{TESS+} webinar

Basic RF theory & Overview of two-way comms

23rd June 2021

V0.5

Read more about {TESS+}: www.wfp.org/telecommunications-security-standards
Email: TESS@wfp.org

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Session objectives

- Describe the components of a radio system
- Understand radio basics (frequency, wavelength, propagation)
- Describe antenna characteristics
- Describe SWR (Standing Wave Ratio)
- Overview of two-way radio comms

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Basic RF theory

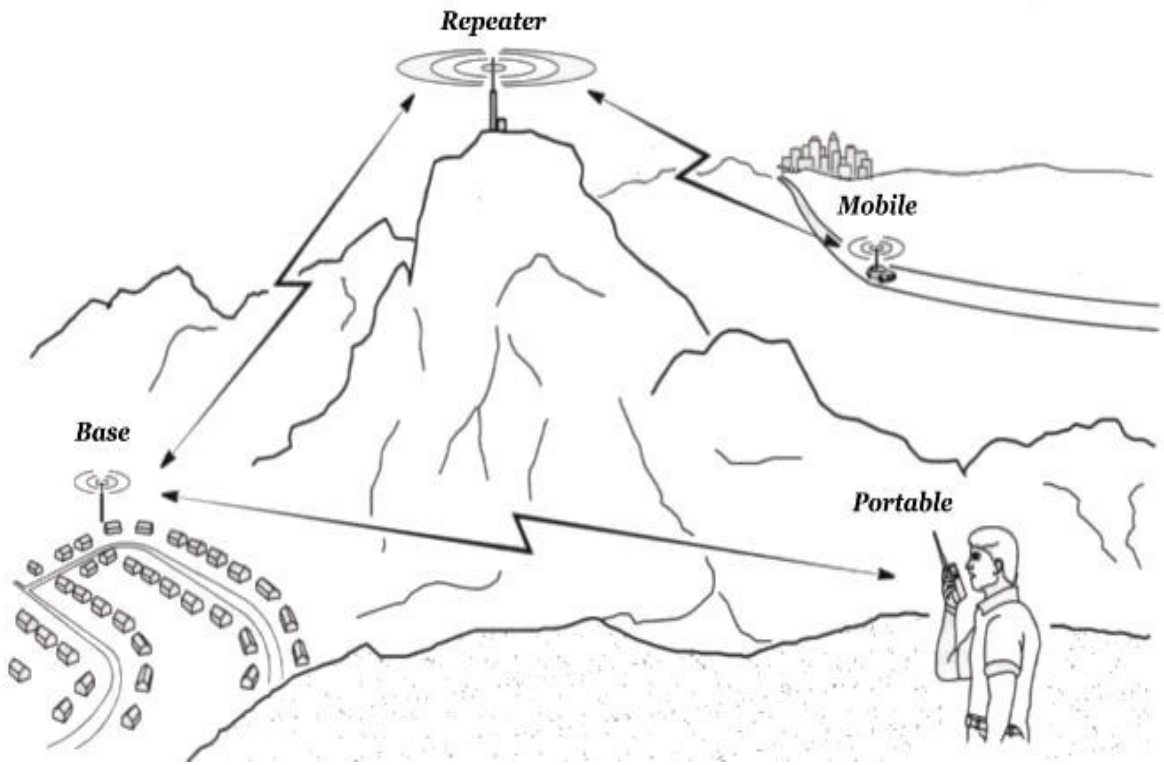
Get ready for today’s quiz!

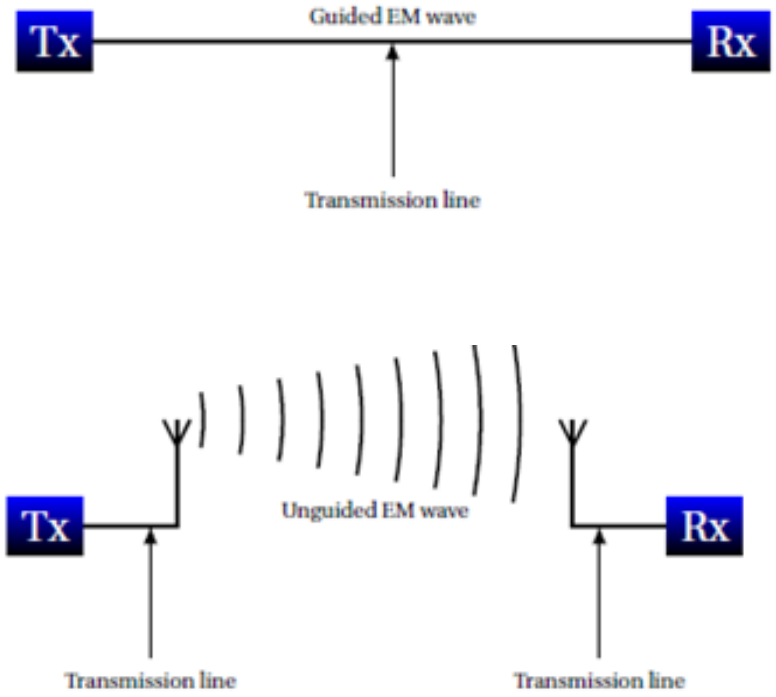
- Let's engage and test our knowledge.
- Register your name via:

  https://app.sli.do/event/dgjixnya
- Or just scan this QR code:

- *Your responses are anonymous*

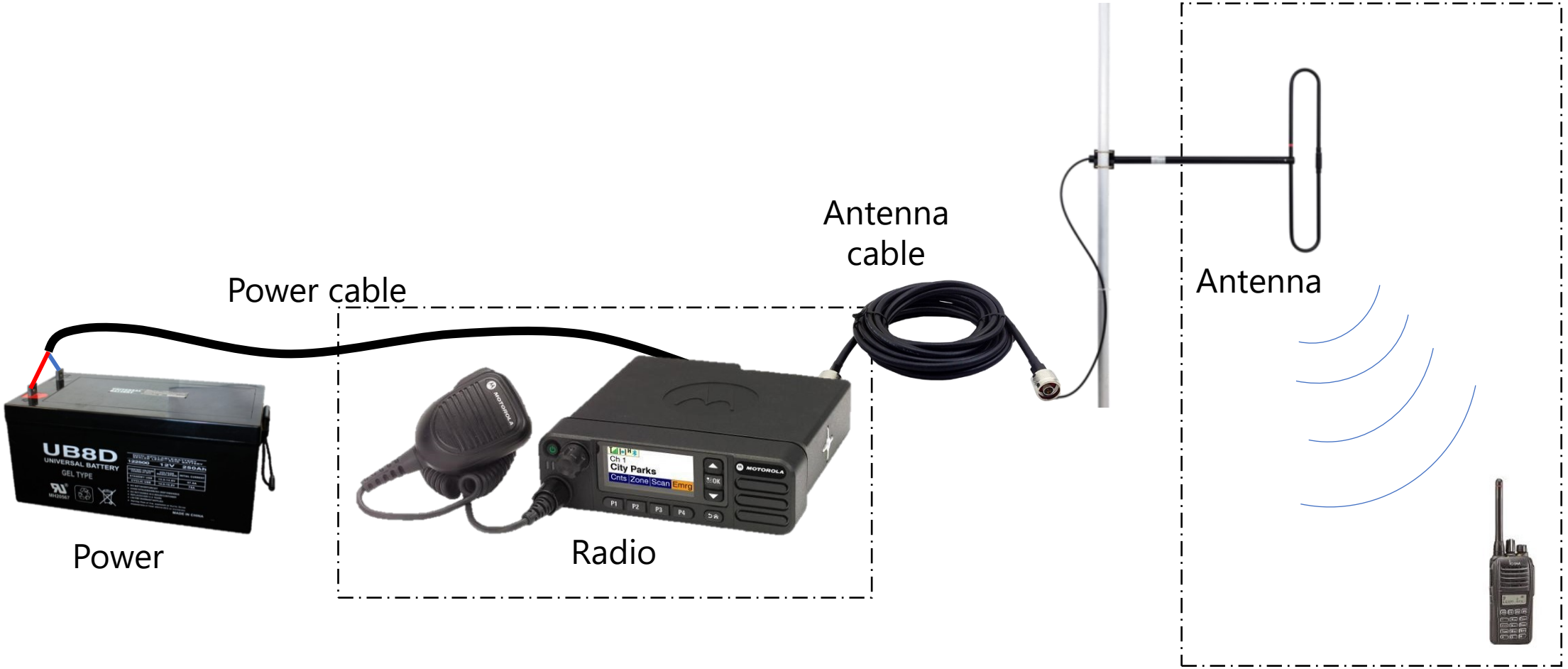
Radio systems





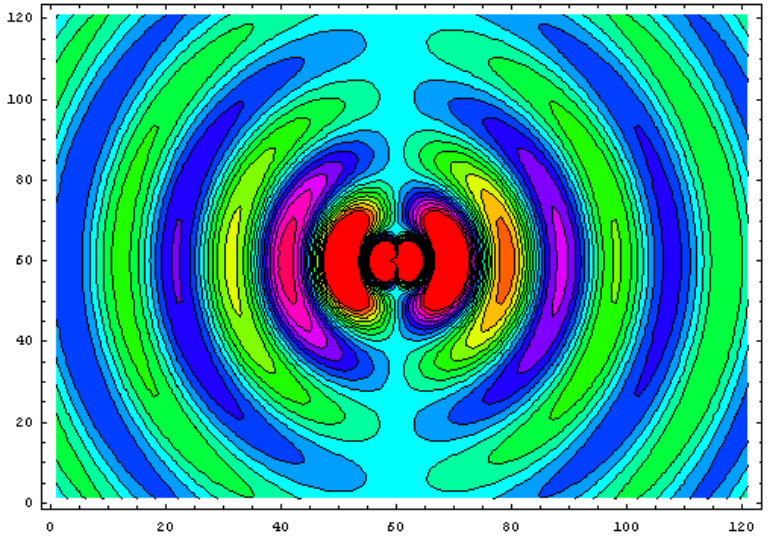
Basic components of a radio system

Basic components of a radio system



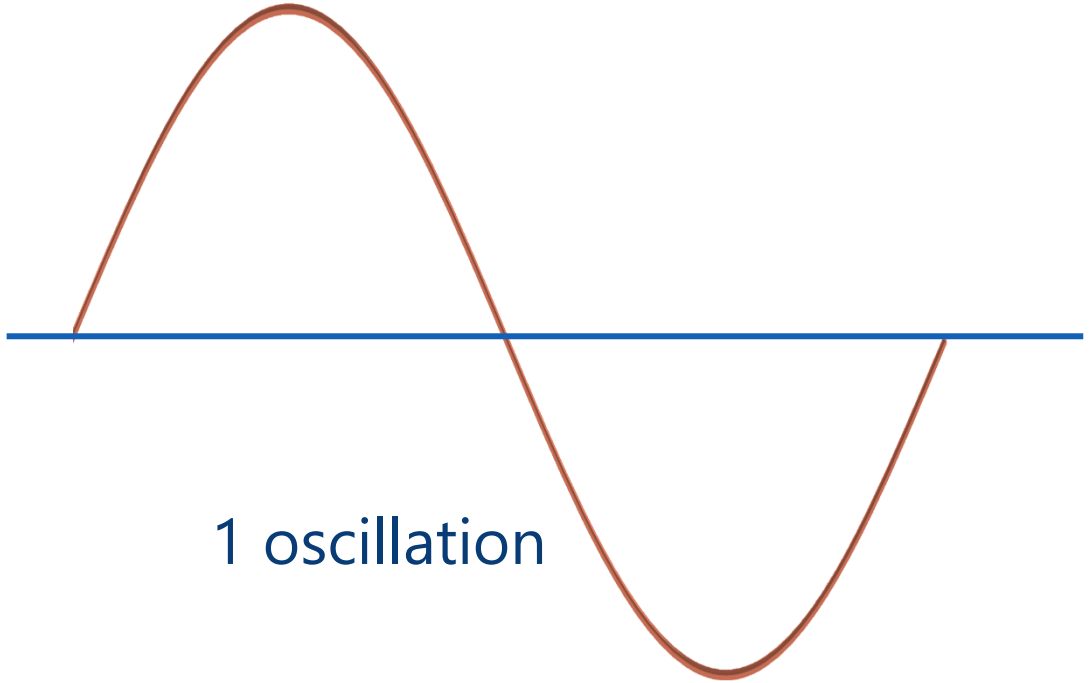
Radio waves

- It is all about waves
- Received and transmitted
