Signals and Noise, Oh Boy!

Overview: Students are introduced to the terms "signal" and "noise" in the context of spacecraft communication. They explore these concepts by listening to a computer-generated signal from two different distances with no additional background noise, and then with background noise and compare their experiences in a science journal page.

Target Grade Level: 3-5

Estimated Duration: about 40 minutes

Learning Goals: Students will be able to…

- understand the terms "signal" and "noise" in the context of spacecraft communications
- compare the apparent volume of a signal at different distances from the source
- compare the apparent volume of a signal at different distances from the source with the addition of background noise

Standards Addressed:

Benchmarks (AAAS, 1993, 2008)

The Nature of Technology, 3A: Technology and Science
The Designed World, 8D: Communication

National Science Education Standards (NRC, 1996)

Science as Inquiry: Science and Technology

Table of Contents:

Teacher Background:

While some spacecraft return to Earth with valuable data as part of their cargo, all require some periodic remote communications as they travel. And for those spacecraft that do not return to Earth, the communication system is our only link to the data collected during its journey.

Not only do spacecraft transmit valuable data, but also spacecraft 'health' information is returned to Earth via these communication systems. It is important to know that the spacecraft's power systems, heating and cooling systems, and instruments are all operating as expected. And of course, signals must be sent to tell the spacecraft where to go or which instrument to operate and when via this system. Such course correction and data collection commands become even more critical as the spacecraft approaches its 'destination,' where course corrections become progressively finer and many of the science goals are to be achieved.

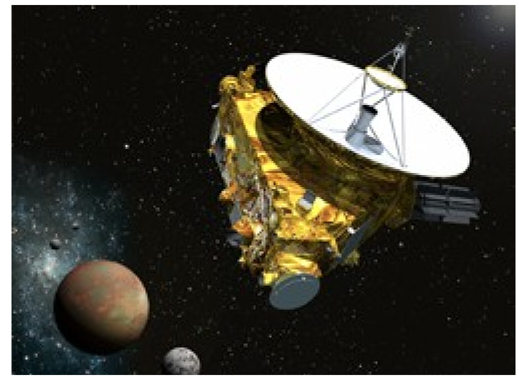


Figure 1. An artist's rendering of the New Horizons spacecraft as it approaches Pluto. The prominent 2.1-meter dish antenna is used to communicate with Earth from up to 7.5 billion kilometers away. (Image credit: JHUAPL/SwRI)

Each mission has its own telecommunications system design, but all use radio waves to transmit signals. Radio waves, like light, are electromagnetic waves.

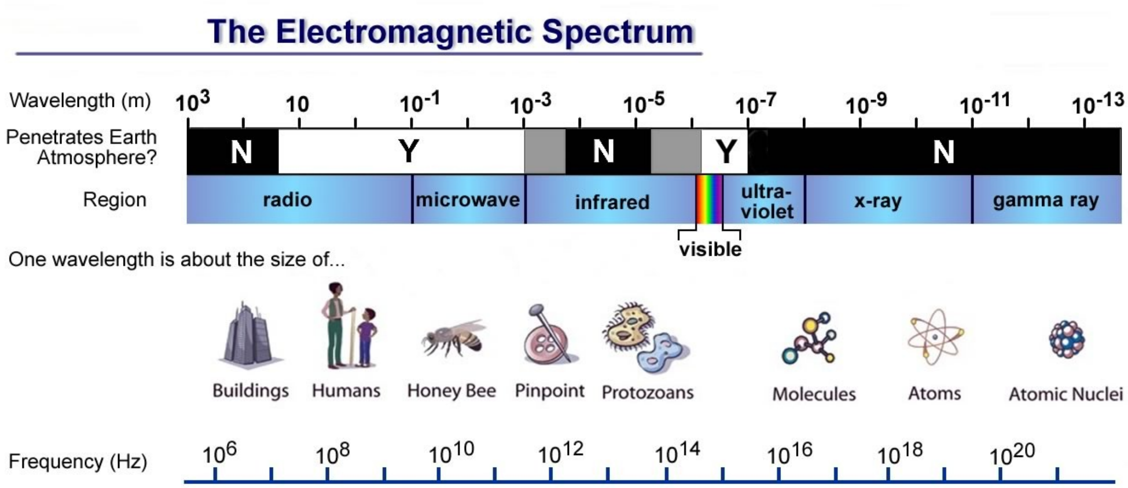


Figure 2. The electromagnetic spectrum. Notice radio waves penetrate Earth's atmosphere, have long wavelengths, and low frequencies. (Image courtesy: NASA).

