

V. Receiver/Transmitter Basics



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Speak to someone and your vocal chords vibrate causing the air surrounding your vocal chords to vibrate sympathetically. These vibrations exert forces on the surrounding air molecules, which in turn exert forces on the next layer of air to be set into vibration. Eventually these disturbances in the air medium carry themselves to someone's eardrum, which in turn vibrates sympathetically with the air nearby. The eardrum vibrations are transmitted into what we perceive as sound by ultra-sophisticated biological machinery. Something to keep in mind here is that by the time the sound reaches the ear, the eardrum is detecting pressure variations so small that they can be measured in parts per million.

Sound travels better through solids. Two tin cans and a wire make an excellent remote audio communications device that can work over a distance of up to 100 feet or more. The mechanical vibrations of sound in a metal are easily transmitted over great distances.

In a way, radio transmitters and receivers are no different, except instead of depending on mechanical waves, which cause matter to vibrate, we depend on radio waves to vibrate electrons. The following analogy is illustrated below.

Transmitter → Intermediary → Receiver

1. Transmitting matter vibrates (e.g. vocal chords) → 2. Nearby matter is set into vibration, creating a sound wave. → 3. The sound wave transmits energy causing receiver matter (e.g. eardrum) to vibrate

2. Charged particles are accelerated (set into vibration) → 2. Electromagnetic waves are transmitted across a background of empty space → 3. The electromagnetic wave transmits energy to other charged particles (receivers), which vibrate with electromagnetic fields.

This simple picture is the basis for all radio communications and radio astronomy. Something happens that causes charged particles to change their state of motion. The difference in energy of the state transition of the charged particle determines the frequency of the radio wave (photon) emission via Planck's law $E = h * f$. Radio waves propagate through space. These electromagnetic waves reach their destination, a charged particle, and the photon is absorbed by an electron, altering its state of motion.

There is a macroscopic (large scale) picture and a microscopic picture. We will talk about electrons, though any charged particle will do. The summary macroscopic picture: electrons shake, shaking electrons create electromagnetic waves like ripples on a pond, and these ripples cause other electrons to shake. The summary microscopic, quantum picture: electron undergoes a quantum state transition (quantum jump), the difference in energy of the quantum jump is carried away by a photon and the photon is absorbed by

another electron affecting it to undergo a quantum state transition of its own. The microscopic summary is the true one although it sounds strange. Many billions and billions of these quantum jumps occurring in concert appear like the macroscopic picture. On a small scale the universe looks lumpy and grainy from a submicroscopic quantum point of view. On a large scale we cannot notice the lumpiness of individual atoms and quantum states, everything appears as a continuum.

Your local radio station shakes electrons so violently that they emit 50,000 Watts of power in the form of radio waves. Only the tiniest portion of this power makes it to your antenna. Your antenna measures milliVolts inside your antenna. The gain producing elements in your radio circuitry magnifies this minute whisper of a signal until it is strong enough to vibrate the membrane of your speaker.

A hydrogen atom consists of one proton and one electron. The electron has a property known as *spin*. Spin can be either up or down. When the electron in the hydrogen atom undergoes a quantum transition from spin up to spin down or vice versa, radiation is emitted at 1420.4 MHz. This would be 1420.4 FM on your FM radio if there were such a thing. You can listen to it. Aim an antenna or radio telescope along the equator of our Milky Way Galaxy and you are certain to find lots of hydrogen this way. The emission spectrum of hydrogen provided the first real hope of mapping our Galaxy beyond the limitations posed by optical observations in which light is absorbed and scattered by interstellar dust.

Deep space is far from empty. The Orion Nebula is full of ammonia masers, pew! Maser stands for microwave amplification but stimulated emission of radiation similar to laser which stands for light amplification but stimulated emission of radiation. Carbon monoxide, silicon monoxide, water and deuterium have all been detected because we can compare the frequency of the radiation observed in space with the frequency of the known emission spectra of atoms and molecules. If you could taste the universe, some parts of it might actually taste sweet for in the black depths of outer space the emission spectra of sugar molecules has been detected. This is not a joke; we repeat this is not a joke! Besides sugars, other organic molecules have been discovered in space. Outer space as it ends up is now the realm of the chemist as well as the astronomer.

