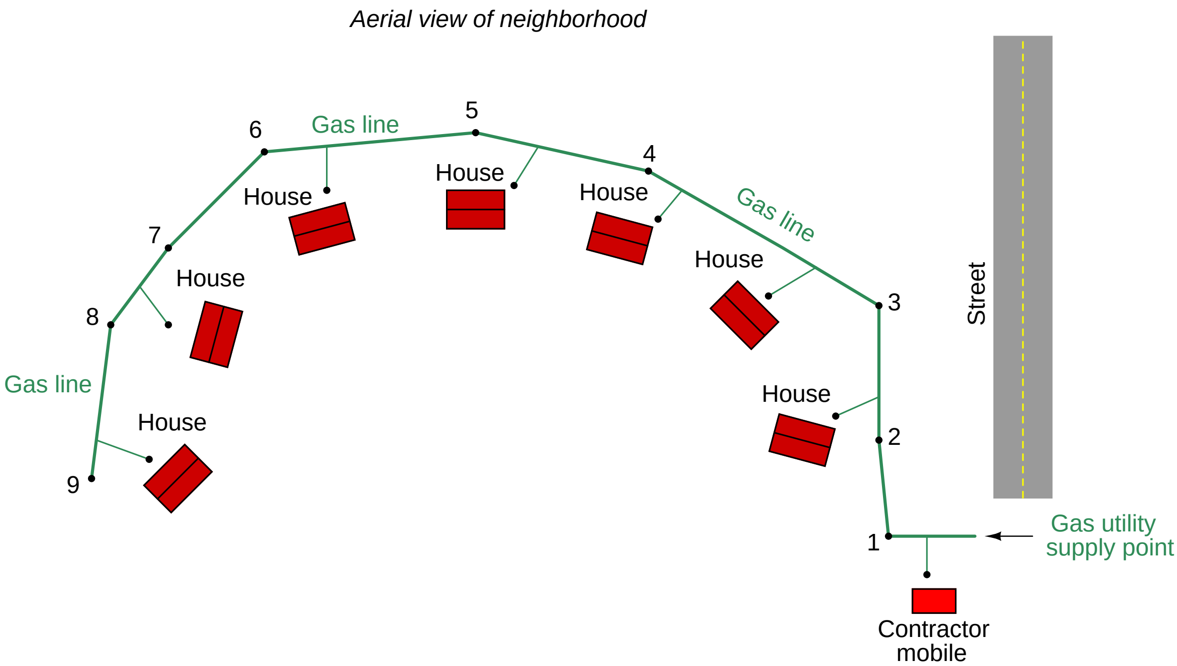
Question 1

A new residential neighborhood is being built, and you are working as a member of the construction crew. One day, when the heating technicians are on-site doing checks of the gas furnaces in each new house, they report that the last house in the neighborhood does not have natural gas. The piping is installed, of course, but when they turn the gas valve on nothing comes out.

The gas pipeline servicing these houses is laid out in the following manner:



Each black dot on the diagram is a shutoff valve, used for isolating different sections of the service pipeline. Based on the heating technician's report, you conclude that the service pipeline going up to that house must not be "live," and that one of the numbered valves was probably left in the *off* position. But which one could it be?

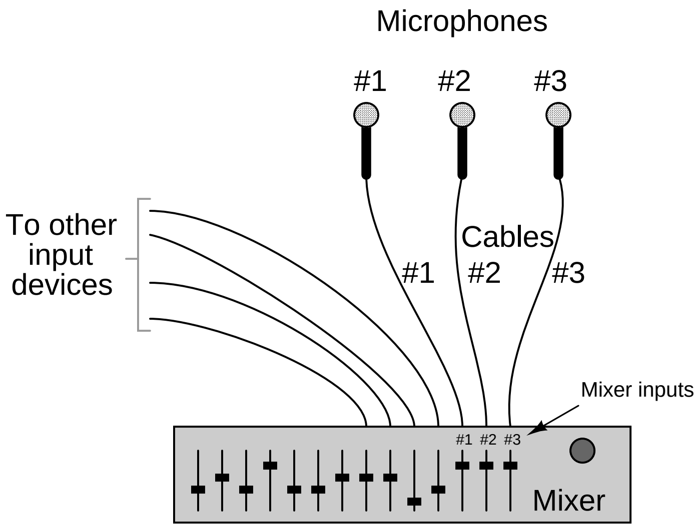
You know that the main utility connection at the street is "live," because the gas heater in the contractor mobile building is working just fine. You decide to go to valve #8 and check for gas pressure at that point in the pipeline with a portable pressure gauge, then checking the pressure at each valve location down the pipeline until you find where there is good gas pressure. However, before you step out of the room to go do this, one of your co-workers suggests you start your search at the middle point of the pipeline instead: at the location of valve #4.

Explain why your co-worker's idea is better, and also what your next step would be if: (a) you did find pressure at that point, and (b) if you did *not* find pressure at that point.

file 01595

Question 2

A music recording studio is equipped with three microphones, each of which connect to the "mixer" panel by means of shielded cables:

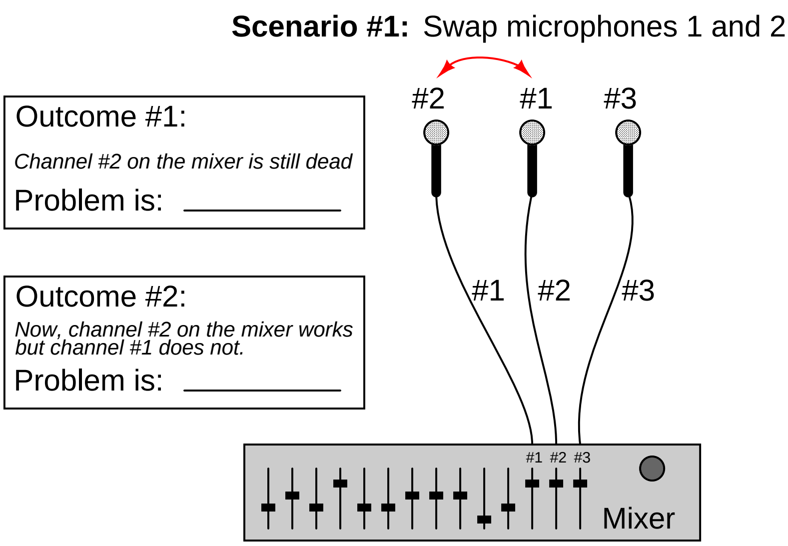


The purpose of the mixer is to function as a multi-channel audio signal amplifier, to control the volume of each sound channel so that a good "mix" is obtained for recording. The studio engineer will use the individual controls on the mixer to "blend" the inputs for the best recording tone and quality.

This system has a problem, though. Microphone #2 seems to be "dead," meaning that channel #2 on the mixer does not register any signal when the singer sings into that microphone. All the other channels are working just fine, though.

Being the studio technician, you job is to troubleshoot this problem in the shortest time possible. Unfortunately, in your rush to get to the job site you forgot to bring your test equipment. That isn't a problem, however, because you know how to troubleshoot systems by swapping interchangeable components.

I will present four different "swap" scenarios to you, with two different outcomes for each. Your task is to declare what is known about the location of the fault based on these scenarios and outcomes.



Scenario #2: Swap cables 2 and 3 at microphones

Outcome #1:

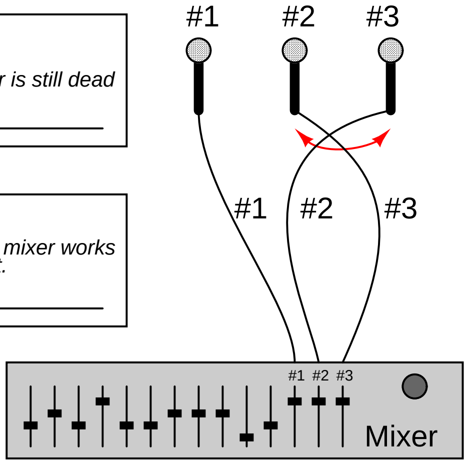
Channel #2 on the mixer is still dead

Problem is: ____________

Outcome #2:

Now, channel #2 on the mixer works but channel #3 does not.

Problem is: ____________



Scenario #3: Swap cables 2 and 3 at mixer

Outcome #1:

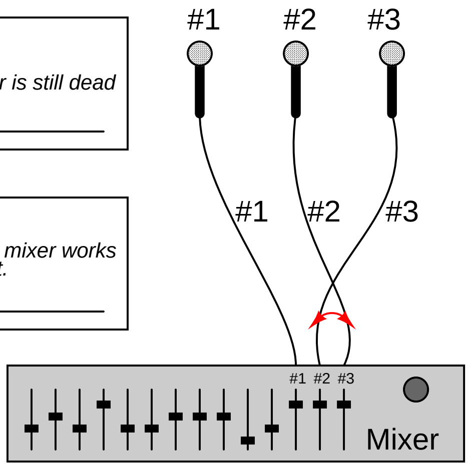
Channel #2 on the mixer is still dead

Problem is: ____________

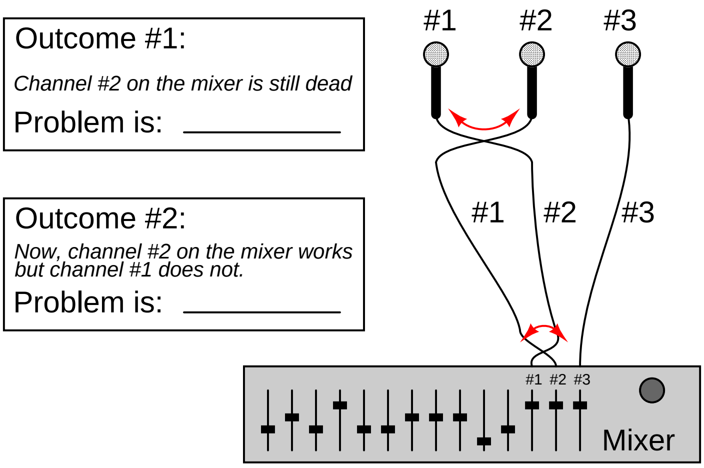
Outcome #2:

Now, channel #2 on the mixer works but channel #3 does not.

Problem is: ____________



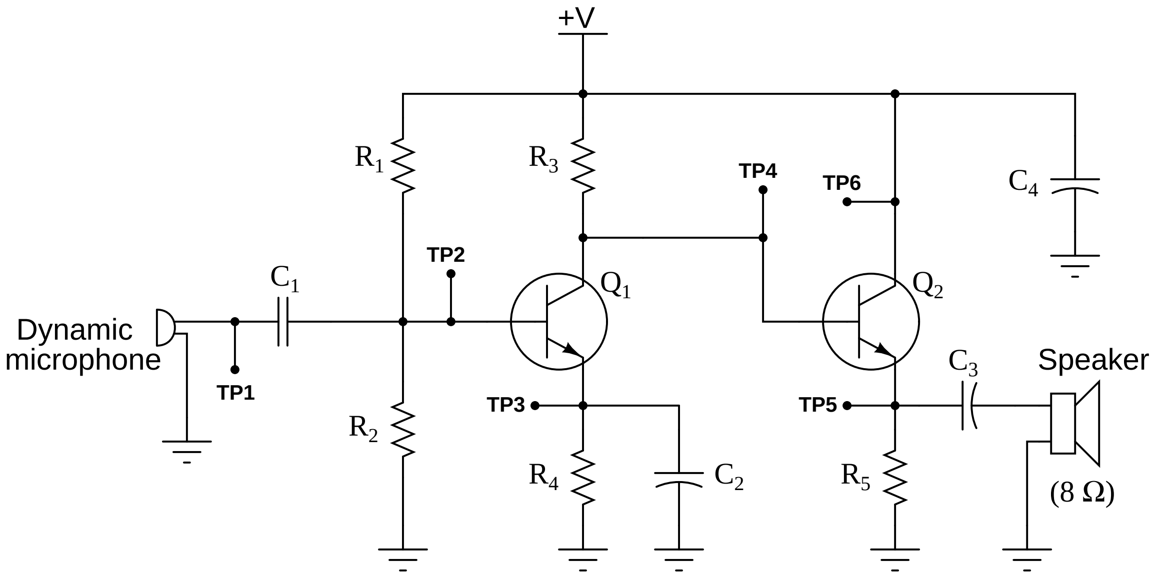
Scenario #4: Swap cables 1 and 2 at both ends



file 01571

Question 3

Study this audio amplifier circuit closely:



Then, determine whether the DC voltage at each test point (V_{TP1} through V_{TP6}) with respect to ground will increase, decrease, or remain the same for each of the given fault conditions:

Fault	V_{TP1}	V_{TP2}	V_{TP3}	V_{TP4}	V_{TP5}	V_{TP6}
R1 failed open	Same					Same
R2 failed open	Same					Same
R3 failed open	Same					Same
R4 failed open	Same					Same
R5 failed open	Same					Same
Short between TP2 and ground	Same					Same
C2 failed shorted	Same					Same
Q1 collector failed open	Same					Same

When analyzing component faults, consider only one fault at a time. That is, for each row in the table, you should analyze the circuit as though the only fault in it is the one listed in the far left column of that row.

file 01593

Question 4

The likelihood that a given component will fail in the "open" mode is quite often not the same as the likelihood that it will fail "shorted." Based on the research you do and your own personal experience with troubleshooting electronic circuits, determine whether the following components are more likely to fail *open* or fail *shorted* (this includes partial, or high-resistance, shorts):

- Resistors:
- Capacitors:
- Inductors:
- Transformers:
- Bipolar transistors:

I encourage you to research information on these devices' failure modes, as well as glean from your own experiences building and troubleshooting electronic circuits.

file 01594

Question 5

A very powerful method for discerning cause-and-effect relationships is *scientific method.* One commonly accepted algorithm (series of steps) for scientific method is the following:

1. Observation
2. Formulate an hypothesis (an educated guess)
3. Predict a unique consequence of that hypothesis
4. Test the prediction by experiment
5. If test fails, go back to step #2. If test passes, hypothesis is provisionally confirmed.

