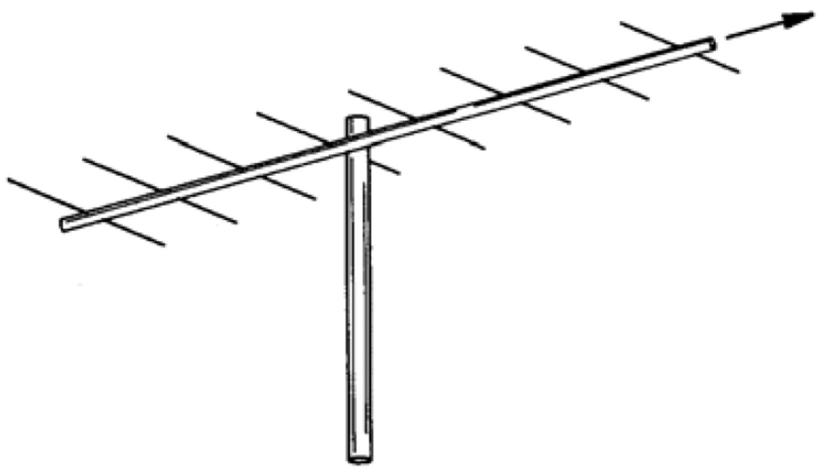
Electromagnetic Radiation & Satellites

Antenna Design



More Lessons from the Sky
Satellite Educators Association
https://SatEd.org

Please see the Acknowledgements section for historical contributions to the development of this lesson plan. This form of “Electromagnetic Radiation and Satellites” lesson plan was published in March 2012 in “More Lessons from the Sky,” a regular feature of the SEA Newsletter, and archived in the SEA Lesson Plan Library. Both the Newsletter and the Library are freely available on-line from the Satellite Educators Association (SEA) at this address: https://SatEd.org.

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Electromagnetic Radiation & Satellites

Antennas, Wavelength, and Frequency

Invitation

How big does an antenna have to be to receive weather satellite signals? Some are very large and some are very small. Is there a “right” size, and if so, what is it? In this activity, learners design and build a scale model antenna of the type needed to receive weather satellite signals and make the connection between wavelength, frequency, the speed of light, and the size of the antenna. They use the connection to determine the size of each antenna element, then build a 1/10 scale model of the real antenna.

Grade Level:	9-12
Time Requirement:	1-2 class periods
Prerequisites:	EMR spectrum; wave properties; grade level math
Relevant Disciplines:	Physical Sciences, Engineering & Technology

Student Learning Outcomes

By the end of this lesson, students should be able to do the following:

- Define, properly use, and discuss the meaning of the following terms:
  - Electromagnetic radiation
  - Speed of light
  - Frequency
  - Wavelength
  - Hertz
- Build and demonstrate a scale model of a full cycle wave.
- Diagram, build, and demonstrate a scale model of a Yagi antenna for receiving radio waves with a frequency of 137.5 MHz.
- Explain and discuss the function of an antenna with respect to frequency and wavelength

Lesson Description

This is a student centered, hands-on activity. It is an extension of the study of wave properties and the electromagnetic spectrum. Students will apply their knowledge to the design of a radio antenna for receiving a specific frequency of radio wave directly from polar orbiting weather satellites. Students should already have a working knowledge of the electromagnetic spectrum and the basic wave properties of wavelength, frequency, and velocity. Some background information is supplied in the Student Activity in the form of Frequency Asked Questions. However, the content and pedagogy of lessons preceding this one are left to the individual teacher.

Students should complete the antenna diagram worksheet in order to determine the actual final lengths of the model antenna elements prior to building the models. The worksheet with conclusion questions provides closure as well as a tool for assessment. It can be completed before or after students attempt the Your Turn activities.

Assignment of one or more of the Your Turn activities can be optional except for the first bullet. Students should be able to calculate the antenna length for 1693 MHz by the end of the model building activity. This is a direct application and repetition of the main lesson concept. Time permitting, the second bullet can be completed with a little student research into antenna designs. Amateur radio publications from sources such as the American Radio Relay League (ARRL) can be very helpful here. Building and testing a real antenna, the third bullet, is a time and resource intensive optional activity. However, the directionality of various antenna designs, the fourth bullet, can be easily researched online. The last Your Turn item, modeling the antenna and parabolic dish reflector for geostationary satellites (1693 MHz) is a great closure/ assessment/application activity for this lesson if time and resources permit.

Ultimately, student comprehension of lesson concepts will be demonstrated readily in the quality of the models and the amount of self-direction the student employs in determining the size of each antenna element and building the actual models.