A supernova ought to be enough to shake things up. When a star dies in this spectacular manner, matter is ejected at near light velocities. The massive acceleration that the charged particles from plasma, atoms and molecules experience causes the charged particles to emit radiation at comparable energies and frequencies. Supernova remnants are full of x-rays created by the initial stellar blast. Mysterious gamma-ray bursts occur regularly and are thought to be caused by ultra high-energy cataclysms such as the merger of neutron stars or the theoretical black holes.

Most of the universe is composed of plasma, a hot soup of charged particles too energetic to form atoms. Streaks of plasma accelerated in Earth's magnetic field are the source of the beautiful auroras toward the North and South poles. Streaks of plasma in far away galaxies and deep interstellar space create auroras of their own. Electrons moving at near

light speed accelerate due to galactic and interstellar magnetic fields. These electrons emit a very distinct type of radiation called **synchrotron radiation**, which at first scientists were unable to explain. Ginzburg and Syrovatskii were the first to answer the riddle posed by these exotic interstellar auroras.

The nighttime used to be a haven for looters, robbers and other malefactors. Thanks to our understanding of electromagnetic radiation these bad guys can run but they can't hide. Police helicopters are equipped with an infrared camera, which can see the light emitted from a fleeing criminal's body heat. Every object with a temperature emits radiation. This radiation is known as thermal radiation or blackbody radiation. Understanding blackbody radiation led to the discovery of the quantum, little packets of matter or energy, and eventually to our present understanding of quantum mechanics, the rulebook that describes the motion and states of these tiny quanta. You can see body heat in infrared but a hot body like the Sun emits at a higher frequency. The Sun's thermal spectrum is made up of mostly visible light. Seeing how this is most of the light that penetrates our atmosphere it only makes sense that our eyes are designed to see it.

So what does all this have to do with two kids communicating using two tin cans and a wire between them? Everything! The same principle is at work. Somewhere in the universe, both nearby and far, far away, charged particles are whirling, shaking, and dancing; making electromagnetic waves on a cosmic sea. All we need is an antenna, a "tin can" for hearing light itself, and we can listen to body heat, electricity in power lines, FM radio waves, interference from a telephone answering machine, the thermal energy of the Sun, gamma-rays from the moon, hydrogen in galaxies, planets, galactic jets and quasars at the edge of the universe.

Questions

1. What are some of the differences between man-made electromagnetic radiation and electromagnetic radiation that occurs in nature? How can we distinguish the two?
2. Distinguishing between man-made radiation and radiation from outer space is a big problem for radio astronomers. Certain bandwidths have been protected by law for radio astronomy. Which bandwidths are being protected and what are some objects that radio astronomers are observing in these bandwidths?
3. Radio receiver and transmitters are very simple in essence. We gave an analogy between radio receivers and transmitters, and two tin cans carrying sound waves through a wire. What might be some limitations of this analogy? Can you suggest a better one?

Constructing a Simple AM Radio Receiver

Materials

- Ear phone with two leads
- Germanium diode (lowest possible voltage)
- 10 yards conducting wire
- Copper ground spike
- Wooden stakes
- Extra wire (shielded), alligator clips

Introduction and Instructions

It is easier than you think to create a radio receiver. This one is perhaps the easiest of all. Radio waves cause electrons inside a wire to oscillate from one end of the wire to the other. All we need to do is listen to them somehow. If you were to apply the two leads of an earphone to the wire you might hear something but the odds are against it. Why? Your earphones respond to direct current (DC). We have alternating current (AC) in the wire because the electrons are going back and forth, waving in the radio waves. We need to somehow change AC in the wire into DC. A diode is a device that allows electrical current to flow only in one direction. (In reality a little bit of current flows back against the direction allowed by the diode but we can ignore it here.) If we attach a diode to the end of the wire and give the electrons a place to flow, a ground, then we can have DC. The electrons that flow past the diode cannot flow back in the opposite direction. The electrons then flow to the ground. If we attach one lead of the earphone in front of the diode and one lead after, we'll have enough current to power our earphone. If that succeeds we can hear a nearby AM radio station. All speakers and earphones work by amplitude modulation so AM signals don't need to be converted.

