R F I

(Radio Frequency Interference)

RFI Projects and Activities by Susan Dunn and Jason Brown

This unit was created under the Research Experience for Teachers (RET) program at MIT Haystack Observatory, summer 2003, and funded by the National Science Foundation.

Introduction to the Radio Frequency Interference (RFI) Unit

This unit was created under the Research Experience for Teachers (RET) program at MIT Haystack Observatory, summer 2003 and updated summer 2004, and funded by the National Science Foundation.

This unit introduces radio frequency interference into the high school classroom to help students understand the concepts behind electromagnetic radiation, matter and energy in the Earth system, the origin and evolution of the universe, and wavelength vs. frequency. These are difficult concepts for students to grasp and the activities in this unit are intended as added tools for the high school Earth Science, Astronomy, or Physics teacher. Some of these activities are stand alone units and others will require some background set-up, electronics, and software. The electronics used were two different radio communications receivers, one used in 2003 and the other in 2004. The receiver used in 2003 is the AR-3000A communications receiver along with the SEARFE scanning software, developed in Australia. This software is available for free from the SEARFE website at www.searfe.atnf.csiro.au. The second receiver used was the WiNRADiO WR-1550e, which comes with the scanning software. For a complete evaluation of both receivers, see www.MIT.Haystack.edu.

The activities in this unit include: **Investigating the Radio Environment**, where students will use a communications receiver to scan various frequencies of the radio spectrum to determine areas of high and low usage; **Time Variation of Background Signal Strength,** where students will investigate how the radio environment changes with the time of day or night; **Signal Strength vs. Location,** students will explore how topographical features affect radio transmission and reception; **Detecting Meteors Using a Communications Receiver,** students will use a communications receiver to listen to and graph meteor intensities; **Mapping the Radio Frequency Environment of Your School,** students will map the radio frequency interference of electronic items around their school.

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Massachusetts Science Curriculum Frameworks Addressed

- **Earth and Space Science, Grade 9 or 10**
  *** Matter and Energy in the Earth System --**
  1.2, 1.3, 1.4, 1.6
  *** The Origin and Evolution of the Universe –**
  4.7

- **Physics, Grade 9 or 10**
  *** Waves –**
  4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7
  *** Electromagnetic Radiation –**
  6.1, 6.2, 6.3, 6.4

Radio Frequency Interference Unit Objectives

I. *Brief Introduction to Radio Astronomy*

II. *Electromagnetic Radiation Basics*

- Understand the nature of electromagnetic radiation
    - Speed of light c= 3* 10^8 m/s
    - Light can travel in vacuum unlike sound waves
    - Not all light is visible e.g. infrared, radio, x-rays
    - Emphasis on the fact that visible light and radio waves are both forms of electromagnetic radiation.

- Understand and correctly label parts of a transverse wave and longitudinal wave

- Produce transverse and longitudinal waves using a slinky. Observe constructive and destructive interference.

- Understand relationship between wavelength, frequency, and wave velocity.
    - $v = f\lambda$

- Perform calculations of wavelength given frequency and calculate frequency given wavelength for light.
    - Qualitatively understand parts of the electromagnetic spectrum from longest wavelength to shortest wavelength
        - *Radio waves*
        - *Microwaves*
        - *Infrared*
        - *Visible*
        - *Ultraviolet*
        - *X-rays*
        - *Gamma rays*
    - Opportunity to apply knowledge of scientific notation
    - Practice calculations using $v = f\lambda$

- Demonstrate a qualitative understanding of photons

- Understand Planck's energy relation E = h f (h = 6.026 * 10^-34 J s). Explain how higher energy processes correspond to higher frequencies of light and lower energy processes correspond to lower frequencies of light.

- Compare are contrast light waves and sound waves.

III. *Bandwidth Basics*

- Investigate where AM, FM, UHF and VHF frequencies are located in the radio spectrum using the AR-3000A by matching frequencies.

- Create a bandwidth allocation chart of AM, FM, UHF, VHF from data obtained from investigation.

- Students will compare their charts obtained by experimentation to the official United States Frequency Allocations of the Radio Spectrum. (have poster)

IV. *Antenna Basics*

- Students will identify some basic antennas including…

    - Yagi antenna
    - Discone antenna
    - Long wire antenna
    - Parabolic reflector antenna
    - VLF Loop Antenna

- Investigate radio waves from the Sun using the Yagi antenna, Discone antenna and long wire antenna connected to the AR-3000A Communications Receiver.

    - Determine which antennas are directional and which are non-directional by pointing them to the Sun and then away.
    - Identify the frequency where each antenna measures the highest power flux from the sun.
    - Compare power flux vs. frequency for different antennas of the same kind.

- Understand resonance and how antenna length is related to the optimal wavelengths (frequencies) for reception.

    - Compare an optimal AM antenna to an FM antenna.
    - Explain how AM signals are detectable by short antennas.
    - Explain how optimal antenna length is often unnecessary to receive a good signal and under what circumstances.

- Students will make a crude antenna map using the whip, Yagi and Discone antennas. (power vs. azimuth) These crude maps will then be compared to actual antenna pattern from Kraus' Radio Astronomy or other antenna manual/reference.

    - Students are encouraged to try to detect these smaller lobe patterns.

- Pringle Can Wireless Antenna
    - Detect microwaves using Pringle Can Antenna

- Use VLF Loop Antenna to detect radiation emissions from power lines.

- Using the SRT, perform an *npoint* scan of the Sun. Explain the results of the npoint scan to the class. Discuss sky temperature, solid angle, frequency, power flux. Calibrate the SRT and explain the importance of calibration for observations in astronomy.

    - Compare the performance of the Discone antenna to the SRT at the same frequencies.

V. *Receiver/ Transmitter Basics*

- Construct a simple radio receiver and hear transmissions using this device.
    - Simple radio receiver: antenna, head phones, diode, ground wire and spike.
    - Construction of other simple radios (optional)

- Attempt identification of transmission source.
    - Determine frequency/wavelength of transmission source if possible and investigate relationship between receiver length and wavelength of source.
    - Discuss the phenomena of **resonance** and how it is related to receiver design.

- Demonstrate the simplest possible transmitter. Static can be transmitted a distance of a few inches and can be detected by an AM receiver tuned to an empty channel. Explain the physics behind how this transmitter works (changing current → accelerating charges). Explain why the static is strongest the instant the nickel taps and disappears or reduces afterwards.

- Construct a simple transmitter and transmit signals to be detected with the detector receiver mentioned earlier.

VI. *Signal Propagation Effects*

- In the evening, students will find the most remote AM radio station they can receive and record the station’s name (frequency) and its location.

- Next day in class, students will share their findings and be asked to tune to those stations using an AM radio. Upon failure to receive these stations students will be introduced to the **scattering** of radio waves off of the **ionosphere**.

- Discuss the radio window (1 cm – 10 m) and optical window (0.4 – 0.8 microns) and its relationship to the ionosphere.

- Students will use the AR-3000A to monitor a narrow bandwidth (0.5 – 1 kHz) encompassing the remote AM stations for 24 hours and interpret the results.

- Students will be able to explain how it is possible to detect a thunderstorm occurring on the opposite end of the Earth with an essay including a diagram.

- Students will investigate space weather and how it can affect transmissions. Recommended resource: www.spaceweather.com

I. Brief Introduction to Radio Astronomy

I. Brief Introduction to Radio Astronomy

The Birth of Radio Astronomy

At this point in your student career you have undoubtedly been introduced to several science courses with some discussion of the scientific method. The scientific method has been traditionally divided up into five steps which typically go something like this.

1. Observe some aspect of the universe.

2. Invent a tentative description, a hypothesis, that is consistent with what you have observed.

3. Use the hypothesis to make predictions.

4. Test those predictions by experiments or further observations and modify the hypothesis in the light of your results.

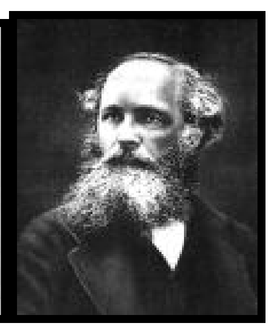
5. Repeat steps 3 and 4 until there are no discrepancies between theory and experiment and/or observation.

If that doesn't put you to sleep, then nothing will! While it's true that the process of scientific discovery can in some way be stretched and molded into the 5 steps outlined above, the true story of scientific discovery has a life of its own and defies simple categorization. Such is the story of how radio astronomy came to be.

For centuries, observations of the cosmos were confined to the optical band 0.4 – 0.7 microns. (1 micron = 10-6 meters) As you have learned, the optical band comprises but a tiny portion of the electromagnetic spectrum. A vast ocean of light waves rippling through the enormous expanse of the cosmos having a much longer wavelength than the optical band was yet to be discovered. This ocean of light exists in the form of radio waves (1 mm to 10 m). These radio waves had stories to tell, bizarre tales of an expanding universe, mysterious quasars, interstellar chemicals in unexpected places, white dwarfs, and black holes. Who would have suspected? We humans often believe only what we can see. Seeing is believing, but what if we had a new kind of eyes?

New Eyes for New Discoveries

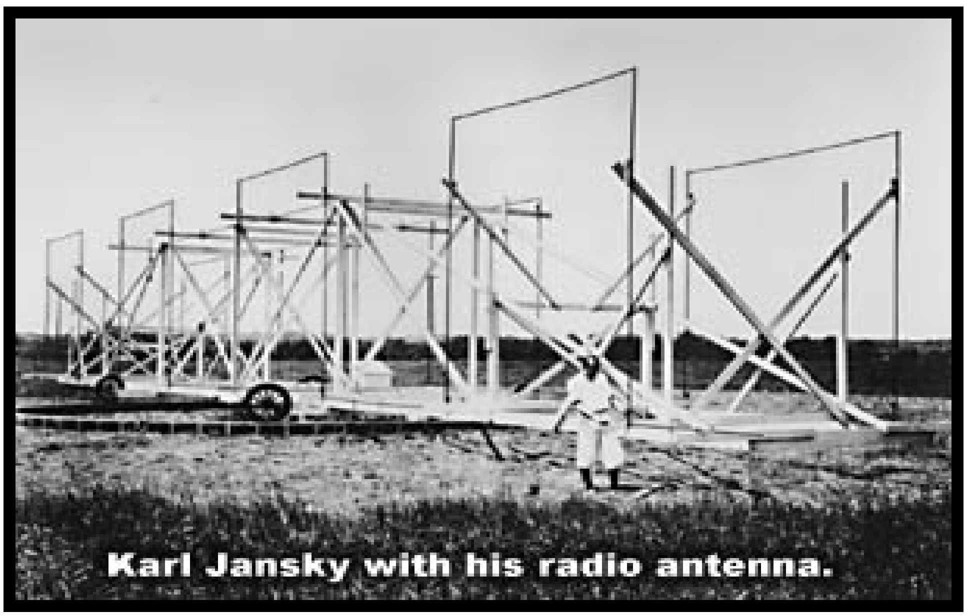
In 1888 Heinrich Hertz built a device that could transmit and receive radio waves. These radio waves were polarized and could interfere just as predicted by James Clerk Maxwell's theory of electromagnetism.

Heinrich Hertz James Clerk Maxwell

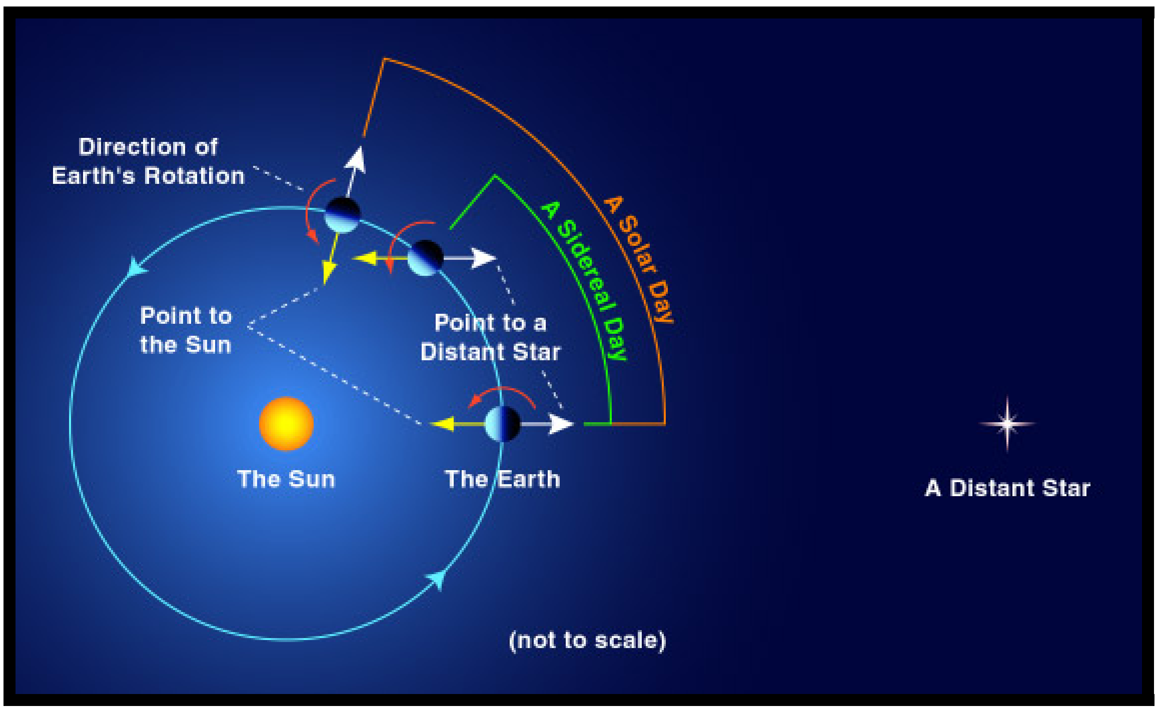
These men saw the light and the new eyes needed to see the light was a radio antenna. Maxwell saw the light with his equations on paper and Hertz was the first to actually detect it. It couldn't have been very long before scientists thought about detecting radio waves from the Sun or other celestial bodies. The first on record to have thought about it was Thomas Alva Edison, you know, the one who invented the light bulb. You might be interested to know that his teacher the Reverend G. B. Engle thought little Thomas Edison was such an idiot that he called him "addled". Other people had the wrong idea about Edison too and mistreated him accordingly. Edison devised an experiment to measure radio waves from the Sun with steel cables wrapped around an iron core. The experiment was never carried out and it wouldn't have worked anyway. The experiment was not very sensitive and the wavelength of radio waves it was designed to detect would have been absorbed in Earth's upper atmosphere.

In 1931, Karl Jansky, a radio engineer working for Bell Telephone Laboratories, was assigned the task of determining the source of radio interference in Bell's transatlantic radio-telephone communications system. Radio static had proved problematic for transoceanic communications and it was Jansky's job to find out if the radio wave interference had a preferred direction, in which case they could easily tune out the interference by using directional antennas pointed away from the source of the interference. Jansky constructed an antenna to study the problem. It was a unidirectional, polarized beam antenna, 30m long by 4m high that was mounted of a circular train track so that the antenna could be rotated in azimuth (azimuth is the rotational angle along the ground.) The antenna structure rotated once every twenty minutes. It operated at a wavelength of 14.6m (20.5 MHz) and was connected to a sensitive receiver where the data obtained by the antenna was logged by a pen-and-paper recorder.


Karl Jansky with his radio antenna.

Jansky worked systematically and identified three sources of radio static: (1) static from local thunderstorms, (2) static from distant thunderstorms found to originate principally from the south, and (3) "…a steady hiss type static of unknown origin." It was this third mysterious source of static which intrigued Jansky. He had worked so systematically that he was well aware that this third source of interference was simply not a mistake or oversight. It was there but what was it? Jansky carefully studied the strange ghostly signals with all his willpower and concentration. At first he thought that his signals might be coming from the Sun. He made careful measurements of how the signal changed throughout the day and it seemed to follow a 24-hr. cycle, implying that the signals were Solar in origin. Upon closer inspection it was determined that the signals followed a 23-hr. 56-min. sidereal cycle. These signals could not therefore be linked with the Sun. What could it be?

The answer to the riddle lay in the 4-minute time discrepancy. As the Earth revolves around the Sun it completes one additional rotation with respect to the fixed stars. The Sun rises and sets 365 ¼ times per year according to someone standing on Earth's surface. There are 366 ¼ **Sidereal** days in one year, each of which is 23-hr. 56-min. Can't see where the additional rotation is coming from? Imagine that the Earth didn't rotate about its own axis. Have the same side of Earth face the Sun as you revolve it once about the Sun. You'll quickly notice that the Earth's actually rotates once about its axis by virtue of having completed one revolution around the Sun. Take out two coins, a quarter for the Sun and a dime for the Earth and try it. Another way to see this is that as Earth rotates about its axis as it revolves around the Sun in such a manner that the next day arrives 4 minutes sooner than if the Earth didn't revolve around the Sun.



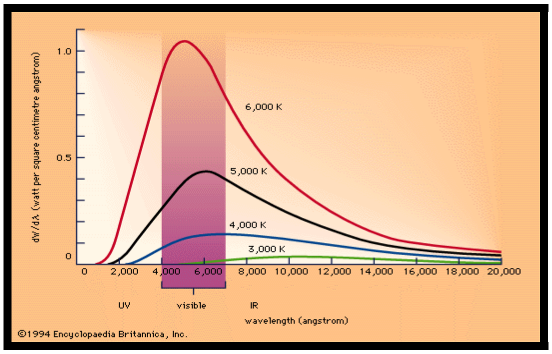
Sidereal and Solar Days

It was clear that the source of the mysterious steady hiss type static was associated with the fixed stars and not with our own solar system or Sun. Jansky found that the signal was strongest when his antenna pointed toward the center of our Milky Way Galaxy. This event marked the beginning of radio astronomy. It was an event of inestimable importance. Mankind saw the cosmos with his new eyes for the first time. Paradoxically, we sometimes can't see things because they're too big. Some discoveries are so important that their significance can only be understood later. The initial enthusiasm faded and Jansky was reassigned. The future of radio astronomy was to be developed by amateur astronomers. Etymology of the word amateur is from the Latin *amator,* meaning one who loves. We usually associate the word amateur with the negative connotation meaning one who lacks skill. This is not its original meaning. An amateur is a devotee, an admirer, someone who engages in a pursuit, study, science, or sport as a pastime rather than as a profession. Radio astronomy was to be continued by just such individuals who saw its potential. It was the good fortune of all mankind that the future of radio astronomy was to find a haven in its nascent stages with such dedicated individuals. One such amateur had an avid interest in the work of Jansky and was determined to continue exploring the vast cosmic oceans of radiation, his name was Grote Reber.

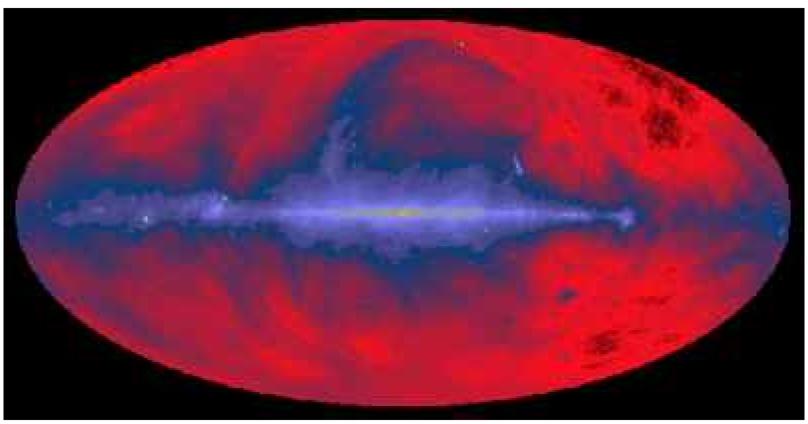
Grote Reber

In 1937, just six years after the groundbreaking discoveries of Jansky, Grote Reber constructed a parabolic-reflector antenna 9.5 m in diameter and operated it from his backyard. He built his antenna at his own expense while working for a radio company. The antenna relied on Earth's rotation to change its right ascension and was adjustable only in declination. Reber's goal was to continue where Jansky left off. He turned his antenna toward the nucleus of the Milky Way Galaxy and investigated the radio waves seen six years earlier by Jansky.

