Submarine Force Museum Lesson Plan

Lesson Name: Electromagnetic Waves & Submarine Antennas
Number of minutes in the Lesson: 45

Intended Audience: Grade School/Middle School/High School

Content Standards (NGSS):

Elementary School (K-5), PS-4 Waves: Light and Sound. 1- Waves: Light and Sound; 4-Waves; K-2 and 3-5 Engineering Design

Middle School, MS PS-4-1, 2, 3; Waves and Electromagnetism. A- Wave Properties; B- EM Radiation; C- IT and Instrumentation

High School, HS PS-4-1, 2, 3, 4, 5; Waves and Electromagnetism. A- Wave Properties; B-EM Radiation; C-IT and Instrumentation

Pre-Visit Materials/Activities: Elementary knowledge of light and sound.

Students who demonstrate understanding can already:

1-PS4-1. **Plan and conduct investigations to provide evidence that vibrating materials can make sound and that sound can make materials vibrate.**

1-PS4-2. **Make observations to construct an evidence-based account that objects in darkness can be seen only when illuminated.**

1-PS4-3. **Plan and conduct investigations to determine the effect of placing objects made with different materials in the path of a beam of light.** Examples of materials could include those that are transparent (clear plastic), translucent (wax paper), opaque (cardboard), and reflective (a mirror).

1-PS4-4. **Use tools and materials to design and build a device that uses light or sound to solve the problem of communicating over a distance.*** Examples of devices could include a light source to send signals, paper cup and string "telephones," and a pattern of drum beats.

4-PS4-1. **Develop a model of waves to describe patterns in terms of amplitude and wavelength and that waves can cause objects to move.** Examples of models could include diagrams, analogies, and physical models using wire to illustrate wavelength and amplitude of waves.

4-PS4-3. **Generate and compare multiple solutions that use patterns to transfer information.** Examples of solutions could include drums sending coded information through sound waves, using a grid of 1's and 0's representing black and white to send information about a picture, and using Morse code to send text.

Set up Before the Lesson Begins: Tour of Submarine Force Museum, or be ready to conduct a virtual tour online at http://www.ussnautilus.org/virtualTour/index.shtml . This could be done as a homework assignment. Then be ready to introduce the basic types of electromagnetic energy in class. It is more than visible light, but a whole range of wavelengths and frequencies, all moving at the speed of light: Radio, Microwave, Infrared, Visible, Ultraviolet, X-ray, Gamma Ray.

Content Objective(s): Differentiate between Sound Waves and Electromagnetic Waves of Different Types, relative to use on a submarine.

Language Objective(s): Describe sound and light waves in pictures, words, and mathematical form, including sine waves, frequency, wavelength, amplitude, and wave speed.

Differentiation: Think about:

Students with special needs How will you differentiate this lesson for special education and gifted students.

Regular education students: Think about how you would differentiate the lesson for all students on all levels.

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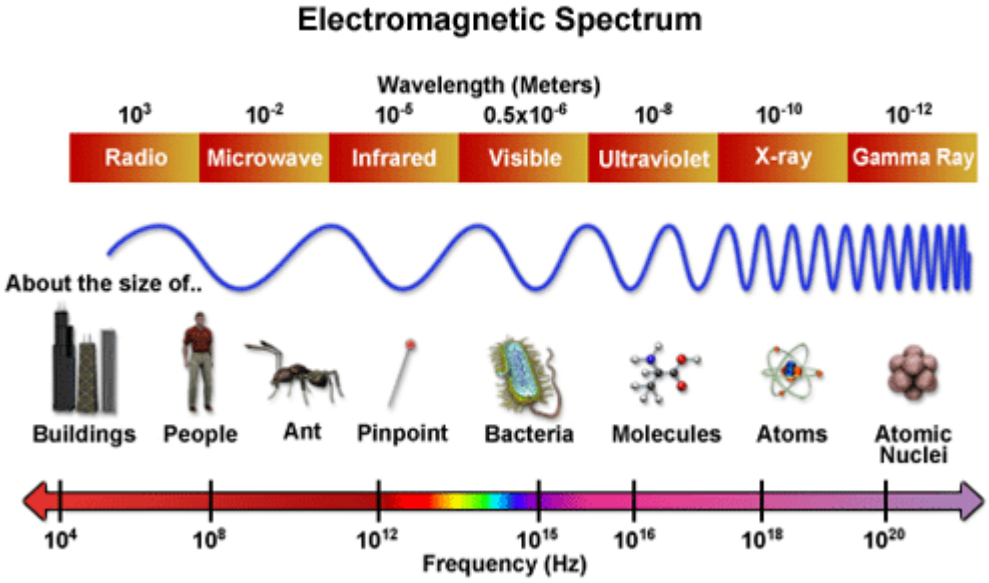
Sheltered Instruction Observation Protocol (SIOP) Strategies for ELL and regular Ed Students:
Identify the S.I.O.P features that support English Learners and all learners including thorough and accurate explanations on how they will assist English Learners. Identify Sheltered Instruction strategies throughout the lesson.

