PURPOSE

To give students a mathematical model of how the Deep Space Network antennas work and how the antennas concentrate electromagnetic radio waves in a single direction.

QUESTION

Does the size of an antenna influence wave detection?

LEARNING OBJECTIVES

The students will learn that it takes mathematics to talk to spacecraft:

- Scientists on Earth must communicate information to spacecraft and be able to receive the faint signals from spacecraft that carry new information about the cosmos.
- The parabolic shape of the antenna dish helps to increase the distance at which radio waves can be detected by means of concentration and directionality.
- Sound waves emitted from a source are a good analog for radio waves used to communicate with spacecraft.
- The volume of the sound decreases as the distance from the source increases, according to the inverse square law.

GRADES 6–8 MATHEMATICAL STANDARDS

(from "Principles and Standards for School Mathematics," NCTM, 2000)

This investigation will encourage students to:

- Communicate their mathematical thinking coherently and clearly to peers, teachers, and others.
- Recognize and apply mathematics in contexts outside of mathematics.
- Develop and evaluate inferences and predictions that are based on data.
- Use observations about differences between two or more samples to make conjectures about the data sets from which the samples were taken.
- Understand both metric and customary systems of measurement.
- Use representations to model and interpret physical, social, and mathematical phenomena.

ADVANCE PREPARATION

For making parabolic dish antennas, make student copies of the antenna pattern on cardstock and collect recycled 1- to 3-liter soda bottles (one per student). Additionally, make copies of the data tables for the activities students will carry out.

ACTIVITIES

There are three activities that can be scheduled over three days, preceded by introductory discussion and development of predictions and hypotheses. There is also an Extension involving discussion of the inverse square law and the logarithmic scale of decibels.

YOU WILL NEED

An open area with at least 120 meters of space (such as a football or soccer field); patterns and student directions for constructing a cardstock parabolic dish antenna, student directions for making an antenna from a soda bottle, scissors and X-acto knife, tape, copies of student data tables in which students will record data, metric measuring tapes or trundle wheels, and two or more umbrellas of different diameters (student groups can change variables by trying different sizes of soda bottles and umbrellas). Additionally, you will need a digital wrist watch with a timer mode that can be used to create a repeating beeping timer (set "timer mode" for "1 second," and "CR"–count down, beep, reset).

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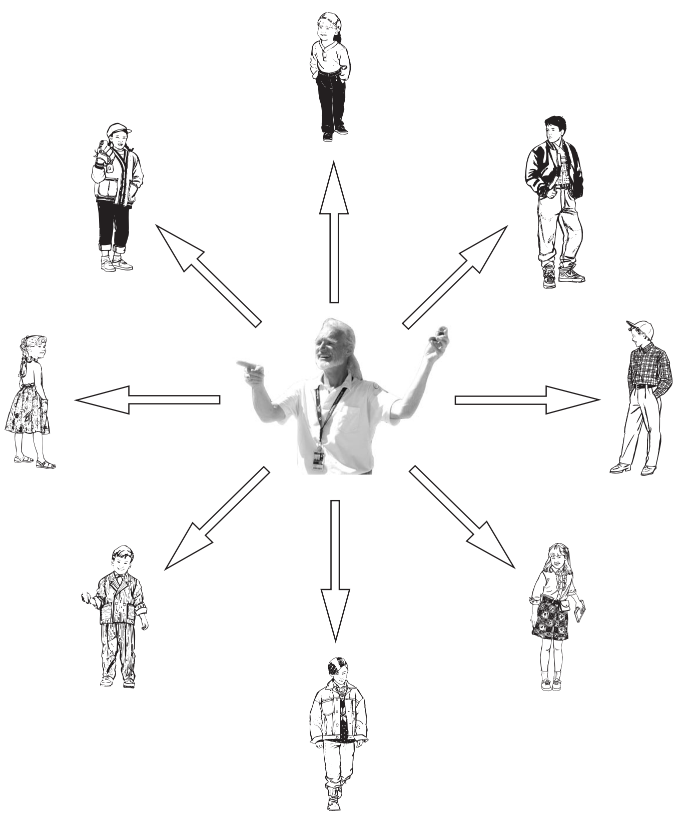
P R E L I M I N A R I E S

HYPOTHESIS/MATHEMATICAL CONTEXT

(Discussion, Inferences, Predictions)

Out in the field: Ask students to gather around to listen to the sound of the timer (watch) beeping at 1-second intervals. (The beeping timer represents a communication signal sent from NASA scientists on Earth to the spacecraft or a signal sent from the spacecraft to Earth.) Ask the students to predict a distance, in meters, they think they can walk away from the source of the beeping and still hear it with their ears alone; have the students write their predictions in their data tables. Now have them develop a hypothesis about how they think using a parabolic antenna will affect their ability to hear the signal the farther away they walk and why.



