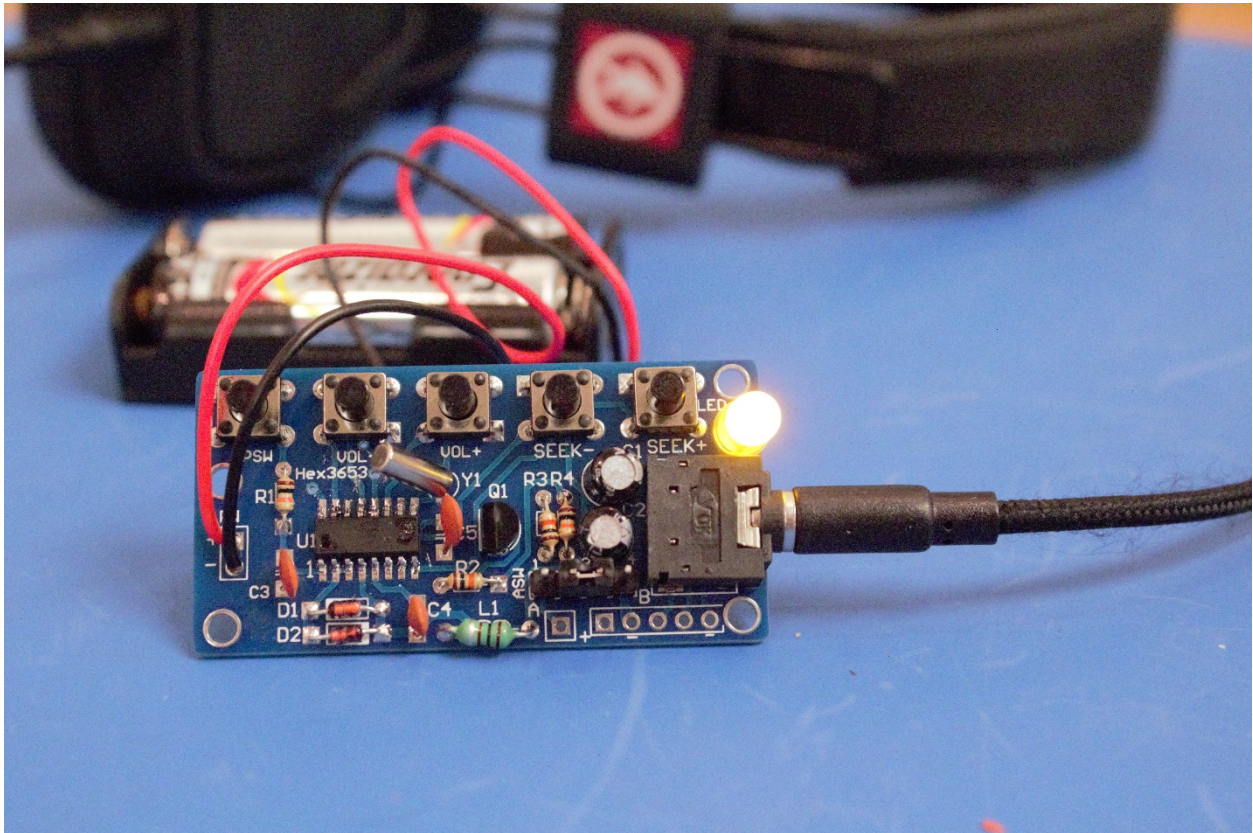


SOLDERING WORKSHOP AND CERTIFICATION



Building an FM Radio Receiver

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INTRODUCTION

Soldering is a critical skill for electronics and circuitry projects. To master the art of soldering, the best method is practice, practice, practice! The most fun way to practice is to build a project that requires a lot of soldering, killing two birds with one stone – learning soldering, and building a cool project.

In this project, you will use bare components to construct an FM radio receiver that you can use to listen to FM radio with headphones or a small speaker with an auxiliary input.

PROJECT GOALS

- Understand how to use soldering equipment safely
- Learn through-hole soldering on a printed circuit board (PCB)
- Learn surface mount soldering with a small chip
- Learn about basic circuit components
- Gain greater insight into how radios work
- Assemble a working FM Radio

MATERIALS NEEDED

- HEX 3653 FM Radio Kit
- 2 AA batteries
- Soldering materials
 - Soldering iron
 - Screwdriver/Chisel and standard soldering tips
 - Solder sucker
 - Solder wick
 - Flux (syringe works best)
 - Wet sponge and brass wool
 - Tweezers
 - Wire snips and wire strippers
 - Helping hands (optional)
- Safety glasses

RECOMMENDED SKILLS

- Recommended for ages 12+ independently, younger with adult help and supervision
- Steady hand and maturity to safely handle a soldering iron
- Basic understanding of electricity/circuits

This guide is divided into several sections which are ordered to deliver the knowledge needed to assemble the radio, assembly, and then a step-by-step explanation how the radio works. First, we will discuss the concept of a circuit diagram, a road map of the circuitry of the entire project. Circuit diagrams show all the wiring and components of an electronic device. Next, we will cover all the components used in the project including photos of the actual kit components and their circuit diagram symbols so that you can locate each component in the circuit diagram and its location on the printed circuit board (PCB). To attach all the components in assembly, we will cover three different soldering techniques and introduce the tools used in soldering. Once we learn what the components are, how to find their location on the diagram and PCB, and how to attach the components using various soldering techniques we will walk through the assembly of the HEX 3653 FM Radio kit step-by-step with photos. There is an additional section following assembly that covers radio operation and troubleshooting. Finally, now that the radio is assembled, and we understand how to operate it, we will learn about radio waves, how a radio turns these waves into sound, and how the individual components work together to accomplish this. Upon completion of this project, you will have a working FM radio, have learned about circuit diagrams and electronic components, learned three different soldering techniques, and will understand how a radio works.

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Authored by Katrina Siegfried 2018

CIRCUIT DIAGRAMS

Circuit diagrams are used by engineers to graphically convey information about electronic circuits in a standard way so that any other engineer can read it. Simple circuits can be conveyed easily with words, such as “The LED is connected to the resistor then to the battery”. Another way to represent this circuit is with a drawing called a circuit diagram, see the figure below.

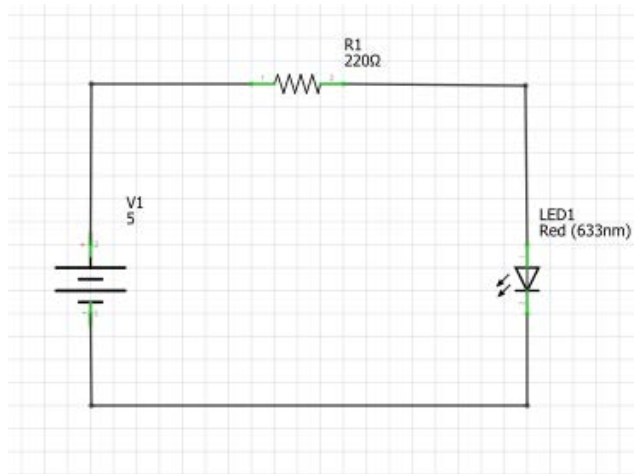


Figure 1: Circuit diagram of a simple LED circuit, generated by Katrina Siegfried using Fritzing software.

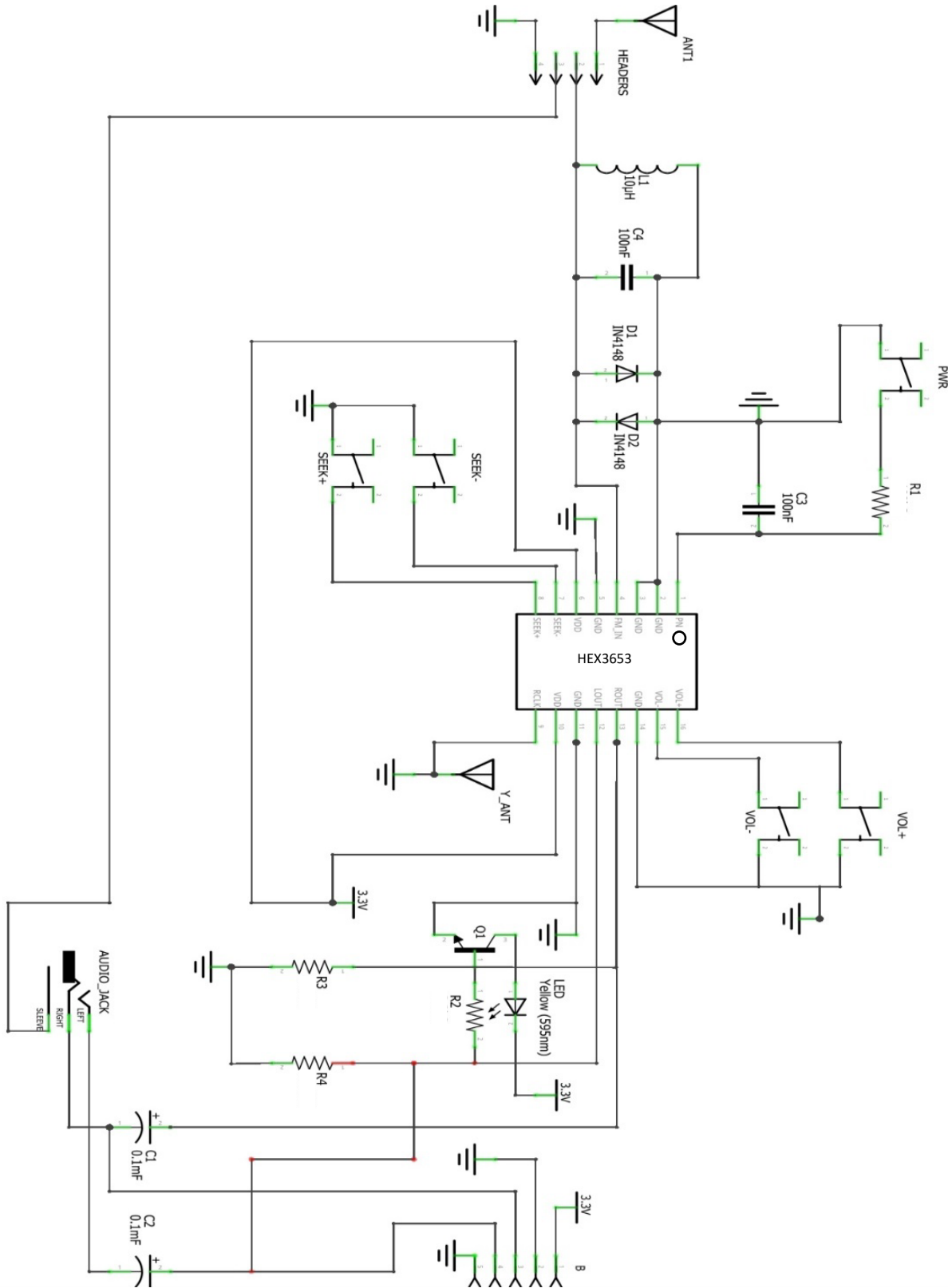
Being able to represent our circuits with a picture becomes increasingly important as the circuits get more complex, such as our radio. A diagram of our radio circuit is on the following page. As we introduce each component in the next section, you can refer to the diagram to see what role it plays in the circuit. We will not discuss the circuit in depth here. To delve further into the basics of circuitry, I recommend continuing to the FM Receiver workshop after this one. To read about how these components work together to function as a radio, refer to page 40 of this guide.

Components will be introduced in the order they will appear in assembly except for the radio chip, which is discussed last. Depending on the workshop or class layout, the chip may come pre-soldered (pre-assembled on the PCB).

The next page shows the entire circuit diagram for the radio. As each component is discussed, note its location on the printed circuit board (PCB) and see if you can find its symbol on the circuit diagram. The Fritzing sketch of the circuit diagram is based on the previous work by Dr. Lui Grough.