As you can see in Figure 2, radio waves have long wavelengths, low frequencies, and—important for our ground-based communications—they penetrate Earth's atmosphere. They don't require as much energy for the spacecraft to produce as shorter wavelength electromagnetic waves do, which allows for more energy to power the instruments and other systems on a spacecraft. And unlike x-rays and shorter wavelengths, you don't have to protect yourself from them because they are harmless to humans. All of these characteristics make radio waves an ideal choice for carrying signals to and from spacecraft, as well as for carrying signals here on Earth for our TVs and radios.

Like all electromagnetic waves, radio waves travel at the speed of light, which is about 300,000,000 meters per second. It is usually denoted by the symbol *c*, for the Latin *celeritas,* meaning "swiftness." Here on Earth, when you turn on the light switch the light seems to reach your eyes instantaneously. However, if you happen to be a mission operations flight controller sending an important command to a spacecraft—a signal that must travel many billions of kilometers—even the speed of light can seem slow. As the New Horizons spacecraft travels further away from Earth, its signals traveling at the speed of light take longer and longer to reach us.

Figure 3. One of NASA's Deep Space Network antennae. This 70-meter (230 feet) antenna is from one of three DSN facilities that are positioned around the globe approximately 120 degrees from each other so that as Earth rotates at least one antenna is always "visible" from space.. (Image courtesy: NASA/JPL)

The signal from the spacecraft is very weak by the time it reaches Earth, since its energy is spread over a wider and wider area as it travels outward from the transmitter. In fact, the Earth-based antenna that receives the signal must be able to detect a signal as weak as a millionth of a trillionth of a watt. If you stored energy transmitted at that rate for 40,000 years you could still light a Christmas tree bulb for only about 3 millionths of a second!

The signal from the spacecraft is not only extremely faint, it is also embedded in a background of space "noise." This noise is produced by all other objects in the universe. It is always present in space, like static on your radio. Even while the New Horizons signal becomes fainter as the spacecraft gets farther away, the background noise remains at a roughly constant level. So the farther away the spacecraft, the more difficult it becomes to distinguish its signal from the noise.

The faintness of the signal in the presence of the background noise will force New Horizons to reduce the rate at which it transmits data to about 1000 bits per second at Pluto. This slower data rate allows for better signal detection. By comparison, if you connect to the internet with DSL or broadband cable modem, you send and receive data at a rate measured in "megabits" or million bits per second! At 1000 bits per second, it will take about 4 hours to receive a picture of Pluto. But it will be well worth the wait!

In this activity, you will explore signals and noise as they relate to spacecraft communication. A "signal" as used in spacecraft communication is defined by the American Heritage Dictionary as, "The sound, image, or message transmitted or received in telegraphy, telephony, radio, television, or radar." Signals used in spacecraft communications resemble television signals, radio signals, and other wireless communication signals (i.e., computers, cellular telephones, etc.).

Students will likely be most familiar with the following definition of "signal," also from the American Heritage Dictionary: An indicator, such as a gesture or colored light, that serves as a means of communication; a message communicated by such means. Common examples of signals under this definition include traffic signals, waving hello or goodbye, and hand gestures used to indicate your intended direction when riding a bike.

The definition of "noise" in spacecraft communication is different from—yet conceptually similar to—the commonly used meaning. When asked what students associate with the term "noise," they will probably respond with ideas similar to this definition: "Sound or a sound that is loud, unpleasant, unexpected, or undesired." (American Heritage Dictionary, 2006). In spacecraft communication, however, noise is defined as, "a disturbance, especially a random and persistent disturbance, that obscures or reduces the clarity of a signal" (American Heritage Dictionary, 2006). For example, "snow" on a television screen, buzzing on a telephone line, or static on a radio are all disturbances to the desired signal.