The assumption was that the radiation earlier observed by Jansky would obey **Planck's blackbody radiation law** (see the Planck blackbody frequency distribution curve). The blackbody distribution curve shows how intensity varies with wavelength for radiation emitted from an ideal **thermal** radiator. This ideal thermal radiator comes close to actual thermal bodies in most cases.



The radiation should therefore be stronger at shorter wavelengths. Reber tuned his receiver to 9.1 cm (3,000 MHz) and his first experiments failed to detect any radiation. His antenna was then adjusted to operate at a wavelength of 33 cm (910 MHz). Still no radiation detected. Undaunted he modified his receiver to pick up 1.87m (160 MHz). Almost two years after he began his experiments, Reber found the first conclusive evidence of radio emission from the Milky Way Galaxy.


Milky Way Radio Image

Reber produced the first brightness maps of the radio sky. These maps helped establish radio astronomy as a viable field of study in the minds of then contemporary astronomers. The brightest areas of the radio sky were the in the direction of the nucleus of our own Milky Way Galaxy. Reber's results demonstrated that the radiation was not stronger at the shorter wavelengths but became more intense at longer wavelengths, a trend in contradiction to Planck blackbody radiation law. The sensible conclusion to all of this is that the radiation observed by Reber and Jansky was not blackbody (thermal) radiation. Other mechanisms of radiation emission had to be at work here but what were they? This mystery remained unsolved until 1950 when Vladimir Ginzburg demonstrated that the observed increase in radiation intensity with increased wavelength could be explained by a mechanism know as **synchrotron** emissions. Synchrotron radiation is caused by high speed electrons moving at near the speed of light within the galactic magnetic fields. The magnetic field causes the electrons to spiral, traveling down a path resembling a long helix. This circular movement implies acceleration and whenever a charge is accelerated, it gives of radiation. Electrons could achieve these very high, near light velocities in cataclysmic events such as **supernovae**. At these very high speeds, Newton's laws of motion breaks down and Einstein's theory of special relativity takes over. Because of this, it is common for scientists to refer to these high velocities as **relativistic** velocities.

Towards the end of his career, Reber made an investigation of very long radio wavelengths, 100-300 meters (1-3 MHz). These investigations were not possible in most places because the signal would be absorbed by the ionosphere. Among the few suitable places on Earth where investigations of the wavelengths could take place is Tasmania, where Reber lived out the rest of his days. Reber donated his backyard radio telescope to NRAO (National Radio Astronomy Observatory) at Green Bank, West Virginia. It was painted red, white and blue and is on display for the general public, a memorial to American ingenuity and amateurs everywhere.

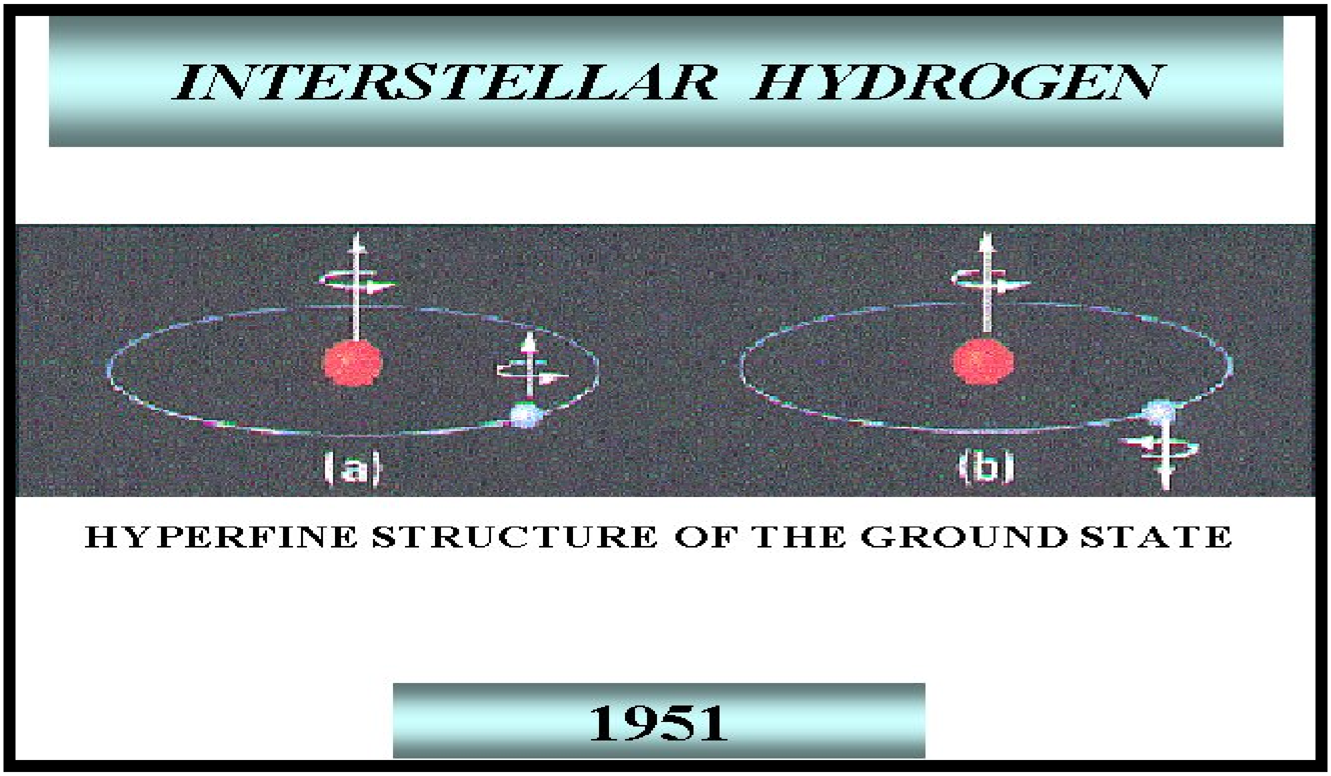
The torch of radio astronomy was passed on to an unlikely place at an unlikely time. World War II ravaged Europe. The entire civilized continent lived in constant fear and anxiety over what the Nazis might do next. Despite the unceasing turmoil and tragedy enveloping the land, some astronomers were able to meet, discuss their theories, have fellowship, and turn their eyes towards the heavens to forget their terrestrial woes if only for a short time.

The Nazis were obsessive about censoring and regulating information inside the countries they occupied. A copy of the Astrophysical Journal managed to reach the Leiden Observatory. Inside were the groundbreaking Galactic maps and discoveries of the pioneering radio astronomers in America. In a time of little hope, this diversion was a Godsend.

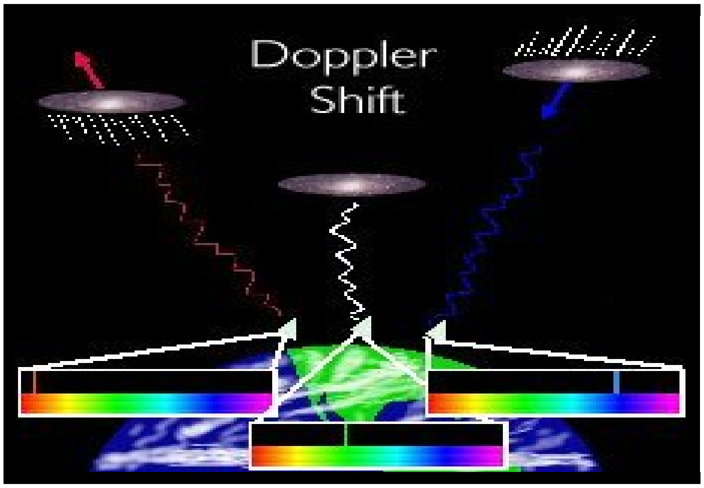
Jan Oort had spent many years exploring the center of the Galaxy. (Whenever galaxy is capitalized it refers to our own Milky Way Galaxy.) His investigations were hampered by the inherent limitations of optical astronomy. On a foggy day, you can't see very far in front of you. If we were somehow able to see in radio waves, everyday would be a clear day. Jan Oort had the same problem. Intergalactic gas absorbed the visible light from the center of our Galaxy before we even had a chance of seeing it. It's as though everyday is a foggy day in our Galaxy. Jan Oort's investigations of galactic rotation met up with these difficulties. The burgeoning science of radio astronomy was the key to unlocking the mysteries hidden away in the center of the Galaxy. Jan Oort wasted no time. He set his graduate student Hendrik Christoffel van de Hulst to the task of investigating which radio frequencies one might observe were associated with the Galactic center. Since the most abundant element in the universe is hydrogen, it was suggested by van de Hulst that they examine the emission spectra of hydrogen's hyperfine structure which corresponds to a wavelength of 21 cm (1421 MHz). The hyperfine structure of hydrogen is a noticeable signature that cannot be mistaken. If the same shape of the hyperfine structure were observed at a slightly different wavelength, it's safe to conclude that it was the hydrogen hyperfine spectrum but **Doppler** shifted.

To understand the physics of what is happening here consider the frequency of the hyperfine structure of hydrogen. The hyperfine structure arises from changes of state inside the hydrogen atom from the proton and electron transitioning from a parallel to anti-parallel arrangement. The energy difference in these two configurations, parallel and anti-parallel inside the hydrogen atom, is related to the frequency of the emission by Planck's relation. This is also called the spin-flip transition.

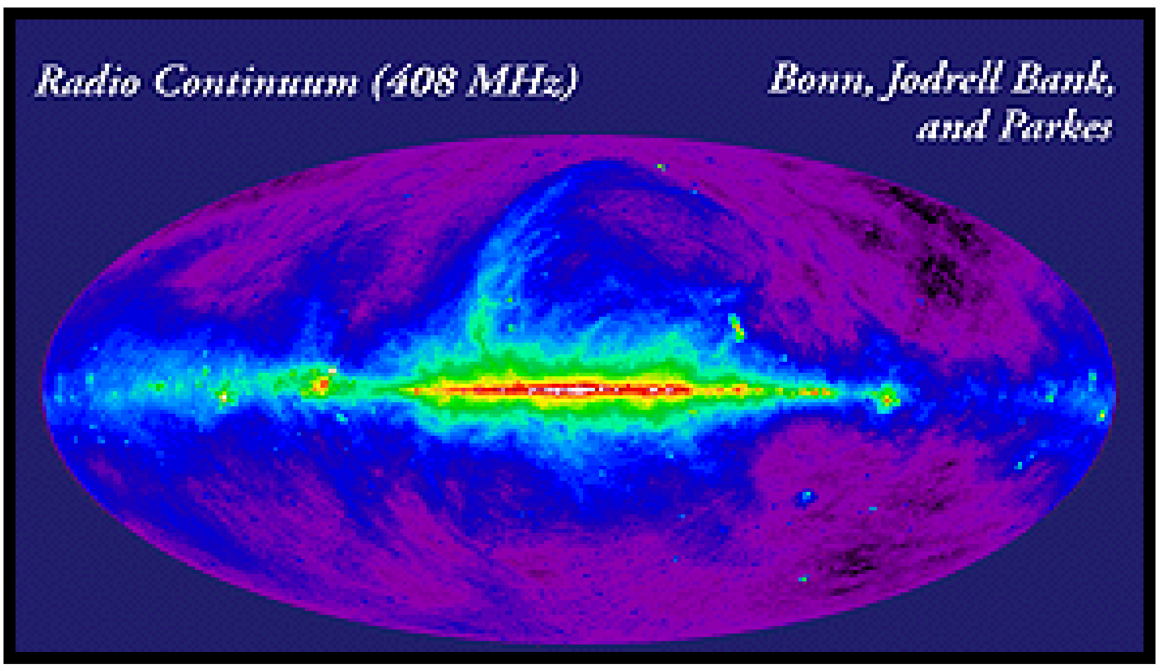
Energy = 6.026 * 10^-34 (Joules * seconds) * Frequency (Hz)



The frequency of the radiation is 1421 Hz. If the source of the radiation is traveling toward or away from us it becomes **blue shifted** or **red shifted**. Most objects in the universe are red shifted meaning they are moving away from us. If the hydrogen is moving away from us, the wavelength will appear to be longer because the source is moving away as the waves are being made. This apparent change in wavelength, and by direct association, also the frequency, is known as the Doppler shift. It is the same phenomena observed when the pitch of a fire truck's siren changes when it approaches and recedes from an observer. The observed Doppler shift in the hyperfine structure of hydrogen makes it possible for scientists to calculate exactly how fast a galaxy or gas cloud is moving toward us or away from us.

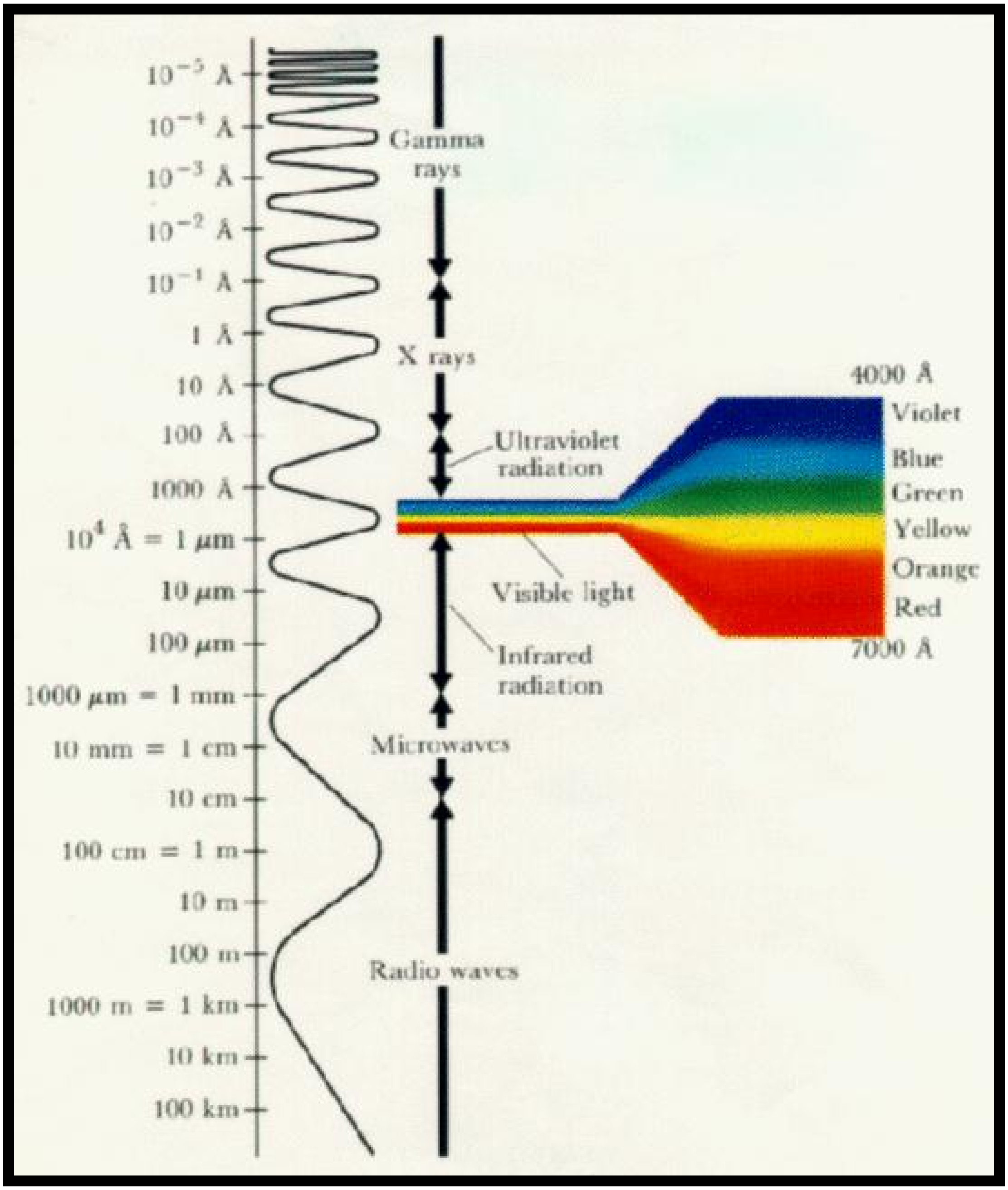


By observing the Doppler shift in the hyperfine spectra of hydrogen, Oort and van de Hulst were able to see past the intergalactic gasses and into the core of our Galaxy. They were the first to accurately map the general features of the Milky Way Galaxy and measure its rotation, a truly monumental achievement.



Radio map of the Milky Way Galaxy

II. Electromagnetic Radiation Basics



II. Electromagnetic Radiation Basics

Introduction

One of the most beautiful experiences we can have is to gaze and wonder at the magnificent displays of nature. Everybody should at least see one sunrise and sunset per year. These moments of serene contemplative solitude remind us of what it is to be human, to wonder, and to imagine. The beautiful displays of light we see in sunrises, sunsets and auroras are no different than the radio waves being broadcast by your favorite FM radio station and received by your radio. In fact, you can even pick up radio waves from the Sun with your radio receiver. You just won't hear the latest rock n' roll song or top 40 music hits coming from the Sun. What you will hear sounds like static and comes primarily from radio waves generated by thermal processes from the Sun, more on that later.

While we're at it, let's correct one of the most common misconceptions about radio waves. *Radio waves are not sound waves*. Radio waves are a type of light which is pure energy and is able to move through the vacuum of space. What radio stations do is to convert sound waves into radio waves which move through the air at roughly the speed of light. These waves reflect off of hills, are absorbed into the atmosphere, bounce off airplanes, reflect off of an ionized trail left behind from a meteor and then finally make it to your radio receiver where they are converted back into sound waves. At first, it seems like visible light and radio waves have nothing to do with each other but they are in fact the same thing. Both are electromagnetic waves. The only thing different about them is their frequency and wavelength. These things will become clearer as we move along so don't worry if some of these details have escaped you. Anything worthwhile takes time to understand and you need to take a few first steps before this all makes perfect sense. You might want to come back later and reread these first two paragraphs after you've gained a handle on the basics to see just how far you've come along.

1.1 Light

Light is just another word for electromagnetic wave.* There are some types of light that you cannot see like infrared and ultraviolet but that doesn't mean it isn't there. Radio waves are also light, just like visible light. X-rays and gamma rays are light also and so are the microwaves that heat your food. Some light is seen with the eye and some types of light are seen with an antenna.

Light travels at a speed of 186,282 miles per second or 299,792,458 meters per second. The speed of light appears to be a natural speed limit. All current theories of physics which have been spectacularly successful set the universal speed limit to the speed of light. There are theories of superluminal travel, of particles called tachyons (Greek for swift) that travel faster than light but these theories have internal contradictions like negative probabilities of being somewhere. Recently, scientists like Lee Smolin and Joao

Migueijo have come up with theories for faster than light travel. Whether their theories stand up to the test of time remains to be seem. For now, we live in a universe where everything travels at or slower than the speed of light.

The speed of light is a universal constant. For this reason it is convenient to name the speed of light by a symbol. The letter c represents the speed of light.

c = 2.997 * 10^8 meters per second.

Because the speed of light is so large, we resort to scientific notation to describe it. Scientific notation is basically a system where every number is described as a power of ten and you are allowed only one digit before the decimal point which has to be between one through nine. (See Appendix for more on scientific notation)

Light moves so quickly that it can travel from the Sun to the Earth in 8½ minutes. If you were to drive your car all day and all night at highway speed it would take you around 160 years to go from Earth to the Sun, assuming you don't burn to a crisp or crash into Mercury or Venus on the way.

