Make Your Own Radio!

April 18th, 2015

Welcome to Expanding Your Horizons (EYH) at Cornell University! Here at Cornell Physics, you are going to be making your own crystal radio set, powered by radio-wave signals traveling through the air!

During today's workshop, we want you to learn how radios work, and about the special materials that make them work. We also want you to learn valuable electronics skills, such as how to recognize components and how to *solder*, or glue, pieces of metal together. Best of all, you will have a radio that you can test out at home!

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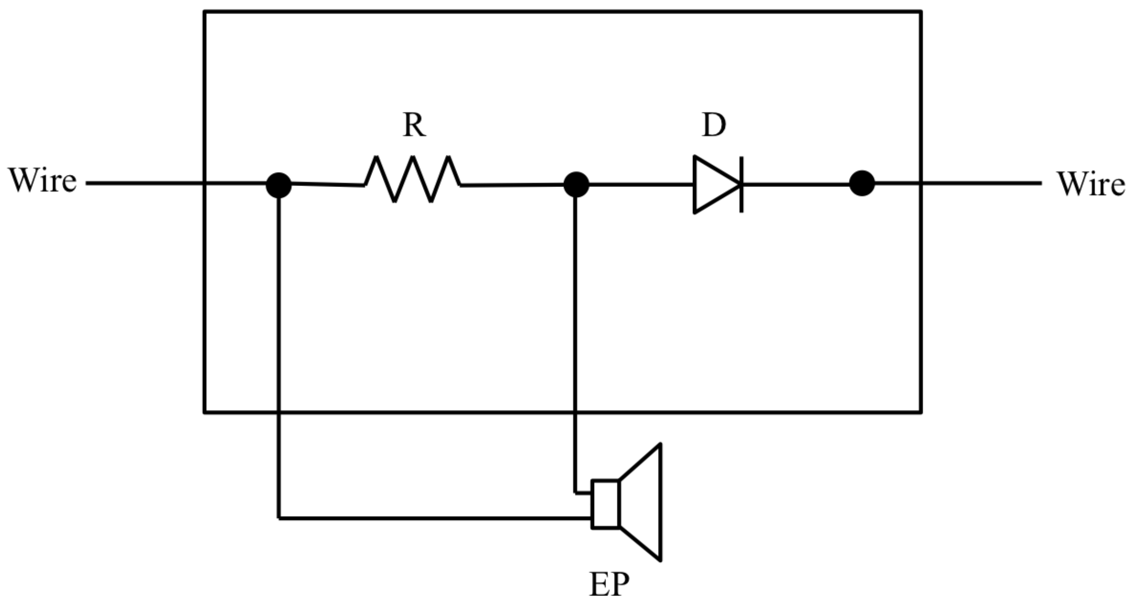
Glossary:

Term	Definition
Electromagnetic (EM) Waves	waves that travel through space carrying energy that is associated with electric and magnetic fields. Light is an EM wave.
Radio Waves	a certain type of EM wave that has longer wavelengths and can be used to carry information over long distances
Current	movement of electric charge due to an electric or magnetic field
Voltage	energy that can be stored or applied, and can move charge from one place to another: it pushes current
Electrical Circuit	a closed loop of wires and other components that allow for current to flow. A circuit may be designed to achieve a certain outcome such as to receive and to relay signals.
Circuit Elements	parts of a circuit
Conductor	a material that allows current to flow easily
Insulator	a material that does not allow current to flow easily
Semiconductor	a material that only lets current flow easily under certain conditions. A semiconductor behaves like an insulator until a certain voltage is applied to it.
Germanium	a certain type of metal that acts as a semiconductor. The diode in the radio in this workshop is made out of Germanium.
Antenna	a piece of metal that receives signals in the form of electromagnetic waves
Ground	part of the circuit that allows signals to exit the radio (in this case, another piece of metal that can receive signals)
Resistor	part of a circuit that releases energy from the circuit for a particular use. A light bulb, for example, is a resistor that releases energy in the form of light and heat.
Cathode	negative end of a diode
Anode	positive end of a diode
Diode	a circuit element that only allows current to flow in one direction
Solder	metal that is melted and then cooled in order to hold other pieces of metal together. You can think of it as metal glue!
Soldering Iron	tool used to heat the solder and the region that you are soldering
Piezoelectric material (piezo)	a material that changes size when a voltage is applied to it (it also produces a voltage when it’s size changes!). The earphone that is used to convert the electrical signals to sound in this radio is made of a piezoelectric material.
Half-Wave Rectifier	a device that keeps only the positive part of the alternating current wave

How to build your radio:

Here is a circuit diagram that shows the electrical layout of the radio.