A C T I V I T Y 1

CAN YOU HEAR ME?

(Ears Alone)

(a) No Antenna (Umbrella)
Students form a circle around the Sender (teacher or a student) who is the transmitter or spacecraft sending a signal with the beeping timer. They should record the number of meters that they are from the signal to start. Tell the students to raise one hand if they hear the signal. The Sender should turn, timer against body, facing the signal in the direction of each student. Why would the direction the Sender is facing change the strength of the signal that each student receives?

Tell the students to step approximately 1 meter farther away from the Sender after each time they hear the signal, until they reach a distance at which the signal is too weak to hear. Repeat the experiment three times and ask the students to record the greatest distance for each test in their data table. Students should calculate their average distance for the three trials and compare data. Why might there be variation in the point at which different students lose the signal?

(b) Sender with Antenna (Umbrella)
Have the sender tape the watch to the umbrella handle, then repeat the activity as shown in picture. Sender should turn as before. Repeat three times and record greatest distances.

Sender holding umbrella; beeping watch is taped to umbrella handle.

ACTIVITY 2

USING AN ANTENNA

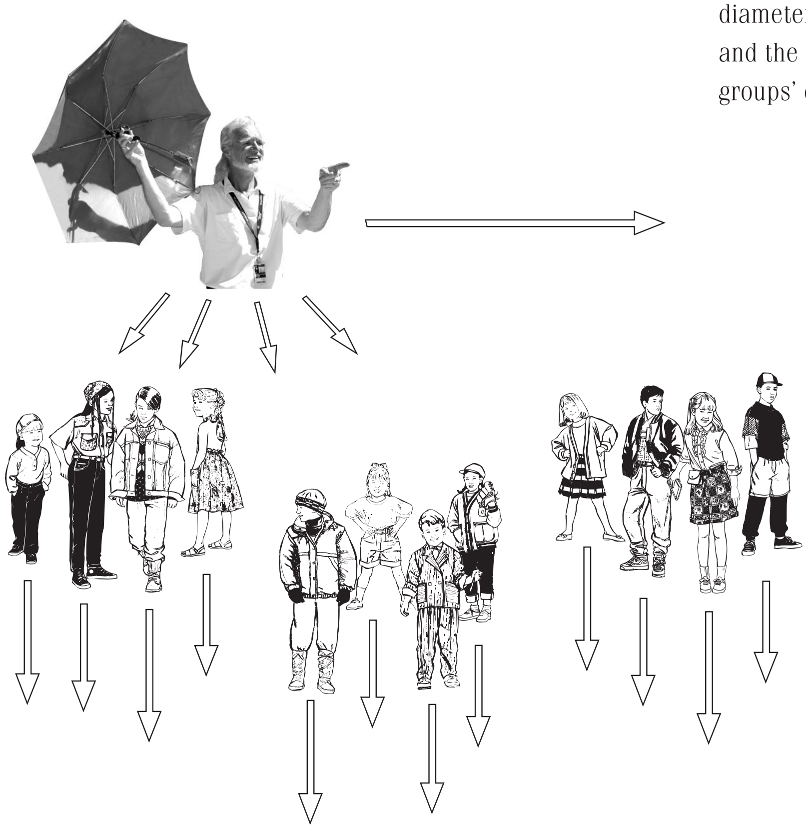
(Ear Antennas and Beeping Watch)

In the classroom, students construct "ear" antennas — cardstock antennas from patterns or antennas made from plastic soda bottles — and then return to the field. Students stand side by side in groups of four across the field, directing their ear antennas toward the Sender with the beeping timer and umbrella antenna. The Sender aims the umbrella handle at each student, keeping the watch in the same position by taping it to the shaft. Students hold their antennas next to their ears and continue to move farther away from the signal each time they hear it. Repeat the experiment three times and ask the students to record the greatest distance for each test in their data tables. Have students calculate their average distances for the three trials. Compare and discuss the observations and the distance data recorded in Activity 1 and Activity 2. How do the antennas increase the distance that the signal can be heard?