You can lengthen or shorten your antenna to receive different frequencies. The wavelength of AM radio waves is around 300 ft. You might notice an improvement in reception at this length or longer wire lengths. AM signals can be received with an antenna that is far from the optimal length however because they are relatively strong signals and don't attenuate in moist air unlike FM.

Assembly

1. Extend wire using wooden stakes to hold it up so that it doesn't touch the ground.
2. Attach germanium diode to wire
3. Connect other end of diode to wire connected to ground spike
4. Attach earphone leads to wire. One lead goes in front of the diode, the other behind it.
5. Listen.

6. Change the length of the wire and record any changes in reception that you encounter.
7. (Optional) Replace the earphone leads with leads connected to an oscilloscope.

Constructing a Simple Transmitter and a Simple AM Voice Transmitter

Part I. A Simple Transmitter

Materials

- AM Radio
- Nickel
- 9-Volt Battery
- Compass
- Wire
- Lantern Battery
- Empty Toilet Paper Roll

We can accelerate electrons around a circle causing them to emit radiation by forming a complete circuit. Tune to an empty AM frequency on the radio. Tap the leads of a nine-volt battery with a nickel while holding the battery about 2-inches away from the antenna. When current is suddenly accelerated around a loop, a tiny burst of radiation strong enough to be detected when the antenna is close, is produced.

Describe the sound produced _____

You can repeat the same experiment by wrapping an empty toilet paper roll with wire. Connect and disconnect the circuit and the current that flows along your coiled wire produces a sufficiently strong magnetic field to deflect a compass needle. See if it can be heard on AM frequencies.

Describe the sound produced _____

PART II. A Simple AM Voice Transmitter

The transmitter in part one is too simple to transmit anything other than Morse code. Morse code is usually transmitted through a wire anyway, so our transmitter in part one is absolutely not practical for any applied purpose. It does show how easy it is to make electromagnetic waves though.

We will now build the simplest practical transmitter that can transmit a useful signal, which we can listen to using our simple receiver. You will need the following supplies.

Materials

- Portable CD player
- 1 MHz crystal oscillator
- 1000 Ω to 8 Ω audio transformer
- Circuit board
- Jack to connect to CD player audio port.
- 9-volt battery clip
- 9-volt battery
- Alligator jumpers
- Insulated wire for an antenna
- Metal can or antenna

How It Works

The crystal oscillator is the most important component of the transmitter. The oscillator has four leads. We will use only three of these leads. When two of the leads are connected to the 9-volt battery, the voltage on the third lead begins oscillating between 0V and 5V, depending on the signal strength received, one million times per second. The third lead is connected to a tin can or antenna to assist in transmitting the signal. The audio transformer serves to modulate the signal strength before it reaches the crystal oscillator, making the signal stronger. Your computer supplies the initial audio signal, which is carried through your computer sound port. The signal amplitude modulations ride on top of the 1MHz signal output. If you tune your radio to 1000 AM you should be able to hear the signal being transmitted by your computer through the waves being generated by the crystal oscillator.

Assembly

1. Attach audio transformer, 9-volt battery clip, and crystal oscillator to the circuit board.
2. Attach two leads of the audio jack to the two 1000 Ω leads of the audio transformer.
3. Attach one of the 8 Ω leads of the audio transformer to a power lead on the crystal oscillator.
4. Attach the other 8 Ω lead of the audio transformer to the positive terminal of a 9-volt battery.
5. Connect the negative end of the 9-volt battery to a second power lead of the crystal oscillator.
6. Connect the third lead of the crystal oscillator to an antenna.
7. Plug audio jack into the portable CD player. Play a selection of music on the CD player. Keep it clean or we'll have to use Johannes Strauss's Favorite Polkas CD.
8. Tune in to 1000 AM. Alternatively, you could use the AR3000-A receiver with the whip antenna. If reception is unclear try moving closer to the transmitter or change the orientation of the antenna connected to the transmitter. Some troubleshooting of your setup may be necessary.

Questions

1. How far can you go from the transmitter and still receive a good signal?
2. Try different antennas. Which antennas work best as transmitters?