- Wave characteristics

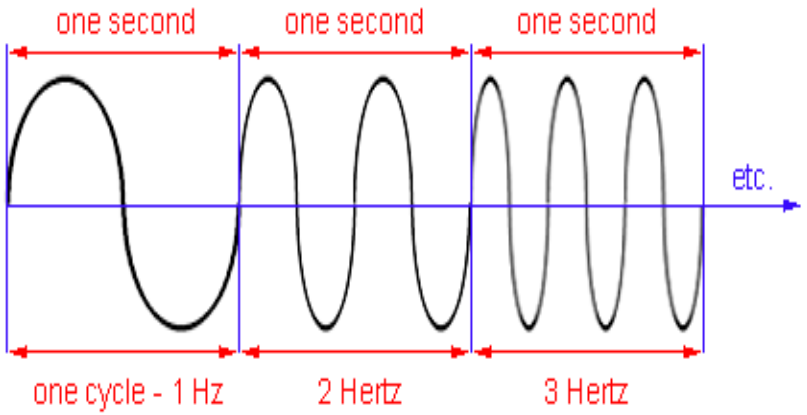


Frequency (f)

- Frequency is the number of oscillations (waves) per second, expressed in Hertz (Hz).



1 oscillation / sec
= 1 Hz



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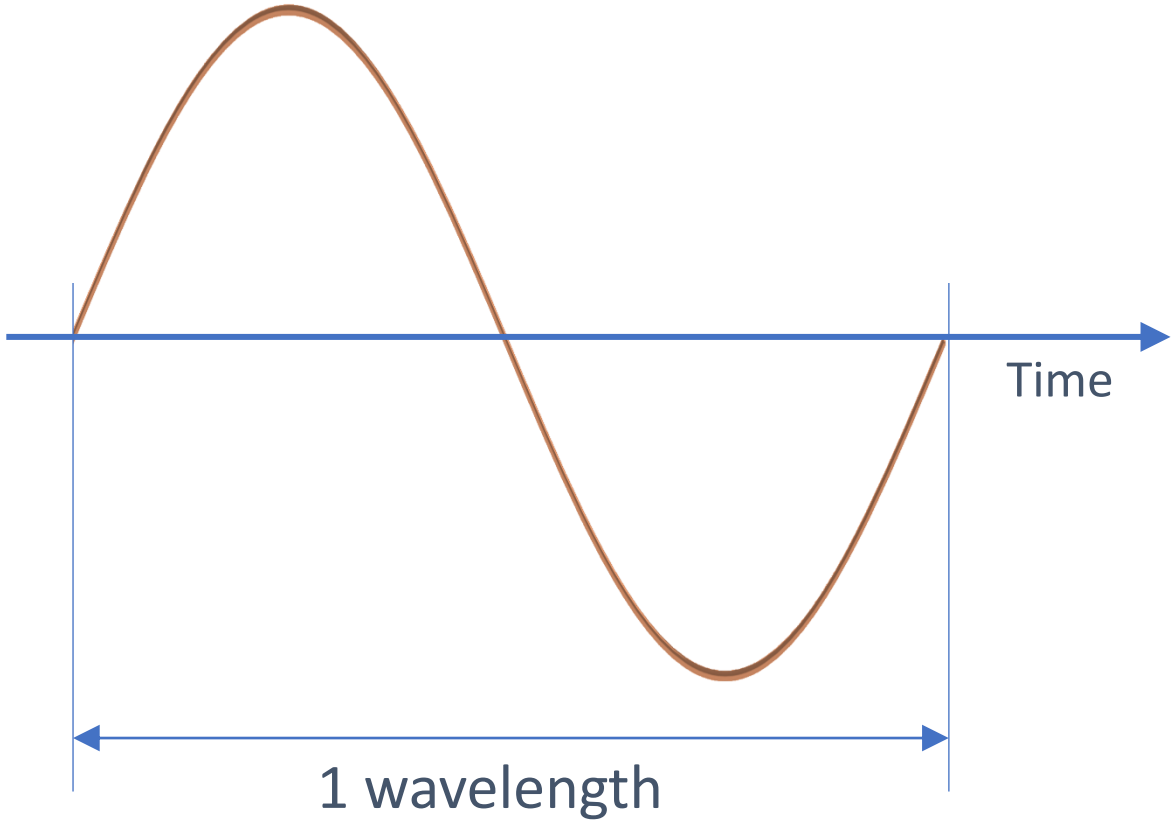
Wavelength (λ)

