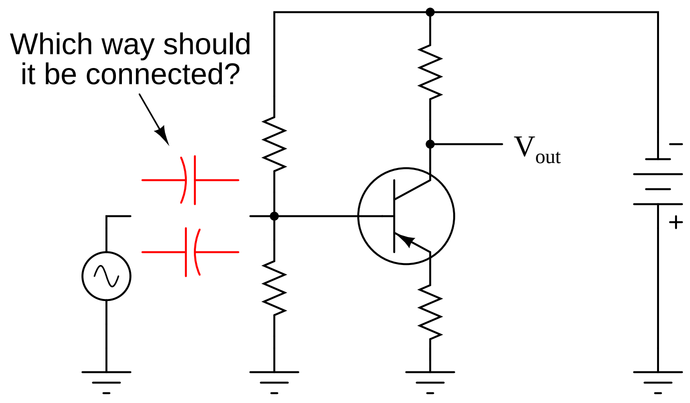
Calculate the potentiometer wiper voltage (V_{bias}) required to maintain the transistor right at the threshold between cutoff and active mode. Then, calculate the input voltage required to drive the transistor right to the threshold between active mode and saturation. Assume ideal silicon transistor behavior, with a constant β of 100:



file 00824

Question 107

When inserting a signal coupling capacitor into the bias network for this transistor amplifier, which way should the (polarized) capacitor go? (Hint: the AC signal source outputs pure AC, with a time-averaged DC value of 0 volts).

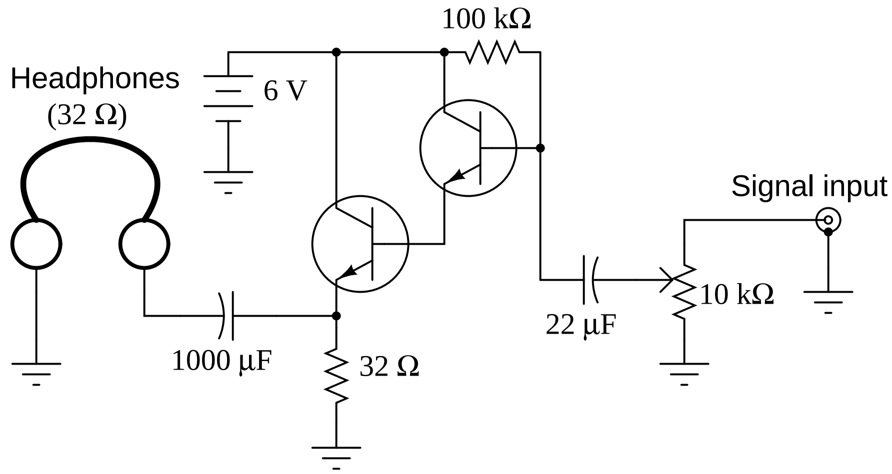


Explain why the orientation of this capacitor matters, and what might happen if it is connected the wrong way.

file 01592

Question 108

Describe how proper biasing is accomplished in this headphone amplifier circuit (suitable for amplifying the audio output of a small radio):

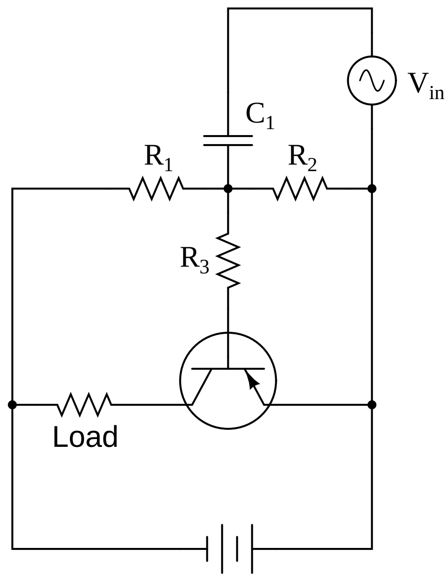


Also, describe the functions of the 10 kΩ potentiometer and the 22 μF capacitor.

file 00750

Question 109

Describe the functions of resistors R1 and R2, and capacitor C1, in this amplifier circuit. What purpose do they serve?

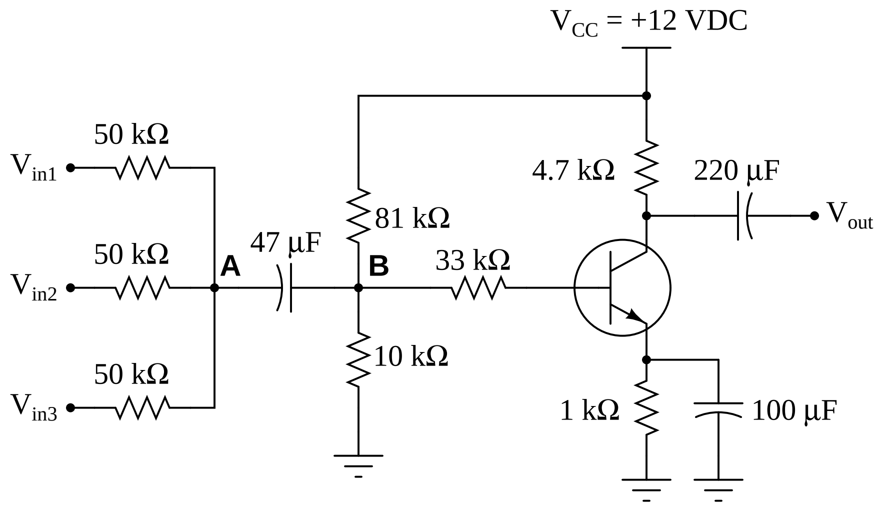


Would it be possible for this amplifier circuit to operate in Class A mode without this voltage divider/capacitor network? Explain your answer.

file 00957

Question 110

The following circuit is a three-channel audio *mixer* circuit, used to blend and amplify three different audio signals (coming from microphones or other signal sources):



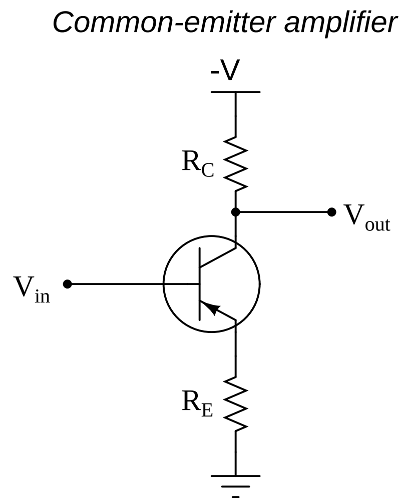
Suppose we measured a 9 kHz sinusoidal voltage of 0.5 volts (peak) at point "A" in the diagram, using an oscilloscope. Determine the voltage at point "B" in the circuit, after this AC signal voltage "passes through" the voltage divider biasing network.

The voltage at point "B" will be a mix of AC and DC, so be sure to express both quantities! Ignore any "loading" effects of the transistor's base current on the voltage divider.

file 00825

Question 111

The following schematic diagram shows a simple *common-emitter* transistor amplifier circuit:



Explain why the voltage gain (A_V) of such an amplifier is approximately $\frac{R_C}{R_E}$, using any or all of these general "rules" of transistor behavior:

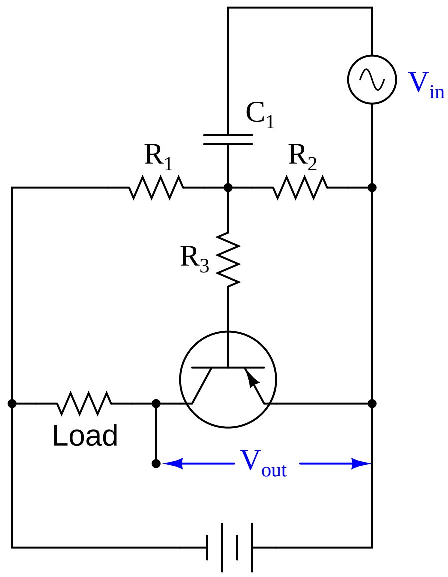
- $I_E = I_C + I_B$
- $I_E \approx I_C$
- $V_{BE} \approx 0.7$ volts
- $\beta = \frac{I_C}{I_B}$

Remember that (AC) voltage gain is defined as $\frac{\Delta V_{out}}{\Delta V_{in}}$. Hint: this question might be easier to answer if you first consider how to explain the unity-gain of a common-collector amplifier circuit (simply eliminate R_C, replacing it with a direct connection to $-V$, and consider V_E to be the output voltage).

file 01524

Question 112

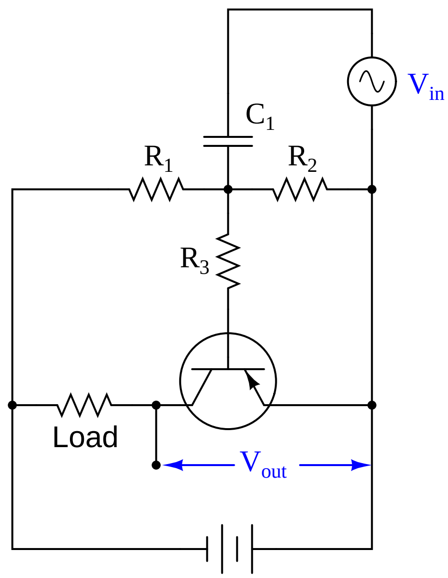
Explain the effects of increasing R3's resistance in this amplifier circuit. As R3 becomes more resistive, will the input signal (V_{in}) have more or less effect on the output voltage (V_{out}) than before? Express your answer in terms of voltage gain (A_V).



file 00958

Question 113

Explain the effects of increasing the load resistance in this amplifier circuit. As the load becomes more resistive, will the input signal (V_{in}) have more or less effect on the output voltage (V_{out}) than before? Express your answer in terms of voltage gain (A_V).

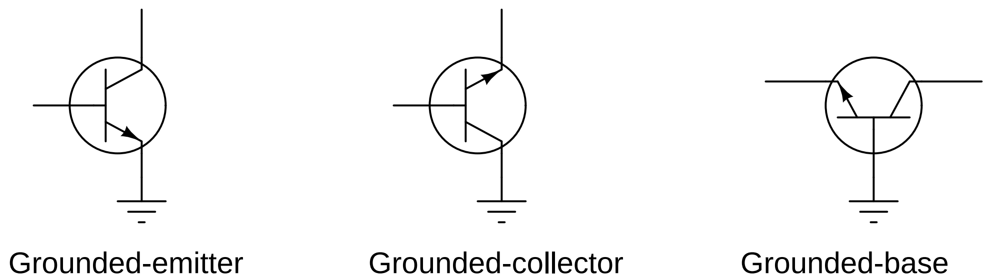


file 00959

Question 114

Common-emitter, common-collector, and common-base amplifier circuits are sometimes referred to as *grounded-emitter*, *grounded-collector*, and *grounded-base*, respectively, because these configurations may actually be built with those respective terminals connected straight to ground.

Although this may not be very practical for ease of biasing, it can be done. Draw the rest of the circuit necessary to provide class-A operation for each of these (partial) transistor circuits. Be sure to show where the DC power source, signal input, and signal output connect:



file 03871

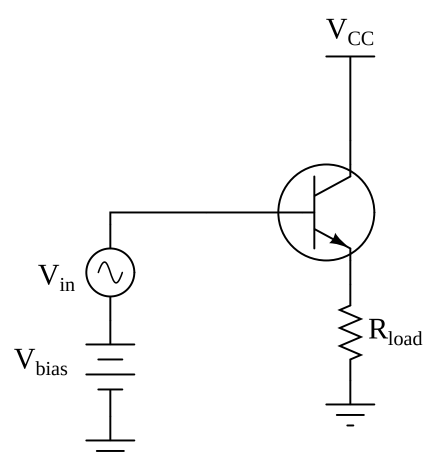
Question 115

Explain how you could *measure* the AC voltage gain of a functioning Class A amplifier circuit, as opposed to *predicting* its gain from known component values.

file 00967

Question 116

The voltage gain of this amplifier circuit, unlike other amplifier configurations, is completely independent of the load resistor value:

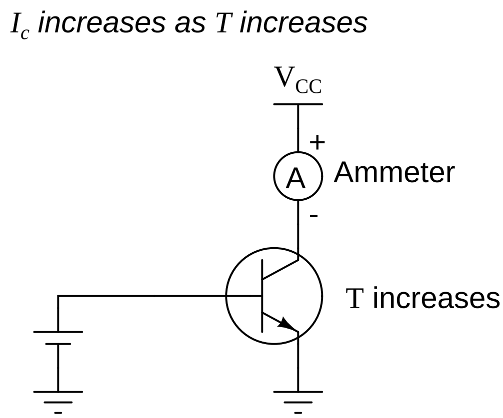


No matter what the resistance of the load, the amplifier's voltage gain remains the same. Explain why this is so.

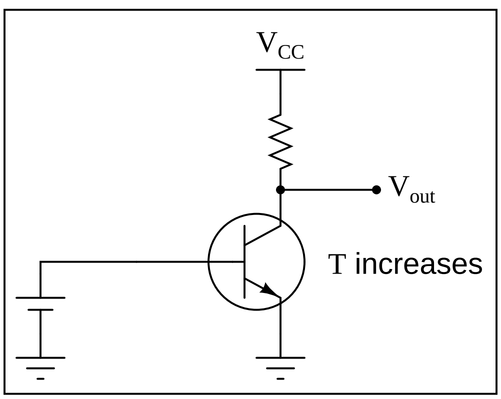
file 00961

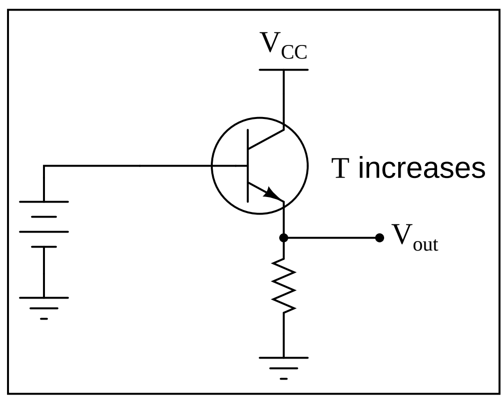
Question 117

Temperature changes are well known to affect transistor operation. For instance, if we were to apply a constant voltage between the base and emitter of a transistor and increase its temperature over time, the collector current would increase:



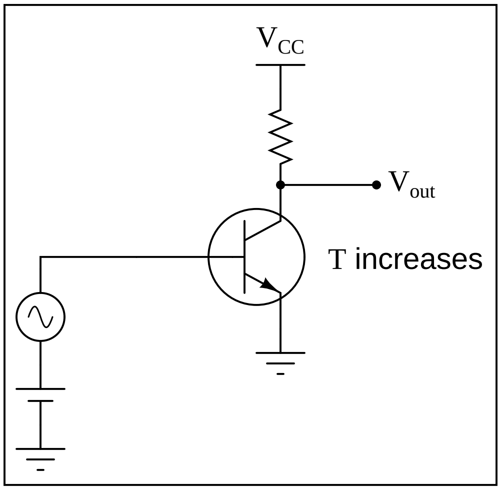
First, describe *why* the collector current changes, if the input voltage is held constant. Then, determine the relative degree of output voltage change (ΔV_{out}) resulting from this thermal effect in the following two amplifier circuits:

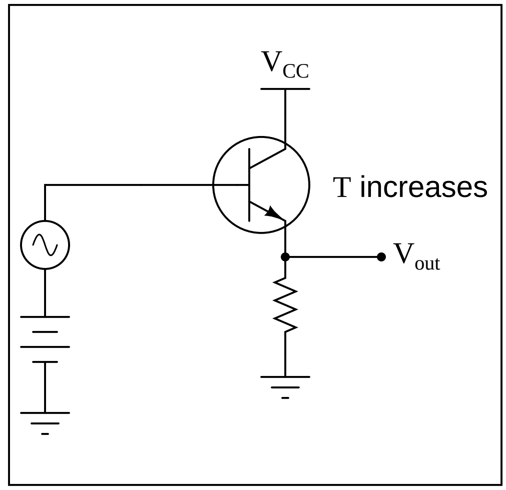




What is different in the responses of these two circuits to temperature changes? Why does one circuit respond so much differently than the other?