Light is different from sound waves in several ways. Sound waves require a **medium** through which to travel. Sound can travel through solids, liquids and gases at varying speeds. Sound cannot travel through a vacuum. An interesting demonstration of this is to place an alarm clock inside a bell jar. You can still hear the clock ticking inside the bell jar if there is air inside the jar. Pump all of the air out of the bell jar and you can no longer hear the clock. (You might hear a little bit of sound but this sound is traveling through the solid bottom upon which the bell jar rests.) All the while you can see the clock just fine because light can travel in a vacuum. Light doesn't require a medium to travel through. For centuries, scientists were disturbed by this fact so they invented an imaginary medium for light to travel through called "ether". Owing to the extremely high speed of light this "ether" had to be incredibly rigid and be of lower density than anything discovered yet, two contradictory properties. The ether was essentially undetectable. The idea of the ether was finally dismissed when Albert Einstein's theory of Special Relativity published in 1905 permanently placed the ether in the drawer of junk science.

Light is a **transverse** wave. Shake a rope tied to a pole at one end and you a creating a transverse wave. The wave is traveling to the pole but the disturbance is traveling up and down or left and right, depending on how you are shaking it. An accurate picture of light is the following. Instead of shaking a rope you are shaking the very vacuum of space. The wave travels toward the pole. The disturbances going up and down are called **electric fields** and the disturbances going side to side are **magnetic fields**. Such a picture is 100% true. The direction that the electric field points toward is called the **polarization** of the light. This of course begs the question, how do you shake the very vacuum of space? The answer is extremely simple. Find a charged object, any electron will do, and shake it up and down. The electron will emit electromagnetic waves which are ripples on the very vacuum of space. An uncharged object like a piece of wood simply won't do.

All light is created this way, a charged object changes it's state of motion and creates electromagnetic waves in the process. How do we detect electromagnetic waves? Easy! An electron shakes thereby emitting light waves. The light waves travel through the vacuum of space. These waves cause the electrons inside your antenna to shake up and down too creating a tiny voltage. Bingo, you have detected an electromagnetic wave! Our eyes do essentially the same thing but through chemical processes involving visible light.

Contrary to what you have thought, radio waves are not complex, they are simple. Suppose you are standing at the shore of a perfectly still body of water. There are two buoys on both sides of the shore. Everyone knows that if you push one buoy up and down it will make waves. These waves spread out and travel across the lake. Eventually the waves reach the other buoy and cause it to move up and down. The lake is the vacuum, the waves are light (electromagnetic waves) and the buoys are electrons.

1.1 Summary and Key Concepts

- Visible, ultraviolet and infrared light, radio waves, microwaves, x-rays, gamma rays are all the same thing, electromagnetic waves.

- The speed of light is 2.997 * 10^8 meters/second.

- Light can travel in a vacuum whereas sound cannot.

- Light is a transverse wave with the electric and magnetic field of light moving at right angles to the direction of the wave.

- Light is intimately related to electricity and magnetism. Light is produced by altering the state of motion of a charged object. Shake an electron and it will make light waves that can shake other distant charged objects.

*** Jargon Alert** – "Electromagnetic wave" has seven syllables, "light" has only one syllable. Scientists just say "light" when they mean "electromagnetic wave" to avoid annoying their colleagues. Since light waves are the same thing as electromagnetic waves, no harm is done. It's the same thing as choosing whether to say "dog", "canine", or "mans best friend". Take your pick. You can also say "radiation" to mean "light".

1.1 Questions and Investigations

1. How many miles can light travel in one day? One month? One year?

2. Light from the edge of the observable universe takes 13.7 billions years to reach Earth. Bizarre objects like quasars at the edge of the observable universe emit lots of radio waves which we can detect. How far away are these objects?

3. Can you infer what a light-year is? Check out if your hunch is right looking in a dictionary or science book. Write down an explanation of what a light-year is for someone who doesn't know. How would you explain it to them?

4. Why does the Sun shine? Where does the light come from? We know light comes from charged particles being shaken or changing their states of motion but what is shaking the particles in the Sun?

5. The most abundant state of matter in the universe is plasma. What's plasma? Could plasma also be a source of electromagnetic waves?

6. Whatever in the universe isn't plasma is either radiation or atoms. Atoms are made up of protons, neutrons and electrons. The net charge of a proton is +1.6 *10^-19 Coulombs. The charge of an electron is -1.6 *10^-19 Coulombs. The net charge of a neutron is zero but if we shake a neutron it still emits electromagnetic waves! What is going on here? (Hint: Look up quarks.)

1.2 Wave Basics

There are two basic types of waves longitudinal and transverse. And now for a little terminology which will all become clear if you apply yourself and practice.

Sound is a perfect example of a longitudinal wave. When you speak, little regions of air vibrate back and forth while the sound wave is traveling forward at around 343 m/s. **Compressions** are regions where the air molecules are closest together in these little regions of air vibrating back and forth. **Rarefactions** are the regions of least air molecule density. The distance between successive compressions is the **wavelength**. The degree to which the air is compressed or stretched can be assigned an **amplitude**, which is a measurement of loudness or of the energy being carried by the sound wave. The time necessary for a fixed region of air to complete a full cycle of compression to rarefaction and back to compression is called its **period** and is usually measured in seconds. The number of cycles per second is called the **frequency** of the sound wave and is usually measured in **Hertz** (Hz). A longitudinal wave is so named because the disturbance that the wave produces is in the same direction that the wave travels.

STUDY HINT: The internet, as with all things in life, can either be good or bad, useful or a waste of time. For seeing a longitudinal wave or sound wave in action, the internet is extremely useful. Java applets are little programs that run in your web browser. These Java applets have been very good for writing short programs that simulate physical phenomena. Go to your favorite search engine and enter "Java physics applets longitudinal sound wave" or something similar. It isn't difficult to find a Java applet for just about any physical phenomena you might wish to see. They are very interesting and entertainingly informative. They can be a resource to help you understand some of the trickier aspects of science and can help make the difference between "kinda-sorta understanding" to solid knowledge and an "easy A".

Shaking a rope tied to a fence is a perfect example of a **transverse** wave. The waves are all traveling toward the fence and the little disturbances (bumps) on the individual segments of rope are moving up and down. Transverse means to lay crossing at a 90˚ angle. The rope itself moves **transversely** to the direction to wave is traveling. The peak of a transverse wave is called the **crest**. The bottom of a transverse wave is called the **trough**. The height of the wave crests is called the **amplitude** of the wave. The point of zero amplitude midway between crests and troughs is called a **node**. Crests and troughs can be referred to as **anti-nodes**. The distance between successive crests is the **wavelength** of the transverse wave. The time lapse between successive crests is the **period**. The number of crests (or complete wavelengths) that go by a fixed point in one second is called the **frequency** of the wave.

Wavelength is given the symbol λ (pronounced "lambda") which is the Greek letter representing the "l" sound. Think of the "l" sound in λ as "length", as in wavelength. Period is given the symbol τ (pronounced "tau", rhymes with "cow") which is the Greek letter representing the "t" sound. Think of the "t" sound in τ as "time", as in time for one complete wavelength to transit a fixed point. Is this all Greek to you? It is to me!

Frequency and period are **reciprocals** of one another. Think about it for a moment. Suppose you are standing on the shore and you count 5 waves going by in one second. The frequency of these waves is 5 Hertz ($f = 5$ Hz). The period, or time it takes for one of these waves to go by, is 1/5 second. Five and 1/5 are reciprocals of one another. Aha! Now you get it!! You genius you!!

Whoa that was hard but as you will see it's not so hard if you get to play a little bit of ***SLINKY*** **!!!**

Diversion 1.2

- You'll need a … Slinky toy
- Flat table surface at least 6' by 3'.
- Two people one at each end of the slinky.

1. Have one person produce a longitudinal wave while the other end of the slinky is held still. Observe the compression traveling through the slinky. A single compression is called a **pulse** wave.

2. The same person will now produce several longitudinal waves, one after another continuously. Observe the areas of compression and rarefaction. If the slinky is

shaken at just the right frequency the compressions and rarefactions will stay in the same place. This is called a **standing wave**.

3. Note that the slinky segments are moving back and forth around what is essentially the same place although the wave is moving forward in one direction. Watch any part of the slinky and compare it to the motion of the wave to see that this is so.

4. Now both people will produce longitudinal waves. Note that the waves pass effortlessly through one another. The sound waves you make in conversation do this all the time.

5. One person will now produce a single transverse pulse wave. (A single pulse will do.) The wave goes forward but the slinky goes side to side.

6. This one is tricky but really cool to watch! One person will produce a single transverse pulse one way and the other person will produce a single pulse wave going the other direction. When the waves meet they cancel. This is called **destructive interference** and is a property of all waves. Even sound waves can cancel each other. After the two waves meet, they continue on as if they had never met.

7. As you might have suspected if waves can cancel each other out by destructive interference, they can also undergo **constructive interference.** Create two pulses that meet each other head on and observe the addition.

8. Shake the slinky at just the right frequency to create **transverse standing waves**. Can you do it?

9. Send a single transverse pulse to the end of the slinky. Notice that some of the energy in the wave is **reflected** back. The rest of the energy was absorbed by your partner at the other end of the table. When the pulse is reflected back is it pointing in the same direction as before or reversed? Try this with a longitudinal pulse.

10. Most mechanical waves, like water waves, are combinations of transverse and longitudinal waves. Experiment with a few combinations on the slinky.

Now give someone else a try!

Wave Velocity

If your car travels 100 miles in two hours, your average speed over that interval is 50 miles per hour. The velocity of a wave is calculated exactly the same way as for ordinary objects except that it's disguised in the language we use to describe waves. The usual formula for velocity (speed) is as follows.

$$\text{velocity} = \text{distance} / \text{time}$$

Now let's talk waves. Instead of distance we like to think about wavelength. Instead of time we like to consider the period, the time it takes for one wavelength to go by. We can just substitute distance for wavelength and period for time.

$$v = \lambda / \tau$$

Since period τ and frequency f are reciprocals of one another we can just write the following.

$$v = f * \lambda$$

This last formula, $v = f * \lambda$, is the one most often used for wave velocity although the former is equally valid. In order for the units to come out correctly e.g. m/s, you need to convert Hz into 1/s so you get m/s instead of m * Hz.

The Electromagnetic Spectrum

All electromagnetic waves are transverse waves that can travel at the speed of light in a vacuum. If you want to listen to 101 FM and you're tuned to 102 FM, you are tuned to the wrong frequency. Our eyes are tuned to receive the wavelength of visible light and microwave radio receivers are designed to detect microwave wavelengths. All of the various parts of the electromagnetic spectrum are just light at different frequencies. Nature makes no distinction between radio waves, visible light, and gamma-rays but we do. Here's a short table of wavelengths and frequencies of the electromagnetic spectrum.

Table 1.2 *

Part of EM Spectrum	Wavelength (m)	Frequency (Hz)
Radio waves	0.3 - 3000	
Microwaves	0.3 – 0.0003	
Infrared light	3e-4 to 4e-7	
Visible light	4e-7 to 7e-7	
Ultraviolet light	4e-7 to 3e-9	

X-rays	3e-9 to 3e-11	
Gamma rays	3e-11 to 3e-13	

* 4e-7 means 4 * 10^-7 (four times ten raised to the minus seventh power)

You might have noticed that the column for frequency was left empty. Your job is to fill in the missing data. Since the speed of light is c, we want to use $c = f * \lambda$ instead of the formula $v = f * \lambda$ because electromagnetic waves always travel at the speed of light. This is an interesting fact because light is confined to one speed. Light is unable to travel slower in a vacuum. It can travel slower however through a piece of glass for instance. Between the molecules in the glass light is traveling at velocity c. When the light bumps into a glass molecule, a small lapse of time occurs before the light is re-emitted. This causes the light to appear to travel slower than c inside the glass. In fact, light never travels slower than c, but light can make a few pit stops on the way to its destination.

Polarization

Take a rope, tie it to a pole. Let the rope pass between the vertical gaps of a picket fence so that it is free to move up and down. Shake the rope vertically and transverse waves pass through the vertical gap in the fence unimpeded. Shake the rope side to side and all but a few waves will get through. This simple picture illustrates the concept of **polarization** in it entirety. You can **polarize** the waves on a rope so that they all point in the same direction. Similarly, light has its own polarization. The polarization is given by the direction of the electric field. When light comes in too many polarizations the result is glare, bright light with no clear image. When light is highly polarized you can see much more clearly and the colors stand out in bold relief. You might have experienced this phenomenon when a cloud passed over the Sun in just the right manner. Everything becomes so nice and colorful. Look at the surface of a lake or stream. Streaks of light due to glare at the surface prevent you from seeing all the way to the bottom. If that light were polarized you could see much further into the water.

1.2 Questions and Reflections

1. Recently scientists have been able to slow the speed of light to 38 mph. How is this possible? Read about it at http://www.rowland.org/atomcool/light.html

2. Unlike other waves, the speed of light must remain constant in a vacuum, unable to travel faster or slower. What effect does increasing the frequency have on wavelength? What effect does shortening wavelength have on the frequency?

3. The names for the various parts of the electromagnetic spectrum are chosen for mankind's convenience, not because nature makes any distinction between them.

To nature, all the different parts of the electromagnetic spectrum are just electromagnetic waves of different frequencies. What are some specific motivations for naming radio waves, microwaves, infrared, visible, ultraviolet, x-rays and gamma rays as they are? Everyone can share results and complete all parts of the spectrum with their historical motivations for their names.

4. What are some examples of light interfering constructively and destructively? Find an easy example you could show the class with a little help from your teacher.

5. Create a poster which labels the parts of a transverse and longitudinal wave and also compares and contrasts sounds waves with light waves.

6. To which color of the visible spectrum is the eye most sensitive? You'll need to do some investigating. Can you imagine a reason for this? Share it.

7. We know that the speed of light is always a constant c = 2.997*10^8 m/s. But, light can appear to move slower because of microscopic collisions resulting in the absorption and emission of light which accounts for lost transit time. What is the speed of light in some materials compared to others? Investigate.

8. If you are feeling ambitious and in need of deep answers to deep questions, what is **refraction** and what is **index of refraction** and how does it relate to the speed of light?

9. What are some advantages to polarizing light when taking pictures with a camera? How is this done?

1.3 Photons and Planck's Relation

Light is an electromagnetic wave but looked at another way it also behaves like a particle. This is known as the **wave-particle duality of light** and is central to modern physics particularly the science of **quantum mechanics**. Tiny packets of light that act as particles are called **photons**. Albert Einstein postulated their existence and won the Nobel Prize in Physics for his explanation of the photo electric effect. Today, a very sensitive photometer can detect individual photons but demonstrating the existence of photons in the past had been problematic, only indirect tests confirming the existence of photons were possible.

Turn on a stove and in a few minutes it will glow red hot. You can actually see the heat from the stove because it is hot enough to glow in the visible part of the spectrum. Allow the stove to cool off and it still glows as before except your eyes can't see it. The glowing light from a cool stove is in the infrared part of the spectrum which is too low of a frequency for our eyes to see. Infrared is extremely useful for night vision because everything glows with its own heat.

In 1899, Max Planck was investigating the power at which an object glows in relation to the frequency of light it emitted. In the course of his study he made an idealization, that the object under study was a perfect absorber and internal reflector, a **black body**. His investigations of black body radiation were motivated by a glaring contradiction between experiment and theory known as the ultraviolet catastrophe. At higher frequencies, black bodies are observed to emit less power for a given temperature. Everybody's theory up to that point was predicting the wrong result. Their theories were saying that at a given temperature the power keeps getting higher with higher frequency, an incorrect result. This puzzled the scientists of the day. The answer to their problem was so simple, even a non-scientist could understand it but it was an answer so simple that even Professor Planck himself was not prepared to accept it.

$$E = h * f$$

$$h = 6.026 * 10^{-34} \text{ Joules} * \text{seconds}$$

That's the answer. The energy of a photon or **excitation** of the electromagnetic field is a function of the frequency times Planck constant h. The constant h was calculated to fit the experiment. It is one of the universal constants of physics along with the speed of light, the charge of an electron, and Newton's gravitational constant.

Increase the energy of individual photons and you increase their frequency. Examine a super nova using a radio telescope and you find lots of high frequency x-rays, remnants of a high-energy event. Light from thermal processes has correspondingly lower energy and lower frequencies. It is important to keep in mind that it is not the total energy that corresponds to frequency but rather the energy of the individual photons themselves. You can have a tremendous amount of energy with a large accumulation of lower energy photons. Total energy doesn't matter. Individual photon energy does.

Total Energy = h * f * number of photons

The above, simplified formula assumes that every photon oscillates at the same frequency. This is not the case in reality. The total energy of a beam of light from a source contains photons of many different frequencies, every frequency contributing a certain amount of energy and having its own number of photons.

An excellent web resource for observing the black body spectrum derived from Plank's Radiation Distribution Law can be found at http://www.mi.infm.it/manini/dida/BlackBody.html.

Questions

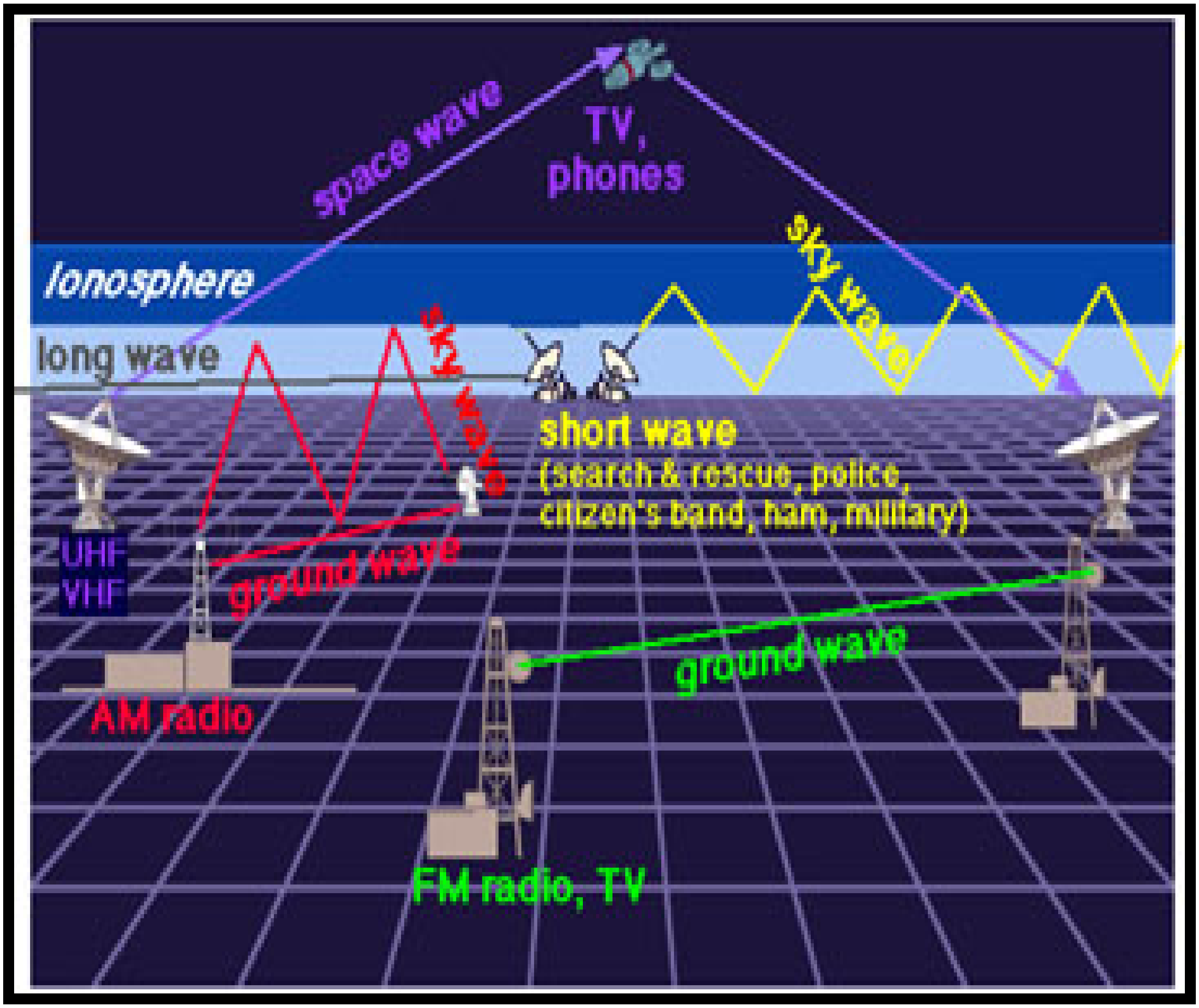
1. If you rub your feet on a shag carpet you can accumulate enough charge to produce a visible spark. A hot stove emits visible light and so must have the same energy as the spark. What's wrong with this thinking?