Figure 4. Astronauts aboard the International Space Station give the "thumbs up" signal. (Image courtesy: NASA)

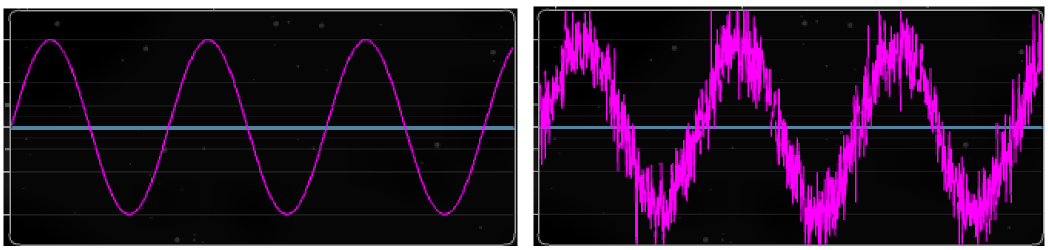


Figure 5. On the left is a graphical illustration of a signal from a pure tone. On the right is a representation of that same pure tone signal in the presence of background noise.

Materials:

- a radio
- a computer with access to the internet or the downloaded interactive: http://patchyvalleyfog.com/signal_noise/ (note: computer must have at least an internal speaker loud enough for students to hear the signal)
- copies of **Signals** science journal page (1 per student)

Procedure:

Brief overview…

What the teacher will do: *Warm up:* As the teacher is calling the class to order but while there is still some talking and shuffling, he/she will very quietly state a command to the class: *raise your right hand*. Eventually, when the class is completely quiet, the teacher will state another command: *raise your left hand*. Then the teacher will ask why everyone didn't raise their right hands the first time they were asked. This will lead to an introduction of "signal" and "noise."

The teacher will begin by playing a radio in the background while asking students what they think of when they hear the word "signal"? When appropriate, he/she will talk about the radio as an example of a signal. He/she will then change the radio station by just a very small amount to introduce some "static" into the signal, while still being able to hear the radio station (i.e, change station from 102.1 to 102.2). The teacher will follow with a similar discussion about the term "noise." He/she will continue to change the radio station in small increments until the "noise" is louder than the "signal." Then the teacher will explain what "signals" and "noise" mean for spacecraft communication using information provided in the **Teacher Background** section, if desired. He/she will divide the class in two groups and facilitate a hands-on activity (**Tuning in to Signals**) exploring signals and noise.

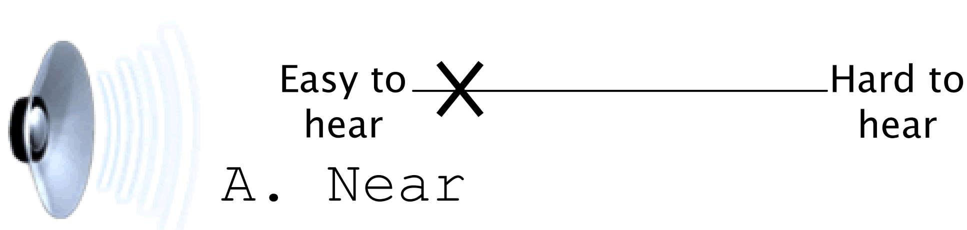
What the students will do: Students will participate in a discussion about the terms "signal" and "noise" led by the teacher. They will then be divided into two groups. They will participate in the **Tuning in to Signals** activity, in which they listen to a signal generated by an online interactive signal from two different distances: near and far. One group will be "near" while the other is "far," then the two groups will switch. During the first part of the activity the groups will be completely silent as they listen to the "signal." Then group 1 will be asked to move to the side and make "noise" as group 2 listens to the signal again from both near and far. Group 2 students will record their observations in their **Signals** science journal page. Then the groups will switch roles and the activity will be repeated.

Advance Preparation

- Make copies as indicated in the **Materials** section
- Bookmark the online interactive: http://patchyvalleyfog.com/signal_noise/signaltonoise.html
- Read the **Teacher Background** section to prepare for discussion and introduction of topics
- Set up the classroom for the **Tuning in to Signals** activity, as follows:
  Around the computer move desks and tables aside so that the class can hear the online interactive signal if gathered "near" the computer or "far" from the computer (NOTE: half of the class will be "near" the signal (tone) and half will be "far" from the signal at one time). The actual distance of "far" varies based on your computer speakers. You should test this in advance by turning on the online signal and walking away until the signal is still audible, but much quieter.