If both these amplifier circuits had AC signal inputs, and were biased for Class A operation, what effect would an increase in temperature have on each of them? State your answer in terms of AC voltage gain and Q-point.



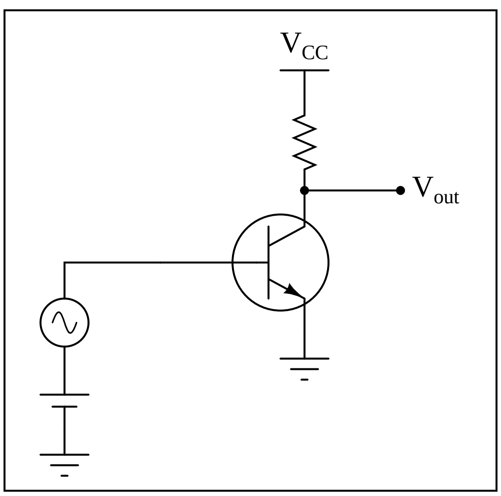


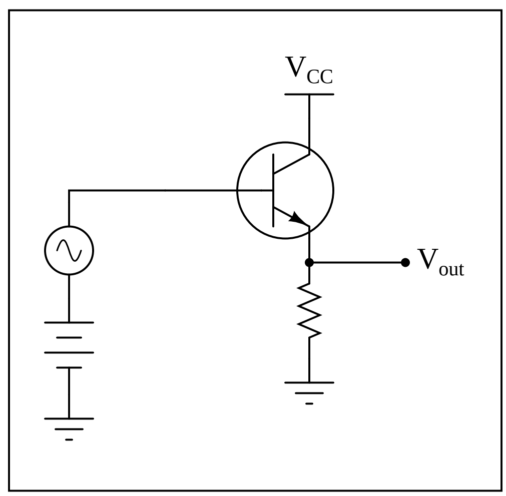
file 00962

Question 118

One major different between a common-emitter amplifier configuration and a common-collector amplifier configuration is a principle called *negative feedback*, where changes in output voltage "feed back" to influence the amplifier's input signal, which in turn influences the output voltage again. Common-collector amplifier circuits have large amounts of negative feedback inherent to their design.

The absence or presence of negative feedback in an amplifier circuit has profound effects on voltage gain (A_V). Compare the relative voltage gains of the following amplifiers:



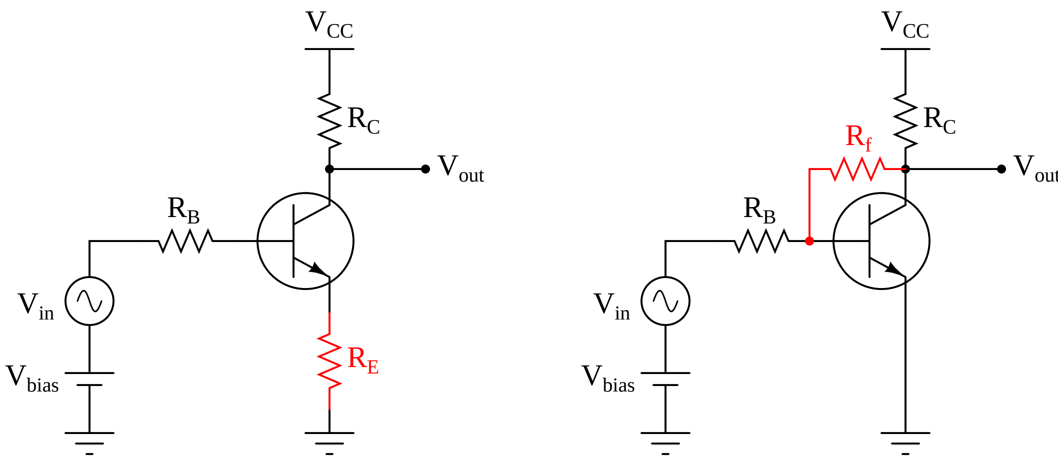


At first, the low voltage gain of the common-collector amplifier may appear to be a disadvantage of that circuit design. However, there is one major benefit relevant to the common-collector amplifier's voltage gain, being a direct result of negative feedback. What is this advantage?

file 00963

Question 119

One way to reap the advantages of negative feedback enjoyed in common-collector amplifier circuits, in a common-emitter amplifier, is to add components that intentionally "feed back" some of the output signal to the transistor's input in a *degenerative* fashion:



Explain what the term *negative* (or *degenerative*) means with reference to feedback, and explain how each of these techniques works to produce this type of feedback. Also, explain one *disadvantage* of applying negative feedback to a common-emitter amplifier circuit.

file 00964

Question 120

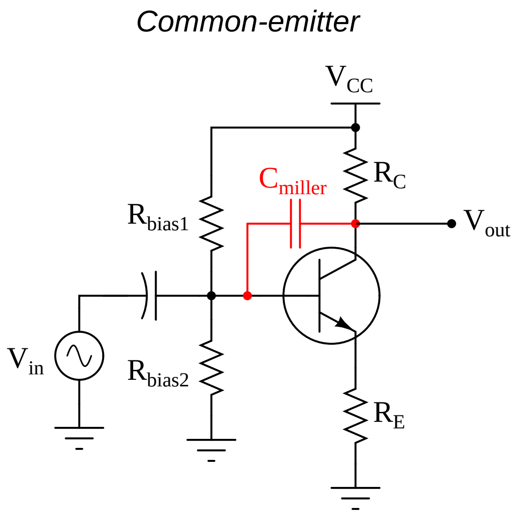
A parasitic property of semiconductor PN junctions is *capacitance* across the depletion regions. This is often referred to as the *Miller Effect*. In transistor circuits, the Miller effect contributes to a decrease in voltage gain as signal frequency increases.

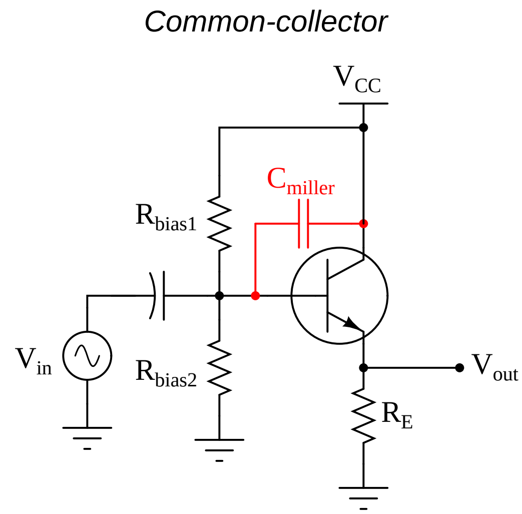
Explain why junction capacitances make the voltage gain of an amplifier decrease with increasing frequency.

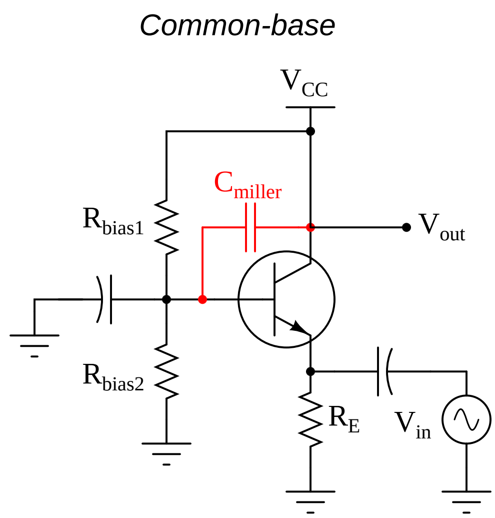
file 00979

Question 121

The BJT amplifier configuration most affected by the Miller effect at high frequencies is the common-emitter. Common-collector and common-base amplifier configurations do not suffer the same great losses of voltage gain at high frequency as the common-emitter circuit does. After examining the following amplifier circuits (with the Miller effect capacitance shown external to the transistors), explain why:







file 02561

Question 122

The "Miller capacitance" of a transistor in a common-emitter configuration is often expressed as the product of the transistor's base-to-collector junction capacitance (C_{BC}) and $\beta + 1$:

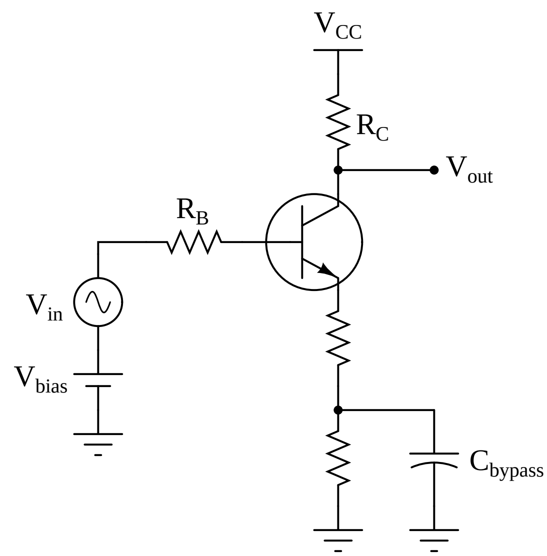
$$C_{miller} = C_{BC} \, (\beta + 1)$$

Why is this? What purpose does it serve to include the transistor's gain into the calculation, rather than just expressing the junction capacitance as it is?

file 01482

Question 123

Some common-emitter amplifier circuits use *partial bypassing* of emitter resistance, with the bypass capacitor connected in parallel with only one of two series resistors:

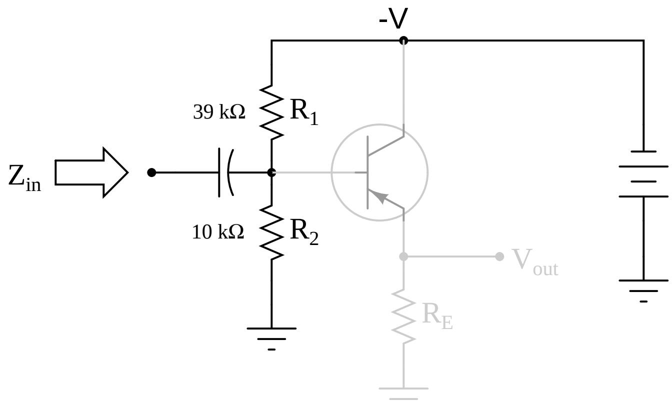


Explain the purpose of this arrangement. How does this differ in performance from the simple one-resistor emitter feedback design, or a grounded-emitter amplifier with no emitter resistor at all?

file 00966

Question 124

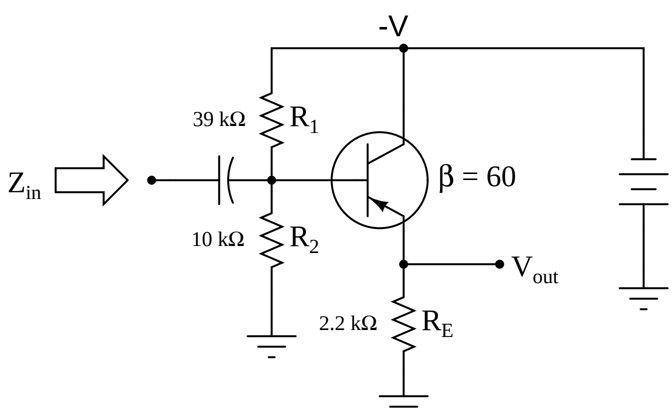
The voltage divider network employed to create a DC bias voltage for many transistor amplifier circuits has its own effect on amplifier input impedance. Without considering the presence of the transistor or the emitter resistance, calculate the impedance as "seen" from the input terminal resulting from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



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

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

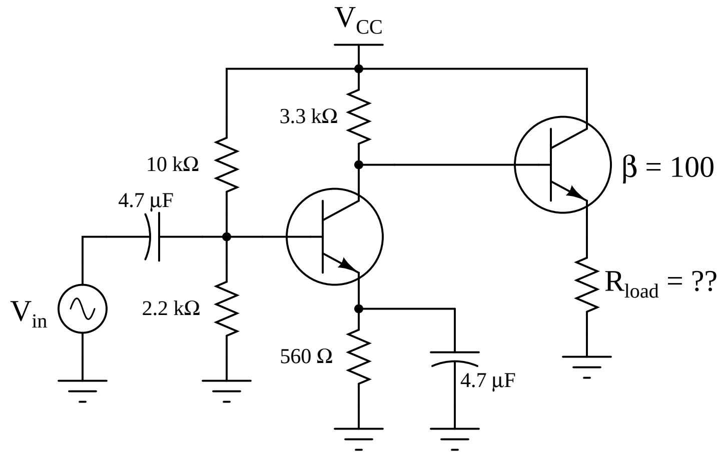
$$Z_B \approx (\beta + 1)R_E$$



Develop an equation from the steps you take in calculating this impedance value.
file 03127

Question 125

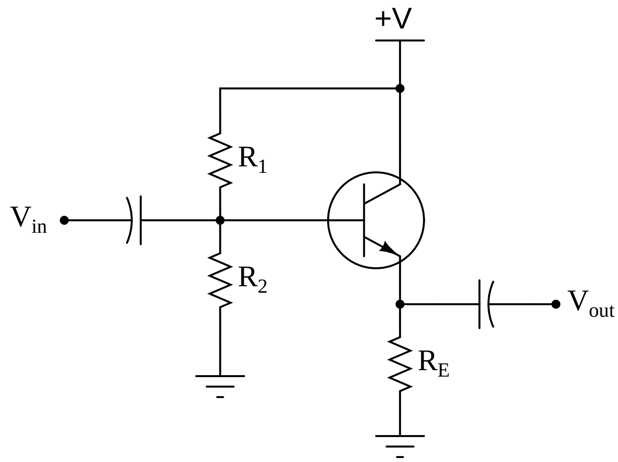
Calculate the ideal amount of load impedance for this amplifier circuit, so that maximum power will be delivered to it:



file 01217

Question 126

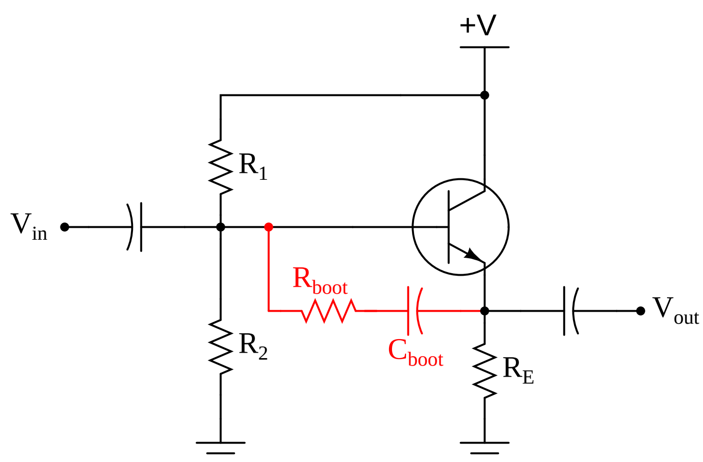
In a common-collector transistor amplifier circuit with voltage divider biasing, the input impedance (Z_{in}) is a function of load impedance, emitter resistance (R_E), and the two biasing resistances (R_1 and R_2). Often, the biasing resistances are of sufficiently low value to swamp the input impedance of the transistor, so that R_1 and R_2 constitute the heaviest load for any input signals driving the amplifier.



$$Z_{in} \approx R_1 \mid\mid R_2 \mid\mid (\beta + 1)[r'_e + (R_E \mid\mid R_{load})]$$

This is a shame, because the only practical purpose served by R_1 and R_2 is to provide a stable bias voltage so the transistor always functions in class A mode. In order to provide a stable bias, these resistors have to be relatively low in value compared to the impedance seen at the base of the transistor (resulting from the load). Otherwise, changes in dynamic emitter resistance (r'_e) could result in significant bias shifts. So, the naturally high input impedance of the common-collector transistor configuration is spoiled by the necessary presence of R_1 and R_2.

A clever way to recover some of that naturally large input impedance is to add a bit of *regenerative* (positive) feedback to the circuit in the form of a capacitor and another resistor. This technique is given an equally clever name: *bootstrapping*.