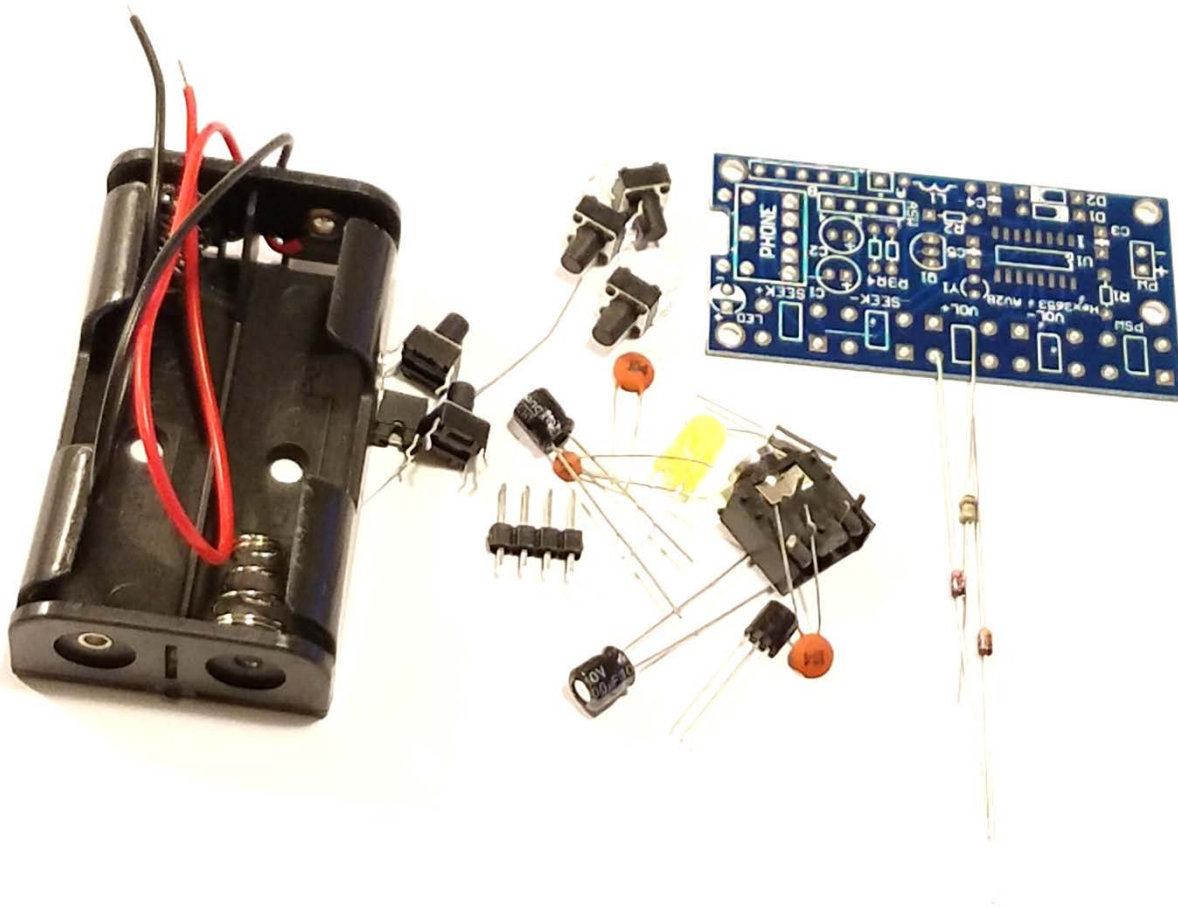
Figure 2: A circuit diagram of the FM Radio kit, generated by the Katrina Siegfried using Fritzing software, based on the work by Dr. Lui Grough.

fritzing



COMPONENTS

Before we begin assembling the radio, we will briefly discuss all the components in the kit, their symbols in circuit diagrams, and why we use them in electronics. The components are all the small electronics pieces that we will attach to the printed circuit board (PCB), which is the blue computer board in the kit. The PCB already has the circuit drawn out in copper sandwiched inside the outer layers which is much smaller and more stable than using wires to connect all the individual components.



RESISTORS

If you think of electrical current as water flowing in a channel, resistors would be gates that limit the flow of the water. Resistors limit the flow of current in an electrical system. They are often very small and made of carbon or ceramic. Resistance is measured in a unit of Ohms, represented by the symbol Ω (Omega) and is equivalent to Volts per Amp. The resistance value of a resistor is often indicated by the color code show below; our kit uses four 10k Ω resistors. Resistors are represented by the letter "R" in circuit diagrams with the symbol as indicated below.

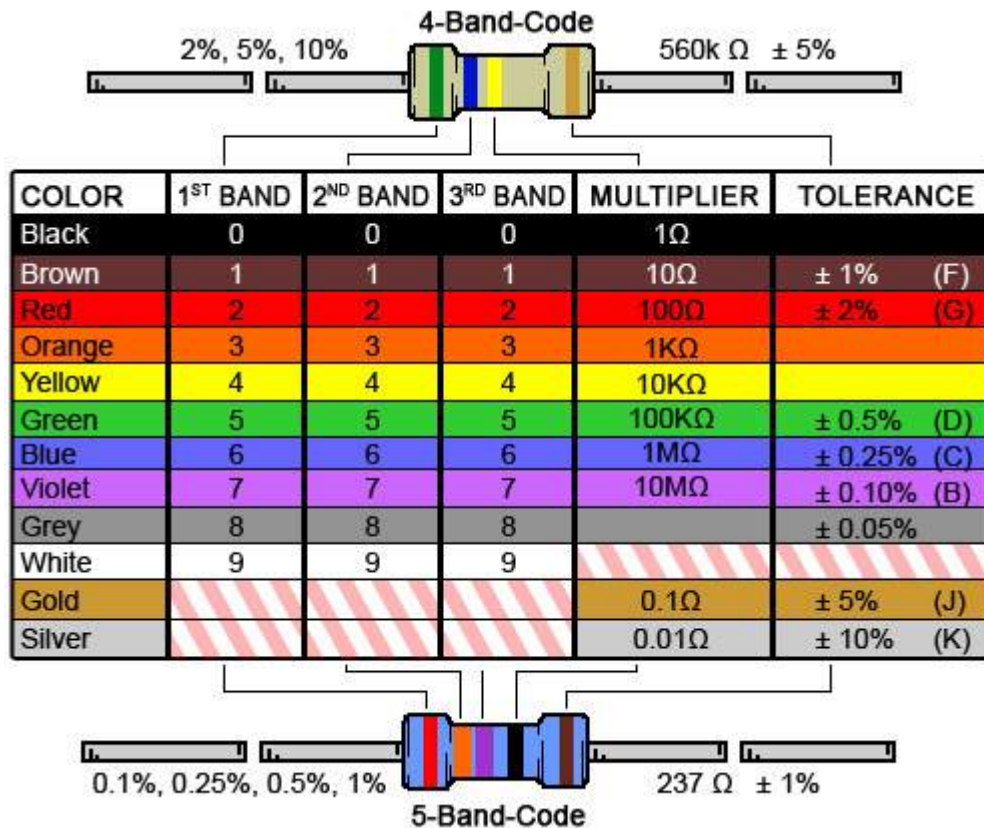
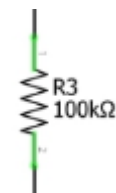
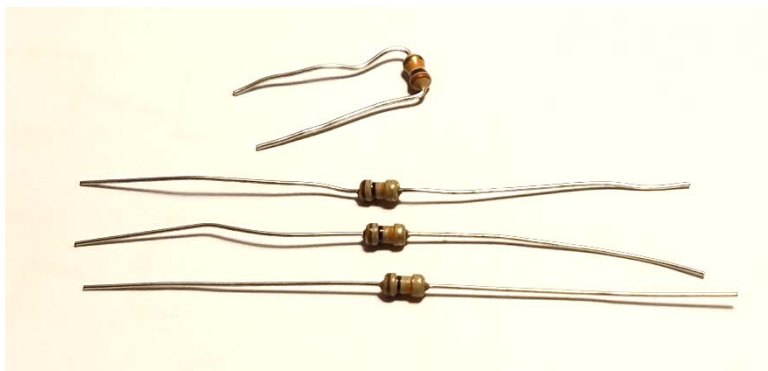
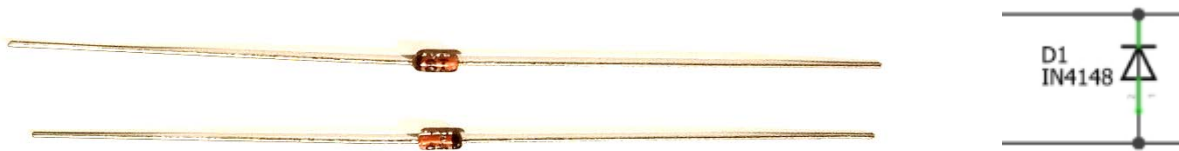


Figure 3: Resistor color-code chart. Image courtesy of <https://www.digikey.com/-/media/Images/Marketing/Resources/Calculators/resistor-color-chart.jpg?la=en-US&ts=72364a89-2139-476a-8a54-8d78dacd29ff>



DIODES

Diodes only permit the flow of current in one direction. Picking up from the water analogy used in resistors, diodes would be like a one-way valve or gate, letting water flow through in only in one direction. Due to their nature, it does matter which way these components are oriented in the circuit. Current will only flow through when positive voltage is applied to the anode (or negative terminal) and negative voltage to the cathode (positive terminal). Diodes are indicated using the letter “D” on circuit diagrams and are represented by the symbol below.



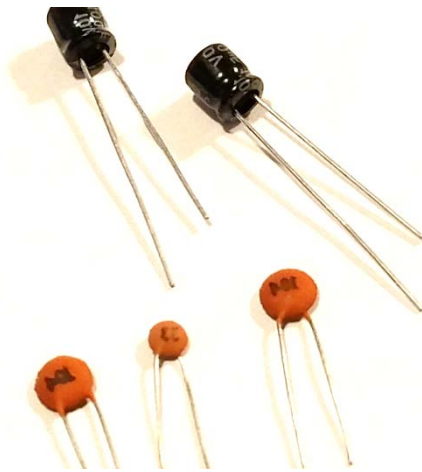
INDUCTORS

Inductors are a coil of wire wrapped around a ferric (iron) core that when placed in a magnetic field generates a current and induces a voltage. In the radio application the inductor's specific task is to transform the electromagnetic waves of the radio signal into an electrical current. We will discuss this more in depth when we talk about radio signal. Inductance is measured in units of henry, or H, which is equivalent to a Volt second per Amp. The letter used to represent inductors on a circuit diagram is “L” and the symbol is shown below.



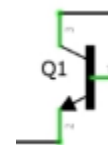
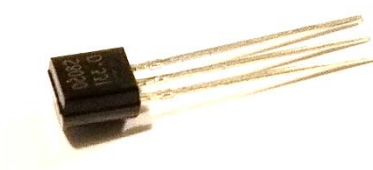
CAPACITORS

Capacitors can store electric charge temporarily for uses where a large amount of current is needed for a short burst. There are two main types of capacitors, and both are used in building the radio. The first is ceramic; in our radio they look like little Advil pills; these are not polarized, that is, their orientation does not matter. The second type are electrolytic, these are often blue or black cylinders with two different length terminals. The shorter terminal is the anode, or negative terminal, and the longer terminal is the cathode or positive terminal. Often their polarity is indicated with a +/- sign. Capacitance is measured in farads (F), or more commonly in small electronics projects, microfarads (μF), which are equal to an Amp second per volt. Capacitors are represented by the letter "C" on circuit diagrams and by the symbols below.



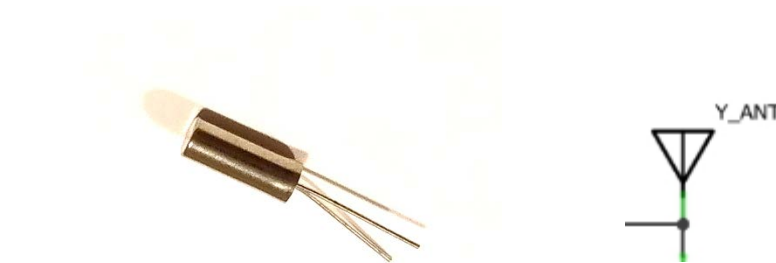
TRANSISTOR

A transistor is a simple switch that can either be used as a switch, as digital logic, or as an amplifier. Transistors have three pins, a collector, a base, and an emitter. They are categorized as either a N-type or P-type, where the N-type permits a large current to flow when a small current flows (amplifier), and the P-type acts more like a voltage-gated switch. The transistor used in this radio is a N-type or amplifier. Transistors often have a flat side and a rounded side to help determine their orientation. They are represented by the letter "Q" and the symbol shown below.



ANTENNA

In our application, building an FM radio receiver, the antenna's function is to intercept some of the energy in a radio wave and produce a tiny current. Antennas usually consist of an arrangement of metallic conductors. An antenna's function will be discussed more in depth later. Antennas are typically represented by the letter "Y" or the letters "ANT" on a circuit diagram, accompanied by the symbol below.



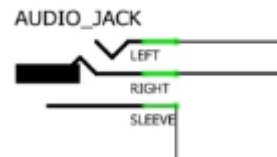
MOMENTARY PUSH BUTTON

There are many different types of buttons, but the ones we use in this radio are called momentary push buttons or momentary push switches. When the user presses down on the button, an electrical connection is made briefly during button press, which redirects the flow of current for a short period of time. Depending on the circuit, the button can have many different actions. In this radio, buttons are used for power (PWR), changing the radio station frequency (SEEK+ and SEEK-), and for the volume (VOL+ and VOL-). Buttons are typically represented on a circuit diagram with a few letters or short phrase indicating what the button's function is; the symbol is shown below.



AUXILLARY AUDIO JACK

The audio jack is the site for audio output from the radio for use with your headphones or small aux-input speaker. The auxiliary jack receives a voltage signal that is used to drive small speakers or with amplification to drive larger ones. This output signal is typically indicated by an open terminal with a label that describes what the output is, such as “AUDIO_JACK” as seen below.