2. How much energy does an individual photon from your favorite FM radio station contain?

3. What frequency would a single photon require in order to raise the temperature of 1 gram of water by 1 Celsius degree?

4. Describe qualitatively the emission spectra for a black body radiator that obeys Plank's Radiation Law. What happens at the lowest and highest frequencies? Is the curve symmetrical like a bell curve or lop-sided? What are the Raleigh-Jeans Radiation Law and Wien's Radiation Law and how do they relate to Planck's Radiation Law? Use all resources available to you.

III. Bandwidth Basics



III. Bandwidth Basics

Transmission and Reception

Modern communications and consumer electronic devices such as TV and radio use radio waves for their transmission and reception of data. Any part of the electromagnetic spectrum will do in theory but for our purposes in the twentieth and twenty-first centuries radio waves are the bandwidth of choice, though microwaves have been used and are still in use in some cases.

Communications consists of at least one transmitter supplying the signal and at least one receiver. In fact, the more receivers the better if you are a modern commercial radio station trying to sell advertising! The communication link between the transmitter and receiver is established as follows. The transmitter, a radio or TV station, broadcasts a signal by pulse radio waves with around 50,000 Watts of power. This enormous power decreases rapidly with distance from the transmission source and diminishes as the inverse square of distance.

Power flux equals = power / area. Imagine a spherical pulse of a radio wave originating at the station. The radius of this spherical pulse grows at the speed of light rapidly increasing the surface area of the pulse. The surface area of the pulse grows larger quite rapidly. Since the surface area of a sphere is 4 * pi * r^2, the surface area grows with the square of the radius. Since power flux is inversely proportional to area, it is readily established the power flux decreases as 1/r^2. This inverse square phenomenon is central to most of physics particularly in fundamental forces of nature like Coulomb's force and Newton's Law of Universal Gravitation. It's the same play with only the actors and stage having been changed.

By the time you pick up a signal with your radio or TV, the signal has faded to a faint milliWatt level. Distance isn't the only factor involved in radio transmission. Radio waves bounce off of all kinds of things. When they bounce off buildings or clouds, some of the radio wave is reflected and some of it is absorbed as heat. The atmosphere attenuates the signal power too. Every little bit of energy you receive has been on a wild ride at the speed of light, going everyplace imaginable before being partially absorbed by the electrons in your antenna. This tiny little "vapor" of energy still carries the signal modulations and information sent by the transmitter and is sufficiently strong for the receiver to decode and play the signal.

There are two schemes for signal **modulation** in wide use. One is AM or amplitude modulation, the other is FM or frequency modulation. Have you ever seen a record player? (Some people call them turntables.) Your parents surely have and with any luck they still have one. The tiny grooves in a 33-rpm record vibrate the needle of the record player creating mechanical vibrations that are transformed into electrical pulses that are amplified and then played by a speaker.

The AM modulation scheme resembles the record player. The frequency of an AM station only plays the role of an identifier. The receiver, your radio, filters out all other frequencies except the frequency of the channel you are tuning to. The frequency carries no signal information and only serves as a means to separate one radio station's transmission from another. The signal information containing the actual sound is carried by **modulating** the amplitude of the radio wave creating little "grooves" in the signal strength resembling the grooves on a 33-rpm record. These tiny modulations in radio wave amplitude are turned into sound waves in exactly the same manner as for the record player.

Another more successful and technologically advanced method of communication is the FM modulation scheme. All sounds are of a particular frequency. Middle C on the piano corresponds to 128 Hz. When you listen to music or hear someone's voice you are bathed in a shower of sound waves all of different frequencies. Why not allow these changes of frequency to be encoded onto a radio wave of much higher frequency that can be decoded back into a sound wave of the original frequency. An example always helps. Suppose you want to broadcast the middle C of a piano from your radio station to some remote listener. This picture is actually a little bit too simple, we eliminate some fine detail, but it illustrates the main idea. Play middle C. A 128-Hz sound wave is produced. The carrier wave frequency of the radio station is 100,000,000-Hz. Add the middle C frequency to the carrier wave frequency and broadcast a 100,000,128-Hz signal. The receiving radio at the other end "chops off" the extra 100,000,000-Hz and plays the 128-Hz signal. The simple change from amplitude modulation to frequency modulation was a significant improvement. Although it is more complicated to design an FM receiver than an AM receiver, frequency is less affected during signal transit than amplitude, resulting in greater signal fidelity for FM signals.

There are more modulation schemes and electrical engineers, academics and devoted amateurs, are always coming up with new ones. Here are a few that are popular: CW, USB, and LSB. FM is further divided into WFM, wide band FM, and NFM, narrow band FM. WFM is the most popular FM and so is often referred to as just FM.

Every transmitter and receiver combination needs to be tuned into a certain frequency in order to communicate with one another. Although possible, tuning into amplitude for obvious reasons is extremely impractical. Frequency is the only natural choice. It is easy to construct a high-pass filter circuit out of a resistor and a capacitor. A high-pass filter allows only signals above a certain cutoff-frequency to pass through unimpeded. Everything below the cutoff is diminished or for practical intents and purposes, virtually eliminated. A low-pass filter functions similarly and allows only frequencies below a certain cutoff to pass by unimpeded. Using a combination of high-pass and low-pass filters, one can filter out all the undesired frequencies and focus on a narrow bandwidth. All of this is based on the concept of **resonance**. An opera soprano singing at the natural frequency of a crystal glass can shatter it if her sound waves carry sufficient power. Wind blowing at the right frequency was enough to demolish the **Tacoma Narrows Bridge** in a few hours. This spectacular event was captured on film and there are video clips of it on the Internet. The glass wouldn't shatter nor would the bridge collapse if the frequency weren't a resonant one. The high-pass and low-pass filters operate on a similar principle. Certain frequencies resonate through the circuit while others do not.

Activity 1.1

Name ________________________ Date ______________ Class _________________

Investigating Frequency Allocations for AM Radio, FM Radio, UHF TV and VHF TV.

You Need:

- A Television able to receive several UHF and VHF channels.
- An AM/FM radio with good reception. A decent quality antenna helps.
- AR3000-A Radio Communications Receiver

Anybody can find a radio station or television station by twiddling a knob and twisting a dial. It's much more interesting to try to find these stations by tuning directly to their frequencies. In this lab you will tune to an AM station on a radio and then try to find its frequency by tuning to it using the AR3000-A receiver. You're goal is to have both the receiver and the radio, side by side, receiving the same frequency. You'll do the same for FM stations. You might notice a pattern how radio stations are numbered with their frequencies. You'll find the range of frequencies occupied by the AM and FM bands by finding the lowest and highest frequency stations in each bandwidth. Switch the receiver mode from AM to FM mode and hear how the same signal sounds under different **demodulating** schemes.

Okay, so that's not such a big deal. How about a real challenge? Television broadcasts simultaneously include an audio band alongside a video band. You can hear the visual part of the band but it just sounds like noise. You can still find the audio part of the band. What modulation scheme do they use? AM or FM? Something else? You can find out by switching modes once you lock on to a TV channel with your receiver. The VHF (Very High Frequency) channels on your TV correspond to the upper dial with the smaller numbers starting at 2 going up to 13. The UHF (Ultra High Frequency) channels belong to the lower dial with higher numbers starting at 22. If your TV doesn't have dials just tune it regularly noting where VHF and UHF begin and end. It is important that your TV is not connected to a cable box because the frequencies won't match and even if they did cable companies use odd modulation schemes to protect their product.

Part A. AM Radio

Call Letters	Station number	Broadcast frequency	Location

Lowest AM frequency received ________________________
Highest AM frequency received ________________________
AM frequency range from experiment ___________________
Size of AM bandwidth ________________________________

Part B. FM Radio

Call Letters	Station number	Broadcast frequency	Location

Lowest FM frequency received ________________________
Highest FM frequency received ________________________
FM frequency range from experiment ___________________
Size of FM bandwidth ________________________________

Part C. VHF TV

Call Letters	Station number	Broadcast frequency	Location

Lowest VHF frequency received ________________________
Highest VHF frequency received ________________________
VHF frequency range from experiment ___________________
Size of VHF bandwidth ________________________________
Best mode ____ (e.g. WFM, NFM, AM…)

Part D. UHF TV

Call Letters	Station number	Broadcast frequency	Location

Lowest VHF frequency received ________________________

Highest VHF frequency received _______________________
VHF frequency range from experiment __________________
Size of VHF bandwidth ______________________________
Best mode ____ (e.g. WFM, NFM, AM…)

Frequency Allocation Chart

Now that you have some raw data to work with, you can create a frequency allocation table of the bandwidths you've investigated. Use a separate color for AM, FM, UHF and VHF. Your graph may be linear or logarithmic (based on powers of ten).

Questions

1. How well does your frequency allocation chart match the official United States Frequency Allocations Chart? (The United States Frequency Allocations Poster is available as a PDF file and can be viewed using Acrobat reader or some other PDF viewer.)

2. What fraction of the total bandwidth of a VHF TV signal is audio? Video? (You need to consult handbooks or the Internet to find this out.)

3. As you can well image by looking at the USFA chart, there's a lot more to the radio bandwidth than AM, FM, UHF, and VHF. Find some interesting stuff like weather stations or aircraft communications. What's the weather like one or two states away? What's air traffic control up to?

4. SETI is an acronym for the Search for Extra-Terrestrial Intelligence. What kind of radio signals are they hoping to find? How are they modulated?

5. Investigate an actual event of someone broadcasting an illegal signal over a bandwidth that belonges to someone else. What happened? "Captain Midnight" is a famous example of this. Can you find others? What happened?

6. What is *Bunny Hunting*? No, it has nothing to do with Elmer Fudd or Waskally Wabbits.

IV. Antenna Basics

IV. Antenna Basics

Detecting Radio Waves from the Sun

Introduction

It may surprise you to find out that Thomas Edison attempted to detect radio waves from the Sun and was unsuccessful. Thomas Edison more than likely wasn't a lone visionary in attempting to detect radio waves from the Sun, but he is the first on record to suggest that radio waves might be detected from celestial objects. In a letter sent to Lick Observatory that dates back to 1890, Thomas Edison described his plan to detect radio waves from the Sun using steel cables wrapped around an iron core. The experiment was more than likely never carried out. No evidence that such an experiment was performed exists. What is important however is that Thomas Edison knew how radio waves were produced and how to detect them. It was his genius that saw the likely possibility of radio waves being exceedingly common, being naturally produced in space as they could be by lightning storms on Earth. You have an opportunity to succeed where Edison failed but be humbled, Edison would surely have found a way to detect radio waves had be persisted along his line of inquiry.

Materials

- AR3000-A Receiver
- Computer with SEARFE spectrum scanning software
- Yagi antenna
- Disconne antenna
- Long wire antenna
- Small Radio Telescope (optional)

Part I: Antenna Directionality

Procedure

1. Connect the AR3000-A Communications Receiver to a computer with the SEARFE spectrum scanning software installed.
2. Connect a Yagi antenna to the AR3000-A receiver. The frequency of the antenna should be around 500 MHz.
3. Adjust the AR3000-A to scan a small bandwidth around the peak efficiency frequency of the antenna. If you are scanning around 300 MHz choose a bandwidth of 10 MHz.
4. **Important: Use caution for this step. Do not look at the Sun. Look at the shadow behind you.** Point the Yagi antenna directly toward the Sun. You can judge whether or not you are pointing directly toward the Sun by looking at the shadow behind you.
5. Perform a single scan with the antenna pointed toward the Sun. Save all scans for later printing to include with your report.
6. Now point the antenna away from the Sun at a 90-degree angle. Perform another scan, this time with the antenna pointed away.
7. Repeat steps 4-6 with the disconne antenna and the long wire antenna respectively.

Note: One could set the receiver remote control to *off* and perform the scans manually using the receiver console.

Questions

1. Based on your experiment which antennas are sensitive to direction and which are not?

2. Did each antenna receive the same amount of power from the Sun? What could account for some of these differences?

Part II: Peak Efficiency Frequency

Every antenna is designed for use at some frequency. An antenna resonates best at its peak efficiency frequency. Although the power from the Sun naturally varies with frequency, one should be able to determine the peak efficiency frequency of an antenna. The peaks observed due to antenna design far outweigh any peaking effects you'll observe from the Sun.

Procedure

1. Point the Yagi Antenna directly at the Sun. Perform a single wide scan using the AR3000-A.
2. Note any peaks in the wide scan. Rescan around the peak in a smaller bandwidth to pinpoint the frequency of maximum antenna gain.
3. Repeat the above procedure for the disconne and long wire antennas.

Antenna	**Maximum gain frequency in MHz**
Yagi	
Disconne	
Long Wire	

Questions

1. Why does an antenna resonate around a particular frequency?

2. Calculate the wavelength of a radio wave with maximum gain for an antenna using the formula $c = f * \lambda$.

3. Does this length or fraction of it, appear in your antennas basic design?

4. How would you construct an optimal AM and FM radio antenna? Why might optimal design actually be a bad idea?

5. How can a sub-optimal antenna length still work and work very well as is the case for AM radio antennas?

6. What is the source of radio waves coming from the Sun? What frequencies can we expect to detect from the Sun?

7. Based on your experimental results what are some practical uses for one type of antenna over another? In which situations would you prefer a Yagi antenna to a disconne? When is a long wire antenna best?

Part III: Wave Polarization

Try rotating the antenna as you point it to toward the Sun and other locations in the sky. You might not notice any effects if there is a lot of glare in the sky. If a cloud passes overhead it might reduce the glare enough to detect a change in power when the antenna is rotated. Try this for all three antennas. If you can't detect any difference, try the experiment at a different time.

1. Why would the polarization of light matter when measuring the gain of an antenna?

2. Which antennas were most successful at measuring polarization? Why do you think this is so?

Mapping Antenna Patterns

Every antenna responds best to certain frequencies and not others. The orientation of an antenna to its source also plays a significant role. The gain of the received signal depends extensively on the direction from which the source is received. We will explore the basic antenna patterns only in the plane between the line of sight of the source (the Sun) and two imaginary points on the ground. The measurements we make here will necessarily be crude. Only a very exacting experiment will expose the fine details of antenna gain patterns. We can however, detect the basic pattern and map it on a graph.

Our graph will be a polar coordinate graph, radius versus angle (r vs. θ). The radial distance from the origin indicates the signal power received at a given angle. This experiment is best performed in the morning when the Sun is low to the ground. We can ignore the elevation of the Sun and simply rotate the antenna to point to various locations along the horizon. (Some variant of the procedure is necessary if noontime measurements are going to be made. The following procedure is intended for early morning when the Sun's elevation is low enough to be ignored.)

Procedure

1. Choose a very narrow bandwidth, 0.1 MHz, around the maximum gain frequency of your antenna.
2. Setup the AR3000-A receiver to scan around this frequency.
3. **Caution: Do not look at the Sun. Use the shadow to determine whether or not you are pointing directly toward the Sun.** Point the antenna toward the Sun. Position a protractor underneath the antenna to measure angle. Estimate the angle as best you can to within 5-degrees.
4. Perform a scan while directly pointing at the Sun.
5. Do not save any graphs made by the computer, there's no purpose in keeping them once you get the main information from them. From the computer graph, note the maximum value of the power received in the bandwidth from the graph displayed on the computer. Enter this value for power in the data table below.
6. Change the angle by 15 degrees counter-clockwise and perform steps 3-5, repeating until all angle values on the data table are used, completing one complete revolution.
7. Perform the same test using the disconne and long wire antenna.

Data Table I. Yagi Antenna Pattern

Maximum gain frequency of antenna ________________

Angle in degrees	Peak Power (Watts) or Peak Power Flux
0	
15	
30	
45	
60	
75	
90	
105	
120	
135	
150	

165	
180	
195	
210	
225	
240	
255	
270	
285	
300	
315	
330	
345	

Data Table II. Disconne Antenna Pattern

Maximum gain frequency of antenna ________________

Angle in degrees	Peak Power (Watts) or Peak Power Flux
0	
15	
30	
45	
60	
75	
90	
105	
120	
135	
150	
165	
180	
195	
210	
225	
240	
255	
270	
285	
300	
315	
330	

345	

Data Table III. Yagi Antenna Pattern

Maximum gain frequency of antenna ________________

Angle in degrees	Peak Power (Watts) or Peak Power Flux
0	
15	
30	
45	
60	
75	
90	
105	
120	
135	
150	
165	
180	
195	
210	
225	
240	
255	
270	
285	
300	
315	
330	
345	

Graphing

Graph power vs. angle where power will be indicated by radial distance from the origin and angle will be given by the angle between the x-axis. An r *vs.* θ graph is very simple to make but takes a little bit of practice. Connect all the dots with a smooth curve to reveal the antenna pattern.

Questions

1. Obtain detailed antenna patterns from Kraus' *Radio Astronomy* or other antenna handbook/reference. Notice the lobe patterns on some of the antennas. Did you observe any lobes on your graphed antenna patterns? Are there any signs of emergent lobes on you graph? What are they?

2. What effect should changing the size of your antenna while preserving the shape have on the antenna pattern and maximum gain frequency?

3. What antenna patterns are most useful for detecting polarization in light? The polarization of light from stars and galaxies carries lots of information about the types of physical processes occurring.

4. Compare your antenna patterns with those published by a handbook. How closely does your pattern resemble the published pattern? Give details.

V. Receiver/Transmitter Basics

V. Receiver/Transmitter Basics

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 to100 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 Suns thermal spectrum is made up of mostly visible light. Seeing how this is most of the light that penetrates out 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 trough 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
- 1000Ω to 8Ω 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 1000Ω leads of the audio transformer.
3. Attach one of the 8Ω leads of the audio transformer to a power lead on the crystal oscillator.
4. Attach the other 8Ω 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?