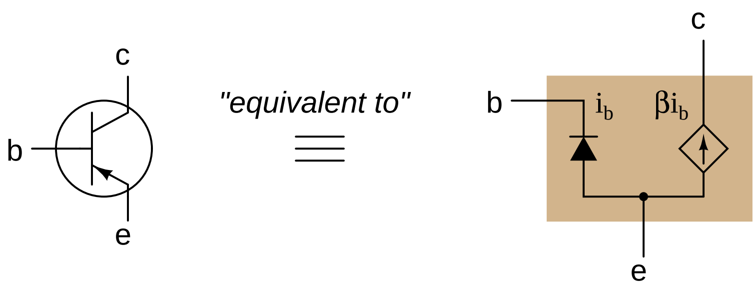


Explain how bootstrapping works, and why that particular name is given to the technique.

file 02768

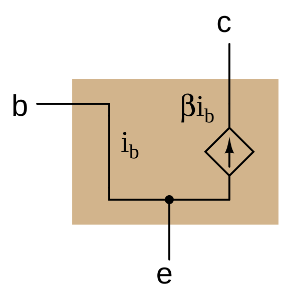
Question 127

Models of complex electronic components are useful for circuit analysis, because they allow us to express the approximate behavior of the device in terms of ideal components with relatively simple mathematical behaviors. Transistors are a good example of components frequently modeled for the sake of amplifier circuit analysis:

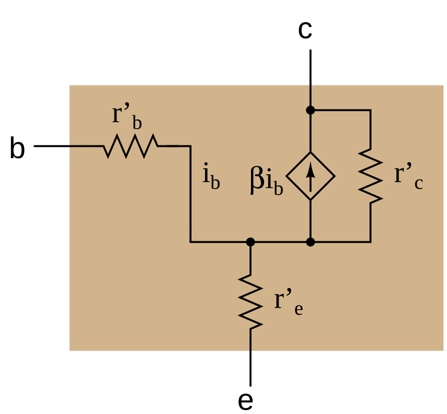


It must be understood that models are never *perfect* replicas of the real thing. At some point, all models fail to precisely emulate the thing being modeled. The only real concern is how accurate we want our approximation to be: which characteristics of the component most concern us, and which do not.

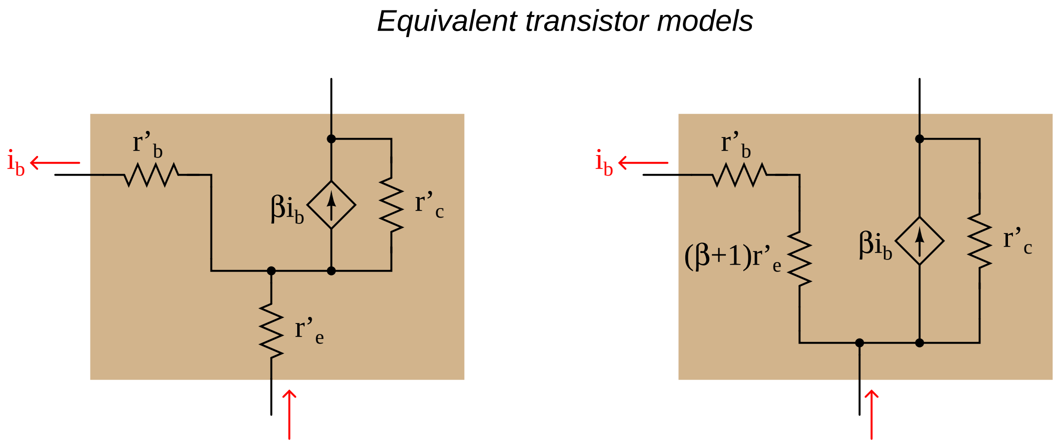
For example, when analyzing the response of transistor amplifier circuits to small AC signals, it is often assumed that the transistor will be "biased" by a DC signal such that the base-emitter diode is always conducting. If this is the case, and all we are concerned with is how the transistor responds to *AC* signals, we may safely eliminate the diode junction from our transistor model:



However, even with the 0.7 volt (nominal) DC voltage drop absent from the model, there is still some impedance that an AC signal will encounter as it flows through the transistor. In fact, several distinct impedances exist within the transistor itself, customarily symbolized by resistors and lower-case r' designators:



From the perspective of an AC current passing through the base-emitter junction of the transistor, explain why the following transistor models are equivalent:



file 02239

Question 128

An important performance parameter for amplifier circuits is *bandwidth*. Explain what "bandwidth" means, and what factor(s) limit the bandwidth for electronic amplifiers.

file 02562

Question 129

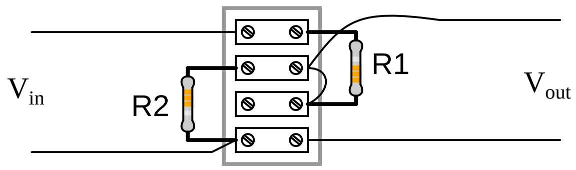
What does it mean to speak of the *gain* of a circuit? This term is very commonly used when describing amplifier circuits, but it may also be used to describe circuits containing nothing but passive components, and are thus incapable of amplifying.

What letter is used to symbolize gain in mathematical equations?

file 00672

Question 130

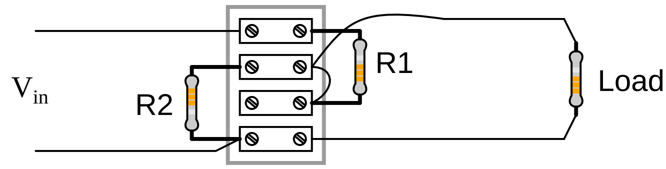
Calculate the voltage gain of this circuit, if R1 has a resistance of 8.1 kΩ and R2 has a resistance of 1.75 kΩ:



file 00673

Question 131

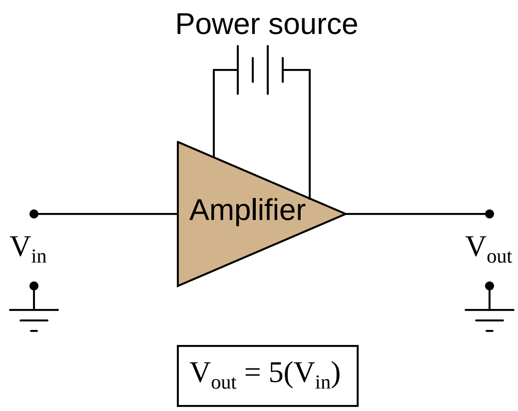
Calculate the power gain of this circuit, if R1 has a resistance of 1 kΩ, R2 has a resistance of 5.1 kΩ, and the load has a resistance of 10 kΩ:



file 00674

Question 132

Suppose an AC signal amplifier circuit has a voltage gain (ratio) of 5. That is, V_{out} is five times as large as V_{in}:



Translate this voltage gain ratio into a decibel figure. Explain why the conversion from voltage gain ratio to decibels is not the same as conversion of a power gain ratio to decibels.

file 00828

Question 133

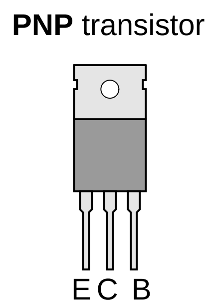
Specialized forms of the decibel unit have been devised to allow easy representation of quantities other than arbitrary ratios of voltage, current, or power. Take for example these units, the first one used extensively in the telecommunications industry:

- dBm
- dBW
- dBk

Define what each of these units represents.

file 00831

Answer 1



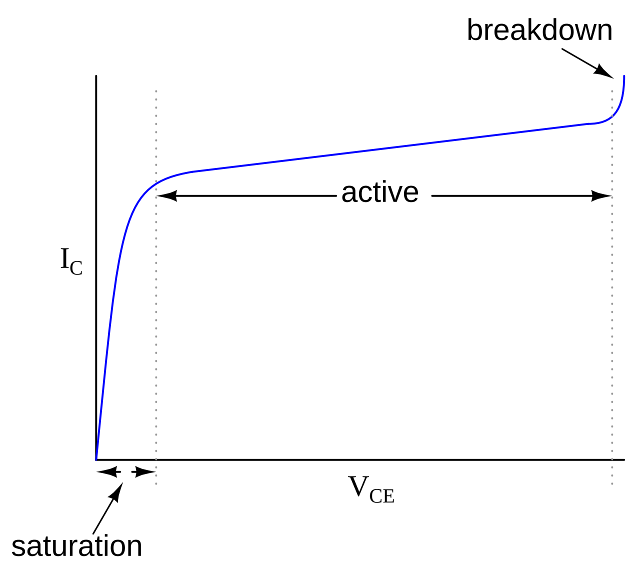
Answer 2

I'll let you determine the directions of all currents in this circuit! Although it is impossible to tell with absolute certainty, the current through R1 is likely to be much greater than the current through R2.

If SW2 opens while SW1 remains closed, both currents will cease. If SW1 opens while SW2 remains closed, there will be no current through R1, but the current through R2 will actually increase.

Follow-up question: what does this indicate about the nature of the two currents? Which current exerts *control* over the other through the transistor?

Answer 3



The transistor's best current-regulation behavior occurs in its "active" region.

Follow-up question: what might the characteristic curves look like for a transistor that is failed *shorted* between its collector and emitter terminals? What about the curves for a transistor that is failed *open*?

Answer 4

The collector current is (for the most part) directly proportional to base current while in the "active" region.

Answer 5

The action of tossing flower petals into the air is analogous to base current injecting charge carriers into the base region of a transistor. The drifting of those tossed petals by the wind is analogous to the sweeping of charge carriers across the base and into the collector by V_{CE}. Like the number of flower petals drifting, the amount of collector current does not depend much on the strength of V_{CE} (the strength of the wind), but rather on the rate of charge carriers injected (the number of petals tossed upward per second).

Answer 6

The collector current will remain (approximately) the same as the variable voltage source increases in magnitude. In this manner, the transistor circuit "looks" like a *current source*.

Answer 7

The collector current will remain (approximately) the same as the variable resistance is changed. In this manner, the transistor circuit "looks" like a *current source* to the variable resistor.

Answer 8

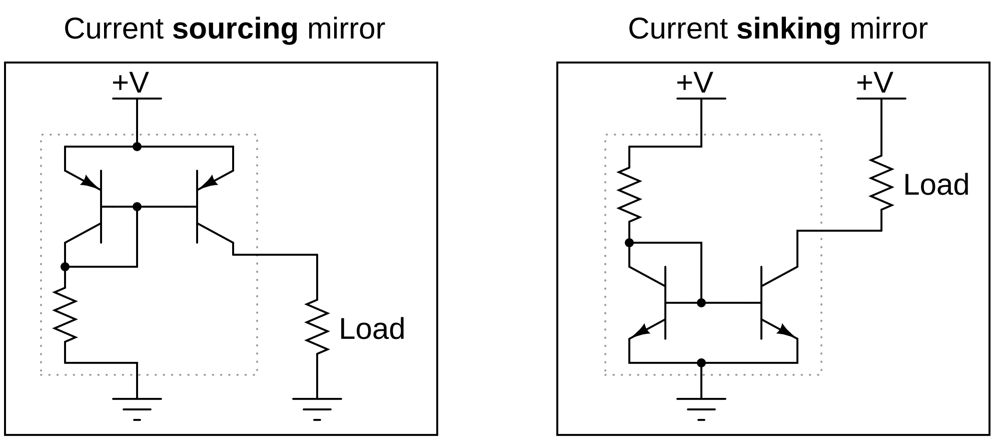
The transistor's collector current rises and falls with the diode's current, as dictated by the variable resistor. Ideally, the transistor collector current *precisely matches* the diode's current.

Answer 9

As the load resistance changes, the current through it remains approximately the same. In the first current mirror circuit where a transistor receives its controlling signal from a diode (rather than another transistor), there is a tendency for the transistor to thermally "run away," allowing more and more current through the load over time.

Follow-up question: explain how to adjust the regulated current's target value in either of these circuits.

Answer 10



Answer 11

$I_C \approx 4.75$ mA

Follow-up question: how much will the collector current rise if the voltage source increases to 35 volts?

Answer 12

$I_{load} \approx 6.5$ mA

Follow-up question: what would have to be changed in this circuit to increase the amount of current through the load resistor without changing the power supply voltage?

Answer 13

$I_{load} \approx 4.57$ mA $\quad$ $P_{Q2} \approx 40.77$ mW

Answer 14

$I_{load} \approx 8.63$ mA $\quad$ $P_{Q1} \approx 6.041$ mW $\quad$ $P_{Q2} \approx 95.41$ mW

Follow-up question: what do the two power dissipation figures tell us about the relative power of two transistors handling the exact same currents? Explain why this is important in a current mirror circuit, and why it is customary to thermally bond Q_1 and Q_2 together in discrete-component current mirrors.

Answer 15

Note that this is just one possible set of values meeting the criteria given for this circuit. Your own answers may be different!

$R_1 = 2.287$ kΩ $\quad$ $V_{supply} = 35$ volts $\quad$ $P_{Q2} \approx 300$ mW

Answer 16

V_{out} will increase, from 0 volts to approximately 9.3 volts (assuming a silicon transistor with a nominal base-emitter voltage drop of 0.7 volts), as the potentiometer wiper is moved closer to +V.

Follow-up question: based on this result, would you be inclined to call this amplifier an *inverting* or a *noninverting* circuit?

Answer 17

V_{in}	V_{out}
0.0 V	0.0 V
0.5 V	0.0 V
1.0 V	0.3 V
1.5 V	0.8 V
5.0 V	4.3 V
7.8 V	7.1 V

The voltage at the transistor's emitter terminal approximately "follows" the voltage applied to the base terminal, hence the name.

Answer 18

V_{in}	V_{out}	I_{in}	I_{out}
0.0 V	0.0 V	0.0 μA	0.0 mA
0.4 V	0.0 V	0.0 μA	0.0 mA
1.2 V	0.5 V	2.498 μA	0.227 mA
3.4 V	2.7 V	13.49 μA	1.227 mA
7.1 V	6.4 V	31.97 μA	2.909 mA
10.8 V	10.1 V	50.45 μA	4.591 mA

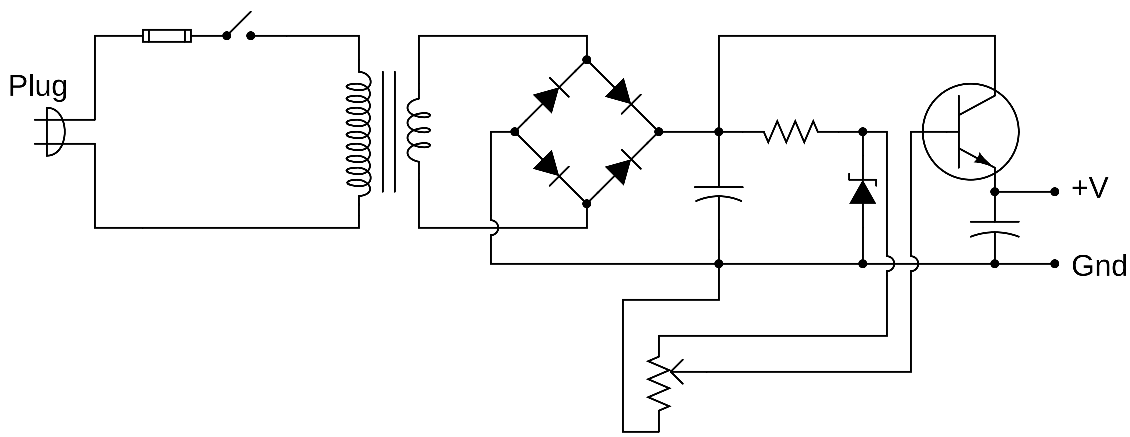
$$A_V = \frac{\Delta V_{out}}{\Delta V_{in}} = 1$$

$$A_I = \frac{\Delta I_{out}}{\Delta I_{in}} = 91$$

Answer 19

The transistor serves to "boost" the current-sourcing capability of the resistor/zener voltage regulator circuit, to provide far more current to a load than possible with the resistor/zener alone.

Answer 20



Challenge question: for any given amount of load current, what voltage setting will cause the transistor to dissipate the most heat energy, low, medium, or high?