- Preparation
- Building Background
- Comprehensible Input
- Strategies
- Interaction
- Practice/Application
- Lesson Delivery and Review/Assessment

Initiation: **Review the general types of electromagnetic waves, and**
Wave length equals peak to peak distance of the oscillating wave, and
Frequency is the number of waves per second passing a point, and
All forms of light have names, and are all electromagnetic waves, and
The speed of light = wave length times frequency, is constant for a given medium (such as outer space, in air, in water, or in other transparent materials)



Lesson Development:

Performance Tasks:

1. **How can humans detect electromagnetic waves? Sound waves?**
2. **How do submarines detect electromagnetic waves? Sound waves?**

Teaching and Learning Strategy:
View the "sail" of the submarine USS *Nautilus* (SSN 571)

Do any of the raised masts look like they can detect electromagnetic waves?

Do any masts look like they can make electromagnetic waves?

View the panel by Nautilus, copied below:

Masts that only detect EM waves: 4, 5, 7, 10
Masts that only generate EM waves: 14
Mast the detect and generate EM waves: 3, 6, 8, 9, 11, 13
Masts that do not detect/generate EM waves: 1, 2, 12, 15, 16, 17
(NOTE: the bell 15 and whistle 17 generate sound waves)

Monitoring and Adjusting:

1. **Describe which masts need the human eye to detect the EM wave <u>inside</u> the submarine?**
2. **What do all the masts and antennas have in common, regarding visible light?**
3. **Do you think any *Nautilus* masts detect infrared, ultra-violet, x-rays or gamma rays?**
4. **Do you think today's submarines can detect infrared and ultra-violet rays? Why?**
5. **Are there detectors that can detect x-rays and gamma rays? Why? Where could these rays come from?**
6. **Why does the submarine sail look black? Why are the masts painted gray with black spots?**

Assessment: Draw a submarine sail for a newer submarine, and the types of masts and antennas it should have for the 21st Century.

Closure: How do you use electromagnetic and sound waves in your daily life? Are you at all like a submarine?

<u>Key Vocabulary</u>: Sine wave, amplitude, frequency, wavelength, electromagnetic, radio, microwave, infrared, visible, ultraviolet, x-ray, gamma ray, photon, speed of light, sound vibration, speed of sound, camouflage.

<u>Extension</u>: Discuss mast and antenna differences on Los Angeles, Seawolf, and Virginia class submarines (photonics mast instead of periscope, high data rate antenna for satellite comms, floating wire antennas to stay fully submerged and remain in radio communication). See also the USS Nautilus OIC lesson Power Point on Submarine Communications. It is available from the Submarine Force Museum's Education Specialist, and is included as a 12 page handout at the end of his lesson plan.

<u>Materials</u>: Museum visit, or virtual tour on-line at http://www.ussnautilus.org/virtualTour/index.shtml plus whiteboards/large paper and markers/pencils/pens.