ACTIVITY 3

FURTHER EXPLORATION

Does the size of the antenna/umbrella make a difference? Students work in groups of four using two different sizes of umbrellas, a wrist-watch beeping timer, and student-made antennas. Students take turns being the Sender (watch holder), Listener, Measurer, and Recorder. The Sender holds the watch at a fixed height and position as the Listener steps away from the beeping signal until he cannot hear it while using his ear antenna. The Measurer measures the diameter of the antennas they are using and the distance between the two students (Sender and Listener). The Recorder writes down the measurements in the data tables. Repeat the experiment using umbrellas of two different sizes. Try sending the signal from both the umbrella antenna (the Deep Space Network) and the student-made antenna (the spacecraft antenna). The students record and compare differences they observe related to the size of the antennas, then analyze their data to see if there is a correlation between the antenna's diameter and the distance between the Sender (watch holder) and the Listener. Discuss the results and conclusions of each groups' experiment.



Sender with beeping watch taped to umbrella handle moves across line of students.

Groups of four students with "ear" antennas move farther away as they hear the signal; students raise their hands each time they still hear the signal.

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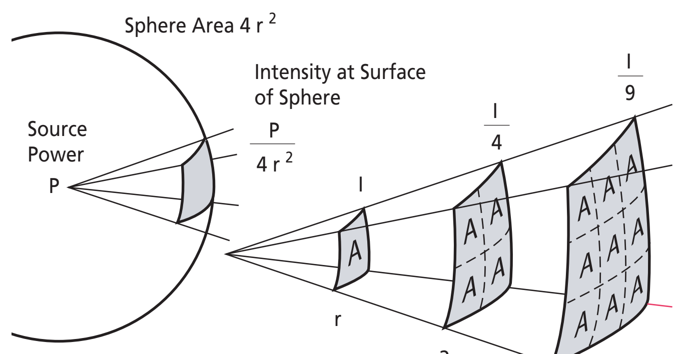
EXTENSION

Discuss the inverse square law and see how it might apply to the data collected. Students can be introduced to the logarithmic scale of decibels and solve mathematical equations related to it. Research the number of watts of the signal that is sent from the Voyager spacecraft compared to the number of watts received by the Deep Space Network. (Voyager = 13 watts compared to one billionth of one billionth of a watt received by Deep Space Network)

INVERSE SQUARE LAW

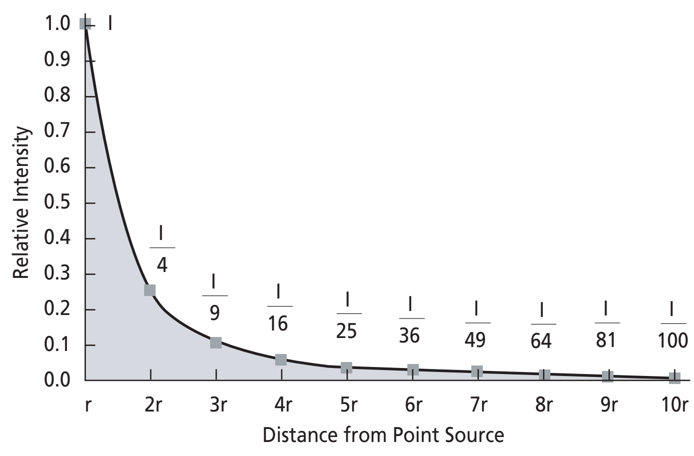
The inverse square law applies to both electromagnetic waves and sound waves. Antennas (radio telescopes) on Earth and spacecraft emit electromagnetic waves; a beeping watch emits sound waves. The beeping watch in the activities described here is similar to the emitting antenna or spacecraft; the person listening is the receiver, similar to the receiving spacecraft or antenna. When the distance between the beeping watch and the listener increases, the volume of the sound decreases by the square of the increased distance. If the volume of the sound at distance r is I, the volume at distance $2r$ is I/r^2, the volume at distance $3r$ is I/r^3, and so on.



The energy twice as far from the source is spread over four times the area, hence one-fourth the intensity.