Answer 21

$V_{out} \approx$ -8.6 V $\qquad I_{zener} \approx 6.71$ mA

Answer 22

$V_{out} \approx 6.2$ V $\qquad I_{zener} \approx 25.6$ mA $\qquad V_{capacitor} = 32.5$ V

Answer 23

Trick question! V_{out} will remain at 0 volts the entire time.

Answer 24

Transistors are essentially DC devices, not AC devices. Consider the base-emitter PN junction that the input signal is sent to: it can only conduct in one direction (base positive and emitter negative).

Answer 25

"Class A" amplifier operation is when the transistor remains in its "active" mode (conducting current) throughout the entire waveform. Biasing may be thought of as a kind of "trick" used to get the transistor (a DC device) to "think" it is amplifying DC when the input signal is really AC.

Answer 26

The purpose of any biasing network in an AC signal amplifier is to provide just enough quiescent current through the base to keep the transistor between the extremes of cutoff and saturation throughout the input signal's waveform cycle.

Answer 27

The common-collector amplifier configuration is defined by having the input and output signals referenced to the base and emitter terminals (respectively), with the collector terminal of the transistor typically having a low AC impedance to ground and thus being "common" to one pole of both the input and output voltages.

Common-collector amplifiers are characterized by high current gains, voltage gains of 1 or (slightly) less, and a noninverting phase relationship between input and output.

Answer 28

Since V_{BE} is relatively constant, $\Delta V_{in} \approx \Delta V_{out}$.

For your discussion response, be prepared to explain why, in mathematical terms, the above statement is true. You will have to use Kirchhoff's Voltage Law as part of your explanation.

Answer 29

I'll let you figure out the output voltage on your own! As for the capacitive reactances, they are just over *1 ohm each* at this frequency: practically a "direct connection" for the AC signal compared to the resistance values throughout the circuit.

Challenge question: calculate the approximate (average) DC voltage dropped across the 1 kΩ emitter resistor.

Answer 30

$V_{out} \approx 2.5$ volts peak or 1.77 volts RMS (assuming a sinusoidal source). A signal frequency of 3.39 kHz or greater will ensure the capacitive reactances will remain less than 1 ohm each.

Follow-up question: calculate the approximate (average) DC voltage dropped across the 1 kΩ emitter resistor.

Answer 31

V_{out} will decrease, from +10 volts to nearly zero volts, as the potentiometer wiper is moved closer to +V.

Follow-up question: based on this result, would you be inclined to call this amplifier an *inverting* or a *noninverting* circuit?

Answer 32

V_B	V_E	I_C	V_{R_C}	V_{CE}	V_C (V_{out})
0.0 V	0.0 V	0.0 mA	0.0 V	15 V	15 V
0.5 V	0.0 V	0.0 mA	0.0 V	15 V	15 V
1.0 V	0.3 V	0.298 mA	1.40 V	13.3 V	13.6 V
1.5 V	0.8 V	0.793 mA	3.73 V	10.47 V	11.27 V
2.0 V	1.3 V	1.29 mA	6.06 V	7.64 V	8.94 V
2.5 V	1.8 V	1.79 mA	8.39 V	4.81 V	6.61 V
3.0 V	2.3 V	2.28 mA	10.7 V	1.98 V	4.28 V
increase	*increase*	*increase*	*increase*	*decrease*	*decrease*

$$A_V = \frac{\Delta V_{out}}{\Delta V_{in}} = 4.66$$

Sometimes the voltage gain of a common-emitter amplifier circuit is expressed as a negative quantity (-4.66 in this case), to indicate the inverse output/input relationship (180^o phase shift).

Follow-up question: what similarity do you notice between the voltage gain value of 4.66 and the two resistor values?

Challenge question: a common assumption used in this type of BJT amplifier circuit is $I_C \approx I_E$. Develop a voltage gain formula based on this assumption, in terms of resistor values R_C and R_E.

Answer 33

Transistors are essentially DC devices, not AC devices. Consider the base-emitter PN junction that the input signal is sent to: it can only conduct in one direction (base positive and emitter negative).

Answer 34

"Class A" amplifier operation is when the transistor remains in its "active" mode (conducting current) throughout the entire waveform. Biasing may be thought of as a kind of "trick" used to get the transistor (a DC device) to "think" it is amplifying DC when the input signal is really AC.

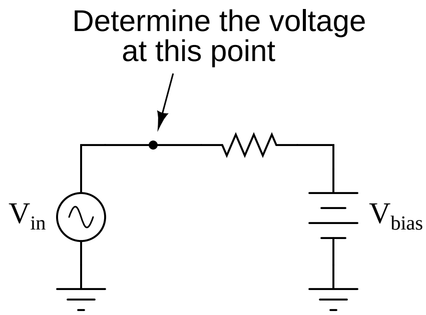
Answer 35

The purpose of any biasing network in an AC signal amplifier is to provide just enough quiescent current through the base to keep the transistor between the extremes of cutoff and saturation throughout the input signal's waveform cycle.

Answer 36

A very good way to understand the AC source's effect on the voltage divider with and without the capacitor is to use *Superposition Theorem* to determine what each source (AC signal, and DC power supply) will do separately.

If this concept is still not clear, consider this circuit:



As far as capacitor size is concerned, it should be large enough that its reactance is negligible. I'll let you determine what factors define negligibility in this context!

Follow-up question: which voltage source (AC or DC?) "wins" at the point specified in the above circuit? Explain why this is so, and then show how a suitably located capacitor would allow both voltage signals to co-exist at that point.

Answer 37

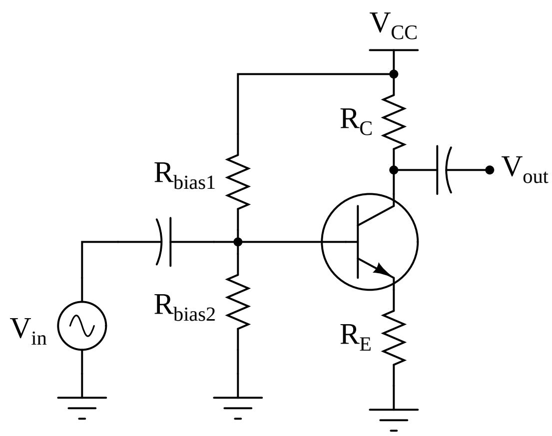
- Resistance R_C increased; A_V *increases*
- Resistance R_E increased; A_V *decreases*
- Resistance R_{bias1} increased; A_V *does not change*
- Resistance R_{bias2} increased; A_V *does not change*

Answer 38

The emitter resistance of a transistor dynamically changes with emitter current and with semiconductor temperature, which is why it is often called the *dynamic emitter resistance*. A commonly approximation for its value is this:

$$r'_e \approx \frac{25 \text{ mV}}{I_E}$$

Follow-up question: explain why this dynamic emitter resistance is often ignored when calculating voltage gain in a common-emitter circuit such as this:



Answer 39

To an AC signal, a large capacitor "looks" like a lower impedance than the emitter resistor. Usually, this capacitor is sized such that X_C is very small.

The addition of a bypass capacitor maintains DC stability, because DC cannot go through the capacitor but must go through the emitter resistor (R_E) just as if the bypass capacitor were not there at all.

Answer 40

The common-emitter amplifier configuration is defined by having the input and output signals referenced to the base and collector terminals (respectively), with the emitter terminal of the transistor typically having a low AC impedance to ground and thus being "common" to one pole of both the input and output voltages.

Common-emitter amplifiers are characterized by moderate voltage and current gains, and an inverting phase relationship between input and output.

Answer 41

- $A_V \approx 4.55$
- $V_B \approx 2.125$ volts
- $V_E \approx 1.425$ volts
- $V_C \approx 9.521$ volts

Answer 42

- $A_V \approx 7.02$
- $V_B \approx 2.273$ volts
- $V_E \approx 1.573$ volts
- $V_C \approx 13.96$ volts

Answer 43

- $A_V \approx 11.8$
- $V_B \approx$ -1.244 volts
- $V_E \approx$ -0.544 volts
- $V_C \approx$ -5.568 volts

Answer 44

The following resistor values are but one solution for this problem. There is actually an infinite number of correct resistor value pairs that will yield the requested voltage gain!

- $R_C = 10$ kΩ
- $R_E = 2$ kΩ

Answer 45

- $A_V \approx 246$
- $V_C \approx 13.85$ volts

Answer 46

V_E	V_B	I_B	I_C	V_{R_C}	V_C
0.0 V	0.0 V	0.0 μA	0.0 mA	0.0 V	15 V
-0.5 V	0.0 V	0.0 μA	0.0 mA	0.0 V	15 V
-0.8 V	-0.1 V	45.5 μA	2.27 mA	2.27 V	12.7 V
-1.0 V	-0.3 V	136.4 μA	6.82 mA	6.82 V	8.18 V
-1.1 V	-0.4 V	181.8 μA	9.09 mA	9.09 V	5.91 V
-1.2 V	-0.5 V	227.3 μA	11.36 mA	11.36 V	3.64 V
-1.3 V	-0.6 V	272.7 μA	13.64 mA	13.64 V	1.36 V

$$A_V = \frac{\Delta V_{out}}{\Delta V_{in}} = 22.7$$

Follow-up question: based on the values for output and input voltage shown in the table, would you say that common-base amplifier circuits are *inverting* or *noninverting*?

Answer 47

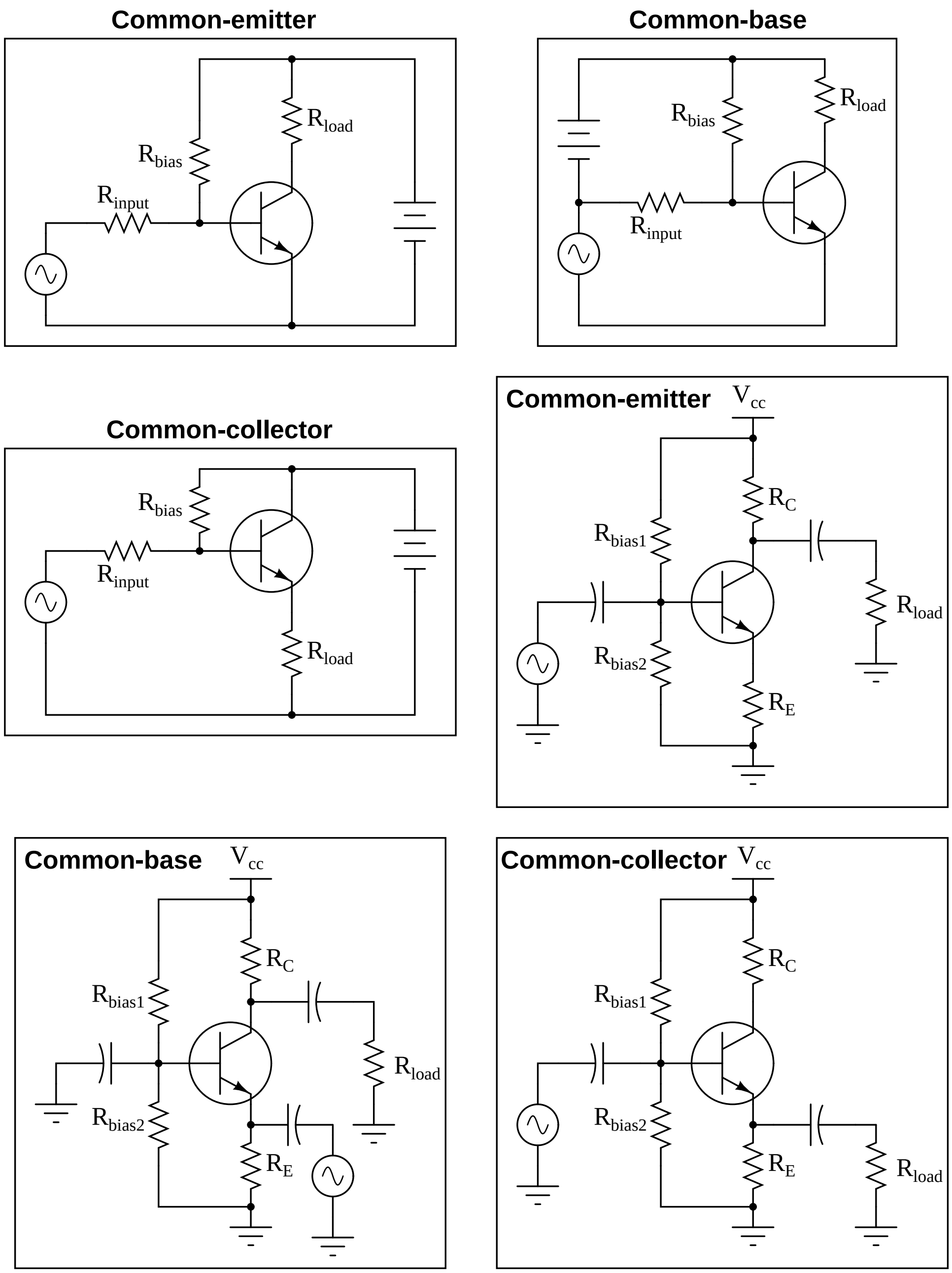
The common-base amplifier configuration is defined by having the input and output signals referenced to the emitter and collector terminals (respectively), with the base terminal of the transistor typically having a low AC impedance to ground and thus being "common" to one pole of both the input and output voltages.

Common-base amplifiers are characterized by high voltage gains, current gains less than unity, and a noninverting phase relationship between input and output.

Answer 48

Common-base amplifier circuits are typified by sub-unity current gains and very low input impedances.

Answer 49



Answer 50

- $A_P = 3$ B ; $A_P = 1000$
- $A_P = 2$ B ; $A_P = 100$
- $A_P = 1$ B ; $A_P = 10$
- $A_P = 0$ B ; $A_P = 1$
- $A_P =$ -1 B ; $A_P = \frac{1}{10}$
- $A_P =$ -2 B ; $A_P = \frac{1}{100}$
- $A_P =$ -3 B ; $A_P = \frac{1}{1000}$

Follow-up question: a geologist, taking a class on electronics, sees this mathematical pattern and remarks, "This is just like the *Richter* scale!" Explain what the geologist means.

