SPARKI: Educator’s Guide

AMATEUR RADIO ON THE INTERNATIONAL SPACE STATION (ARISS) RADIO EXPERIMENTERS KIT

June 2023

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AMATEUR RADIO DIGITAL COMMUNICATIONS

For the most up to date version of this document, please visit:
https://ariss-usa.org/wp-content/uploads/2023/06/ARISS-Radio-Kit-Handbook-Current-Version.pdf

Contents

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Foreword

About ARISS

Amateur Radio on the International Space Station (ARISS) inspires, engages and educates youth in the fields of Science, Technology, Engineering, Arts, and Mathematics (STEAM) by giving them an opportunity to talk directly with the on-orbit crew via amateur radio. Through ARISS ham radio connections, students ask the ISS crew questions about life in space, career opportunities or other space-related topics. Students can fully engage in the ARISS contact by helping set up an amateur radio ground station at the school and then using that station to talk directly with the onboard crew member for approximately ten minutes, the time of an ISS overhead pass. Preparation for the experience motivates youth to learn about radio waves, space technology, ISS research, science, geography and the space environment. In many cases, the students help write press releases, convey ARISS activities through social media and give presentations on the contact to their fellow students and to the local community. ARISS youth activities span a diverse set of educational venues, including K-16 schools, scout groups, museums, libraries, after school programs, and national or international events. The amateur radio systems on ISS have been developed to also provide a life-long learning experience for students and adults 24/7/365 by enabling direct radio communication experimentation. Capability examples include digital communications relays, using APRS, where individuals can bounce their twitter-like messages through the ISS radio, and reception and social media posting of picture images, called SSTV, during periodic picture downlink events.

Amateur Radio organizations, and space agencies in the USA, Russia, Canada, Japan and Europe sponsor this educational opportunity by providing the equipment and operational support to enable direct communication between crew on the ISS and students around the world via Amateur Radio. Hundreds of Amateur Radio operators around the world work behind the scenes to make these educational experiences possible. Amateur Radio is a popular hobby and a service in which licensed participants operate communications equipment with a deep appreciation of the radio art.

ARISS was created and is managed by an international working group, including several countries in Europe as well as Japan, Russia, Canada, and the USA. The organization is run by volunteers from the national amateur radio organizations and the international AMSAT (Radio Amateur Satellite Corporation) organizations from each country. Since ARISS is international in scope, the team coordinates locally with their respective space agency and as an international team through ARISS working group meetings, teleconferences and webinars. The ARISS program has several goals:

- Inspire an interest in science, technology, engineering, arts and math (STEAM) subjects and in STEAM careers among young people
- Provide an educational opportunity for students, teachers and the general public to learn about space exploration, space technologies and satellite communications
- Provide an educational opportunity for students, teachers and the general public to learn about wireless technology and radio science through Amateur Radio
- Provide an opportunity for Amateur Radio experimentation and evaluation of new technologies
- Provide a contingency communications system for NASA and the ISS crew
- Provide crew with another means to directly interact with a larger community outside the ISS, including friends and family

More can be learned about the ARISS program at www.ariss.org. Further information about the ISS National Laboratory and its many programs can be found at: https://www.issnationallab.org/ and https://www.spacestationexplorers.org/

About the ARISS SPARKI Radio Experimenters Kit

The Space Pioneers Amateur Radio Kit Initiative (SPARKI) Radio Experimenters Kit, or SPARKI for short, was developed as part of the ARISS Student and Teacher Education via Radio Experimentation and Operations (STEREO) initiative.

The goals of the STEREO initiative are to enhance STEAM efforts and outcomes in various learning environments (schools, scout groups, homeschool groups, etc.) in three distinct ways:

1. Sending a SPARKI kit free of charge to schools in advance of a planned ARISS radio contact;
2. Conducting workshops and outreach for teachers on (a) how to use the SPARKI kit components and related suggested activities, and (b) how to develop winning ARISS radio contact proposals; and
3. Assuring continued ARISS success in achieving astronaut contacts by funding a portion of the mission operations costs.

The SPARKI kit is made up of components that facilitate learning about topics relevant to radio communications including electromagnetic waves, electronics, encoding/decoding, and software defined radios. It includes this SPARKI Educator's Guide that provides educators with educational material from which they can derive lesson plans tailored to their academic environment, including engaging hands-on activity suggestions to enhance the students' learning. The kit also includes various components that are used during the hands-on activities including springs, a Snap Circuits set, a specially programmed Raspberry Pi that works in concert with a provided Software Defined Radio (SDR) dongle, a large monitor, rabbit ear antennas, and all the required cabling for the suggested activities.

The SPARKI kit was developed with the generous support of the Amateur Radio Digital Communications (ARDC) foundation to further the ARISS objectives in the teaching environment.

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List of Materials in SPARKI Kit

Out of the box!

- Slinky and Helical (Long) Spring
- SC-300 Snap Circuits® Classic Kit
- Snap Circuits® Additional Hands-on Lessons for Basic Electricity and Electronics
    - Includes two experiment manuals (projects 1-100 & 102-305)
    - Link to Student Guide: https://www.elenco.com/wp-content/uploads/2019/05/SC-300R_500R_750R_REV-B_Part-1.pdf
    - Link to Teacher Guide: https://www.elenco.com/wp-content/uploads/2022/04/SC-100R_Teacher-Guide.pdf

      *Note that the Student/Teacher guides can be downloaded and used only in conjunction with Snap Circuit activities, per an agreement with Elenco.
- Morse Code Key
- Tape Measure
- Jumper cables (snap to banana) to connect Morse Code Key to SC-300
- RTL-SDR Software Defined Radio Dongle with Rabbit Ear Antennas and stand
- ARISS Radio Pi, which includes:
    - Raspberry Pi computer and power supply
    - SD Card with ARISS Radio Pi software embedded in Raspberry Pi
    - Raspberry Pi Keyboard and Mouse
- 50-foot USB extender cable to connect RTL-SDR to ARISS Radio Pi
- HP HDMI Monitor with built in speakers
- HDMI Cable
- Necessary cables and connectors
- ARRL US Amateur Radio Bands Quick Reference Card
- Book: Ada Lace, Take Me to Your Leader

Using the SPARKI Kit

The ARISS SPARKI kit is divided into four separate teaching modules:

1) Understanding Waves and Frequency
2) Electronics investigation: Series and Parallel Circuits
3) Codes and Ciphers
4) Software Defined Radio using the ARISS Radio Pi

Each element of this kit includes a set of equipment, instructions, and grab and go educational activities. For some elements, additional links and YouTube video tutorials are provided.

The basic kit includes the following hardware associated with the following modules:

Module Titles	Materials Provided in Kit
Waves and Propagation	Slinky and Helical (Long) Spring
Basic Electronics: Series and Parallel Circuits	Snap Circuits® Classic SC-300 with Batteries included Snap Circuits® Additional Hands-on Lessons for Basic Electricity and Electronics ● Student Guide ● Teacher Guide
Codes and Ciphers	Morse Code Key Snap Circuits SC-300 Jumper cables to connect Code Key to SC-300
ARISS Radio Pi for Software Defined Radio (SDR) Investigations	Raspberry Pi microprocessor RTL-SDR Software Defined Radio with Antenna and Stand 50 foot USB extender cable SD Card with ARISS Radio Pi software included HDMI Cable HP Monitor with built-in speakers Rabbit Ear Antenna

Waves and Frequency

OVERVIEW

Through a series of activities, students will use different items to demonstrate waves and frequency patterns and how changes in the frequency affect the waves. Students will also explore radio waves, the electromagnetic spectrum, and consider what types of everyday items use radio signals.

BY THE END OF THIS LESSON, YOU WILL BE ABLE TO ANSWER:

- What types of radio transmissions have you heard before?
- What are radio waves?
- What is radio frequency?
- What is the difference between a long and a short wave frequency pattern?

KEY TERMS	MATERIALS YOU WILL NEED
• Waves • Wavelength • Frequency • Transverse waves • Longitudinal waves • Propagation • Mechanical Wave • Constructive Interference • Destructive Interference • Electromagnetic radiation • Electromagnetic spectrum	• Slinky and Long spring (part of SPARKI kit) • Optional: Water bottles • String, cardboard, pencil • Ruler

CONCEPT INTRODUCTION

WHY SHOULD WE LEARN ABOUT WAVES?

By learning about waves, we began to grasp many physical phenomena in the world around us, such as light, sound, water waves, seismic waves, and electromagnetic waves, to name a few.

ENGAGEMENT TIP! Introduce new concepts with questions, such as:

- Have you ever wondered how radio signals make it to your radio or cellphone?
- Have you thought about how sound reaches your ears?
- Have you thought about how dolphins communicate under water?

We harness the power of waves in our everyday lives in many different ways. For example, we encode music onto radio waves that travel through the air to bring us radio stations. Our phones' Bluetooth and Wifi communicate using radio waves. We use the energy from microwaves to heat our food. Many medical devices rely on x-ray and gamma ray wave properties to diagnose and treat medical conditions. Animals such as dolphins, bats, and whales rely on sonar waves to communicate with one another.

INSTRUCTION

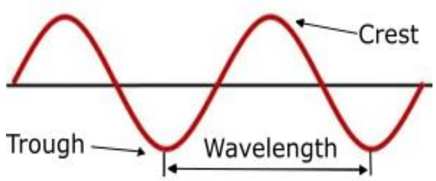
WHAT IS A WAVE?

A <u>wave</u> can be described as a disturbance or oscillation (an up and down or back and forth motion) that carries energy from place to place. Waves are all around us, though we can only see some types. For example, we can see ocean waves, but we can't see sound waves.

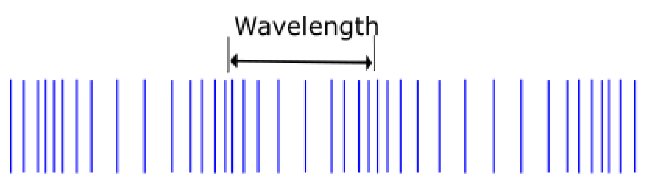
A wave can be mechanical or electromagnetic. Mechanical waves need a physical medium to travel, such as air or water (for example sound, or ripples in water when a pebble is thrown in), while electromagnetic waves do not require a medium and can travel anywhere, including through the vacuum of space (for example light and GPS signals).

A radio wave is a special type of electromagnetic wave that travels through space unseen, but that can be picked up with specialized equipment, such as radios, televisions, cellphones, and computers.

Waves come in two types: transverse and longitudinal. Transverse waves travel in alternating crests and troughs that are perpendicular to the wave direction. A crest is the highest point of a wave, whereas a trough is the lowest point of a wave. Longitudinal waves travel in the form of alternating compressions and expansions that are parallel to the wave direction.



Transverse Wave



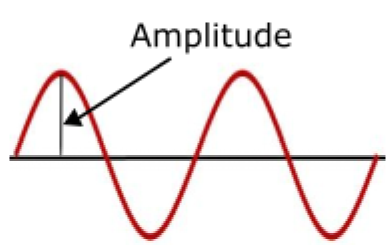
Longitudinal Wave

WHAT IS WAVELENGTH?

A wavelength is defined as the distance between two waves. For transverse waves, it's measured from crest to crest or from trough to trough of adjacent waves. For longitudinal waves, it's measured between adjacent compressions or expansions.

WHAT IS AMPLITUDE?

The amplitude of a wave is the measure of its height, measured from the resting position. It determines how much energy a wave has. The taller the wave pattern, the more energy the wave carries. For example, loud sounds would have very high wave patterns, while quieter sounds would have shallower wave patterns.



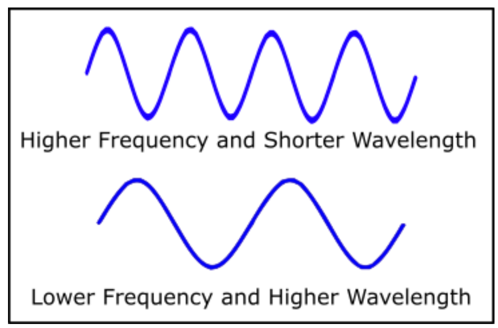
WHAT IS FREQUENCY?

Frequency is a measure of how frequently a complete wave cycle occurs within a second, and it's measured in the units "Hertz" (Hz). One complete wave cycle in 1 second is defined as 1 Hertz (Hz), two complete wave cycles in 1 second is 2 Hz, etc.

Radio frequency (RF) refers to the frequency range of electromagnetic waves that are suitable for use in telecommunications, with frequencies ranging from 9 kilohertz (kHz) to 300 gigahertz (GHz). As an example, when one tunes in to various stations on a car radio, each station has a different radio frequency. Similarly, cellphones and computers use RF energy to transmit and receive information. Most cell phones these days contain at least four RF radios and an antenna for each! These include: cellular communications, GPS, Wi-Fi, and Bluetooth.

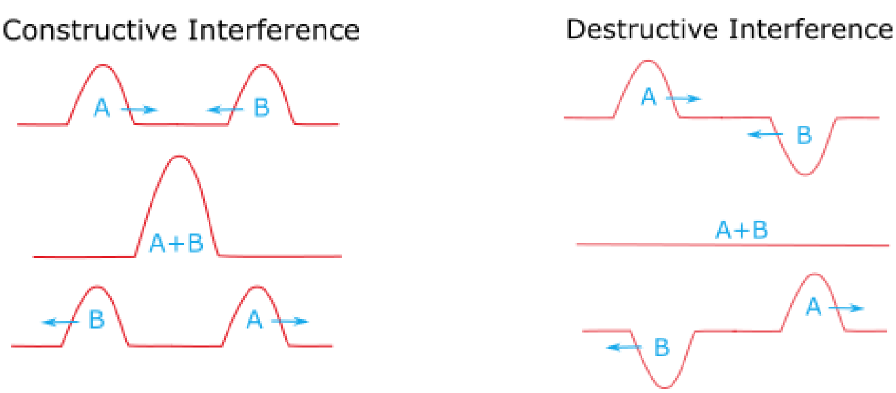
WHAT IS THE RELATIONSHIP BETWEEN WAVELENGTH AND FREQUENCY?

Long wavelengths have a low frequency of waves (fewer number of complete waves per second), while short wavelengths have high frequency of waves (greater number of complete waves per second). Frequency and wavelength are inversely proportional to each other.



WHAT IS WAVE INTERFERENCE?

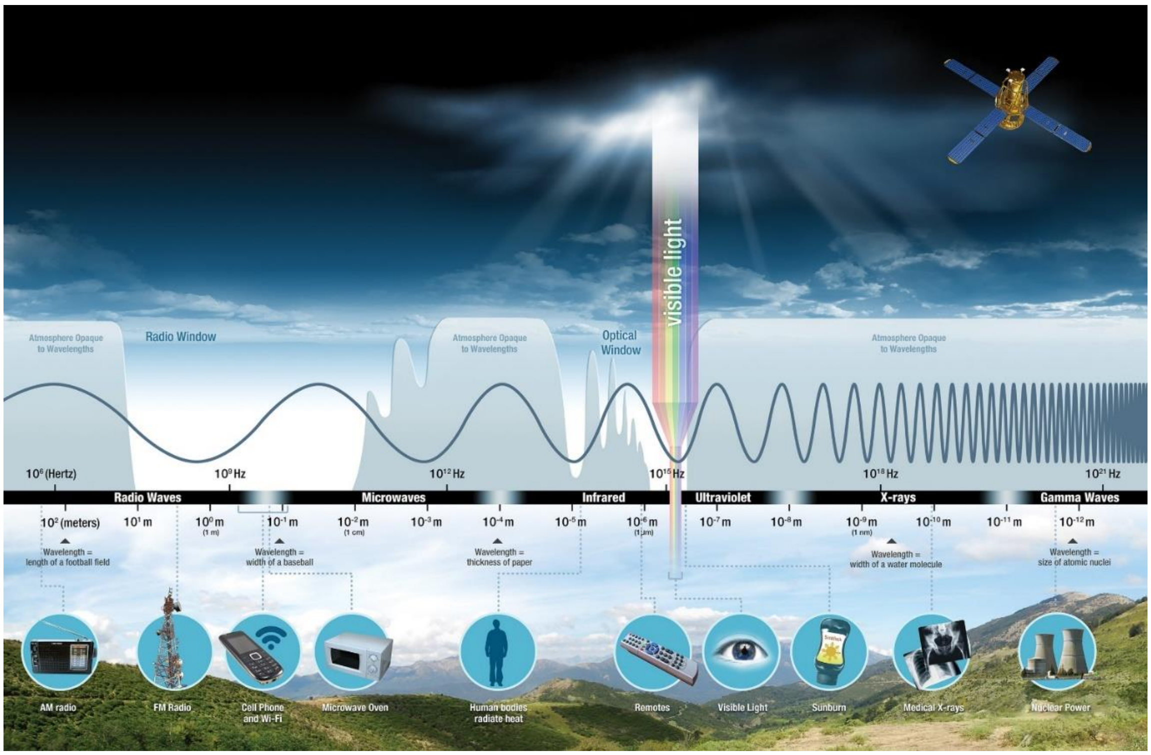
When waves collide with one another as they are traveling through the same medium, it affects their amplitude. Depending on how the peaks and troughs are aligned as the waves meet, they may add together, causing a higher amplitude (known as constructive interference), or partially or completely cancel each other out (known as destructive interference). Once the waves completely pass each other, they continue traveling in their original form and motion.