VI. Signal Propagation Effects

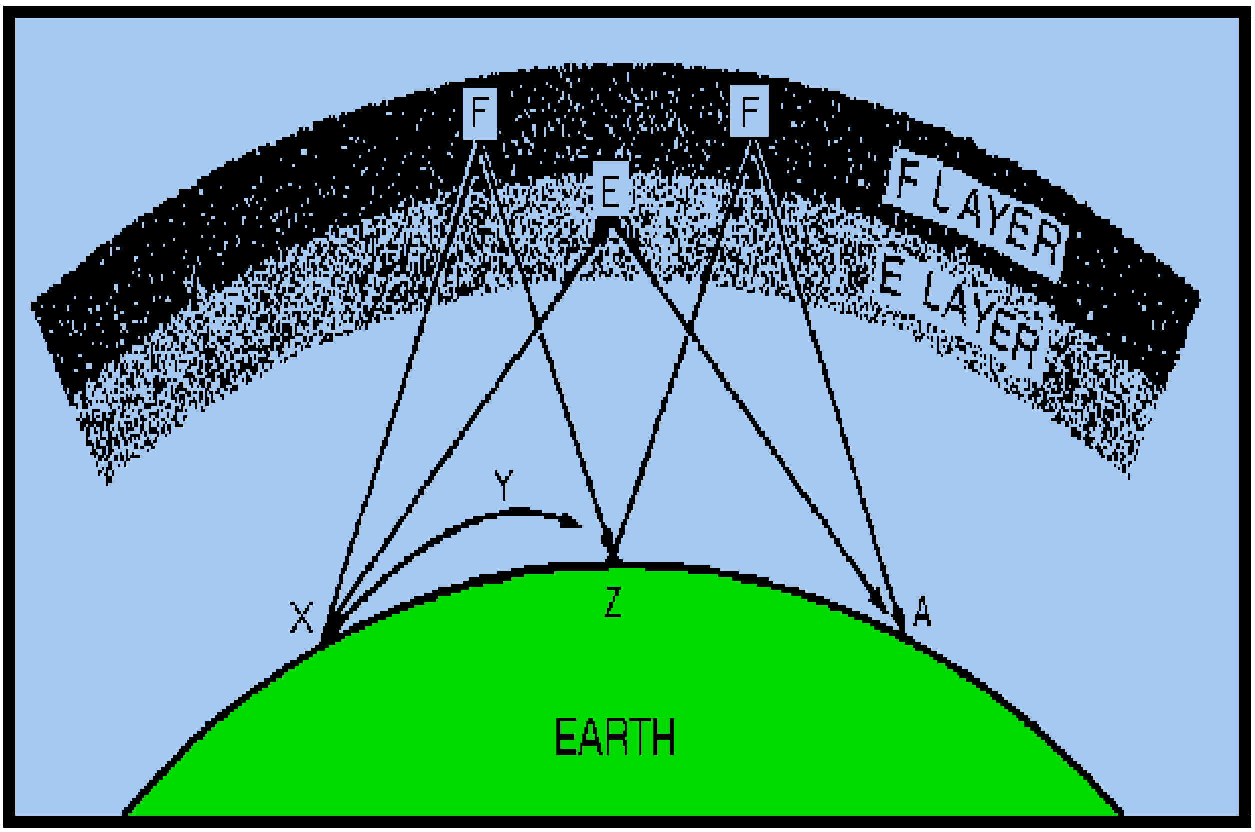


Image courtesy of www.tpub.com

VI. Signal Propagation Effects

Name __________________ Date __________________ Class ___________________

At Home Assignment

Tune to the most remote AM station you can find. You should attempt to find to other stations of comparable distances. Fill in the data below and bring to class tomorrow. Use the Internet to find the location of your remote AM station.

Station Name	Location and distance	Time of Reception

You are no doubt surprised that your AM radio stations aren't coming in clearly if at all. Don't worry. We believe you really did hear those remote AM stations. There is some very interesting physics at work here.

If you stand outside and look all around you, you can see about 2.5 – 3.0 miles at eye level before the horizon, where the land meets the sky. If you were a radio station and your transmission antenna were placed at eye level, you could transmit signals for a distance of 2.5 – 3.0 miles before the land features prevented anyone from hearing your signal. Why does this happen? We found out a long time ago that the Earth is round. If you travel directly outward in a straight line, as radio waves do, the Earth curves beneath you. Two people at eye level sending and receiving radio signals cannot communicate with each other beyond a certain distance because the transmitted signal will go right over their head. Again, the Earth is curved. Your friend might want to receive your signal but can't because your friend has descended approximately 1m in altitude relative to your line of sight just by being far away.

Going to higher altitude can enlarge the horizon. At the top of a mountain, you can see for miles and miles. In a jet plane you can actually see the curve of the Earth's horizon if you look closely. AM radio towers are large and have a transmission height at around 500 feet. At this height, the horizon is approximately 100 miles away. If the land is smooth and devoid of any unusual features, the station can transmit a clear signal within 100 miles. Beyond 100 miles, the Earth's curvature drops any receiver below the AM stations line of transmission (line of sight).

But wait you say, how can I still receive stations that are more than 100 miles away? We'll come back to that question in just a moment. To answer the question, let's first examine how FM radio waves behave. FM radio waves can't be heard beyond the horizon of the transmitter. Above the FM transmitter, the radio waves propagate through the atmosphere, through the ionosphere and into deep space. Perhaps someone on Alpha Centauri has already heard our FM radio transmissions. It takes 4.22 years for radio waves to go from Earth to our nearest star, Alpha Centauri. Let's just hope that if there are intelligent beings in the Alpha Centauri system listening to our FM stations, they won't be turned off and ignore us assuming there's no intelligent life here!

So FM radio waves pass effortlessly into the icy blackness of deep space. You suppose we're going to tell you AM radio waves are different. Well, yes, we are. The ionosphere reflects radio waves with a frequency less than 10 MHz. FM radio station waves occupy the 88 – 107 MHz bandwidth and thus pass right through the ionosphere. AM radio stations transmit at 535 –1605 kHz. AM radio waves are very reflective against the ionosphere. The result being that AM stations get to have their signals retransmitted from the height of the ionosphere! A significant improvement of 500 feet! Depending on how much power these signals are transmitted with, an AM signal can reflect from the ionosphere and ground several times, and be received over most of the Earth. Long distance radio communication was based on this phenomenon. Ship-to-shore communications, aircraft links and some military communications depend on the ionosphere to reflect their signals.

The shape of the ionosphere changes during the day. The ionosphere is made up of several distinct layers. The D and E layers absorb AM radio signals during the day. Since the D and E layers are made up of ions from the Sun and lay closer (100 km) to the thicker layers of Earth's atmosphere, these ions recombine with the atmosphere during the nighttime and the D and E layers disappear almost entirely at night. While the D and E layers are facing the Sun in the daytime, these ions are constantly replenished as the lower atmospheric layers siphon the ions away. The D and E layers are strongest at high noon. With the absorbing D and E layers gone at nighttime, the reflective F layer is exposed making long distance communication at AM frequencies.

Note to teachers:
Students will find the most remote AM station they can locate using their radios at home. They will make a record of the time that they received these AM signals. Students should be encouraged to make these measurements after sunset when it is dark. Upon returning to class the next day, collect their results. Place some results on the board and ask students to tune to the stations they found from the previous night. Few, if any of the signals these stations transmit should be heard during day.

At this point, introduce students to how the ionosphere affects the propagation of radio signals and why they were able to hear their distant AM radio stations and night but not during the day.

Encourage students to monitor space weather for a week. The Internet is an excellent resource. Have students go to www.spaceweather.com. A brief discussion at the start of class might be appropriate particularly if we are in an active time in the 11-year solar cycle.

Students will monitor a tiny bandwidth of a distant AM radio station overnight using the AR3000-A communications receiver and SEARFE software. They will see firsthand how signal strength varies with time of day. If there was any special solar event, e.g. a flare, from the spaceweather.com website, we might be able to see its effects during a scan.

This is an opportune time to introduce students to more features of the AR3000-A radio communications receiver and how it interfaces with the SEARFE software. A quick scan over a weather station or FM station band might be helpful in illustrating its use.

Questions and Further Investigations

1. Radio emissions from lightning from thunderstorms are fairly noisy. Their frequency distributions resemble a blow from a hammer, a chaotic distribution of overtones, instead of the organized frequencies and overtones of Itzhak Perlman playing a single note on the violin. How is it possible to detect a thunderstorm from half way around the world using a radio? Are all frequencies from the lightning carried? Why or why not? Most of all, what does lightning sound like on the radio? How can we know for sure that we are hearing lightning?

2. Investigate the layers of the ionosphere. The ionosphere is not so simple as it seems. There are layers within layers, for example, the F layer splits into F1 and F2 at night. Each layer has it own unique set of effects. So far we have concerned ourselves only with the D, E and F layers. What other effects are there? Make a poster of your finding and share it with the class.

3. FM radio waves pass unaffected through the ionosphere but they have trouble passing through water. Why is the so? Investigate the transmission of FM radio waves through fog and rain. Do AM radio waves have the same problem? FM radio sounds best in the morning. Why? FM radio has trouble on hot summer days? Why? Share you findings.

4. Investigate the optical window and the radio window. Prepare a poster and a couple of lecture notes and share your findings with your peers. Which atmospheric features are responsible for the attenuation of certain frequency bandwidths?

5. Molecules and atoms absorb light of certain frequencies but not others. This happens because certain transitions or quantum jumps inside the atom or molecule involve a specific amount of energy. Only this amount of energy is allowed to affect the transition. According to Planck's formula $E = h * f$, energy corresponds to frequency thus only certain frequencies are allowed to affect transitions. Prepare a poster explaining why molecules are responsive to only certain frequencies (not every detail has been explained here, you'll need to investigate)

and give the frequencies of some common molecules like oxygen, nitrogen, water, and ammonia. What phenomena are associated with these transitions of Earth and in space?

6. The ionosphere has its own weather just like the troposphere, which closely blankets the Earth's surface. The Sun follows an 11-year cycle. At the bottom of the cycle, the Sun is rather quiet. At the height of its cycle the Sun is active with sunspots and flares that bombard Earth's magnetic field with a stream of ions from the solar wind. What effects can space weather have on communications? What events have happened in the past where solar weather produced a significant disturbance here on Earth? Resource: www.spaceweather.com

Activity: Monitoring Remote AM Radio Stations

Equipment

- AR3000-A Communications Receiver
- SEARFE Software
- AM radio station 100 km or more away
- Stopwatch

Procedure

1. Load up the SEARFE Spectrum Scanning Software.
2. The *Spectrum Scanning Wizard* should appear.
3. Choose new scan
4. The *Spectrum Scan Conditions* window should appear. Change antenna to the appropriate type either whip or disconne. Click next.
5. The *Receiver Setup* window should appear. Set the baud rate to 4800 and the receiver type to AR3000-A. Click next.
6. The *Scan Settings* windows should appear. Set the start frequency to 5 kHz below and the stop frequency 5 kHz above the remote AM station under investigation. Set the frequency increment to 0.01 kHz. Note: the SEARFE software uses MHz as its frequency unit. Converting kHz to MHz is necessary. Set the dwell time to 100 milliseconds. Set the scan number to one.
7. Using a stop watch figure out the time for one complete scan to occur. Press start to begin scanning.

   Time for one scan ________________________

8. Calculate the number of scans attainable during a 24-hour period.

   Number of scans during 24-hour period ___________________

Scans per hour ____

9. Go back and change the number of scans so that the scanner will survey the background for a 24-hour period. Calculate the number of scans per hour.

Data Table and Graph

From the SEARFE scanning data, construct a data table and graph of maximum signal strength vs. time for you data over the entire 24-hour period. You should have one data point per hour. Examine the SEARFE data for a one-hour period and estimate the average maximum signal strength for that time interval. Ignore sudden spikes in the signal when performing your average. The spikes are due to spurious signals or disturbances in the ionosphere. Note any significant spikes and when they occurred on a separate sheet of paper.

Questions and Interpretation

1. At what time did the D and E layers of the ionosphere diminish?

2. During what times was the AM signal strongest?

3. Did the time of strongest transmission coincide with 12 O'clock midnight? Does it necessarily need to do be strongest at midnight? Explain.

4. What happened to the signal during the daytime?

5. Identify any irregularities on your graph during the 24-hour scan.

6. Go to www.spaceweather.com. Investigate the space weather for the previous day. Were there any events that might have produced fluctuations in the ionosphere thus affecting your transmission?

7. Sound cannot travel in a vacuum. Yet if space is a vacuum, how can scientists actually hear sound waves from the Sun? Investigate. What is the sound in space traveling through?

Activities

Activity 1

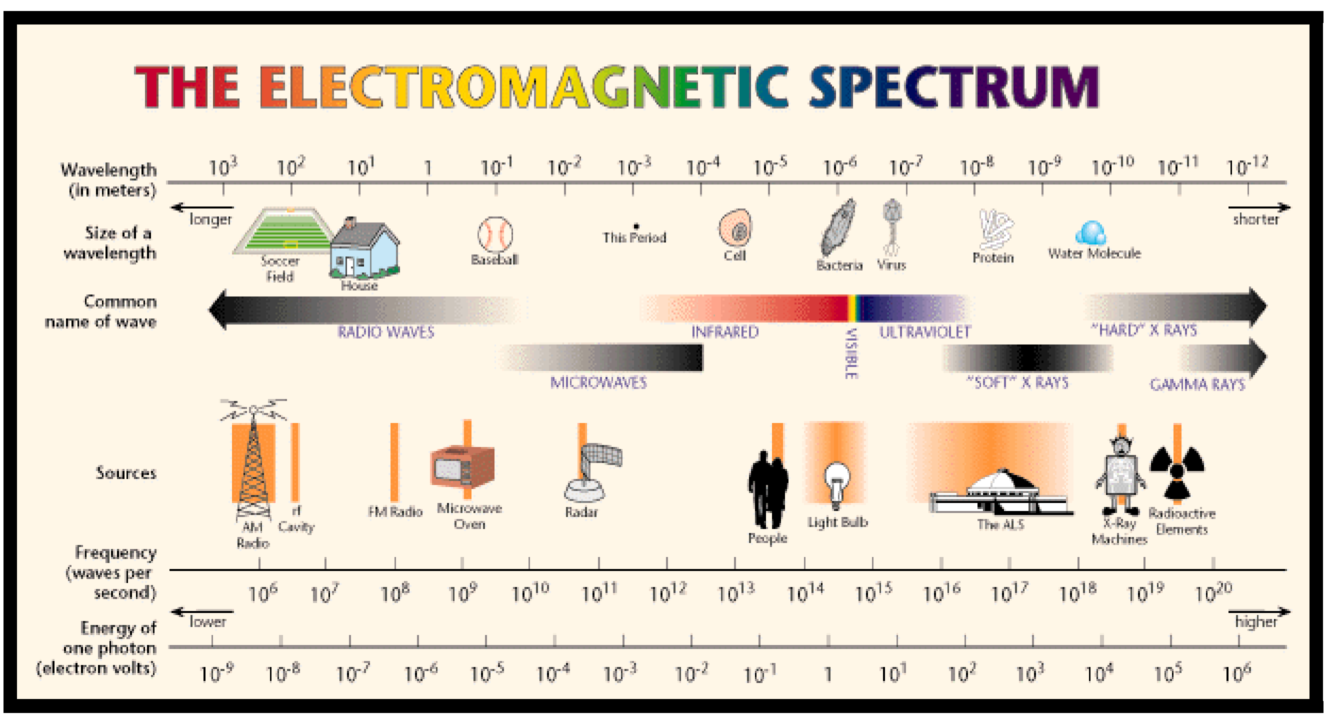
Investigating the Radio Environment

Purpose

- Survey the local radio environment
- Try to identify various radio sources
- Introduce the AR3000-A receiver and SEARFE scanning software

Discussion

The electromagnetic spectrum spans a very large range of wavelengths and the radio bandwidth covers a large part of this spectrum. Certain radio frequencies have greater signal intensity than others and can come from natural or man-made sources. Your job is to survey the features of the radio environment and try to identify their sources. Some of these sources should be obvious, others less obvious. You will perform several scans over a very broad range of radio frequencies and several smaller scans to investigate certain bandwidths in greater detail. Then, you will try to identify the sources of these signals and interpret the graphs to determine the distribution of radio signals across the radio spectrum bandwidth.



Part A.   Wide Scan 20 MHz – 2000 MHz

1. Connect the AR3000-A radio scanner to COM1 port of a PC computer. Make sure the remote switch on the back of the AR3000-A is set to *ON*. (If the remote switch is off, control belongs to the AR3000-A console. When the remote is on, control is given to an external device such as a computer.)

2. Download the spectrum scanner software from www.searfe.atnf.csiro.au. Open the *Spectrum Scanner 3.4* software by clicking on the *Spectrum Scanner 3.4* desktop icon. Windows should appear with the following toolbar options: **File Tools Help**. There should also be a single folder called **Scans** in the window.

3. Click on **File**, to open a pull down menu and select **New Scan**.

4. A separate **Spectrum Scan Wizard** window should open. The top of the windows read **Spectrum Scan Conditions**. For now, ignore the *Location*, *Longitude*, *Latitude* and *Operator Name* options. Set the antenna option to the appropriate setting, either discone or whip antenna (the discone antenna is a much more sensitive antenna and is available as an add on, it's placed outside on a pole and is then connected to the receiver through a cable). The remaining options; *Antenna Transmission Line*, *Low Noise Amplifier*, *Low Noise Amplifier Attenuator Setting*, and *Low Noise Amplifier Transmission Line* should be set to *none*. Notes may be left empty for now (unless you feel inclined to write any). After checking these settings click on the **Next** button.

5. In the **Receiver Setup** window, select the AR -3000A radio button. Make sure the *Comm Port* is set to COM1, the *Baud Rate* set to 4800, and the *Shortwave Preamp* to Off. After checking these settings click on the **Next** button.

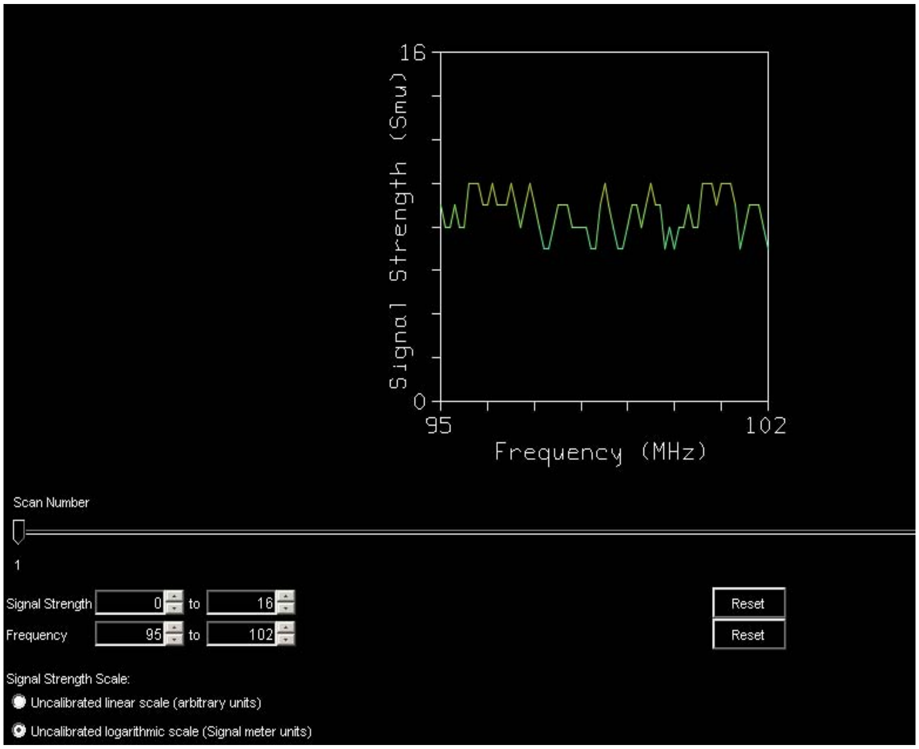
6. In the **Scan Settings** window, set the *Receiver Mode* to WFM, and *Receiver RF Attenuator* to Off. Set the ***Start Frequency*** to 20 MHz and the ***Stop Frequency*** to 2000 MHz. (You will be setting the *Start Frequency* and *Stop Frequency* setting to different values in later scans.) The ***Frequency Increment*** should be set to 20 MHz. This value will change for different scans. You will have to figure out which *Frequency Increment* to use in later scans. The ***Dwell*** should be set to 50 milliseconds. *Number of Scans* should be 2 and *Delay between Scans* should be 0.0 hours. After checking these settings click on the **Next** button.