- Wavelength (λ) is the length of one oscillation, expressed in meters. It is measured in the direction of the wave.



$$\lambda = \frac{\text{wave speed}}{\text{frequency}}$$

Inversely proportional

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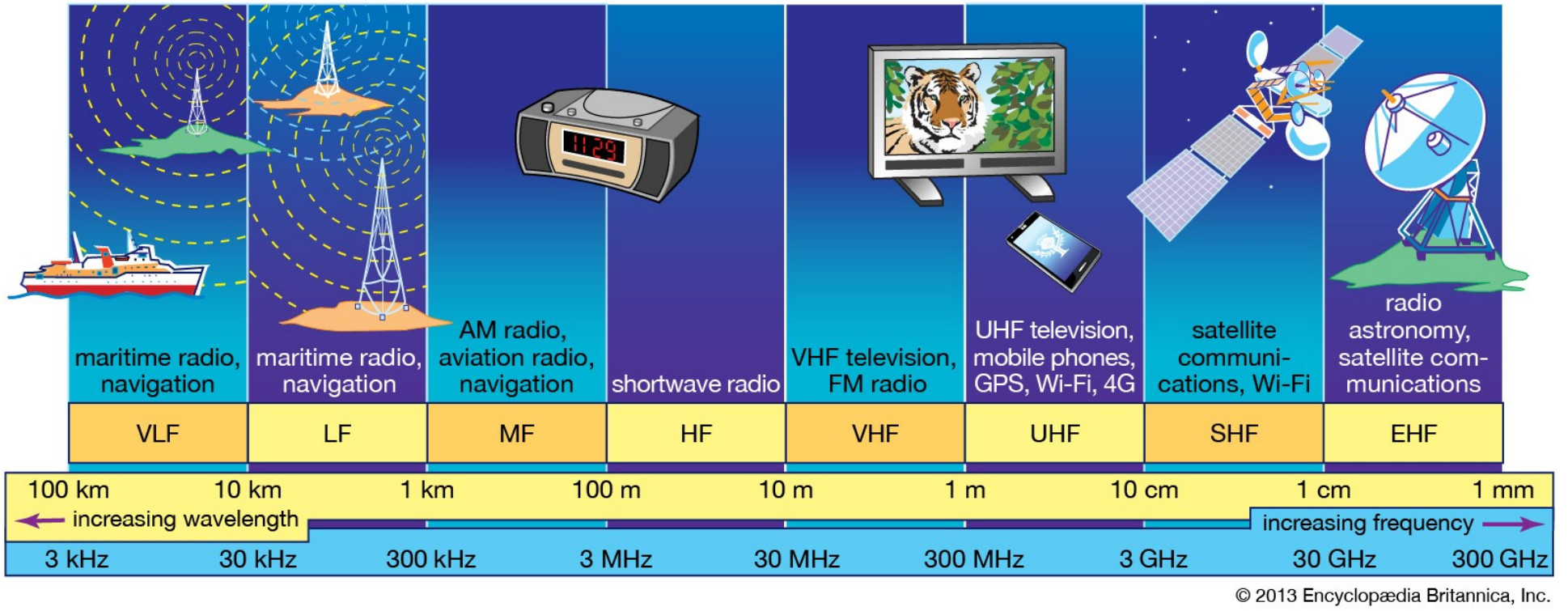
Radio spectrum

- The higher the frequency, the shorter the antenna (important)

Radio spectrum



Radio spectrum

- Different frequencies have different characteristics and are used for specific purposes.
- Based on this we can choose the correct frequency band depending on the purpose.
- Higher frequencies, short antennas, short distance. (VHF, UHF)

The frequency band we use for UN radio systems is usually VHF band. In some countries, based on the local regulation, the UHF band is used instead.