<u>Resources</u>:
http://www.ussnautilus.org/education/stemlessonplans.shtml

Monitoring and Adjusting: (Possible Answers)

7. **Describe which masts need the human eye to detect the EM wave inside the submarine?** ***Periscopes (masts 10 and 11) use lenses and mirrors to reflect EM waves from outside, through the periscope to the submariner's eye.***

8. **What do all the masts and antennas have in common, regarding visible light?** *Each reflects the visible light of the color you see, and absorbs the other colors.*

9. **Do you think any *Nautilus* masts detect infrared, ultra-violet, x-rays or gamma rays?** ***Some probably do for seeing at night or detecting radio waves from shore, ships, planes and satellites.***

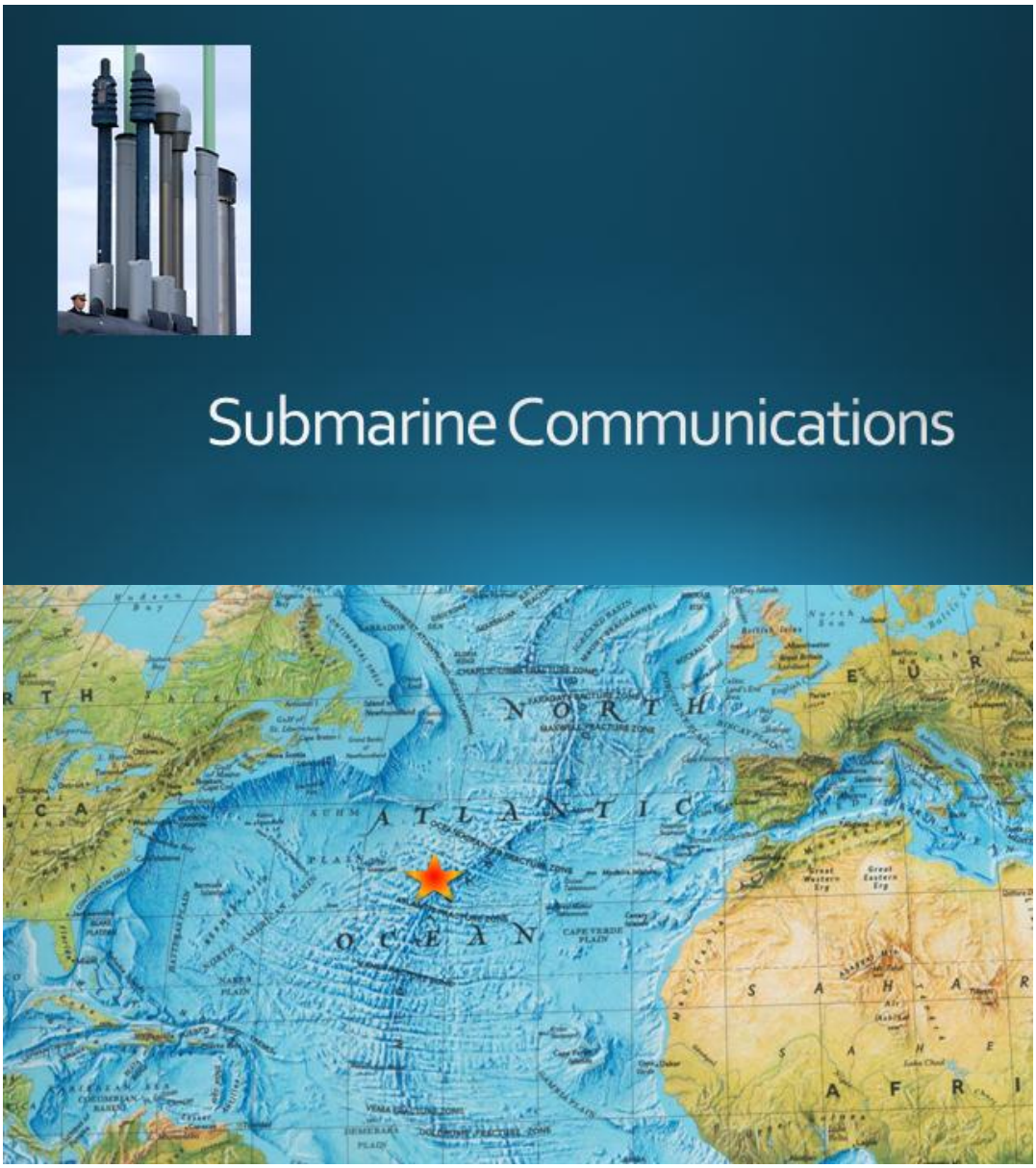
10. **Do you think today's submarines can detect infrared and ultra-violet rays? Why?** ***Modern technology has probably progressed beyond visible light detection only, for improved submarine capability.***