7. In the **Spectrum Scan Status…** window, select the radio button *Display Graphs* and check the check box *Signal Strength vs Frequency*. The *File Name* and *Start Time* should be automatically selected for you. Now click on the **Start** button (No! Not the Start button in the lower left hand corner.☺) The scan should begin automatically. You can watch the green *Scanner* display scan through the various frequencies. It shows the current frequency being scanned.

8. When the scan is finished return to the *Spectrum Scanner 3.4* window (The one we first opened). Click on one of the '+' signs and expand the menu until you see a scan file (for example 2003-07-08 14-10-33 -0400). ('-' will collapse any undesired menu expansions) Select the *Signal Strength vs Frequency* file. A black graphing menu should appear. Using the slider bar will alter the scan number. In this case we did only two scans so the slider bar will be entirely to the right or left to see one or the other scan. You also have the option of altering the *Strength* and *Frequency* ranges and whether to view linear or logarithmic displays.

9. Print your graph. Interpret the various features on the graph. You may want to pencil in some details onto the graph itself. You may want to consult the radio frequency chart.

HINT: You can print your graph by pressing the **Print Screen** key on your keyboard usually located between the alphanumeric section and numeric keypad. Before pressing **Print Screen** you should make sure that the graph is in the active window. If it isn't, click somewhere on the graph window to make it the active window. **Print Screen** puts the entire window inside a buffer (just like your typical cut and paste function). Try opening MS Word or PhotoShop and select **Paste**. The entire windows should now appear. Crop the graph and save for later printing.



A sample scan

Wide Scan Graph Features

Peaks:

Valleys:

Fluctuation in noise level:

Possible Sources:

Part B. Narrower Scans

1. Perform the same steps as in **Part A**. Modifying the ***Start Frequency*** and Stop ***Frequency*** to match the desired frequency ranges indicated below. In each scan choose a ***Frequency Increment*** so that you get around 50 (+/- 25) samplings in the frequency range.

2. Print out each of the indicated scans. Interpret your scan exactly as before in **Part A**.

Scan 1: 10 MHz – 50 MHz

Peaks:

Valleys:

Fluctuation in noise level:

Possible Sources:

Scan 2: 50 MHz – 150 MHz

Peaks:

Valleys:

Fluctuation in noise level:

Possible Sources:

Scan 3: 100 MHz – 500 MHz

Peaks:

Valleys:

Fluctuation in noise level:

Possible Sources:

Scan 4: 500 MHz – 2000 MHz

Peaks:

Valleys:

Fluctuation in noise level:

Possible Sources:

Research

Choose one of the following research topics. Write your findings on a separate sheet(s) of paper (1-2 pages). Your group will share their results in front of the class.

1. What are the local radio transmitters in your area? Try to list them all. At what frequencies do they broadcast? How much power (Watts) do they emit? Can you find definite evidence of your local radio broadcasters on your graphs? You may wish to perform additional scans at a frequency of your choosing. How large are the peaks from local radio stations in relation to other signals?

2. Other sources of radio waves include computers, garage door openers, telephones, or just about any other electronics device you can imagine. What frequencies do these devices emit? Try to list as many devices with their respective frequencies as you can. Some of this data can be found on the internet. Is there evidence on your graphs of some of the devices in school? You might want to do additional scans with a particular device turned on and then turned off. Compare the two scans and try to find the frequencies emitted by the chosen device. What role does the FCC play in all of this? Why might this be important to you local radio astronomer?

Teacher Guide for Activity 2: Time Variation of Background Signal Strength

This activity is appropriate for students in grades 9 through 12.

Materials needed:

- communications receiver
- antenna
- SEARFE software
- United States Frequency Allocation map (can be accessed on line at www.ntia.doc.gov/osmhome/allochrt.pdf)

Preparation and set-up time: 45 min

Time needed to complete activity:

- Day 1, gathering scan data, about 20 min.
- Day 2, making a poster and answering questions, about 50 min.

For additional information and lesson plans on signal strength variation access the MIT Haystack website at www.haystack.edu/ and click on pre-college resources.

Activity 2

Time Variation of Background Signal Strength.

Purpose

- Investigate the variation of the RF background with time.
- Describe reasons, both natural and man-made for this variation.
- Identify layers of the Earth's atmosphere

Discussion

We have determined some of the general features of the radio frequency (RF) background in **Activity 1**. We will now investigate the change in this background with time and try to attribute causes to the variations we observe. As before, we will perform a broad scan and a couple of smaller scans. As a matter of expediency, it is practical to delegate responsibility for scans among groups or individuals. **PLAN AHEAD!**

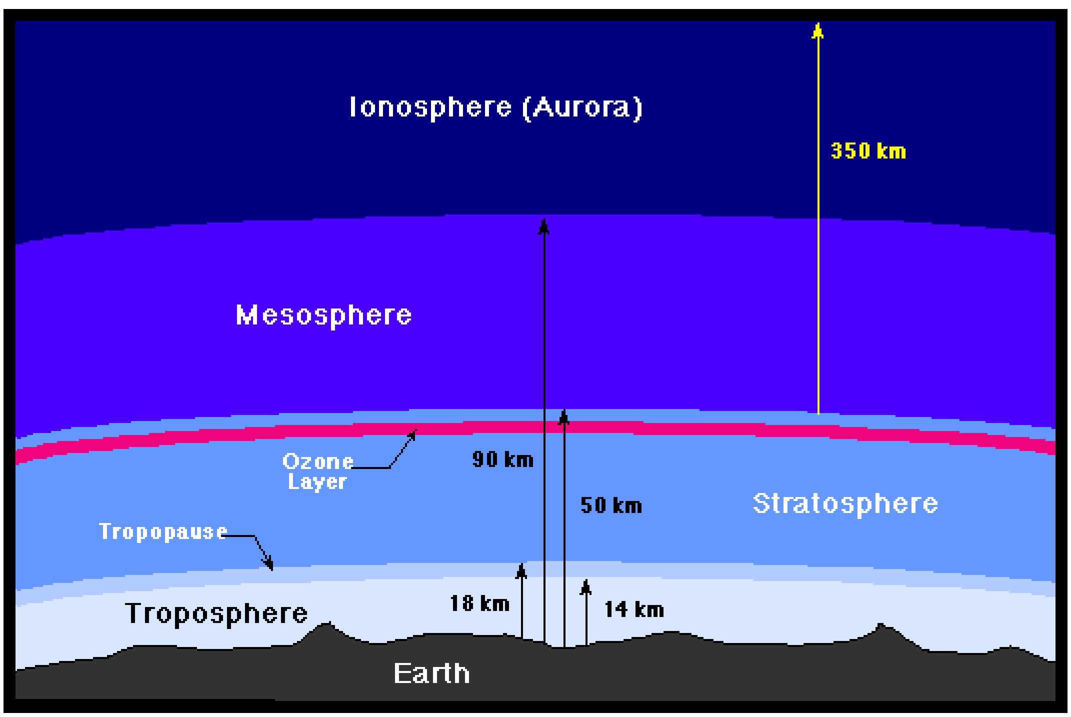


Figure 1

One of the most important natural effects on RF signal strength with time pertains to the ionosphere. The ionosphere has a direct influence on certain frequencies and no effect on others. You must find out for yourself what effects the ionosphere has on radio frequencies depending on the time of day. The school library, local library or internet is a good place to start. Find out what the radio window is. Compare this to the optical window. This is one of the questions you'll be asked at the end of this activity.

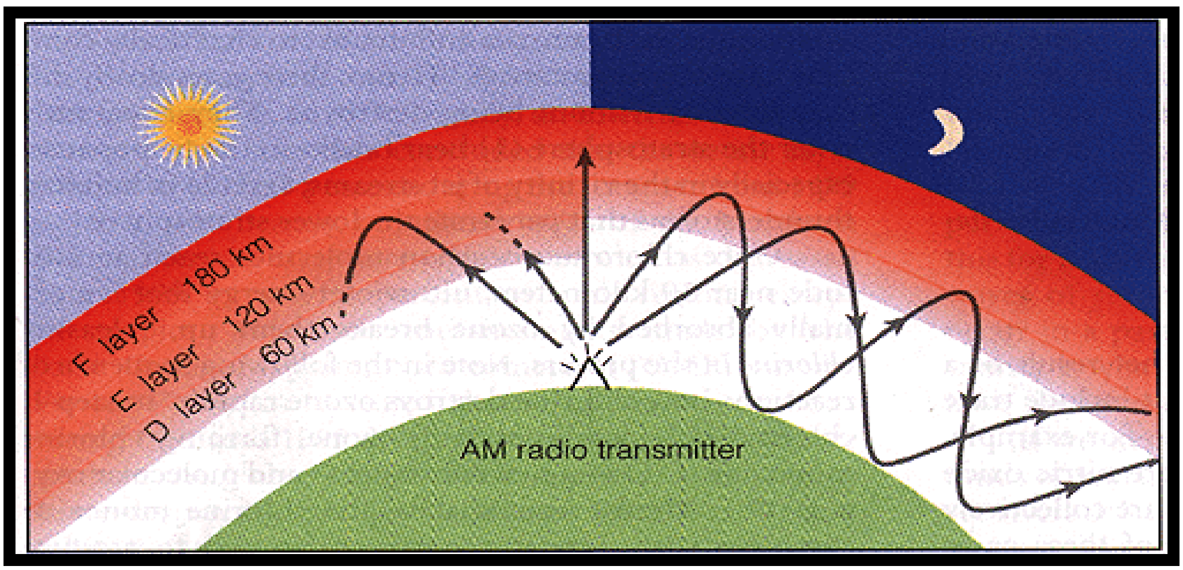


Image from Meteorology Today by C. Donald Ahrens
Figure 2

If you successfully identified certain RF sources in the last activity (hopefully you did!), pay particularly close attention to those frequencies when conducting this experiment. Try to identify the reason for any time variation in these signals.

Part A. Broad Scan

50 MHz – 2000 MHz (25 MHz increments)

1. Conduct measurements hourly starting in the early morning when schools begins. Continue measurements as late as possible. Make some measurements after dark when upper atmospheric conditions change. (This will require some creative planning.)

2. Organize your graphs onto a poster. Identify any interesting data and include this in your poster. Interpret your results and prepare a short oral presentation of your findings to share with the class.

Part B. Narrow Scans

1. Perform a scan from 10 MHz – 30 MHz in 0.25 MHz increments. Follow the steps outlined in **Part A** for this scan.
2. Examine the United States Frequency Allocation of The Radio Spectrum Map. (Your teacher has this in a PDF file, ask for it and have a copy for your convenience.) Select two bandwidths you would like to scan and follow the steps outlined in **Part A** for these scans.

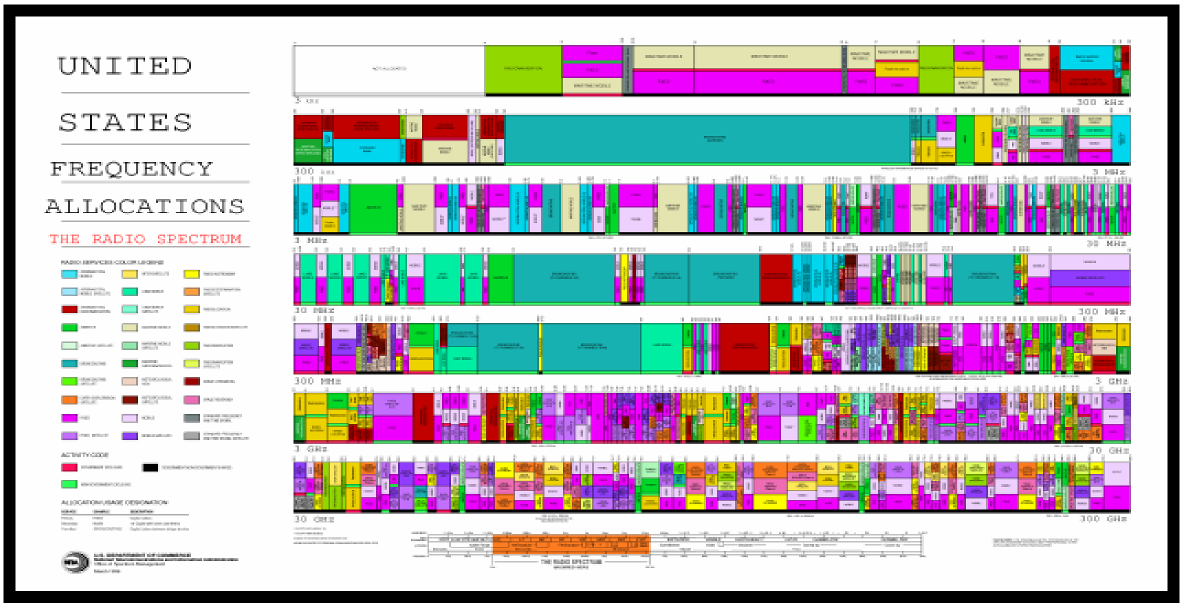


Figure 3

Questions

1. What are the radio and optical "windows"?

2. What role does the ionosphere play in the transmission/reception of radio waves?

3. Do your graphs correspond to the chart of U.S. Frequency Allocations and can you locate the AM, FM, TV broadcast areas?

4. Why is the ionosphere more reflective of radio waves at night than it is during the daytime?

5. Why do you think that AM frequencies are affected by this nighttime reflection more than FM or TV?

6. What properties about the ionosphere make it reflect radio waves whereas the stratosphere doesn't?

Teacher Guide for Activity 3: Signal Strength vs. Location

This activity is appropriate for students in grades 9 through 12.

Materials needed:

- topographic map of your location, available for order at www.topomaps.usgs.gov, each map costs $6.00 and shipping is $7.00, allow 3-5 business days for delivery
- communications receiver
- antenna

Preparation and set-up time: 30 min.

Time needed to complete activity: 1 or 2 class days

Activity 3

Signal Strength vs. Location

Purpose

- Explore how topographical features affect radio transmission and reception.
- Examine the role of weather in radio broadcasts

Discussion

Radio waves bounce and reflect off of just about anything you can imagine. Gamma rays residing at the high frequency/short wavelength end of the electromagnetic spectrum won't reflect or bounce very much because they are so energetic that they'll just pass through ordinary objects or get absorbed in the process. Not so with radio waves. Radio waves will echo much like sound. In fact, radio waves from the BBC (British Broadcasting Corporation) "echo" off the ionosphere and the ocean surface many times making it possible for people in the United States to listen to the BBC at night, which broadcasts from London, England.

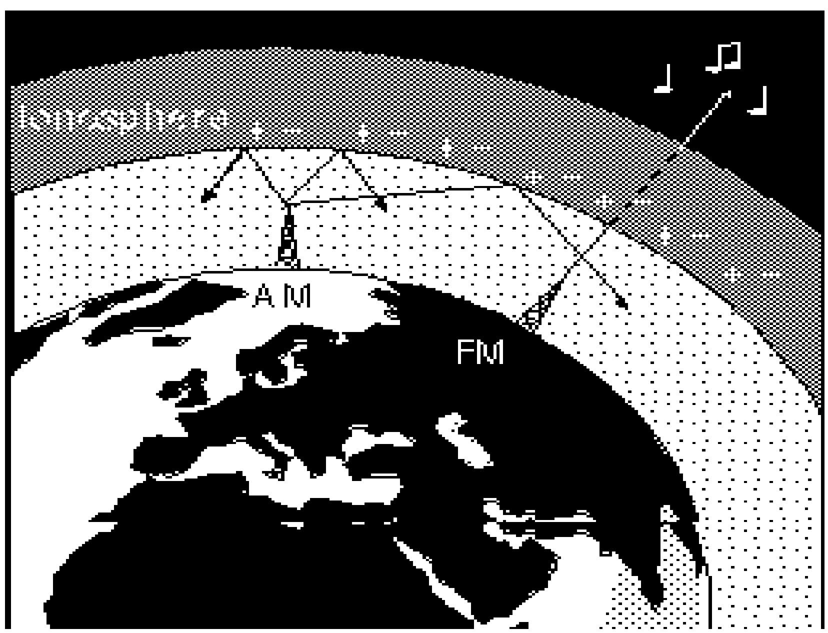


Figure 1

The topography of your home town has a lot to do with how well radio signals are broadcasted and received. Reception in and around hills and valleys, under bridges, or inside and outside of buildings varies. The weather plays a significant role in how radio signals and transmitted and received. Certain frequencies are known to attenuate depending on weather conditions.

Figure 2

Procedure

1. Obtain a topographical map of your town and surrounding area. Topographic maps are available from the USGS at the following address: www.topomaps.usgs.gov . Place the topographical map on a bulletin board and use color coded pins to identify sites.

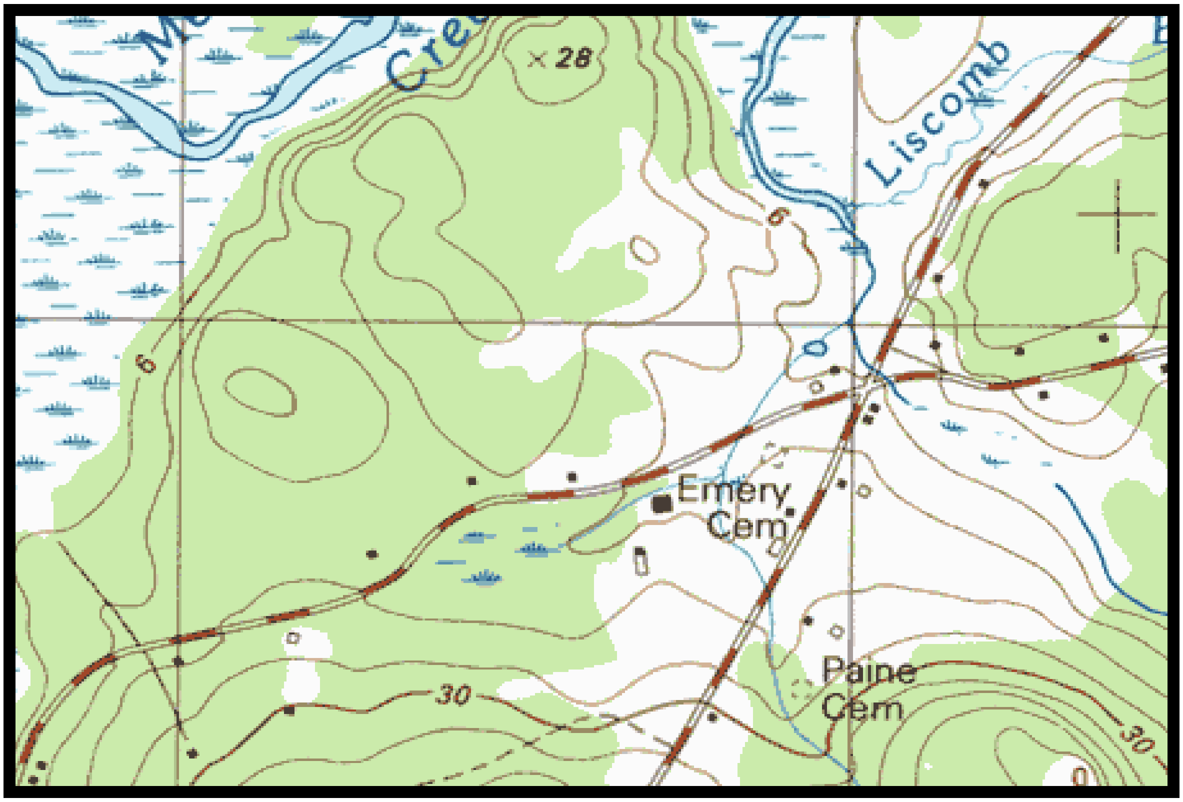


Figure 3

2. Make a catalog of local radio station transmitters and post them on the bulletin board. Use a separate color code for each transmitter.

3. Make a catalog of remote radio station transmitters and post them on the **border** of your bulletin board. Use a separate color for remote transmitters. Draw an arrow at the border indicating the direction of the remote source as well as distance and elevation data.