This methodology is also very useful in technical troubleshooting, since troubleshooting is fundamentally a determination of cause for an observed effect. Read the following description of an experienced troubleshooter diagnosing an mechanical noise problem in a bicycle, and match the troubleshooter's steps to those five steps previously described for scientific method:

> One day a bicyclist called a mechanic friend of his over the telephone, and describes a problem with his bicycle. The bicycle is making a rhythmic "clicking" sound as it is pedaled, but the bicyclist is not very mechanically inclined, and cannot determine the cause of the noise.
>
> The mechanic considered some of the options. Being a rhythmic noise, it was probably being caused by one of the bicycle's rotating objects. This includes the wheels, crank, and chain, which all rotate at different speeds. After a bit of thought, the mechanic asked his bicyclist friend a question.
>
> "Does the pace of the clicking increase as you ride faster?" The bicyclist answered, "Yes, it does."
>
> "If you shift into a higher gear so that your crank is turning slower for the same road speed, does the pace of the clicking change?" asked the mechanic. The bicyclist admitted he didn't know the answer to this question, as he hadn't thought to pay attention to this detail. After riding the bike once again to test the mechanic's idea, the bicyclist reported back. "No, the pace of the clicking does not change when I shift gears. It only changes with changes in road speed."
>
> Upon hearing this, the mechanic knew the general location of the problem, and continued his troubleshooting over the telephone with further questions for the bicyclist.

Where is the clicking sound coming from on this bicycle, based on the information presented here? How do you (and the mechanic) know?

file 01596

Question 6

As a technician, you are sent to troubleshoot a complex piece of electronic equipment that has stopped working. Upon opening the cabinet door for this equipment, your nose is greeted by the pungent odor of burnt circuit board (a smell you are unlikely to forget, once having experienced it). What does this simple fact indicate (or possibly indicate) about the nature of the equipment's fault?

file 01576

Question 7

Two computer technicians are called to troubleshoot malfunctioning computer systems. Although the symptoms in each system are very similar, the histories of the two systems are not. The first computer is a unit that has been in operation for over two years, while the second system is a brand-new prototype, still in the developmental stages.

Without knowing any more details on these two computer systems, what recommendations can you give to the two technicians about to troubleshoot them? If you were asked to troubleshoot each system, how would you approach the two systems differently? What ranges of problems might you expect from each system?

file 01580

Question 8

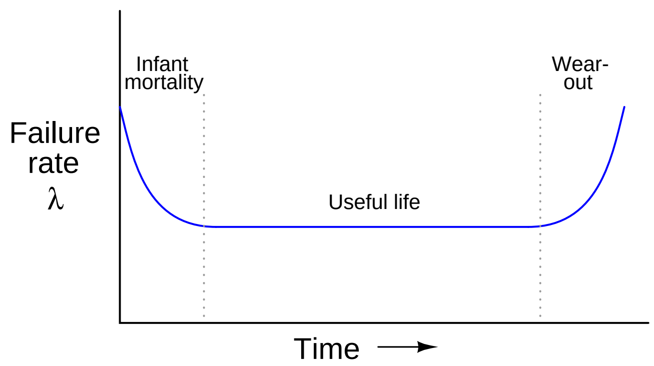
As an instructor of electronics, I am called upon frequently to help students troubleshoot their malfunctioning lab circuits. When I approach a student's self-built circuit to troubleshoot it, though, I often begin the process with a very different mindset than if I were troubleshooting a malfunctioning circuit on a real job site.

Aside from different safety considerations and a very different work environment, what else do you think I might consider differently when approaching a student-built circuit? Specifically, how might the range of probable faults differ between a professionally-installed electronic system that malfunctions and a student's lab project that malfunctions? What generalizations might you make about this difference in troubleshooting perspective, regarding the construction and operational history of the circuit in question?

file 01583

Question 9

The component failure rate of complex systems usually follows a trend known in the industry as the "bathtub curve":

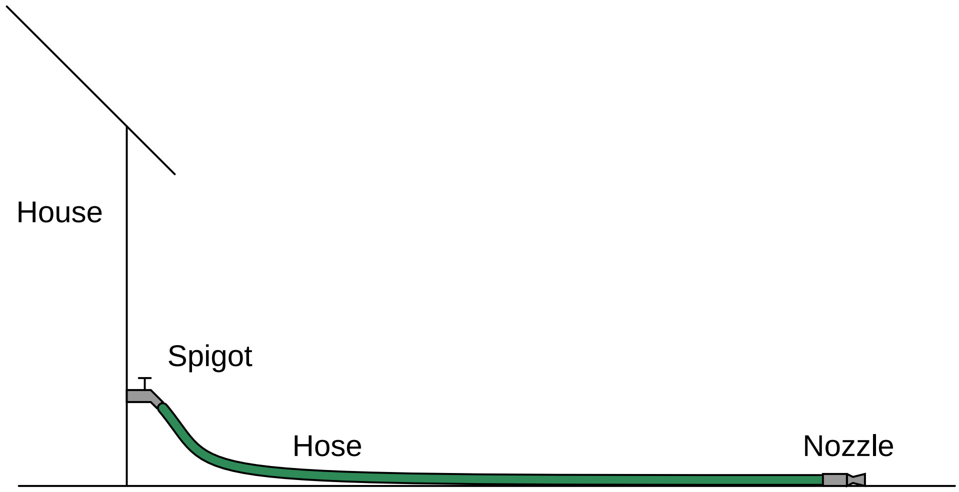


While the "Useful life" and "Wear-out" phases of the system life-cycle are easy to understand, the initial "Infant mortality" phase is not so intuitive. Explain what factors might lead to premature component failure during this initial phase of a system's lifespan.

file 01332

Question 10

One day you decide to water your garden, using a garden hose that is already connected to a spigot on the side of your house:

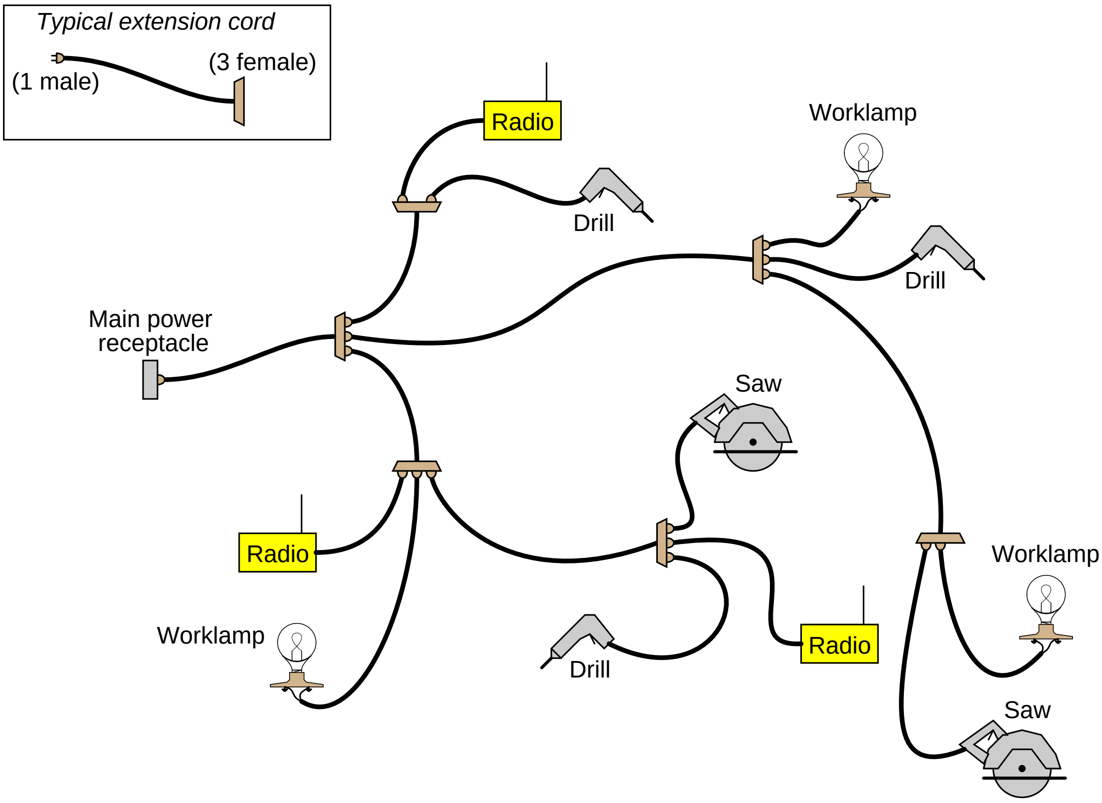


When you turn on the valve at the spigot, though, no water comes out the nozzle at the other end of the hose. Explain the steps you would take to troubleshoot this problem.

file 01568

Question 11

At a construction site, workers have used power extension cords to create a "network" of power cabling for their various electric tools. Each cord has one (male) plug and a receptacle (female) end that accepts up to three plugs:



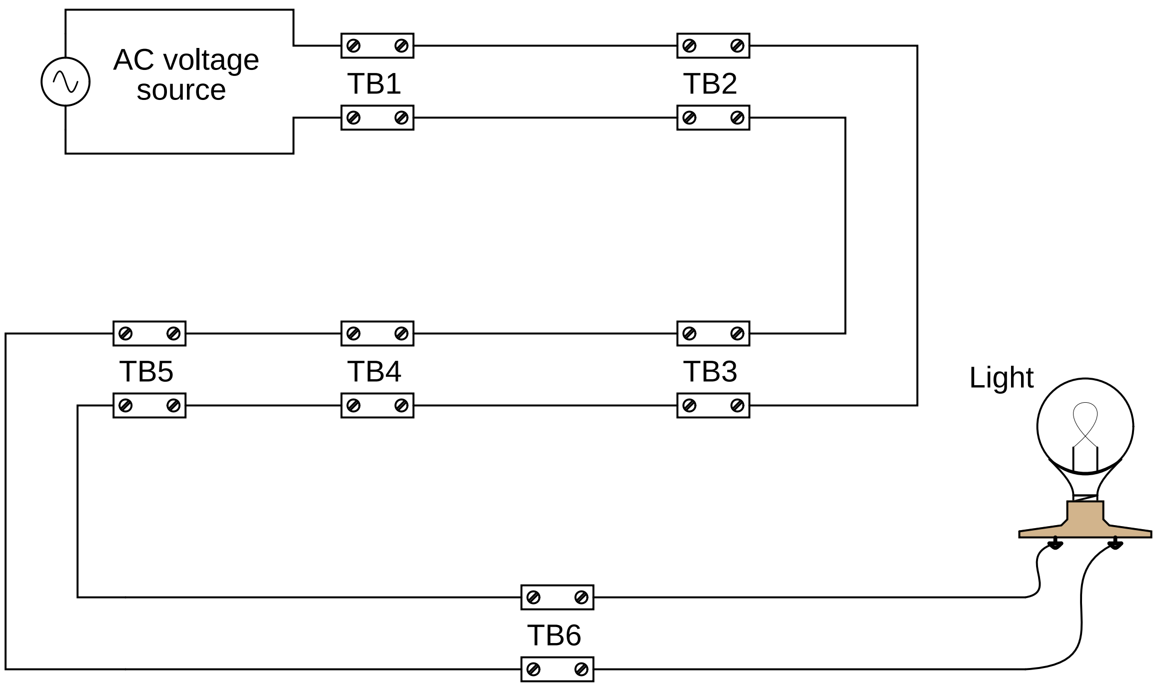
Despite this dangerous wiring, all tools have functioned so far without trouble. Then suddenly both the worklight and the circular saw in the lower-right corner of the illustration stop working. All the other tools continue to function properly (including all the radios, which is very fortunate because the workers become irritable without their music).

From this information alone, determine what sections of this "network" are good, and what sections are suspect.

file 01575

Question 12

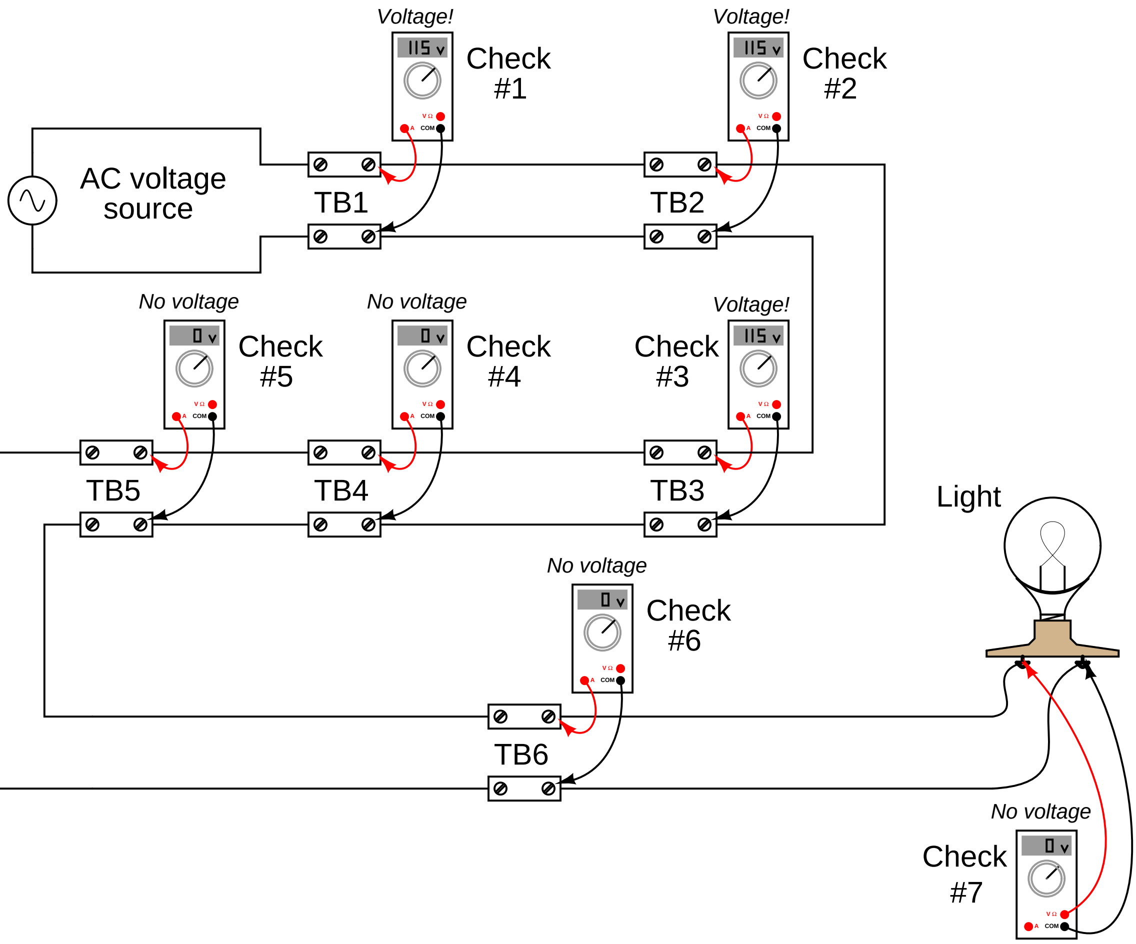
An electrician is troubleshooting a faulty light circuit, where the power source and light bulb are far removed from one another:



As you can see in the diagram, there are several terminal blocks ("TB") through which electrical power is routed to the light bulb. These terminal blocks provide convenient connection points to join wires together, enabling sections of wire to be removed and replaced if necessary, without removing and replacing *all* the wiring.