11. **Are there detectors that can detect x-rays and gamma rays? Why? Where could these rays come from?** ***Yes, in the event there is a source of radiation that could harm the crew. The radiation could come from the cosmic radiation of outer space, from a casualty to the ship's nuclear propulsion plant, airborne contamination from outside the ship which is ventilating into the ship, illegal testing of nuclear materials, a "dirty-bomb" made-up from a mixture of explosives and radioactive material, or hostile use of nuclear weapons.***

12. **Why does the submarine sail look black? Why are the masts painted gray with black spots?** ***The sail is black, because the type of paint used absorbs all the colors with no reflections. The masts are painted gray and black to reduce detection by breaking-up the solid colors—known as camouflage.***

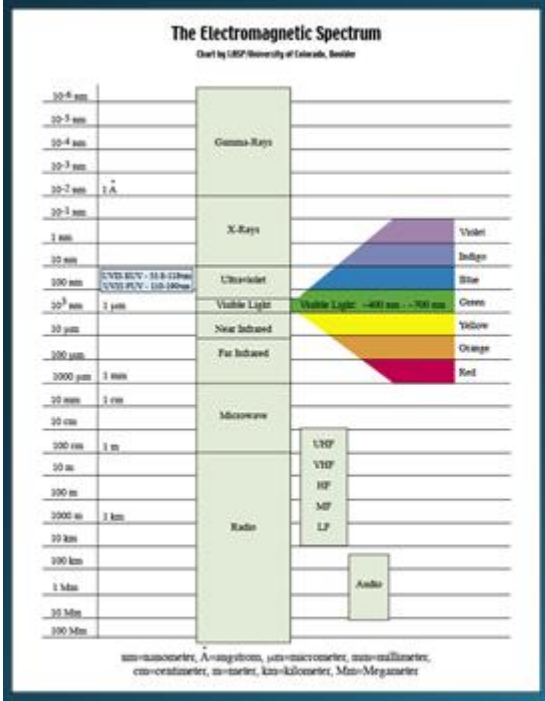
Assessment: Draw a submarine sail for a newer submarine, and the types of masts and antennas it should have for the 21st Century. (See page 5 for a current sail configuration).

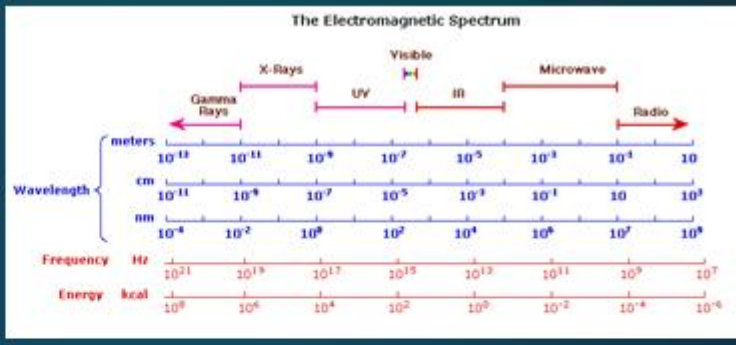
Closure: How do you use electromagnetic and sound waves in your daily life? Are you at all like a submarine? ***Simple answer: eyes and ears. Eyes detect visible electromagnetic waves, and your ears and central nervous system detect sound waves and vibrations, converting mechanical motion of these vibrations to electrical impulses into your brain.***