Answer 51

$$A_{P(Bels)} = \log A_{P(ratio)}$$

- $A_P = 250$; $A_P = 2.398$ B
- $A_P = 1275$; $A_P = 3.106$ B
- $A_P = 10$; $A_P = 1$ B
- $A_P = 1$; $A_P = 0$ B
- $A_P = 0.1$; $A_P =$ -1 B
- $A_P = 0.025$; $A_P =$ -1.602 B
- $A_P = 0.00009$; $A_P =$ -4.046 B

Answer 52

$$A_{P(ratio)} = 10^{\frac{A_{P(dB)}}{10}}$$

$$A_{P(dB)} = 10 \log A_{P(ratio)}$$

Power gain of 2 (ratio) $\approx$ 3 dB

Power loss of 50% (ratio) $\approx$ -3 dB

Answer 53

Power ratio = 4:1

Answer 54

$A_P = 6.02$ dB

Answer 55

$$\log a^b = b \log a$$

Challenge question: knowing this algebraic law, solve for x in the following equation:

$$520 = 8^x$$

Answer 56

- $A_P = 25$; $A_{P(dB)} = 13.98$ dB
- $A_V = 10$; $A_{V(dB)} = 20$ dB
- $A_I = 37$; $A_{I(dB)} = 31.36$ dB
- $A_P = 150$; $A_{P(dB)} = 21.76$ dB
- $A_I = 41$; $A_{I(dB)} = 32.26$ dB
- $A_V = 3.4$; $A_{V(dB)} = 10.63$ dB
- $A_P = 18$; $A_{P(dB)} = 12.55$ dB
- $A_V = 100$; $A_{V(dB)} = 40$ dB

Answer 57

- $A_P = 5$ dB ; $A_{P(ratio)} = 3.16$
- $A_V = 23$ dB ; $A_{V(ratio)} = 14.13$
- $A_I = 20$ dB ; $A_{I(ratio)} = 10$
- $A_P = 2.5$ dB ; $A_{P(ratio)} = 1.78$
- $A_I = 7.4$ dB ; $A_{I(ratio)} = 2.34$
- $A_V = 45$ dB ; $A_{V(ratio)} = 177.8$
- $A_P = 12.8$ dB ; $A_{P(ratio)} = 19.05$
- $A_V = 30$ dB ; $A_{V(ratio)} = 31.62$

Answer 58

- $A_V = 14.1$ dB ; $A_{V(ratio)} = 5.07$
- $A_I = 202$; $A_{I(dB)} = 46.1$ dB
- $A_P = 15$ dB ; $A_{P(ratio)} = 31.62$
- $A_I = 33$; $A_{I(dB)} = 30.37$ dB
- $A_P = 49$ dB ; $A_{P(ratio)} = 79{,}432$
- $A_V = 57$; $A_{V(dB)} = 35.12$ dB
- $A_P = 8.8$ dB ; $A_{P(ratio)} = 7.59$
- $A_V = 30$; $A_{V(dB)} = 29.54$ dB

Answer 59

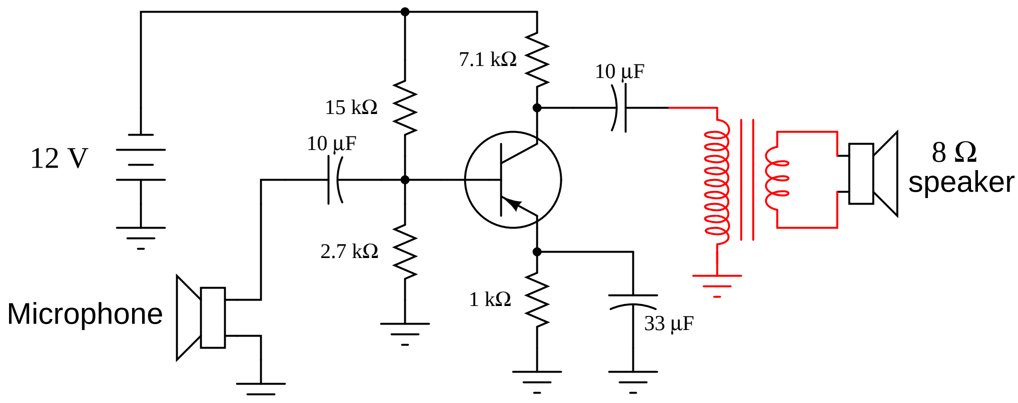
- A_V (as a ratio) ≈ 1
- A_V (in decibels) ≈ 0 dB
- $V_{load(DC)} \approx 6.8$ volts

Answer 60

- A_V (as a ratio) $\approx$ 8.148
- A_V (in decibels) $\approx$ 18.22 dB
- $V_B \approx$ -1.355 volts
- $V_E \approx$ -0.655 volts
- $V_C \approx$ -6.664 volts

Answer 61

I won't reveal all the answers here, but I will provide a visual hint:



Ideally, the impedance-matching transformer will have a turns ratio of approximately 30:1 to match the output impedance of the amplifier circuit with the impedance of the speaker.

Answer 62

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

Answer 63

V_{in}	V_{out}	I_{in}	I_{out}
0.8 V	0.1 V	2.80 μA	0.213 mA
1.5 V	0.8 V	22.4 μA	1.70 mA
3.0 V	2.3 V	64.4 μA	4.89 mA
4.5 V	3.8 V	106 μA	8.09 mA
6.0 V	5.3 V	148 μA	11.3 mA
7.5 V	6.8 V	190 μA	14.5 mA

$$Z_{in} = \frac{\Delta V_{in}}{\Delta I_{in}} = 35.72 \text{ k}\Omega$$

Answer 64

$Z_{in} = 152$ kΩ

I won't directly tell you why input impedance is an important factor for amplifier circuits, but I'll give you a hint: *Maximum Power Transfer Theorem.*

Answer 65

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

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

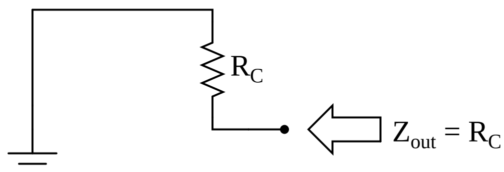
Answer 66

Z_{in} (without considering transistor) = 11 kΩ

Z_{in} (complete circuit) ≈ 9.4 kΩ

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

Answer 67



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

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

Answer 68

$R_{load} = 3.3$ kΩ

To match this amplifier to an 8 Ω speaker, we could use a matching transformer, or (better yet) a common-collector final transistor stage.

Answer 69

The answers I leave for you to figure out!

Answer 70

The answers I leave for you to figure out!

Answer 71

The answers I leave for you to figure out!

Answer 72

$$Z_{in} \approx R_1 \,||\, R_2$$

Follow-up question: how does the similar simplification of the "swamped" common-emitter amplifier's input impedance equation compare?

$$Z_{in} \approx R_1 \,||\, R_2 \,||\, (\beta + 1)(r'_e + R_E) \qquad \text{Assuming a finite-beta transistor}$$

Answer 73

$$Z_{in} \approx R_1 \,||\, R_2$$

$$Z_{out} \approx R_E \,||\, r'_e$$

Much simpler, don't you think?

Answer 74

- A_V (as a ratio) ≈ 1
- A_V (in decibels) ≈ 0 dB
- $Z_{in} \approx 5.962$ kΩ
- $Z_{out} \approx 39.6$ Ω

Follow-up question: how would these figures change, if at all, supposing the transistor had an infinite current gain ($\beta = \infty$)?

Answer 75

- A_V (as a ratio) ≈ 112.5
- A_V (in decibels) ≈ 41.02 dB
- $Z_{in} \approx 2.175$ kΩ
- $Z_{out} \approx 9.1$ kΩ

Follow-up question: how would these figures change, if at all, supposing the transistor had an infinite current gain ($\beta = \infty$)?

Answer 76

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

Answer 77

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

Answer 78

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

Answer 79

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

Answer 80

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

Answer 81

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

Answer 82

I do not provide a grading rubric here, but elsewhere.

Answer 83

Be sure to document all steps taken and conclusions made in your troubleshooting!

Answer 84

- Resistor R_1 fails open: *No current through Q_1, no current through Q_2, no current through load, no voltage dropped across Q_1, full voltage dropped across collector-emitter of Q_2.*
- Transistor Q_1 fails open, collector to emitter: *Approximately the same current through R_1, increased current through Q_2 base, increased current through Q_2 collector (load current),and less voltage dropped between collector-emitter of Q_2.*
- Transistor Q_1 fails shorted, collector to emitter: *Increased current through R_1, almost zero current through all terminals of Q_2 and the load, full voltage dropped across collector-emitter of Q_2.*
- Transistor Q_2 fails open, collector to emitter: *No change in current for R_1 or Q_1, zero load current, full voltage dropped across collector-emitter of Q_2.*
- Transistor Q_2 fails shorted, collector to emitter: *Current through R_1 will most likely increase, zero voltage dropped across collector-emitter of Q_2, increased current through Q_2 and load.*
- Load fails shorted: *No change in any current (in reality, load current will slightly increase), increased voltage drop across collector-emitter of Q_2, possible overheating of Q_2.*

Answer 85

- Transformer T_1 primary winding fails shorted: *Fuse immediately blows, then output voltage falls to zero (after filter capacitors have discharged).*
- Transformer T_1 secondary winding fails open: *Output voltage falls to zero (after filter capacitors C_1 and C_2 have discharged).*
- Rectifying diode D_3 fails open: *No change in output voltage (except when heavily loaded, where there will be increased ripple voltage).*
- Zener diode D_5 fails open: *Output voltage rises to approximately same level as unregulated voltage (across capacitor C_1).*
- Zener diode D_5 fails shorted: *Output voltage falls to zero (as quickly as C_2 can discharge), resistor R_1 may overheat.*
- Resistor R_1 fails open: *Output voltage falls to zero (as quickly as C_2 can discharge).*
- Capacitor C_2 fails shorted: *Output voltage falls to a very low value, transistor Q_1 will most likely overheat.*

Answer 86

Most likely R_1 failed open or the zener diode D_5 failed shorted, such that the transistor is not being "told" to output any voltage at its emitter terminal.

Answer 87

If the DC bias voltage shifts far enough away from the normal (quiescent) levels, the transistor may be forced into saturation or cutoff so it cannot reproduce the AC signal.

Answer 88

- Capacitor C_{in} fails open: *All transistor currents assume quiescent (DC) values, no output signal.*
- Solder bridge (short) past resistor R_1: *Transistor saturates (large increase in all currents), no output signal.*
- Resistor R_1 fails open: *All transistor currents fall to zero (transistor in complete cutoff mode), no output signal.*
- Resistor R_E fails open: *All transistor currents fall to zero (transistor in complete cutoff mode), no output signal.*

Answer 89

- Capacitor C_{in} fails open: *All transistor currents assume quiescent (DC) values, no output signal.*
- Solder bridge (short) past resistor R_1: *Transistor saturates (large increase in all currents), no output signal.*
- Resistor R_1 fails open: *All transistor currents fall to zero (transistor in complete cutoff mode), no output signal.*
- Resistor R_C fails open: *Transistor base current will decrease, zero collector current, greatly decreased emitter current, no output signal.*
- Resistor R_E fails open: *All transistor currents fall to zero (transistor in complete cutoff mode), no output signal.*
- Capacitor C_{bypass} fails shorted: *Transistor saturates (large increase in all currents), no output signal.*

Answer 90

- Capacitor C_{out} fails open: *Transistor currents unaffected, no output signal.*
- Solder bridge (short) past resistor R_1: *Transistor saturates (large increase in all currents), no output signal.*
- Resistor R_1 fails open: *All transistor currents fall to zero (transistor in complete cutoff mode), no output signal.*
- Resistor R_C fails open: *Transistor base current will decrease, zero collector current, greatly decreased emitter current, no output signal.*
- Resistor R_E fails open: *All transistor currents fall to zero (transistor in complete cutoff mode), no output signal.*
- Capacitor C_{bypass} fails shorted: *All transistor currents fall to zero (transistor in complete cutoff mode), no output signal.*

Answer 91

- Microphone coil fails open: *No AC voltage at all across microphone terminals when sound is present.*
- Capacitor C_1 fails shorted: *DC voltage present across microphone terminals.*
- Resistor R_1 fails open: *Full DC supply voltage dropped across R_1, no DC voltage dropped across R_2 (could indicate a shorted R_2 as well – no way to tell unless a resistance measurement is taken).*
- Resistor R_2 fails open: *Increased DC voltage drop across R_2, decreased DC voltage drop across R_1, reasonable transistor DC voltages (V_E 0.7 volts less than V_B, V_C as expected based on value of V_E and R_3, R_4 values) indicate that Q_1 is probably not the source of the trouble.*
- Capacitor C_3 fails open: *Larger-than-normal AC voltage at collector terminal, with no AC voltage present across transformer primary winding.*
- Transformer T_1 primary winding fails open: *Larger-than-normal AC voltage across transformer primary winding, with no AC voltage across transformer secondary winding.*

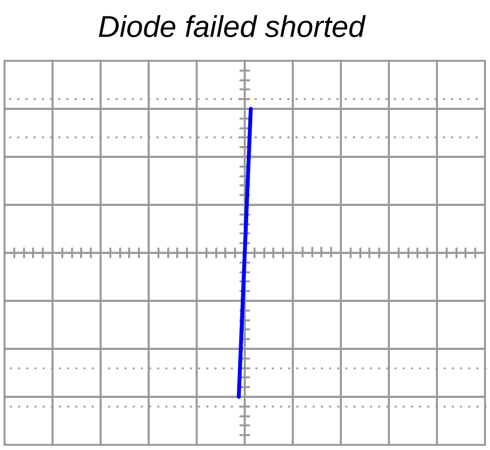
Answer 92

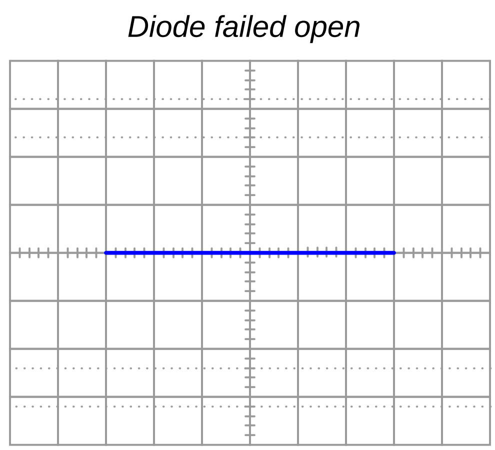
The problem is *not* in any of the four resistors, or the transistor. The most likely components to suspect at this point would be the microphone, capacitors, transformer, and/or speaker.

Answer 93

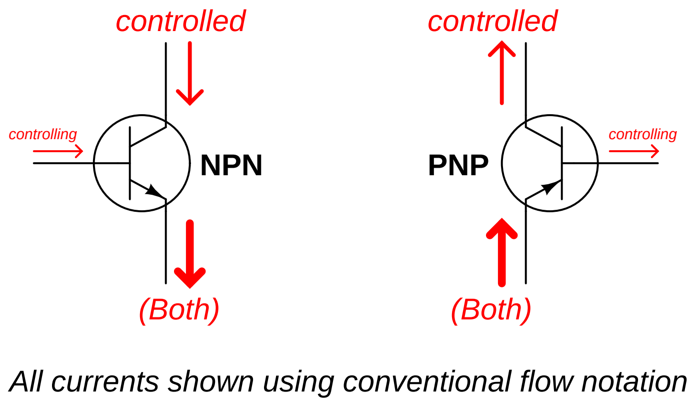
The amplifier's gain will increase, possibly to the point of distorting the signal.

Answer 94





Answer 95



Answer 96

β is defined as the ratio between collector and base current. I'll let you research some typical values. Here are some transistor part numbers you could research datasheets for:

- 2N2222
- 2N2905
- 2N2907
- 2N3403
- 2N3703
- 2N3904
- 2N3906
- 2N4125
- 2N4403
- 2N3055
- TIP 29
- TIP 31
- TIP 32
- TIP 41
- TIP 42

Follow-up question #1: what conditions affect the β ratio of a transistor?

Follow-up question #2: re-write the β equation to solve for the other variables ($I_C = \cdots$, $I_B = \cdots$).

Answer 97

Because the BJT is a minority carrier device, the vast majority of collector current is the result of charge carriers injected from the emitter into the base region. Since this rate of charge carrier injection is a function of base-emitter junction excitation, base current (or more properly, base-to-emitter voltage) primarily determines collector current with collector-to-emitter voltage playing a relatively minor role.

Answer 98

Sit down before you read this, and brace yourself for the hard truth: bipolar junction transistors are technically *not* current-controlled devices. You were sitting down, right? Good.

Follow-up question: if BJTs are not controlled by base current, then what *are* they controlled by? Express this in the form of an equation if possible. Hint: research the "diode equation" for clues.

Answer 99

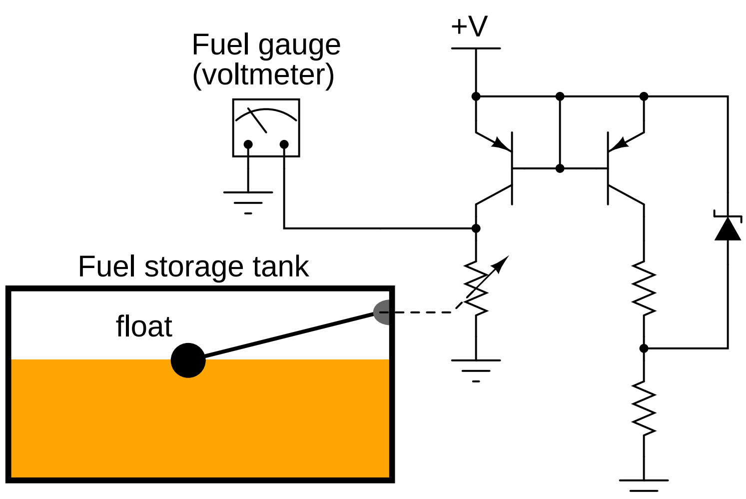
Small signal analysis is where the signals are presumed to be small enough in magnitude that the active device(s) should respond in a nearly linear manner. *Large signal analysis* is where the signals are presumed to be large enough that component nonlinearities become significant.