The electrician is using a voltmeter to check for the presence of voltage between pairs of terminals in the circuit. The terminal blocks are located too far apart to allow for voltage checks between blocks (say, between one connection in TB2 and another connection in TB3). The voltmeter's test leads are only long enough to check for voltage between pairs of connections at each terminal block.

In the next diagram, you can see the electrician's voltage checks, in the sequence that they were taken:

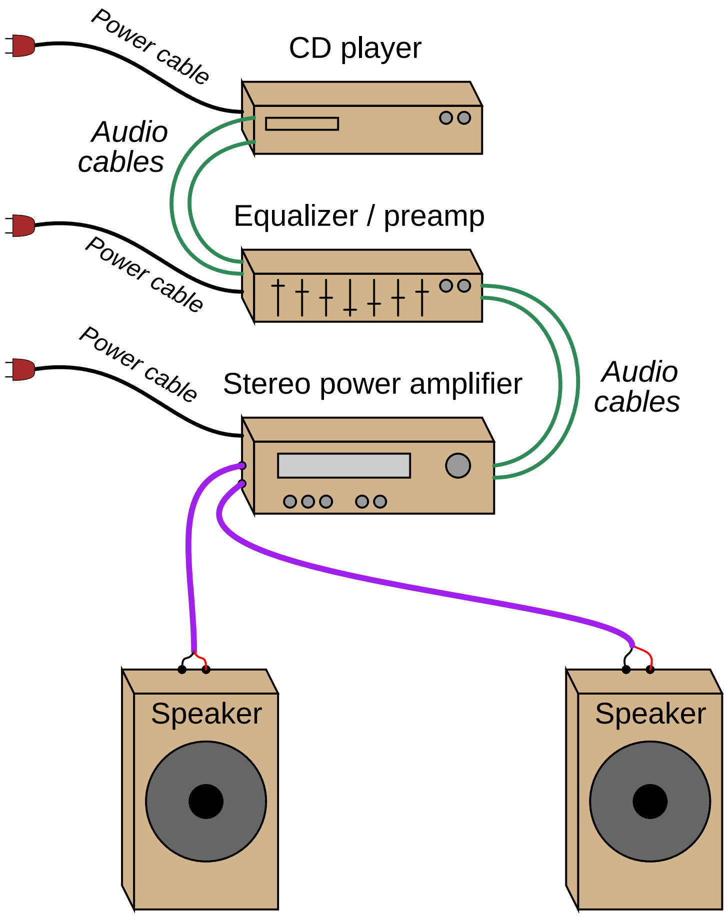


Based on the voltage indications shown, can you determine the location of the circuit fault? What about the electrician's choice of steps – do you think the voltage measurements taken were performed in the most efficient sequence, or would you recommend a different order to save time?

file 01578

Question 13

Examine the following "component" stereo system closely:



The CD player generates the audio signal to be amplified, while the equalizer/preamp modifies the tone of the signal to suit the listener's preferences and the power amplifier provides adequate power to drive the speakers.

Suppose this system has a problem: no sound at all coming out of either speaker. All components in the system are turned on, as indicated by power lights on the front panels. All control knobs seem to be set to their proper positions, as well. The CD player indicates the disk is being played, and that it is presently playing a song. Despite all these good indicators, though, no sound is heard from the speakers.

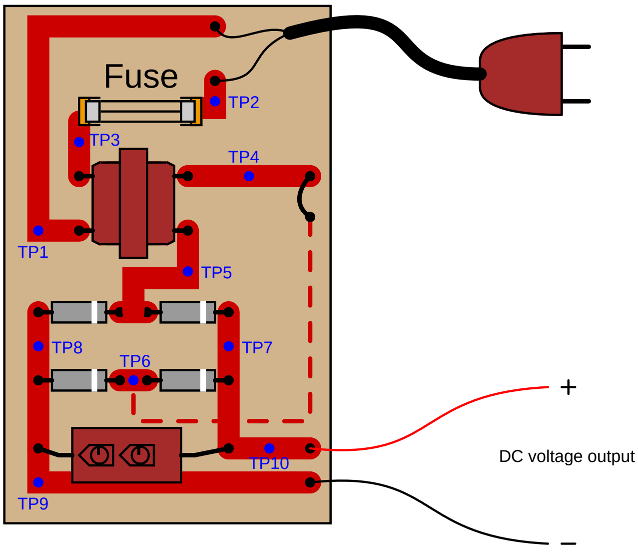
Being prepared at all times to troubleshoot electronic systems, you have a digital multimeter close by which you may use to check for the presence of audio signals (set the meter to measure AC millivolts). All audio signal cables (including the speaker cables) may be unplugged to provide access for your meter's test probes.

At what point in the system would you begin testing for the presence of an audio signal? Explain why you chose that point, and describe your subsequent actions based on the results of that test.

file 01585

Question 14

A technician is troubleshooting a power supply circuit with no DC output voltage. The output voltage is supposed to be 15 volts DC:



The technician begins making voltage measurements between some of the test points (TP) on the circuit board. What follows is a sequential record of his measurements:

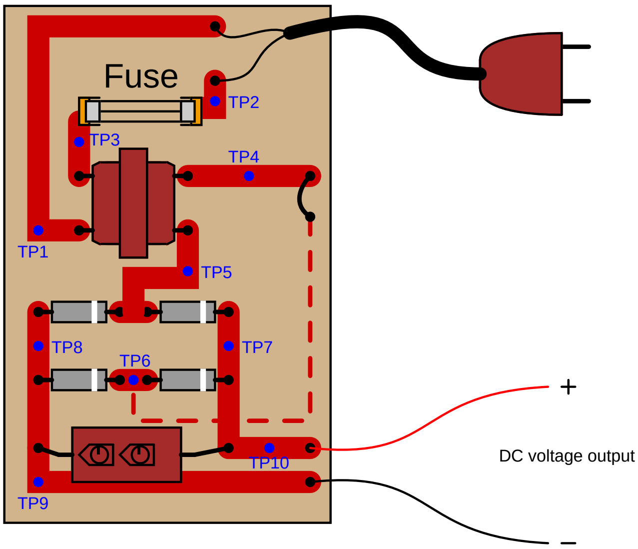
1. $V_{TP9-TP10} = 0$ volts DC
2. $V_{TP8-TP7} = 0$ volts DC
3. $V_{TP8-TP5} = 0$ volts DC
4. $V_{TP6-TP7} = 0$ volts DC
5. $V_{TP4-TP5} = 0$ volts AC
6. $V_{TP1-TP3} = 0$ volts AC
7. $V_{TP1-TP2} = 116$ volts AC

Based on these measurements, what do you suspect has failed in this supply circuit? Explain your answer. Also, critique this technician's troubleshooting technique and make your own suggestions for a more efficient pattern of steps.

file 00795

Question 15

A technician is troubleshooting a power supply circuit with no DC output voltage. The output voltage is supposed to be 15 volts DC:



The technician begins making voltage measurements between some of the test points (TP) on the circuit board. What follows is a sequential record of her measurements:

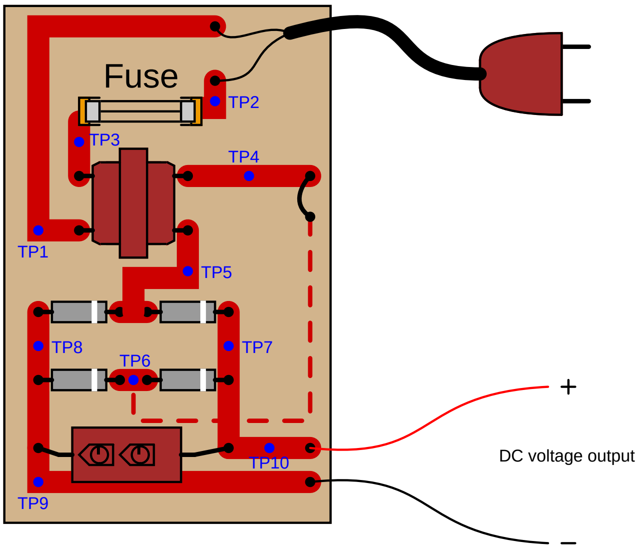
1. $V_{TP1-TP2} = 118$ volts AC
2. $V_{TP3-TP2} = 0$ volts AC
3. $V_{TP1-TP3} = 118$ volts AC
4. $V_{TP4-TP5} = 0.5$ volts AC
5. $V_{TP7-TP8} = 1.1$ volts DC
6. $V_{TP9-TP10} = 1.1$ volts DC

Based on these measurements, what do you suspect has failed in this supply circuit? Explain your answer. Also, critique this technician's troubleshooting technique and make your own suggestions for a more efficient pattern of steps.

file 00796

Question 16

A technician is troubleshooting a power supply circuit with no DC output voltage. The output voltage is supposed to be 15 volts DC:



The technician begins making voltage measurements between some of the test points (TP) on the circuit board. What follows is a sequential record of his measurements:

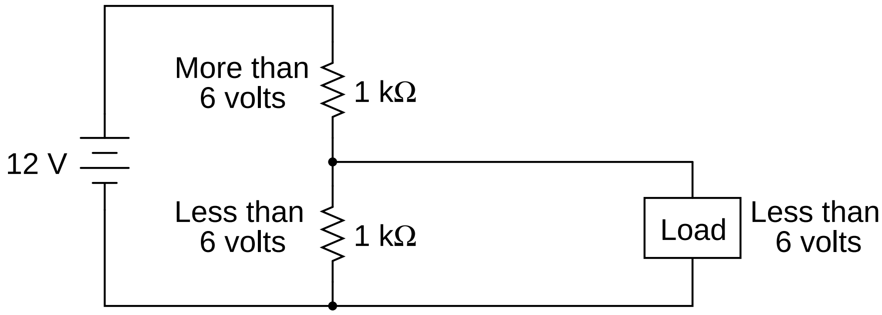
1. $V_{TP9-TP10} = 0$ volts DC
2. $V_{TP1-TP2} = 117$ volts AC
3. $V_{TP1-TP3} = 117$ volts AC
4. $V_{TP5-TP6} = 0$ volts AC
5. $V_{TP7-TP8} = 0.1$ volts DC
6. $V_{TP5-TP4} = 12$ volts AC
7. $V_{TP7-TP6} = 0$ volts DC

Based on these measurements, what do you suspect has failed in this supply circuit? Explain your answer. Also, critique this technician's troubleshooting technique and make your own suggestions for a more efficient pattern of steps.

file 00797

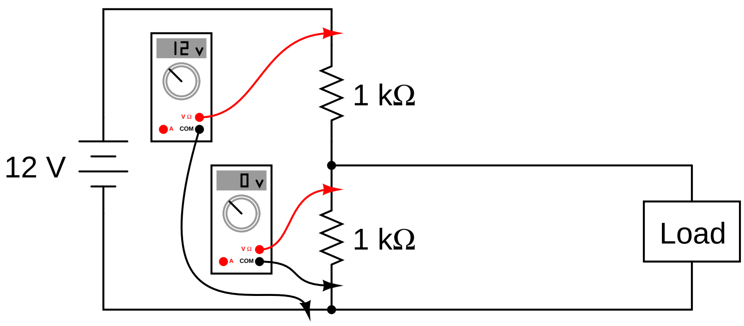
Question 17

This circuit is called a *voltage divider*, because it presents a fractional portion of the total voltage to the load:



(Of course, with no load connected, the voltage across the lower resistor would be precisely 6 volts. With the load connected, the parallel combination of load and 1 kΩ resistor results in an effective resistance of less than 1 kΩ on the lower half of the divider, resulting in a voltage of less than half the total supply voltage.)

Suppose that something goes wrong in this voltage divider circuit, and the load voltage suddenly falls to zero. A technician following the "divide-and-conquer" troubleshooting strategy begins by measuring voltage across the lower resistor (finding 0 volts), then measuring voltage across both resistors (finding 12 volts):



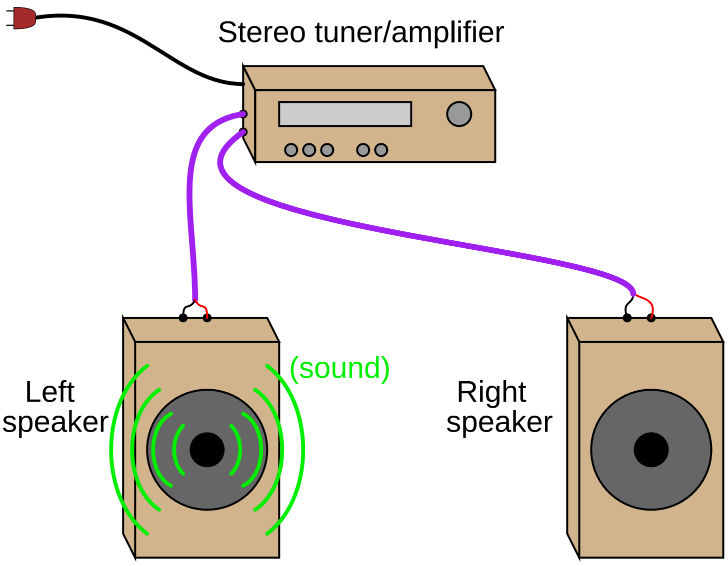
Based on these measurements, the technician concludes that the upper resistor must be failed open. Upon disassembling the divider circuit and checking resistance with an ohmmeter, though, both resistors are revealed to be in perfect operating condition.