Submarine Communications
NORTH
ATLANTIC
OCEAN

Submarine Communication Challenges

- Small antenna sizes
  - Stealth (visual, radar, IR)
  - Sail limitations
- Low height above water
- Antenna stability in high sea states
- Minimizing number of masts and antennas raised (stealth)
- Transmission & receiving vs. receiving only ("EMCON")
- PD vs Deep
  - Ultimate goal: communications at speed & depth
- Range vs. detectability; LOS vs. OTH





Typical antenna lengths are either one half or one quarter the wavelength:

- ½ wave horizontal dipole $\frac{\lambda}{2}$
- ¼ vertical "whip" antenna $\frac{\lambda}{4}$

Antennas

- Dipole, Yagi-Uda, random wire, horn, parabolic, patch, etc.
- Directional vs. Omnidirectional
- Bandwidth
- Null areas
- Gain
- Efficiency
- Polarization

Radio Frequency Spectrum

Band	Freq	Wavelength	Notes, Uses
Extremely low frequency (ELF)	3-30 Hz	100,000 – 10,000 km	Penetrates seawater, earth, rock
Super low frequency (SLF)	30-300 Hz	10,000 – 1000 km	Penetrates seawater, earth, rock
Ultra low frequency (ULF)	300-3000 Hz	1000 – 100 km	Penetrates seawater, earth, rock
Very low frequency (VLF)	3-30 kHz	100 – 10 km	Penetrates shallow seawater, earth, rock
Low frequency (LF)	30-300 kHz	10 – 1 km	Time signals
Medium frequency (MF)	300-3000 kHz	1000 – 100 m	AM
High frequency (HF)	3-30 MHz	100 – 10 m	CB
Very high frequency (VHF)	30-300 MHz	10 – 1 m	Marine radios (LOS), FM, TV, amateur radio
Ultra high frequency (UHF)	300-3000 MHz	1000 – 100 mm	Digital TV, Microwaves, mobile phones, WiFi, GPS
Super high frequency (SHF)	3-30 GHz	100 – 10 mm	Satellite communications, WiFi, Radar
Extremely high frequency (EHF)	30-300 GHz	10 – 1 mm	Satellite communications, mm radar

IEEE Radar Frequency Bands

Band designation	Frequency range	Other Names
HF	3 to 30 MHz	High Frequency
VHF	30 to 300 MHz	Very High Frequency
UHF	300 to 1000 MHz	Ultra High Frequency
L	1 to 2 GHz	Long wave
S	2 to 4 GHz	Short wave
C	4 to 8 GHz	Compromise between S and X
X	8 to 12 GHz	WW II for FC, some mil radars
Ku	12 to 18 GHz	Kurz-under
K	18 to 27 GHz	German Kurz (short)
Ka	27 to 40 GHz	Kurz-above
V	40 to 75 GHz	
W	75 to 110 GHz	
mm	110 to 300 GHz	Millimeter

ELF (3-30 Hz) / SLF (30-300 Hz)

- World-wide coverage using 76Hz signal
  - US used two locations: One each in Wisconsin & Michigan
  - Antenna length >50KM
- One-way comms
- Very slow data rates (a few character per minute)
- Penetrates the ocean (100s of meters)
  - Used as a "bell ringer"
- Very difficult and expensive to build
  - Only US and USSR/Russia have done it
  - Huge electrical power requirements
- US system no longer in use

VLF (3-30 kHz)

- Penetrates about 10-40M / 30-130 feet of seawater
  - Submarines use towed, buoyant antennas
- Reflected by the earth's ionosphere
  - Range can be 1000s of km/miles
- Low data rates only (no voice)
  - 300 bps (about 35 characters per second)
- High power required for long distance communications
  - 10s, 100s, or 1000s of kW
  - Cutler ME operates at 24kHz at 2MW of power

MF (300-3000 kHz)