Follow-up question: why would engineers bother with two modes of analysis instead of just one (large signal), where the components' true (nonlinear) behavior is taken into account? Explain this in terms of network theorems and other mathematical "tools" available to engineers for circuit analysis.

Answer 100

As R_{load} increases, $R_{transistor}$ will decrease in resistance so as to maintain a constant current through the load and a constant R_{total}.

Answer 101



Answer 102

Transistor Q2 turns on in the event that excessive current goes through the load, effectively connecting the zener diode's cathode to the +V output terminal, which decreases the regulation setpoint voltage until the load current diminishes to an acceptable level.

Follow-up question: what component value(s) would we have to change in order to adjust the current limit in this power supply circuit?

Answer 103

The DC bias voltage (V_{bias}) is excessive.

Answer 104

Set the signal generator to "sine-wave," and the aural difference between a pure sine wave and a distorted ("clipped") sine wave will be very apparent.

Answer 105

$I_B = 38.3\ \mu$A

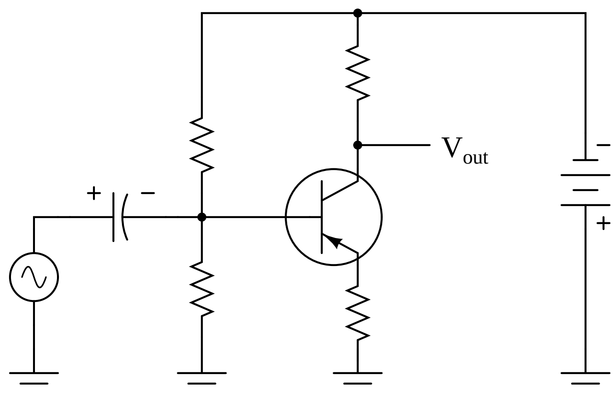
Answer 106

At the threshold between cutoff and active mode, V_{bias} = -0.7 volts

At the threshold between active mode and saturation, V_{bias} = -1.72 volts (assuming 0 volts V_{CE} at saturation)

Follow-up question: if we were using the potentiometer to establish a bias voltage for an AC signal, what amount of DC bias voltage would place the transistor directly between these two extremes of operation (cutoff versus saturation), so as to allow the AC input signal to "swing" equal amounts positive and negative at the distortion limit? In other words, what voltage setting is exactly between -0.7 volts and -1.72 volts?

Answer 107



Answer 108

Biasing is accomplished through the 100 kΩ resistor. The 10 kΩ potentiometer is the volume control, and the 22 μF capacitor serves to "couple" the input signal to the transistor's base, while blocking any DC bias voltage from being "fed back" to the audio signal source.

Challenge question: there is a name used to describe the dual-transistor configuration used in this circuit, where a pair of PNP or NPN transistors is cascaded, with the emitter of one going to the base of the other. What is this name, and what advantage does this configuration provide over a single transistor?

Answer 109

Resistors R1 and R2 produce a DC biasing voltage, and capacitor C1 "couples" the AC input signal to the biasing network, preventing any DC bias from the signal source to influence the amplifier's Q point.

While other biasing networks are possible for a Class A amplifier circuit, some type of DC bias voltage is necessary to make a bipolar junction transistor operate in Class A mode.

Answer 110

V_B = 1.318 VDC + 0.5 VAC (peak)

Answer 111

Since V_{BE} is relatively constant, $\Delta V_{in} \approx \Delta V_E$. The next essential step in the explanation for the voltage gain formula is to couple this fact with $I_E \approx I_C$. The rest I'll leave for you to explain.

For your discussion response, be prepared to explain everything in mathematical terms. You will have to use Kirchhoff's Voltage Law at least once to be able to do this completely.

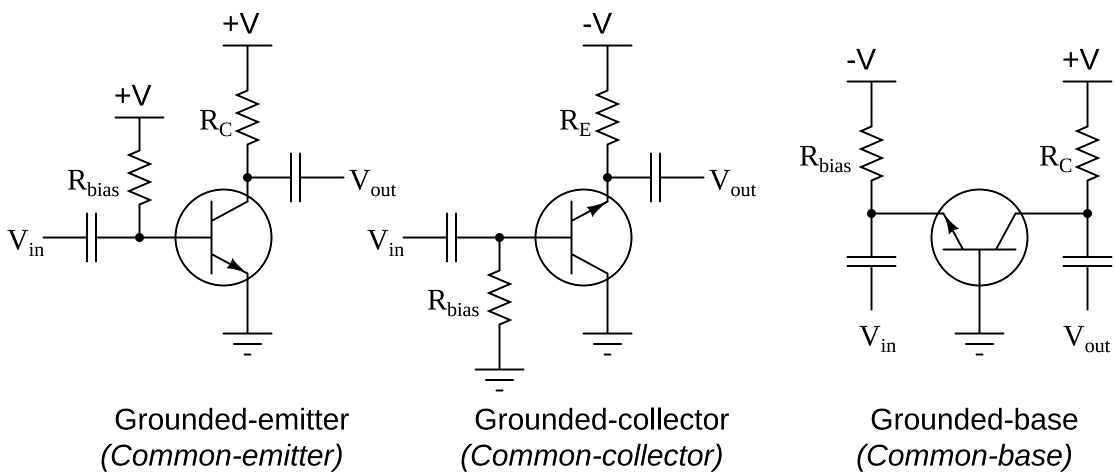
Answer 112

As resistor R3 increases in value, the voltage gain of the amplifier will decrease.

Answer 113

As the load resistor increases in value, the voltage gain of the amplifier will increase.

Answer 114



Answer 115

Measuring input and output voltage with an AC voltmeter or oscilloscope:

$$A_V = \frac{V_{out}}{V_{in}}$$

Answer 116

I'll let you determine the answer to this question on your own!

Answer 117

The collector current of a warming transistor increases even with constant input voltage because its intrinsic emitter resistance decreases with increased charge carrier activity.

In the common-emitter amplifier circuit, the output voltage will change substantially with changes in transistor temperature. In the common-collector circuit, the output voltage will hardly change at all as transistor temperature changes.

When amplifying AC input signals, the common-emitter amplifier's voltage gain will increase, while the common-collector amplifier's voltage gain will remain at unity. Likewise, the common-emitter amplifier's Q point will shift substantially, while the common-collector amplifier's Q point will not.

Answer 118

Although the common-collector amplifier has a very low voltage gain ($A_V = 1$), that gain is absolutely *stable* over a wide range of operating conditions and component selection.

Answer 119

"Negative" or "degenerative" feedback means that any change on the output gets "fed back" in such a way that it tries to cancel itself.

The use of an emitter resistor (R_E) simply makes the amplifier circuit look more like a common-collector configuration, and the feedback functions in the same way. The use of a "feedback" resistor (R_f) takes advantage of the common-emitter's inverting nature, the output signal being 180^o out of phase with the input.

Applying negative feedback to a common-emitter amplifier has the effect of decreasing its voltage gain.

Answer 120

The Miller capacitance between collector and base in a transistor forms a *negative feedback loop* for AC signals.

Challenge question: is there any way you can think of to cancel out this negative feedback in an amplifier circuit?

Answer 121

In the common-emitter circuit, the Miller capacitance provides a path for the (inverted) output signal at the collector terminal to degeneratively feed back to the input at the base terminal, decreasing voltage gain. In the common-collector circuit, there is no signal inversion at all, and so no degenerative feedback can happen at all.

The common-base circuit is interesting: it would seem there is a possibility for negative feedback through the Miller capacitance here, from the collector to the base. However, since the base terminal is effectively grounded (as far as AC signals are concerned) by the bypass capacitor, any feedback through the Miller capacitance becomes shunted straight to ground where is has no effect on the amplifier's operation.

Answer 122

Since C_{BC} "couples" the collector to the base, changes in collector voltage result in far more collector current than would result from C_{BC} coupling to ground. In other words, the transistor's gain effectively multiplies the Miller-effect capacitance as "seen" from the collector terminal to ground:

$$i_C \approx C_{BC} \left(\beta + 1 \right) \frac{dV_C}{dt} >> C_{BC} \frac{dV_C}{dt}$$

Answer 123

This design is a compromise between full bypassing and no emitter resistor at all. It provides all the DC voltage gain and Q-point stability of full bypassing, while providing more AC voltage gain stability than full bypassing.

Answer 124

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

Z_{in} (complete circuit) $\approx$ 7.514 kΩ

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

Answer 125

$R_{load} = 33\ \Omega$ (approximate)

Answer 126

By feeding some of the emitter signal to the base of the transistor, the transistor helps drive itself, reducing the load on the signal source (connected at V_{in}). This is analogous to the fanciful scenario of someone making themselves lighter by pulling up on their own bootstraps.

Answer 127

These two models are equivalent because a given current (i_b) will cause the exact same amount of voltage drop between base and emitter ($v = ir$):

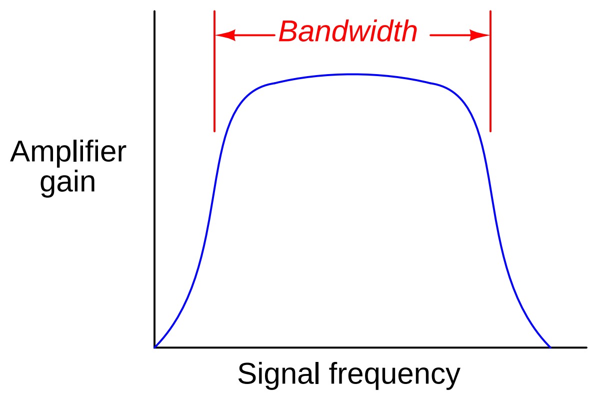
$$v = i_b r'_b + (i_b + \beta i_b) r'_e \qquad \text{Left-hand model}$$

$$v = i_b \left[r'_b + (\beta + 1) r'_e \right] \qquad \text{Right-hand model}$$

The mathematical equivalence of these two expressions may be shown by factoring i_b from all the terms in the left-hand model equation.

Answer 128

Bandwidth is the measure of the signal frequency *range* that an amplifier can effectively handle while maintaining usable gain:



Rolloff at the high-frequency end is largely due to the Miller effect, while rolloff at the low-frequency end is usually due to coupling capacitors in the circuit.

Answer 129

"Gain" (A) refers to the ratio of output signal compared to input signal.

Answer 130

$A_V = 0.178$

Follow-up question: how does this gain figure (A_V) relate to the "voltage divider formula"?

$$E_R = E_{total} \left(\frac{R}{R_{total}} \right)$$

Answer 131

$A_P = 0.261$

Follow-up question: what *unit* does this figure have, if any?

Answer 132

$A_V = 13.98$ dB

Answer 133

"dBm" represents the magnitude of a voltage in relation to 1 mW of power dissipated by a 600 Ω load. "dBW" and "dBk" units represent the magnitude of a voltage in relation to 1 W and 1 kW of power dissipated by the same load, respectively.

Follow-up question: how many volts is 2 dBm equivalent to?

Notes 1

It is a very useful skill to be able to identify a BJT using nothing more than the "diode check" function on a multimeter.

Notes 2

The most important principle in this question is that of *dependency*: one of the transistor's currents needs the other in order to exist, but not visa-versa. I like to emphasize this relationship with the words *controlling* and *controlled*.

Notes 3

Ask your students what a perfect current-regulating curve would look like. How does this perfect curve compare with the characteristic curve shown in this question for a typical transistor?

A word of caution is in order: I do not recommend that a test circuit such as the one shown in the question be built for collecting curve data. If the transistor dissipates power for any substantial amount of time, it will heat up and its curves will change dramatically. Real transistor curves are generated by a piece of test equipment called a "curve tracer," which sweeps the collector-emitter voltage and steps the base current very rapidly (fast enough to "paint" all curves on an oscilloscope screen before the phosphor stops glowing).

Notes 4

Ask your students what the characteristic curves would look like for a *perfect* transistor: one that was a perfect regulator of collector current over the full range of collector-emitter voltage.

Notes 5

This is one of my better analogies for explaining BJT operation, especially for illustrating the why I_C is almost independent of V_{CE}. It also helps to explain reverse recovery time for transistors: imagine how long it takes the air to clear of tossed flower petals after you stop tossing them, analogous to latent charge carriers having to be swept out of the base region by V_{CE} after base current stops.

Notes 6

This question is really nothing more than review of a transistor's characteristic curves. You might want to ask your students to relate this circuit's behavior to the common characteristic curves shown in textbooks for bipolar junction transistors. What portion of the characteristic curve is this transistor operating in while it regulates current?

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Notes 8

This circuit is really the beginning of a *current mirror*. I have found this to be an excellent starting point for student learning on linear transistor operation, as well as a good practical introduction of current regulation circuits. Once students recognize that bipolar transistors are essentially voltage-controlled current regulators (albeit very nonlinear!), they are ready to comprehend their application as signal amplifiers.

Notes 9

Current mirrors confuse beginning students primarily because they cannot be understood following the simplistic model of a silicon PN junction always dropping 0.7 volts. Rather, their operation is inextricably connected with Shockley's diode equation. This question is therefore not only a good review of that equation, but it also illustrates how the "models" we use to explain things are sometimes shown to be inadequate.

Notes 10

This question challenges students' ability to "manipulate" the basic current mirror circuit into two different configurations. Depending on how well your students grasp the basic concept, you might want to spend extra discussion time comparing the two circuits, tracing current through each and discussing their operation in general.

Although it may seem trivial to an experienced instructor or electronics professional, variations of circuit designs consisting solely of inverting components are often quite confusing to students, especially those weak in spatial-relations skills. I encourage you to work with those students regularly to build this important visualization skill.

Notes 11

This question is nothing more than an exercise in interpreting characteristic curves.

Notes 12

Ask your students to explain how they obtained the answer to this question, step by step.

Notes 13

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Notes 14

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The follow-up question is an important one for a few reasons. First, students must be aware that transistor power dissipation is determined by more than just collector current. Secondly, the disparate dissipations of these two transistors will lead to inaccuracies in regulated current in a current mirror circuit if measures are not taken to equalize their temperatures.

Notes 15

Since there is more than one current answer for this design problem, be sure to ask students to present different solutions to it, asking them to explain how they obtained their answers to this question.

Notes 16

Although this circuit is very simple, it is also very important to master. Be sure to discuss its operation thoroughly with your students, so they understand.

Notes 17

At first, the "emitter follower" transistor circuit may seem pointless, since the output voltage practically equals the input voltage (especially for input voltages greatly exceeding 0.7 volts DC). "What possible good is a circuit like this?" some of your students may ask. The answer to this question, of course, has to do with *currents* in the circuit, and not necessarily voltages.

Notes 18

The purpose of this question, besides providing practice for common-collector circuit DC analysis, is to show the current-amplification properties of the common-collector amplifier. This is an important feature, as there is no voltage amplification in this type of amplifier circuit.

This approach to determining transistor amplifier circuit voltage gain is one that does not require prior knowledge of amplifier configurations. In order to obtain the necessary data to calculate voltage gain, all one needs to know are the "first principles" of Ohm's Law, Kirchhoff's Laws, and basic operating principles of a bipolar junction transistor. This question is really just a *thought experiment*: exploring an unknown form of circuit by applying known rules of circuit components. If students doubt the efficacy of "thought experiments," one need only to reflect on the success of Albert Einstein, whose thought experiments as a patent clerk (without the aid of experimental equipment) allowed him to formulate the basis of his Theories of Relativity.

Notes 19

Ask your students to identify the configuration of this transistor amplifier (common-base, common-emitter, or common collector?). After they have done this, ask them to identify the current gain of such an amplifier, given a transistor β value of 90.

Notes 20

Some students may choose to place the potentiometer on the output of the power supply (connecting to the transistor's emitter terminal). While this will work, technically, it is not a good solution because the load current will be severely limited by the potentiometer's resistance. Discuss with your students why the circuit drawn in the answer is more practical.

The answer to the challenge question is nonintuitive, but it makes sense once you determine what variables affect transistor power dissipation (emitter current, and V_{CE}).

Notes 21

Calculating the output voltage is a much simpler task than calculating the zener diode's current! Have your students explain their problem-solving techniques for this circuit.