There are going to be three nodes, or junctions (large dots on the diagram) on a block of wood (the rectangle).

Before you solder the junctions together, you should twist together the wires you wish to connect.

Left Node: Connect a stripped end of a a cable wire (Wire) and one lead of the earphone (EP) to one end of a resistor (R).

Step 2: Connect one end of a diode (D) and the other wire from the EP to the other side of the resistor.. The cathode (little red stripe) of the diode can be pointed in either direction. You have now built a half-wave rectifier that powers your radio!

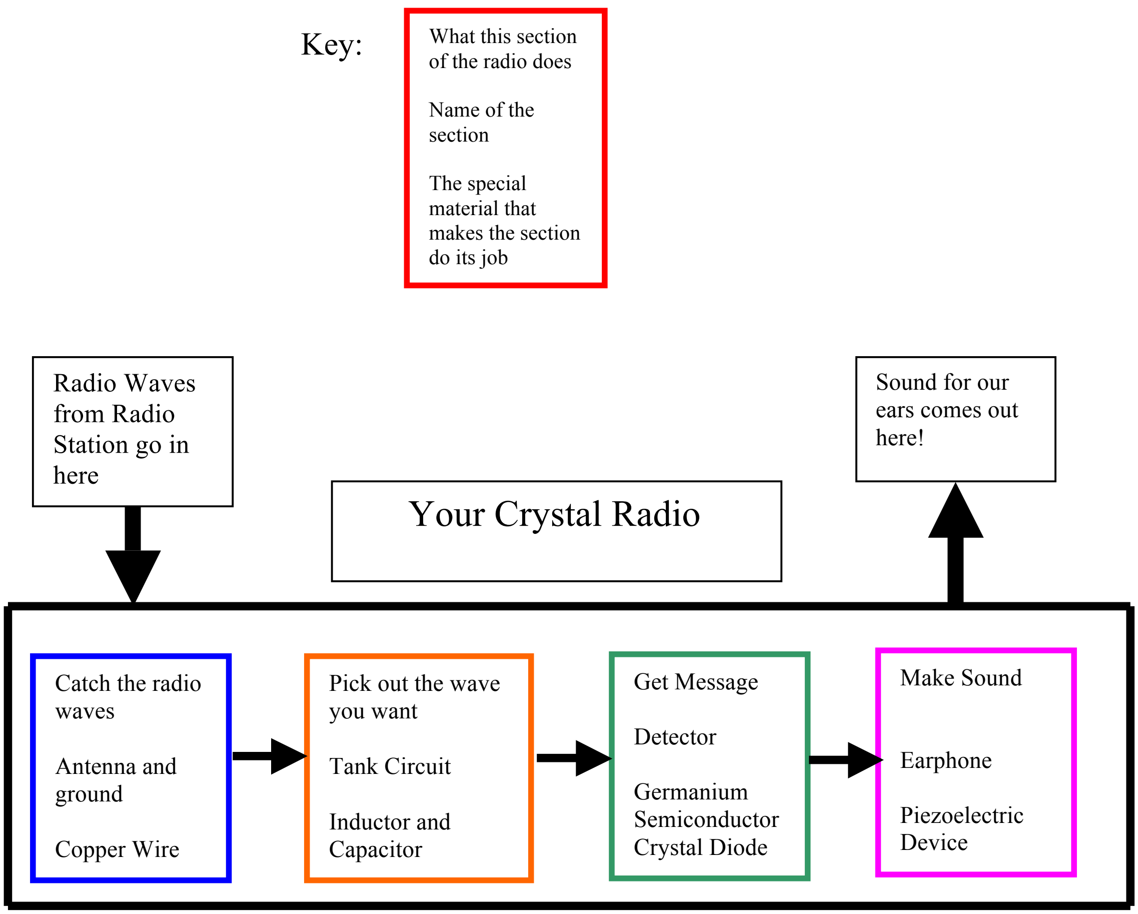
Steps 3 and 4: On the other end , solder a cable wire (Wire) whose ends have been stripped for conducting electricity. Either wire can be antenna or ground (it doesn't matter because an AC signal oscillates between a positive and negative voltage, so flipping the polarity of the wires doesn't change anything).