Important Terms

Antenna	Radiator (antenna part)
Director (antenna part)	Reflector (antenna part)
Electromagnetic radiation	Speed of light
Frequency	Wavelength
Hertz	Yagi

Assessment Suggestions

- Clarity and accuracy of definitions
- Accuracy of vocabulary use in discussions
- Quality and accuracy of wave model
- Quality and accuracy of antenna model
- Explanation of antenna function with respect to frequency and wavelength
- Completion, quality, and accuracy of a Your Turn activity

Next Generation Science Standards

These are the Next Generation Science Standards addressed in this lesson.

Performance Expectations & Disciplinary Core Ideas

Grades 9-12: Energy

PE- HS-PS3-5 - Develop and use a model of two objects interacting through electrical or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to interaction.

DCI- HS-PS3.C - When two objects interacting through a field change relative position, the energy stored in the field is changed.

Grades 9-12: Waves and Their Applications in Technologies for Information Transfer

PE- HS-PS4-1- Use mathematical representations to support a claim regarding relationships among frequency, wavelength, and speed of waves traveling in various media.

DCI- HS-PSPS4.A- The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.

Grades 9-12: Engineering Design – Optimizing the Design Solution

PE- HS-ETS1-2 - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

DCI- HS-ETS1.C - Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others may be needed.

Science and Engineering Practices

– Develop and use a model based on evidence to illustrate the relationships between systems or between compounds of a system.
– Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations.
– Design a solution to a complex real-world problem, based on evidence, prioritized criteria, and tradeoff considerations.

Crosscutting Concepts

– Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
– Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller-scale mechanisms within the system.

Preparation

The main action of this lesson is students building a scale model wave and a scale model antenna using chenille or pipe cleaner. Each model will require at least 9 pieces of chenille each at least 12 inches long. Using at least 5 different colors affords students the ability to distinguish between the driven element (radiator), the reflector and the directors. For example, using the colors suggested in the Student Activity, 1 red, 1 dark blue, 1 white, 2 green, and 4 black chenille lengths are needed. The colors are arbitrary and can be varied as supply dictates. The chenille can be twist tied together and pulled straight if a longer piece is needed or cut with small, diagonal wire cutters where shorter pieces are needed. Each student building a model should also have a metric ruler measuring 0.1 cm. The typical maplewood or plastic English-metric ruler found in many schools works well. Since one piece of chenille representing, say, the driven element (or radiator) will be twisted around the length of chenille that represents the boom to hold it in place and perpendicular to the boom, it is suggested students measure and cut the chenille for each of the 5 elements ***after*** attaching them to the boom. If the element chenille is cut first, wrapping around the boom shortens it producing an inaccurate model. A marking pen can also be used to mark the position of each element on the boom.

Duplicate the Student Activity pages and distribute a copy to each learner. To conserve paper: the three pages of instructions can be shared; “Spacing, Arrangement, Dimensions” (the Antenna worksheet) and Conclusion Questions can be printed on two sides of a single sheet; and the Your Turn activities can be completed in teams.

This lesson module is provided in portable document format (.pdf) and requires a PDF reader, such as Adobe Reader or equivalent, to view and print the file. If needed, Adobe Reader is freely available from https://get.adobe.com/reader/. The Student Activity pages are supplied in the pdf file and in Microsoft Word document format to facilitate the teacher's adaptation of the lesson to the needs of the students, the curriculum, and the classroom situation.

Background

Electromagnetic radiation is energy that radiates, or travels out, from its source in the form of transverse magnetic and electric waves. It includes all visible light as well as infrared, ultraviolet, radio waves, microwaves, and X-rays among others.

A little history: In 1678, Christian Huygens professed light was composed of waves based on his observations of the behavior of visible light in a prism. In 1704, Isaac Newton countered Huygens when he described light as particulate by mathematical application of his three laws of motion. This wave vs. particle controversy continued for more than two hundred years. Then, in 1900, Max Plank explained black-body radiation (the energy radiated from an object as it is heated) by postulating that the emitted radiation was directly proportional to its frequency, a property of waves, in the equation $E = h\nu$, where E is energy, ν is frequency, and h is a constant of proportionality (now called Plank's Constant) equal to $6.626 x 10^{34}$ J/Hz. Plank thought the radiated energy consisted of small indivisible units of $h\nu$ he called energy quanta. Albert Einstein called each $h\nu$ quantum a photon in his description of the photoelectric effect in 1903. When photons of light struck a metal plate, electrons were emitted from the plate and collected on another plate when a voltage was applied between them. The energy of each electron was the energy of the absorbed photon. This was a fairly clear demonstration of the particle-like nature of photons. Then, in 1905, Einstein formulated the special theory of relativity in which his famous $E=mc^2$ described matter and energy in a proportional relationship with the velocity of light in a vacuum, *c*. With matter, or mass, represented by m, this, too, is a distinctive statement of the particle-like nature of photons. Additionally, Einstein believed the velocity of photons in a vacuum (the speed of light) was a universal constant unrelated to the observer's perspective and was the upper limit of velocity in the universe. Louis de Broglie, in his 1923 doctoral thesis, hypothesized a dual nature, both particle-like and wave-like, not just for photons but for all matter. A simplified way to visualize this connection is by equating Plank's $E=h\nu$ with Einstein's $E=mc^2$. If energy, E, is the same in each equation and both h and c are constants, then a simple substitution and rearrangement shows frequency, ν, a wave property, inversely proportional to momentum, mc (or mv), a particle property. Experimental evidence to support de Broglie's hypothesis was found by Davisson and Germer at the Bell Labs within a few short years. So, photons travel like waves and impact matter like particles.