LOGARITHMIC SCALE OF DECIBELS

The volume, or intensity, of sound waves can be measured in watts per square meter. The inverse square law can be used easily with these units. However, the preferred units for volume intensity are decibels (abbreviated dB). Decibels do not easily follow the inverse square law because they are logarithmic — every increase by 10 decibels is an increase in sound of 10 times. This means that 10 decibels are 10 times greater than 0 decibels, 20 decibels are 10 times greater than 10 decibels, 30 decibels are 10 times greater than 20 decibels, and so on. Here are the equations to switch between watts per square meter to decibels:



I(dB) = 10*log(I/I0)

I = I0*10^(I(dB)/10)

I(dB) is volume intensity in decibels

log is logarithm base 10

I is volume intensity in watts per square meter

I0 is the threshold of hearing, 10^–12 watts per square meter

Diagrams courtesy of HyperPhysics ©C.R. Nave, 2002, Georgia State University. Used with permission. HyperPhysics is at http://www.phy-astr.gsu.edu.

ACTIVITY 1

CAN YOU HEAR ME?

NAME_________________________DATE____________________

Distance Where Signal Is First Inaudible		
	(a) No Umbrella, distance (m)	(b) Watch with Umbrella, distance (m)
Prediction		
Trial 1		
Trial 2		
Trial 3		
Average of 3 trials		

ACTIVITY 2

USING AN ANTENNA

NAME_________________________DATE____________________

Diameter of Sending Umbrella______________________________

Diameter of Receiving "Ear" Antenna ________________________

Distance Where Signal Is First Inaudible	
	Student with Antenna, distance (m)
Prediction	
Trial 1	
Trial 2	
Trial 3	
Average of 3 trials	

ACTIVITY 3

FURTHER EXPLORATION

NAME_________________________DATE____________________

Diameter of Umbrella 1___________________________________

Diameter of Receiving "Ear" Antenna________________________

Distance Where Signal Is First Inaudible	
	Student with Antenna, distance (m)
Prediction	
Trial 1	
Trial 2	
Trial 3	
Average of 3 trials	

Diameter of Umbrella 2___________________________________

Diameter of Receiving "Ear" Antenna________________________

Distance Where Signal Is First Inaudible	
	Student with Antenna, distance (m)
Prediction	
Trial 1	
Trial 2	
Trial 3	
Average of 3 trials	

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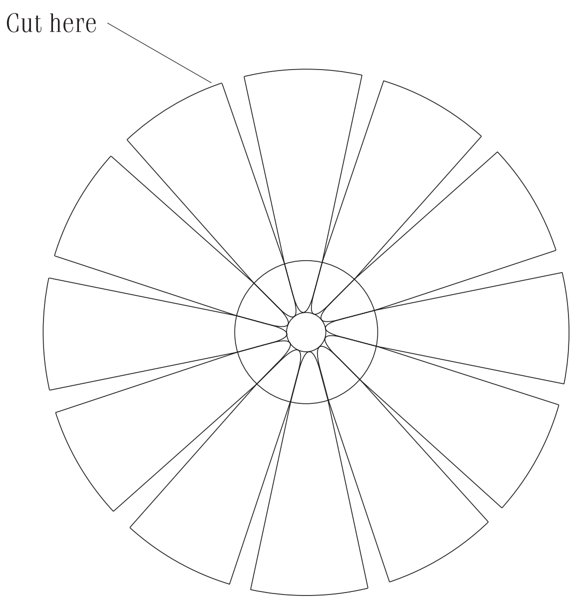
CARDSTOCK PARABOLIC DISH ANTENNA

Teacher

Using cardstock, enlarge the antenna pattern twice on a photocopier: once at 165%, then enlarge at 165% again.

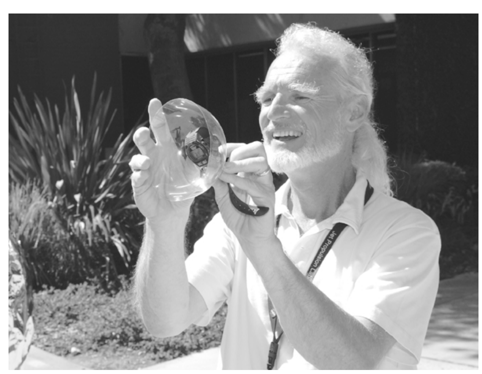
Student

Cut between the petals, stopping at the first circle. Bring the petals together, overlapping them slightly and taping them on the back, forming a curved dish. Cut a small hole in the center of the dish at the innermost circle, then reinforce the center hole on the back with tape.



SODA BOTTLE PARABOLIC DISH ANTENNA

Use an X-acto knife (caution — very sharp) and/or scissors to cut the top off a plastic soda bottle above the label and at the bottom of the neck. This cut-off section will become your parabolic dish antenna. Trim off any rough edges with the scissors.



Example of "ear" antenna made from soda bottle.