In-class Procedure

1. *Warm up*. As you are calling the class to order (but while there is still some talking and shuffling), quietly state a command to the class: *raise your right hand*. Eventually, when the class is completely quiet, state another command: *raise your left hand*. Then ask why everyone didn't raise their right hands the first time they were asked.
2. Introduce the terms "signal" by playing a radio in the background while asking students what they think of when they hear the word "signal." First students will likely supply examples such as: traffic lights, smoke signals, and hand signals. When appropriate, talk about the radio as an example of a different, yet similar type of signal. The signals used by spacecraft to communicate are like those that you hear on your radio, television, telephone, or cellular telephone. These types of signals send information such as pictures or commands to and from the spacecraft.
3. Ask students what they think of when they hear the word "noise." The will likely talk about loud or unpleasant sounds. Then change the radio station by just a very small amount to introduce some "static" into the signal, while still being able to hear the radio station (i.e, change station from 102.1 to 102.2). Use this to introduce the concept of "noise" as it relates to spacecraft communication. In this context, noise is a disturbance in the desired signal. Continue to change the radio station in small increments until the "noise" is louder than the "signal." Ask the class to come up with other ideas of noise in a signal, such as "snow" on a television screen or buzzing on a telephone line.
4. Once you feel students understand "signals" and "noise" as they relate to spacecraft communication, divide the class into two groups. Distribute the **Signals** science journal page to each student and explain to students they will be participating in an activity called **Tuning in to Signals.**
5. In this activity, an area of the room near the computer is set up so that one group can gather "near" the computer and listen to the "signal" (online "Signal-to-Noise Ratio interactive tone), while the other begins "far" from the computer. Note: students do not need to *see* the online tone, they just need to *hear* it.
6. Once the groups are in place, explain to students that they should be very quiet so they can hear the signal/tone. In the "Sound Controls" box, click on the "on" button next to the "TONE" and ask students to listen carefully. You will not be using the sliding speaker at the bottom of the interactive for this activity; keep the speaker close to the ear as it is by default when you navigate to this interactive.
7. Explain to students that they should complete their science journal page as they go through the activity (as follows). ****Demonstrate for them** that they should put an "x" on the line corresponding to how well they can hear the signal in the "Quiet background" and "Near" or "Far" (depending on their location) part of the **Signals** science journal page. (Note: that is section 1, part A or B). For example, if they are "near" the signal and can hear it well, they would place an "x" in the science journal page like this:



After all students have recorded their observations, turn the signal off by clicking in the "off" radio button next to "TONE".

8. Then ask the groups to switch places (the "near" group moves to the "far" location and the "far" group moves to the "near" location). Again, students should be very quiet as you turn on the signal (TONE). They should record what they hear in their **Signals** science journal page in section 1, A or B. Turn the signal off.
9. Now ask group 1 to move to the side while group 2 moves to the "near" position. This time ask group 1 to "make noise" by talking in a normal volume to each other as the students in group 2 try to listen to the signal. And again, group 2 students should record their observations in the **Signals** science journal page, section 2. Noisy background, A. Near. Turn the signal off. NOTE: While there is a "NOISE" button on the online interactive, it will be easier to distinguish and more personally relevant to the students if *they* generate the noise.
10. Ask the group 2 students to move to the same "far" location, and again group 1 students will be "making noise" by talking normally. Turn the signal on and ask group 2 students to record what they hear in the science journal page in 2. B.
11. Switch groups and repeat the "noise" part of the activity. (i.e., group 2 students move to the side and make noise as group 1 students listen to the signal from "near" and "far," recording what they hear in their **Signals** science journal pages).
12. After the class has participated in both activities, ask them to return to their seats and look at their **Signals** science journal pages. Help them interpret the results by asking questions like:
    a. In which situation was it easiest to hear the signal? (Ideally, "1. Quiet background" and "A. Near").
    b. In which situation was it most difficult to hear the signal? (Likely "2. Noisy background" and "B. Far".
    c. How does background noise affect your ability to hear a signal?
13. Explain that there is "background noise" in all of space, and scientists and engineers have developed very sophisticated techniques to "remove" that background noise so they can better hear the signal (like pictures and data) from spacecraft.