WHAT IS THE ELECTROMAGNETIC SPECTRUM

The electromagnetic (EM) spectrum is the complete range of all the different types of electromagnetic radiation, or energy. This energy travels in waves and spans a broad wavelength range from long waves, like AM radio, to very short waves, like gamma-rays.

You encounter various portions of the EM spectrum throughout the day! Visible light is the most observable part of the EM spectrum. For example, each color of the rainbow (red, orange, yellow, green, blue, and violet, frequently referred to as ROY-G-BIV) vibrates at a unique visible frequency. The visible spectrum is just one very small part of the entire EM spectrum. Other parts of the EM spectrum include radio waves, which are useful for broadcasting radio and television signals and other forms of telecommunications; gamma rays that are useful in medical diagnostic equipment; and even microwaves that are the source of the energy in your microwave oven that cooks your food!



Electromagnetic Spectrum (Courtesy NASA Science Directorate)

EXPERIMENTATION

ACTIVITY 1: SLINKY AND HELICAL (LONG) SPRING EXPERIMENTS

Purpose: To demonstrate the relationship between wavelength and frequency using springs.

Materials

- Slinky
- Long Spring
- Water bottles (or other heavy objects)
- String for measuring
- Ruler
- Lots of ground space
- 3 people
- Timer

This activity can be accomplished in a multitude of forms depending on the age of participants and available space. The main objective is to use the long coil and slinky as visual tools to represent the different wave forms. Hands-on activities can be accomplished through the various methods described below.

Part 1: Wavelength Demonstrations with long spring

1. Arrange 9 water bottles (or similar heavy objects) in a staggered line, each about 25 cm. apart.
2. Loop the long spring around the bottles without stretching the coil. Measure one of these wavelengths in centimeters. (Remind students that one wavelength is the distance between successive crests or troughs of a wave.)
   - ➔ How long is one complete wavelength in centimeters?
   - ➔ How many waves can be made with this length of coil?
3. Move the bottles to about 60-70 cm. apart, and once again loop the long coil around the bottles without stretching the coil. Measure one of these wavelengths in centimeters.
   - ➔ How long is one complete wavelength in centimeters?

- ➔ How many waves can be made now, and why did it change? (It changed because the wavelength of each wave is now longer.)

Part 2: Frequency demonstrations with slinky

For reference, consider watching C. Stephen Murray's "Slinky Demo" video on YouTube: (https://www.youtube.com/watch?v=SCtf-z4t9L8) and repeat the wave motions demonstrated with the slinky.

TRANSVERSE WAVE EXPERIMENT

1. Stretch out the slinky about 3 meters without touching the floor, having one person at each end hold it waist high. (Caution the students that if the slinky is stretched too far, it will snap!) This activity can also be tried with the long coil.
2. Have a third person "pluck" the slinky in the middle by stretching it 20-30 centimeters in a transverse (sideways) direction before letting go. (Note: The slinky can also be plucked in the vertical direction if this helps with visibility in some settings.)
   - ➔ How many wave cycles occur over a duration of 5 seconds? (use a timer)
3. Repeat these steps, only this time, one person releases one end of the slinky and instead holds it in the middle. Now, only half the slinky is stretched out. Once again, the third person plucks the slinky in the new middle.
   - ➔ Now how many wave cycles occur over a duration of 5 seconds?
   - ➔ Is the wave frequency different? Which one is faster? Why? (*The frequency is higher because the wavelength is shorter. Frequency and wavelength are inversely proportional*).
4. Try different variations such as arranging the slinky on the floor instead of in the air. What changes? (*e.g. effects of friction*)

LONGITUDINAL WAVE EXPERIMENT

1. Stretch out the slinky about 3 meters without touching the floor, having one person at each end hold it waist high. (Caution the students that if the slinky is stretched too far, it will snap!)
2. Have a person on one end quickly push the slinky in and back out toward the other end. Note how the wave now travels along the slinky itself rather than up and down. This type of wave is called a longitudinal wave.

- ➔ How many wave cycles occur over a duration of 5 seconds? (use a timer).

3. Repeat these steps using only about half the slinky (the remainder of the slinky is bunched up in the second person's hand)
   - ➔ Now how many wave cycles occur over a duration of 5 seconds?
   - ➔ Can you see differences in the wave frequencies? Why is one faster? (*A shorter wavelength results in a higher frequency since wavelength and frequency are inversely proportional.*)

Part 3: Wave Interference Demonstrations with Long Spring

Caution: The long spring can be dangerous when mishandled, so it should only be used with an adult present and is recommended for ages 10 and up.

With the long spring, you will be observing very similar wave properties as the ones you saw in Part 2 with the slinky. Perform the same steps as you did in Part 2. After you have finished, consider the following questions:

- ➔ When wavelength is increasing, how is frequency changing? What does this mean about when wavelength is decreasing? (*Wavelength and frequency are inversely proportional.*)
- ➔ When some waves interfere, why do they create larger waves, while when other waves interfere, they simply cancel each other out? (*If the waves meet at the crests of both waves, the amplitudes will be added together; if they meet at the trough of one and the crest of another, they will cancel each other out to the degree of the amplitude of each wave where they meet.*)
- ➔ What happens when the spring is "plucked" by displacing it 12 centimeters versus when displacing it 24 centimeters? How are they similar, and how are they different? (*The wavelength is shorter when displaced 12 cm, thus the frequency is greater*)

ACTIVITY 2: WAVELENGTH VS. PITCH EXPERIMENT

Purpose: To demonstrate how wavelength and pitch are related.

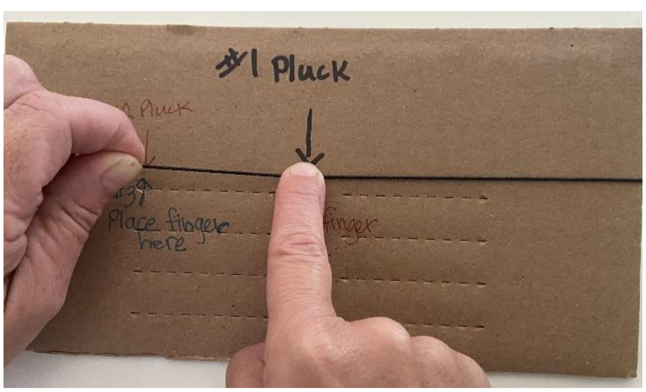
Materials

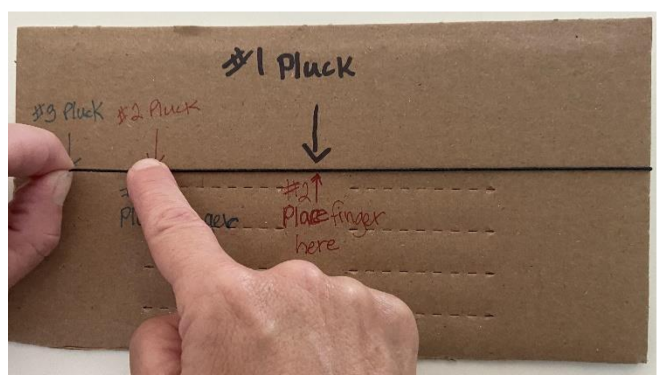
- Foam board, cardboard, or a tissue box
- String
- Pencil

To learn about the relationship between wavelength and pitch, we will be using simple materials like cardboard, foam board, tissue boxes, string, and a pencil.

Note: *Twist pencil to tighten string on board for the best sound.*

1. Attach a string to the cardboard by wrapping it around long ways and tying a knot on the back tightly. Tie a pencil to the back and twist to tighten. Alternately, wrap the string around a tissue box.
2. Pluck the string until you hear a sound in the center.
3. Place a finger halfway down the string and pluck again.
   - ➔ What happens to the change in sound? Why?
4. Repeat for 1/3 of the string, then 1/4, then 1/8.
   - ➔ Notice the change in pitch as you move your finger and shorten the wave. Why does this happen?





FOR FURTHER INVESTIGATION:

THE US FREQUENCY ALLOCATIONS CHART

Take a look at the US Frequency Allocation Chart at the following website:

https://www.ntia.doc.gov/files/ntia/publications/january_2016_spectrum_wall_chart.pdf

Ask students to answer the following questions:

- What frequency range does the United States use for FM broadcasting? For AM broadcasting?
- What is the frequency range for Amateur Radio at the 3MHz band? What is it at the 30 MHz band?
- What frequency bands does television broadcast at?
- What do all types of electromagnetic radiation have in common?
- What is different about the different parts of the electromagnetic spectrum?

MORE WAVE BEHAVIOR ACTIVITIES

- Read through a NASA article at https://science.nasa.gov/ems/03_behaviors, which discusses reflection, diffraction, absorption, scatter, and refraction.

  Ask students to answer the following questions:

  - How does the energy of the different waves of the spectrum vary with frequency? With wavelength?
  - What is the frequency range of UV light? What about infrared light?
  - If you are using night-vision goggles, what part of the spectrum are you detecting?

- Assign students different portions of the Electromagnetic Spectrum to investigate, and have them put together a report or presentation on their findings.

- The following websites and YouTube videos have helpful demonstrations:
  - Demonstration of Longitudinal Wave:

    https://www.youtube.com/watch?v=Bcqp6t4ybxU
  - Interactive "Wave on a String" visualization tool:
    http://phet.colorado.edu/sims/html/wave-on-a-string/latest/wave-on-a-string_en.html

Imagine the Universe –

This NASA website teaches about the electromagnetic spectrum.

https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html

Signals and Noise, Oh Boy! NASA Lesson

The following NASA website includes a lesson that teaches about signals and noise in the context of spacecraft communications.

https://www.nasa.gov/pdf/513840main_Signals_and_Noise_3-5.pdf

NASA SCaN Activities:

String Can Telephone - Observe sound moving as a wave (modulation) from one cup to another.
https://www.nasa.gov/sites/default/files/atoms/files/scan_activities.pdf

Frequency Board - Explore electromagnetic spectrum, phases and wavelengths, compare radio waves and infrared waves, wave cycle, patterns, repeat waves.

Electrical Circuits

OVERVIEW

Through this lesson and activities, students will build various circuits to learn about basic electronics, voltage, and current. Students will also gain a basic understanding of how electricity works and how this applies to electricity usage by everyday items.

BY THE END OF THIS LESSON, YOU WILL BE ABLE TO ANSWER:

- What is electricity
- What is an electrical circuit?
- What happens when a switch is opened/closed in a circuit?
- What is a disadvantage of a series circuit?

TERMS YOU WILL LEARN

- Electricity
- Voltage
- Electrical Current
- Conductor
- Parallel Circuit
- Series Circuit
- Direct Current (DC)
- Alternating Current (AC)
- Open Circuit
- Closed Circuit
- Ohm's Law
- Electric Power

MATERIALS YOU WILL NEED

- SC-130 Snap Circuit® Kit
- Project #5 in the SC-300 Experiments 1-101 booklet (page 10)
- Project #6 in the SC-300 Experiments 1-101 booklet (page 10)
- Project #242 in the SC-300 Experiments 102-305 booklet (page 50)

CONCEPT INTRODUCTION

WHY IS ELECTRITY IMPORTANT?

Electricity is an essential part of our modern lives! Many of the items we use on a daily basis require electricity to operate. For example, lights, fans, appliances, machinery, cell phones, computers, and important medical equipment. Can you think of others?

ENGAGEMENT TIP!

- Have you ever wondered why a light flickers and then burns out? Have you looked at the burned light bulb?
- Did you ever notice that batteries for your remote controls fit into a slot with metal tabs at one end?
- If you put the batteries in wrong, it doesn't work. Why?

INSTRUCTION

WHAT IS ELECTRICITY?

Electricity is a type of energy that, when released, can move very tiny particles called electrons through conductors (like wires), and this flow of electrons is referred to as electrical current. Batteries can be used to store electrical energy. Power lines bring electricity to our homes from power plants.

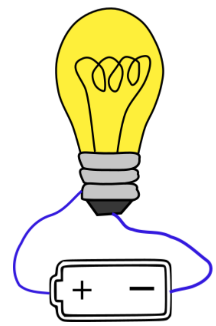
WHAT IS THE RELATIONSHIP BETWEEN VOLTAGE AND CURRENT?

Voltage is the amount of energy, or force, needed to push electrons through a component. A simple analogy for current and voltage is water flowing through a pipe. The electrical current is like the flow of the water through the pipe, while the voltage is like the pressure of the water, or how forcefully it is flowing. Current cannot flow without an adequate amount of voltage. Current is measured in Amps, while Voltage is measured in Volts.

WHAT IS A CIRCUIT?

An electrical circuit is a path through which electricity can flow. It generally has a power source (such as a battery), items that require the electrical energy from that power source to work (like fans, lights, motors, etc.), and wires (conductors) to connect them all together. The direction of current flow is away from the positive terminal of the power source, toward the negative terminal.

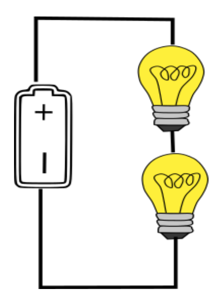
Here's an example of a simple circuit: An incandescent bulb has a super thin wire inside, called a filament, that glows when electricity flow through it. The bulb has two metal places on the bottom, called terminals, to connect it to conductors. If you take a battery and attach a wire to both ends, then you attach the other end of the wires to the two terminals of the light bulb, it will begin to glow.



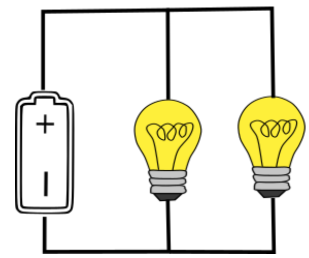
If you place a switch in this electrical loop, you can then control when the electricity flows. The switch breaks the flow of electricity by breaking (opening) the path through which the electricity flows. When the switch is open, no electricity flows (called an "open-circuit"), and when the switch is closed, electricity will once again flow (called a "closed-circuit").

WHAT IS A SERIES CIRCUIT?

In the lightbulb example above, the battery and the lightbulb are connected in a simple loop. When all the components are connected end-to-end like this, they form a single path for the electricity to flow through. This type of circuit is called a series circuit. The same amount of current flows through all the components in a series circuit, and the voltage (energy) is divided between the components.



WHAT IS A PARALLEL CIRCUIT?



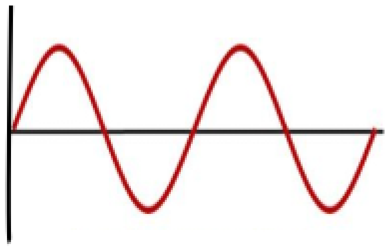
In a parallel circuit, the components are connected across from each other, in parallel with the energy source (e.g. the battery). The electric current branches and divides, flowing through each parallel path. One of the benefits of this type of circuit is that even when one of the parallel components stops working (e.g. the wire breaks), the other parallel components continue to work because they still have current flowing through them.

A great example of this is a string of Christmas tree lights. The bulbs in older strings were all wired in series, so when one bulb went out, the entire string went out. Newer lights are now wired in parallel, so even if one light bulb goes out, the rest of the lights continue working.

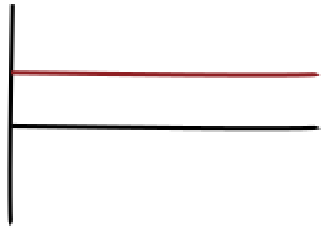
DIRECT CURRENT VS. ALTERNATING CURRENT?

In direct current (DC), the electric charge flows in one direction at all times. DC power sources include batteries, solar panels, and fuel cells. Most electronic and hand held devices (like cell phones, lap tops, flashlights, etc), and electric vehicles run on direct current. In some cases, for example a laptop computer, an AC to DC adapter is needed to convert AC power from a wall outlet to the DC power required to run the laptop. When graphed, DC power looks like a line.