Notes 22

Calculating the output voltage is a much simpler task than calculating the zener diode's current! Have your students explain their problem-solving techniques for this circuit.

Notes 23

This might not be the result many students expect! It is important, though, for them to understand the importance of polarity in transistor circuits. This example should make that abundantly clear.

Notes 24

Sometimes it is helpful for students to re-draw the circuit using a transistor model showing the base-emitter junction as a diode. If you think this model would help some of your students understand the concept here, have another student draw the transistor model on the whiteboard, and use that drawing as a discussion aid. Like any PN junction, the base-emitter junction of a BJT only "wants" to conduct current in one direction.

Notes 25

A "trick" it may be, but a very useful and very common "trick" it is! Discuss this concept with your students at length, being sure they have ample time and opportunity to ask questions of their own.

One question that may arise is, "how much DC bias voltage is necessary?" If no one asks this question, ask it yourself! Discuss with your students what would constitute the minimum amount of bias voltage necessary to ensure the transistor never goes into "cutoff" anywhere in the waveform's cycle, and also the maximum bias voltage to prevent the transistor from "saturating".

Notes 26

All three biasing techniques are commonly used in transistor amplifier circuitry, so it behooves each student to understand them well. In each case, resistors provide a "trickle" of current through the base of the transistor to keep it turned partially "on" at all times.

One exercise you might have your students do is come up to the board in front of the room and draw an example of this circuit, then everyone may refer to the drawn image when discussing the circuit's characteristics.

Notes 27

The answers to the question may be easily found in any fundamental electronics text, but it is important to ensure students know *why* these characteristics are such. I always like to tell my students, "Memory *will* fail you, so you need to build an understanding of *why* things are, not just *what* things are."

Notes 28

Although the given answer seems complete, what I'm looking for here is a good analytical understanding of why the voltage gain is approximately 1. Placing the requirement of using KVL on the students' answers ensures that they will have to explore the concept further than the given answer does.

Notes 29

Students should know the AC voltage gain of this amplifier configuration to be approximately 1, so the output voltage calculation should be trivial. This question is really a test to see whether or not students are able to apply their knowledge of voltage gain to a specific application.

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Notes 32

The purpose of this question, besides providing practice for common-emitter circuit DC analysis, is to show the signal-inverting and voltage-amplification properties of the common-emitter amplifier. Some students experience difficulty understanding why V_C (the output voltage) decreases with increasing base voltage (V_B). Working through the numbers in this table gives concrete proof why it is so.

This approach to determining transistor amplifier circuit voltage gain is one that does not require prior knowledge of amplifier configurations. In order to obtain the necessary data to calculate voltage gain, all one needs to know are the "first principles" of Ohm's Law, Kirchhoff's Laws, and basic operating principles of a bipolar junction transistor. This question is really just a *thought experiment*: exploring an unknown form of circuit by applying known rules of circuit components. If students doubt the efficacy of "thought experiments," one need only to reflect on the success of Albert Einstein, whose thought experiments as a patent clerk (without the aid of experimental equipment) allowed him to formulate the basis of his Theories of Relativity.

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All three biasing techniques are commonly used in transistor amplifier circuitry, so it behooves each student to understand them well. In each case, resistors provide a "trickle" of current through the base of the transistor to keep it turned partially "on" at all times.

Notes 36

Many beginning students experience difficulty understanding the purpose of the coupling capacitor, and transistor amplifier biasing in general. Be sure to spend plenty of time discussing the principle of this circuit, because it is very commonplace in transistor circuitry.

Notes 37

The purpose of this question is to get students to apply their knowledge of common-emitter amplifier voltage gain to hypothetical changes in resistance. These are important concepts, so be sure to discuss them adequately, challenging your students to explain *why* the voltage gain is affected as described, not just explained by blindly following a gain formula.

Many students experience difficulty understanding why voltage gain is directly proportional to collector resistance. What they visualize when they consider a greater collector resistance is *less* collector voltage, which they understandably equate to less output signal and thus less gain. While the quiescent (DC) output voltage *does* decrease with increasing R_C, what is not so obvious is that *change in collector voltage* (ΔV_C) increases with increasing R_C.

Ask your students to explain why changes in bias resistor values do not (significantly) effect voltage gain. Does this mean the values are arbitrary? Discuss with them the purpose of bias resistors, if necessary, and what would happen if they were not there or if they were grossly mis-sized.

Notes 38

This question may serve as a good starting point for a discussion on thermal runaway, discussing how r'_e decreases with temperature, increasing I_E, once again decreasing r'_e, an infinitum, ad *destructum*.

The follow-up question provides a good opportunity to discuss the engineering principle of *swamping*: when two quantities are unequal to the extent that one renders the other relatively insignificant. This concept is very important in analysis because it allows us to construct simpler models of realistic processes than we could if we had to take every factor into account. It is also important in design because it allows us to overshadow certain unwanted effects.

Notes 39

This question provides a good opportunity to review capacitive reactance (X_C). The polarized capacitor symbol hints at the capacitor's relatively large value, and your students should realize that a large capacitor's reactance will be relatively low to most AC signals. An idea to help communicate the "bypass" concept is to have one of your students re-draw the circuit as "seen" from the perspective of an AC signal, not a DC signal. With the capacitor effectively acting as a short-circuit to AC signals, what does the amplifier circuit look like to those signals?

Notes 40

The answers to the question may be easily found in any fundamental electronics text, but it is important to ensure students know *why* these characteristics are such. I always like to tell my students, "Memory *will* fail you, so you need to build an understanding of *why* things are, not just *what* things are."

One exercise you might have your students do is come up to the board in front of the room and draw an example of this circuit, then everyone may refer to the drawn image when discussing the circuit's characteristics.

Notes 41

Nothing much to comment on here – just some practice on common-emitter amplifier calculations. Note that the approximations given here are based on the following assumptions:

- 0.7 volts drop (exactly) across base-emitter junction.
- Infinite DC current gain (β) for transistor ($I_B = 0\ \mu$A ; $I_C = I_E$).
- Negligible loading of bias voltage divider by the emitter resistance.
- Negligible dynamic emitter resistance ($r'_e = 0\ \Omega$)

This question lends itself well to group discussions on component failure scenarios. After discussing how to calculate the requested values, you might want to ask students to consider how these values would change given some specific component failures (open resistors, primarily, since this is perhaps the most common way that a resistor could fail).

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Notes 44

You might want to ask your students what practical maximum and minimum resistor values they would choose between when designing such an amplifier circuit. What would be the danger of selecting resistors too low in value? What would be wrong with choosing resistors too high in value? They might not be ready to answer these questions (especially the latter) until after having studied amplifier impedance calculations, though!

Notes 45

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- 0.7 volts drop (exactly) across base-emitter junction.
- Infinite DC current gain (β) for transistor ($I_B = 0\,\mu$A ; $I_C = I_E$).
- Negligible loading of bias voltage divider by the emitter resistance.
- Negligible dynamic emitter resistance ($r'_e = 0\,\Omega$)

This question lends itself well to group discussions on component failure scenarios. After discussing how to calculate the requested values, you might want to ask students to consider how these values would change given some specific component failures (open resistors, primarily, since this is perhaps the most common way that a resistor could fail).

Notes 46

The purpose of this question, besides providing practice for common-base circuit DC analysis, is to show the noninverting and voltage-amplification properties of the common-base amplifier, as well as to showcase its low current gain.

The negative values shown for emitter voltage (V_{in}) are correct and intentional. It is necessary to view the input voltage as a negative quantity to confidently determine the phase relationship between input and output.

This approach to determining transistor amplifier circuit voltage gain is one that does not require prior knowledge of amplifier configurations. In order to obtain the necessary data to calculate voltage gain, all one needs to know are the "first principles" of Ohm's Law, Kirchhoff's Laws, and basic operating principles of a bipolar junction transistor. This question is really just a *thought experiment*: exploring an unknown form of circuit by applying known rules of circuit components. If students doubt the efficacy of "thought experiments," one need only to reflect on the success of Albert Einstein, whose thought experiments as a patent clerk (without the aid of experimental equipment) allowed him to formulate the basis of his Theories of Relativity.

Notes 47

The answers to the question may be easily found in any fundamental electronics text, but it is important to ensure students know *why* these characteristics are such. I always like to tell my students, "Memory *will* fail you, so you need to build an understanding of *why* things are, not just *what* things are."

One exercise you might have your students do is come up to the board in front of the room and draw an example of this circuit, then everyone may refer to the drawn image when discussing the circuit's characteristics.

Notes 48

Perhaps the most frequent application of the common-base amplifier topology is the so-called *cascode* amplifier circuit, where a common-emitter stage acts as a "front-end" buffer to the common-base stage to provide reasonable input impedance and current gain. The grounded-base configuration of the final output stage virtually eliminates the undesirable effects of Miller (collector-to-base) capacitance, resulting in an amplifier capable of high-frequency operation with little or no neutralization required.

Notes 49

I have seen more than one method for determining the "common-ness" of an amplifier configuration, and not all are satisfying. Rather than telling your students how to distinguish one amplifier type from the others, let them examine the different configurations in the answer and figure out their own method(s)!

Notes 50

Ask your students how these two systems of power gain expression (Bels versus ratios) compare in terms of *range*. Which system of expression encompasses the greatest range of power gains or losses, with the smallest changes in numerical value?

Notes 51

Challenge your students to estimate the log values without using their calculators. For example, they should be able to estimate the log of 1275 as being between 3 and 4; the log of 0.025 as being between -1 and -2. Work together to devise a technique for doing this, where there will be no guessing.

Mathematical estimation is an important skill for technical people to possess. Not only is it useful in the event no calculator is readily available, but it also helps greatly in students being able check their (electronically) calculated work. I can't tell you how many times I've seen students blindly enter numbers into a calculator, only to arrive at an answer that is *grossly* in error, and not realize it at all because they cannot do the estimation mentally.

Notes 52

It is important that students work through the original equations algebraically to obtain the answers rather than just look up these formulae in a book. Have your students write their work on the whiteboard in front of the other students, so that everyone has the opportunity to examine the technique(s) and ask pertinent questions.

Be sure to let your students know that the figure of "3 dB", either positive or negative, is very common in electronics calculations. Your students might remember this expression used to describe the cutoff frequency of a filter circuit (f_{-3dB}).

Notes 53

An easy way to illustrate this principle is to ask your students to calculate the power dissipation of a 1200 watt heating element rated for 120 volts, if connected to a 240 volt source. The answer is *not* 2400 watts!

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Notes 55

Logarithms are a confusing, but powerful, algebraic tool. In this example, we see how the logarithm of a power function is converted into a simple multiplication function.

The challenge question asks students to apply this relationship to an equation not containing logarithms at all. However, the fundamental rule of algebra is that you may perform any operation (including logarithms) to any equation so long as you apply it equally to *both sides* of the equation. Logarithms allow us to take an algebra problem such as this and simplify it significantly.

Notes 56

Nothing special here, just straightforward ratio-to-decibel calculations. Have your students share and discuss the steps necessary to do all these conversions.

Notes 57

Nothing special here, just straightforward decibel-to-ratio calculations. Have your students share and discuss the steps necessary to do all these conversions.

Notes 58

Nothing special here, just straightforward decibel-ratio calculations. Have your students share and discuss the steps necessary to do all these conversions.

Notes 59

Nothing much to comment on here – just some practice on common-collector amplifier calculations. Note that the approximations given here are based on the following assumptions:

- 0.7 volts drop (exactly) across base-emitter junction.
- Infinite DC current gain (β) for transistor ($I_B = 0\ \mu$A ; $I_C = I_E$).
- Negligible loading of bias voltage divider by the emitter resistance.
- Negligible dynamic emitter resistance ($r'_e = 0\,\Omega$)

This question lends itself well to group discussions on component failure scenarios. After discussing how to calculate the requested values, you might want to ask students to consider how these values would change given some specific component failures (open resistors, primarily, since this is perhaps the most common way that a resistor could fail).

Notes 60

Nothing much to comment on here – just some practice on common-emitter amplifier calculations. Note that the approximations given here are based on the following assumptions:

- 0.7 volts drop (exactly) across base-emitter junction.
- Infinite DC current gain (β) for transistor ($I_B = 0\,\mu$A ; $I_C = I_E$).
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Notes 61

Note to your students that the addition of a transformer is not the only viable option for solving this impedance mis-match problem. One could add another stage of transistor amplification (of the right type, of course).

One point not touched upon in the answer is a possible mis-match of impedances between the microphone and the amplifier *input*. Since the microphone impedance was not specified, one cannot tell whether there is an impedance mis-match or not.

Notes 62

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

Notes 63

The purpose of this question, besides providing practice for common-collector circuit DC analysis, is to show the current-amplification properties of the common-collector amplifier. This is an important feature, as there is no voltage amplification in this type of amplifier circuit.

This approach to determining transistor amplifier circuit impedance is one that does not require prior knowledge of amplifier configurations. In order to obtain the necessary data to calculate voltage gain, all one needs to know are the "first principles" of Ohm's Law, Kirchhoff's Laws, and basic operating principles of a bipolar junction transistor. This question is really just a *thought experiment*: exploring an unknown form of circuit by applying known rules of circuit components. If students doubt the efficacy of "thought experiments," one need only to reflect on the success of Albert Einstein, whose thought experiments as a patent clerk (without the aid of experimental equipment) allowed him to formulate the basis of his Theories of Relativity.

Notes 64

Ask you students to compare the input impedance of this amplifier with the load impedance. Does the transistor "match" impedances like a transformer does? Ask them to explain both the similarities and the differences between transformers and transistors as impedance-matching devices.

Notes 65

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

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

Notes 66

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

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

Notes 67

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

Notes 68

Ask your students to explain whether they would connect a matching transformer as a step-up or a step-down to match source and load impedances in this example. How do we know which way we need to use the transformer?

Challenge your students by asking them how they might calculate the necessary transformer winding ratio for this impedance matching application. I wouldn't be surprised if many of your students do not remember the impedance ratio relationship to turns ratio back from their education in AC circuit theory. However, they *should* remember how turns ratio relates to voltage and current ratios, and from this they should be able to figure out the impedance transformation ratio of a transformer!

An important skill to have is the ability to reconstruct forgotten information by setting up "thought experiments" and deriving results from known (remembered) principles. I can't tell you how many times in my professional and academic life that this skill has been helpful to me.

Notes 69

The approximations for voltage gain, input impedance, and output impedance vary somewhat according to how precise the author(s) intended them to be. What you see here may be simpler or more complex than what you find in your textbook(s). The purpose of this question is to summarize gain and impedance calculations for this type of amplifier circuit, as well as to stimulate thought and discussion on the rationale for each. If students simply try to memorize these equations, they will forget them soon afterward. If they *understand why* each one is as it is from principles previously learned, both comprehension and retention will be much improved.

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Notes 72

The purpose of this question is for students to see how (more) approximate predictions for circuits may be obtained through simplification. A good exercise is to calculate impedances for a given amplifier circuit using both the original and the simplified equations, to see just how "approximate" the simplified answers are. Knowing how to eliminate complicated terms in equations (and what terms may be safely eliminated!) is key to estimating in the absence of a calculator.

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Notes 74

Nothing much to comment on here – just some practice on common-collector amplifier calculations. In calculating the dynamic emitter resistance, the following assumptions were taken:

- $r'_e = 25 \text{ mV}/I_E$
- 0.7 volts drop (exactly) across base-emitter junction.
- Negligible loading of bias voltage divider by the emitter resistance.

After calculating r'_e, the following equations were used to approximate the impedances:

$$Z_{in} \approx R_1 \,||\, R_2 \,||\, (\beta + 1)[r'_e + (R_E \,||\, R_{load})]$$

$$Z_{out} \approx R_E \,||\, \left(r'_e + \frac{R_1 \,||\, R_2 \,||\, R_{source}}{\beta + 1} \right)$$

This question lends itself well to group discussions on component failure scenarios. After discussing how to calculate the requested values, you might want to ask students to consider how these values would change given some specific component failures (open resistors, primarily, since this is perhaps the most common way that a resistor could fail).