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Frequency bands

- The radio spectrum is divided into different “frequency bands”

Name	Symbol	Frequency
Extremely low frequency	ELF	3–30 Hz
Super low frequency	SLF	30–300 Hz
Ultra low frequency	ULF	300–3000 Hz
Very low frequency	VLF	3–30 kHz
Low frequency	LF	30–300 kHz
Medium frequency	MF	300–3000 kHz
High frequency	HF	3–30 MHz
Very high frequency	VHF	30–300 MHz
Ultra high frequency	UHF	300–3000 MHz
Super high frequency	SHF	3–30 GHz
Extremely high frequency	EHF	30–300 GHz

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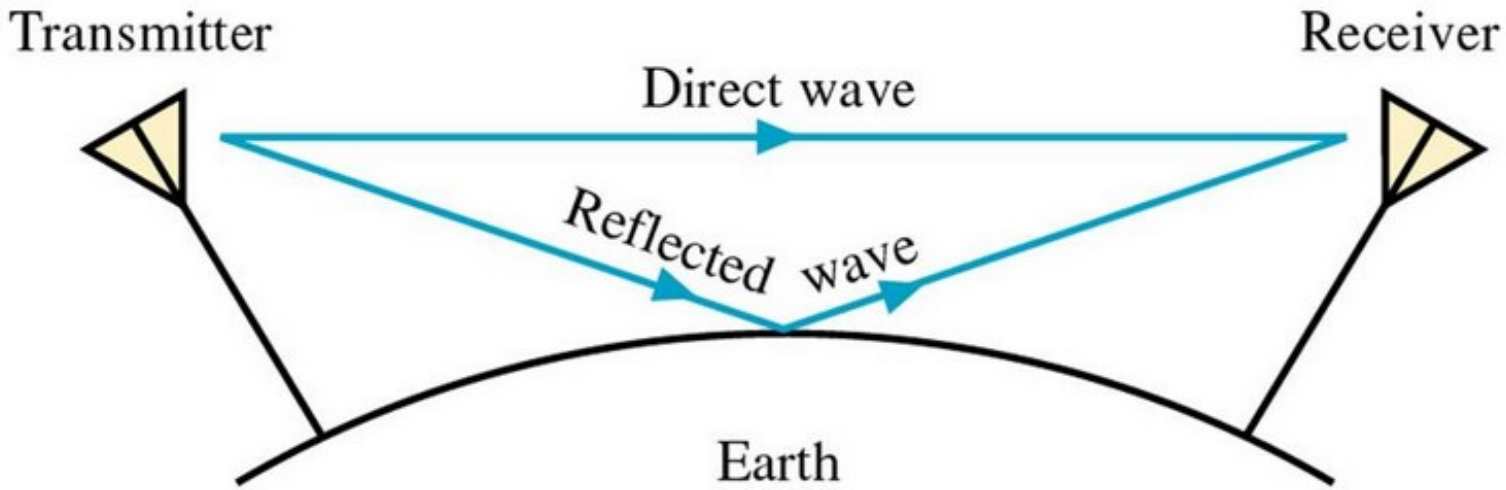
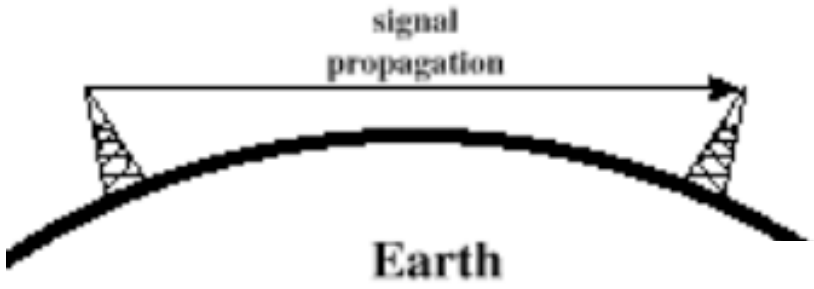
Wave propagation

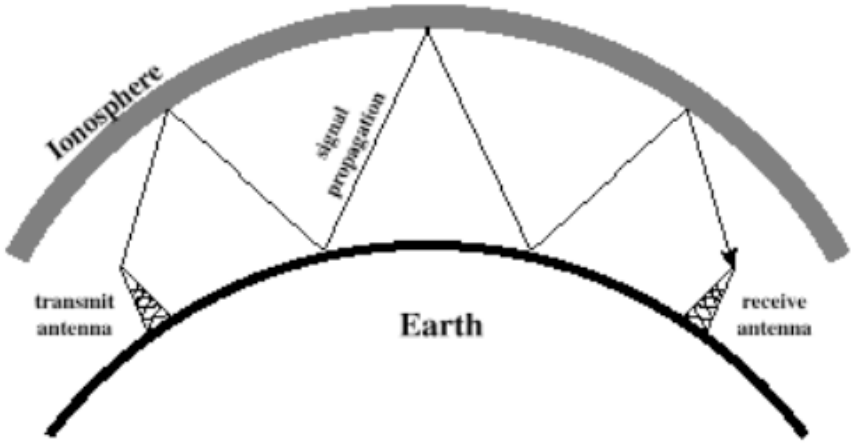
- Direct waves work when there is line-of-sight (LoS)
- Keeping other conditions constant, the distance a wave can travel depends on the height of the two antennas and the output power.