Without delving into quantum mechanics, it can simply be said that today light is described with both wave and particle properties and understood to be both electrical and magnetic in nature. Physicists have known since the nineteenth century that moving electric charges, such as electrons, create a magnetic field that in turn induces an electric field. Foundational to the work of Plank and Einstein was Maxwell's discovery, in 1864, of the connection between optical, magnetic, and electrical phenomena and the equations with which he described their related fields. We understand today that waves of a magnetic field travel in the same direction as the waves of the coincident electrical field, simultaneously, and with one at right angles to the other.

The speed of light in a vacuum has been treated as a cosmic constant for more than a century. The velocity of light (including visible light and radio waves) is 299,792,458 m/s. (This value was often expressed as 3.00×10^8 m/s in three significant figures; three was the number of significant figures used for slide rule calculations before the common use of electronic calculators and computers.) Einstein's 1905 Special Theory of Relativity predicts mass becoming infinite as it approaches the speed of light. Consequently, this velocity stands as a hallmark upper limit in the world of physics today. While fans of *Star Trek*, *Stargate*, and *Dune* may welcome a discussion of wormholes, warping space, and methods for traveling from one part of the universe to another at speeds effectively faster than light, a discussion of antenna function must turn its attention to lower speeds. It is understood by those studying the radio arts that electromagnetic energy induces electron motion (an electric current) in metals. The metal, in turn, resists the motion and slows the electrons. Thus, the velocity of electromagnetic radiation in a metal wire or antenna drops to 2.80225×10^8 m/s. This is significant when considering the relationship between wavelength and frequency of electromagnetic energy in a metal antenna.

In addition to velocity, wave properties include wavelength, amplitude, and frequency. A typical exemplar wave has the shape of a sine wave with crests and troughs. The distance from one crest to the next is one full wave or one wavelength. It is generally represented by λ and expressed in meters. Frequency is the number of wave peaks or crests that pass a specific point each second. It is generally represented by ν and expressed in Hertz (the name for 1/sec). Wavelength multiplied by frequency (that is, meters X 1/sec) equals velocity (the speed of light, m/s), in the equation $\lambda\nu = c$. Notice that frequency and wavelength are inversely proportional. As one increases, the other decreases proportionally to the speed of light. Polar-orbiting weather satellites transmit their APT, or automatic picture transmission, signal at a frequency of 137.5 MHz (137,500,000 waves/sec). Dividing this frequency into the speed of light gives us an associated wavelength of 2.18 meters.

An antenna is an arrangement of metal raised off the ground and used for radiating or collecting electromagnetic energy as part of a radio transmitting or receiving system. In this activity, students will investigate the relationship between wavelength and the length of the elements of a "Yagi" antenna. The Yagi-Uda antenna was invented in 1926 by Shintaro Uda in collaboration with Hidetsugu Yagi, both of Tohoku Imperial University, Sendai, Japan. This is a highly directional and selective antenna consisting of a driven element made of one or two dipoles connected to the receiver or transmitter and several parasitic elements, usually a reflector and one or more directors.

How an antenna functions to propagate radio wave transmission is beyond the scope of this lesson plan and will not be discussed here. For those interested, there are dozens of YouTube videos available will all manner of descriptions attempting to address this question. However, one stands out as an excellent, clear, and straight forward explanation of antenna physics produced by the Royal Canadian Air Force as a 12-minute training film in 1959. Titled "Antenna Theory Propagation," it was posted on YouTube by Doug LeBlanc and is available at https://youtu.be/-F7KYLO4Bkg.

The physical size of each of these antenna elements is determined by the wavelength or frequency of the transmissions it is intended to receive, in our case, 137.5 MHz. This frequency is in a range of frequencies known as "very high frequency" or VHF. In the early days of amateur radio, licensed amateurs experimentally determined that a VHF antenna was most efficient when the radiator or driven element was cut to a length close to ½ or ¼ of the fundamental wavelength. If the frequency of 137.5 MHz is equivalent to a wavelength of 2.18 meters, then a driven element cut to ½ wavelength would have a length of 1.09 meters. Remembering, however, that electromagnetic radiation travels at a lower velocity in metal, we must recalculate by dividing 137.5 MHz into 2.80225×10^8 m/s giving us an effective wavelength of 2.038 meters. Now, we can see that our ½ wavelength driven element must be cut to 1.019 meters or 101.9 cm.