4. Choose several sites of interest in your local area to test these signals. You may want to try hills and valleys, behind and in front of local AM radio stations. Be creative and think of anything you may wish to test. Perhaps your local AM radio station might have a few areas they would like you to test. Use a separate color code for test sites.

5. Perform scans encompassing the bandwidth of the local and remote transmitters at your chosen observation sites. Perform several scans to account for any variations in signal strength.

6. Assemble all data and devise a method for analysis. Describe your method of analysis in 1-2 pages.

7. Interpret your results and explain your findings in a 1-2 page scientific report.

Teacher Guide for Activity 4: Detecting Meteors using a Communications Receiver

This activity is appropriate for students in grades 9 through 12.

Materials needed:

- Communications receiver
- Antenna
- List of upcoming meteor showers

Preparation and set-up time: 30 min.

Time needed to complete activity: 1 or 2 class days

Activity 4

Detecting Meteors Using a Communications Receiver

Figure 1

Purpose

- Learn the difference between annual meteor showers and random sporadic particles
- Use a communications receiver to listen to and graph meteor intensities
- Compare data collected from random sporadic particles to known meteor showers

Discussion

Everyone has a favorite radio station that they listen to, Kiss108, Oldies 103.3, and Magic 106.7, for instance. The radio signals are broadcast over a specific frequency and an antenna picks up the signals, processes the received information, and translates that data into sound. But, all of these signals are produced right here on Earth, how about listening to something that's not from the Earth but has been traveling through our solar system for billions of years…meteors!

Most people are familiar with the streak of light produced by a meteor, but a meteor also produces a column of ionized atoms and molecules in a path behind it. It is this ionized trail that is capable of scattering signals from Earth based radio stations (such as FM and TV broadcasts) and redirects the signal back to Earth. This process is similar to the way that the ionosphere reflects signals back to the Earth and why certain stations farther away can be heard at night (see figure 2).

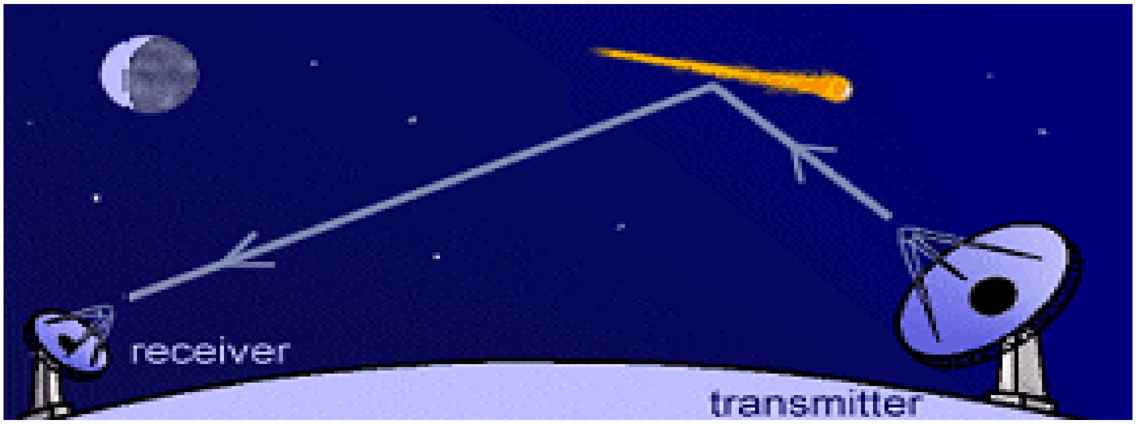


Figure2

Optical astronomers may have their view of meteors obscured by cloud cover or inhibited by moonlight. Also, optical observers can only observe at night and only those meteors with bright trails. Whereas, radio astronomers can listen 24 hours a day, regardless of cloud cover and several meteor showers each year occur only during daylight hours. Much smaller meteors can be detected by radio means than would ordinarily be visible thus enabling the radio astronomer to potentially hear hundreds of meteors per night as compared to only visually observing tens per night.

There are two categories of meteor events, **meteor showers** and **random sporadic particles.** A meteor shower is an annual, predictable event when Earth's orbit passes through a stream of dust from a comet. There are many such events that occur throughout the year and a complete list of meteor showers for both visual observation and radio observation can be found on the International Meteor Organization's web site: http://www.imo.net . Look under the heading Further Information and click on meteor shower calendar. Check it out!!!

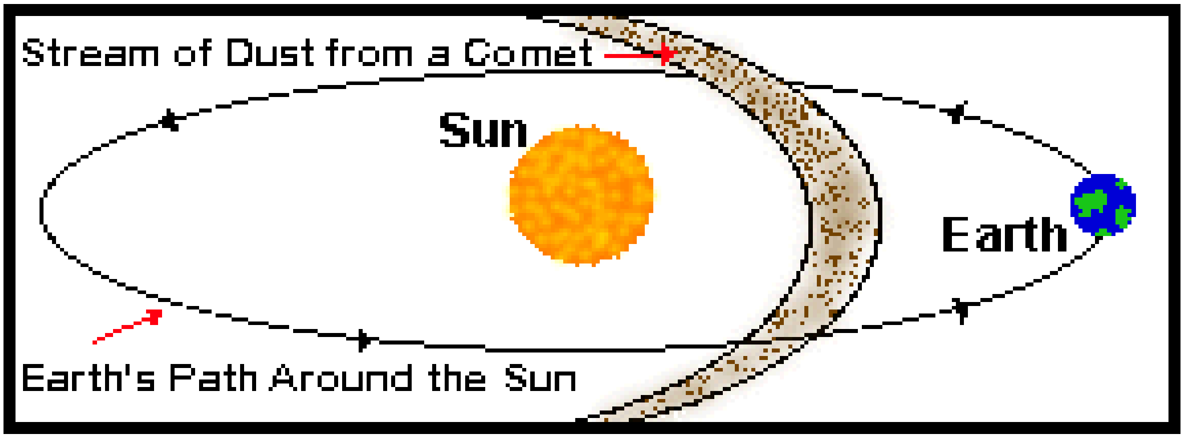


Figure 3

The second category of meteors is the **random sporadic particles**. On any given dark, moonless night 12 – 15 meteors may be visually observed. This is only a small fraction of the thousands of meteors that pass through our atmosphere daily, many of which are too faint to be observed visually and can only be detected at radio frequencies**.** In fact, each day the Earth collects about 400 tons of meteoric debris! Radio detection rates are higher than visual observation rates because particles down to 10-10 kg can be detected by radio whereas only particles down to 10-5 kg can be detected visually. It is this type of sporadic meteor event that allows radio observers to listen to meteors every day of the year. The sporadic meteor rate peaks at about 6:00am and is at it's minimum around 6:00pm. This is because as the Earth rotates on its axis the leading edge or "forward side" sweeps up more meteors than the "trailing side", see figure 4.

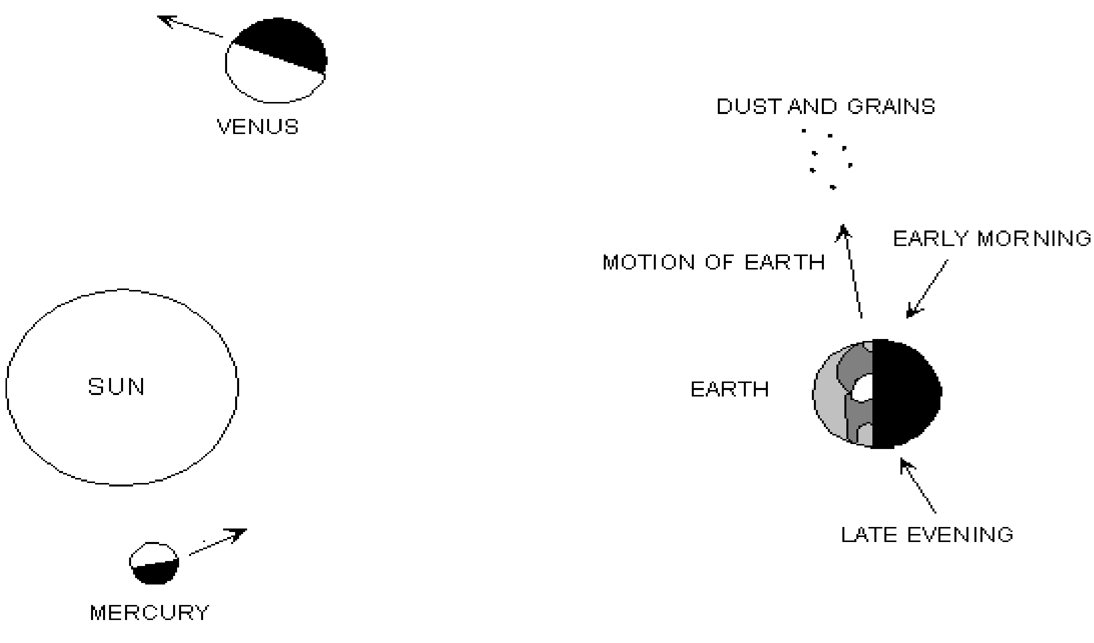


Figure 4

Part A. Set-up

1. The equipment needed for detecting radio meteors is a communications receiver and an antenna. The best frequencies for detecting radio meteors are usually

between 50 and 120 MHz this is because the lower the frequency the longer the meteor signal lasts.

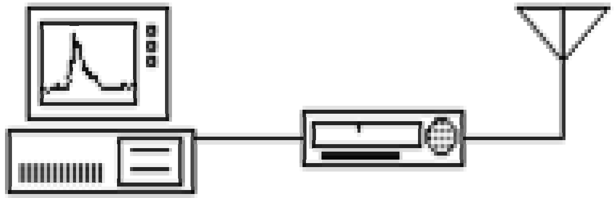


Figure 5

2. Many observers use a simple FM tunable radio and an FM/TV antenna for their set up. The receiver should be tuned to a distant radio transmitter between 200 and 500 miles away. It should be a station that you can just barely get with your receiver. Commercial radio stations, TV stations and radar transmitters are all suitable if they are located the right distance away. Under normal circumstances the transmitting station should be difficult or impossible to detect, but when a meteor passes between the transmitter and your receiver, the signal "hops" over the horizon and a brief fragment of the transmission can be heard (see figure 2). This is similar to the propagation effect when an AM radio signal reflects off of the ionosphere at night and can be heard farther away. Depending on the type of transmitter, the signal might sound like a tone, bit of music or voice. The contact lasts for as long as the meteor trail persists, usually from 100 milliseconds to a few seconds.

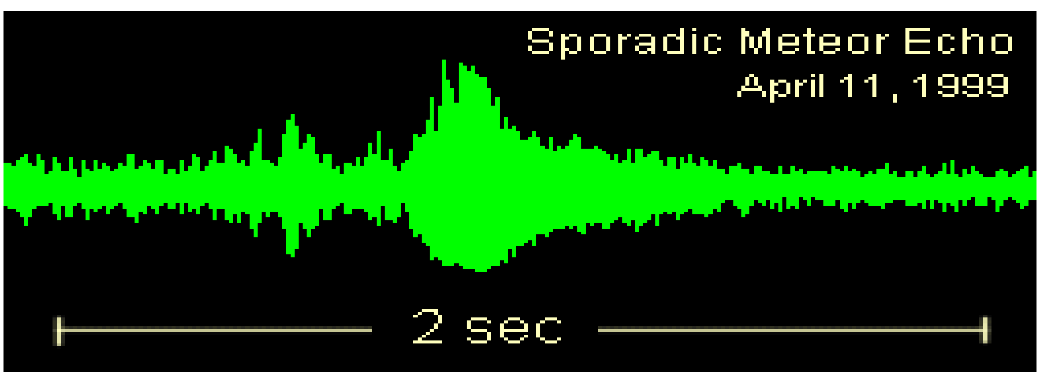
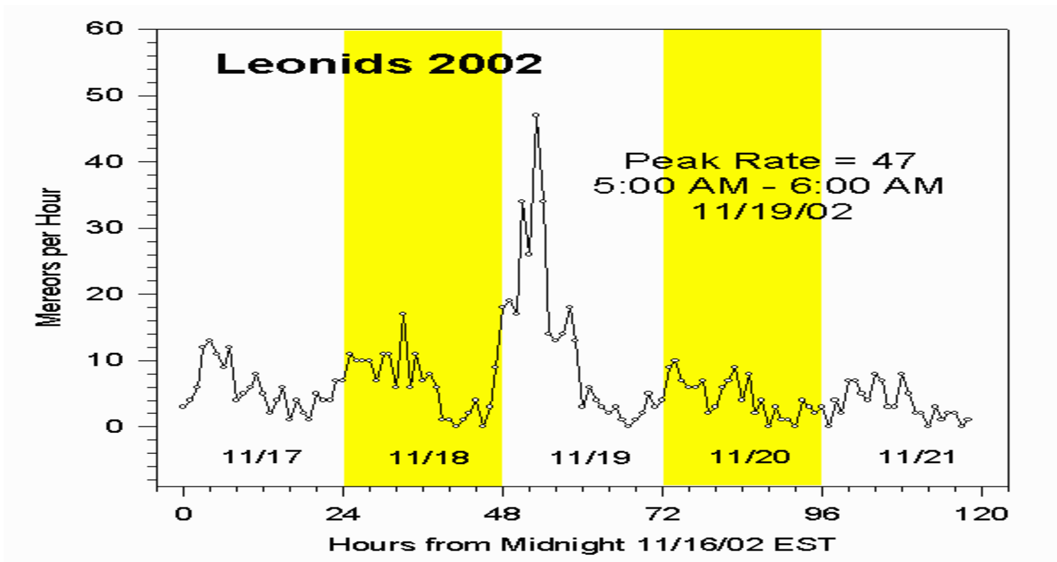


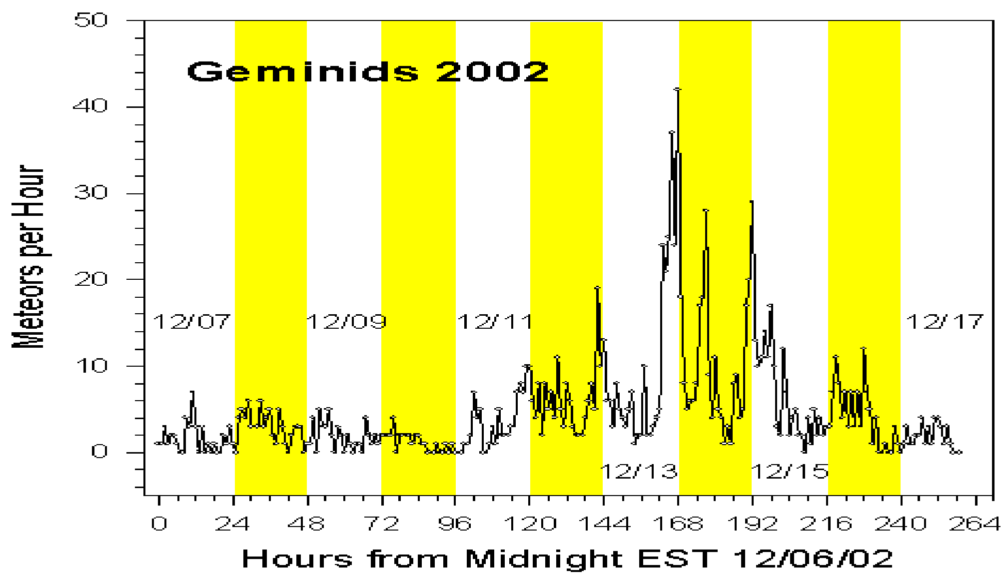
Figure 6

Part B. Projects

1. Compare peak intensities (meteors-per-hour rate) between the annual Leonid Meteor Shower (Nov. 16) and the Geminid Meteor Shower (Dec. 13). Then plot and graph the data to determine if the peak intensities were equivalent to the predicted intensities for each event. For a brief tutorial on meteor showers go to www.amsmeteors.org



(Marianne Gualtieri)



(Marianne Gualtieri)

2. Observe a meteor shower using both visual and radio techniques simultaneously. For a list of annual meteor showers go to the International Meteor Organization's web site at www.imo.net. The best time to observe meteors is usually very early in the morning, around 3:00-5:00 am. Set up the radio, tuned to a distant station, and sit back and wait. Hopefully you will get lucky and be able to see some meteors and hear their trails on the receiver. This reinforces concepts in multiwavelength astronomy demonstrating both visible and invisible frequencies of light. This may need to be done over

several nights since meteor sightings cannot be predicted with a great amount of accuracy.

3. Compare and contrast data from a previously recorded meteor shower event (meteors-per-hour rate) and several radio observing sessions from random sporadic particle events. Plot data from both events on a graph and discuss similarities or differences on intensities and durations.

Teacher Guide for Activity 5: Mapping the Radio Frequency Environment of your School Building and Surrounding Area

This activity is appropriate for students in grades 9 through 12.

Materials needed:

- Communications receiver
- Antenna
- Computer
- Map of your school

Preparation and set-up time: 30 min.

Time needed to complete activity: 1 or 2 class days

Activity 5

Mapping the Radio Frequency Environment of your School Building and Surrounding Area

Discussion

The inside of your school building is an interesting site in which to investigate the RF environment. The radio waves transmitted from outside your school might be bouncing off the walls of your school. The radio waves that make it to the inside can experience multiple reflections leading to unexpected results. Metal frames and or pipes inside the walls of your school building can have interesting effects on RF, shielding the building from certain radio frequencies. Devices such as portable phones cannot transmit/receive from some buildings for this reason.

If your school has its own student news channel, the transmission bandwidth can be monitored from various locations within the building or even outside. Knowing the location of the transmitter and its antenna pattern, you can examine how the features of your physical plant block and reflect the signal. It is also interesting to try to find harmonics generated by the transmitter. Harmonics are caused by extra sympathetic vibrations in transmitting the main frequency. For example, if your school were broadcasting at 90 MHz the equipment might generate another unintended signal at 180 MHz. Harmonics contribute to radio pollution, a problem which is growing much to the distress of people who need radio quiet zones.

The computer room of your school generates a lot of RF that is worth investigating. Look for similarities between rooms having a lot of computers such as the library and computer lab. Walkie-talkies and other hand held communication devices used by school staff also contribute to the radio environment. A transmitter that is broken will contribute noise to the RF background. The Van der Graff generator in the physics lab is also a source of RF. Every electronics device in your building from the PA system to a handheld video game contributes to the RF background. As you investigate the environment around your school, take notice of the location of all these devices and many more not discussed here.

Procedure

- Obtain a map of your school. If one is unavailable or unsatisfactory, construct one.

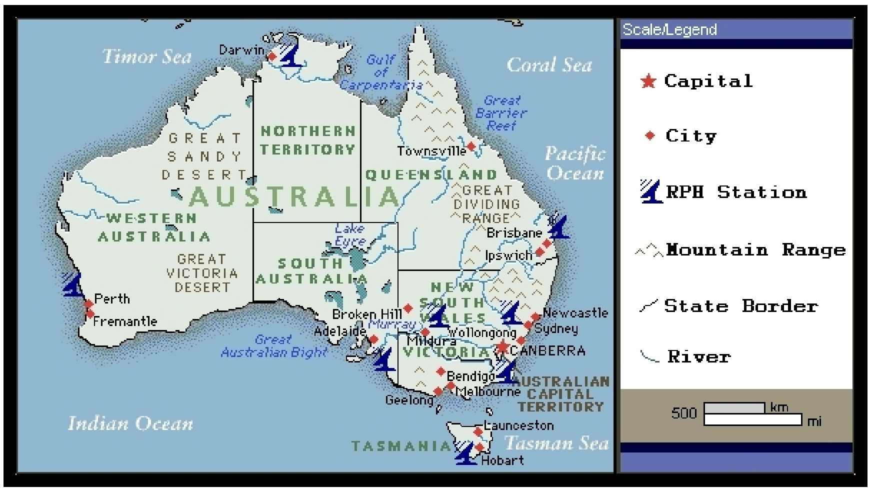
- Find out the transmission frequency of your schools student news station if you have one.