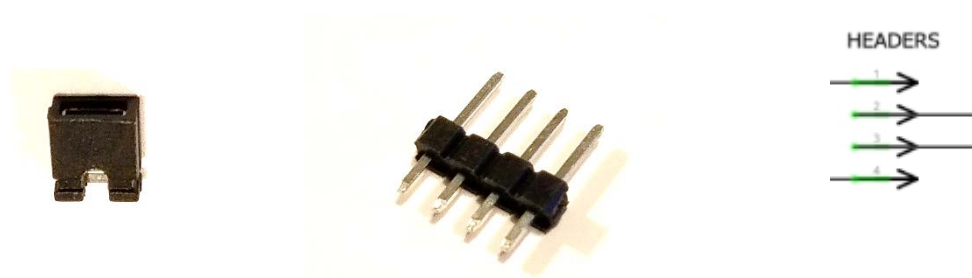
LED (LIGHT EMITTING DIODE)

An LED light bulb is simply a diode that also emits light. It functions in the same way as a regular diode, ensuring current only flows in one direction. An LED is indicated on a circuit diagram by the letters “LED” and the symbol shown below.



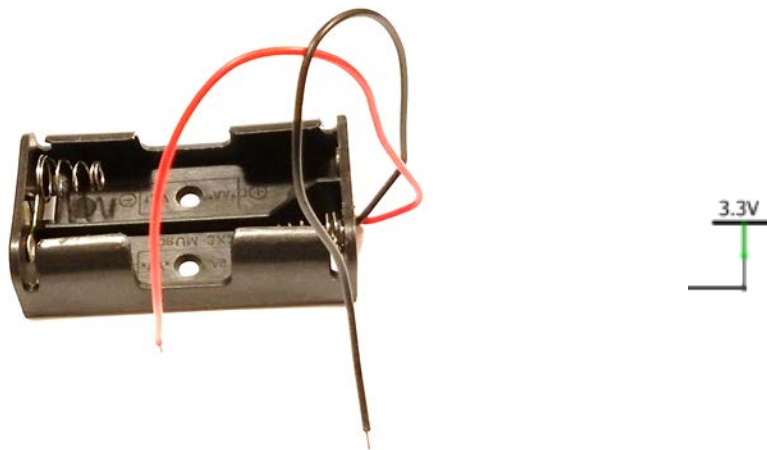
HEADER PINS AND JUMPER SLEEVE

Header pins are simply metal pins that are designed to attach to PCB's for easy and temporary connections to other devices or circuits without soldering. A jumper sleeve is a small sleeve that fits over two or more header pins to connect them in a circuit. Header pin locations are often indicated on a circuit diagram by an open terminal with labels for the individual pins, see the image below.



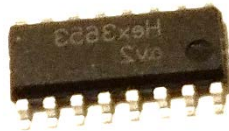
BATTERY POWER SUPPLY

This radio is powered by two AA batteries in series, for a total of 3V. In series simply means that the positive terminal of one battery is connected to the negative terminal of the next. The batteries are held in a battery holder that already has the wiring between individual batteries built in and connects to the PCB with two wires – a red positive voltage wire, and a black negative voltage wire. Battery power supplies are often indicated on circuit diagrams by the letters “PW” or “PWR” or sometimes just by their voltage rating, such as “3V”. The positive and negative terminals are almost always indicated with “+” and “-” signs. The symbol for a generic supply of power is shown below.



HEX 3653 RADIO CHIP

The small black chip included in the kit is a HEX 3653 single-chip broadcast FM radio tuner. This chip is the heart of the radio. It supports frequencies 76Mhz to 108MHz. Radio frequencies will be discussed in more detail later on. The chip has 16 different pins, each with a different function which is shown below. All the pins are different so the orientation of the chip DOES matter. In this instance, the orientation can be found from aligning the small round indentation on the chip to the matching mark on the PCB. On a circuit diagram or on a PCB, chips are often indicated with a rectangular box with the name of the chip and each pin a labeled with its appropriate function, see below.



SOLDERING

Soldering is the joining of two items by melting a material called solder which then bonds to each of the surfaces, creating a joint. The term soldering is used in plumbing and jewelry making as well as electronics, and though the techniques may be similar, the equipment and techniques discussed here will refer to electronics soldering only. Soldering is an essential skill for the electronics enthusiast and is one that, with a little practice, is easily mastered.



TOOLS

To properly learn the art of soldering, there are certain tools you need to have. Below, we will discuss each tool and its basic uses. The use of safety glasses is highly recommended. For those with longer hair it should be tied back, and any loose or dangling clothing should be secured.

SOLDERING IRON

A soldering iron is a specially designed tool that heats up a pointy metal tip to about 600°F and is used to warm up the components and melt the solder. Some soldering irons will have adjustable temperature, separate power supplies, and interchangeable tips. Hold the iron on the grip like you would a pencil.



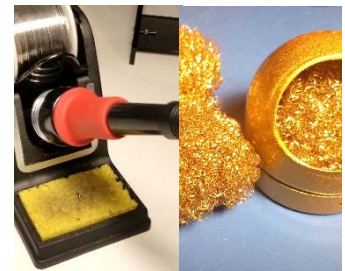
SOLDERING IRON TIPS

The tip of the soldering iron is the pointy part at the end that gets hot. In many irons the tips can be interchanged. The two basic tips referred to in this guide are the standard tip which is just a pointy end piece used for general soldering and through-hole PCB soldering, and a screwdriver or chisel tip, which looks like a flat head screwdriver and is used for surface mount soldering.



WET SPONGE AND BRASS WOOL

A wet sponge is used to wipe the soldering iron tips on to knock off extra solder and oxidized flux. Brass wool is handy when trying to remove thicker layers of oxidized flux or stubborn excess solder. Brass wool can be used with or without a holder.



FLUX

Flux is a chemical that prevents oxidation on the components during soldering. Flux helps the solder flow better, dissipates heat, and prevents oxidation. In simple wire soldering or through-hole PCB soldering, the flux that is part of the solder is sufficient, but when using a different technique for surface mount soldering, additional flux must be used to protect the components. Rosin flux is preferred for electronics soldering. The easiest



application for surface mount soldering is the syringe or brush packaging. Whichever flux you use, be sure it is indicated for electronics use!

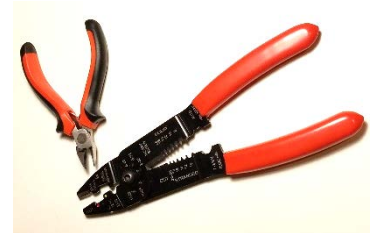
SOLDER

Soldering is not possible without solder. Solder is made up of low-temperature melting alloy (typically lead and tin) used for joining less fusible metals. In the case of electronics work, the solder used also has a rosin flux core. Solder does come in many different configurations – with or without flux, lead free or leaded, and various alloys for higher temperatures. The recommended solder for this application is 60/40 lead/tin solder, 0.025in diameter, with 2.2% flux. Any solder you choose to use **MUST BE INDICATED FOR USE WITH ELECTRONICS**. Typically the solder is held in the opposite hand as the iron about four inches from the end of the solder like a pencil.



WIRE SNIPS AND WIRE STRIPPERS

Wire snips do exactly what their name indicates – snip wire. The snips will be used to trim the excess terminal wires on the components after they have been soldered. Wire strippers are used to remove the insulation from wires and have markings on the tool as to what diameter wire goes where. Some wire strippers have wire snips as a part of the tool, though it is often easier to use a dedicated wire snip.



HELPING HANDS, MAGNIFIER, LIGHT – OPTIONAL

All the following tools are optional. Helping hands are small stands with alligator clips that help hold wires and boards during soldering. Be sure if they are used for this project, the clips are placed on the corners of the board away from any circuitry. Magnifiers can be helpful for those with poor vision up close. Additional lighting can be helpful if the workplace is not bright enough and is recommended when a magnifying glass is being used.



TINNING THE SOLDERING IRON TIP

An important part of maintaining your soldering iron is called tinning the tip, which simply means applying a thin, clean layer of solder to the tip of the iron before and after use. This thin layer of solder serves several purposes – it allows better transfer of heat from the iron to the element to be soldered, it allows solder to flow better between the iron and the elements, and it prevents the tip from damage due to oxidation.

STEP 1: HEAT UP THE IRON

The iron needs to be heated up to the appropriate temperature (at least 550 degrees F) for the application.

STEP 2: REMOVE OXIDATION

Use a brass wool sponge to “scrape” off the black oxidized flux and soldering residue from the tip of the iron. As it is “scratched” off the tip will become shinier. Techniques include dabbing the iron tip into the wool or using the wool like sand paper to pull off the oxidation.



STEP 3: ADD SOLDER AND TIN THE TIP

Add a small bead of solder to the tip of the iron and wipe the iron vigorously against the damp sponge. Repeat this step until the tip of the iron is nice and shiny.

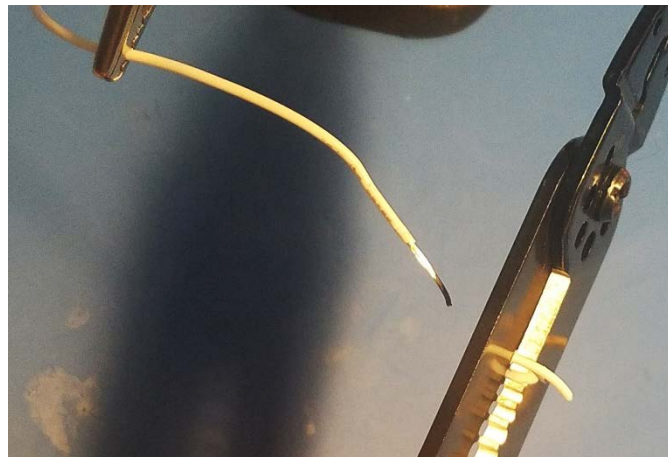


SOLDERING TECHNIQUE FOR TWO WIRES

Before delving into through-hole soldering or surface mount soldering, it can be helpful to review joining two wires, which can help reinforce important techniques. Make sure the iron is turned on and set at the appropriate temperature (about 700 degrees F for leaded solder, and 800 degrees F for lead-free solder) and the tip is tinned.

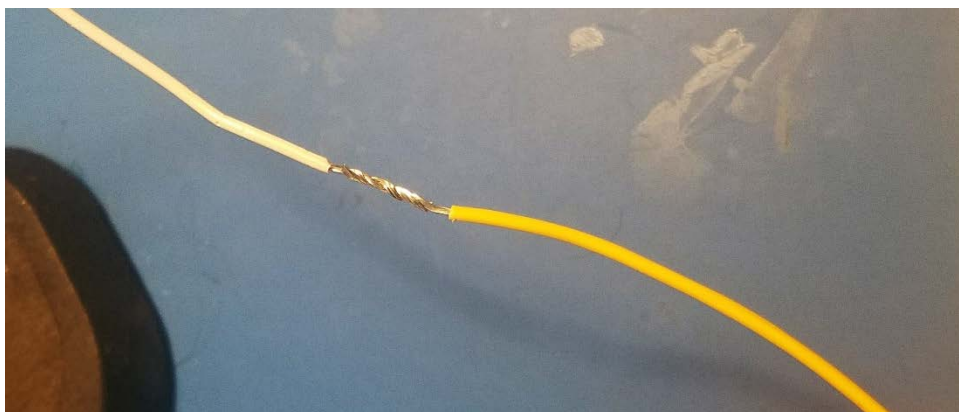
STEP 1: STRIP WIRES

Use the wire strippers to strip the wire insulation off the last ½"-1" of each wire to be joined. Match the wire diameter to the appropriate hole on the tool, clamp down and pull away towards the end of the wire to remove the insulation.



STEP 2: TWIST WIRES

Twist the wires together. This will make it easier for the wires to be joined as they won't fall away from one another when soldering. I prefer to align them parallel to one another and then twist them which will reduce stress concentrations as opposed to twisting them perpendicularly. At this point if you have helping hands you can place the wires in the helping hands.



STEP 3: SOLDERING

When soldering wires, the soldering iron is always brought to the wires first to heat them up for 1-2 seconds, and then the solder is brought to the heated wires and melted. The solder will flow on to the wires and between them with the help of the flux in the wire core.



The iron should not be held against the wires for more than 3-4 seconds total. If an attempt is unsuccessful, pull the iron off and let everything cool for about 10 seconds and try again.

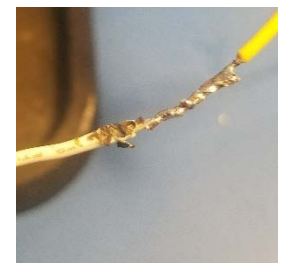
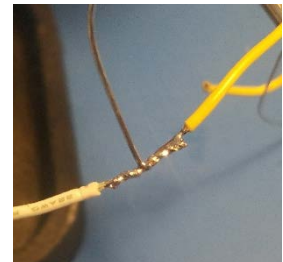
TROUBLESHOOTING

The solder is stuck to the wires.