In alternating current, the electric current periodically reverses its direction in an oscillating pattern. Alternating current is used in well-known applications such as the electricity that wires a household (e.g. from an electrical outlet) or electric appliances such as fans, light bulbs, and some motors. When graphed, AC power looks like a sinusoidal wave. The AC power that powers our homes has a frequency of 60 Hz.



Alternating Current (AC)



Direct Current (AC)

WHAT ARE SOME COMMON ELECTRONIC ELEMENTS?

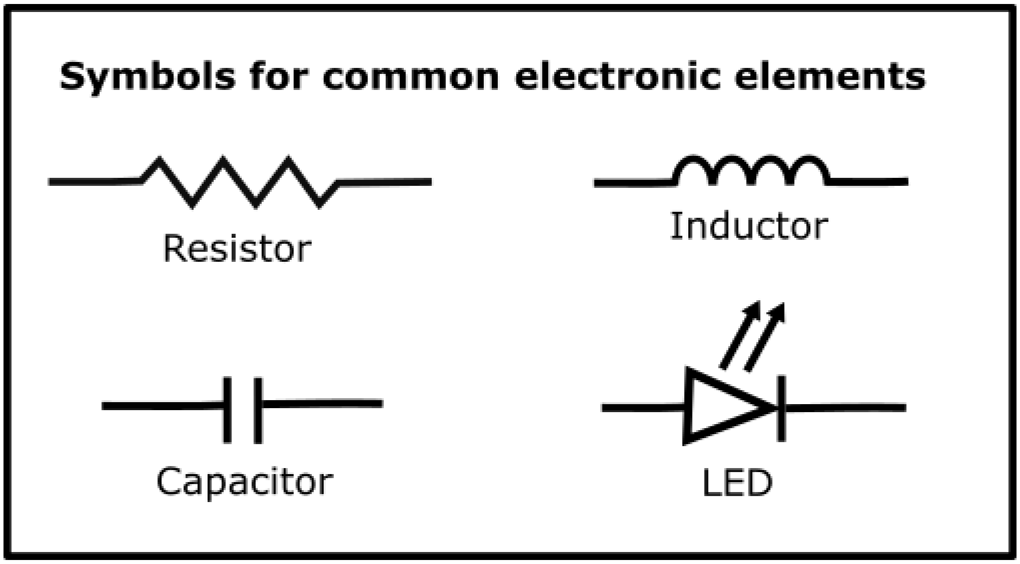
Many electric appliances and circuits are made with specific core elements that are common to them all. These elements include resistors, capacitors, inductors, and LEDs.

Resistors are the part of a circuit that limits the electrical current flowing through the circuit, like electrical friction. This component can be useful when creating a new circuit because it allows you to control and lessen the specific voltage you want to achieve. Resistance is measured in Ohms, and is represented by the omega symbol: **Ω**

Capacitors are the part of a circuit that stores electric energy. In simple terms, capacitors are like batteries except for the fact that they charge and discharge much faster. A capacitor is made up of two conducting plates that are separated by an insulating material known as a dielectric. The way this device stores energy is by accumulating electric charge on these two conducting plates. Capacitors can be used to help maintain the voltage of a circuit at a certain level. Capacitance is measured in Farads (F).

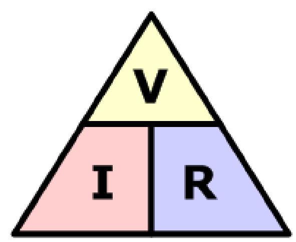
Inductors are the component of an electric circuit that opposes any change in the electric current. An inductor is usually made from conducting material such as copper or iron that is coiled and wrapped around a magnetic core. An inductor is essentially able to convert electric energy to magnetic energy that can be stored inside the inductor itself. Inductance is measured in henrys (H).

LEDs are light emitting diodes that are essentially smaller versions of lightbulbs that can be connected to circuits. These are semiconductors that can emit light when a current is passed through them. LEDs are very efficient because they convert most of the energy passed through them into light instead of emitting it as heat.

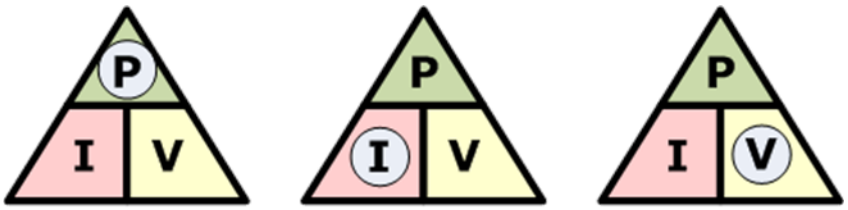


OHMS LAW AND ELECTRIC POWER

Ohms law states that voltage is equal to resistance multiplied by current. This essentially is saying that the amount of current present is inversely proportional to the resistance and directly proportional to the voltage.



Power is equal to current multiplied by voltage. This is saying that the power is directly proportional to both current and voltage (as either the current or the voltage increases, so does the power).



$$P = I \times V \qquad I = \frac{P}{V} \qquad V = \frac{P}{I}$$

EXPERIMENTATION

ACTIVITY 1: BUILD A SERIES CIRCUIT

This experiment uses the Electronic Snap Circuits Experiments 1-101 manual included in the kit, Project #5 on page 10 ("Lamp and Fan in Series").

1. Proceed by holding up each circuit element that will be used in this activity, describing it and what it does in the circuit. Explain the grid system on the snap board (letters along the side and numbers across the top to ensure they have enough room to build their circuit. (*Please note that the typo in the circuit diagram. The L1 lamp is 3V, not 2.5V.*)
2. Before the group begins work, the teacher states they are to <u>carefully</u> review their circuit once they complete it to ensure all connections are correct before switching it on. Remind them to read all of the Project #5 text before starting the build.
3. The students work together in constructing the series electric circuit, closely following the diagram and instructions in the snap circuits manual.
4. Explain that part of the voltage goes across the light and the rest goes across the fan. Have students remove the fan from the circuit, placing a blue conductor # 3 strip in its place.

→ What happened when the fan was removed? *(The light got brighter, because the battery's energy didn't need to be shared with the fan)*.
→ What happens when the switch is open/closed? Why does this happen? *(Current flows in a closed circuit but not in an open circuit.)*

ACTIVITY 2: BUILD A PARALLEL CIRCUIT

This experiment uses the Electronic Snap Circuits Experiments 1-101 manual included in the kit, Project #6 on page 10 ("Lamp and Fan in Parallel").

1. Proceed by holding up each circuit element that will be used in this activity, describing it and what it does in the circuit.
2. Before the group begins work, the teacher states they are to carefully review their circuit once they complete it to ensure all connections are correct before switching it on. Remind them to read all of the Project #6 text before starting the build.
3. The students work together in constructing the parallel electric circuit, closely following the diagram and instructions in the snap circuits manual.
4. Explain that the voltage goes across the light and the fan equally, but the current divides between the two.

→ What happens when the fan is removed? (*The light continues to work because it still makes a closed circuit with the battery.)*

ACTIVITY 3: BUILD AN AM RADIO

This experiment uses the Electronic Snap Circuits Experiments 102-305 manual included in the kit, Project #242 on page 50 ("AM Radio"). The objective is to make a complete working AM radio!

1. Before the group begins work, the teacher states they are to carefully review their circuit once they complete it to ensure all connections are correct before switching it on.
2. The students work together in constructing the AM Radio circuit, closely following the diagram and instructions in the snap circuits manual.
3. Play with varying the adjustable capacitor to tune to different stations, and with the adjustable resistor to increase/decrease the volume.

After these activities, encourage students to create circuits of their own! Create circuits using the rest of the components in the kit and the manuals.

FOR FURTHER INVESTIGATION:

HOW DO YOU GET ELECTRICITY ON THE SPACE STATION?

https://www.nasa.gov/mission_pages/station/structure/elements/solar_arrays.html

OTHER READING MATERIAL

- The book Much Ado About Almost Nothing: Man's Encounter with the Electron, by Hans Camenzind, provides an engaging history of electricity and electronics; geared more toward middle and high school students.

Codes and Ciphers

OVERVIEW

Students will understand the importance of coding in our society through a series of activities and challenges that allow them to try out different types of code and cipher activities. This includes encoding, decoding, practicing Morse code with a Snap Circuit code oscillator circuit, and using the phonetic alphabet.

BY THE END OF THIS LESSON, YOU WILL BE ABLE TO ANSWER:

- What is a code?
- What is a cipher?
- Why was Morse code invented?
- How does Morse code continue to play a strong role in Amateur Radio?
- What was the use of the Q Code?
- What is the purpose of the Phonetic Alphabet?

TERMS YOU WILL LEARN

- Encode/Decode
- Ham Radio
- Code/Cipher
- Morse Code
- Phonetic Alphabet
- Q Code
- Wireless Communication

MATERIALS YOU WILL NEED

- Paper and pencil
- Cipher worksheet Morse code key
- Morse Code Generator Project #228 from the SC-300 Snap Circuit Kit
- White board or chalkboard
- Laptop with internet connection

CONCEPT INTRODUCTION

WHY ARE CODES AND CIPHERS IMPORTANT?

Codes and ciphers have been an important means of communicating with others for thousands of years. The study of codes and ciphers in known as "Cryptology" . An early example of code is the invention of language and writing. People invented language to communicate to others what they saw, heard, or felt. As we evolved, spoken language was converted into visual symbols (writing), which allowed information to be preserved and shared with anyone who knew how to read and write.

People have also used ciphers for thousands of years to send private or secret messages back and forth to others in a way that the meaning couldn't be understood if the message got into the wrong hands. Catchers and pitchers in a baseball game use hand signals to communicate what type of pitch to throw next to make it difficult for the opponent to hit the ball. Kids have created secret codes, languages, and symbols for ages just for fun. But there are far more serious uses as well, such as to protect national security, to safely control spacecraft, to keep our phone conversations private and secure, and many more examples.

ENGAGEMENT TIP! Introduce new concepts with questions, such as:

- Did you ever make up a secret handshake or secret code to communicate with a friend?
- Have you heard of a decoder ring?
- Did you ever wonder how ships communicated with each other before radios were invented?
- Have you ever heard of truck drivers or first-responders communicating with short-hand language such as "10-4" (meaning "OK"), "10-20?" (meaning "What's your location?"), etc.?

Codes can help to make communicating faster and more efficient by condensing information so that it can be communicated in a shorter time period, as we'll learn about when we discuss Morse code. Codes are also used in amateur radio communications. For example, each ham radio station is uniquely identified with its own unique code, or "call sign". The call sign conveys important information such as identifying the individual/entity using the radio. Even the International Space Station has a call sign! It's NA1SS.

INSTRUCTION

WHAT ARE CODES?

Codes are a set of rules to convert information into another form or representation for efficient communication. We use codes every day to effectively communicate with one another. Letters, words, sounds, images, and gestures are all demonstrations of codes.

WHAT ARE Q-CODES?

Q-codes are three-letter codes used for efficient radio communication in amateur radio. They are used extensively by the amateur radio community to simplify voice communications by substituting these codes for common phrases. The Q-codes even mean the same thing in different languages, making it easier to communicate with people in other countries! Each Q-code starts with the letter Q and includes two other letters. Here are a few examples:

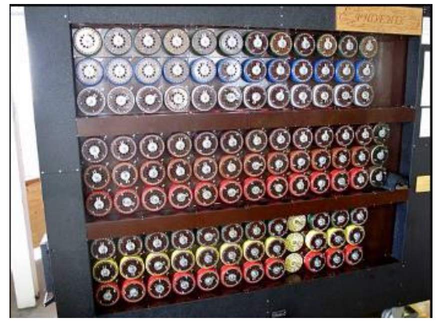
QRZ: Who is calling me?	QSY: Change Frequencies
QSO: Radio Contact	QRT: I will stop sending
QSL: Acknowledge receipt	QRM: Transmission has interference

Fun Fact: Many amateur radio operators (hams) enjoy exchanging QSL cards to have written confirmation of their on-air contact with one another for the first time. These QSL cards are a form of postcard, and are uniquely designed by each person/organization. They are exchanged in friendship, and include information such as the ham's call sign, radio equipment, date and time of the contact, and geographic location. Many of the cards end with the code "73", which means "best regards". The appendix includes an activity to design a QSL card for your school or group.

WHAT ARE CIPHERS AND HOW ARE THEY USED?

A cipher is a way to disguise a message so that it cannot be understood by anyone except the intended recipient. Ciphers uses a set of instructions (called a "key") to "encode" or "encrypt" a message, and the recipient must have the "key" to subsequently "decode" or "decrypt" the message so it can be understood.

A famous cipher from history was the Enigma, which was a cipher device used by the German military during World War II to encode its strategic messages. As one can imagine, much effort was invested by many countries to try to decrypt this code to gain a military advantage during the war. An English mathematician named Alan Turing led a team that was ultimately able to crack the code and make a successful decryption machine.

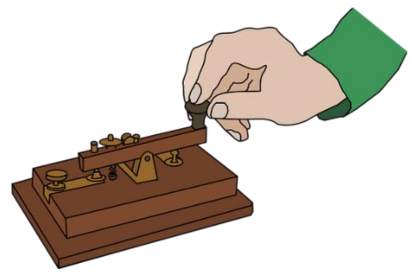


Enigma Decryption Machine

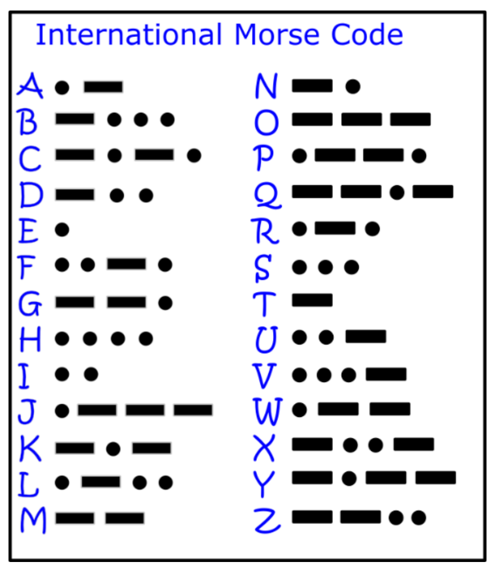
Today, encryption and decryption are used extensively in the world of computers to protect our online activities and information from unauthorized access.

WHAT IS MORSE CODE?

Morse code is named after Samuel Morse, an inventor of the telegraph in the 1830's and 1840's. The telegraph, which preceded the invention of telephones, revolutionized long-distance communication. With the first successful telegraph, short electrical pulses were able to be sent across wires through long distances. The first successful messages were between Washington, DC and Baltimore.

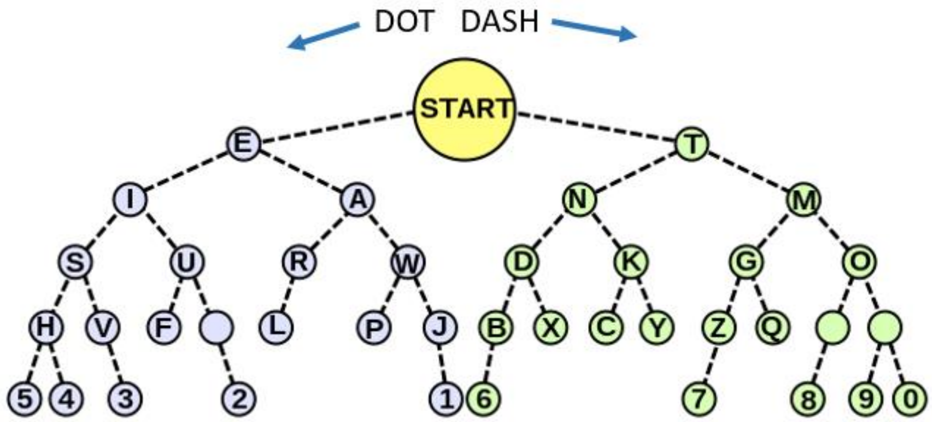


To make this capability useful for communications, Samuel Morse invented a code that consisted of dots and dashes to represent the alphabet as a sound, or even as a light pulse if connected to a bulb. The telegraph sender would use a code key, as shown in the picture to the left, to tap out the letters, and the receiver would decode the message. Morse code took off and became an important means of communication at that time.



Today, the International Morse Code encodes the 26 English letters A through Z, including some non-English letters, the Arabic numerals and a small set of punctuation and procedural signals. Each character is represented by a set of dots and dashes and there is no distinction between upper and lowercase letters. The dots and dashes were initially assigned based on the frequency of use of each character. For example, the letter "E" received a simple code since it is used very frequently in the English language, while the letter "X" received a more complex code since it's used infrequently. This allowed for more efficient transmission across telegraph lines.