- Go around the school and monitor as many sources of radio transmissions as possible. Be sure to check out the school's main office, computer labs, shop areas, cafeteria, library and various classrooms. Use the receiver and SEARFE software to record and save these scans for future analysis.

- Next, go outside and take several more scans around the perimeter of the school, athletic fields, stadium, and track area. How do these scans compare to the scans taken of the interior? Record and save these scans as well for future analysis.

- On the school map color code areas where radio signals were detected for example, the highest signal strength areas color blue, the lowest detected signal strength color yellow, and where no signal was detected color tan. When finished, you should have a detailed map of the radio frequency environment of your school similar to the radio coverage map of eastern Massachusetts below

- Over the internet, you can contact a school in Australia to compare your school's radio map to theirs (SEARFE website http://www.searfe.atnf.csiro.au). Note any similarities and differences between the two schools.



Teacher Guide for Activity 6: AM Radio Interference

This activity is appropriate for students in grades 9 through 12.

Materials needed:

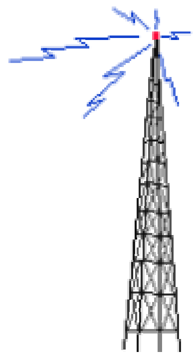
- Communications receiver
- Antenna
- computer

Preparation and set-up time: 30 min.

Time needed to complete activity: 1 class period

ACTIVITY 6

AM Radio Interference



Discussion

It isn't unusual to hear someone claim that they cannot receive some AM stations in their neighborhood despite the fact that there is an AM station right in town. Your job is to start from scratch and devise a study of the problem using any equipment available to you in addition to the AR-3000A. Here are some helpful hints which might help start you on your way.

Interference sources you can turn off

When you are looking for interference it helps to know what the likely sources of interference are. Unfortunately there are many sources of interference. Here is a list of interference sources that you can simply turn off if the source is in your home.

1. florescent lights
2. incandescent lights that are about to burn out
3. blinking Christmas lights
4. television
5. computers and monitors
6. electric motors
7. vacuum cleaners
8. microwave ovens
9. electronic bug zappers
10. electric blankets

Interference sources you can not simply turn off

Unfortunately, there are many other interference sources that can not simply be turned off. Here are some of the more common ones with suggested solutions.

Touch lamps, the type you turn on by simply touching the base, have to be unplugged not just turned off.

Light dimmers can cause interference even if they are in your neighbor's apartment. If you have one in your home, you can have it replaced with a regular switch. I have not had to deal with a dimmer switch built into the wall but I have dealt with dimmer switches built into lamps. I have found that if I turned the light off completely the interference was eliminated, which is contrary to the normal story. Perhaps this is only true of dimmer switches built into lamps.

Hard wired smoke detectors cause interference; they can be replaced by battery powered models.

Aquarium heaters, particularly some cheaper models, cause interference. You can upgrade to a better model. The key point is the way the thermostat turns the heater on and off. In cheap heaters the electricity can arch when the heater is about to turn on. In the more expensive models little magnets pull together and complete the circuit in a quick way that prevents arching.

Automatic on/off night lights and outdoor yard lights which come on automatically also generate interference.

Dirty or faulty insulators on utility poles can cause interference, you can phone the utility company and ask to have them repaired or replaced.

A faulty electric switch in your house can cause interference. You can have it replaced. This might be a good idea even if you are not concerned with AM reception.

The interference maybe coming through the electric socket that powers the radio. If the problem disappears when you use a battery-powered radio then you have found the source of the interference.

Some older radios have plugs that are not polarized. If you can flip the plug over then the plug is not polarized. Sometimes the interference can be cut by turning the plug over and putting the prongs in the opposite socket holes.

There maybe other sources of interference in your neighborhood that you will have to live with: medical equipment, radio equipment, and neon signs. You can deal with these in several ways.

First, minimize the interference by pointing the ends of the antenna toward the source of the interference.

Second, move the radio as far away from the source of interference as you can. If the interference is very close by this can work wonders.

Third, sometimes there is interference for only part of the day.

Investigation

- Scan the FCC Rules and how they apply to the AM Bandwidth (this file is rather large). There may be consumer electronic devices that claim to be FCC compliant but in fact aren't.

Federal Communications web site:

http://www.fcc.gov/oet/info/rules/

- Consult electrical engineers or any other experts on radio transmission regarding your investigation. Prepare a list of questions you have. Contact your local AM station

- Hypothesize sources of radio interference. Note any demographic factors that might contribute to interference. Use a map to identify field research sites you select.

- Propose solutions to the problems people may have in AM radio reception. You might want to investigate whether certain antenna types work better than others.

- Compile your finding and investigations into a formal report. Use actual scientific journals as a model for how to write your report.

- Science journals, magazines, handbooks, and just about any source imaginable might contain useful information in your investigation.

Teacher Guide for Activity 7: Are They Really Compliant?

This activity is appropriate for students in grades 9 through 12.

Materials needed:

- Communications receiver
- Antenna
- computer
- Several electronic devices
- Faraday cage - wire mesh, wood frame

Preparation and set-up time: 45 min.

Time needed to complete activity: 1 class period

ACTIVITY 7

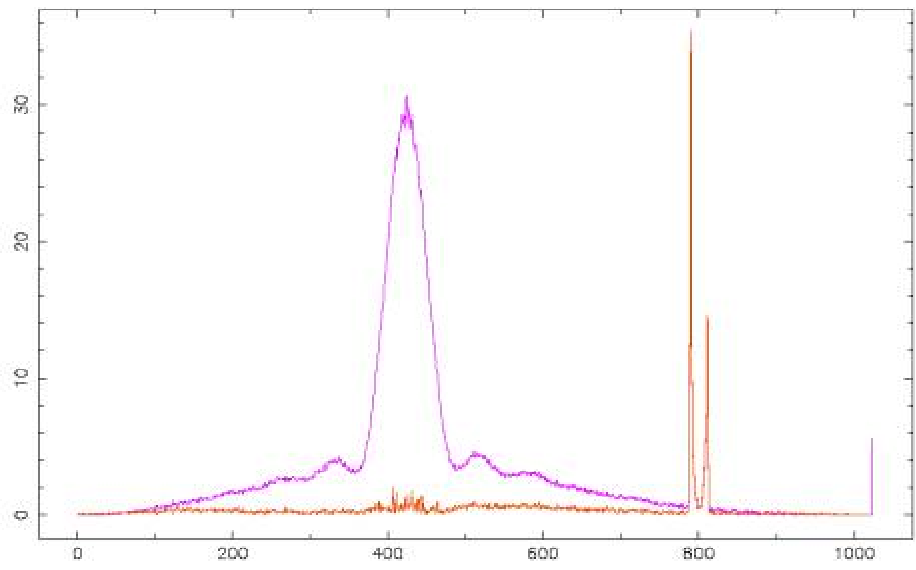
Are They Really Compliant?

Investigating FCC Compliance/Non-Compliance of Consumer Electronic Devices

Discussion

The FCC (Federal Communications Commission) was established to promote and enforce fair use of bandwidth among transmitters. You might be listening to your favorite FM station and a really cool song that you like is suddenly interrupted by someone transmitting at the same frequency as your favorite FM station. It is essential that other radio stations keep to their own frequency without spilling over into someone else's. Advertising revenues and therefore jobs depend on reliable, uninterrupted transmission. Sometimes the interference comes from someone transmitting radio signals into someone else's allocated bandwidth (frequency range). Other times the radio interference can be as simple as Dad using his electric shaver blissfully unaware that he is broadcasting radio waves all over the neighborhood!

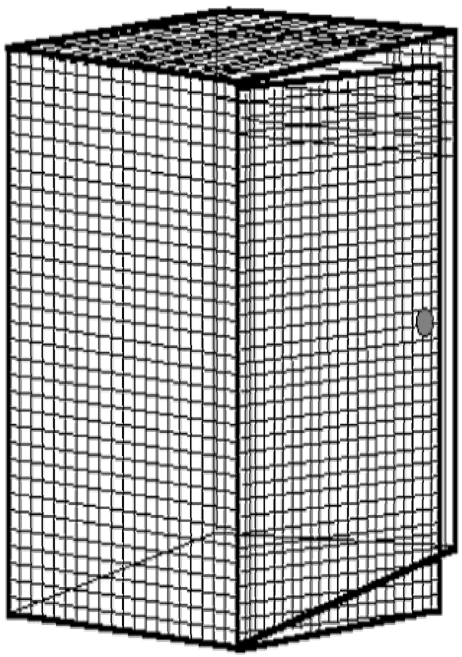
The situation for radio astronomers is no different. Operating your cell phone near an experiment could have unintended consequences. (well… we hope unintended… don't want to give you any crazy ideas!) Radio astronomers often struggle with interference from their own equipment and even computers are known to generate interference spikes. In order that communications and other needs for radio bandwidth can be met and ensuing chaos avoided, the FCC has allocated frequencies to individuals with specific uses. The FCC has also set guidelines for manufacturers of consumer electronics so their products don't generate any unwanted RFI (Radio Frequency Interference).



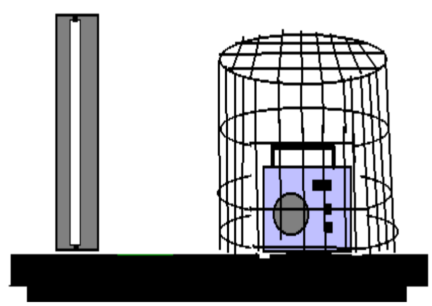
Interference spike

Your task is to investigate the FCC compliance of consumer electronics devices and compare what is claimed versus your experimental finding. In order to perform your investigations you will need to set up a *Faraday Cage*. The electric field inside any conductor is zero and the reason for this is that charge accumulates on the outside of the conductor in such a way as to cancel any electric fields from the outside. This phenomenon is independent of whether the conductor is hollow or solid; it only needs to have a closed surface to prevent RF leaks. Our Faraday cage is going to be a wire mesh arranged into a closed booth. Even the top and bottom (floor) of the cage needs to be covered with wire mesh. Electric fields from within the cage can be measured while all other electric fields from the outside will be screened out which is just what we want.

Construction of Faraday Cage



Faraday cage



Constructing a Faraday cage is relatively simple. Construct a wooden frame roughly 1 cubic yard in size. Design an opening or hinged door for easy insertion of consumer electronics devices to be tested. If your school has a wood shop, consult the shop teacher who certainly has valuable input for your design and construction. After building the frame every square centimeter of the box needs to be covered with wire mesh. Make sure that the surface of the door opening and surfaces of the wooden frame are 100% covered. There are alternative to this basic design. For example, a cardboard box or other box will do just fine in make cases as a frame.

Attach the whip antenna to the AR-3000A receiver. Connect the remote cable to the AR3000A. The remote cable needs to fit through a small hole in the Faraday cage so that the radio is inside the cage and the computer is on the outside as shown. The hole should be no larger that 0.75 cm. Cover the cable hole with aluminum foil, small pieces of wire mesh and/or duct tape to prevent RF from getting inside. Load the SEARFE software. Test the effectiveness of the Faraday cage by running a broad scan (1 MHz to 2020 MHz in 1 MHz increments). Any bumps in the scan indicate internal noise generated by our system or defects in the Faraday cage. This could be noise from the computer traveling through the cable. If you suspect interference from the computer, try to move the computer as far back as possible and rescan noting any changes. Next, examine the cage for any leaks. Keep your scans as a baseline for future scans. If there is some RFI due to our system we want to be able to subtract those signals from our RFI measurements of consumer electronics devices.

Method

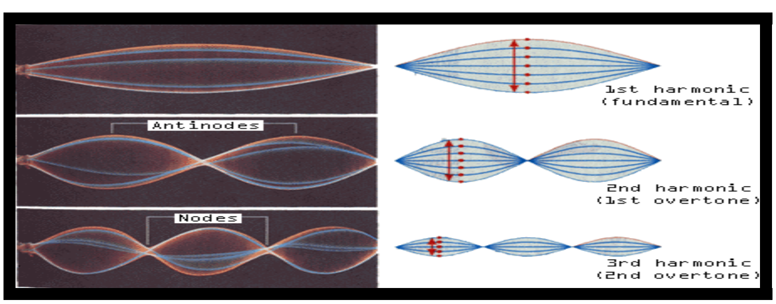
- Select a consumer electronics device for investigation. Try to include the device manual if at all possible. If not available, try to find a copy of the manual on the internet. Bookmark the website containing the manual for future convenience. It is <u>not</u> necessary to print out the manual.

- Look up any FCC compliance information about the device. This is usually available on the manufacturer's website which is listed in the device manual.

- Perform several scans of the device under investigation while inside the Faraday cage. These scans should include ranges that we investigated in previous activities. Below are some suggested scanning frequencies to use although you may certainly have good reason to change them at any time. Note any RF spikes.

- Return to any RF spikes and try to pin point the exact frequency of these spikes. Write these frequencies right on the graphs of your RF scans with arrows pointing to their respective peaks.

- Look for RF spikes that are an integer or half-integer multiple of one another. These could be *harmonics* of the same interference source.



- Any modification of this procedure in your investigation is absolutely fine. Make a note of any changes you feel are necessary. Flexibility and team input are often necessary in projects of this sort.

Suggested Scans
0.1 MHz – 3 MHz in 0.1 MHz increments
3 MHz – 30 MHz in 0.5 MHz increments
30 MHz – 300 MHz in 1 MHz increments
300 MHz – 1000 MHz in 10 MHz increments
1000 MHZ – 2020 MHz in 10 MHz increments

Report

- Include in your written report an outline in precise language of your procedure/method used to investigate FCC compliance/non-compliance of consumer electronic devices. You may include diagrams and charts. (1-2 pages)

- Include in your written report a summary of your findings for each consumer electronic device investigated. Note any non-compliance. (2-3 pages)

- Prepare a poster board display of your project. Different aspects of your project should be organized separately and logically displayed.

- Give an oral presentation of your project. Different members of your group can be assigned different aspects of your project. Someone could explain the Faraday cage and do a demonstration. Someone else can explain the results of the experiment. Another could demonstrate the Searfe software and perform a sample test of a device in front of the class. Each student engaged in the project should contribute equally in the oral presentation.

Teacher Guide for Activity 8: Using the Small Radio Telescope to Further Investigate RFI

This activity is appropriate for students in grades 9 through 12.

Materials needed:

- Communications receiver
- Antenna
- Small Radio Telescope

Preparation and set-up time: 2 hours.

Time needed to complete activity: 1 or 2 class days

ACTIVITY 8

Using the SRT (Small Radio Telescope) to Further Investigate RFI

The MIT Haystack SRT is a radio telescope capable of spectral line (1420 MHz hydrogen) and continuum observations using source tracking, 25-point maps, and drift scans. The SRT is able to scan a frequency range of 1370-1800 MHz and has been recently upgraded with a digital receiver. Several projects have already been developed for the SRT which are suitable for pre-college students such as; instrument evaluation, galactic hydrogen line spectrum, galactic rotation curve, and daily solar radio flux monitoring. For further information and project directions go to the MIT Haystack Observatory website: http://web.haystack.mit.edu/SRT/srtprojects.html.

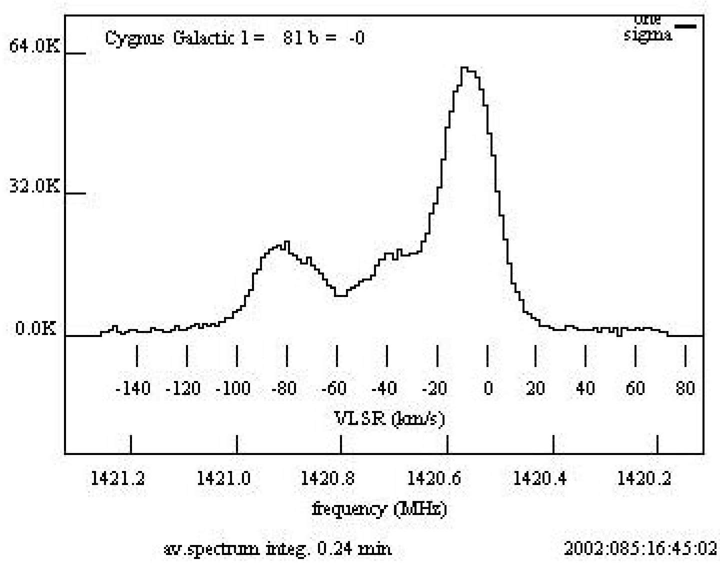
SRT (small radio telescope)

Radio Frequency Interference

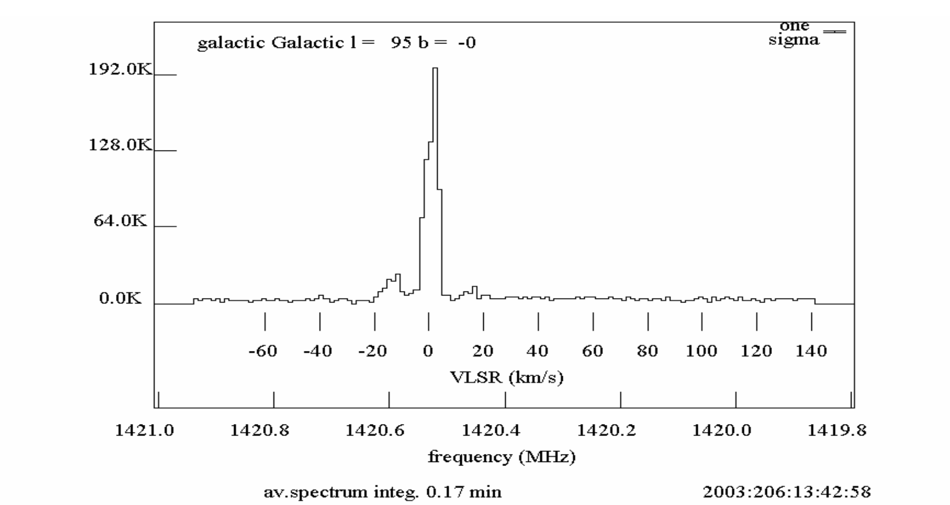
When students are observing the galactic hydrogen line at 1420MHz occasionally, another spike is detected close to that frequency and can cause some inaccurate readings. This spike must be taken out of the data in order to get a true reading of the galactic hydrogen. What is causing this spike? Is it from somewhere else in the galaxy or is the source from someplace nearby on the Earth? In this activity, students will obtain SRT data from galactic hydrogen, determine if an extraneous spike is observed, use the AR-3000A receiver to scan the frequency range in order to determine the source of the interference.

Procedure

Students will run several scans for galactic hydrogen from 1420.2MHz to 1421.2MHz. Scans will be taken over several days and at different times. Below is a sample of data that have already been observed at these frequencies.



Notice the strong hydrogen spike at 1420.5MHz. The next graph shows a similar galactic hydrogen scan but notice the smaller spikes on either side of the main spike. Are these somehow related to the galactic hydrogen curve or are they some sort of interference from another source?



After students have run multiple SRT scans over the course of several days, compare the various data charts. Are there any offset spikes visible on your data graphs? There might not be, but if there are have students do some more investigations. Use the AR-3000A receiver to run scans of various electronic equipment associated with the SRT. Then run scans on other electrical devices in the near vicinity. Run the scans with the devices on and off as well. Do any of these devices produce spikes in the same frequencies that were detected by the SRT? Once students have identified several possible candidates, run a few more SRT scans with the devices on and then off. Are there any changes in the SRT graphs or are the data unchanged? Radio frequency interference and be a real annoyance to astronomers and is capable of interfering with extremely faint incoming signals from outer space. Currently, the FCC has allocated protected bandwidths for the use of radio astronomy but as demand for more consumer bandwidth increases, some of these protected bands may be reduced.