If the solder is stuck on the wires, simply bring the iron to the junction of the wire and solder, heat it up, and pull the solder away.

The insulation on the wires has melted.

This is not a huge problem, though it can be an issue if not addressed. The insulation on the wire will melt if the wire is too hot (soldering iron against the wire for too long) or if the iron brushes the insulation. If you need to fix it to prevent a short circuit, you can use heat shrink or electrical tape.

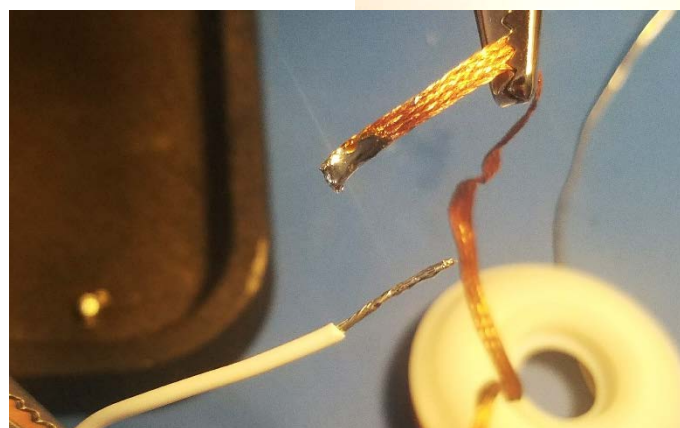
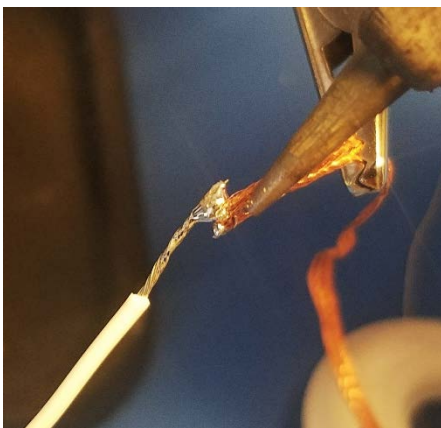


USING SOLDER WICK AND SOLDER SUCKER

Sometimes, solder needs to be removed, this could happen for several reasons – too much was applied, it was applied in the wrong area, or for certain instances of disassembly. The two main techniques discussed here will be solder wick and using a solder sucker.

SOLDER WICK

Solder wick is a copper braid that is used to “suck” up solder via capillary action. For higher iron temperatures, solder wick can be placed directly over the solder to be removed and under the iron tip (sandwiched in between). The heat is transferred through the wick and melts the solder, which is then pulled into the braid. For lower iron temperatures the solder may need to be melted directly with the iron, and the wick pulled across the melted solder where it is pulled into the braid.



SOLDER SUCKER

A solder sucker is a spring-loaded syringe that can be loaded and then released with a button. Upon release, the negative pressure in the syringe will pull the solder into the chamber. The tip of the solder sucker is made of silicon, so it will not melt even when placed against the iron tip. Use the iron to melt the solder and immediately bring the solder sucker to the melted solder, push against the melted solder, and press the release button.



SOLDERING TECHNIQUE FOR THROUGH-HOLE

Through-hole soldering refers to soldering wires or pins to a printed circuit board or a proto-breadboard where the wire or pin is pushed through the hole before it is soldered and attached. This technique is like wire soldering but there are important differences. First, let's discuss what makes a good solder joint for a through-hole solder.

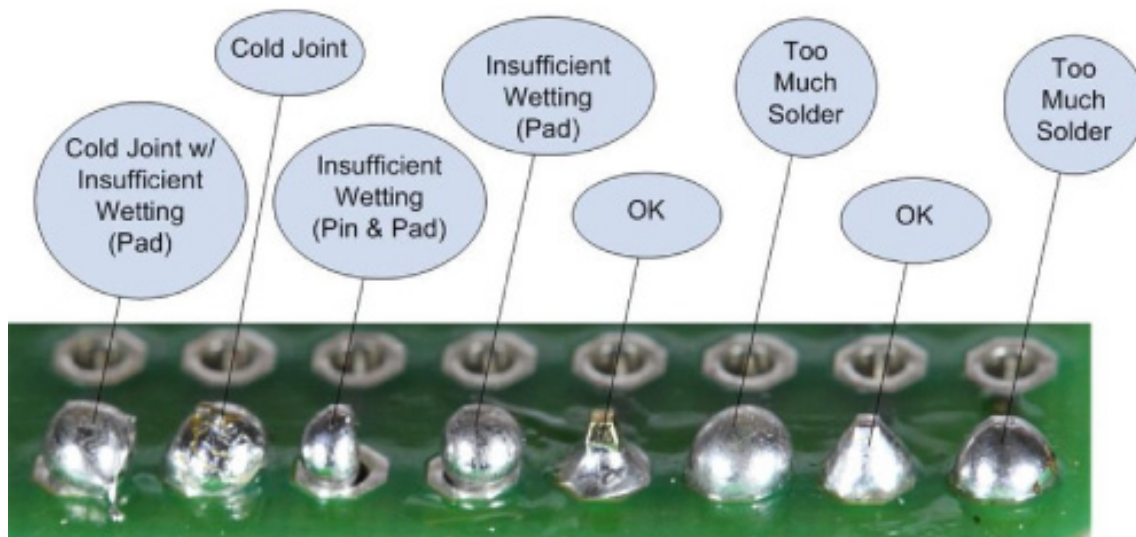


Figure 4: A few example through-hole solders demonstrating what makes a "good" solder, and other examples of poorly connected solders, called cold joints. Image courtesy of <https://www.mikroe.com/blog/through-hole-soldering>

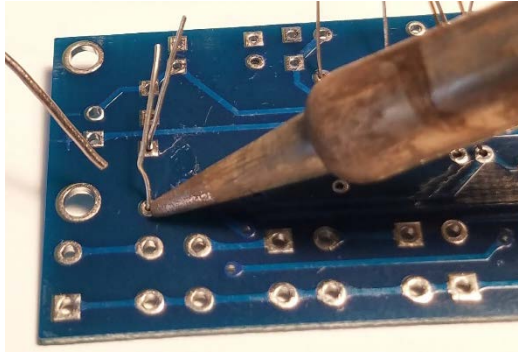
The quality of a through-hole solder is easily deduced from the way the solder joint looks. In the above image there are multiple solder joints. The joints second and fourth from the right are perfect solder joints, notice that it tapers at the base and at the pin, and looks kind of like a circus tent. The other joints are referred to as "cold" joints because they do not properly join the pin and the board, and therefore won't conduct electricity. Notice how there is not a great connection between the pins and the board on the cold joints. Each cold joint through-hole solder is labeled with the reason for poor connection such as insufficient contact with the pad (wetting) or too much solder.

STEP 1: HEAT UP THE IRON

Heat up the iron to around 650 degrees F, a slightly lower temperature is used in through-hole than with wires because our joints are smaller and too much heat can easily damage the board. Make sure the tip is well tinned.

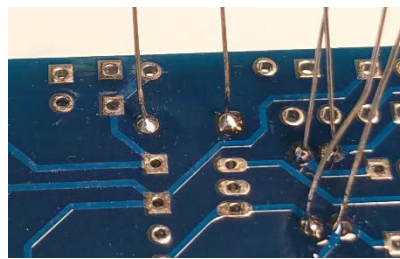
STEP 2: HEAT UP THE ELEMENTS

Bring the soldering iron to the junction of the pin and the hole as seen in the photo below. Leave the iron in contact for 1-2 seconds to heat the elements up. It is extremely important that the iron is not left to heat the elements for any longer or there is a risk the board will be damaged. DO NOT LEAVE THE IRON IN CONTACT WITH THE BOARD OR PIN FOR MORE THAN 3-4 SECONDS AT A TIME.



STEP 3: ADD SOLDER

Bring the solder to the iron at the junction of the pin and the board and dab it into the heated junction for about $\frac{1}{2}$ second, or just long enough to melt the solder and pull the iron and the solder away. DO NOT LEAVE THE IRON IN CONTACT WITH THE BOARD OR PIN FOR MORE THAN 3-4 SECONDS AT A TIME. If the first attempt is unsuccessful, pull the iron away, wait 10 seconds for everything to cool off, and try again.



STEP 4: CORRECT AND MODIFY IF NEEDED

If the joint is not perfect, this is the time to modify and make corrections. For cold joints, simply bring the iron to the joint again and heat up the solder that is already on the joint for 1-2 seconds or until it flows into the correct formation. If there is not enough solder, repeat steps 1-3 and add a small amount of solder. If there is too much solder, heat the solder up with the iron and drag the excess up the pin away from the joint.

TROUBLESHOOTING

The board has a brown tinge to it and looks a bit burnt.

The brown tinge is from the flux in the solder oxidizing as it heats up. The brown tinge is not in and of itself harmful and can typically be wiped off with a micro-cloth or PCB brush after soldering is finished. Seeing burnt flux should immediately have you questioning the amount of time you are leaving your soldering iron in contact with the PCB, or the temperature of your soldering iron!

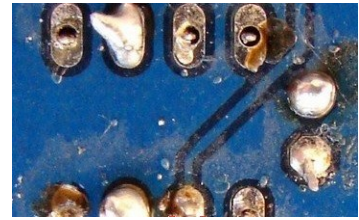


Figure 5: Burnt flux. Image courtesy of <https://file.pcbway.com/2013122616518284.jpg>

The board has a white or black burn mark on it and/or has bubbled up.

This is bad. This is from the plastic in the board burning from being overheated, and typically happens when the iron has been in contact with the board for far too long and the plastic begins to burn. If this has occurred, it warrants a close inspection of the PCB circuitry and layers to ensure no catastrophic damage has occurred. This is not an easily fixable problem.

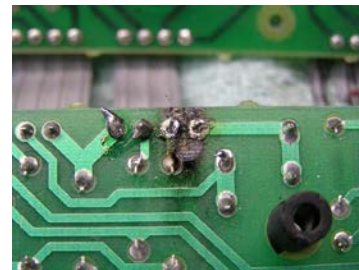


Figure 6: Burnt PCB. Image courtesy of http://billmaudio.com/wp/wp-content/uploads/2010/04/burnt_plate_screen.jpg

SURFACE MOUNT DEVICE SOLDERING (SMD)

Surface mount device (SMD) soldering involves a different technique and soldering tip than through-hole soldering. This technique is a bit more difficult and can be intimidating for beginners, but with a steady hand and practice, SMD soldering can be mastered.

The technique discussed here is only for surface mount devices with small exposed feet such as the chip in this kit (seen below) or a chip with accessible contacts. Different techniques and equipment are required for SMD's with inaccessible contacts.

Materials

- Flux (syringe works best)
- Screwdriver or chisel tip for soldering iron
- Tweezers
- Solder

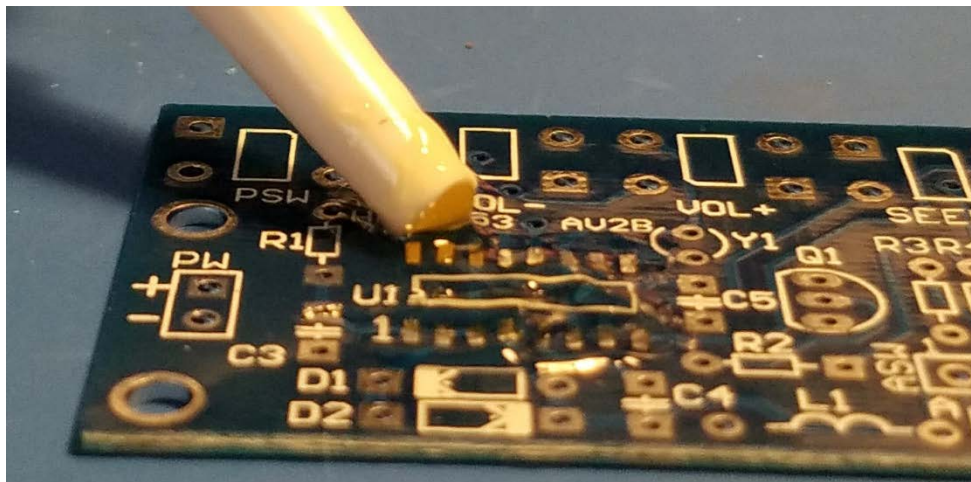


STEP 1: CHANGE THE TIP / HEAT UP THE IRON

For SMD soldering, replace the tip of the iron with a screwdriver or chisel tip. The iron for surface mount soldering needs to be even cooler than for through-hole or wires as the heat can quickly damage the small surface mount devices. Ensure the tip is well tinned.