What error did the technician make in concluding the upper resistor must have been failed open? Where do you think the problem is in this circuit?

file 01579

Question 18

This stereo system has a problem: only one of the two speakers is emitting sound. While the left speaker seems to be working just fine, the right speaker is silent regardless of where any of the stereo's controls are set:



Identify three possible faults that could cause this problem to occur, and identify what components of the stereo system are known to be okay (be sure to count each cable as a separate component of the system!).

Possible faults in the system:

- Fault #1:
- Fault #2:
- Fault #3:

Components known to be okay in the system:

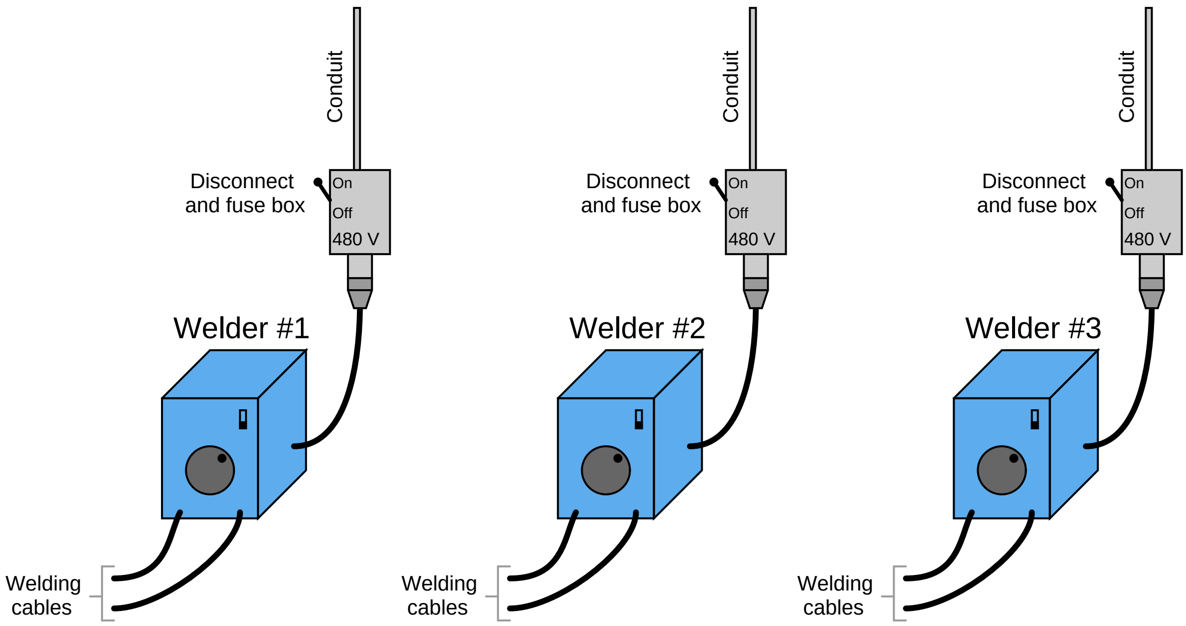
- Component #1:
- Component #2:
- Component #3:

Explain how you might go about troubleshooting this problem, using no test equipment whatsoever. Remember that the speaker cables detach easily from the speakers and from the amplifier.

file 01570

Question 19

At a construction site, several electric "arc" welders are plugged into 480 volt receptacles. Each receptacle has its own safety disconnect switch and fuse overcurrent protection:



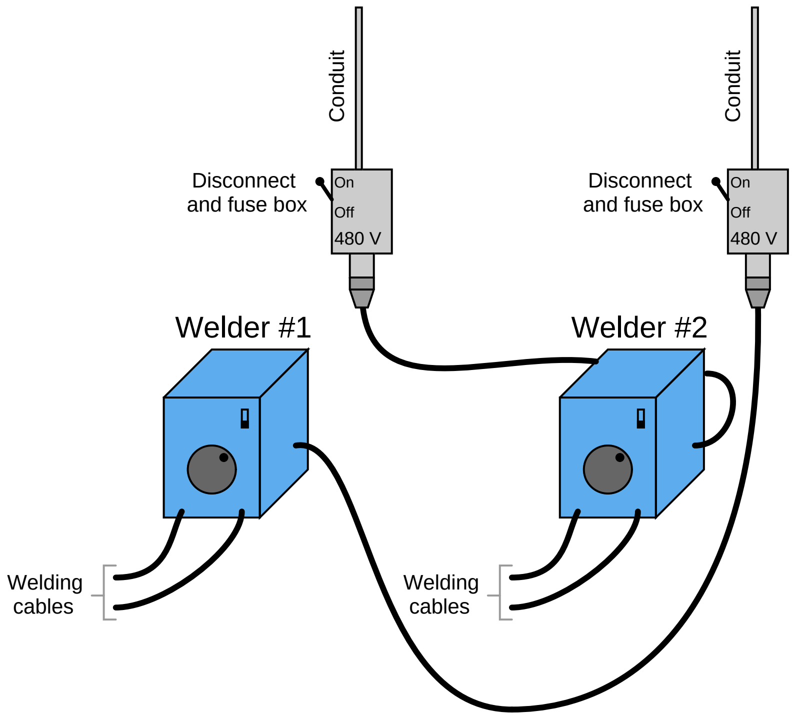
You, as an electronics technician working at the job site, happen to be walking past these welders when one of the welding personnel stops you to ask for help.

"You're an electrician, right?"

"Not exactly," you reply, "but maybe I can help you anyway."

"My welder's dead – it doesn't even turn on. Can you check it out?"

You didn't bring your multimeter or any other test equipment, so you can't check for voltage at the receptacle. As you look around the job site, you notice that no one is using welder #2. When you flip it's power switch on, welder #2 turns on just like it should. Deciding to apply your "swap interchangeable components" troubleshooting strategy, you turn off both welders' power switches, then turn off the disconnect switches at both receptacles and swap the power cables between receptacles:



When you turn the disconnect switches on and try to start both welders, you find that *neither* one turns on now! Switching the power cables back to their original receptacles doesn't make things better, either. Both welders #1 and #2 are still "dead," which is a worse situation than what you first encountered. This is not good, because the person who called you for help is beginning to cast angry looks in your direction, and you are fairly sure the operator of welder #2 won't be much happier when he returns to find his welder non-functional as well.

Identify the most likely location of the fault in this system, and explain why the "swap interchangeable components" strategy got you into trouble.

file 01572

Question 20

A friend of yours brings you their damaged stereo amplifier, hoping that perhaps you would be able to repair it cheaper than the local electronics repair shop. The amplifier was damaged at a recent party, when one of your friend's guests turned up the volume to full and left it there until smoke billowed out of the power amplifier chassis.

Your friend has already done some troubleshooting of his own: after turning off the amplifier and letting the smoke clear, he turned it back on at low volume to find that the left channel is dead, but the right channel is still working. He then swapped speakers and speaker wires, and consistently found that whatever speaker was plugged into the left channel did not make sound, but the speaker plugged into the right channel always did.

You remove the chassis cover on the amplifier and look inside. There, the damage is visually apparent: both of the power transistors for the left channel output are burnt beyond recognition. You unsolder the transistors from the circuit board and unscrew them from the heat sink, but you cannot read the part numbers on their cases due to the thermal damage. This is not good, because without knowing the proper part numbers, your friend cannot order the proper replacement transistors to repair the amplifier.

As usual, there is no schematic diagram supplied with this amplifier that would indicate the proper part numbers. What do you do?

file 01589

Question 21

Here are a few good steps to take prior to applying any specific troubleshooting strategies to a malfunctioning amplifier circuit:

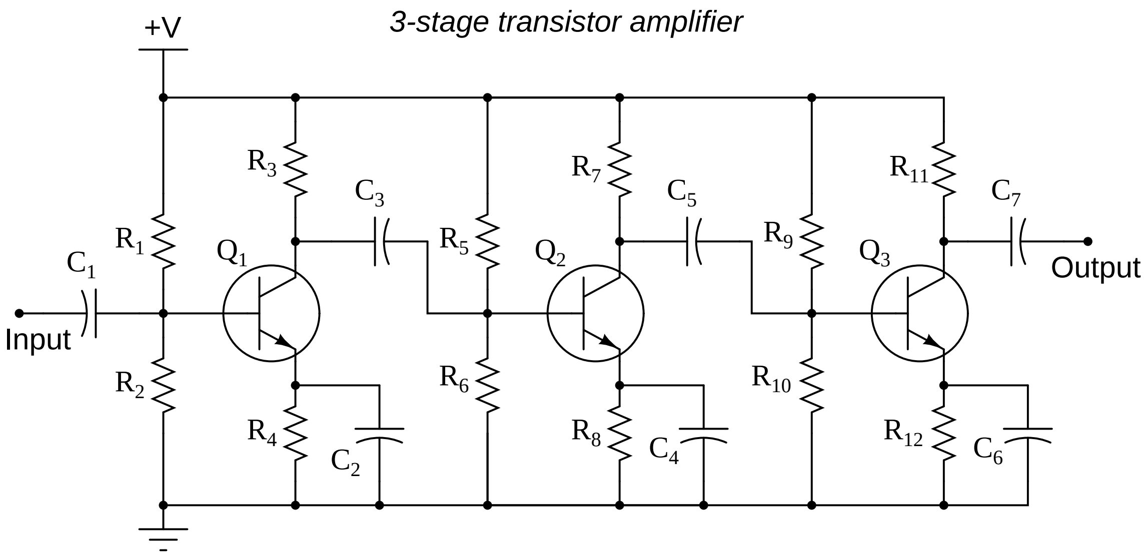
- Measure the output signal with an oscilloscope.
- Determine if the amplifier is receiving a good input signal.
- Check to see that the amplifier is receiving good-quality power.

Explain why taking these simple steps may save a lot of time in the troubleshooting process. For example, why bother checking the amplifier's output signal if you already know it isn't outputting what it's supposed to? What, exactly, constitutes "good-quality" power for an amplifier circuit?

file 01584

Question 22

The three-stage amplifier shown here has a problem. Despite being supplied with good, "clean" DC power and an adequate input signal to amplify, there is no output signal whatsoever:



Explain how you would use the "divide and conquer" or "divide by two" strategy of troubleshooting to locate the amplification stage where the fault is. (This is where you divide the signal path into different sections, then test for good signal at points along that path so as to narrow the problem down to one-half of the circuit, then to one-quarter of the circuit, etc.)

Show the lines of demarcation where you would divide the circuit into distinct sections, and identify input and output test points for each of those sections.

file 01586

Question 23

A very powerful method for discerning cause-and-effect relationships is *scientific method*. One commonly accepted algorithm (series of steps) for scientific method is the following:

1. Observation
2. Formulate an hypothesis (an educated guess)
3. Predict a unique consequence of that hypothesis
4. Test the prediction by experiment
5. If test fails, go back to step #2. If test passes, hypothesis is provisionally confirmed.

This methodology is also very useful in technical troubleshooting, since troubleshooting is fundamentally a determination of cause for an observed effect. Read the following description of an experienced troubleshooter diagnosing an automotive electrical problem, and match the troubleshooter's steps to those five steps previously described for scientific method:

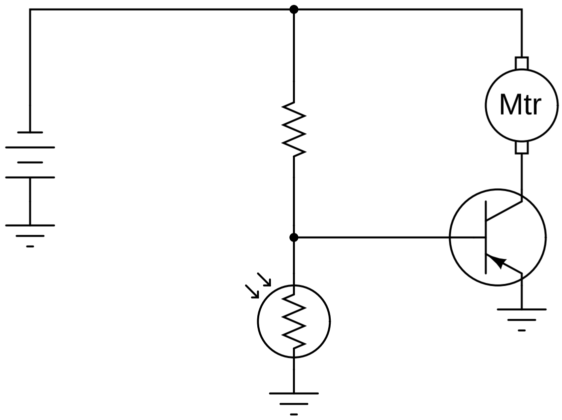
> One day a car owner approached a mechanic friend of theirs with a problem. The battery in this car seemed to be dying, requiring frequent jump-starts from other vehicles, or the application of a battery charger overnight, to be able to start reliably. "What could be the problem?" asked the car owner to the mechanic.
>
> The mechanic considered some of the options. One possibility was that a parasitic load was draining the battery of its charge when the car was shut off. Another possibility was that the car's charging system (the engine-driven generator and its associated circuitry) was faulty and not charging the battery when the engine was running. A third possibility was that the battery itself was defective, and unable to hold a charge.
>
> "Let's check the battery voltage with the engine stopped, and with the engine running," said the mechanic. The two walked over to the car and opened the hood, then the mechanic connected a voltmeter to the battery's terminals. It read 11.3 volts DC. This was a 12-volt (nominal) battery.
>
> "Start the car," said the mechanic, still watching the voltmeter. As the electric starting motor labored to turn the engine, the voltmeter's reading sagged to 9 volts. Once the engine started and the electric starter disengaged, the voltmeter rebounded to 11.2 volts.
>
> "That's the problem!" shouted the mechanic. With that, the owner stopped the car's engine.