Extensions and Adaptations:

- As an extension that explores the standards below, observe an online tuning fork or a real tuning fork before it is making a sound and after it is "clicked" or struck to produce the tone. Ask students to note any changes (e.g. the tuning fork is vibrating when it is making a sound, but is not vibrating when it is not making a sound). (online tuning fork: http://www.onlinetuningfork.com/)

  National Science Education Standards, Science as Inquiry, grades K-4

  Physical Science, Content Standard B: Position and Motion of Objects: Sound is produced by vibrating objects.

  Benchmarks, K-2

  Chapter 4. The Physical Setting

  F. Motion: Things that make sound vibrate.

  Note that the online tuning fork or a real tuning fork won't work well for this activity because both are loud when you strike them, and gradually becomes quieter. The online signal from the "Signal-to-Noise Ratio" interactive maintains a steady volume.

- While the online interactive "Signal-to-Noise Ratio" is designed for older students, for this grade level it is useful tool for hearing impaired students. Either at another time or on another computer with a set of headphones help them with the following adaptation to the classroom activity:
  - Turn on the "tone" or signal
  - Have them watch the "Waveform Monitor" as the speaker is moved away from the ear in the "Sound Distance" panel at the bottom. Allow them to move the speaker toward and away from the ear to see how the wave becomes smaller as the speaker moves away from the ear. This is similar to the classroom activity, where students physically increase their distance from the tone, however here it is also represented visually in the Waveform Monitor.
  - Then turn on the "noise" button so they can see how it obscures the signal. Move the speaker away from the ear and let them see how the signal is more difficult to distinguish from the noise as the speaker moves further from the ear.

- Introduce students to another way to hear a signal using a "sound cone." Students could stand at the "far" position with and without a sound cone to see how it improves their ability to hear the signal. The "sound cone" is similar to the function of a large antenna used in spacecraft communication. Here is an activity outlining the construction and use of a "sound cone": http://spaceplace.nasa.gov/en/kids/tmodact.shtml

References:

- The New Horizons website: http://pluto.jhuapl.edu/
  Or, the direct link to the educational materials for New Horizons:
  http://pluto.jhuapl.edu/education/index.php
- For more information about the Deep Space Network, visit their website:
  http://deepspace.jpl.nasa.gov/dsn/
  Or, for a student-version of their website: http://spaceplace.nasa.gov/en/kids/dsn_fact1.shtml
- Additional background information and a more advanced activity called "Speaking in Phases": http://spaceplace.nasa.gov/en/educators/dsn_signal_mod_web.pdf
- An excellent resource for students and teachers alike that explores how we communicate with spacecraft, including a short video outlining the process ("Yelling across the solar system"): http://spaceplace.nasa.gov/en/kids/st5xband/st5xband.shtml

Standards:

National Science Education Standards

Science as Inquiry, grades K-4

Science and Technology, Content Standard E:

- Understanding about science and technology: Tools help scientists make better observations, measurements, and equipment for investigations. They help scientists see, measure, and do things that they could not otherwise see, measure, and do.

Benchmarks

Grades 3-5

Chapter 3. The Nature of Technology

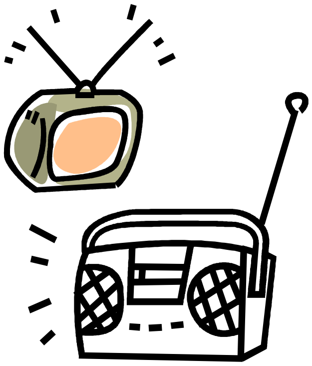
A. Technology and Science:

- Technology enables scientists and others to observe things that are too small or too far away to be seen otherwise and to study the motion of objects that are moving very rapidly or are hardly moving at all.

Chapter 8. The Designed World

D. Communication:

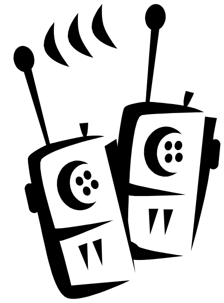
- Communication technologies make it possible to send and receive information more and more reliably, quickly, and cheaply over long distances.



Signals

Science Journal Page

Name: ___________________________



1. Quiet background

Easy to hear ________________________ Hard to hear

A. Near

Easy to hear ________________________ Hard to hear

B. Far

2. Noisy background

Easy to hear ________________________ Hard to hear

A. Near

Easy to hear ________________________ Hard to hear

B. Far