A Binary tree is frequently used to facilitate decoding a Morse code message. For each dot heard, one would travel toward the left branch, and for each dash heard, one would travel toward the right branch, moving down one level for each received dot and dash. For example, for the letter R (dot dash dot), first a dot is heard so traverse to the left (toward E), then a dash is heard so traverse to the right (toward A) and finally a dot is heard so traverse to the left toward R.



Morse Code Binary Tree Diagram (Courtesy DMGualtieri)

Morse code isn't used as frequently nowadays because technology has continued to evolve and improve, but it is still has some uses. For example, amateur radio operators sometimes use Morse code to communicate about emergency situations. There are also certain situations where Morse code is the best means of communication when there are power and infrastructure limitations. Today, Morse code has also become an assistive technology to help people with a variety of disabilities communicate.

WHAT IS THE PHONETIC ALPHABET?

The phonetic alphabet, also known as the radiotelephone alphabet, is widely used as a way to communicate when letters sound similar, specifically during wireless and long-range transmissions by radio or telephone, especially when language differences exist. Each alphabetical letter is assigned a code word. For example, here are the code words for the letters A through F: Alpha, Bravo, Charlie, Delta, Echo, Foxtrot.

EXPERIMENTATION

ACTIVITY 1: CREATE A CAESER CIPHER AND MAKE YOUR OWN SECRET MESSAGE!

1. Write out the alphabet.
2. Choose a number of spaces to advance every letter (rotate) and then re-write the alphabet directly below for your cipher code. Start your new code at the exact number of spaces you chose to rotate to, then when you reach “Z”, continue your new alphabet starting back at A. See below.
3. Create your first coded message!

For example, ROTATE 3 spaces, like this (“Rot 3”):

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	2	3	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W

Start over at the beginning to complete the cipher, like this:

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W

Here is an encoded message using a rotation of 3 spaces (Rot 3). Can you figure out what the secret message is?

Tb xob dlfkd ql qeb Jllk!

How do you decode this message? Write the encrypted message in the top row of boxes. Then use the same cipher to find the original letters and record them directly below to read the secret message!

T	b		x	o	b		d	l	f	k	d		q	l		q	e	b		J	l	l	k	!	

And here's the secret message!

T	b		x	o	b		d	l	f	k	d		q	l		q	e	b		J	l	l	k	!	
W	e		a	r	e		g	o	i	n	g		t	o		t	h	e		M	o	o	n	!	

ARE YOU READY TO MAKE YOUR OWN CIPHER?

1. Create your own Cipher - Rotation Number: ___

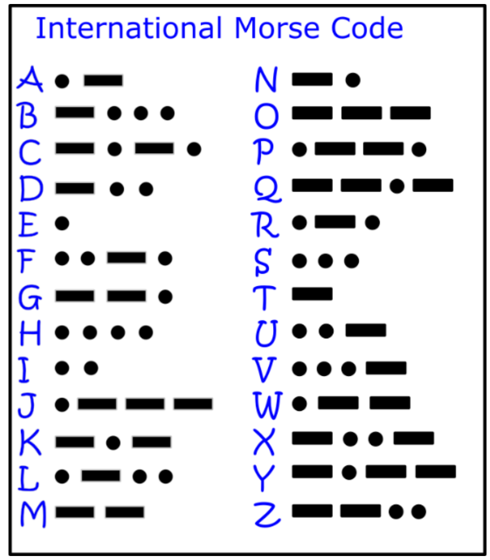
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z

2. Write the letters you want to encode (encrypt) in the top row of boxes. Leave an empty space between words. In the bottom row, fill in the proper coded letter to replace your original letter directly below each letter.

Write your new SECRET MESSAGE here!

How do you decode (decrypt) a message? Write the encrypted message in the top row of boxes. Then use the new cipher you created to find the original letters and record them directly below to read the secret message!

ACTIVITY 2: PRACTICING MORSE CODE



1. SOS! That's the universal code word a ship at sea uses to alert others of an emergency.
- Tap out 3 dots, 3 dashes, and 3 dots on your Morse code key.
- Show students how they can practice by tapping their fingers on their desks, pausing for dashes.

2. Have the instructor either tap out a Morse message or let students listen to a recording of Morse code (we recommend https://en.wikipedia.org/wiki/Morse_code). Listen to a recording of Morse code here. With the provided source you can scroll towards the bottom of the page and play a number of different Morse code recordings.

3. Relate to the students through recent TV shows and movies. Reference Sandra Bullock in Gravity, in which Amateur Radio allowed her to hear a dog barking and someone speaking on earth from the broken spacecraft. Mention the series *Stranger Things*, which features an AV Teacher that is a licensed Amateur Radio operator.

4. Direct students to write the letters of their name on a piece of paper in Morse code. Students should practice "tapping out" their name either on their desk or on the Morse code key. Additionally, let various students take turns encoding words for the class to guess. Use common letters for the first lesson, such as SOS, ISS, and ARISS. Focus on decoding what the dots and dashes mean. Students should use a piece of scratch paper to note the dots and dashes they hear. Each word should be heard three times. You could additionally challenge students by having them think of short words that include some of the letters already practiced. Simple ideas could include having them write out their school name, mascot, motto, or their teacher's name for more practice.

ACTIVITY 3: LEARNING ABOUT THE PHONETIC ALPHABET

1. Think of the letters of the alphabet and notice which letters sound very similar.
Example:

- B, C …What other letters end with the long E sound? (D, E, G, P, V, Z)
- What letter has the same vowel sound as J? (K)
- What other letters have the same vowel sound? (Q and U) What other letters might get confused? (M and N)

2. Say the alphabet in phonetics from A to Z!
Go around the room and have each students say their name in phonetics.

3. Have students decode this, or a similar, message:

> “Sierra Charlie India Echo November Charlie Echo, India Sierra, Foxtrot Uniform November.” (Science is Fun)

___ ___ ___ ___ ___ ___ ___   ___ ___   ___ ___ ___

Alpha	•–
Bravo	–•••
Charlie	–•–•
Delta	–••
Echo	•
Foxtrot	••–•
Golf	––•
Hotel	••••
India	••
Juliet	•–––
Kilo	–•–
Lima	•–••
Mike	––
November	–•
Oscar	–––
Papa	•––•
Quebec	––•–
Romeo	•–•
Sierra	•••
Tango	–
Uniform	••–
Victor	•••–
Whiskey	•––
X-ray	–••–
Yankee	–•––
Zulu	––••

ACTIVITY 4: BUILD A MORSE CODE GENERATOR WITH SNAP CIRCUIT KIT TO PRACTICE MORSE CODE!

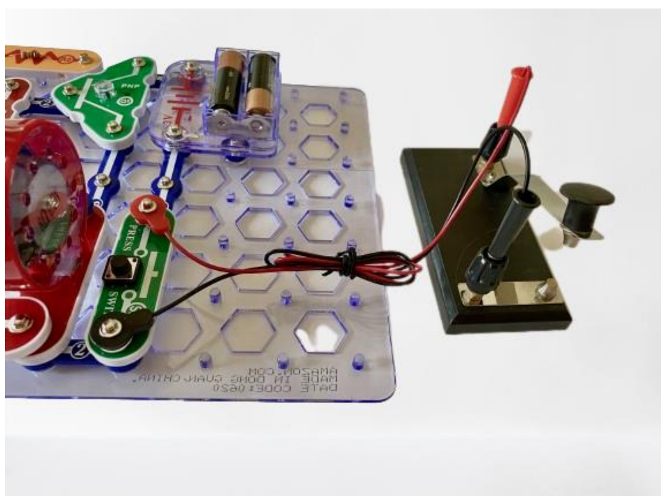
This experiment uses the Snap Circuits kit and the Experiments 102-305 manual included with the kit. We will be building Project #228 on page 44 of that manual.

1. Before the group begins work, the teacher states they are to carefully review their circuit once they build it to ensure all connections are correct before switching it on.

2. The students work together in constructing the circuit on pg. 44 of the Snap Circuit Experiment manual, closely following the parts layout. After building the circuit, the students can connect the Morse code key to switch S2 as shown in the image below using the included "snap to banana" cables. Depressing either the pushbutton switch or the key will result in sound being heard.

3. Students use the code key to sound out their names according to the dot & dash chart shown above in the Morse code lesson.

4. Note how the pitch changes as the slider switch (RV) is adjusted.



FUN FACTS! The International Space Station (ISS) uses an onboard Amateur Radio for communications during educational activities to connect students to astronauts LIVE in space! ARISS leads this activity and provides the hardware onboard the ISS. In the past, the ISS has used Amateur Radio to talk with family. Amateur radio serves as a backup communications capability during unplanned communications outages.

During weather-related disasters or massive power outages, hams can provide a network of communication for local law enforcement and emergency services.

OTHER READING MATERIAL

- The book Ada Lace, Take Me to Your Leader, by Emily Calandrelli, is included in the radio kit. It tells the story of young Ada Lace experimenting with ham radio equipment and encountering strange signals from space. It is an inspiring STEM book for young children ages 6-10.
- For older students, consider reading the book Endurance: Shackleton's Incredible Voyage, by Alfred Lansing. It's the harrowing story of the attempt by Shackleton and his crew on the Endurance to reach the South Pole in 1914.

ADDITIONAL RELATED ACTIVITIES IN THE APPENDIX INCLUDE:

- Make Morse code keychains and bookmarks
- Read the article "Why the Navy Sees Morse Code as the Future of Communication"
- Play Battleship game using Morse Code
- Work with the school's art department to design a QSL Card

CODES AND CIPHERS SECTION REVIEW QUESTIONS

Ask the students to answer and discuss the following questions:

- How are ciphers used for encoding and decoding?
    - A 'rotation" number for moving the letters of the alphabet to match in a different way can be created to generate a "secret code".

- How did Morse code transform communication?
    - It guaranteed a solid way to communicate by assigning a code to each letter of the alphabet. It could be written or heard (tapped out).

- What important events were happening at the time that benefited from this invention?
    - Westward migration, transcontinental railroad, civil war
    - World War, emergencies at sea (via radio)

- Where is Morse code used today?
    - Morse code is used in VOR and ILS navigation beacons for aviation, and in the Navy between ships. See extended activity at bottom of page on this article.
    - Assistive Technology
    - Ham operators use Morse code for communication, beacons, and telemetry.

- Have you ever heard someone use words to spell out each letter of a word over the phone because they have a bad connection or because of language barriers?
    - Demonstrate that many letters can sound the same, such as the letters B, C, D, E, G, P, T, V, and Z.

- What was the purpose of the Q Code?
    - Its purpose was to create an international set of codes that everyone could use for radiotelegraph to coordinate transmissions. The Q Code is most popular among Amateur Radio bands.

Software Defined Radio (ARISS Radio Pi)

OVERVIEW

The ARISS Radio Pi introduces the utility of a Software Defined Radio (SDR). It allows for experimentation of radio signals in your neighborhood on a variety of bands and in different modes. Exploration is through listening and visualizing the signals. Ultimately, this can lead to students eventually receiving signals from space, including telemetry from orbiting satellites, weather pictures from space, and images transmitted from the ISS.

A series of YouTube videos explaining some of the many things you can do with the SDR can be found at:
https://www.youtube.com/playlist?list=PL-pgyk1pc4_P2wv84pcIsDarCyM4_H9ni

BY THE END OF THIS LESSON, YOU WILL BE ABLE TO ANSWER:

- What is software defined radio (SDR) and how do you use it?
- What are squelch and noise floor?
- What types of radio transmissions can you receive with software defined radio (SDR)?
- How can the SDR be used to track satellites and view their telemetry?

KEY TERMS

- SDR Dongle
- Web SDR
- Waterfall
- Squelch/Noise Floor
- RF Interference
- APRS and SSTV
- Antenna types - Dipole, directional, and omnidirectional antennas
- Satellite tracking and telemetry- footprint, orbital path, and AOS/LOS

MATERIALS YOU WILL NEED (all in kit)

- ARISS Radio Pi (Raspberry Pi with ARISS memory card)
- Raspberry Pi Keyboard and Mouse
- RTL-SDR Software Defined Radio
- Rabbit Ear Antenna and Stand
- HP Monitor with built-in speakers
- HDMI, Power, and USB Cables
- 50 foot USB extender cable

CONCEPT INTRODUCTION

WHAT IS SOFTWARE DEFINED RADIO?

Traditional radios are hardware-based, using analog components like mixers, modulators, demodulators, and other analog circuits to tune to various frequency ranges. They are by design limited in the frequency ranges they can support without hardware modifications.

In contrast, a Software Defined Radio (SDR) uses software or firmware to tune to various frequencies, offering greater flexibility, configurability, and affordability. SDRs can operate over a very broad range of frequencies. They use an analog "front-end" to handle the RF transmit/receive functions and analog to digital conversion, then use reconfigurable firmware to modulate and demodulate the signals, process them, and deliver them to the user through software. The SDR re-configurability through software and firmware means that it can be easily modified without having to change any hardware!

The first SDR was developed in the early 1980's by the Radio Corporation of America (RCA) but with improvements in digital electronics throughout the past few decades, more sophisticated SDRs are now possible and they are gaining in popularity and use. For example, they are used in cell phones, medical imaging, satellite testing, and military radio applications. Additionally, SDRs are used extensively by amateur radio operators to receive signals because of their flexibility and ease of use.

WHAT IS THE ARISS RADIO PI?

There are many commercially available SDRs these days. For the ARISS SPARKI kit, we us a repurposed digital TV tuner chip (the "RTL" part of the name) coupled with the Software Defined Radio (the "SDR" part of the name). All of this has been packaged into something the size of a USB flash drive! We call this device an RTL-SDR dongle.

For the SPARKI kit, we use a specially designed Raspberry Pi-based stand-alone computer that is pre-loaded with various applications and tools to enable the user to see and interact with different kinds of signals (e.g. NOAA weather radio, AM/FM radio stations, digital data packets from satellites and balloons, etc.). The ARISS Radio Pi doesn't require any connection to the internet, so there should be no fire-wall issues that are sometimes encountered in school settings. ARISS Radio Pi SDR lets users see the "big picture" of radio transmitted signals and allows them to pick signals of interest to investigate.

In the activities that follow we will use several of the applications that come preloaded on the ARISS Radio Pi. They require the ARISS Radio Pi to be properly configured per the directions in the next section, and connected to an antenna. The applications we will investigate include:

WebSDR: Allows the user to tune into, listen to, and explore many different types of RF signals visually on a waterfall display.