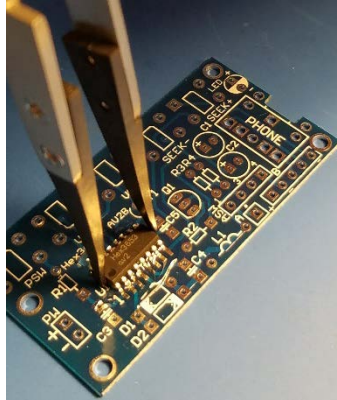
STEP 2: APPLY THE FLUX

Using either a small brush or a syringe, apply flux over the contact points for the SMD on the PCB. The layer should be thick enough to evenly cover the contacts, but no thicker than that will be difficult to place the SMD.



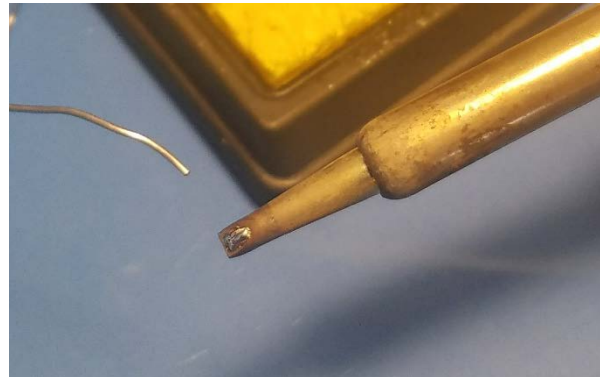
STEP 3: PLACE THE SMD

Using the tweezers, place the SMD on to the flux-covered contacts with the feet/contacts aligned against their contact pads on the PCB.



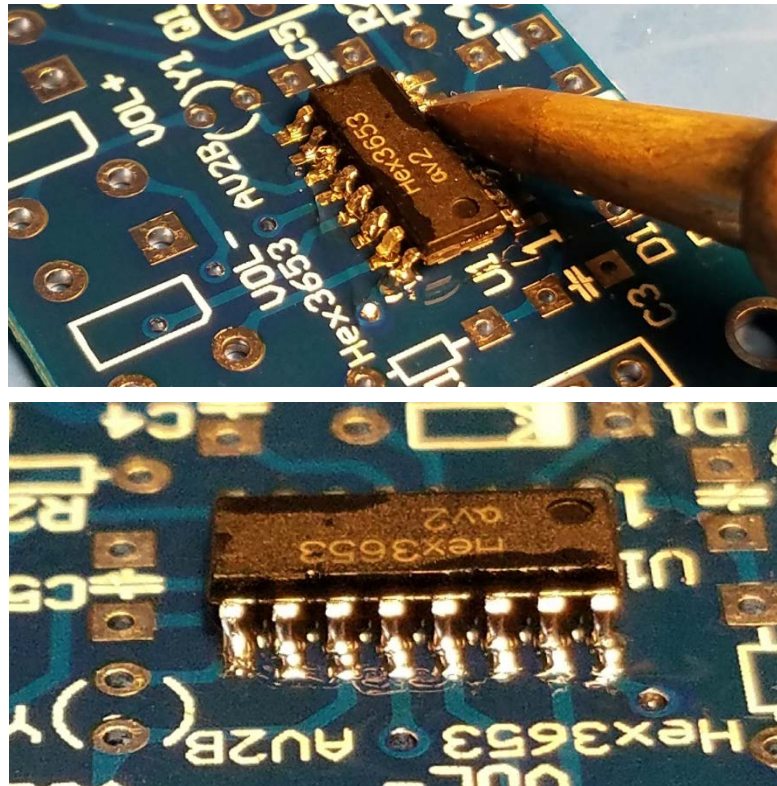
STEP 4: ADD SOLDER TO THE TIP RESEVOIR

With the flat end of the soldering iron tip pointing up, melt a small amount of solder into the reservoir. The solder should form a bead on the tip of the iron.



STEP 5: APPLY THE SOLDER

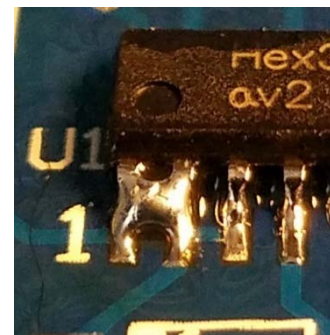
This is the tricky part which takes practice. Using the tweezers to secure the SMD chip in its place, turn the soldering tip with the solder facing down, and gently drag the iron across the contacts. Move the iron at a medium speed with a very light touch, pausing between each pass to examine the flow of the solder into the contacts. Capillary action will pull the solder in between the contacts. Once a few of the pins have been soldered, you can pull the tweezers away while the other pins are soldered. Continue making passes until all pins have a good connection. Remember, it is always better to add too little than too much. Reference the photo at the top of the next page.



TROUBLESHOOTING

The pins are connected by too much solder.

This is a common problem when learning how to SMD solder. If too much solder causes a short between legs/contacts, there are a few techniques that can be utilized. First, try using a clean soldering iron tip to melt and then pull the solder away. Next, soldering braid can be dragged against the melted solder to pull it away. Last, a solder sucker can be placed directly against the soldering tip and used to suck up the solder.



The solder is not flowing on to the chip and pads

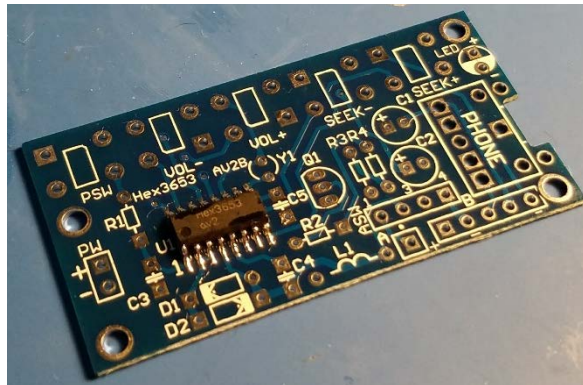
This technique is difficult the first time but does get easier with practice. Two common reasons the solder isn't flowing are the angle of the soldering iron tip relative to the board, and too little flux. The iron should be held relatively flat to the pins and pad, moving parallel to the board. Sometimes the flux gets thinned out during placement and more may be needed to get the solder to flow properly.

ASSEMBLY

The order in which the radio is assembled is important and done in the order of shortest component to tallest because the soldering is done from underneath. When the board is flipped over the pressure against the component holds it in place during soldering. Reference back to the component section for information about each individual component. Feel free to bend component leads out of the way to reach others to be soldered.

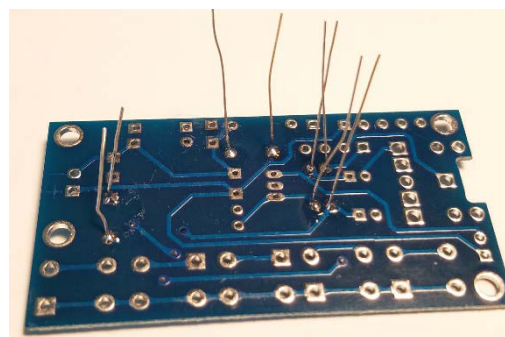
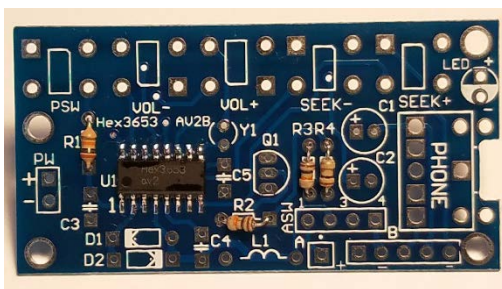
1. HEX 3653 CHIP

Using the SMD soldering technique, attach the radio chip to the PCB. There is a small circle imprinted in the top of the chip and it needs to be aligned to the circle imprinted on the PCB where the chip contacts are located – with the circle pointing toward the C3 capacitor. This is VERY important. This first step is the most time-limiting step of the entire assembly.



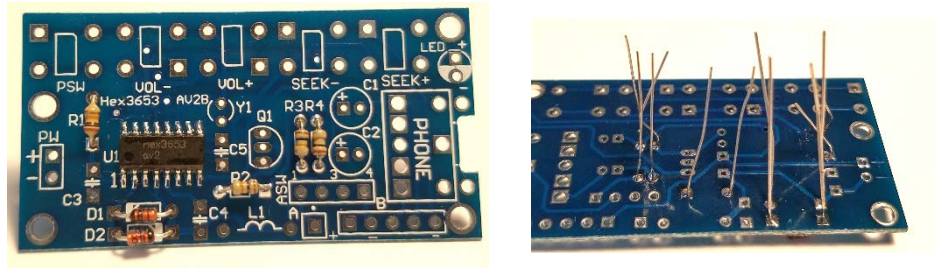
2. RESISTORS

From this point forward, you will insert the component on the top of the PCB (labeled side) and solder from the bottom. There are four 10kΩ resistors labeled R1, R2, R3, and R4 on the PCB. Remember that resistors are not polarized so it doesn't matter which way they are oriented, and they are all the same part, so it does not matter which resistor is placed where. Solder them to the PCB using the through-hole soldering technique



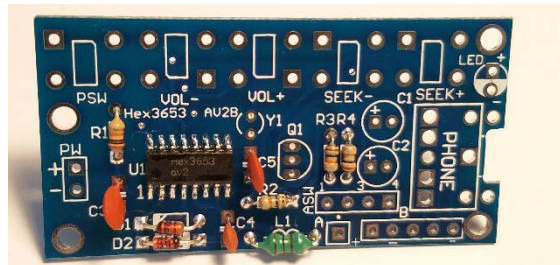
3. DIODES

Remember, diodes are polarized, so their orientation is **EXTREMELY** important. The two diodes are labeled on the PCB as D1 and D2, note that they are oriented in opposing directions. The black end of each diode needs to be aligned to the thick white bar on the PCB. Incorrect placement of the diode can result in catastrophic failure of the radio, take time to double check before moving on. Utilize the through-hole soldering technique.



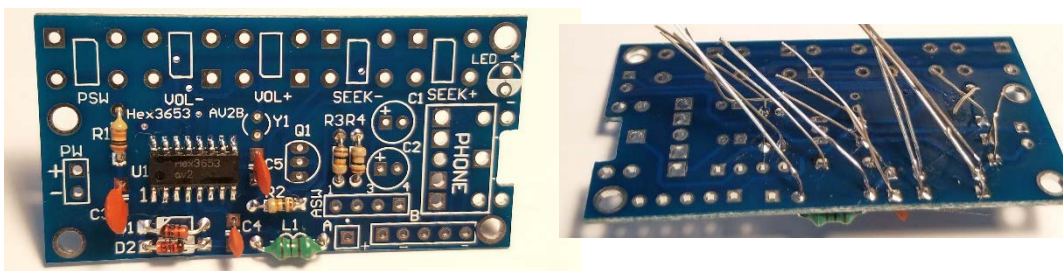
4. INDUCTOR

The inductor looks like a teal resistor and is labeled on the PCB as L1. Like the resistors it is not polarized and its orientation does not matter. Use the through-hole soldering technique.



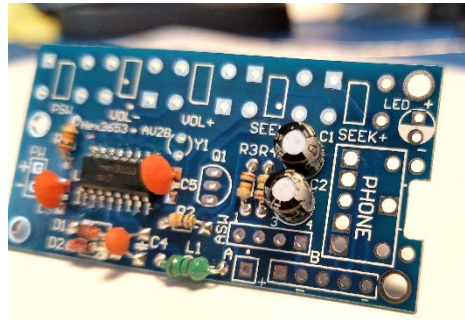
5. CERAMIC CAPACITORS

The ceramic capacitors are to be inserted in C3, C4, and C5, and look like mini Advil's. There are two different sizes, a smaller one labeled "22" or "33" and two larger ones labeled "104". These ceramic capacitors are not polarized, and their orientation does not matter, however their placement on the PCB does – the smaller capacitor at C4, and the larger ones at C3 and C5. Use the through-hole soldering technique.



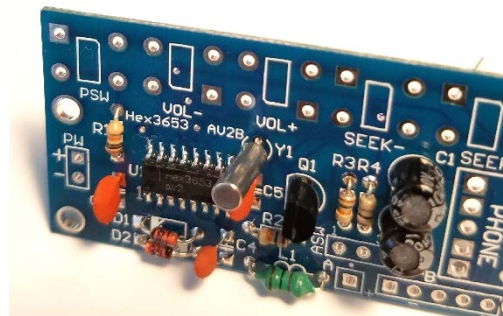
6. ELECTROLYTIC CAPACITORS

The electrolytic capacitors look like two black cylinders and are labeled “10V 100 μ F”. These are polarized, and their orientations DO matter. The electrolytic capacitors are labeled with a white stripe that indicates the negative lead. The negative lead, or anode, is also the shorter of the two leads. Their positions are labeled C1 and C2 on the board with positive lead holes indicated. Use the through-hole soldering technique.



7. TRANSISTOR

The transistor has a black top with one flat side and one round side and three leads. Its location is indicated on the board by Q1 with a similar shape shown. Align the transistor on the PCB to the shape outlined and use the through-hole soldering technique.