Explain which of the three hypotheses was confirmed by the voltmeter's reading, and how the mechanic was able to know this.

file 01577

Question 24

In this circuit, the electric motor is supposed to turn on whenever the cadmium sulfide photocell is darkened:



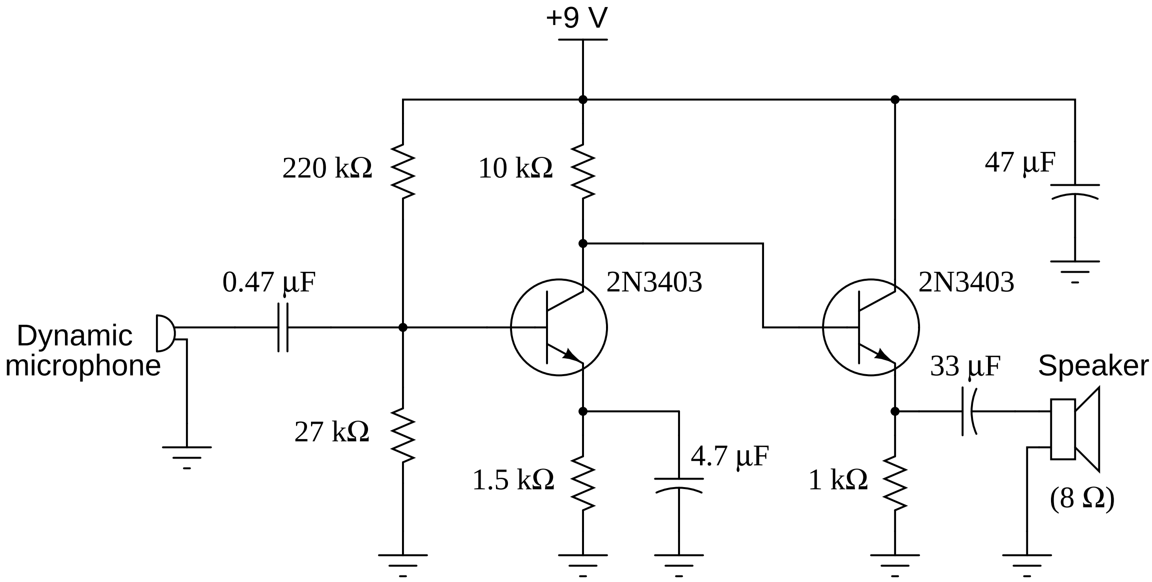
Unfortunately, though, the motor refuses to turn on no matter how little light strikes the photocell. In an attempt to troubleshoot the circuit, a technician measures voltage between the collector and emitter terminals of the transistor with the photocell covered by a piece of dark tape, and measures full battery voltage. The technician also measures voltage between the collector and base terminals of the transistor, and measures full battery voltage. At that point, the technician gives up and hands the problem to you.

Based on this information, what do you suspect is faulty in this circuit, and how might you determine the exact location of the fault? Also, identify what you know to be *not* faulted in the circuit, based on the information given here.

file 00501

Question 25

In order to successfully troubleshoot any electronic circuit to the component level, one must have a good understanding of each component's function within the context of that circuit. Transistor amplifiers are no exception to this rule. The following schematic shows a simple, two-stage audio amplifier circuit:



Identify the role of the following components in this audio amplifier circuit:

- The 0.47 μF capacitor connected to the microphone
- The 220 kΩ and 27 kΩ resistor pair
- The 4.7 μF electrolytic capacitor connected across the 1.5 kΩ resistor
- The 33 μF electrolytic capacitor connected to the speaker
- The 47 μF electrolytic capacitor connected to the power supply rail

Additionally, answer the following questions concerning the circuit's design:

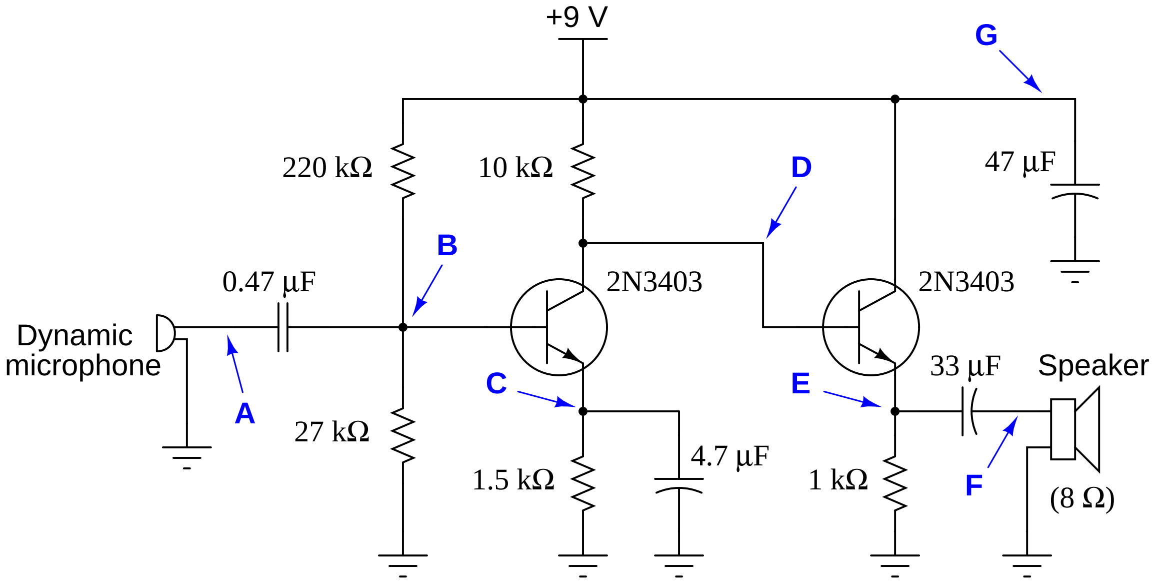
- What configuration is each stage (common-base, common-collector, common-emitter)?
- Why not just use one transistor stage to drive the speaker? Why is an additional stage necessary?
- What might happen if the 47 μF "decoupling" capacitor were not in the circuit?
- Why does the second stage of the amplifier not need its own voltage divider to set bias voltage as the first stage does?

file 01587

Question 26

Often times, component failures in transistor circuits will cause significant shifting of DC (quiescent) parameters. This is a benefit for the troubleshooter, as it means many faults may be located simply by measuring DC voltages (with no signal input) and comparing those voltages against what is expected. The most difficult part, though, is determining what DC voltage levels to expect at various points in an amplifier circuit.

Examine this two-stage audio amplifier circuit, and estimate the DC voltages at all the points marked by bold letters and arrows (**A** through **G**), with reference to ground. Assume that conducting PN junctions will drop 0.7 volts, that loading effects on the voltage divider are negligible, and that the transistor's collector and emitter currents are virtually the same magnitude:



$V_A \approx$

$V_B \approx$

$V_C \approx$

$V_D \approx$

$V_E \approx$

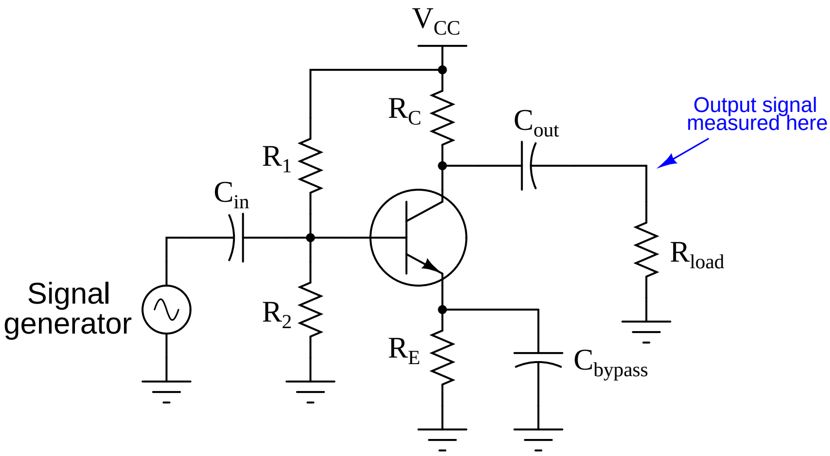
$V_F \approx$

$V_G \approx$

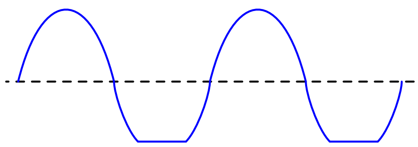
file 01588

Question 27

Suppose you were troubleshooting the following amplifier circuit, and found the output signal to be "clipped" on the negative peaks:



Output signal:

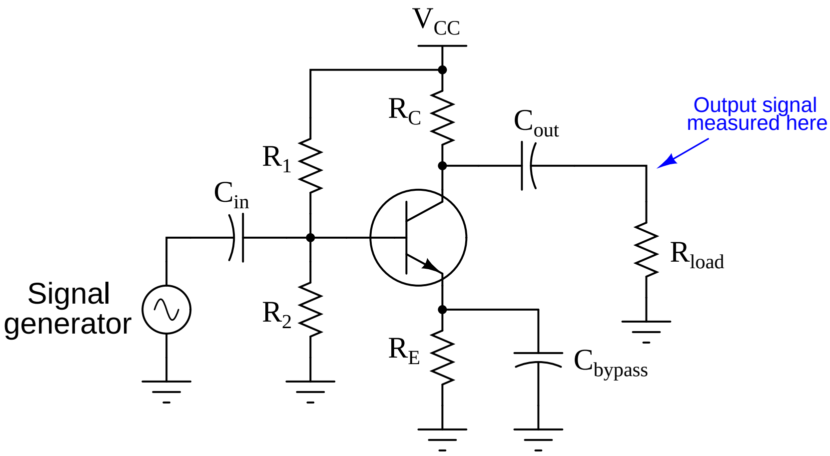


If you knew that this amplifier was a new design, and might not have all its components properly sized, what type of problem would you suspect in the circuit? Please be as specific as possible.

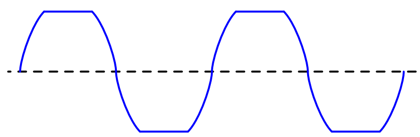
file 01581

Question 28

Suppose you were troubleshooting the following amplifier circuit, and found the output signal to be symmetrically "clipped" on both the positive and negative peaks:



Output signal:

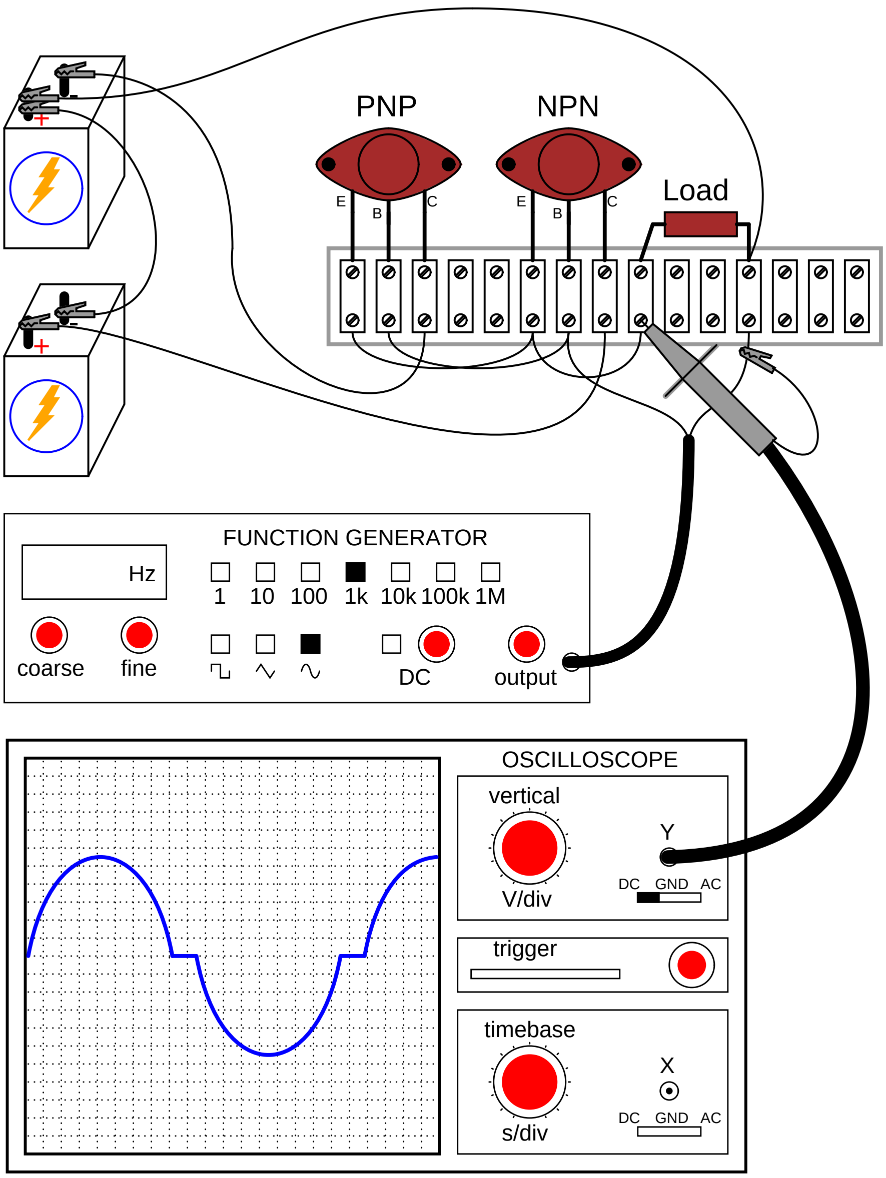


If you knew that this amplifier was a new design, and might not have all its components properly sized, what type of problem would you suspect in the circuit? Please be as specific as possible.