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$$Z_{in} \approx R_1 \,||\, R_2 \,||\, (\beta + 1)r'_e$$

$$Z_{out} \approx R_C$$

Voltage gain was approximated through the use of this equation:

$$A_V \approx \frac{R_C \,||\, R_{load}}{r'_e}$$

This question lends itself well to group discussions on component failure scenarios. After discussing how to calculate the requested values, you might want to ask students to consider how these values would change given some specific component failures (open resistors, primarily, since this is perhaps the most common way that a resistor could fail).

Notes 76

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 77

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.

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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

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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.

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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 81

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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:

- $R_1 = 1 \text{ k}\Omega$
- $R_2 = 100 \text{ k}\Omega$
- $R_3 = 100 \text{ k}\Omega$
- $R_4 = 1 \text{ k}\Omega$
- $R_5 = 100 \text{ k}\Omega$
- $R_6 = 100 \text{ k}\Omega$
- $R_7 = 1 \text{ k}\Omega$
- $R_8 = 10 \text{ k}\Omega$
- $R_9 = 4.7 \text{ k}\Omega$
- $R_{pot} = 10 \text{ k}\Omega$
- $C_1 = 0.047 \ \mu\text{F}$
- $C_2 = 0.047 \ \mu\text{F}$
- $C_3 = 0.1 \ \mu\text{F}$
- $C_4 = 0.047 \ \mu\text{F}$
- $C_5 = 1 \ \mu\text{F}$
- $C_6 = 1 \ \mu\text{F}$
- $C_7 = 33 \ \mu\text{F}$

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 82

The idea of a troubleshooting log is three-fold. First, it gets students in the habit of documenting their troubleshooting procedure and thought process. This is a valuable habit to get into, as it translates to more efficient (and easier-followed) troubleshooting on the job. Second, it provides a way to document student steps for the assessment process, making your job as an instructor easier. Third, it reinforces the notion that each and every measurement or action should be followed by reflection (conclusion), making the troubleshooting process more efficient.

Notes 83

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

Notes 84

The purpose of this question is to approach the domain of circuit troubleshooting from a perspective of knowing what the fault is, rather than only knowing what the symptoms are. Although this is not necessarily a realistic perspective, it helps students build the foundational knowledge necessary to diagnose a faulted circuit from empirical data. Questions such as this should be followed (eventually) by other questions asking students to identify likely faults based on measurements.

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Notes 86

Ask your students why the diagnostic measurements described in the question are good points to check (in the order that they were taken).

Notes 87

This question asks students to explore the possibility of complete AC signal failure due to a simple shift in DC bias, based on their understanding of how transistor amplifiers function. It may seem paradoxical that such a "small" fault could have such a large effect on an amplifier circuit, but it should make sense once students grasp how important bias is to class-A amplifier operation.

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Notes 92

Ask your students why the normal DC voltage measurements indicate healthy resistors and transistor. How can we quickly eliminate those components as being faulty based on simple DC voltage measurements?

Notes 93

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Notes 94

Characteristic curves are not the easiest concept for some students to grasp, but they are incredibly informative. Not only can they illustrate the electrical behavior of a nonlinear device, but they can also be used to diagnose otherwise hard-to-measure faults. Letting students figure out what shorted and open curves look like is a good way to open their minds to this diagnostic tool, and to the nature of characteristic curves in general.

Although it is far from obvious, one of the oscilloscope channels will have to be "inverted" in order for the characteristic curve to appear in the correct quadrant(s) of the display. Most dual-trace oscilloscopes have a "channel invert" function that works well for this purpose. If engaging the channel invert function on the oscilloscope flips the wrong axis, you may reverse the connections of the test device to the curve tracer circuit, flipping both axes simultaneously. Between reversing device connections and reversing one channel of the oscilloscope, you can get the curve to plot any way you want it to!

Notes 95

I have heard questions of this sort asked on technician job interviews. Knowing which way currents go through a BJT is considered a very fundamental aspect of electronics technician knowledge, and for good reason. It is impossible to understand the function of many transistor circuits without a firm grasp on which signal exerts control over which other signal in a circuit.

Notes 96

Ask your students to show you at least one datasheets for one of the listed transistors. With internet access, datasheets are extremely easy to locate. Your students will need to be able to locate component datasheets and application notes as part of their work responsibilities, so be sure they know how and where to access these valuable documents!

The follow-up question is an important one to discuss, as β is far from stable for most transistors! This point is often overlooked in basic electronics textbooks, leaving students with the false impression that transistor circuit calculations using β are far more accurate than they actually are.

Notes 97

The current-regulating nature of a BJT is made more understandable by analyzing an energy band diagram of the transistor in active mode.

Notes 98

For discussion purposes, you might want to show your students this equation, accurate over a wide range of operating conditions for base-emitter voltages in excess of 100 mV:

$$I_C = I_{ES} \left(e^{V_{BE}/V_T} - 1 \right)$$

This equation is nonlinear: increases in V_{BE} do not produce proportional increases in I_C. It is therefore much easier to think of BJT operation in terms of base and collector *currents*, the relationship between those two variables being more linear. Except when it isn't, of course. Such is the tradeoff between simplicity and accuracy. In an effort to make things simpler, we often end up making them *wrong*.

It should be noted here that although bipolar junction transistors aren't really current-controlled devices, they still may be considered to be (approximately) current-*controlling* devices. This is an important distinction that is easily lost in questions such as this when basic assumptions are challenged.

Notes 99

When researching engineering textbooks and other resources, these terms are quite often used without introduction, leaving many beginning students confused.

Notes 100

This model of current mirror transistor behavior, albeit crude, serves as a good introduction to the subject of *active loads* in transistor amplifier circuits. This is where a transistor is configured to operate as a constant-current regulator, then placed in series with an amplifying transistor to yield much greater voltage gains than what is possible with a passive (fixed resistor) load.

Notes 101

Students may try to implement a voltage regulation system for the entire circuit, sensor and everything, but this is unnecessary. Using a zener diode to regulate voltage for the right-hand portion of the current mirror circuit so that the right-hand transistor (acting as diode) receives constant current is all that is necessary. The left-hand transistor should faithfully regulate current through the sensor despite changes in sensor resistance *and* changes in supply voltage.

Notes 102

Ask your students to identify what it is that turns transistor Q2 on.

If students have difficulty understanding the limiting function of transistor Q2, just tell them to replace Q2 with a direct short (between the collector and emitter terminals of Q2), and re-analyze the circuit. They should see that transistor Q1 is unable to turn on in this condition.

A very helpful strategy in analyzing what happens in an electronic circuit as variables change is to imagine those variables assuming extreme states. In this case, to see the trend that occurs when Q2 starts to conduct, imagine Q2 conducting perfectly (a short between collector and emitter). Conversely, if we wanted to see what the circuit would do under conditions where Q2 is in cutoff mode, just replace Q2 with an open-circuit. While not always reliable, this technique often helps to overcome mental obstacles in analysis, and is a skill you should encourage in your students' discussion sessions often.

Notes 103

Ask your students how they can tell the difference between excessive biasing and insufficient biasing, by inspection of the output waveform. There is a difference to be seen, but it requires a good understanding of how the circuit works! Students may be tempted to simply memorize waveforms ("when I see this kind of waveform, I know the problem is excessive biasing . . ."), so prepare to challenge their understanding with questions such as:

- What polarity of input signal drives the transistor toward cutoff?
- What polarity of input signal drives the transistor toward saturation?
- Where on the output waveform is the transistor in cutoff (if at all)?
- Where on the output waveform is the transistor in saturation (if at all)?
- Where on the output waveform is the transistor in its active mode?

Another point worth mentioning: some students may be confused by the phasing of the input and output waveforms, comparing the two different oscilloscope displays. For a common-emitter (inverting) amplifier such as this, they expect to see the output voltage peak positive whenever the input voltage peaks negative, and visa-versa, but here the two oscilloscope displays show positive peaks occurring right next to the left-hand side of the screen. Why is this? Because the oscilloscope does not represent phase unless it is in dual-trace mode! When you disconnect the input probe and move it to another point in the circuit, any time reference is lost, the oscilloscope's triggering function placing the first waveform peak right where you tell it to, usually near the left-hand side of the display.

Notes 104

The answer I want for this question is not just a parroting of the answer I've given. Anyone can say "a distorted wave will sound different." I want to know *how* it sounds different, and this answer can only come by direct experimentation!

Notes 105

This circuit was purposely drawn in a convoluted fashion to force students to identify its configuration apart from the standard layout. Many people lack the spatial reasoning skills to do this easily, and require a lot of practice before they become proficient. Ask your more proficient students if they have any "tips" for helping those who struggle with problems like these. Are there any simple methods which we may use to re-draw this circuit in an easier-to-understand form?

Notes 106

If your students are experiencing difficulty analyzing this circuit, ask them to begin by calculating the transistor *currents* at the thresholds of cutoff and saturation.

A mathematical trick I've found helpful through the years for finding the midpoint between two values is to add the two values together and then divide by two. Challenge your students to use other means of calculating this midpoint value, though.

Notes 107

It is easy to miss the detail of the power supply's polarity being "backward" from what is typically seen (negative instead of positive). Actually, I am surprised to see how many introductory textbooks have the coupling capacitor drawn the wrong way, so expect that some students may become confused by researching their texts for the answer!

Notes 108

This circuit is simple enough to assemble and test in an hour or two, on a solderless breadboard. It would make a great lab experiment, and can be used by the students outside of class!

Notes 109

Discuss with your students the meaning of "Class A" amplification, and why DC biasing is necessary in order to achieve this mode of operation in a BJT circuit.

Notes 110

Ask your students what purpose the 47 μF capacitor serves. Since its presence does not noticeably attenuate the AC signal at point "A" (the whole 0.5 volts AC getting to point B), why not just replace it with a straight piece of wire?

Notes 111

Although the given answer seems complete, what I'm looking for here is a good analytical understanding of why the voltage gain is what it is. Placing the requirement of using KVL on the students' answers ensures that they will have to explore the concept further than the given answer does.

Notes 112

While the answer to this question will be obvious to some, it will not be obvious to all. Ask those students who do understand the answer to explain – using their own words – why the voltage gain decreases as R3's resistance increases.

Ask your students to imagine two scenarios of extreme resistance change for R3: shorted and open. Qualitative analysis of the circuit should be rather easy given these extreme conditions! Then, ask your students to relate the results of these hypothetical scenarios with a simple increase in resistance. Is there a general problem-solving technique at work here? Challenge your students to explain how this technique works.

Notes 113

Ask your students to imagine two scenarios of extreme resistance change for R3: shorted and open. Does this "thought experiment" help to see the effects of changing load resistance? If not, imagine two (lesser) extreme load resistance values: 1 ohm versus 1 million ohms. Now is the effect of load resistance change apparent?

Another question to provoke deep thought about this circuit is to ask what the effects of load resistance change will be on this circuit's load line. Does a greater load resistance make for a steeper load line, or a shallower load line? How does this relate to voltage gain?

Notes 114

Although it is more common in modern times to refer to the three BJT amplifier configurations as common-(e, c, b) rather than as *grounded*-(e, c, b), it may help some students grasp why the word "common" came to be used. "Grounded" makes more literal sense, and seeing these three circuit configurations with directly grounded terminals may serve as a starting point for identifying configurations where the "common" terminals are not directly grounded.

Notes 115

This skill is important if students are to build amplifier circuits and empirically compare their performance against predicted results.

Notes 116

I have found it helpful to approach this amplifier circuit from the perspective of a constant DC input voltage, qualitatively analyzing the voltage across the load resistor as it increases from a power-up condition. Students will see that the transistor goes into cutoff mode if the load voltage ever exceeds the total DC input voltage at the transistor's base terminal, and will saturate if the load voltage ever falls below V_{in} - 0.7 volts.

Notes 117

Discuss the impact of emitter resistance change on base current, and then transfer this concept to the two amplifier circuits and note the effects. Students should immediately realize the effects of this change in the common-emitter circuit, but the effects in the common-collector circuit will be a bit more difficult to follow. Work with your students in the analysis of the common-collector circuit, noting the effect changes in load voltage (voltage across the resistor) have on base current.

This question also previews the concept of negative feedback, which will be essential to your students' understanding of electronic circuits later in their studies.

Notes 118

Discuss with your students the many factors that can influence voltage gain in a common-emitter amplifier circuit, and then compare that relative instability with the rock-solid stability of the common-collector amplifier's voltage gain. What benefit is it to a circuit designer to have a stable voltage gain from a particular amplifier design?

Notes 119

Negative feedback is a vitally important principle for electronics students to understand. It is the basis of almost every type of control system, and it makes standardized amplifier design possible. Take as much time as necessary to discuss this with your students, and to make sure they understand how and why negative feedback works as it does.

Be sure to discuss the twin effects of negative feedback: increased voltage gain stability, and decreased voltage gain. Ask your students why anyone would want their amplifier circuit to suffer a loss of voltage gain just for the sake of gain stability. Why is the stability if voltage gain important?

Notes 120

Ask your students to explain what a "negative feedback loop" is, and how exactly the base-collector junction capacitance forms one in a transistor circuit. Also, review the formula for capacitive reactance (X_C), and ask your students to relate this frequency dependence to the degree of negative feedback established in an amplifier circuit.

The challenge question may be answered with a little research into the Miller-effect. There is a method for cancellation of this unwanted negative feedback loop, but it may not be possible to implement in all amplifier circuit topologies.

Notes 121

Here I give more explanation than is usual for me, because the concept is not easy to understand, and is often presented in a muddled fashion by textbooks.

Notes 122

This effect of base-collector capacitance "multiplication," while being a nuisance in typical amplifier applications, may be exploited for positive benefit in other circuits. Many an op-amp circuit has been built specifically to "multiply" the value of a passive component, when some exceptionally large value is needed that will not fit on a circuit board. This technique has its limits, of course, but is good to keep in mind.

Some students may not be familiar with the double-chevron notation (>> or <<). It means *much greater than*, and *much less than*, respectively.

Notes 123

After reviewing the simple (no-resistor) common-emitter circuit design, and the full-bypass design, it should be apparent to students that this circuit is a hybrid of the two previous designs. Likewise, it should come as little surprise that its performance characteristics lie somewhere between the two previous designs.

Notes 124

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

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

Notes 125

Ask your students to explain the mathematics behind this answer. What procedure gives them the quantity of 33 Ω from the given component values? Why is this answer only approximate? What factors might affect it?

Also, ask your students to explain why the common-collector transistor stage does not require a biasing network or coupling capacitor, as the common-emitter stage does.

Notes 126

Bootstrapping is an oft-used technique to boost amplifier input impedance, and it hints at the amazing potential of signal feedback in amplifier circuits. You might want to mention that bootstrapping is practical only if the feedback gain is slightly *less* than 1. If there is too much positive feedback, the amplifier will turn into an oscillator!

Notes 127

The purpose of this question is to introduce students to the concept of BJT modeling, and also to familiarize them with some of the symbols and expressions commonly used in these models (as well as a bit of DC resistor network theory and algebra review, of course!).

Notes 128

If the graph given in the answer reminds students of a band-pass filter, then they have been paying attention!

Notes 129

Discuss what it means for a circuit to have a designated "output" and "input". Can they think of any circuits studied thus far that have places to input and output signals?

Notes 130

Students should readily recognize this circuit as a voltage divider, from their education in basic DC circuits. Though it may seem strange to calculate the "gain" of a completely passive and indeed *dissipative* circuit, it is entirely valid.

Discuss with your students the maximum and minimum possible power gain values for a circuit of this type.

Notes 131

Students should readily recognize this circuit from their education in basic DC circuits. Though it may seem strange to calculate the "gain" of a completely passive and indeed *dissipative* circuit, it is entirely valid.

Discuss with your students the maximum and minimum possible power gain values for a circuit of this type. Also discuss with them the nature of ratios with regard to units.

Notes 132

Discuss with your students the nature of the "Bel" unit: it is fundamentally a unit of *power* gain, not voltage or current gain. So, representing voltage or current gains in units of either Bels or decibels means representing those voltage or current gains *in terms of how much power gain they equate to.*

Notes 133

Here we see the decibel unit being used to represent *absolute* quantities rather than relative ratios. Ask your students what benefit would there be in doing this. Why not just represent signal magnitudes in units of "volts" instead? Why would we want to use an obscure unit such as the decibel?