FM Broadcast Radio: Allows users to tune into Broadcast FM Radio and to download static Slow Scan Television (SSTV) image signals, including those originating from the ISS

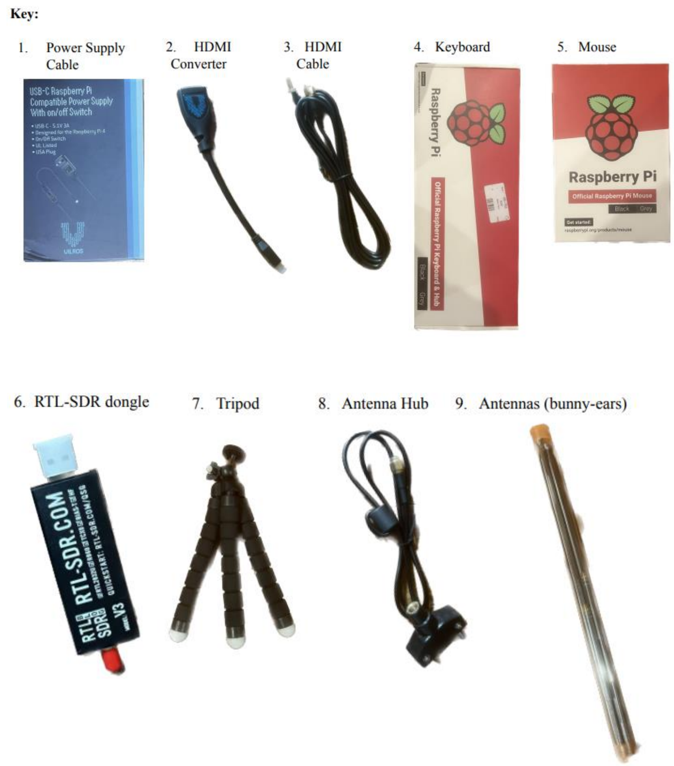
GPredict: A real-time satellite tracking and orbit prediction application

FoxTelem: Receives telemetry information from various spacecraft and decodes it for the user

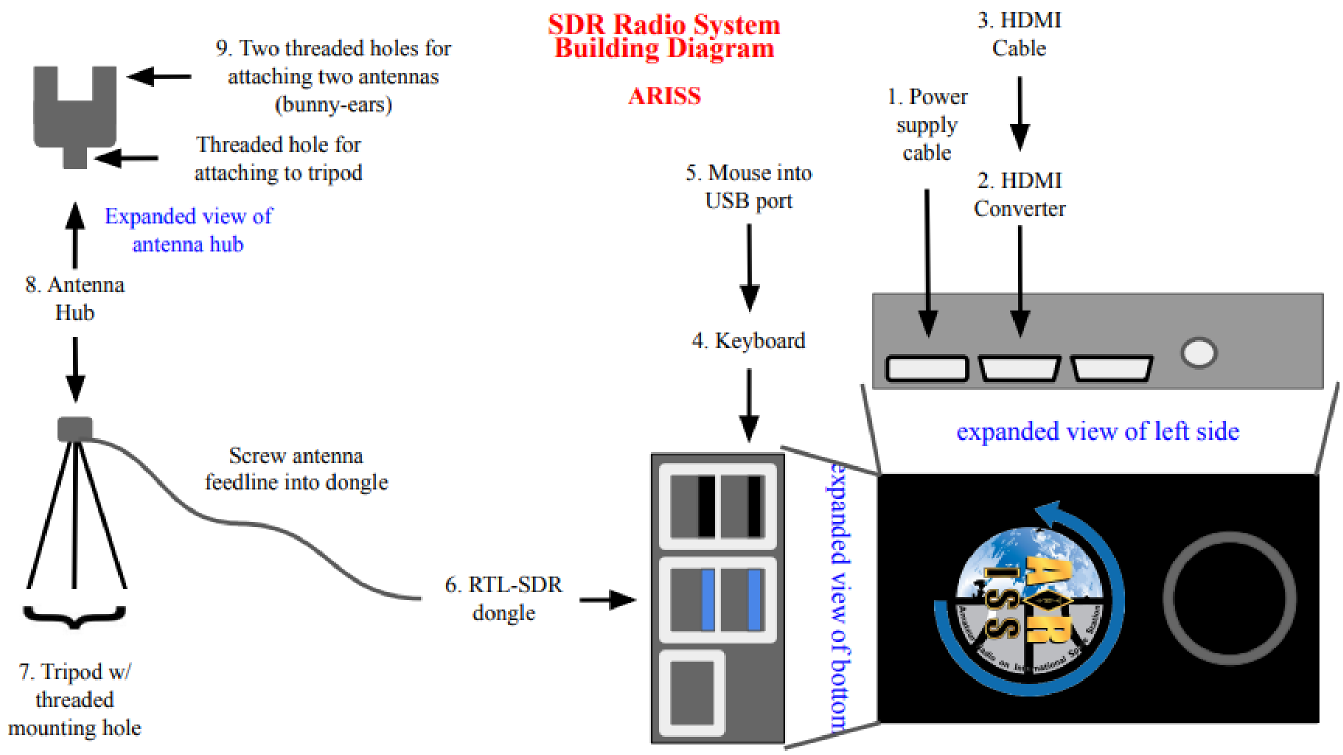
SETTING UP THE ARISS RADIO PI

The following SPARKI kit items make up the ARISS Radio Pi (refer to the numbered diagram below):

1. Raspberry Pi power supply cable with on/off switch
2. HDMI Converter cable (mini to regular, female to female)
3. HDMI Cable (comes with HP Monitor)
4. Raspberry Pi Keyboard with USB hub
5. Raspberry Pi Mouse
6. RTL-SDR dongle
7. Tripod
8. Antenna Hub with feed line
9. Rabbit Ear Antennas (2-sets) (attaches to tripod)
10. Fully configured and programmed Raspberry Pi 4 in a housing with special ARISS Radio Pi software included (not pictured)
11. 50-foot USB extension cable (not pictured)
12. HP 23.8" monitor with speakers (not pictured)



* Note that the kit includes items that aren't used in this setup, including a coax extension cable, and a suction mount for the antenna hub.



ARISS RADIO PI SETUP PROCEDURE

Set up your Radio Pi and antenna by following the steps below and referring to the setup diagram:

1. Identify all the component parts.

2. Plug the power supply cable (1) into the Raspberry Pi (10) *but not into the wall outlet.* As you look at the side of the Raspberry Pi this is the USB C connector (looks like a very flat oval).

3. Plug the HDMI converter (2) into the Raspberry Pi micro HDMI connector next to the power connector. The Raspberry Pi has two HDMI connectors and for the SDR to function properly the micro HDMI converter *must* be plugged into the connector closest to the power connector.

4. Plug the regular HDMI cable that came with the monitor (3) into the other end of the micro HDMI to HDMI converter (2).

5. Plug the free end of the regular HDMI cable (3) into the monitor (12).

6. Plug the Keyboard (4) into one of the USB connectors on the Raspberry Pi (it does not matter which one you use).

7. Plug the Mouse (5) into another USB connector on the Raspberry Pi. It may be more convenient to plug the mouse into one of the USB connectors on the back of the keyboard. Either USB port works fine.

8. Plug the RTL-SDR dongle (6) into a free USB connector on the Raspberry Pi.

9. Thread the antennas (9) into the antenna hub (8), one on each side (use the longer set for better reception).

10. Thread the other side of the antenna hub (8) into the top screw of the tripod (7) and tighten the thumb screw.

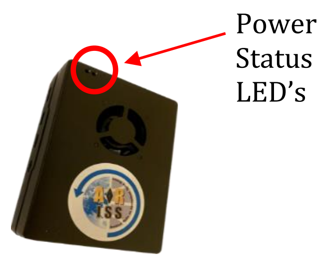
11. Attach the antenna hub (8) feedline coax connector to the antenna connector of the RTL-SDR dongle (6).

12. Set the assembled RTL-SDR and antenna assembly in the nearest window (or feed it through a window and place the antenna outside, if possible).

13. Plug in the HP Monitor and turn it on (bottom right hand side of monitor).

14. Set the monitor source to HDMI.

15. Plug the Raspberry Pi power supply (1) into the wall outlet and use the switch to turn it on. Two LED lights in the Raspberry Pi case indicate when power is on. (The Raspberry Pi may immediately switch on if the switch was previously left in the on position.)

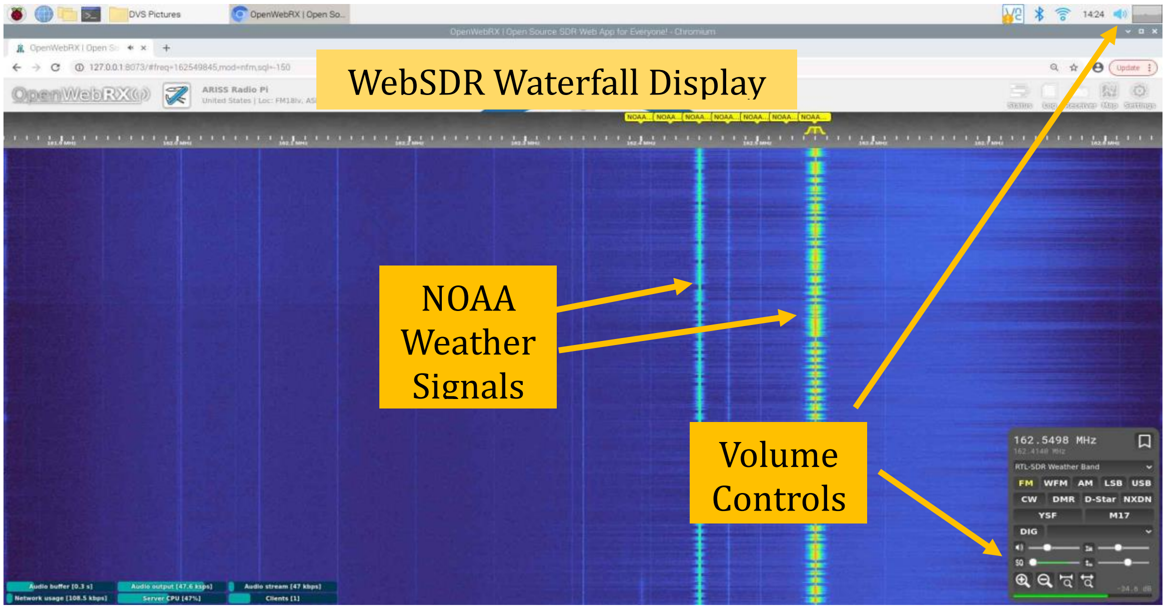


16. Wait for the Raspberry Pi to fully boot up (takes about 80 seconds). It defaults to the WebSDR application. You will know it is fully booted when you see the waterfall display screen as shown on the next page and you hear radio static noise. It defaults to NOAA Weather Radio.

17. Occasionally, settings need to be adjusted to hear the volume. If you don't hear any sound, but are seeing the waterfall display, follow these steps:

    a. The gray controls box in the lower right hand side of the WebSDR screen has volume controls. These include a speaker button, an "SQ" button, and sliders for each. Occasionally, the buttons and/or sliders need to be manipulated to turn on the sound.
    b. If there is still no sound, click on the speaker icon on the upper right hand side of the main Raspberry Pi window and ensure it is not muted and the volume is not turned too low.

c. If there is still no sound, right click on the speaker icon on the upper right hand side of the main Raspberry Pi window and click on "Volume Control Setting". Ensure it is set to HDMI and *not analog.* Left click on the word HDMI if it is not already highlighted.



18. To enable the Raspberry Pi Wi-Fi capability, click the Wi-Fi indicator on the upper right hand side of the screen, ensure it is on, then connect to your Wi-Fi network.

19. A 50 ft. USB extension cable has been provided as an option to allow the RTL-SDR dongle and the antenna to be placed close to a window (or outside) for better reception while the Raspberry Pi and monitor are located at the front of the classroom or teaching space. To use it, plug the USB extension cable into an open USB connector on the Raspberry Pi and then plug the RTL-SDR dongle into the other end.

At this point you should be setup and ready to go. Enjoy your ARISS Radio Pi as you experiment with the following activities!

Exploring the ARISS Radio Pi SDR

Activity 1: Experimenting with the WebSDR Application

The WebSDR app lets users connect to the RTL-SDR functionality through a Chromium web browser using the ARISS Radio Pi to explore various radio frequencies.

1. Setup the Radio Pi per the ARISS Radio Pi Setup Procedure. (Note, the antenna must be attached to receive a signal. With no antenna or SDR dongle attached, an error message will display that says "This receiver is currently unavailable due to technical issues. Error Message: No SDR Devices available".)

2. If the WebSDR application isn't open yet, open it by clicking on its app on the main screen. The app defaults to the NOAA Weather radio frequencies. The shown frequencies are known as Narrow Band FM.


Web SDR

3. Discuss the "Waterfall Display". The waterfall display is a near real-time display of RF signals on a selected range of frequencies. It is called a waterfall because it has the appearance of water going over the edge of a cliff and down to the bottom of the screen. The waterfall is a great way to see where different signals are within a radio band. The presence of a waterfall makes moving around radio bands easier since signals are easy to see. The signals are color-coded to indicate their amplitude, or strength, displayed over time. Weak signals are shown in blue, medium strength signals in yellow, and the strongest signals are shown in red.

4. Discuss the NOAA Weather Channel signals. Try to center the yellow bracket over the top of the strongest signal. The yellow bracket indicates the bandwidth of the given signal, and centering the middle of the bracket on the signal gives the best reception. Note that you can zoom in on various frequencies either using the mouse scroll wheel while the pointer is over the waterfall display, or using the + and – buttons in the gray controls box. This can help you to better center over the strongest part of the signal.
   - ➔ What do you see?
   - ➔ What do you hear?
   - ➔ How does the color change with signal strength?
   - ➔ What happens when you aren't centered on the strongest part of the signal?
   - ➔ What are the different NOAA frequencies?
   - ➔ What frequency has the strongest signal in your area?

5. Discuss Noise Floor and Squelch: RF noise comes from a variety of sources, including thermal noise, atmospheric noise, and noise from other equipment (e.g. RF interference generated by microwaves, motors, electronics, and other man-made items), and this noise is picked up by the antenna. The <u>noise floor</u> is the sum of all these noise sources. A useful signal must be stronger than this noise floor level in order to be heard well. <u>Squelch</u> is used to tune out the

audible noise. It tells the SDR to ignore any signals that are weaker than a given (adjustable) threshold. Without squelch engaged, all the noise is allowed to come through to the speaker. The best practice is to set the squelch just slightly above the noise floor. If the squelch is set too high, than it won't let actual signals through and you won't be able to hear them.

In the WebSDR control box, the squelch ("SQ" button) can be toggled on and off, or adjusted with the slider bar. Pressing the "SQ" button will automatically set the Squelch level.

- ➔ Play with the squelch control to try to eliminate some of the static noise when you are tuned into an interesting frequency.
- ➔ How does the squelch affect the sound?
- ➔ What happens when you set the squelch too high?

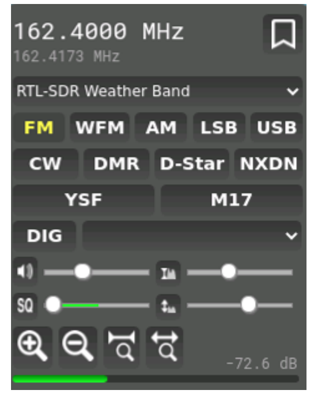
6. Discuss the Radio Frequency (RF) spectrum. The RF spectrum includes frequencies from 30 Hz to 300 GHz. It's divided into several ranges, or bands, as shown in the chart below. The RTL-SDR included with SPARKI is capable of displaying frequencies from 500 kHz to 1.75 GHz. In the US, radio frequencies are divided into licensed and unlicensed bands, with the Federal Communications Commission (FCC) serving as the licensing agency. Devices such as AM/FM radio, cell networks, television, and satellite communications all require licensing to transmit their signals.

Frequency Designation	Frequency Range	Wavelength
Very Low Frequency (VLF)	3 kHz to 30 kHz	100 km to 10 km
Low Frequency (LF)	30 kHz to 300 kHz	10 km to 1 km
Medium Frequency (MF)	300 kHz to 3 MHz	1km to 100 m
High Frequency (HF)	3 MHz to 30 MHz	100 m to 10 m
Very High Frequency (VHF)	30 MHz to 300 MHz	10 m to 1 m
Ultra-high Frequency (UHF)	300 MHz to 3 GHz	1 m to 100 mm
Super-high Frequency (SHF)	3 GHz to 30 GHz	100 mm to 10 mm
Extremely-high Frequency (EHF)	30 GHz to 300 GHz	10 mm to 1 mm

Amateur radio operators frequently use a "band chart" as a cheat-sheet to see at a quick glance which frequency ranges they are permitted to transmit on. (See the "US Amateur Radio Bands Quick Reference Card" included in the SPARKI Kit). Different classes of operator licenses have different operating privileges, with "Technician" class having the least privilege, and "Amateur Extra" class having the most privilege.

Since the SDR only receives signals and doesn't transmit, users can look at all the frequencies that the SDR is capable of displaying!

7. Learn about the various controls in the WebSDR control box. Notice across the top of the screenshot to the right that the SDR is currently tuned to 162.4000 MHz. The indicators "FM", "WFM", "AM", "LSB", etc. are various demodulation methods (see box below for what these designations mean). The WebSDR automatically chooses the best demodulation method for each band, but play with them to see what happens to the sound and signal.
   To change frequency bands, click the down-arrow next to "RTL-SDR Weather Band". Notice the huge listing of possible bands to listen to! Some bands work well with the provided rabbit ear antennas, while others require a more powerful antenna to pick up the signals. Rabbit ear antennas work best for the UHF and VHF frequency bands. Practice tuning into different bands and frequencies.



FM	Frequency Modulation	Commonly used by walkie talkie radios, weather radio, and mos VHF/UHF digfital signals
WFM	Wide Frequency Modulation	Used for Broadcast FM radio stations
AM	Amplitude Modulation	Used by broadcast AM stations that can be received by shorwave radios and used by aircraft and air traffic control
LSB/USB	Lower Side Band/Upper Side Band	Used by the amateur radio community to transmit voice and dta efficiently with small bandwidths
CW	Continuous Wave	Used for listening to Morse Code
DMR	Digital Mobile Radio	Digital Radio Modes
D-Star	Digital Smart Technologies for Amateur Radio	
NXDN	Next Generation Digital Narrowband	
YSF	Yaesu System Fusion	
M17	Open source digital radio mode	

➔ Using the dropdown box, select "RTL-SDR 160m Band HF". Center the yellow bracket over the strongest signals. What do you hear? (AM Radio stations!)

➔ Next, select the "RTL-SDR 70cm Ham Band 435 MHz". Do you see any CubeSatSim signals?

➔ Select the "RTL-SDR FM Band". Can you pick up any FM radio stations?