Step 5: Finally, connect an earphone (EP) onto the pennies that are connected by the resistor.

Extra Step: You are now ready to connect the separate wires to ground and an antenna and listen to your radio!

How the “Crystal” Radio works

Here is a chart showing how signals flow through the four different parts of the radio. In the next four sections, the handout goes over what each of the four parts does and describes the material that is needed for each part to work.



Here is an overview of what each part of the radio does, and the role each material plays:

Part 1: Catch the radio waves!

(Key Material: Metal Conductors)

Radios are excellent for communicating over long distances. Radio waves can carry your voice a whole lot further than you ever could send it just by yelling through the air.

So, where do these radio waves come from?
Radio stations launch electric and magnetic forces through space that come and go a million times per second. These electromagnetic vibrations are not always the same and produce waves with different strengths and frequencies. In fact, a radio station can change the strength of these waves very slowly—often thousands of times per second—in order to carry messages in the form of words or music that they want us to hear.

How do we catch these radio waves?
To catch radio waves, we can often use large pieces of metal that readily allow electricity to flow through them. Materials that let electricity easily flow through are called conductors. We use electric forces in the radio waves to set electric current (moving back and forth in time, which is called an alternating-current or AC signal) to the wave in the copper metal wires (more good conductors) that connect our radio at the antenna and ground connections. Since copper is a good conductor, it can facilitate the movement of these currents across the radio.

Which parts of the radio catch the radio waves?
Radio engineers call the conductor that "catches the wave" in space the "antenna." It can be the wire that comes with your set alone, or a piece of metal such as a gutter or an air duct. The "ground" is a connection that allows a desired electric current to pass from the antenna and through your radio. When running a home crystal set, one can frequently use a cold water pipe, so long as it is made out of metal (often copper). The "ground" does not have to actually be connected to the earth.

What makes a good conductor?
When you look for a good antenna and ground combination, you are really seeking two large conductors that are appropriately shaped and oriented and not already connected to each other. (Try to see what works!). You can then hook up your radio between them (one side of the cable wire connects to the antenna, and the other side connects to the ground) and catch the AC radio signals that pass back and forth between the antenna and the ground.

WARNING:
DO NOT stick your radio's wires into wall outlets. DO NOT connect your antenna and ground cables to power lines. Please talk to your parents before you test out your radio at home. ☺

Why doesn't the radio waves just leave the wires as it is traveling through?
To prevent the loss of our radio signal, we use wires that have colored plastic around them. Materials that do not allow electricity to pass through them – like the plastic – are called insulators. You will need many forms of insulators in your radio (why?). Try to see if you and your instructor can find some!

Part 2: Pick out the wave you want!
(Key Material: Variable Capacitor)

What radio stations can we listen to?
In today's workshop, you will build a radio consisting of just (1) a resistor, (2) a germanium diode, (3) an earphone, (4) a wire to connect to the antenna, and (5) another wire to go to ground. After you build your radio, you may have notice that unlike other radios, you cannot tune this one to any station you want (so far…). Additionally, depending on how many different antennas you tested, you may have noticed that with a different antenna, you were able to listen to a different radio station. This is because the different antennas that you tested had different properties. Specifically, each antenna has a different inductance that corresponds to a particular frequency of radio station.

With this particular radio, there is no separate inductor or capacitor. The setup of just the resistor, diode, and three pennies is enough to pick out one or two AM radio stations.

(➔ BONUS: TAKE-HOME ACTIVITY ⇦)

Can I modify the radio to listen to more radio stations?
Yes! By adding a coil of wire with a fixed inductance and a variable capacitor to vary the frequency of the waves, you can modify your radio so that you can tune it to your favorite station!

Why does this work?
Just as a playground swing swings best when we pump it at the right rate, the tank circuit composed of the coil and a capacitor will set an electric current swinging back and forth if it is tuned for the right station, Around Ithaca, the station WTKO vibrates waves at 1,470,000 times per second (1,470 kHz, or 1470 AM) and the station WHCU vibrates waves at 870,000 times per second (870 kHz, or 870 AM). By adjusting the tank circuit to the right rate of electric vibration, you can not just selecting the station we

want, but you are also making the signal stronger, just like we pump a swing at the right frequency to make it swing with a stable oscillation.

Part 3: Get the Message!