- Maritime ship-to-shore radio
- Propagates using ground waves and skywaves (OTH)
  - Ranges can be 100s or 1000s of miles (weather dependent)
- The lack of a tall antenna (mast) limits submarine's ability to transmit effectively on MF
  - Ideally MF transmission antennas are 100s of feet high

HF (3-30MHz)

- Skywave propagation (OTH)
  - Intercontinental communications possible
  - Affected by weather, solar activity, seasonal, time of day, etc.
- Voice or Data
- Susceptible to interference from a variety of sources

VHF (30-300 MHz)

- LOS, range limited by antenna height:

  Range in nm = $\sqrt{(1.5)(antenna\ height\ in\ feet)}$

  Range in km = $\sqrt{(12.746)(antenna\ height\ in\ meters)}$

- Wavelengths small enough for handheld device antennas
- Common Navy uses include VHF marine voice channels, NOAA weather stations, aircraft comms and air traffic control

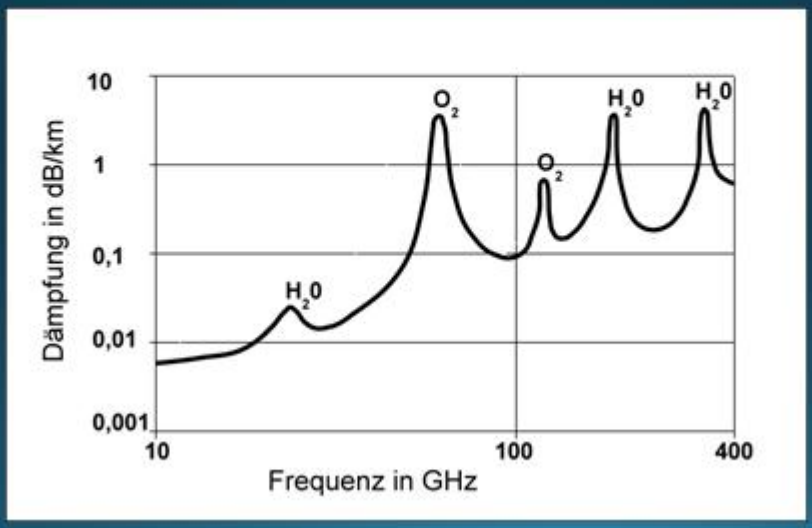
UHF (300-3000MHz)

- Generally LOS, some reflection by objects of similar wavelengths
- Limited penetration of walls, trees, etc. more effected by moisture
- Military uses include communications, GPS, and older satellites communications

SHF (3-30 GHz) / EHF (30-300 GHz)

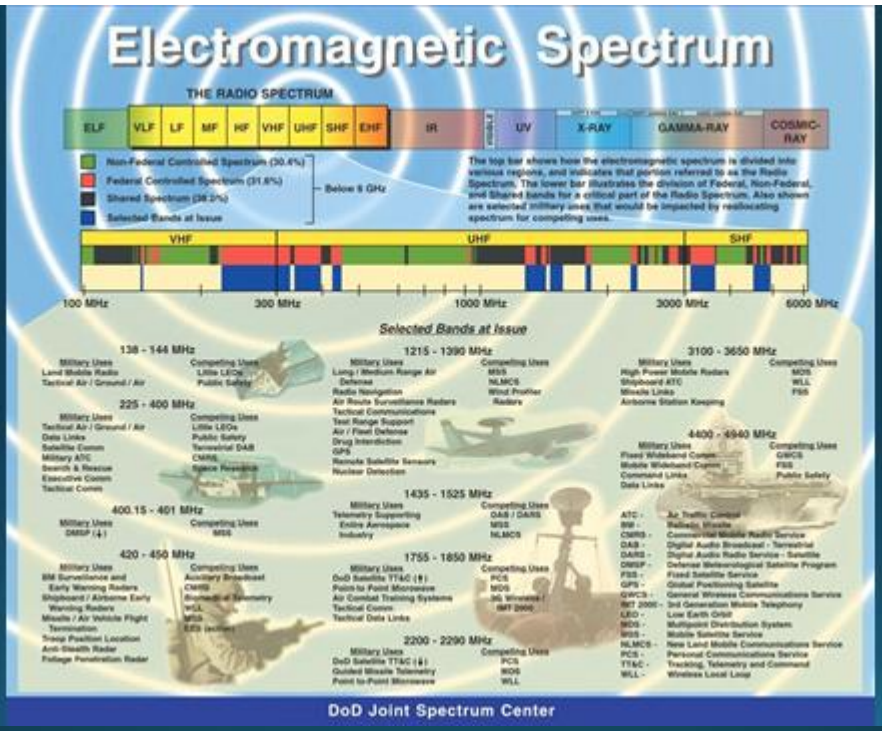
- LOS
- Narrow, directed beams. Mostly parabolic, slot, and horn antennas
- Waveguides (vice wires) used
- Higher frequencies, especially 57–64 GHz, have high atmospheric attenuation
- Most radars, satellite communications are in the SHF band
- High speed data links, fire control and other high-accuracy radars use EHF