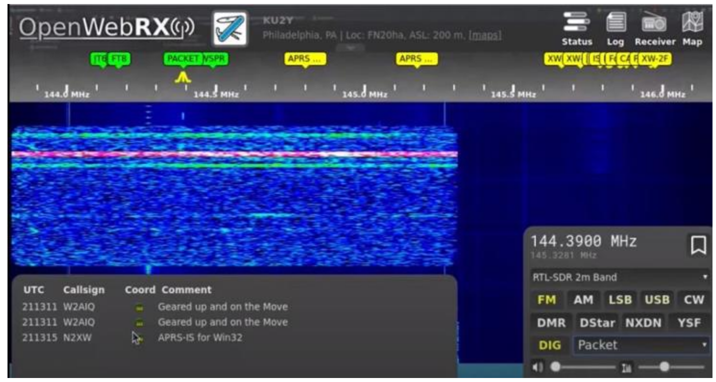
➔ Tune to the range 119 – 136 MHz: Aircraft and (google "airport frequencies" to find the frequencies of the airports in your area. Can you pick up any conversations?

➔ Listen to some signals using the wrong modulation setting. How does this impact their sound? Are they distorted? (For example, try to listen to the NOAA signal with LSB or USB modulation).

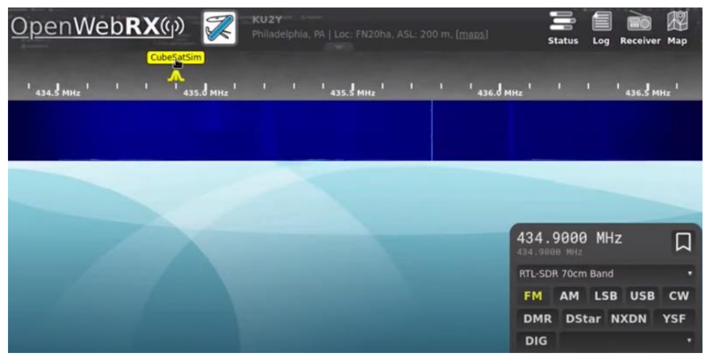
8. Learn about WebSDR digital modes, such as FT8, RTTY, and packet modes like APRS. RF streams can be encoded into data streams creating a category of digital communication options. There are many different digital modes, each with different characteristics and uses. The WebSDR is able to auto-detect many of these digital modes and display the received data on the screen. Digital modes are very efficient in terms of bandwidth and are very effective at relaying complex and detailed messages.
   One such digital communication mode is the Automatic Packet Reporting System (APRS). It's used by Amateur radio operators to send real-time digital data in the local area. It works by sending packets of information such as GPS coordinates, sensor data, text messages, emergency information, and other data to stations in range at a rate of 1200 bits/sec. APRS is frequently used to track high- and mid-altitude balloons used by students to study atmospheric conditions. The balloons are equipped with various sensors, a GPS, and a transmitter.

The WebSDR has built-in APRS decoding, so if a strong APRS packet is detected by the SDR, it is decoded on the screen.

➔ Use the frequency pull-down menu and select the “RTL-SDR 2m Band”. Note the various yellow and green call-out boxes in the frequency bar (e.g. FT8, Packet, APRS, etc.). These are all digital packets that have been detected. Click one of these call-out boxes, such as “PACKET”. If the SDR was able to pick up any digital packets, it would display them in a box such as the one shown in the screen shot here. The displayed data in the lower box includes the callsign of the transmitter along with other pertinent data. Notice what the packet transmissions sound like when they are received, and note the horizontal lines that they generate. They sound very different from audio transmissions.



➔ Note: A CubeSat simulator is needed for this step, as demonstrated in the SPARKI Workshop. (A CubeSat Simulator is a Raspberry Pi-based functional model of a CubeSat satellite that transmits data such as voltage, current, temperature, and other parameters.)
Use the frequency pull-down menu and select “RTL-SDR 70cm Band”. Click on the CubeSatSim yellow call-out box. Note the data that appears when the SDR decodes the transmitted packets.



➔ Watch this brief video. It shows what different types of digital transmissions sound like: https://www.hamradioschool.com/technician-learning (Select “Digital Mode Sounds (vid)” in box 10: “Digital Modes”.

This completes the WebSDR lesson. You may exit the application by clicking the “x” in the upper right hand corner. To power down the Raspberry Pi, click on the Raspberry image in the upper left hand corner, choose “Logout” from the pull-down menu, and then click “Shutdown”.

Activity 2: Experimenting with FM Broadcast Radio and the CubicSDR App

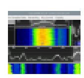
This lesson will discuss wide-band FM broadcasts, like you would hear from your car radio.

The radio from FM is a broadcast station, which is much different than amateur radio. With a wide band FM broadcast station, radio stations send out a large signal across a frequently large, but regional area. FM Broadcast in the United States is between 88.0 - 108.0 Mhz, and is divided into 100 channels, each 200 kHz wide.

FM stands for frequency modulation. FM and AM (amplitude modulation) are types of modulation, or signal encoding. For FM, the signal is changed (modulated) by frequency. For AM, the signal is modulated by changing the amplitude, or overall strength, of the signal. You've probably noticed that FM radio stations tend to have less static than AM radio stations. Since AM radio relies on amplitude to carry the signal, changes in amplitude as the signal is propagating through the air results in static. With an FM broadcast, these slight signal amplitude changes don't affect the signal because it relies on frequency instead of amplitude to carry the signal.

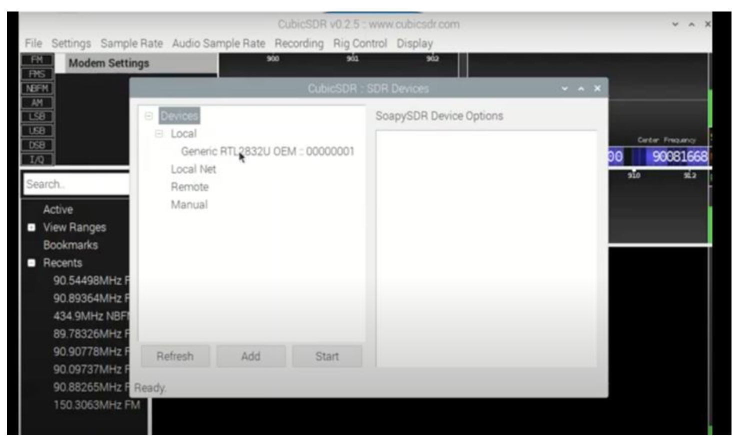
Many amateur radio enthusiasts also use FM to communicate. These FM waves are on a different frequency band (in the 2-meter band around 144 MHz) than FM broadcast radio so as not to interfere.

1. Set up the Radio Pi per the ARISS Radio Pi Setup Procedure and turn on the SDR. Make sure the antenna is also connected.

2. Open the CubicSDR from the Pi screen. 

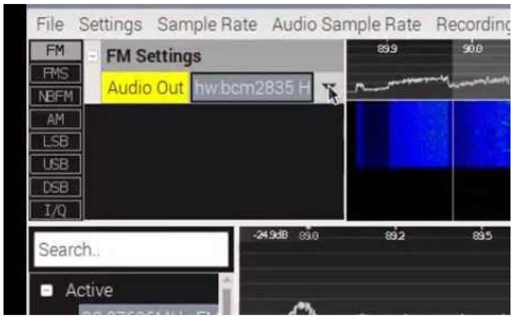
CubicSDR

➔ Select the SDR from the drop down box as shown in the screen shot (there is only one: Generic RTL2832U), then click "start".



➔ This app defaults to the FM band. FM signals are strong and can be heard even deep inside buildings, sometimes even without an antenna.

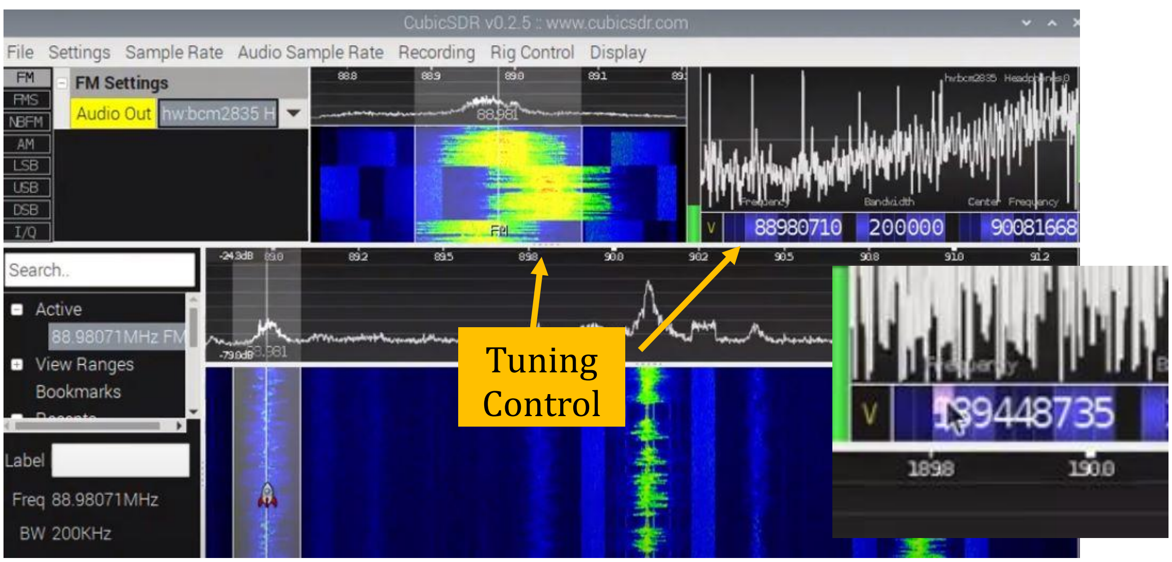
➔ You may also need to adjust your sound output to hear the stations. Go the "Audio Out" drop box in the FM settings window and ensure it is connected to HDMI.



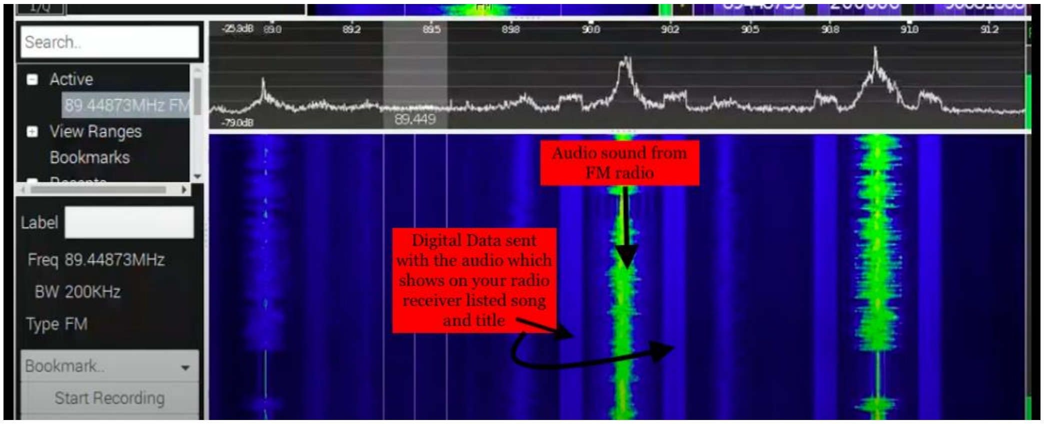
3. Learn about and experiment with the different features that this app provides.

➔ Notice the various peaks in the signal strength window, measured in decibels, and how they coincide with stronger waterfall signals.

➔ Tuning: Move around the waterfall display and tune into various frequencies to hear different radio stations by clicking on them in the bottom waterfall part of the screen. Fine tuning can be accomplished in two ways, as shown in the screenshot below. In the top mini-waterfall window, drag the highlighted window to the left or right to better center the signal. Or for the most precise tuning (i.e. to get to a known radio station in your area) simply adjust the individual numbers themselves, as shown in the zoomed-in inset box below. If you hover just to the left of each number, you will see little boxes appear where each number can be adjusted up or down.



➔ Notice how the waterfall looks slightly different than the waterfall in the previous lesson. It demonstrates how both digital and audio (voice) signals are now transmitted by most radio stations. When viewing the waterfall, you will be able to see both in one area, as shown in this screenshot.



➔ Discuss that many radios now display the title of the song and artist. This information is shared with the radio station. In the image above, the radio station and songs are shown in green. On the side of each major station, there are blue bars to the left and right of the station. These bars are sent to a radio along with the music from the station. The song and artist are sent digitally within these blue bars. The 'blue bar' data is sent on a slightly different frequency (megahertz) than the music itself. If they were both sent at the same frequency, the signals would interfere with each other. When the signal arrives at the radio in your car, the data is decoded into words you can read on your radio (for new radio models) while the music is the audio you can hear.

Activity 3: Investigate Slow Scan Television

This lesson explores narrow band FM broadcasts as are used for Slow Scan Television (SSTV) signals to send encoded pictures.

1. SSTV (also known as narrowband television) is a picture transmission method that is sometimes used by amateur radio operators, who enjoy tracking these types of signals, recording them, then decoding them into static pictures. The ARISS Radio Pi can pick up these signals and display them using the "SSTV Decode" application.

2. SSTV uses frequency modulation (FM). A transmission consists of a series of horizontal lines, scanned from left to right, that when viewed together with decoding software, make up a static image. Each different value of brightness in the image is encoded with a different audio frequency, so for example, the frequency shifts up or down to designate brighter or darker pixels, and the color components are sent separately, one line after another. A single picture may take from 8 seconds to a couple of minutes to fully display, depending on the mode used. In contrast, TV stations broadcast images much more frequently, at 25 to 30 picture frames per second, and those "moving picture" images are also much clearer.
While there are some disadvantages to using SSTV due to the lower picture quality and the time

to receive to receive an image, there are also advantages. SSTV is frequently used by the high altitude balloon community and satellites because it is easier and less expensive to send pictures down using radio waves rather than using other more costly methods.

It's interesting to note that the sound of SSTV is different than the burst of sound from the packet radio in APRS and the music from the FM station or the audio from the NOAA weather station. Different sounds are a result of different types of data being sent.

3. Learn about SSTV on the International Space Station
   ARISS has hardware onboard the ISS that transmits SSTV signals to the ground over its amateur radio equipment about 4 times per year. ARISS announces these events at the following website: http://ariss-sstv.blogspot.com/. You can also find the pertinent frequency information at this site (it is 148.800 MHz), and a link to a gallery where you can submit and view ISS images captured by amateur radio enthusiasts around the world!

   ➔ Discuss this sample SSTV picture sent from the ARISS hardware onboard the International Space Station. What do you notice about it? (Grainy, noise, resolution, etc.)

- ➔ Since SSTV is decoded line by line, starting from the top and moving to the bottom of the image, when there is an interruption in the signal as it is received, any line missed becomes static and cannot be translated. Notice the static in the following picture:

4. Experiment with trying to find SSTV signals with the ARISS Radio Pi

- ➔ Open the "SSTV Decode" app on the SDR. Select "SSTV Test SSTV decoding with WAV file" to see a sample SSTV signal.

WRAP UP

For a refresher on the WebSDR and the CubicSDR apps and the concepts discussed in this section, watch the following two videos on YouTube:

Introduction to the WebSDR on the ARISS Radio Pi:
https://www.youtube.com/watch?v=g_UNOoptDgI&list=PL-pgyk1pc4_P2wv84pclsDarCyM4_H9ni&index=2

Introduction to the CubicSDR in ARISS Pi Radio:
https://www.youtube.com/watch?v=dCSQRiLZ8HQ&list=PL-pgyk1pc4_P2wv84pclsDarCyM4_H9ni&index=3&t=303s

Exploring Antennas

The *antenna* is an important and often overlooked part of any radio system. The purpose of the antenna is to convert the electromagnetic waves we studied in earlier portions of the ARISS SPARKI Kit into electrical currents that are processed by radio, here the RTL-SDR.

Antennas come in many forms. We will focus on the simplest type of antenna, known as dipole antenna. The "rabbit ear" antenna in the SPARKI kit are a type of dipole antenna.

Recall from previous exercises that one characteristic of all radio waves is *wavelength*. Antennas work best when the length of the antenna is a submultiple or a multiple of the wavelength. Specifically, for the *dipole* antenna, the antenna works best when it is ½ of the wavelength of the frequency in question.

Activity 1: Learn to calculate dipole antenna length for best reception

Listen to the weather band around 162.4 MHz (megahertz) using your RTL-SDR and the included rabbit ear (dipole) antennas. For the best reception, it's helpful to know how long each side of the rabbit ears should be adjusted to. The formula for estimating this length is 234/f (where f is the frequency you want to tune to). Note that since there are 2 "ears" on the dipole antennas, each side of the antenna needs to be half the size of the overall calculated length.