(Key Material: Germanium Semiconductor Diode)

What part of the radio turns the radio wave into a message?

The neatest trick in the whole radio is pulling the message—broadcasted music or speech—off of the AC current that comes from the tank circuit. This happens in the detector stage, and is accomplished by our most special material: the germanium crystal diode. This is what makes our radio work, and this material is what makes our radio a "crystal radio." Germanium, like so many materials that are at the heart of today's electronics, is a material that conducts electricity much more than an insulator, but not as well as a metal conductor. That's why germanium is called a *semiconductor*.

How is the message encoded in the radio wave?

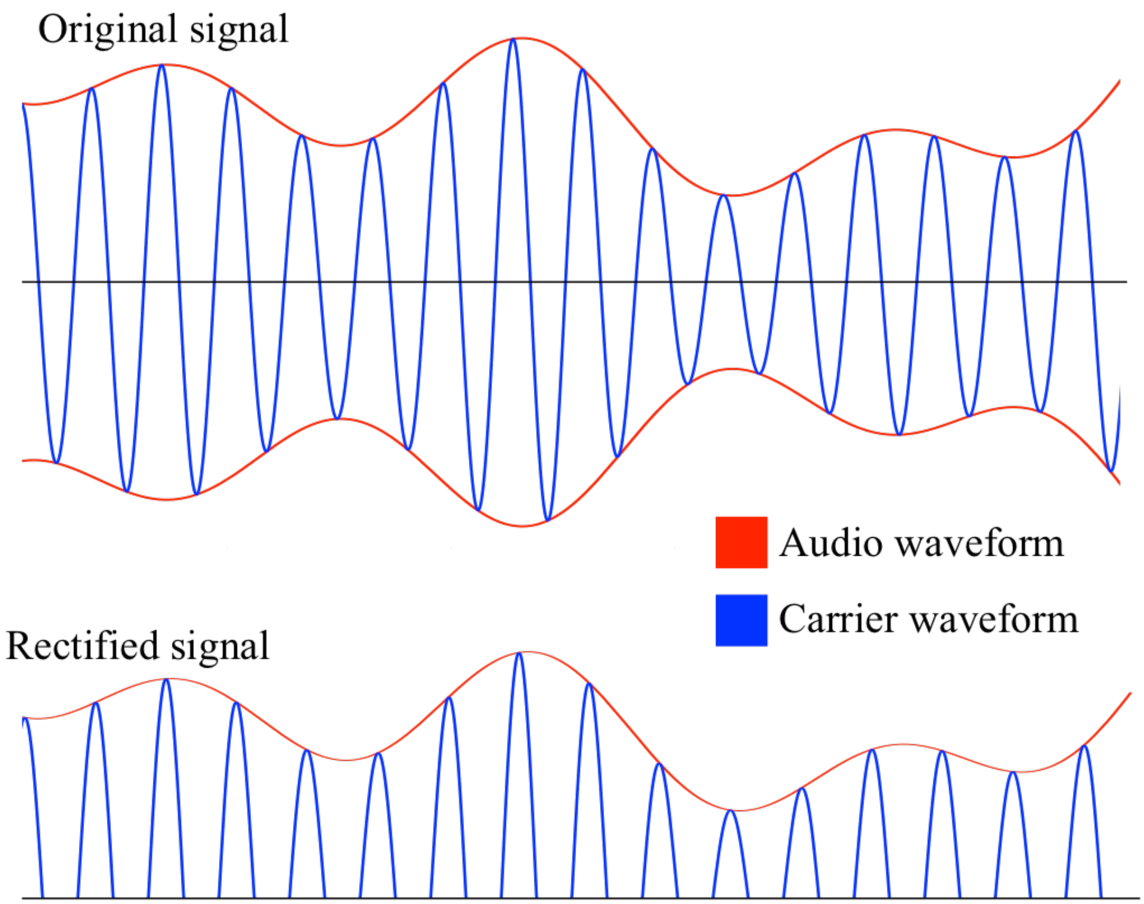
Our crystal diode has a special property that is essential for pulling the message off the vibrating current: it passes current better in one-direction than in the opposite direction. The diode can be thought as being a one-way switch. This allows slow changes in AC electrical signals—the vibrations that generate music and speech—to be detected easily. We can explain this in detail as follows: following the tuner stage, the radio uses a germanium diode to extract the audio signal from the much higher frequency radio wave that has carried it to this point. The AC signal is encoded based on how strong the radio wave is jiggling (we call this the "amplitude" of the AC signal).