EHF atmospheric attenuation in dB/km



In Summary…

Lower Frequencies	Higher Frequencies
Longer ranges more penetration (water, land, etc.)	Directional High data rates Smaller antennas Lower Tx power
More power Larger antennas Slower data rates	LOS No penetration Interference/Jamming



Communications Security

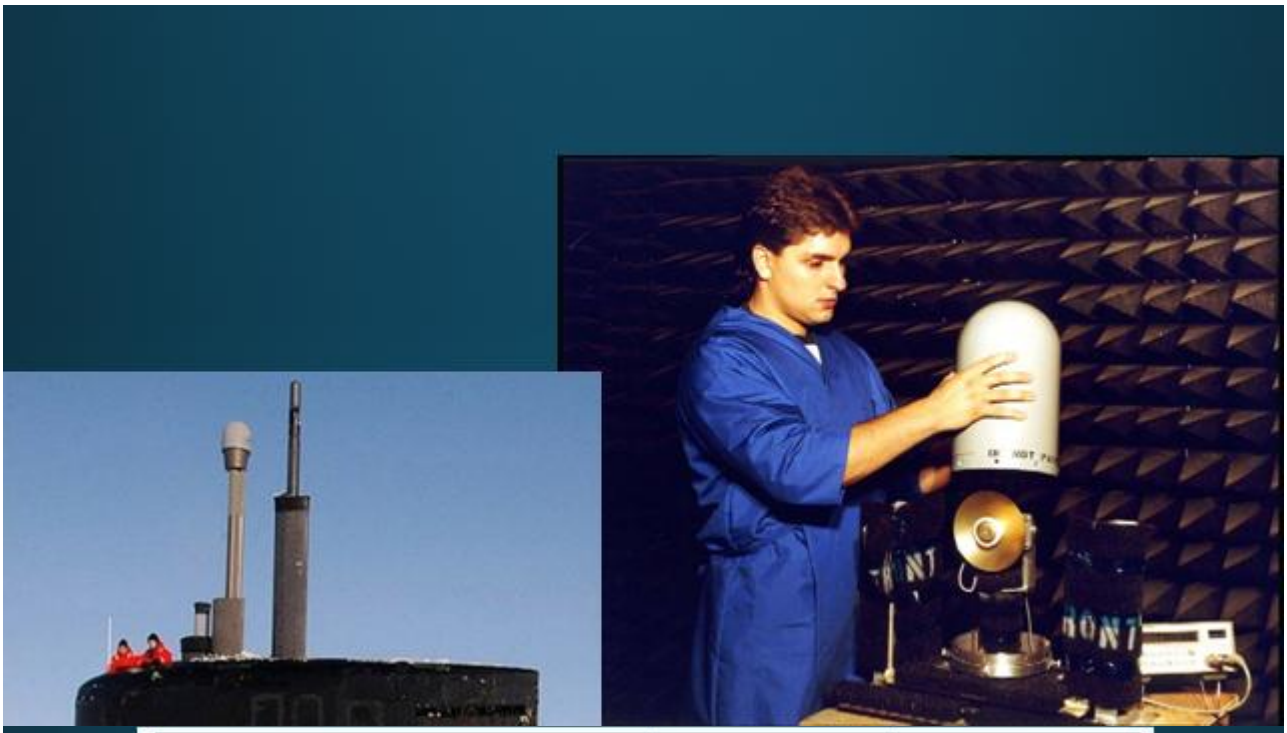
- Passive vs. Duplex (receive only vs. transmit & receive)
- Length of transmission
- Cryptography
- Code words and slang
- Directionality, LOS, ability to intercept and triangulate