In a 5-element Yagi antenna, there are 3 directors and a reflector in addition to the driven element or radiator. Each parasitic element is insulated from the radiator. The reflector that follows the radiator reflects missed waves back to the radiator. It is typically cut 10% longer than the radiator. The directors precede the radiator and serve to focus the waves onto the radiator. The first director, the element immediately preceding the radiator, is typically cut 5% shorter than the radiator. The second director is 5% shorter than the first, and the third and each succeeding director are each 5% shorter than the previous one. Thus, a Yagi antenna is highly directional and provides higher gain (a stronger signal) than a simple dipole antenna.

The length of each element of our Yagi antenna for 137.5 MHz and our 1:10 scale model are listed below.

Element	Element Length	Model Length
Third Director, D_3	87.4 cm	8.7 cm
Second Director, D_2	92.0 cm	9.2 cm
First Director, D_1	96.8 cm	9.7 cm
Radiator, RA	101.9 cm	10.2 cm
Reflector, RE	112.1 cm	11.2 cm

NOAA polar orbiting environmental (weather) satellites (POES) orbit the earth at an average altitude of about 833 km (517 miles) about every 101 minutes in a sun synchronous, polar orbit. Geostationary weather satellites (GOES), on the other hand, orbit the earth at 35,786 km (22,236 miles) at a speed that allows the satellite to appear motionless over a single equatorial ground position. POES imagery provides closer detail of local atmosphere and ground whereas GOES imagery easily shows large scale and global trends. GOES satellites transmit a fresh image of the Earth every 5 minutes on a frequency of 1681.6 MHz. The length of ½ wave antenna for this frequency is actually quite short, only 8.33 cm (3.28 in). The antenna is so small, a very large reflector is commonly used to significantly increase the number waves actually hitting the antenna. The most common reflector style is a parabolic dish shape with the antenna mounted near the parabola's focal point. The antenna is usually mounted in a resonating can with its opening pointed at the reflecting dish. Thus the "satellite dish" style antenna. A common misconception is that the reflecting dish itself is the antenna not just a reflector.

A final historical note. The first polar orbiting weather satellite, TIROS-1 (Television and Infrared Observation Satellite) was launched by the United States in 1960. The TIROS series program was followed by NOAA series and, more recently, the JPSS (Joint Polar Satellite System), the nation's advanced series of polar-orbiting environmental satellites. Automatic picture transmission (APT) slow-scan capability first appeared on TIROS-8 launched in 1963. APT was a standard instrument package on each polar orbiting weather satellite through NOAA-19 launched June 2009. The equipment needed for receiving and imaging the APT signal is relatively easy for students to assemble and operate. Receiving this signal is the primary subject of the Joe Summers book described below. Today, after more than a half century of technological advancements, the current series of polar orbiting weather satellites, such as JPSS-2 (which became NOAA-21 when it reached stable orbit in 2022) do not include APT. As of the date of this lesson plan update, however, the APT is still operational on NOAA-15 (137.62 MHz), NOAA-18 (137.9125 MHz), and NOAA-19 (137.1 MHz). The antenna modeled in this lesson is designed specifically for 137.5 MHz (another common APT transmission frequency). The principles of antenna design are the same whether applied to a Yagi antenna or a single element antenna sporting a parabolic reflector or some other antenna arrangement. Teachers and students are invited to explore Using Satellites in Education at https://SatEd.org/satellites.htm for more detailed information, how-to-do-it videos and much more for receiving APT and higher resolution imagery from weather satellites.

Acknowledgements

In the early 1980s, Joe Summers, a Biology teacher at Chambersburg High School in Pennsylvania, guided his students to building and operating a weather satellite receiving station complete with wet-paper facsimile printer such as those in airport weather offices at the time. The project enabled the students to receive weather satellite imagery of the atmosphere directly from polar-orbiting satellites in real time thus developing a better understanding of the application of technology to the study of environmental factors in their Biology class. Summers worked with the National Environmental Satellite Data and Information Service (NESDIS), a division of the National Oceanic and Atmospheric Administration (NOAA) of the United States Department of Commerce, to develop a publication available to teachers, the *Educators Guide for Building and Operating Environmental Satellite Receiving Stations* - NOAA Technical Bulletin NESDIS 44. The guide included a full description of, and directions for building, a crossed Yagi antenna for receiving the Automatic Picture Transmission (APT) signal from weather satellites. Included was a diagram of a 5-element Yagi antenna. Helen Martin, an Earth and Space Science teacher at Unionville High School, Pennsylvania, designed an original lesson plan and worksheet based on that diagram. The lesson led students to explore, through modeling, the relationship between frequency and wavelength and between wavelength and the size of an antenna.