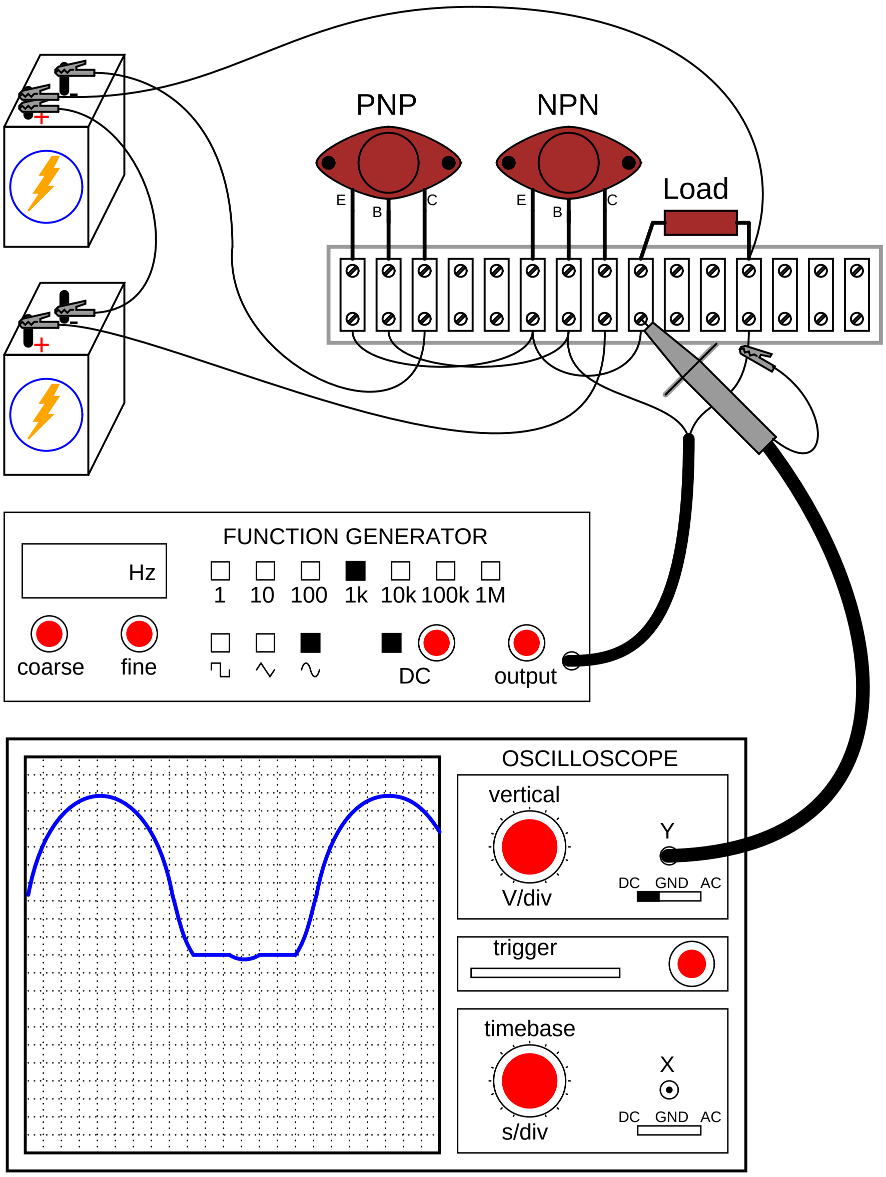
file 01582

Question 29

A student builds the following push-pull amplifier circuit, and notices that the output waveform is distorted from the original sine-wave shape output by the function generator:



Thinking that perhaps this circuit requires DC biasing, just like Class A amplifier circuits, the student turns on the "DC offset" feature of the function generator and introduces some DC voltage to the input signal. The result is actually worse:

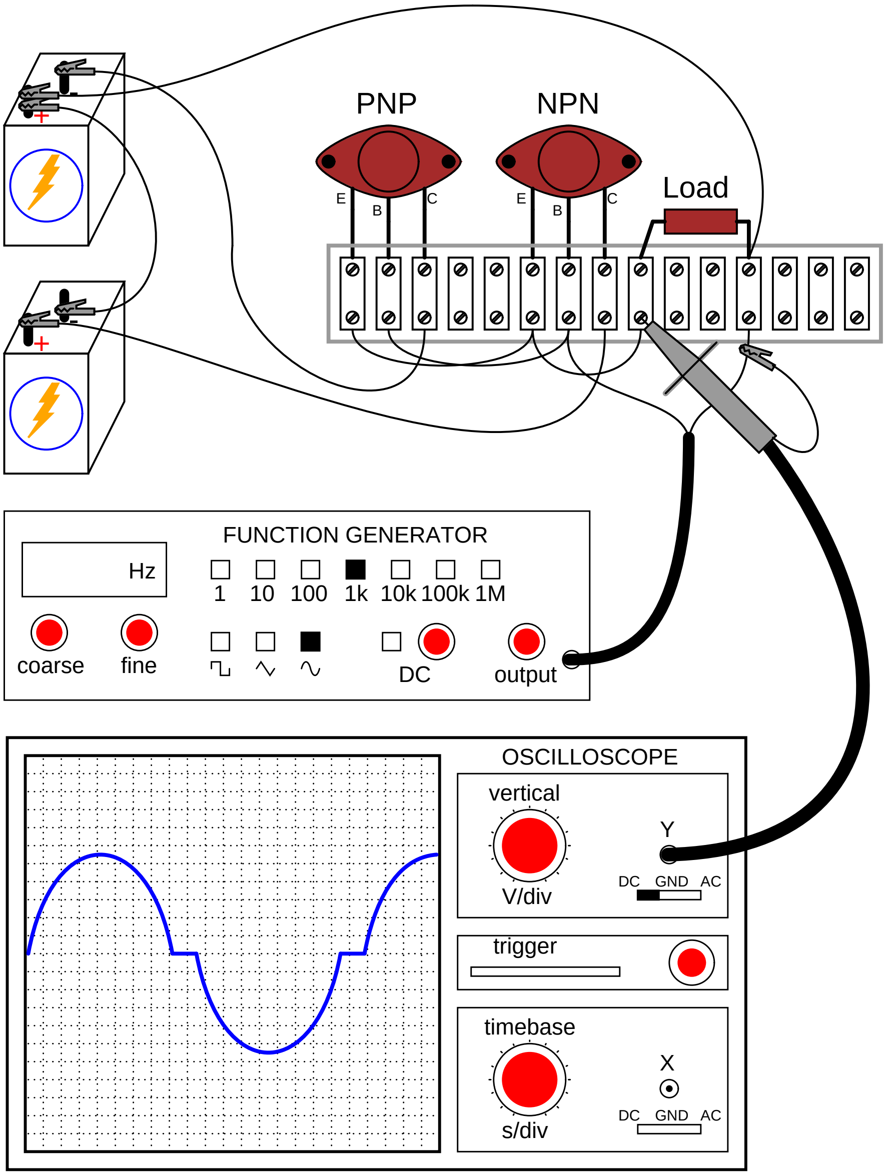


Obviously, the problem will not be fixed by biasing the AC input signal, so what causes this distortion in the output waveform?

file 00969

Question 30

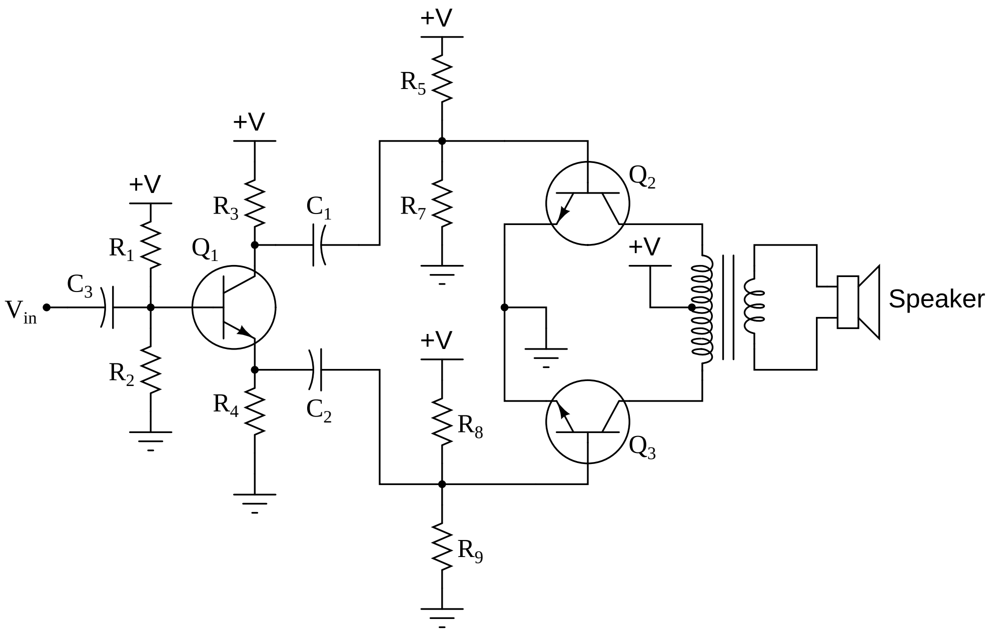
What would happen to the output voltage waveform of this amplifier if the NPN transistor failed open between collector and emitter?



file 00971

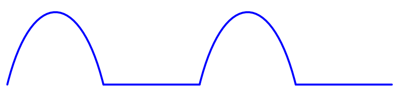
Question 31

This class-B audio power amplifier circuit has a problem: its output is very distorted, resembling half of a sine wave when tested with an input signal from a function generator:



Output signal:

(measured by oscilloscope at speaker terminals)



List some of the possible faults in this system, based on the output signal shown by the oscilloscope. Also, determine which components, if any, are known to be good based on the same data:

Possible faults in the system:

- Fault #1:
- Fault #2:
- Fault #3:

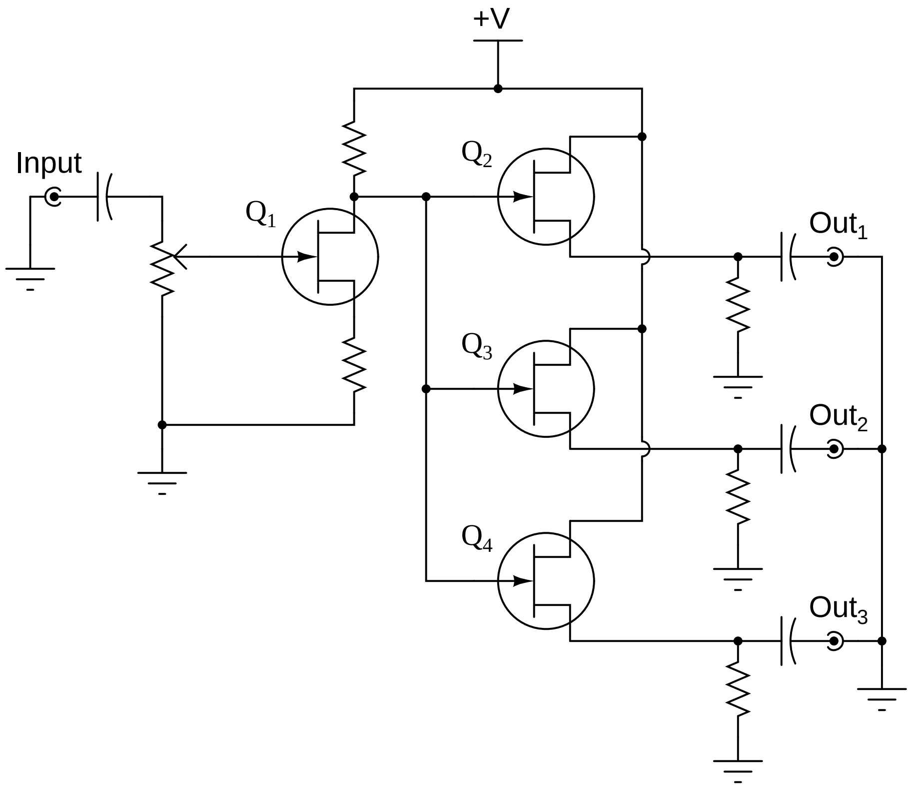
Components known to be okay in the system:

- Component #1:
- Component #2:
- Component #3:

file 01590

Question 32

The following circuit is a "multicoupler" for audio signals: one audio signal source (such as a microphone) is distributed to three different outputs:



Suppose an audio signal is getting through from the input to outputs 2 and 3, but not through to output 1. Identify possible failures in the circuit that could cause this. Be as specific as you can, and identify how you would confirm each type of failure using a multimeter.

file 01185

Question 33

An important consideration when working around circuits containing MOSFETs is *electrostatic discharge*, or *ESD*. Describe what this phenomenon is, and why it is an important consideration for MOSFET circuits.

file 01067

Question 34

Anti-static wrist straps are commonly worn by technicians when performing work on circuits containing MOSFETs. Explain how these straps are used, and how you would test one to ensure it is functioning properly.

file 01068

Answers

Answer 1

Your co-worker's strategy is based on the principle of dividing the gas pipeline into halves, and checking for pressure at the half-way point. This troubleshooting strategy is sometimes referred to as the "divide-and-conquer" method, because it divides the system into small sections to optimize troubleshooting time and effort.

Answer 2

Scenario #1, outcome #1: problem is *not* in the microphone.

Scenario #2, outcome #2: microphone #2 is faulty.

Scenario #2, outcome #1: problem is *not* in the microphone.

Scenario #2, outcome #2: microphone #2 is faulty.

Scenario #3, outcome #1: mixer input #2 is faulty.

Scenario #3, outcome #2: the problem is *not* in the mixer.

Scenario #4, outcome #1: the problem is *not* in the cable.

Scenario #4, outcome #2: cable #2 is faulty.

Answer 3

If the voltage changes to zero, I show 0 in the table. If the increase or decrease is relatively small, I use thin arrows ($\uparrow$ or $\downarrow$). If the change is great, I use thick arrows ($\Uparrow$ or $\Downarrow$).

Fault	V_{TP1}	V_{TP2}	V_{TP3}	V_{TP4}	V_{TP5}	V_{TP6}
R1 failed open	Same	0	0	$\Uparrow$	$\Uparrow$	Same
R2 failed open	Same	$\uparrow$	$\uparrow$	$\Downarrow$	$\Downarrow$	Same
R3 failed open	Same	$\downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	Same
R4 failed open	Same	Same	$\uparrow$	$\Uparrow$	$\Uparrow$	Same
R5 failed open	Same	$\approx$ Same	$\approx$ Same	$\uparrow$	$\uparrow$	Same
Short between TP2 and ground	Same	0	0	$\Uparrow$	$\Uparrow$	Same
C2 failed shorted	Same	$\downarrow$	0	$\Downarrow$	$\Downarrow$	Same
Q1 collector failed open	Same	$\downarrow$	$\Downarrow$	$\Uparrow$	$\Uparrow$	Same

Follow-up question: why don't test point voltages V_{TP1} or V_{TP6} ever change?