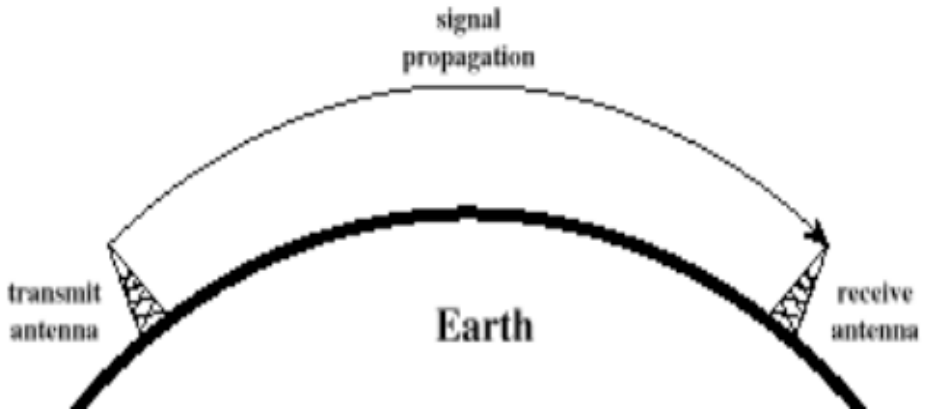


Wave propagation

- Ground **vs** sky **vs** line-of-sight (LoS)







VHF/UHF bands

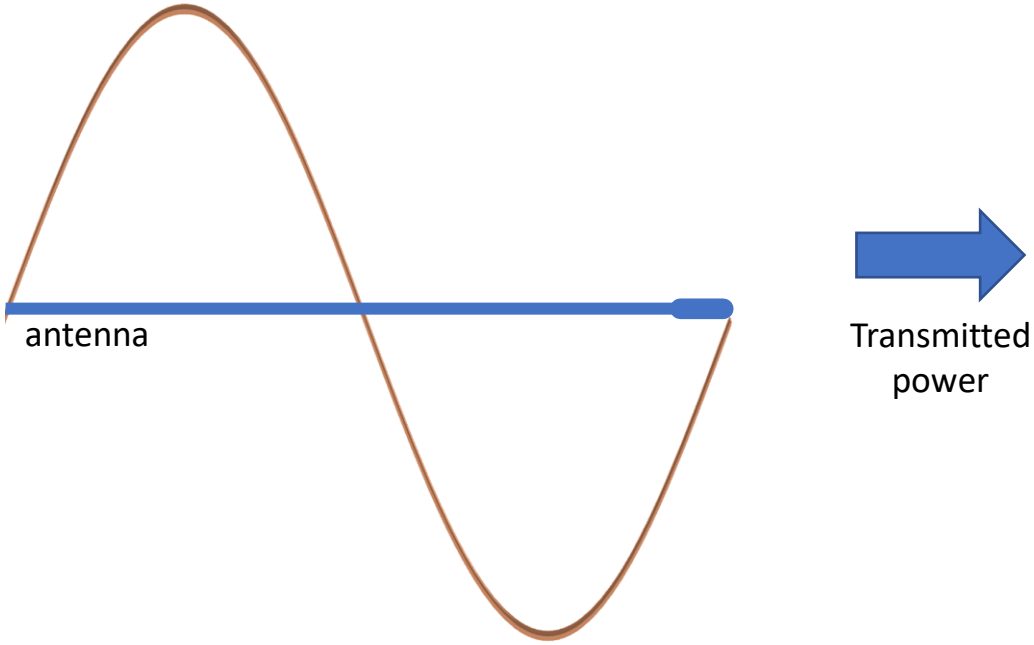
- Frequencies in the VHF and UHF band use “line-of-sight” (LOS), meaning that they are blocked by hills and mountains.
- To a certain degree the signal can penetrate buildings and walls, but this will weaken the signal.

Antennas

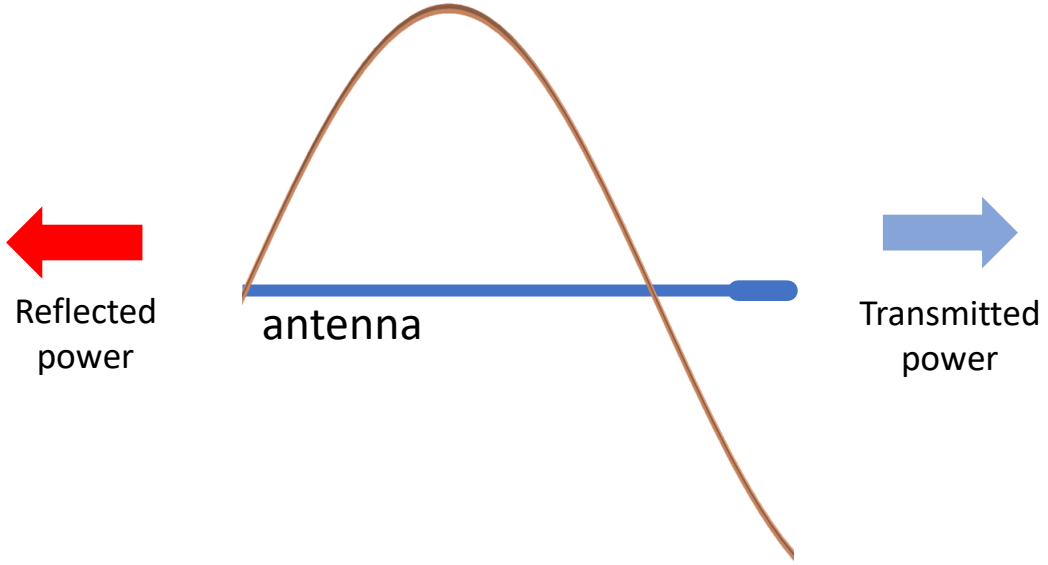
- An antenna is a conductor (e.g. copper, aluminium, iron) that captures and/or transmits radio waves.
- Antennas come in many different shapes and sizes:

Antenna length is important

Right antenna length



Wrong antenna length



Wavelength vs antenna length

- Antenna is designed by wavelength
- There are many designs e.g. quarter wavelength, half, 5/8, etc.

$$\text{Length} = \lambda = \frac{c = (3 \times 10^8)\ \text{m/s}}{\text{Frequency (Hz)}}$$

- We would like to design an antenna that works for 15MHz
- f= 15MHz = 15 x 10^6
- c= 3x10^8 m/s *(ie. speed of light)*
- λ= c/f = 3x10^8 / 15x10^6
- λ= 300/15 = 20 metres

- 15 MHz => **L = 20 m**
- 150 MHz => **L = 3/1.5 = 2m**
- 1.5 GHz => **L = 0.2 m / 20 cm**

- That's why HF (3-30MHz) antennas are long!

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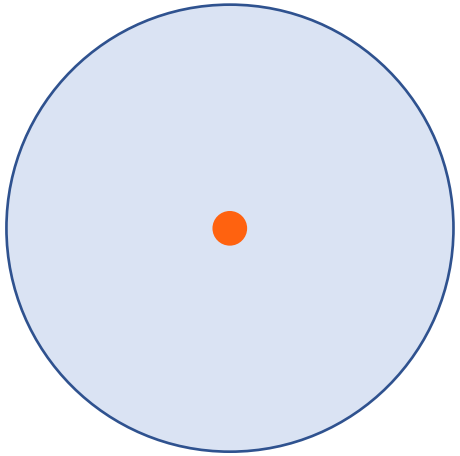
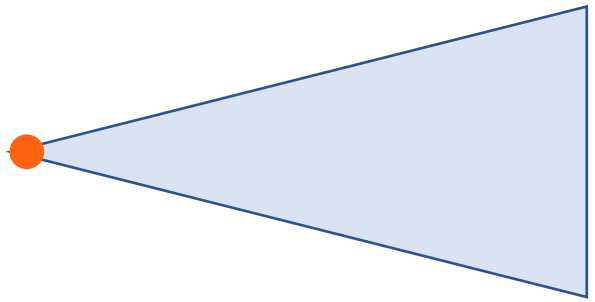
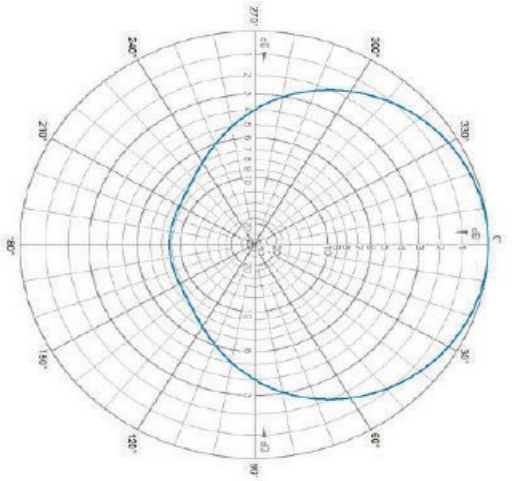
Antennas - directivity and patterns



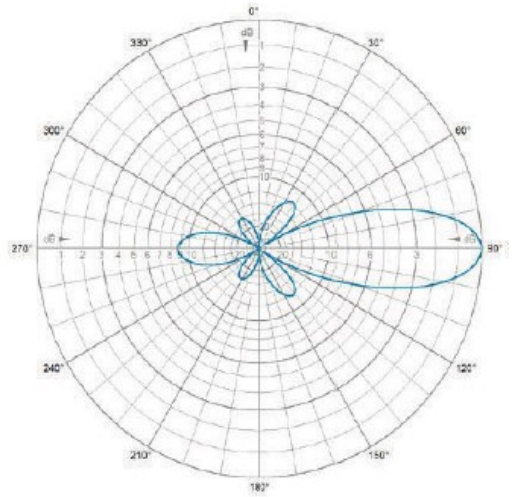
Omni-directional



Directional



H-plane (160 MHz)



E-plane (160 MHz)