Martin's lesson plan was one of more than fifty lessons compiled by Satellite Educators Association, Inc. and published in *Lessons from the Sky,* © 1995 by Amereon, Ltd. The current lesson module is an adaptation of Martin's original lesson.

This lesson module, including this edition of Teaching Notes and supplemental materials, were developed by J.P. Arvedson for the Satellite Educators Association as part of *More Lessons from the Sky*, a regular feature of the *SEA Newsletter* published periodically online. More information about the Satellite Educators Association, its annual Satellites & Education Conference for teachers, its international K-12 environmental research collaborative, and free access to its on-line newsletter can be

found at this address: http://SatEd.org.

All *More Lessons from the Sky* lesson plans are archived in the on-line SEA Lesson Plan Library available at http://SatEd.org. The web site features a description of the library contents, how the lessons are matched to the National Science Education Standards and the Next Generation Science Standards, several search tools for finding lessons easily, separate resource files for lessons where needed, and the library's Analysis Toolbox.

Updates and revisions of the original *Guide* evolved into the *User's Guide for Building and Operating Environmental Satellite Receiving Stations* (2009) which is still available from NOAA. Sadly, the Yagi antenna diagram and construction details were deleted from later editions. An on-line search can usually find one or more of the earlier revisions available for download in PDF format from a variety of sources. The antenna diagram can be downloaded from this address: http://SatEd.org/library/Resources.htm.

When duplicating or otherwise using any portion of this lesson or its associated materials, full credit to all contributors to the lesson and its associated materials must be included.

Resources

Note: All of these URLs were current and active as of this writing. If any are unreachable as printed, the use of on-line search engines such as DuckDuckGo, Google, Ask, or Bing is suggested to find current links.

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Answers to Conclusion Questions in Student Activity

1. Why is it called "electro" and "magnetic" radiation?
   It called "electro" and "magnetic" radiation because it consists of two fields simultaneously, one electric field and one magnetic field at right angles to the electric field.

2. Define each of the following terms. Explain how each is related to designing and building an antenna:
   Answers will vary:
   a. A **sine wave** is the wave shape of theoretical alternating current and the shape of a wave of electromagnetic radiation. The determined length of a sine wave, from crest to crest for example, is a factor in determining the size of the antenna, usually ½ or ¼ of the specified wavelength.

   b. **Resistance** is the total opposition to the flow of direct current in an electric circuit. It is a scalar quantity with only magnitude. It is directly proportional to the applied voltage and inversely proportional to the current (Ohm's Law). *Antenna resistance* is equal to the power supplied to an entire antenna circuit divided by the rms (root mean square) antenna current at a specified point. It is used in conjunction with *radiation resistance* to calculate the power loss due to a variety of antenna design factors and therefore the effectiveness of a particular antenna design.

   c. **Impedance** is the total opposition to the flow of alternating current when a voltage is applied in an electric circuit. Impedance extends the idea of resistance to alternating current circuits. In direct current circuits, resistance has only magnitude. In alternating current circuits, impedance has both magnitude and phase. Thus impedance is an important consideration when designing an antenna as the incoming wave of electromagnetic energy sets up an alternating current in the antenna.