8. ANTENNA

The antenna is a skinny silver cylinder indicated on the PCB by Y1. Its orientation does not matter as it is not polarized. You can bend it down a bit after soldering. Use the through-hole soldering technique.



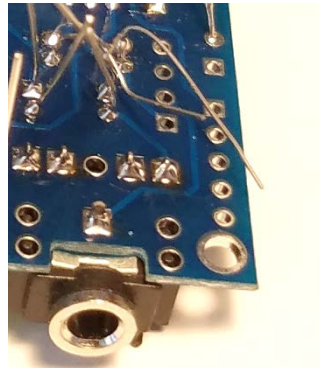
9. PUSH BUTTONS

There are five push buttons to be placed along the one long edge over the rectangles printed on the PCB. The buttons are slightly longer in one direction than the other and you will find they lend themselves to seat one way better than the other. Use the through-hole soldering technique.



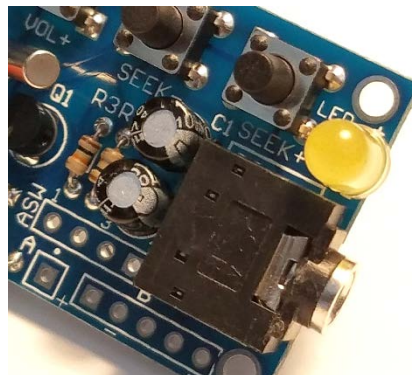
10. AUDIO OUT

The auxiliary out port will only align in one way and is labeled “PHONE” on the PCB. Do not solder any holes that do not have pins through them. The holes for these pins are larger and will require more solder. Use the through-hole soldering technique



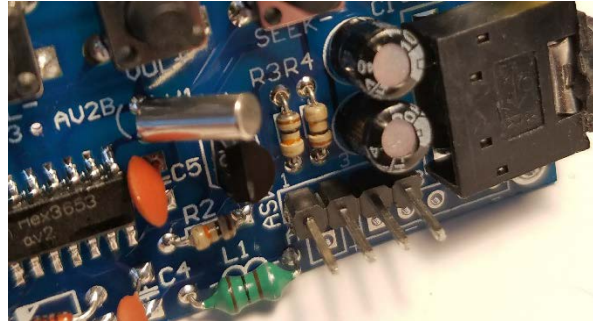
11. LED – flat end points to negative marking on PCB

The LED is a polarized component, and its orientation is important. The negative lead, or anode is the shorter lead, and there is a flat spot on the negative side of the LED. The LED position is labeled on the PCB with positive and negative lead labels. Use the through-hole soldering technique.



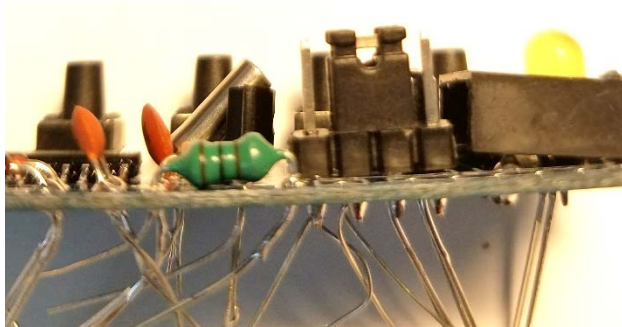
12. HEADER PINS

The header pins are the four gold pins held together by a strip of black plastic. One side of the pins is longer than the other, the shorter side gets inserted into the PCB at the four holes labeled “ASW B”. Use the through-hole soldering technique.



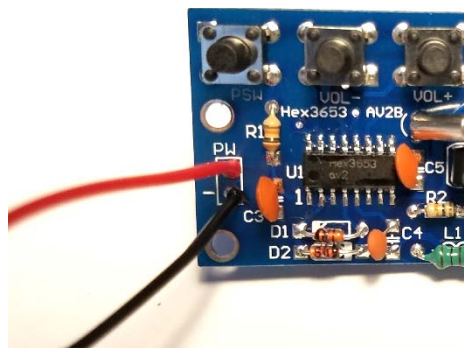
13. JUMPER SLEEVE

The jumper sleeve is a small plastic sleeve with metal connectors on the inside that will slide over the two middle header pins and connect them together. Push the sleeve all the way down.



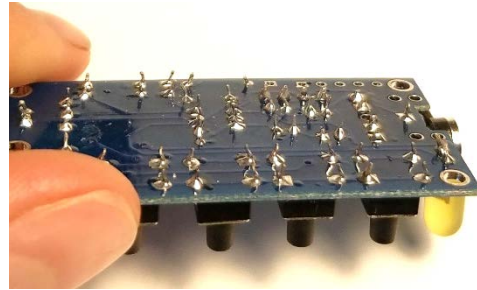
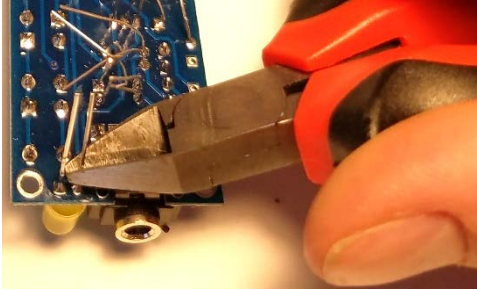
14. POWER SUPPLY – black is negative red is positive

The last step is to attach the power supply. The battery holder has two wires, a positive red wire and a negative black wire. The location for these wires is indicated on the PCB by “PW” and “+” and “-” for each wire. It is recommended to thread the wire from the top of the PCB to the bottom.

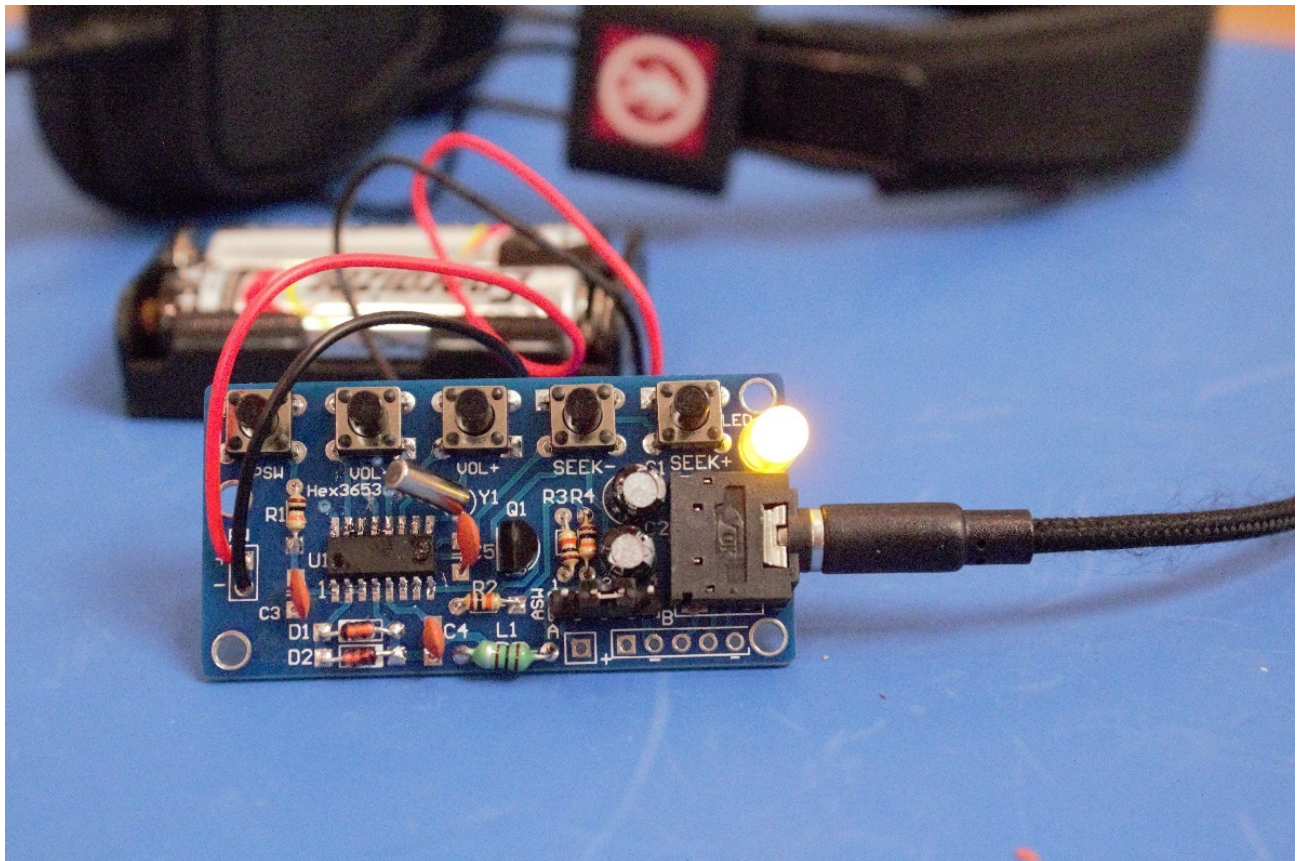


15. TRIM THE LEADS

After all components have been soldered to the PCB, use a set of cutters or strippers with a cutting blade to trim the component leads down



That's it, the board is assembled! Continue to the next page to read about how to operate your radio before turning the radio on.



RADIO OPERATION AND TROUBLESHOOTING

TURNING YOUR RADIO ON FOR THE FIRST TIME

When operating your radio for the first time, be mindful of any odd sounds, temperature changes, smoking, or other anomalies upon startup. Plug in a pair of headphones. Insert the two AA batteries into the battery holder and press the power button. The radio should begin generating audio and the LED should turn on. If the LED does not turn on or the radio does not produce sound, remove the batteries and proceed to troubleshooting.

RADIO OPERATION

PWR BUTTON	Press this button to turn your radio on and off.
YELLOW LED	The yellow LED indicates if the radio is on or off.
SEEK-	The SEEK- button moves the tuner to the next lower-frequency channel with a reliable signal.
SEEK+	The SEEK+ button moves the tuner to the next higher-frequency channel with a reliable signal.
VOL+	The VOL+ button increases the volume coming from the auxiliary jack.
VOL-	The VOL- button decreases the volume coming from the auxiliary jack.
JUMPER SLEEVE	The jumper sleeve on the middle two header pins selects the cord connected to the auxiliary jack as the antenna. Changing the sleeve to pins 1 and 2 will select an external antenna that would connect to pin 1.

TROUBLESHOOTING

The radio turns on and picks up signal, but the LED doesn't light.

Check that there is not a short between the three solders on the transistor. Also check that there is a solid solder between each leg of the HEX 3653 chip and the contact pad on the PCB. If not, remove the batteries and add more solder – remember to use flux. Also, be sure to check that the LED is aligned correctly, with the flat end facing towards the audio jack.

The radio does not turn on.

This is most likely the result of poor connections at the chip. Before doing anything, ensure there is not a short between the chip legs from excess solder. Remove the batteries before soldering. Using the screwdriver / chisel tip, add a small amount of solder

and touch it directly to the leg and contact pad, allowing additional solder to flow on. Remember to use flux.

The radio does not turn on and the board gets hot.

REMOVE THE BATTERIES IMMEDIATELY. This is likely a misplacement of the diodes, one of the diodes is likely not positioned correctly. Check the alignment of the diodes (black end of the diode facing the white bar on the PCB). If a diode is placed incorrectly, touch the soldering iron to the joint of the diode lead and pull the diode away; do this for both leads. Heat up the solder-filled hole and push the correct leg of the diode through the melted solder. Repeat on the other side of the diode.

The battery pack wires keep coming disconnected

The wires from the battery pack are thin, and if not handled with care can tear from the PCB. If this happens, use the soldering iron to heat up the solder on the PCB where the wires tore from, and remove the wire remnants. Cut, and strip the wires from the battery pack, and then twist and tin the wire ends. Heat the solder in the holes on the PCB and push the newly stripped wires through the melted solder. Electrical tape, heat shrink, and hot glue can be added to reinforce the junction.

I only hear static.

The configuration used in this guide uses the cord connected to the auxiliary jack as the antenna, this is not the most powerful antenna choice and can change depending on the cord used. Reception can be improved by changing the orientation of the radio, lifting the tuner antenna on the PCB (Y1) up a bit off the board, and by moving near a window or outdoors.

WHAT IS RADIO?

In 1901, Italian engineer Guglielmo Marconi transmitted the first transatlantic radio signal – a wireless signal traveling without cables like the earlier telegraph. The first radio signals were used to communicate with naval ships. Later in the 1900's radio was used for mass broadcast of music, news, and entertainment. Using large radio telescopes, scientists and engineers examine stars and gasses in outer space which also emit radio waves!

Radio is something that, in the modern age, we often take for granted. Radio communication is used in FM radios such as the one built in this guide, AM radios, cellular communications, satellite communications, Bluetooth, and antenna TV. In order to understand how the FM radio you have built works, you need to understand what radio waves are, how radio waves can transmit information, and how these signals are broadcasted and received. Finally, we will discuss the circuitry of our radio and how the circuitry and components work together to receive the FM signals.