Answer 4

Remember that each of these answers merely represents the *most likely* of the two failure modes, either open or shorted, and that probabilities may shift with operating conditions (i.e. switches may be more prone to failing shorted due to welded contacts if they are routinely abused with excessive current upon closure).

- Resistors: **open**
- Capacitors: **shorted**
- Inductors: **open or short equally probable**
- Transformers: **open or short equally probable**
- Bipolar transistors: **shorted**

Follow-up question: When bipolar transistors fail shorted, the short is usually apparent between the collector and emitter terminals (although sometimes all three terminals may register shorted, as though the transistor were nothing more than a junction between three wires). Why do you suppose this is? What is it about the base terminal that makes it less likely to "fuse" with the other terminals?

Answer 5

The clicking noise has something to do with one of the wheels, and not the chain or crank.

Answer 6

The fact that you can *smell* trouble indicates you are most likely dealing with a catastrophic failure caused by (or resulting in) excessive current. When components have been heated to such a degree that they emit strong odors, the damage is often visible as well, which makes it easier to locate problem areas.

Follow-up question: upon further investigation, you locate the charred remains of an electronic component, located on one of the system's circuit boards. Is this the only fault, being that it is the only component visibly damaged? Explain why or why not.

Answer 7

I'll let you determine the answers to this question! I do not expect that you will provide specific, technical answers, because I have given very little information about the malfunctioning systems. What I want is for you to think in general terms: how might the scope of possible problems differ between *any* two similar systems, one of which is proven while the other is untried?

Answer 8

If the circuit in question is untried, literally *anything* could be wrong with it.

Answer 9

Gross manufacturing defects, incorrect installation, and design flaws, to name a few.

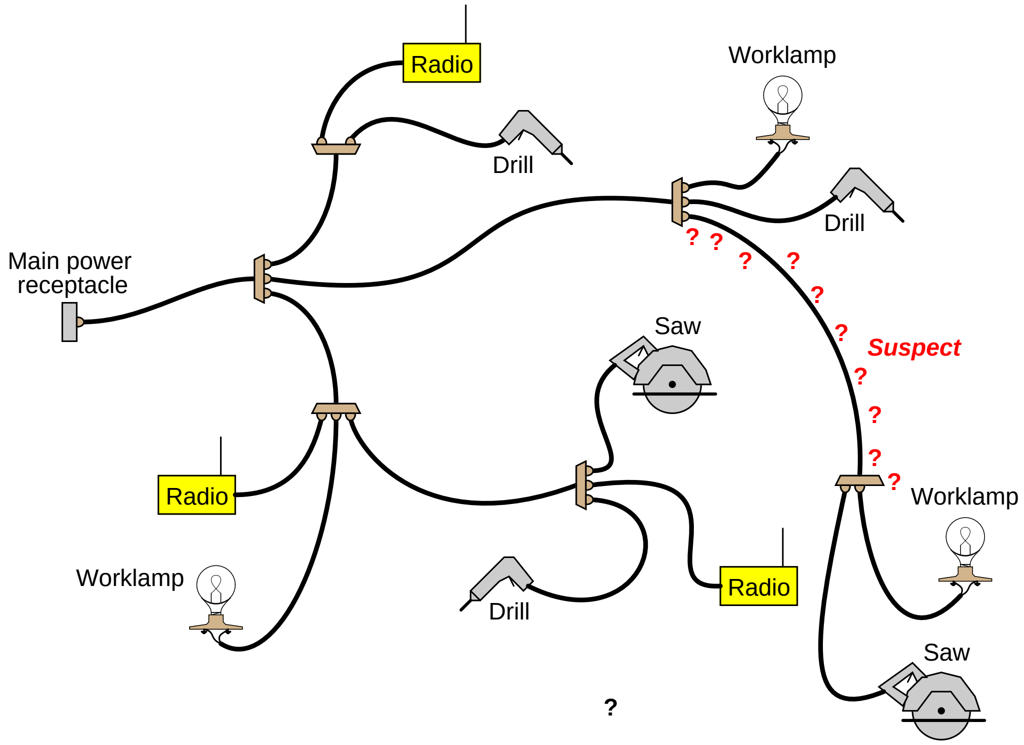
Follow-up question: is it important to know which phase of the life-cycle a system is in before you begin to troubleshoot a problem in it? Explain your answer.

Answer 10

This is an excellent question for discussion amongst your classmates! Two things I recommend, though:

- Identify some probable sources of trouble in this garden hose "system."
- Proceed in a logical manner to find the trouble as efficiently as possible.

Answer 11



Follow-up question: describe the general principle you used to locate the suspect area of this power network.

Answer 12

The fault is located somewhere between TB3 and TB4. Whether or not the electrician's sequence was the most efficient depends on two factors not given in the problem:

- The distance between terminal blocks.
- The time required to gain access for a voltage check, upon reaching the terminal block location.

Follow-up question: describe a scenario where the given sequence of voltage readings would be the most efficient. Describe another scenario where a different sequence of voltage readings could have saved time in locating the problem.

Answer 13

My personal preference would be to unplug the output cables from the equalizer/preamp unit and test for signal output there. I'll leave the other steps up to you, to elaborate on in class discussion with your peers!

Answer 14

The fuse is blown open.

Follow-up question: with regard to the troubleshooting technique, this technician seems to have started from one end of the circuit and moved incrementally toward the other, checking voltage at almost every point in between. Can you think of a more efficient strategy than to start at one end and work slowly toward the other?

Answer 15

The transformer has an open winding.

Follow-up question #1: with regard to the troubleshooting technique, this technician seems to have started from one end of the circuit and moved incrementally toward the other, checking voltage at almost every point in between. Can you think of a more efficient strategy than to start at one end and work slowly toward the other?

Challenge question: based on the voltage measurements taken, which do you think is the more likely failure, an open primary winding or an open secondary winding?

Follow-up question #2: how could you test the two windings of the transformer for a possible open fault? In other words, is there another type of measurement that could verify our hypothesis of a failed winding?

Answer 16

There is an "open" fault between TP4 and TP6.

Follow-up question: with regard to the troubleshooting technique, this technician seems to have started from one end of the circuit and moved incrementally toward the other, checking voltage at almost every point in between. Can you think of a more efficient strategy than to start at one end and work slowly toward the other?

Answer 17

The technician wrongly assumed that an open (upper) resistor was the only possible fault that could have caused the observed voltage readings.

Answer 18

Components known to be okay include the left speaker, left speaker cable, and power cord for the amplifier. There are, of course, more known "good" components in this system that the three mentioned here, especially if you count discrete electronic components inside the amplifier itself.

Possible faults include the right speaker, the right speaker cable, and the right output channel of the amplifier. A very good way to determine which of these components is faulted is to swap cables and speakers between sides, but I'll let you determine which component swaps test which components.

Answer 19

The likely location of the fault is in welder #1. I'll let you determine what the nature of this fault most likely is, and why the strategy employed in this scenario probably wasn't the wisest.

Answer 20

Read the part numbers off the power transistors for the right channel output!

Answer 21

It is usually a good idea to verify the exact nature of the malfunction before proceeding with troubleshooting strategies, even if someone has already informed you of the problem. Seeing the malfunction with your own eyes may illuminate the problem better than if you simply acted on someone else's description, or worse yet your own assumptions.

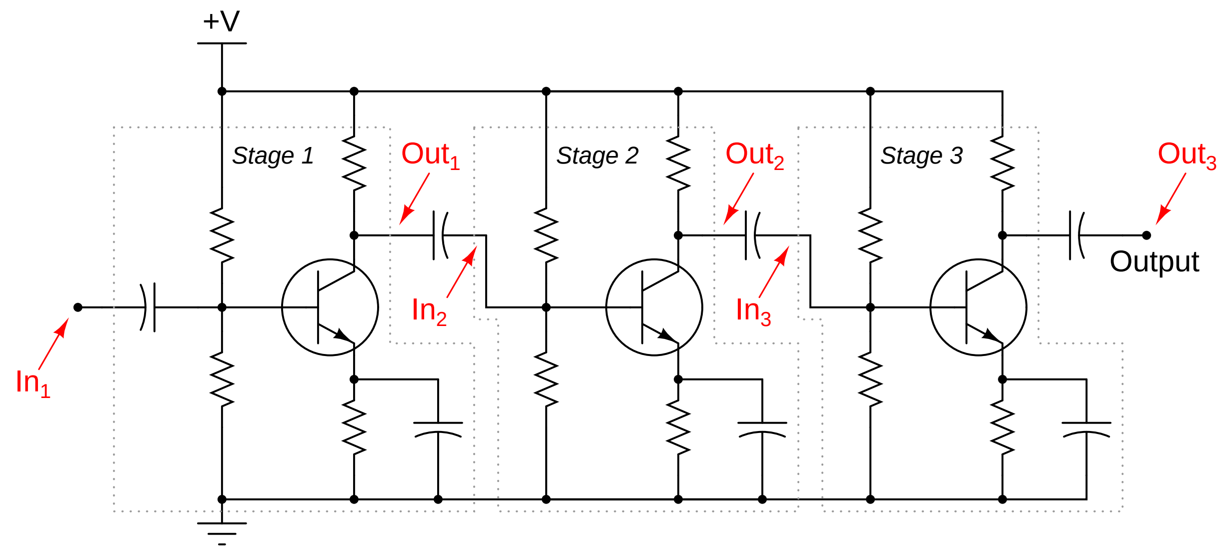
The rationale for checking the input signal should be easy to understand. I'll let you answer this one!

"Good-quality" power consists of DC within the proper voltage range of the amplifier circuit, with negligible ripple voltage.

Follow-up question #1: suppose you discover that the "faulty" amplifier is in fact *not* receiving any input signal at all? Does this test exonerate the amplifier itself? How would might you simulate a proper input signal for the amplifier, for the purposes of testing it?

Follow-up question #2: explain how to measure power supply ripple voltage, using only a digital multimeter. How would you measure ripple using an oscilloscope?

Answer 22



Challenge question: how well do you suppose this same troubleshooting strategy would work to locate the fault *within* a particular amplification stage?

Answer 23

Steps in the scientific method are indicated by superscript numbers at the end of sentences in the original narrative:

> One day a car owner approached a mechanic friend of theirs with a problem. The battery in this car seemed to be dying, requiring frequent jump-starts from other vehicles, or the application of a battery charger overnight, to be able to start reliably.[1] "What could be the problem?" asked the car owner to the mechanic.
>
> The mechanic considered some of the probable causes. One possibility was that a parasitic load was draining the battery of its charge when the car was shut off.[2] Another possibility was that the car's charging system (the engine-drive generator and its associated circuitry) was faulty and not charging the battery when the engine was running.[2] A third possibility was that the battery itself was defective, and unable to hold a charge.[2]
>
> "Let's check the battery voltage with the engine stopped, and with the engine running," said the mechanic.[(3)] The two walked over to the car and opened the hood, then the mechanic connected a voltmeter to the battery's terminals. It read 11.3 volts DC. This was a 12-volt (nominal) battery.
>
> "Start the car," said the mechanic, still watching the voltmeter. As the electric starting motor labored to turn the engine, the voltmeter's reading sagged to 9 volts. Once the engine started and the electric starter disengaged, the voltmeter rebounded to 11.2 volts.[4]
>
> "That's the problem!" shouted the mechanic.[(5)] With that, the owner stopped the car's engine.

Steps 3 and 5 are labeled parenthetically because the story does not tell what the mechanic was thinking. It doesn't indicate, for example, what the mechanic's prediction was when deciding to do a voltage check of the battery with the engine stopped and with the engine running. I've left these steps for *you* to elaborate.

Answer 24

The battery, and its connections to the rest of the circuit, are in good condition. Also, we know that the motor is not failed open. In all likelihood, the transistor is not being "told" to turn on.

Answer 25

- The 0.47 μF capacitor connected to the microphone: *passes (AC) audio signal, blocks DC bias voltage from reaching microphone*
- The 220 kΩ and 27 kΩ resistor pair: *sets DC bias voltage for first transistor stage*
- The 4.7μF electrolytic capacitor connected across the 1.5 kΩ resistor: *bypasses (AC) audio signal around emitter resistor, for maximum AC voltage gain*
- The 33 μF electrolytic capacitor connected to the speaker: *couples (AC) audio signal to speaker while blocking DC bias voltage from speaker*
- The 47 μF electrolytic capacitor connected to the power supply rail: *"decouples" any AC signal from the power supply, by providing a low-impedance (short) path to ground*

The question regarding the necessity of the 47 μF decoupling capacitor is tricky to answer, so I'll elaborate a bit here. Power supply decoupling is a good design practice, because it can ward off a wide range of problems. AC "ripple" voltage should never be present on the power supply "rail" conductors, as transistor circuits function best with pure DC power. The purpose of a decoupling capacitor is to subdue any ripple, whatever its source, by acting as a low-impedance "short" to ground for AC while not presenting any loading to the DC power.

Although it may not seem possible at first inspection, the lack of a decoupling capacitor in this audio amplifier circuit can actually lead to self-oscillation (where the amplifier becomes a tone generator) under certain power supply and load conditions! If the power supply is poorly regulated and/or poorly filtered, the presence of a decoupling capacitor will greatly diminish line-frequency "hum" noise heard in the speaker.

For the rest of the questions, I'll let you figure out answers on your own!

Answer 26

$V_A = 0$ volts (precisely)
$V_B \approx 0.98$ volts
$V_C \approx 0.28$ volts
$V_D \approx 7.1$ volts
$V_E \approx 6.4$ volts
$V_F = 0$ volts (precisely)
$V_G = 9$ volts (precisely)

Follow-up question: explain why voltages V_A, V_F, and V_G can be precisely known, while all the other DC voltages in this circuit are approximate. Why is this helpful to know when troubleshooting a faulted amplifier circuit?