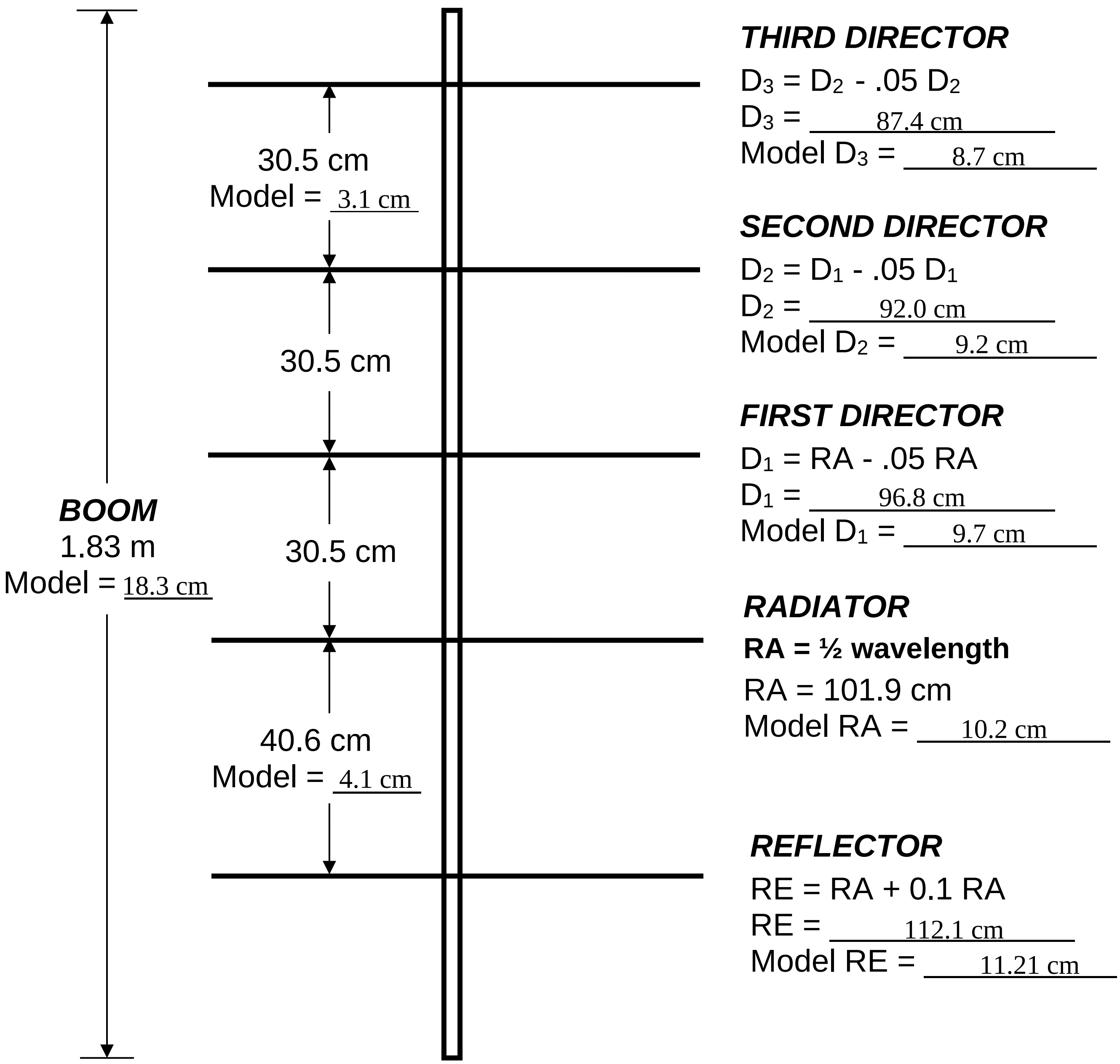
3. Clearly show the calculations for determining the correct length of an antenna for receiving 137.5 MHz.
   Let's start with the speed of light (electromagnetic radiation):
   c_v = speed in a vacuum = 3.00×10^8 m/s = $300. \times 10^6$ m/s
   c_m = speed in metal = 280.225×10^6 m/s. Use this value for an antenna.

   $c_m = \lambda v$ and $\lambda = \frac{c_m}{v} = \frac{280.225 \times 10^6 \text{ m/s}}{137.5 \times 10^6 \text{ Hz}}$

   $\lambda = 2.038$ m and $\lambda/2 = 1.019$ m = antenna length

4. Describe the process by which a wave of electromagnetic energy is collected by the antenna of a radio receiving system. Be sure to correctly use each of the following terms in your description: electromagnetic radiation, speed of light, frequency, wavelength, Hertz, antenna, radiator (or driven element), reflector, director, Yagi.
   Answers will vary. Assume the transmitted wave of electromagnetic radiation (radio wave) is horizontal. For this wave, a horizontally oriented antenna is best. As the wave approaches and passes through the antenna element, at one moment a node of the wave is at one end of the antenna while an antinode is at the other end. This creates a differential voltage between the two ends of the antenna element used by the radio receiver detection circuit. The wave position with respect to the antenna varies as the wave continues, the node-antinode juxtaposition reverses, and the process repeated at regular intervals. The antenna is most effective when the length of the driven element is about one-half a wavelength. The length must be calculated from the frequency of the transmitted signal (measured in Hertz, or 1/sec) and the speed of light in the antenna's metal (2.80225×10^8 m/s), not the speed of light in a vacuum. In a Yagi antenna, waves are focused by the directors so they are collected more efficiently by the driven element. The reflector bounces back missed waves to increase efficiency even further.

Spacing, Arrangement, Dimensions
One Set of Elements of a Crossed Yagi Antenna for APT Reception



Adapted from Summers, R. Joe, *Educator's Guide For Building and Operating Environmental Satellite Receiving Stations,* NOAA Technical Report NESDIS 44, U.S. Department of Commerce, February 1989.

Electromagnetic Radiation & Satellites

Antennas, Wavelength, and Frequency

Introduction

How big does an antenna have to be to receive weather satellite signals? Some are very large and some are very small. Is there a "right" size, and if so, what is it? Design and build a scale model Yagi antenna of the type needed to receive weather satellite signals. Then make the connection between wavelength, frequency, the speed of light, and the size of the antenna. Use that connection to determine the size of each element of the antenna. Then build a 1/10 scale model of the real antenna.

Frequently Asked Questions

Consider these frequently asked questions (FAQ) and their answers.

What is electromagnetic radiation?
Electromagnetic radiation is energy that radiates, or travels out, from its source. Electromagnetic radiation includes visible light, infrared, ultraviolet, radio waves, microwaves, and X-rays, among others.