<u>Example</u>: If trying to tune to a frequency of 162.4 MHz, the full antenna length should be:

Antenna Length = 234/162.4 = 1.44' (or 17.3")

Each "ear" would need to be half of this, or 17.3"/2 = 8.64"

- ➔ How long would the antenna need to be for the AM Aircraft band at 122 MHz? (Answer: 122/162.4/2=0.375 ft, or 4.5")

- ➔ Practice calculating antenna lengths for other frequencies you might want to explore

Activity 2: Learn about Antenna Directivity

All antennas exhibit something called "directivity" meaning they receive signals from one direction better than others. Some antennas are designed specifically to be omnidirectional, meaning they receive signals equally well in all directions. A dipole antenna, such as the one provided in the SPARKI kit, works best when it is perpendicular to the signal source and worst when either end is pointed directly toward the signal source. For best performance, place the antenna close to a window on the side of the building closest to where the signal is coming from if you happen to know it.

- ➔ Set up the Radio Pi per the ARISS Radio Pi Setup Procedure and start the WebSDR application.
- ➔ With your dipole antenna attached to the ARISS Radio PI, locate a weak signal on the waterfall, one that is light blue or very faint
- ➔ Turn your antenna around slowly in a circle. What happens to the signal strength? Is the signal louder in some directions than others?

Exploring Satellite Tracking and Telemetry Decoding

To be able to track a satellite relative to your location, the computer first must know your latitude and longitude. Probably the easiest way to determine your latitude and longitude is to use an app such as *HamGPS* (free on Android as are others including those for iPhone). Simply start the app and note the longitude and latitude and altitude in meters on the display. Remember that by convention longitudes in the western hemisphere are either indicated with a "W" or a "-" sign. Alternatively, many web pages will look up your location and display it for you. For example, if you go to https://gps-coordinates.org/ and select "Allow", it will display your location.

To locate a satellite in space, some pretty fancy math is involved. The motion of the satellite is described by a set of numbers called the Keplerian elements (named after Johannes Kepler). The numbers are presented in two rows, known as the TLE's (Two Line Elements). The ARISS Radio Pi has a software application called GPredict that does all the math and predicts where a satellite is at any given time relative to your provided location.

Most satellites broadcast signals to tell controllers on the ground how they are doing. This is called telemetry. Some satellites have been built by radio amateurs (for example some CubeSats). They all carry telemetry with data such as temperatures, pressures, error codes, systems health status, etc. FoxTelem is an application on the ARISS Radio Pi that can download and decode this telemetry.

Activity 1: Learn about Satellite Tracking Using the GPredict Application

Watch the YouTube video Introduction to Satellite tracking and Telemetry Decoding on the ARISS Radio Pi: https://www.youtube.com/watch?v=QyDI8LXcU_g&list=PL-pgyk1pc4_P2wv84pcIsDarCyM4_H9ni&index=4

Three terms come into play when tracking satellites:

- Footprint – those points on the surface of the earth that can see the satellite at the same time because they have line-of-sight contact with it.
- AOS (Acquisition of Signal) – when you can first hear the signal from any given satellite
- LOS (Loss of Signal) – the point at which the satellite drops over your horizon and you can no longer hear it

➔ Set up the Radio Pi per the ARISS Radio Pi Setup Procedure and start the GPredict application from the main screen. Note that the program comes loaded with a default set of interesting satellites, but others can be added by the user.

➔ Load your location into GPredict as follows: From the "Edit" tab, select "preferences", then select the "Ground Stations" tab. It shows a default location. Double-click this location, then edit the details, paying particular attention to entering the correct latitude and longitude for your area. When finished, click the “OK” button and “x” out of this window.

- ➔ Next, we need to update the known location of the satellites. If this isn’t done, the program won’t display the accurate position of the satellites. This data is updated every couple of days, and it will be out of date if it hasn’t been recently updated. To accomplish this, from the “Edit” tab, select “Update TLE data from network”, and let the app download the current data. Close the window when it is finished.
- ➔ How many satellites can you see at the current moment from your location?
- ➔ Choose a given satellite to inspect further. How large is its footprint? When will you first see this satellite (AOS)? For about how long will you be able to see it? Can you predict when you will lose its signal (LOS)?
- ➔ Note in the upper right hand corner of the map, the next predicted satellite to pass over your location is shown in green text.

Activity 2: Learn about Satellite Telemetry Decoding Using the FoxTelem Application

In this activity we will learn about the FoxTelem app. It’s an AMSAT (Radio Amateur Satellite Corporation) app that is used to acquire telemetry from a series of AMSAT CubeSats. It’s called “FoxTelem” because the current series of AMSAT satellites are known as the “Fox 1” series.
(Note that this activity requires an Arrow antenna and can’t be done with Rabbit Ears.)


FoxTelem

- ➔ Set up the Radio Pi per the ARISS Radio Pi Setup Procedure and start the FoxTelem application from the main screen.
- ➔ Load your location into FoxTelem as follows: From the “File” tab, select “Setting”. In the Setting window, enter the latitude (“Lat”) and longitude (“Long”) for your location, then press the “Save” button.
- ➔ One nice setting is the “Auto Start” feature in the far right hand box. When this box is checked, the app will automatically begin decoding telemetry when a satellite’s footprint is overhead.
- ➔ Right now AO-91 is probably the easiest satellite to track and decode. It is easier to do if you are outside. Using the Arrow antenna do the following steps.
- ➔ Move to a location where the Arrow with the RTL-SDR attached is outside. The Raspberry Pi, etc. can be inside on the other end of the 50-foot USB extended cable.
- ➔ From GPredict identify the heading and time for both AOS and LOS. Use a road cone or some other object to mark both AOS and LOS headings and locate them about twenty to thirty feet from the position at which you will be standing. It is also useful to place a marker twenty or thirty feet from you at the heading where the satellite or the ISS will be highest in the sky.
- ➔ You will need someone to keep time for you. As AOS approaches, point the antenna at the AOS marker on the horizon. Continue to sweep along the arc between AOS and LOS.

Halfway through the pass you should be at the midpoint marker in the pass. At LOS you should be back to the horizon and the LOS marker.

➔ Click on the AO-91 tab. What do you see? What is the battery voltage on the Z+ axis?

Summary of SDR Section

We have only begun to scratch the surface of the capabilities of the ARISS Radio Pi. We encourage you to explore and see what else you can find within the capabilities of this powerful tool. We welcome your feedback on what you have learned!

Stay tuned for further releases of the software as we continue to develop the ARISS Radio Pi capabilities through your guidance and suggestions.

Appendix

Additional documents as referenced in the lessons are attached here including handouts, online resources, links to YouTube videos, and supporting documents for the radio kit activities.

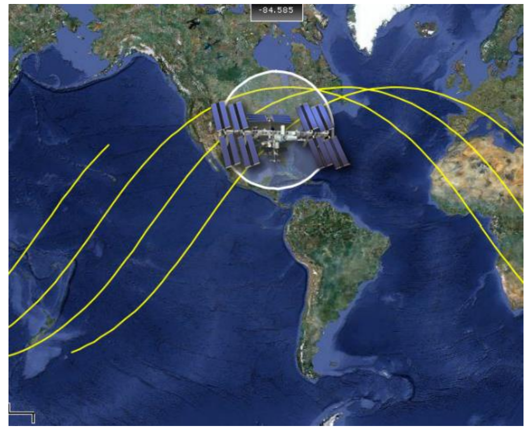
Slinky Wave Demo - Link to Slinky Demo -Written permission to use.
NASA SCaN Interactives on Radio, Communication, and Navigation - https://www.nasa.gov/directorates/heo/scan/communications/outreach/interactive_games
NASA SCaN Lessons - String Can Telephone and Frequency Board https://www.nasa.gov/sites/default/files/atoms/files/scan_activities.pdf
Waves Scavenger Hunt https://www.nasa.gov/sites/default/files/atoms/files/scan_scavenger_hunt_and_coloring_page.pdf
NASA SCaN - LIVE data transmissions are shown here in real-time for the Near Earth Network, Deep Space Network, and Space Network. https://scan-now.gsfc.nasa.gov/
***ARRL Education* Activities** - This link is provided by the national organization for Amateur Radio. http://www.arrl.org/home
Morse Code Bookmark and Keychain Lesson (Original documents and Instructional Slides)

Additional educational content may be found at the following link:
https://ariss-usa.org/educational-content/

Contact diana.schuler@ariss-usa.org if you have any questions.

ARISS Contact Proposal Information

What is an ARISS Contact



An ARISS contact is a voice communication via Amateur Radio between the International Space Station (ISS) crew and classrooms and communities throughout the world. ARISS contacts allow education audiences to learn firsthand from astronauts what it is like to work and live in space. These scheduled contact opportunities are offered to formal and informal education institutions and organizations, individually or working together. The radio contacts are approximately 10 minutes in length due to the radio communication window permitted by the logistics of orbital passes of the ISS. During the contact, students interact directly with astronauts and cosmonauts in space using a question and answer format. For many who participate (both students and staff), it is an incredibly rewarding, inspiring, and emotional experience. While the ISS contact itself only lasts about 10 minutes, the entire process from start to finish requires a commitment of about 9 to 12 months.

How to Apply

Twice each year (typically October/November and February/March), ARISS opens up a proposal window during which schools, libraries, museums, scout groups, or other organizations may apply for an ARISS contact. The proposals are reviewed by educators who have conducted ARISS contacts in the past with their schools/organizations and selections are based on many factors.

Each proposal includes three basic sections:
- Who: Who will be involved in the activity?
- Why: Why is your organization interested in this project?
- How: How will you organize the educational opportunity?

The reviewers are looking for proposals that include 1) an effective education plan that lays out semester or year-long learning goals, 2) evidence of a team approach since the logistics to pull off a contact requires help from a local ham community and buy in from many individuals, including administrative, IT, and facility staff, 3) proposals that make the 10-minute contact experience a broad event (think full-school/full district/full community event, larger scale than just a single class/grade complete with Media Outreach).

Things to consider
- What's your schedule like? Are you wanting to do the contact during the school year? Summer? Do you have a specific day/week in mind? The more flexible you are, the better!
- Do you want to do a direct or a telebridge contact? In a direct radio contact, the ISS is passing directly over your venue at the time of the contact. This type of contact requires an amateur radio station at your location to receive the radio signals. In a telebridge radio contact, the contact is made while the ISS passes over the telebridge ground stations in other parts of the world. Host organizations connect to the remote amateur radio station by either telephone line or an internet bridge. Both provide hands-on radio experience and a one-on-one dialog with an ISS crewmember.
- How can you get others involved in this opportunity?
- As much information should be included in each section as possible.
- Letters of interest from outside organizations to show their interest in supporting you with your contact are very helpful.

Examples of STEM/STEAM Activities for Education Plans

There are many types of activities/investigations that can be included in an education plan. Here are just a few examples: study radio technology; work with electronics kits; space exploration and space science research; physics; satellite communications and satellite orbits; space art.

ARISS Proposal Website

For further details of the ARISS Proposal process, including a Proposal Guide and Proposal Form, please visit the following website: https://ariss-usa.org/proposal-forms/

SPARKI RESOURCE LIST

Following is a listing of sources to purchase additional components of the SPARKI kit:

A complete kit may be purchased from ARISS for $1K by contacting diana.schuler@ariss-usa.org.

ITEM	SOURCE	APPROX COST ($)
Raspberry Pi Keyboard	Vilros.com https://vilros.com/products/raspberry-pi-keyboard-and-hub	17
Raspberry Pi Keyboard	Viros.com https://vilros.com/products/official-raspberry-pi-mouse-red-white	9
Snap Circuit SC-300	Amazon.com https://www.amazon.com/Snap-Circuits-SC-300-Electronics-Exploration/dp/B0000683A4/ref=sxts_b2b_sx_reorder_acb_customer?content-id=amzn1.sym.44ecadb3-1930-4ae5-8e7f-c0670e7d86ce%3Aamzn1.sym.44ecadb3-1930-4ae5-8e7f-c0670e7d86ce&crid=2LK50MZYGJF3I&cv_ct_cx=snap+circuit+300&keywords=snap+circuit+300&pd_rd_i=B0000683A4&pd_rd_r=2c24ee6f-80d8-4129-a3fb-47c3b238a8ad&pd_rd_w=obi4D&pd_rd_wg=MFBk4&pf_rd_p=44ecadb3-1930-4ae5-8e7f-c0670e7d86ce&pf_rd_r=D4VST25EQF0FHAZGEHJR&qid=1686841580&sprefix=snap+circuit+300%2Caps%2C117&sr=1-1-62d64017-76a9-4f2a-8002-d7ec97456eea	62
Morse Code Key	https://www.amazon.com/United-Scientific-Supplies-TGKY01-Telegraph/dp/B01MT3T676/ref=sxts_b2b_sx_reorder_acb_customer?content-id=amzn1.sym.44ecadb3-1930-4ae5-8e7f-c0670e7d86ce%3Aamzn1.sym.44ecadb3-1930-4ae5-8e7f-c0670e7d86ce&crid=2HV2R80AURKKS&cv_ct_cx=morse+code+key&keywords=morse+code+key&pd_rd_i=B01MT3T676&pd_rd_r=77b6deee-4c90-4763-964d-3a5b88b87d1f&pd_rd_w=vly0T&pd_rd_wg=vdmBb&pf_rd_p=44ecadb3-1930-4ae5-8e7f-c0670e7d86ce&pf_rd_r=7Q7ZWME3Q1ZAKWN5K7X3&qid	6

	=1686841454&sprefix=morse+code+key%2Caps%2C98&sr=1-1-62d64017-76a9-4f2a-8002-d7ec97456eea	
Snap to Banana connectors	Elenco: https://elenco.shptron.com/p/snap-to-banana-plug-red https://elenco.shptron.com/p/snap-to-banana-plug-black	3
Long Helical Spring/Coil (Snaky)	Arbor Scientific: https://www.arborsci.com/products/helical-spring	20
Slinky	Amazon https://www.amazon.com/Original-Slinky-Walking-Spring-Slinkys/dp/B08GHB4BGB/ref=sxts_b2b_sx_reorder_acb_customer?content-id=amzn1.sym.44ecadb3-1930-4ae5-8e7f-c0670e7d86ce%3Aamzn1.sym.44ecadb3-1930-4ae5-8e7f-c0670e7d86ce&cv_ct_cx=slinky&keywords=slinky&pd_rd_i=B08GHB4BGB&pd_rd_r=c42a5375-d2db-46f4-8cf4-473f4b6bf002&pd_rd_w=lck5o&pd_rd_wg=hr0ss&pf_rd_p=44ecadb3-1930-4ae5-8e7f-c0670e7d86ce&pf_rd_r=2AKA0R2PB5HC6YYGFHW4&qid=1686841980&sr=1-1-62d64017-76a9-4f2a-8002-d7ec97456eea	3 for $10
HP 23.8" Monitor	Amazon https://www.amazon.com/gp/product/B072M34RQC/ref=ppx_yo_dt_b_asin_title_o02_s00?ie=UTF8&psc=1	230
ARISS RADIO PI (Includes Raspberry Pi pre-loaded with ARISS software, SDR dongle + antenna kit)	ARISS (Website TBD) Contact diana.schuler@ariss-usa.org for further information.	Cost TBD

What is Amateur Radio, and How to Get Your License

What is Amateur Radio

Amateur Radio, otherwise known as ham radio, is a popular hobby for enthusiasts ("hams") of all ages. Many children under the age of 10 have even become licensed ham radio operators! People use ham radio to communicate with others all around the world mostly just for fun and as an educational activity. But ham radio also has an important use in emergency situations are in remote areas where other forms of communication aren't available.

Anyone can receive radio frequency signals on their equipment without being licensed. The activities in our Software Defined Radio (SDR) section are examples of this kind of activity that does not require a license. However, if one wishes to be able to transmit over radio frequencies, one must first become licensed by the Federal Communications Commission (FCC). ARISS contacts require a licensed ham radio operator since they involve two-way communications between earth and the spacecraft (transmit and receive). Typically for an ARISS contact, the school or informal education setting coordinates with a local amateur radio organization to facilitate the contact and to properly configure all associated hardware and software components (for example, having an antenna mounted on top of the school building).

Here is an excellent Amateur Radio Relay League (ARRL) video describing ham radio that you can show your students:
https://www.youtube.com/watch?v=wDn-6SDxyD4&t=41s

Amateur Radio Licensing

The basic requirements to become licensed include having a valid US mailing address, a valid Social Security Number (SSN), and registering for an FCC Registration Number (FRN). The following website contains instructions about how to get an FRN:
https://www.fcc.gov/wireless/support/knowledge-base/universal-licensing-system-uls-resources/getting-fcc-registration.
The FRN registration process must be completed prior to taking the licensing exam.

