Sound Jumper: Now You Can See the Light and Hear It Too

By Stephen Barry, Harper Creek High School; John Burdette, Lakeview High School; Tara Egnatuk, Calhoun Community High School; Lindsey McConney, Portage Northern High School; Charles Henderson, Western Michigan University

Goal Statement:

This lesson is designed to help students understand some of the basic principles of how electromagnetic waves are used in communication devices. It begins with a device that uses carrier waves in the visible portion of the electromagnetic spectrum. Then, via an examination of three radio devices students determine the relationship between the carrier frequency and the antenna length of each device.

Target Audience

- High School Physics

Time Required

- Teacher preparation time
  The building of the device for the energy transformation demonstration requires some time (about 1 hour). However, once you have the device you can use it numerous times.
- Lesson time
  2, 50 minute class periods

Michigan Content Standards addressed through this lesson

- **P4.2 B** Name the devices that transform specific types of energy into other types (e.g., a device that transforms electricity into motion).
- **P4.6e** Explain why antennas are needed for radio, television, and cell phone transmission and reception.
- **P4.6g** Explain how different electromagnetic signals (e.g., radio station broadcasts or cell phone conversations) can take place without interfering with each other.
- **P4.6h** Explain the relationship between the frequency of an electromagnetic wave and its technological uses.

Learning Objectives

After this lesson, students will understand.....

- Electromagnetic waves transfer energy and information from place to place without a material medium.

Student Misconceptions Related to this Lesson

Common student misconceptions	Scientific Explanation
Different types of electromagnetic waves are fundamentally different (e.g. radio waves versus light waves).	The same basic physics principles apply to all electromagnetic waves.
Radio waves are sound waves.	Radio waves are electromagnetic waves and radios transforms the electromagnetic signal into sound waves which are created by the mechanical vibration of the speaker.
Electromagnetic waves travel instantaneously.	Electromagnetic waves travel very fast (at the speed of light in a vacuum).
A device such as a cell phone draws the electromagnetic waves to it.	Electromagnetic waves are all around us all the time whether a receiving device is on or not; the device just picks up the signal.

- All electromagnetic waves move at or near the speed of light.
- Electromagnetic waves come in a range of frequencies and wavelengths each with unique properties and applications.
- The length of a receiving antenna is directly proportional to the length of the carrier wave it receives.

Materials needed

- Various devices with antennas (cell phones, car, radio, etc.)
- Meter sticks
- Sound device (computer, MP3 player, etc.)
- Calculators
- Sound Jumper Device
- Parts List (item numbers for RadioShack):
    - Mini Amplifier, 277-1008, $14.99
    - 10 mm Red LED, 276-086, $2.79
    - Infra-Red LED, 276-143, $1.99
    - 1/8" Mono Phone Plug (2-pack), 274-286, $2.99
    - 100 Ohm, 1W Resistor (2-pack), 271-152, $1.49
    - Audio Cable, 42-2420, $3.99
    - Silicon Solar Cell, 276-124, $4.99 (these are fragile; you may want to buy 2)
- You may have the following:
    - 6, 14" (alligator clips) (35.3cm) Insulated Test/Jumper Leads, 278-1156, $7.69
    - Fully Insulated 9V Battery Snap Connectors (5-pack), 270-325, $1.99
    - 2, 9V Battery, 23-875, $0.99
    - 75-Ft. 24-Gauge Clear 2-Conductor Speaker Wire, 278-1509, $4.39

Lesson Outline

How this lesson fits into a broader unit on electromagnetic waves

This activity is part of a unit on electromagnetic waves that generally follows a unit on mechanical waves. Some of the key activities for this unit are: 1) a research project on the technological applications of waves and 2) a webquest where students investigate the key concepts and portions of the electromagnetic spectrum. Both activities can be found at www.wmich.edu/science/blast.

Sound Jumper Demonstration

This portion of the lesson uses tangible regions of the electromagnetic spectrum (visible and infrared) as an example of how electromagnetic waves can be used for communication. (*Complete instructions for building this demonstration tool can be found at www.wmich.edu/science/blast* .)