Underwater acoustic communication

- "Gertrude"
- Use modulated SONAR transmissions to carry voice or data
- Low fidelity/low data rate
- NOT stealthy (a form of active SONAR)

Non-electronic communications

- Signal lights
- Flags
- USPS / Courier
- Posture, appearance, and perception



CORE		LOW RISK	OVERT
STEALTH	COVERT		
ICE COPY EHF LDR/MDR SHF UHF	ESM COMMS P/D EHF LDR/MDR SHF UHF	BROACHED EHF MDR SHF UHF	SURFACED EHF MDR SHF UHF
VLF ELF VHF HF VLF ELF	VHF HF VLF ELF	VHF HF VLF ELF	VHF HF VLF ELF
	LOW-MED	HIGH	HIGH

Communication Capabilities for Submarine Operations

Table A-2. Existing Submarine Communication Antenna Systems (Page 1 of 2)

Antenna	Frequency Range	Mode/ Data Rate (bps)	Application		
			SSN 688	SSN 21	SSBN 726
OE-315(V)/BRC	10 Hz - 400 MHz	Data, Voice 50 - 75	X	X	X
AN/BRA-34	VLF/LF 5 kHz - 150 kHz	Data 50	X	X	
	MF/HF 2 MHz - 30 MHz	Data, Voice 50 - 2250	X	X	
	UHF 225 MHz - 400 MHz	Data, Voice 75 - 9600	X	X	
	UHF 240 MHz - 315 MHz	Data, Voice 75 - 9600	X	X	
	IFF 950 MHz - 1150 MHz	N/A	X	X	
	GPS 1227 MHz and 1575 MHz	N/A	X	X	
OE-207/BR	VLF/LF 10 kHz - 160 kHz	Data 50			X
	MF/HF 2 MHz - 30 MHz	Data, Voice 50 - 75			X
	UHF 225 MHz - 400 MHz	Data, Voice 75 - 2400			X

Table A-2. Existing Submarine Communication Antenna Systems (Page 2 of 2)

Antenna	Frequency Range	Mode/ Data Rate (bps)	Application		
			SSN 688	SSN 21	SSBN 726
OE-207/BR (Continued)	UHF 240 MHz - 320 MHz	Data, Voice 75 - 2400			X
	IFF 950 MHz - 1150 MHz	N/A			X
	GPS 1227 MHz and 1575 MHz	N/A			X
AT-441/MRC	MF/HF 2 MHz - 30 MHz	Data, Voice 50 - 75	X	X	X
AT-774/UR	MF/HF 2 MHz - 30 MHz	Data, Voice 50, 75	X	X	X
AN/BRR-6	VLF-HF 10 MHz - 160 MHz 2 MHz - 30 MHz	Data 50			X
Type 18 (RO)	MF-UHF 5 kHz-500 MHz	Data, Voice 75 - 9600	X	X	
	VHF-UHF 32 kHz - 500 MHz	Data, Voice 75 - 9600	X	X	
Type 15 (RO)	VLF-UHF 0.5 kHz - 500 MHz	Data, Voice 75 - 2400			X
Type 8 Mod 3 (RO)	VLF-UHF 12 kHz - 500 MHz	Data, Voice 75 - 2400			X
Type 8 Mod 3 EHF Antenna	EHF 43.5 - 45.5 GHz Uplink 20.2 - 21.2 GHz Downlink	Data, Voice 75 - 2400	X	X	X