Is electromagnetic radiation composed of waves or particles?
Electromagnetic radiation exhibits properties of both waves and particles. Thus, it is considered to have a dual-nature.

What are wave properties?
Properties of waves include velocity, wavelength, amplitude, and frequency.

A typical wave has crests and troughs. The distance from one crest to the next is one full wave or one wavelength. It is generally represented by the Greek letter lambda (λ) and expressed in meters.

Frequency is the number of wave peaks or crests that pass a specific point each second. It is generally represented by the Greek letter nu (ν) and expressed in Hertz (or 1/sec).

Wavelength multiplied by frequency (meters X 1/sec) equals velocity (m/s). The velocity of light is represented by the letter *c* in the equation $\lambda\nu = c$. The speed of light in a vacuum is considered a universal constant. Notice in this equation that frequency and wavelength are inversely proportional. As one increases, the other decreases.

Amplitude is the height of the wave from trough bottom to crest top.

Is the speed of light a constant?
The speed of light (electromagnetic radiation) in a vacuum is 3.00×10^8 m/s (299,792,458 m/s). The velocity of light in a vacuum has been accepted as a constant and the upper limit of velocity in the universe for more than a century. It is believed that no matter can travel faster. However, when waves of electromagnetic radiation induce an electric current in a metal, the metal resists the flow of electrons (electric current) and lowers their velocity to 2.80225×10^8 m/s.

Can I receive weather satellite signals directly from the satellite in real time?
Yes, with an appropriate antenna, radio receiver, signal decoder and imager (computer).

What is an antenna?
An antenna is a device that captures waves of electromagnetic radiation.

The size of the antenna is determined by the wavelength it is intended to receive. Typically, the most effective antenna is cut to ½ the wavelength of the radio signal.

What will I do in this activity?
In this activity, you will first build a $1/10^{th}$ scale model of a radio wave with a frequency of 137.5 MHz (137,500,000 Hz). Then you will calculate the length of each of the five elements of a 5-element Yagi antenna designed to receive weather satellite signals at the same frequency. Dividing each length by 10 will give you the actual length of each element in the $1/10^{th}$ scale model of the antenna you will construct. Finally, you will explain how an antenna of this design and size will effectively receive radio waves of 137.5 MHz and demonstrate the action with your models.

Activity

1. Using chenille, make a scale model of a wave:
   a. Scale: Let 1 mm on the model = 1 cm on the full-scale wave
   b. Using the black wire chenille, make a model of 2 complete wave cycles whose wavelength is 2.038 meters. The model should have the shape of a sine wave. (Remember 2.038 m = 203.8 cm. In our 1/10 scale model, it is represented by 203.8 mm)
   c. Have your teacher check the accuracy of your wave model.