To use this device, an electronic music player with a headphones output must be utilized. This demonstration shows basic wireless technology and how electromagnetic energy can be used to transfer information by transforming one type of energy to another.

How the Sound Jumper Device Works

1. The Sound Jumper is a modified version of the Laser PA System ("Teacher's Guide," n.d.). The device essentially turns an electrical signal from the computer into visible light which is then turned back into an electrical signal and finally into sound. Here is the breakdown of how this functions:
2. The device attaches information from the audio source to the carrier wave (the light produced by the LED) by modifying the amplitude of the light.
3. The intensity of the LED is now changing based on the audio signal via amplitude modulation (AM). This happens too fast for the human eye to detect.
4. The solar cell uses the photoelectric effect to turn the light from the LED into electrical signal. The solar cell functions similarly to a receiving antenna in that it is tuned to the frequency of the carrier wave.
5. Electricity running into the speaker causes the diaphragm to vibrate at ▶

the same rate as the original audio signal from the computer.

6. A vibrating speaker creates sound mimicking the intensity fluctuations.

Using the Sound Jumper Device

Teacher should set up the demonstration in the classroom and give a basic explanation of the set up.

- Students observe the device and come up with an individual explanation of what is happening using the words 'waves' and 'energy'.
- Students then pair and share explanations with the rest of the class.
- A class discussion can be used to clarify what is actually happening.

Teacher Tip: A digital camera can be used to verify the infrared LED working.

Possible extensions

- Teacher could have students develop some questions associated with the set-up. For example "What happens if you move the light farther away from the solar cell? What happens if you integrate a lens into the set-up?". Students' ideas could then be tested.
- Using the demonstration set-up as an example, students should be able to identify objects in the real world that use the same principles. Examples include: cell phones, radios, TV remote controls, etc.

Antenna activity

Bridge into the antenna activity by asking the class why light is not typically used for everyday communications.

In this activity, students will make connections between the carrier waves used in communications and the antennas used to receive them. We chose to use three communication devices: CB radios, car radios and cellular phones. *(Two worksheets, differentiated by readiness level, and teacher keys for this activity can be found at www.wmich.edu/science/blast .)*

This activity has three parts. In part *I* students realize antenna lengths and the carrier frequencies are inversely related. In

Figure 1: Photograph of the Sound Jumper device (the computer provides the input sound source).

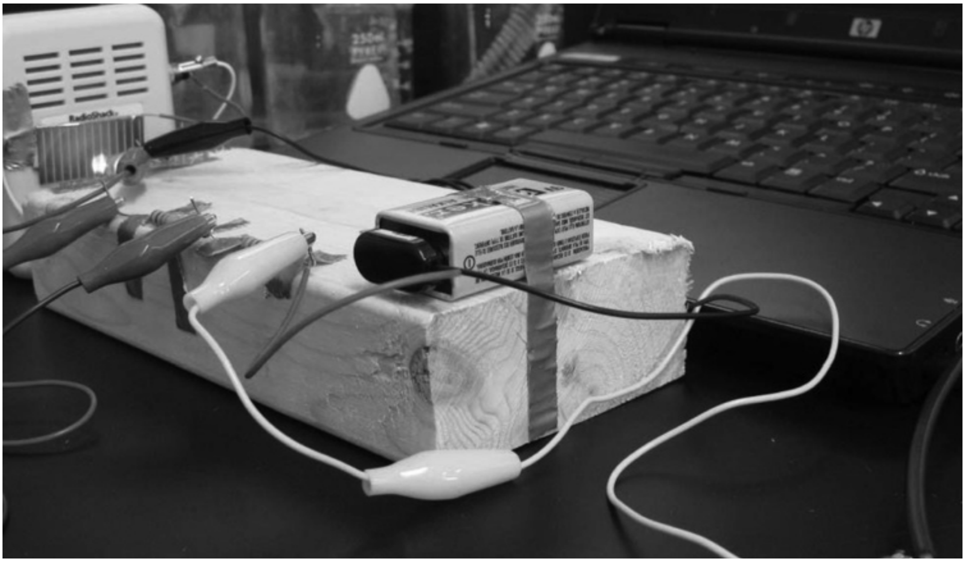
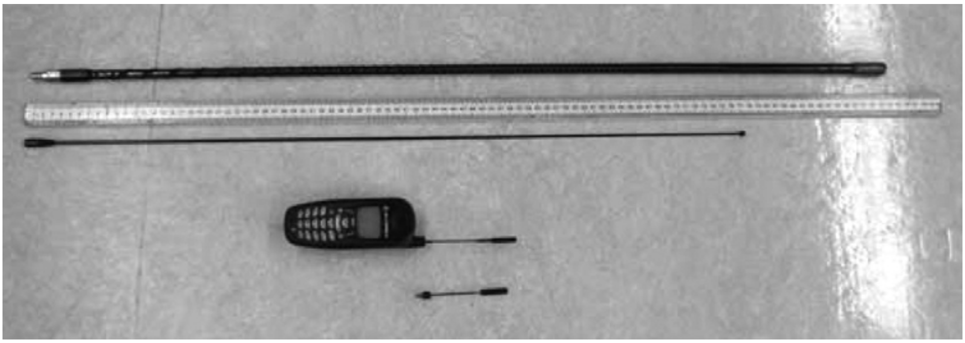