How do we turn the wave into a current (that will later be read as a message?)

The diode rectifies half of the AC signal, blocking the other half. This is very similar to how household appliances have a "brick" power transformer that takes in AC signals from the power outlet, and converts them to DC (direct-current, or fixed-voltage) signals. Half-wave rectification is really like a one-way valve for electric current. Rather than confront the earphone with an AC voltage that swings between positive and negative values (our ears would not detect such rapid variations anyway), we use the diode to pass current in only one direction. Once smoothed by the earphone circuitry, this half-wave appears as an immediately recognizable sound.

Quick Summary

To repeat: a radio wave carried a signal through vast distances in the air. The diode in your radio pulls the audio message off of the wave by passing its rapidly oscillating AC current in only one direction. The resultant signal is then smoothed into a slowly varying wave. If we had not rectified the signal, then successive swings of the radio wave would have cancelled each other out during the smoothing process. Can you think of other things at home that need to do tricky electrical transformations to do their job?



Part 4: Make Sound!

(Key Material: Piezoelectric Earphone)

How does the earphone turn the current into a message?

The last step is to turn the electric *currents* representing speech or music back into sound that we can hear. Our earphone does this. It uses a special material that has the property of being *piezoelectric*: when we apply a voltage across the piezo, it changes its size, and this change in size is enough to make the air around the earphone vibrate a sound wave that you can hear.

Do you know about other devices that we use all the time to make electrical currents into sound? What about the other way around? One of the neatest features of your radio is that it gets all its power from the radio wave itself! It doesn't need a battery, and it doesn't need to be plugged into the wall! Isn't that neat?

Tips about using your radio at home:

WARNING: Antennas and Grounds!

You'll need to connect your antenna and ground to the appropriate terminals through the clips on wires that you made up. Please be very careful not connect to live electric wires (conduit casing is fine for a ground, however). Most importantly, don't throw antenna wires over any utility cables: it is *really really really* dangerous if you get your radio cable on an electric power wire. Also, don't ground to gas lines. Outdoor antennas are fine as long as they are temporary and are not left connected to your radio or house in times of possible lightning strikes. If you use a permanent outdoor antenna, you will need a lightning arrestor. A licensed electrician knows how to set one up, but that could be costly.

A swell ground is provided by a metal (not plastic, that won't conduct electricity!) cold water pipe. We have also had good luck with the metal nut on the outside of the coaxial cable connector for televisions (be careful not to connect to the center conductor). You can also make a better antenna by simply stringing up your antenna wire as far as it will stretch. Outdoors, it helps to get your antenna off the ground, at least by a few feet. An antenna may also be provided by large pieces of metal such as a metal doorframe or rain gutter (again, think about the possibility of lightning and don't leave your set connected when not in use).

One of the best antennas we have found is an air duct. For an outdoor birthday party, we found that a garden hose faucet made a swell ground. For the antenna, we found that a fine gauge magnet wire sent up about 50' into a treetop by a big Mylar helium balloon worked really well! The trick is to be patient and willing to experiment (for example, try aiming the antenna in different directions). You should try to bite through paint with your clips to make contact with bare metal. It is possible, however, to make a connection by simply wrapping wire without making bare metal contact.

In short: *Generally, avoid overlapping the antenna and ground wires.* It will be fun to discover what works for you!

What to Listen for and When to Listen

You may be surprised to discover more stations at night than you can hear during the day. This is because the high reaches of the atmosphere can sometimes reflect radio waves from far way. If you're persistent, you may become an expert on this effect. Also, you may even pull in new stations that are higher in frequency than the usual broadcast band.

Troubleshooting Defective Earphones

We have found that sometimes a good strong signal will fade away for no apparent reason while you are listening. If this happens to you, try tapping on the earphone (don't smash it, or else it'll break! Striking the shell of the earphone with you finger with the force of a finger snap is the trick). If this doesn't work, and your earphone seems to be broken, then please let us know, and we'll give you a replacement earphone (as long as we are in stock) in exchange for the defective one. We are pre-testing our earphones, but you may still get a poor performer based on what happens when it's connected to the radio.

We would be delighted to hear about you using your crystal radio at home! Feel free to contact us with any comments or questions about using your radio or adding a tuner to the radio. Our main email address is sps.cornell.outreach@gmail.com, but you could also email us individually.

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