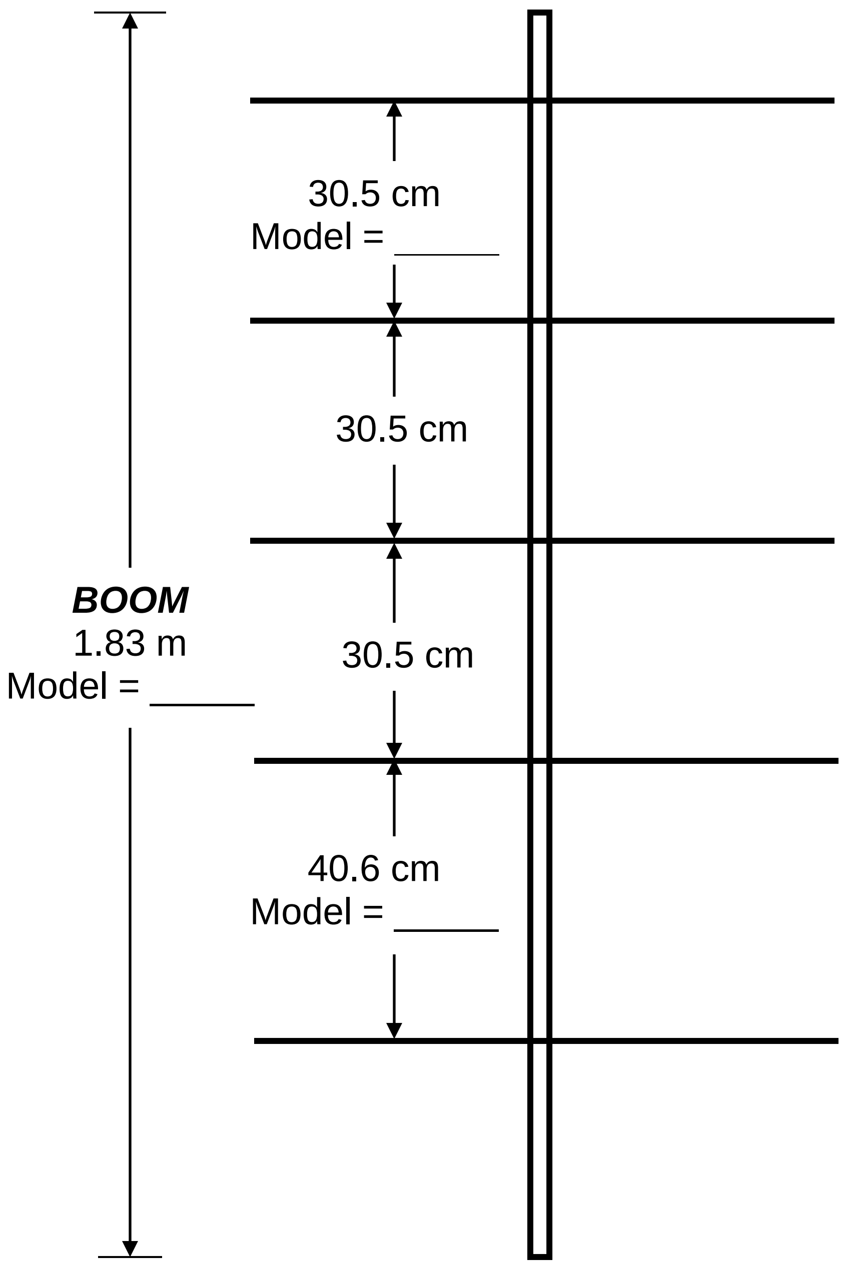
2. Using chenille and the following references, build a scale model of a Yagi antenna designed to receive a weather satellite signal with a frequency of 137.5MHz. Follow these steps:
   a. Complete the worksheet “Spacing, Arrangement and Dimensions of One Set of Elements of a Crossed Yagi Antenna Used for APT Reception.”
   b. Using the lengths shown on your completed worksheet, build a 1/10 scale model of a Yagi antenna for 137.5 MHz. Use the following color code for the chenille:
      - Main boom to which all elements are attached = White
      - Radiator = Red
      - Reflector = Dark Blue
      - Directors = Green

      Construction Hints
      - For 1/10 scale, let one mm of wire chenille represent 1 cm of full-size antenna
      - Using a marker, measure and mark the boom to correctly place the elements on the boom.
      - Be sure to attach the chenille “elements” to the boom before measuring the length of the chenille element and cutting it. Twist-tying it to the boom will effectively shorten the chenille. After attaching the element to the boom, use a metric ruler to measure the chenille and cut it or fold the end over to the correct length.
   c. Complete the Conclusion Questions worksheet.
3. Complete the first Your Turn activity plus any one of the other four.

Your Turn

- Clearly show the calculations for determining the correct length for a half-wavelength antenna made of metal for a frequency of 1693 MHz.
- Research and build a variety of scale model antennae from wire chenille and compare their characteristics.
- Build a variety of real antennas and determine which is the most effective for satellite reception in your situation.
- Compare real data received from a “crossed Yagi” and an “omni-directional” (such as a “turnstile” or quadrafilar helix antenna) antenna to determine how the strength of the received signal is affected by the direction in which the antenna is pointed.
- Design and build from chicken wire a dish for reception of GOES data; use the mathematical formulas for determining the curvature, focal length, and antenna length for your system.

Spacing, Arrangement, Dimensions
One Set of Elements of a Crossed Yagi Antenna for APT Reception



THIRD DIRECTOR

$D_3 = D_2 - .05\ D_2$

D_3 = _______________

Model D_3 = ____________

SECOND DIRECTOR

$D_2 = D_1 - .05\ D_1$

D_2 = _______________

Model D_2 = ____________

FIRST DIRECTOR

$D_1 = RA - .05\ RA$

D_1 = _______________

Model D_1 = ____________

RADIATOR

RA = ½ wavelength

RA = 101.9 cm

Model RA = ____________

REFLECTOR

RE = RA + 0.1 RA

RE = _______________

Model RE = ____________

Adapted from Summers, R. Joe, *Educator's Guide for Building and Operating Environmental Satellite Receiving Stations,* NOAA Technical Report NESDIS 44, U.S. Department of Commerce, February 1989.

Electromagnetic Radiation & Satellites

Conclusion Questions

1. Why is it called "electro" and "magnetic" radiation?

2. Define each of the following terms. Explain how each is related to designing and building an antenna:
   a. sine wave

   b. resistance

   c. impedance

3. Clearly show the calculations for determining the correct length of an antenna for receiving 137.5 MHz.

4. Describe the process by which a wave of electromagnetic energy is collected by the antenna of a radio receiving system. Be sure to correctly use each of the following terms in your description: electromagnetic radiation, speed of light, frequency, wavelength, Hertz, antenna, radiator (or driven element), reflector, director, Yagi.