Figure 2: Antennas from three radio devices: CB (top), FM Car Radio (middle), Cell Phone (bottom).

Device	Carrier Frequency	Antenna Length
CB Radio	27 MHz	~3m
FM Car Radio	88 thru 108 MHz	~0.75m
Cellular Phone	880 or 1900 MHz	0.085m or 0.039m

Table 1: Carrier frequency and antenna length for three common radio devices used in this activity. [Note that the CB antenna shown in Figure 2 is a coiled antenna. This means that the effective length is much longer than the length of the actual antenna.]



part *II* the size of the wavelength of each carrier wave is determined by using the equation $c = \lambda f$, where c is the speed of light, λ is the wavelength, and f is the frequency. In part *III* students find the antenna length in each case is approximately ¼ the wavelength found in Part *II*.

Teacher Tips

- Students work in groups (or by themselves depending on the class dynamic) and a class discussion on progress should be held at the end of each part.
- Students should have access to different antennas to measure for Part III, although giving students the lengths can also work if necessary.
- Extension questions can be done as partners or individuals.
- Worksheet can be turned in for grading.
- CB antennas and old cell phones can sometimes be found at thrift shops.

Assessment

During the course of the lesson, students will be working on relating the wavelength to the frequency of electromagnetic waves. They will also be using observations to make connections between antenna length and the wavelength at which the device operates. These provide opportunities for formative assessment during the lesson.

The following questions can be used on a quiz or during a class discussion as additional probes of student understanding:

1. Why are radio waves used instead of visible light for communications? What are some possible problems with using visible light for communication between rooms?
   (Possible correct responses: Light does not penetrate walls. Transmission towers would be an eyesore and create light pollution)
2. What length should an antenna be to receive signal via blue light (500 nm)?
   (Correct response: 1.25×10^{-7}m. ▶

This, of course, is not practical.)

3. Why are some CB radio (27 MHz) antennas coiled? (Hint: Consider the practical applications of the antenna.)
   (Possible correct response: To save space, since a 3m antenna would be cumbersome.)
4. Does the sound jumper device transfer information similarly to FM or AM radio broadcasting? Explain your answer
   (Correct response: AM, it modifies amplitude not frequency)
5. Older cellular phones using the 880 MHz are seen with external antennas. New models use the 1900 MHz frequency and have no external antenna. Explain why new cell phones can have internal antennas.
   (Possible correct response: The antennas can be smaller because the devices utilize a higher frequency)

Extensions

Michigan Content Standards that can be addressed through extensions of the lesson:

- **P4.6f** Explain how radio waves are modified to send information in radio and television programs, radio-control cars, cell phone conversations, and GPS systems.