Answer 27

This amplifier most likely suffers from improper biasing, which may be remedied by changing the value of R_1 or R_2. (I'll let you determine which way the chosen resistor value must be altered, increase or decrease!)

Answer 28

This amplifier suffers from excessive gain, which may be remedied by changing the value of R_C or R_E. (I'll let you determine which way the chosen resistor value must be altered, increase or decrease!)

Of course, changing either of these resistor values will alter the bias ("Q") point of the amplifier, which may necessitate subsequent changes in the value of either R_1 or R_2!

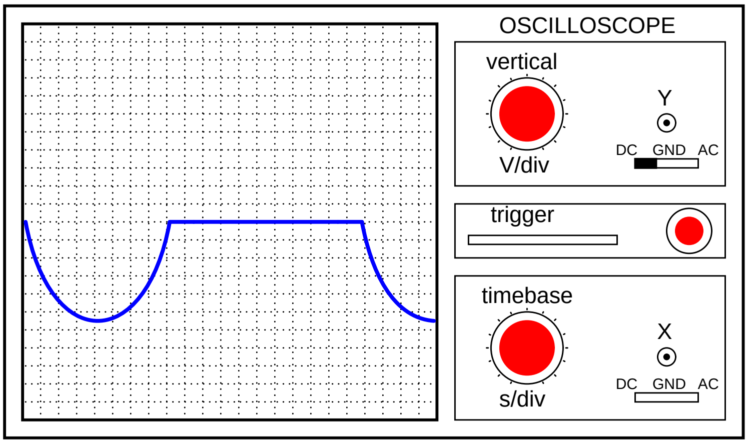
Answer 29

I'll give you a hint: this type of distortion is called *crossover distortion*, and it is the most prevalent type of distortion in Class B amplifier designs.

Challenge question: since this type of transistor amplifier is often referred to as a "push-pull" design, describe the cause of this distortion in terms of the transistors "pushing" and "pulling".

Answer 30

The positive half of the waveform would be "missing":



Answer 31

First, realize that we cannot know which half of the push-pull circuit is failed, due to the isolation of the transformer and the resulting uncertainty of polarity. *Please note that the lists shown here are not exhaustive.*

Possible faults in the system:

- Fault #1: Transistor Q_2 or Q_3 failed open
- Fault #2: Resistor R_5 or R_8 failed open
- Fault #3: Half of transformer primary winding failed open

Components known to be okay in the system:

- Component #1: Secondary winding of transformer
- Component #2: Resistor R_4
- Component #3: Input coupling capacitor C_3

Follow-up question #1: suppose that after testing this amplifier on your workbench with a "dummy" load (8 Ω resistor connected to the speaker terminals), you happened to notice that transistor Q_2 was slightly warm to the touch, while transistor Q_3 was still at room temperature. What would this extra information indicate about the amplifier's problem?

Follow-up question #2: describe the potential safety hazards involved with touching a power transistor in an operating circuit. If you wished to compare the operating temperature of these two transistors, how could you safely do it?

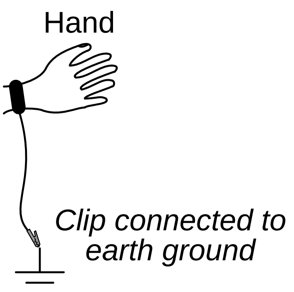
Answer 32

Given the existence of multiple answers for this question, I will defer the answer(s) to your instructor, to review during class discussion.

Answer 33

"Electrostatic discharge" is the application of very high voltages to circuit components as a result of contact or proximity with an electrically charged body, such as a human being. The high voltages exhibited by static electricity are very damaging to MOSFETs. I'll let you research why!

Answer 34



A simple ohmmeter test should reveal mega-ohm levels of resistance between the strap's skin contact point and the metal grounding clip.

Follow-up question: why is there resistance intentionally placed between the wrist strap and the grounding clip? What would be wrong with simply having a 0 Ω connection between the strap and earth ground (i.e. an uninterrupted length of wire)?

Notes

Notes 1

This problem gives students a chance to explore the "divide and conquer" strategy of troubleshooting in a context that is very simple and does not require knowledge of electricity.

Notes 2

Your more adept students will immediately recognize that scenarios 1 and 2 are really quite the same. The logical thinking behind this troubleshooting strategy may confound some of your students, so be prepared to spend adequate time covering and re-covering (if necessary) this question. By the way, this type of question is excellent for a written test!

Notes 3

I was able to verify specific voltages by building this circuit and faulting each component as described. Although I was not always able to predict the magnitude of the change, I could always predict the direction. This is really all that should be expected of beginning students.

The really important aspect of this question is for students to understand *why* the test point voltages change as they do. Discuss each fault with your students, and how one can predict the effects just by looking at the circuit.

Notes 4

Emphasize to your students how a good understanding of common failure modes is important to efficient troubleshooting technique. Knowing which way a particular component is more likely to fail under normal operating conditions enables the troubleshooter to make better judgments when assessing the most probable cause of a system failure.

Of course, proper troubleshooting technique should always reveal the source of trouble, whether or not the troubleshooter has any experience with the failure modes of particular devices. However, possessing a detailed knowledge of failure probabilities allows one to check the most likely sources of trouble first, which generally leads to faster repairs.

An organization known as the *Reliability Analysis Center*, or *RAC*, publishes detailed analyses of failure modes for a wide variety of components, electronic as well as non-electronic. They may be contacted at 201 Mill Street, Rome, New York, 13440-6916. Data for this question was gleaned from the RAC's publication, *Part Failure Mode Distributions*.

Notes 5

Discuss with your students the relationship between the mechanic's steps and the steps given for scientific method. Have them locate the observation, hypothesis, prediction, and test.

Once students have successfully identified the mechanic's reasoning, ask them to explain how the prediction of noise rhythm distinguishes which part of the bicycle is making the noise.

Also, discuss whether this concludes the diagnostic procedures, or if there is more troubleshooting left to do. What steps are recommended to take next, if any?

Notes 6

It is important for students to understand that not all faults become visible, even if catastrophic!

Be sure to discuss with your students that the burnt component may very well be a *victim* of another component failure, and not the *cause* of the system fault. For instance, shorted wiring located far from the equipment enclosure may have caused the components to destruct. This is a common assumption made by beginning troubleshooters: that the most obvious failure is the only failure, or that it must be the primary failure.

Notes 7

As an illustration of this principle, you might want to elaborate on your own experiences as an electronics instructor. When assisting students with lab projects, what typical problems do you encounter with the circuits they build, and how do these problems typically differ from problems you've seen in real-life electronic equipment?

Notes 8

Although sound troubleshooting technique will ultimately yield a solution, asking "pre-diagnostic" questions such as this will greatly enhance your efficiency as a troubleshooter. Discuss this with your students, enlightening them if possible with anecdotes from your own troubleshooting experiences.

Notes 9

The follow-up question is especially important to discuss with your students. Knowing what portion of the life-cycle a system is in can make a huge difference in your troubleshooting effectiveness. Ask your students why this is. If possible, enlighten the discussion with examples from your own professional experience.

Notes 10

Discuss with your students both probable causes of this problem as well as strategies for locating the problem. Encourage students to analyze the system by dividing it into sections. Since garden hoses easily detach from spigots and nozzles alike, they lend themselves well to the so-called "divide-and-conquer" method of troubleshooting.

Notes 11

Now, of course, it is possible that both the worklight and the saw suffered independent, simultaneous failures, and all the extension cords are good, but this is not very likely. Be sure to discuss this possibility with your students, and the reasoning why the one extension cord would be more likely to be faulted than two separate devices.

Notes 12

One of the most common troubleshooting techniques taught to technicians is the so-called "divide and conquer" method, whereby the system or signal path is divided into halves with each measurement, until the location of the fault is pinpointed. However, there are some situations where it might actually save time to perform measurements in a linear progression (from one end to the other, until the power or signal is lost). Efficient troubleshooters never limit themselves to a rigid methodology if other methods are more efficient.

Notes 13

Discuss with your students how this is an ideal application for the "divide-and-conquer" strategy of troubleshooting, where you divide the signal path into halves, checking for the presence of a signal at each half-way point, narrowing in on the location of the faulted component in a rapid manner.

Notes 14

Troubleshooting scenarios are always good for stimulating class discussion. Be sure to spend plenty of time in class with your students developing efficient and logical diagnostic procedures, as this will assist them greatly in their careers.

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Students may be puzzled by the presence of DC voltage between TP7 and TP8, and also between TP9 and TP10 (1.1 volts), given that there is less than that amount of AC voltage at the rectifier's input. However, this is a common phenomenon with electrolytic capacitors, to "recover" a small voltage after having been discharged.

Notes 16

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Notes 17

This is a common mistake students make when applying the "divide-and-conquer" method of troubleshooting: that whatever component(s) located between the point of good measurement and the point of bad measurement must be the source of the problem. While this simple reasoning may apply in finding "open" faults in long lengths of wire, it does not necessarily hold true for more complex circuits, as other faults may result in similar effects.

Notes 18

Swapping components can be a very powerful means of troubleshooting system problems where interchangeable components exist.

Notes 19

This situation is very realistic, and underscores the need for careful thinking on the part of the troubleshooter when deciding what specific troubleshooting strategy to apply. Despite the undeniable power of the "swap interchangeable components" strategy, it is not fool-proof.

Notes 20

Some students may question this logic, believing that the left and right channels of a stereo amplifier would be mirror-symmetric rather than identical, and thus possibly contain different components. You may answer this objection by appealing to the indistinguishable sound of the two channels, when listened to separately (mono). There is nothing "right-handed" or "left-handed" about the two channels. Each one is identical to the other at the circuit level, because each channel is expected to perform exactly the same.

Notes 21

In my own experience I have found these steps to be valuable time-savers prior to beginning any formal troubleshooting process. In general terms, *check for output*, *check for input*, and *check for power*.

New technicians are often surprised at how often complex problems may be caused by something as simple as "dirty" power. Since it only takes a few moments to check, and can lead to a wide range of problems, it is not wasted effort.

Notes 22

Multi-stage amplifier circuits lend themselves well to the "divide and conquer" strategy of troubleshooting, especially when the stages are as symmetrical as these.

Notes 23

Once students have successfully identified the mechanic's reasoning, ask them to explain how the prediction of battery voltage *uniquely* relates to only one of the three hypotheses stated.

Also, discuss whether this concludes the diagnostic procedures, or if there is more troubleshooting left to do. What steps are recommended to take next, if any?

Notes 24

It is just as important for your students to be able to identify what is *not* faulted in a system as it is for them to be able to identify what is faulted. Replacing components that are not faulted is expensive and wasteful!

An essential part of answering this question is what the photocell does when light strikes it. Obviously, it undergoes a change in electrical resistance, but which way? This is something your students will have to determine before they can successfully troubleshoot the system. If they do not understand what the system is *supposed* to do, they will be helpless in interpreting what it is presently doing.

Notes 25

Incidentally, this circuit makes a good "intercom" amplifier for a student project. Using a small dynamic speaker for the microphone, and another speaker (or audio headset) on the receiving end of a long cable connected to the amplifier output, students can easily talk between two rooms in a building, or even between buildings.

Notes 26

The calculations used to estimate these values are quite simple, and should prove no trouble for students to derive who have a basic knowledge of DC circuit calculations (voltage dividers, series voltage drops, etc.).

Notes 27

Discuss with your students how to determine whether the bias voltage is too great or too small, based on the observed output waveform. It isn't difficult to do so long as students understand *why* biasing exists and how it works.

Notes 28

Discuss with your students how to determine the necessary changes in resistor values, based on the determination that the gain is excessive. This is actually very easy to do just by examining the gain formula for a common-emitter amplifier.

Another option to consider here is the addition of a negative feedback signal path to tame the amplifier's gain. This modification would have the added benefit of improving circuit linearity.

Notes 29

Crossover distortion is fairly easy to understand, but more difficult to fix than the one-sided "clipping" distortion students are used to seeing in Class A amplifier designs. If you think it might help your students understand better, ask them how a push-pull amplifier circuit would respond to a *slowly changing* DC input voltage: one that started negative, went to zero volts, then increased in the positive direction. Carefully monitor the transistors' status as this input signal slowly changes from negative to positive, and the reason for this form of distortion should be evident to all.

Notes 30

Ask your students to identify which transistor "sources" current to the load, and which transistor "sinks" current from the load, and the answer should be easy to understand.

Notes 31

The symmetry inherent in push-pull amplifiers makes troubleshooting easier in some respects. As always, though, component-level troubleshooting requires a detailed understanding of component function within the context of the specific circuit being diagnosed. No matter how "simple" the circuit may be, a student will be helpless to troubleshoot it down to the component level unless they understand how and why each component functions.

Giving the clue regarding transistor temperature is important for two reasons. First, it provides more data for students to use in confirming fault possibilities. Second, it underscores the importance of non-electrical data. Efficient troubleshooters make (safe) use of all available data when investigating a problem, and that often requires creative thinking.

Notes 32

Always be sure to spend plenty of time discussing troubleshooting scenarios with your students, because diagnostic skills are the highest level (and the most valuable) to develop.

Some of your students may be unfamiliar with the symbols used for the input and output jacks. Elaborate on this symbolism, if necessary.

Ask your students to identify the configuration (common-source, common-drain, or common-gate) of each JFET in this circuit, and how these respective configurations relate to the voltage gain (A_V) of each amplification stage.

Notes 33

Be sure to ask students to explain the mechanism of transistor damage resulting from ESD, and to discuss the sheer magnitude of static voltages typically generated in dry-air conditions. If you have any microphotographs of IC damage from ESD, present a few of them during discussion time for your students' viewing pleasure.

Notes 34

A good question to ask your students is *why* anti-static protection is important when working with MOSFET devices. You should never assume this is obvious, unless the subject was covered in a question immediately previous to this one!

Your students should have an anti-static wrist strap as part of their regular tool collection. When discussing this question, it would be good to have students use their ohmmeters to verify the operation of their wrist straps.