RADIO WAVES ARE ELECTROMAGNETIC WAVES

Electromagnetic (EM) waves are created by the vibration of electrons, creating a wave that has both electrical and magnetic components, and can propagate, or travel, without a medium (i.e. can travel in a vacuum). EM waves occur along a spectrum, where different types of waves are defined by the energy they carry. Some types of electromagnetic waves you are probably familiar with – visible light, x-rays, and infrared. The difference between radio waves and these other types of EM waves are the range of wavelengths (or frequencies), in which they occur. In the diagram you can see the electromagnetic spectrum with the different types of waves labeled, notice that radio waves are longer and more spread out and thus the lowest energy of the EM

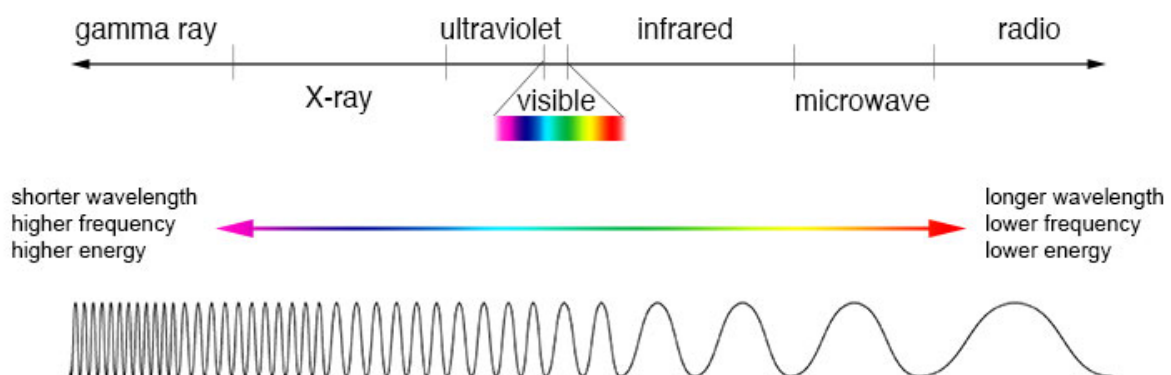


Figure 7: The electromagnetic (EM) spectrum with various types of EM waves labeled. Notice that radio waves have the longest wavelengths of the portion of the spectrum shown, and therefore the lowest energy. Image courtesy of NASA, https://imagine.gsfc.nasa.gov/Images/science/EM_spectrum_compare_level1_lg.jpg

wave types shown. Gamma rays, on the other hand, has waves that are very close together, and therefore carry much more energy. Like visible light and all EM waves, radio waves travel at the speed of light, approximately 3×10^8 m/s!

CHARACTERISTICS OF ELECTROMAGNETIC WAVES

Frequency, wavelengths, and energy are all characteristics of EM waves that define them. Understanding the basics of each of these characteristics is all that is required to understand how a radio works. An in-depth mathematical understanding is **not** necessary but will be discussed here to provide a deeper understanding for those who are interested.

A wavelength is one cycle (called a period in physics) of a repeating wave; wavelengths are measured in meters. The symbol for wavelength is the Greek symbol lambda, λ . In the figure to the right, one wavelength is measured from one point on the wave to the next identical point.

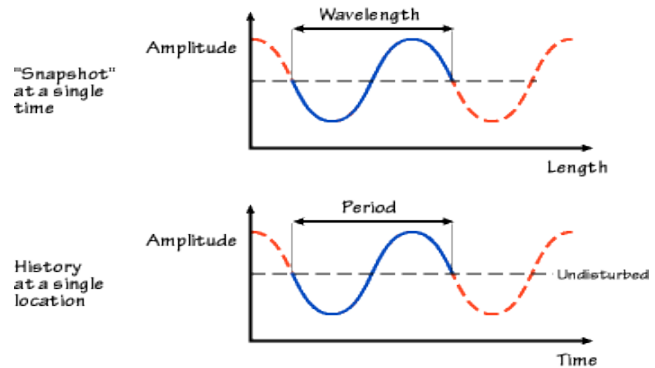


Figure 8: This image shows a wave as a function of length (top graph) and a wave as a function of time (bottom graph). Notice that one repeating unit of the wave, called a wavelength, occurs in a period of time called the period. Image courtesy of Penn State's Seismology laboratory,, http://eqseis.geosc.psu.edu/~cammon/HTML/Classes/IntroQuakes/Notes/Images_specific/wave_def.gif

The frequency of a wavelength is the number of waves observed to pass in one second, represented by the symbol f . The units of frequency are Hertz (Hz) equal to s^{-1} .

Frequency and wavelength are related by the constant c , the speed of light (and the speed of all EM radiation), which is equal to 2.998×10^8 m/s; for most purposes the constant can be approximated as 3×10^8 m/s. Frequency is equal to the speed of light constant divided by wavelength. Below is the mathematical equation that relates frequency to wavelength.

$$f = \frac{c}{\lambda} \text{ or } \lambda = \frac{c}{f}$$

The last term mentioned in the image above that has not yet been discussed, amplitude, is the height of a wave from zero or the absolute value of the average wave height. In the image above, the amplitude is the height of the wave from the dashed line.

Energy, E , is a function of frequency or wavelength, meaning you can use the frequency or wavelength to determine the amount of energy carried by an EM wave. This next equation is the

mathematical relationship. Note that h , refers to the Planck constant, equal to 6.63×10^{-34} Js (Joules x seconds).

$$E = hf = \frac{hc}{f}$$

Again, understanding the basic idea of energy is all that is required to understand how our radio works.

From the energy equation, we can affirm that waves with higher frequencies (like gamma rays) have higher energies, and waves with longer wavelengths (like radio waves) have smaller energies. We can see this to be the case in the EM spectrum image at the beginning of this section.

Specifically speaking about radio waves, we have now shown mathematically that radio waves have very large wavelengths, and thus, very low energy. Radio waves have wavelengths varying from within 1mm to several hundred km, falling in the range of frequencies of 300 GHz to 3 Hz. FM radio signals, the radio waves that are received on the radio receiver you have built, occur in the frequency range of 88 to 108 MHz.

RADIO WAVES CAN ENCODE INFORMATION

When people talk about radio waves they are typically speaking about AM or FM signals. AM and FM signals are different in two important ways – their frequency range, and how the type of signal transmits information.

Unlike FM signals which occur in the frequency range of 88 to 108 MHz, AM signals occur in the range of 540 to 1600 kHz, and so have much longer wavelengths.

AM stands for amplitude modulation while FM stands for frequency modulation. Modulation is the manipulation of a characteristic of the original radio wave, or carrier wave, in order to transmit information. As their names imply, AM and FM signals encode information in different ways.

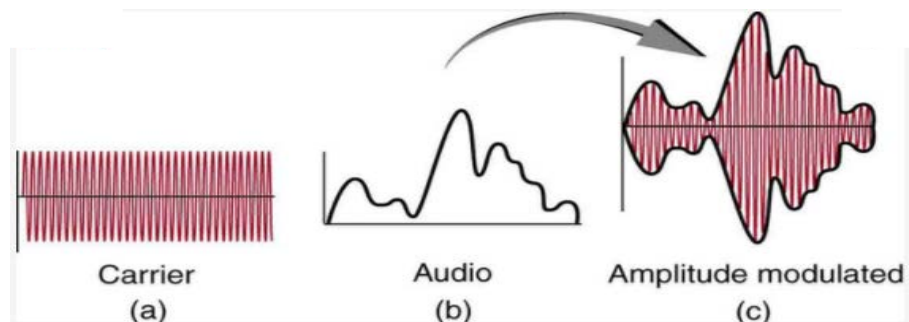


Figure 9: Amplitude modulation for AM radio. A carrier signal's amplitude at the station's basic frequency (a) is modulated, or changed, to encode the audio information (b) which results in an amplitude modulated signal (c). Image courtesy of <https://courses.lumenlearning.com/boundless-physics/chapter/the-electromagnetic-spectrum/>

Amplitude modulation is the change of signal amplitude to code for audio signal information; the frequency and wavelength remain the same, which allows different information to be sent on frequencies that are close together. In the image on the previous page, you can see how an AM carrier wave is modulated, or changed, to carry audio information. The benefit of AM over FM signals is that it can be carried over much further distances and can accommodate more stations in a given frequency range.

Frequency modulation is the change of signal frequency to code for audio signal information.; the amplitude doesn't matter, but the frequency does change slightly from the station's basic frequency. Therefore, each channel of information needs a frequency buffer around it, so fewer channels of information can be sent in a range of frequencies. However, because amplitude doesn't matter, the stray noise from other radio sources (power lines, lightening, outer space) does not interfere with the FM signals, so although the FM signals are not as far-reaching as AM signals, they are much less noisy. In the image at right, you can see how FM carrier waves are modulated, or changed, to carry audio information.

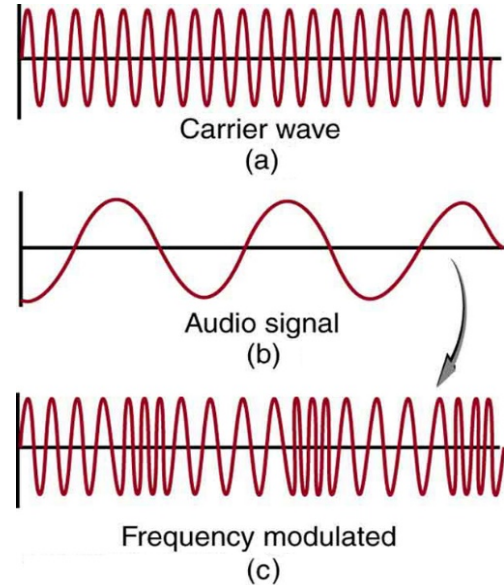


Figure 10: Frequency modulation for FM radio. A carrier signal's frequency at the station's basic frequency (a) is modulated, or changed, to encode the audio information (b) which results in a frequency modulated signal (c). Image courtesy of <https://courses.lumenlearning.com/boundless-physics/chapter/the-electromagnetic-spectrum/>

HOW ARE RADIO WAVES SENT AND RECEIVED?

Radio waves are sent and received using electric currents and the entire process of radio communication requires both a transmitter and a receiver. As in the previous sections, the nuances of these processes is not required for understanding, but is discussed for those who desire a deeper understanding.

A radio transmitter is composed of a power supply, oscillator, modulator, amplifier, and antenna. The power supply provides the electrical power to operate the transmitter. Current (which you can think of as the energy flowing through the circuit) from the power supply travels into the oscillator which turns the (typically) direct current from the battery into an alternating current at the basic frequency of the carrier signal to the transmitter. In

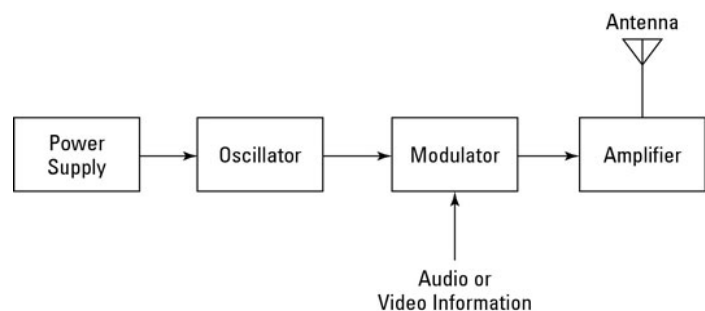


Figure 11: A flow chart of the inner workings of a radio transmitter. Image courtesy of <http://www.dummies.com/programming/electronics/components/radio-electronics-transmitters-and-receivers/>

other words, the linear (straight-line) signal of the DC current is turned into a repeating (sinusoidal) wave centered on the frequency of the radio station tuned into by the user. The current wave then passes into the modulator which encodes the audio information into the wave. In the case of FM radio, the modulator will slightly increase or decrease the frequency to code the information. The modulated signal then passes into the amplifier which increases the power of the signal. Finally, the current signal passes into an antenna which causes electrons in the antenna to vibrate up and down, producing radio waves. As our radio that we have built is a receiver, all the radio transmission will occur at the sources of the signals, such as the radio station towers broadcasting on each frequency.