By now students have established that any portion of the electromagnetic spectrum could be used for communication. As an extension have them write a story about what life would be like if we actually used a different portion of the spectrum for communication.

The Sound Jumper Device can be built in class by students. For example, students can create a circuit diagram from the existing demonstration device and then follow the circuit diagram to build their own.

The Sound Jumper Device can also be used to help demonstrate the following:

- Electromagnetic waves can travel through space and sound cannot. This can be demonstrated by placing the transmitter in a vacuum chamber and the speaker outside the chamber.
- By placing a laser or a flashlight perpendicular to the light from the LED it can be shown that different electromagnetic signals can cross without interfering with each other.

Content Background

This lesson is designed to help students understand some of the basic principles of how electromagnetic waves are used in communication devices. Modern communication devices are very complicated, but they all involve a transmitter and a receiver. The transmitter takes the input signal (for example, a spoken word) and 'attaches' the information from the input signal onto an electromagnetic 'carrier' wave. Two basic ways to do this are Amplitude Modulation (AM) and Frequency Modulation (FM). (Teachers' Domain, 2004). The carrier wave is then picked up by the receiver and the attached signal is extracted from the carrier wave. This signal can then be converted to the desired format (for example, a speaker will convert the electric signal to a sound wave).

An important emphasis of this lesson is the relationship between the length of the receiving antenna and the wavelength of the electromagnetic carrier wave. Although there are a variety of types of receiving antennas, common designs are half-wave and quarter-wave ("Dipole Antenna," 2009). This means that the antenna length is one-half or one-quarter of the wavelength of the carrier wave. This helps to amplify the received electrical signal in the antenna due to constructive interference, or resonance (Mooney, 2004). Many common handheld devices use a quarter-wave antenna known as a whip antenna ("Whip Antenna," 2009).

Thus, the antenna length on many common radio devices is approximately one-quarter the wavelength of the carrier wave. We say approximately because almost all electromagnetic communication devices operate within a range of frequencies. For example, FM radio operates within a frequency of 88MHz to 108 MHz. Thus, a properly tuned quarter-wavelength antenna would range from

$$\frac{1}{4}\lambda = \frac{1}{4}\,\frac{c}{f} = \frac{1}{4}\;\frac{3\text{x}10^{3\text{m}}/_{\text{s}}}{88\text{x}10^{61}/_{\text{s}}} = .85m \text{ to } \frac{1}{4}\,\lambda = \frac{1}{4}\,\frac{c}{f} = \frac{1}{4}\;\frac{3\text{x}10^{3\text{m}}/_{\text{s}}}{108\text{x}10^{61}/_{\text{s}}} = .69m$$

So, typical FM antennas have a length somewhere in-between these two measurements. Not being perfectly tuned to the wavelength of the carrier wave means that the antennas lose some ability to pick up the carrier signal. This is a tradeoff for the ability to operate different carrier frequencies (i.e., radio stations).

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About the Authors:

- **Stephen Barry,** Harper Creek Community Schools, 7454 B Drive North, Battle Creek, MI 49014, Phone: 269-979-1121, Fax: 269-962-6034, BarryS@harpercreek.net, Home: 269-963-1477
- **John Burdette,** Lakeview High School, 15060 South Helmer, Battle Creek, MI 49015, Phone: (269) 565-3710, Fax: (269) 565-3708, JBurdette@lakeviewspartans.org, Home Phone: (810) 625-1192
- **Tara Egnatuk,** Calhoun Community High School, 15 Arbor Street, Battle Creek, MI 49015, Phone: 269-565-4782, Fax: 269-565-4784, tegnatuk@lakeviewspartans.org, 269-789-2765
- **Lindsey McConney,** Portage Northern High School, 1000 Idaho Ave., Portage MI 49024, Phone: 269-323-5400, Fax: 269-323-5405, lmcconney@gmail.com, home phone: 269-808-4417
- **Charles Henderson,** Western Michigan University, 1903 W. Michigan Ave., Kalamazoo, MI 49008, Phone: 269-387-4951, Fax: 269-387-4939, Charles.Henderson@wmich.edu, Home phone: 269-385-1298