Each candidate must pass the necessary licensing exam for the level that they wish to achieve. The FCC offers 3 license classes as follows:

1. Technician License;
2. General License; and

3. Amateur Extra

Each of these levels builds on the previous in terms of required knowledge, and authorizes transmitting on more frequencies and with greater transmitting power (i.e. provides more operating privileges). The Technician license is a great way to begin and provides sufficient operating privileges for many ham operators for many years of fun!

There is a $15 fee to take the exam, and a $35 fee to register with the FCC for an FRN as of this writing. Children under 18 are eligible for a reduced exam fee of $5.

It is permissible to take multiple license level exams in the same day for no additional fee, assuming each preceding level is passed satisfactorily. The exams are administered by a team of volunteer examiners (VE's). Assistance in finding a VE team in your area can be found at the following website:

https://www.fcc.gov/wireless/bureau-divisions/mobility-division/amateur-radio-service/volunteer-examiner-coordinators

The Technician test consists of 35 questions that are drawn from a pool of approximately 450 questions. A passing score of 74% is required (i.e. 26 correctly answered questions). There are many approaches to studying for the exam. Some people choose to take licensing classes offered in their area. Others study on their own with books from the library, a bookstore, or Amazon. It's important to take several practice exams to get a feel for what the exams are like. The pool of questions doesn't change for any given year, so many of the correct answers began to appear familiar just through practicing! The pool of questions can also be downloaded from the ARRL website. Check out the ARRL Licensing, Education, & Training website for more information: http://www.arrl.org/licensing-education-training

A great benefit of becoming licensed amateur radio operators is that ARRL funds over 100 college scholarships each year, ranging from $500 to $25,000! See the following website for more information: http://www.arrl.org/scholarship-program.

Another Great Teacher Resource: ARRL Teacher Institute on Wireless Technology

ARRL offers an expenses-paid professional development program for teachers to learn about wireless technology so they can pass this knowledge on to their students. It includes lectures, hands-on activities, and demonstrations to equip teachers with tools and strategies

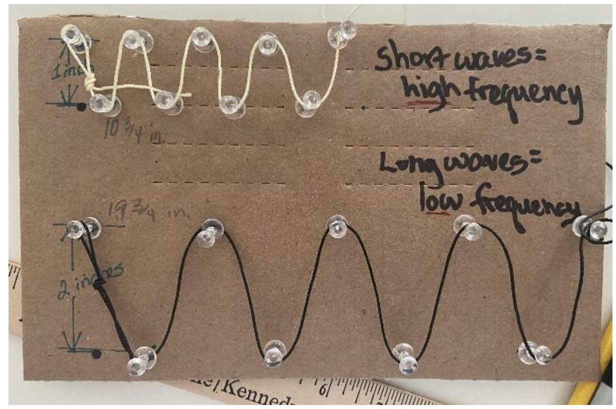
to introduce their students to basic electronics, radio science, satellite communications, Amateur Radio, weather science, microcontrollers, and electronic sensors. More information on this program can be found at the following website:
http://www.arrl.org/teachers-institute-on-wireless-technology

Frequency Board Experiment

Purpose: To understand waves and wavelengths and to demonstrate the difference between high and low frequency.

Materials

- Foam board or cardboard (about 15 cm x 30 cm)
- 18 pushpins
- About 1 meter of string or yarn
- Ruler



Sample

SETUP AND PROCEDURE

- On a small foam board or cardboard as shown in the picture, use an equal amount of pushpins to make 2 sets of staggered parallel lines. Place one set of pushpins further apart horizontally than the other set to demonstrate a longer wavelength. Try to keep the vertical distance between both sets of pushpins the same (i.e. the amplitude of the wave). Use an equal amount of wave cycles for both the low and high frequency models. (The example shown models 4 wave cycles using 9 pushpins for each set of waves.)

- Use string or yarn to create the waves for each set of lines by attaching the string to the first pushpin by making a loop, and then winding it around the pushpins to form the waves.

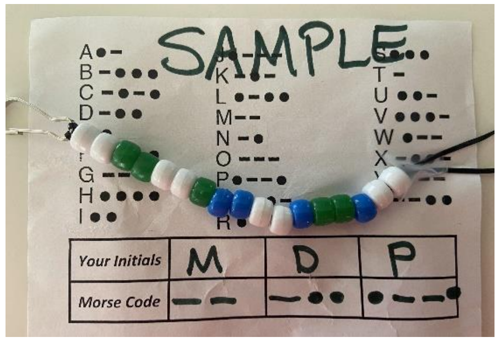
- Unwind both pieces of string and measure each of their lengths (for the 4 waves) to the nearest centimeter. A complete wave cycle (or wavelength) travels from peak to valley to peak.

Consider the following questions:

- How many complete wavelengths are represented in this model? (4 complete cycles)
- How far did the signal travel in the model for the short wave at 4 cycles? (measure the string in centimeters)
- How far did the signal travel in the model for the long wave at 4 cycles? (measure the string in centimeters)
- How can you calculate the wavelength for each of these waves? (Measure the length of one complete wave cycle.)
- Examine the relationship between wavelength and frequency, noting that the longer waves produce a lower frequency (less frequent) than the shorter waves. Short waves occur more frequently so that makes them higher frequency.
- In the model you created, notice the difference in distance that each wave travelled. What implications does wavelength have for using a radio? (longer wavelengths travel further)

Morse Code Keychain and Bookmark

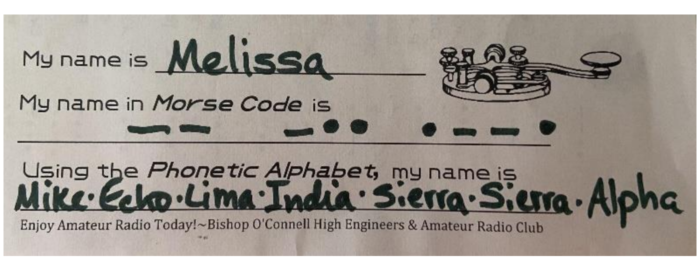
MATERIALS - 3 colors of beads (enough of each color for each students name), 24 inches of string or cord, and a paperclip.

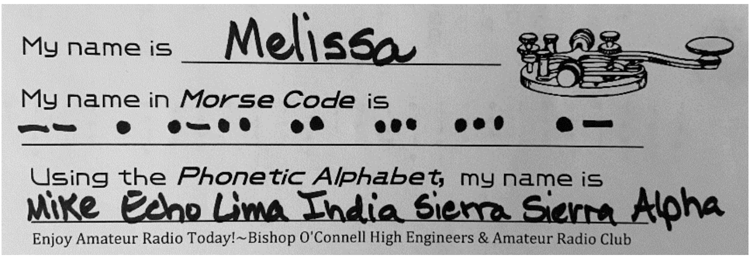


Start with 3 colors of beads and a string or cord. It is also nice to have some sort of hook, fastener, carabiner, metal loop, or paperclip for attaching to keys or backpack.
Use one color for spaces (something neutral like clear or white), one color for dots, and one color for dashes. It is fun to choose a color theme, your school colors, or something planetary like...

- ***Earth*** - blue and green with white or clear spacers
- **Moon** - black and grey with white or clear spacers
- **MARS** - red and grey with white or clear spacers

Also included is a template for a bookmark for more practice with Morse code and using the phonetic alphabet with the letters of your name. First have students use a highlighter to mark the phonetic words that match the letters of their first name. After practice saying it, they can write this on the other side and translate their name to Morse code. This template can also be customized to include your school mascot to make it more personal and fun!





A •–	J •–––	S •••
B –•••	K –•–	T –
C –•–•	L •–••	U ••–
D –••	M ––	V •••–
E •	N –•	W •––
F ••–•	O –––	X –••–
G ––•	P •––•	Y –•––
H ••••	Q ––•–	Z ––••
I ••	R •–•	

Your Initials			
Morse Code			

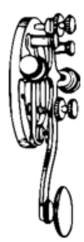
A •–	J •–––	S •••
B –•••	K –•–	T –
C –•–•	L •–••	U ••–
D –••	M ––	V •••–
E •	N –•	W •––
F ••–•	O –––	X –••–
G ––•	P •––•	Y –•––
H ••••	Q ––•–	Z ––••
I ••	R •–•	

Your Initials			
Morse Code			

My name is ______________

My name in *Morse Code* is ______________

Using the *Phonetic Alphabet*, my name is ______________



Alpha	•–
Bravo	–•••
Charlie	–•–•
Delta	–••
Echo	•
Foxtrot	••–•
Golf	––•
Hotel	••••
India	••
Juliet	•–––
Kilo	–•–
Lima	•–••
Mike	––
November	–•
Oscar	–––
Papa	•––•
Quebec	––•–
Romeo	•–•
Sierra	•••
Tango	–
Uniform	••–
Victor	•••–
Whiskey	•––
X-ray	–••–
Yankee	–•––
Zulu	––••

Article: "Why the Navy Sees Morse Code as the Future of Communication"

Read the article linked below to get an overview of how sailors can use light pulses for emergency communication.
https://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/15283/Why-the-Navy-Sees-Morse-Code-as-the-Future-of-Communication.aspx

History of Signal Lamps: The Navy and sailors at sea all over the world for that matter, have long incorporated signal lamps into their communication network. A large lamp is used to flash light in patterns by opening and closing a shutter on the lamp. Sailors would then use binoculars to decode the words and a signalman would translate the Morse Light Code to text. Later, algorithms were developed so high speed communication could occur using methods that are still used today to decode light pulses. Not only naval vessels use light for communication, but airports and pilots do as well. For example, airport control towers are equipped with basic words for emergencies using color signals for land, stop, or clearance, in the event an aircraft has a complete radio failure.
Other technology innovations in translating Morse Light Code include using a video camera to decode data instead of a human decoding through binoculars. A GoPro camera can be used now to interface receiving light flashes as fast as you can text. This is a current solution for naval communications and emergency system management in the event of radio failure and it improves the speed of communication and efficiency to respond in an emergency.

- Have you ever flashed a light switch to get someone's attention?
- Have you ever been to an actual lighthouse?
- Have you ever heard of "smoke signals"?
- Do you think sending an emergency in text or Morse Code is faster if the receiver had both capabilities? The answer is referenced in the article and can be asked again to students after reviewing the article,
- Answer-shorter words using Morse Code means that a sailor can send the transmission even faster by shortening his sentences to a few letters in Morse Code. So if you were to use TEXT for data communications in addition to Morse Code, you can shorten your transmission time and response even further.

Morse Code Battleship Game

https://www.sarcnet.org/morse-code-battleships-game.html

[This site is a free on-line resource for anyone associated with or thinking about setting up a School Amateur Radio Club. That is, a fun, school lunch-time activity for a select group of students, who would rather be tinkering with electronic gadgets and exploring the air waves than dodging footballs or watching cricket.

School Amateur Radio Clubs are a neat way to get in an extra shot of Science, Technology, Engineering and Mathematics (STEM) while exercising your on-air conversational skills and tuning up your enquiring minds. This site is for school principals, teachers, parents, students and amateur radio enthusiasts. It provides inspiration, ideas, articles, news and activities all free to download, modify and use as you wish.]

Imagine you're in the communications center (COMCEN) of a real battleship: It is a US DDG class Guided Missile Destroyer. It is your job to send missile launch commands to the fleet using Morse code. You better get this right or else those missiles won't hit their targets. Watch out for reports of incoming missiles too. "All hands. Battle Stations. Battle Stations. We're under attack."

Introduction

Radio telegraphy using Morse code was vital during World War II, especially in carrying messages between the warships and the naval bases. Long-range ship-to-ship communication was by radio telegraphy, using encrypted messages, because the voice radio systems on ships then were quite limited in both their range and their security.

Preparation

Two teams sit facing each other in a room. Each team has a Morse code practice key and a playing board as shown below. Members of each team take turns to send launch codes to the other team.

	1 •————	2 ••———	3 •••——	4 ••••—	5 •••••	6 —••••	7 ——•••	8 ———••	9 ————•	0 —————
A •—										
B —•••										
C —•—•										
D —••										
E •										
F ••—•										
G ——•										
H ••••										
I ••										
J •———										
K —•—										
L •—••										
M ——										
N —•										
O ———										
P •——•										
Q ——•—										
R •—•										
S •••										
T —										
U ••—										
V •••—										
W •——										
X —••—										
Y —•——										
Z ——••										

Play

Each team secretly places 5 battleships (marked with an X) randomly on their grid (A-Z, 0-9) above. Toss a coin to see who goes first.

Take turns to:

1. Send a grid square to attack. E.g. "C3".
2. Any enemy battleships in that square and in the 8 adjacent squares will be destroyed
3. Color in all 9 squares you have attacked with any color pencil or marker.
4. Wait for a report to see what happened…

5. Receive each grid square of any battleships sunk: E.g. "B2", "D4" or "." ●–●–●– for a total miss.
6. Draw a circle "O" in the grid square of any battleship sunk
7. Receive the grid square of incoming missiles. Any of your ships in that square and in the 8 adjacent squares will be sunk.
8. Send the damage report: The grid squares of each sunk vessel or "." ●–●–●– for a total miss.

Play at home with your friends and family:

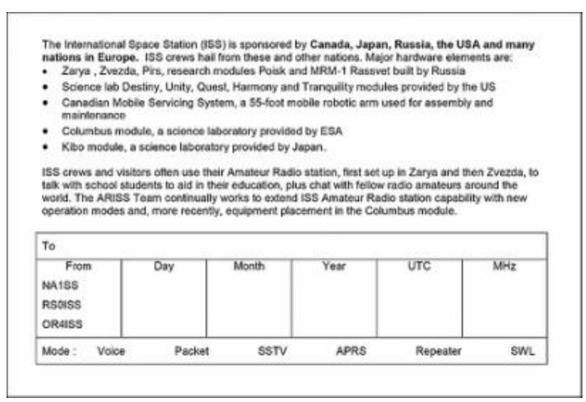
Copy the playing board and have a game with your friends and members of your family. If you don't have a Morse code key practice set, you can use a whistle or flashlight instead. There are also easy-to-make clothespin Morse code practice key projects online that you can make at home with simple supplies from around the house.

Coding Online

For practice with coding, try an online platform with multiple languages. You can use a drag and drop interface to practice using Python and Java on sites like **MakeCode.org** (click on **MicroBit**) or **Scratch.mit.edu**. This allows students to make the connection on how code can be used with software programming. The drag and drop ability provides an easy way to link actions/commands together like puzzle pieces in a sequential order while seeing the output of your code in the same window. MakeCode.org includes virtual hardware (MicroBit) that has two virtual input buttons, 20 LED lights, light sensor, radio & bluetooth, compass, accelerometer, and more to help you create amazing code! Scratch includes an output window that focuses on building a character and creating interaction between the character and elements you create.

Design a QSL card Activity

A QSL card is a uniquely designed postcard that Amateur Radio operators (hams) can exchange in the mail for fun when they first make contact with another ham, proving that the contact was made. Engage your students' inner artists or maybe your art department and have them design a QSL card for your school! Each card should be roughly 140mm x 90mm (3.5" x 5") and should include a call sign, name and postal address, including country. The cards normally detail the band or frequency that was used, along with the time and date of the contact. Search "QSL Card examples" in any web browser for many examples. Here are the front and back of the ARISS QSL cards:


The International Space Station (ISS) is sponsored by **Canada, Japan, Russia, the USA and many nations in Europe.** ISS crews hail from these and other nations. Major hardware elements are:

- Zarya , Zvezda, Pirs, research modules Poisk and MRM-1 Rassvet built by Russia
- Science lab Destiny, Unity, Quest, Harmony and Tranquility modules provided by the US
- Canadian Mobile Servicing System, a 55-foot mobile robotic arm used for assembly and maintenance
- Columbus module, a science laboratory provided by ESA
- Kibo module, a science laboratory provided by Japan.

ISS crews and visitors often use their Amateur Radio station, first set up in Zarya and then Zvezda, to talk with school students to aid in their education, plus chat with fellow radio amateurs around the world. The ARISS Team continually works to extend ISS Amateur Radio station capability with new operation modes and, more recently, equipment placement in the Columbus module.

To					
From NA1SS RS0ISS OR4ISS	Day	Month	Year	UTC	MHz
Mode : Voice	Packet	SSTV	APRS	Repeater	SWL

The ARISS-USA Radio Experimenters Kit team wishes to recognize and extend our appreciation to the ARISS-USA national and international partners and sponsors. This initiative would not have been successful without your ideas and encouragement.

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Amateur Radio Leadership

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