We have built a radio receiver; how is something so small grabbing invisible radio signals out of the air and transforming them into sound? Where a transmitter turned direct electrical current into an alternating modulated current that produced a radio wave signal, receivers take that

radio wave, turn it into an alternating modulated current, and finally turn it back into a direct current. Like transmitters, receivers also have antennas which work the same way but in reverse. The antenna on the receiver intercepts the radio signal which causes electrons in the antenna to move up

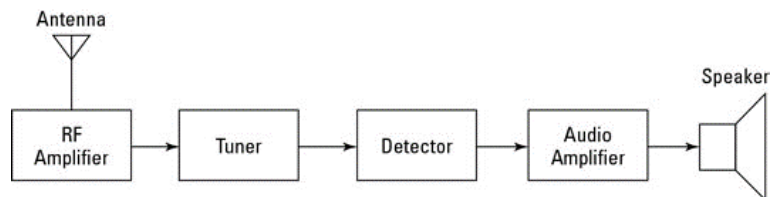


Figure 12: A flow chart of the inner workings of a radio receiver. Image courtesy of <http://www.dummies.com/programming/electronics/components/radio-electronics-transmitters-and-receivers/>

and down the antenna, generating a small alternating electrical current. To make the small alternating current bigger it passes through an amplifier so that the signal can be processed more effectively. Next, a tuner extracts only signals at the frequency desired. In a typical FM radio, the tuner will filter out all signals that are not at the frequency of the station the radio is tuned to. The modulated alternating wave signal of only one frequency then travels into the detector which removes the alternating wave, leaving only a direct current that encodes the audio information. Finally, the direct current information signal passes into an audio amplifier which can be used to drive a small speaker

HOW SIMPLE COMPONENTS TURN RADIO WAVE TO SOUND

Now that we understand what radio waves are, how they encode information, and how this information is transmitted and received, let's walk through the basics of how all the electrical components in our radio work together to receive that radio signal.

Note that there is some wiring in the schematic that is not utilized in basic radio use, so those portions will be omitted from this discussion. The circuit diagram was constructed using the Hex 3653 datasheet and a drawing of the basic radio PCB circuitry and discussion by Dr. Lui Gough of goughlui.com. Portions of the Fritzing circuit diagram have been highlighted as in Dr. Lui Gough's

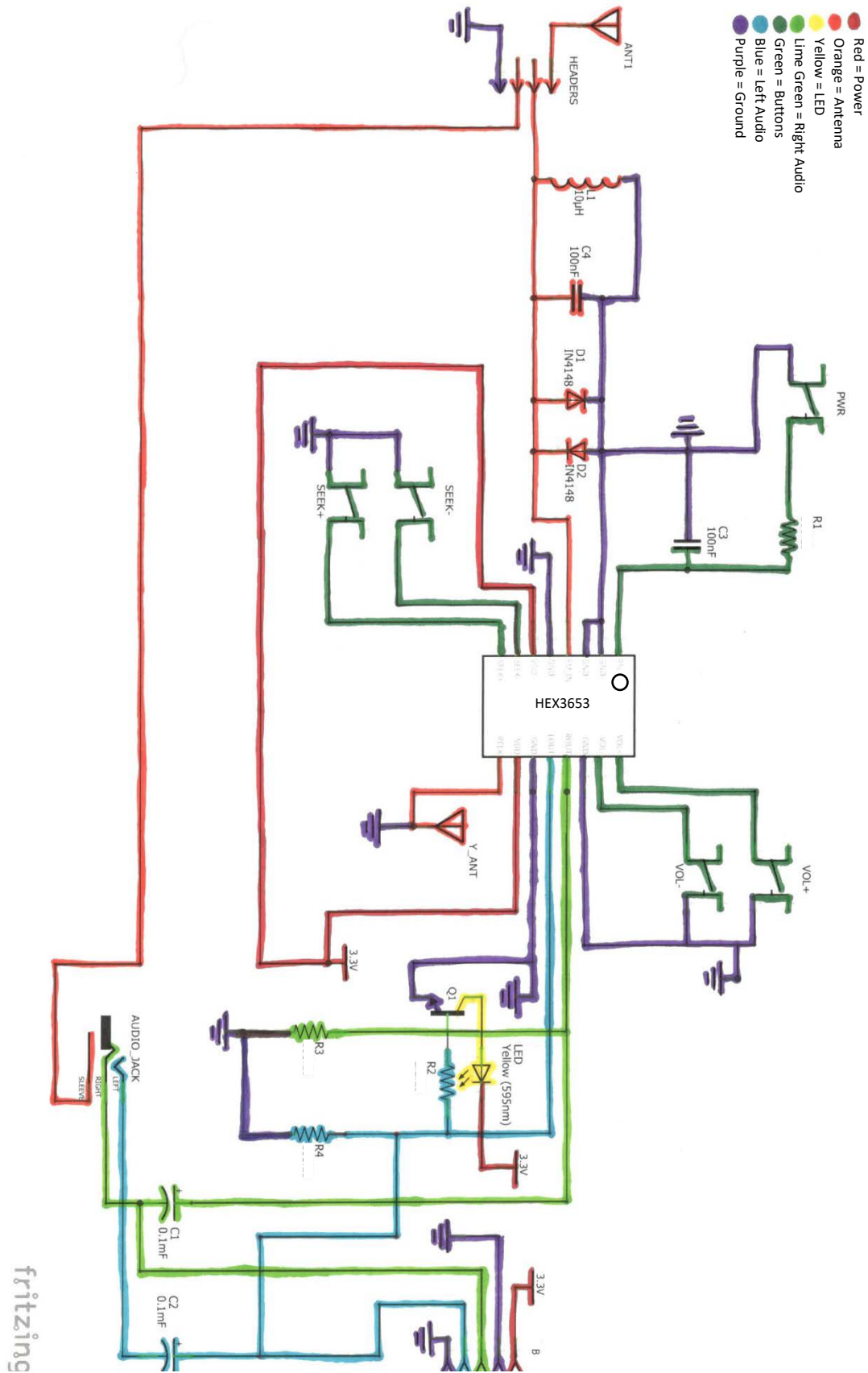


Figure 13: The circuit diagram of the radio generated using Fritzing software by Katrina Siegfried, based on the work of Dr. Lui Grough. This diagram has been color coded to show the function of each circuit in the radio as it pertains to the overall function of the radio.

original drawing to help distinguish individual circuits. See the highlighted diagram on the previous page. The author would like to thank Dr. Lui Gough for his work which serves as the foundation of this discussion.

Table 1: This is a table of the pin descriptions for the HEX 3653 FM Radio chip. Table courtesy of <http://www.datasheetq.com/HEX3653-doc-Unspecified>

SYMBOL	PIN	DESCRIPTION
GND	2,3,5,11,14	Ground. Connect to ground plane on PCB
FM_IN	4	FM single input
RCLK	9	32.768KHz reference clock input
VDD	6,10	Power supply
LOUT,ROUT	12,13	Right/Left audio output
SEEK-,SEEK+	7,8	seek up,seek down
VOL- VOL+,	15,16	Volume control
PN	1	Powerup/powerdown Enable

All the sub-circuits in the circuit diagram of the radio in Figure 13 have been highlighted in different colors to better showcase their distinct functions. Portions of the circuitry related to the antenna and signal reception are highlighted in orange. Power-related wiring is highlighted in red. Right and left audio signals are highlighted in lime green and blue, respectively. LED connections are shown in yellow. Button connections are shown in darker green. All ground connections are shown in purple.

Let's begin at the antenna; antenna circuits are highlighted in orange in Figure 13. As radio waves are intercepted by the antenna, electrons in the antenna begin to vibrate up and down. The antenna signal originates at the header pins. Pin 1 on the header is for connection of an external antenna. Pin 2 is connected back to the HEX chip. Pin 3 connects to the audio jack antenna shield, which allows the auxiliary cord to serve as an antenna. Adding the jumper sleeve over pins 2 and 3, the auxiliary cord is used as an antenna. Adding the jumper sleeve over pins 1 and 2 allows an external antenna to be used. The remaining fourth header pin is connected to ground. Since our configuration has the jumper sleeve placement on pins 2 and 3, the auxiliary cord or headphone cord is acting as the antenna, so the antenna signal is being received at the headers from pin 3 and passed to pin 2.

Via pin 2 of the header pins the alternating electrical current passes through the inductor (L1) and a capacitor (C4) as well as the "back-to-back" diodes (D1 and D2). These components serve to limit the pin voltage to about 0.3V to protect the chip from damage. The signal enters the chip at FM_IN and the chip compares the incoming signal to the reference signal received from the small

on-board antenna (Y1) that enters the chip at RCLK, which is controlled by the SEEK+ and SEEK- buttons. The tuning, detection, and amplification of the signal all occurs internally inside the chip.

The audio signal leaves the chip from ROUT (lime green) and LOUT (blue) and both circuits are loaded down with 10kΩ resistors and each is passed through a 100uF electrolytic capacitor to prevent any DC signal with 0Hz frequency from passing through, called DC blocking. This DC block acts as a high-pass filter, only allowing the audio signal to pass through and removing any added noise.

The left and right audio signals have an added base voltage to the signal by the chip, called DC bias. This “extra-voltage” is diverted by the transistor (Q1) to power the LED.

Both audio signals eventually terminate at the audio jack where the signals will drive small speakers.

The audio signals are also connected to the through-hole connections labeled “B” on the PCB and circuit diagram. These allow for the module to be used in an integrated manner.

Last, the power button (PWR) is slightly different than the SEEK and VOL buttons in that it is not a pull-down input. A pull-down button is one whose opposing terminals are only connected while the button is pushed; when the button is not pushed, the configuration pulls the circuit to ground, and no connection is made. The power button needs to generate a signal that is long enough to turn on the board, and thus is a signal that lasts beyond the momentary push of the button. To do this, the power button is “held” with a 0.1uF capacitor which increases the length of the generated signal when the power button is pressed.

When connected in just the right ways, all the individual electrical components work together with the HEX 3653 FM Radio chip, which handles most of the signal processing, to create a working FM radio!

Review

After completing this project, you should have a foundational understanding of basic electronic components, several soldering techniques (including surface mount, through-hole, and wire joining), how to build the HEX 3653 FM Radio kit, and the fundamental concept of what a radio is and how it works.

CIRCUIT DIAGRAM

A circuit diagram is used as a standardized picture of what a circuit looks like and how it is connected. A standard representation allows many different engineers to read and understand the circuit.

ELECTRICAL COMPONENTS

We learned about each electrical component in the FM Radio Receiver kit, what its function is, and how it is represented on a circuit diagram. Resistors limit the current traveling through wires. Diodes are used like one-way valves to ensure the current flows in only one direction; they are polarized, meaning their orientation in the circuit matters. Inductors induce a voltage when placed in a magnetic field. Capacitors temporarily store electric charge; some capacitors (electrolytic) are polarized and others are not (ceramic). Transistors have several uses, but the N-type in our kit is used as an amplifier, passing a larger current when receiving a smaller one. Antennas intercept radio wave signals and turn them into current. Push buttons allow the user to temporarily connect a circuit and cause a change in the electrical system. LED's are light emitting diodes that are polarized and function the same way that the other diodes do, except they light up. The audio jack allows a user to insert headphones or a small 3.5mm auxiliary cord speaker to listen to the audio output. Header pins allow for the user to connect to parts of the circuit. In our radio, we used a jumper sleeve to side over two of the header pins to connect them together. The battery holder allows us to add two AA batteries to power the radio. Finally, the HEX 3653 radio chip handles all of the internal processing of the signal; it has 16 pins each with different functions and is the heart of the radio.

SOLDERING TECHNIQUES

Soldering is used to join two less-fusible materials, and in electronics soldering is used to join materials in a way that will conduct electricity. Several tools are used in soldering, including a soldering iron, different types of soldering tips, sponges and wool to care for the tip, flux to help

solder flow and prevent oxidation, and solder which is a low-melting point metal that conducts electricity. There are different techniques for different types of soldering joints, such as joining two wires, through-hole soldering, and surface mount soldering. Solder wick and solder suckers are two tools that can be used when solder is to be removed. Soldering is an essential skill for electronics hobbyists, engineers, and in assembly of this FM radio.

HOW TO ASSEMBLE THE HEX 3653 RADIO KIT

The radio is assembled from shortest component to the tallest so that when the board is flipped over, the weight of the printed circuit board (PCB) holds the components in place during soldering.

OPERATING AND TROUBLESHOOTING THE RADIO

The radio takes two AA batteries and has five momentary push buttons used in operation. If the radio does not work as intended, several solutions are discussed.

HOW RADIOS WORK

Radio waves are electromagnetic waves (EM) just like visible light and x rays. EM waves can travel in the vacuum of space and through the air, and are defined by their wavelength (or frequency) and amplitude. Radio waves have very long wavelengths, and thus have lower frequencies and lower energy. We can modulate, or change, these radio waves to encode information. FM radios, such as the one we have built in our kit, use frequency modulation which involves changing the frequency of the wave slightly to encode the audio information. The radio built in this kit is a radio receiver; the basic steps in radio reception are signal reception at the antenna, amplification, tuning, detection, and finally audio amplification. The individual electrical components of our radio work together with the HEX 3653 chip to achieve all of these steps and turn radio waves into sound.

ADDITIONAL RESOURCES

If you are seeking to build upon the skills and topics discussed here, navigate to the various resources listed in the “References” section.

NEXT STEPS

Once you have completed this project and would like to continue your learning trajectory, there are several options:

1. Participating in the Soldering Workshop Part 2 – Radio Transmitter
2. Applying your skills to independent projects
3. Exploring opportunities for an in-person class

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