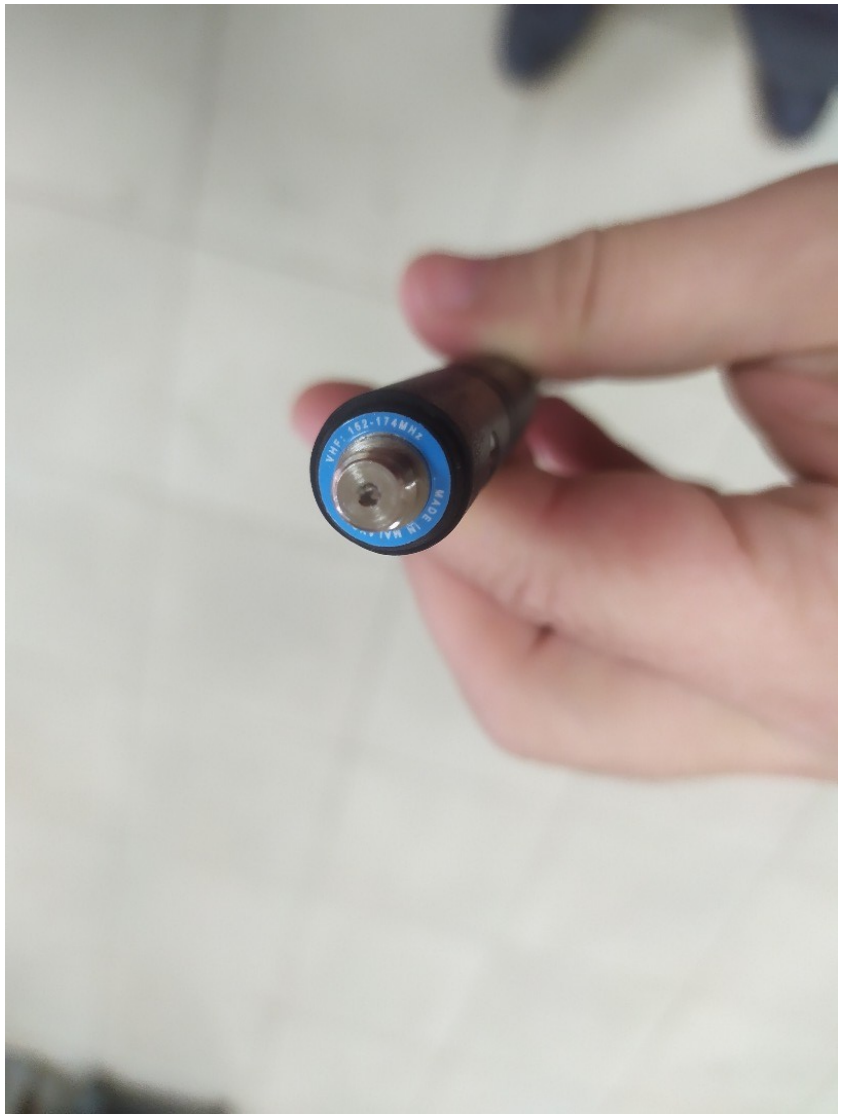
Antennas - types

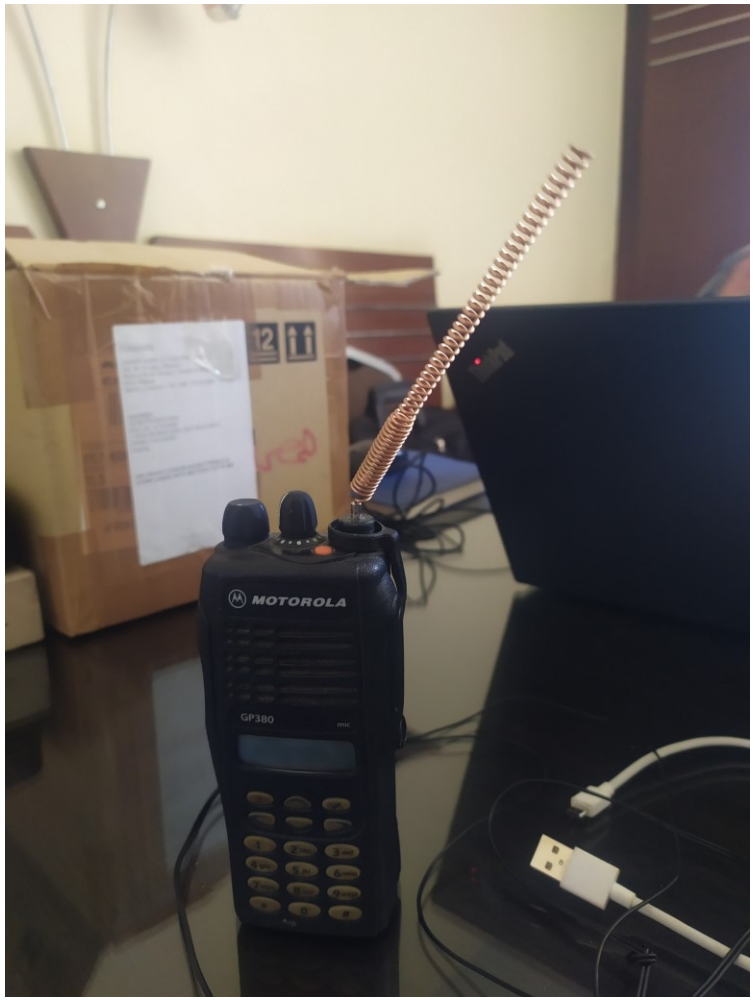
- There are many types for different usage:
  - Dipoles
  - Monopoles
  - Loop
  - Sector antennas
  - Parabolic
  - ..

Antennas – in real-life

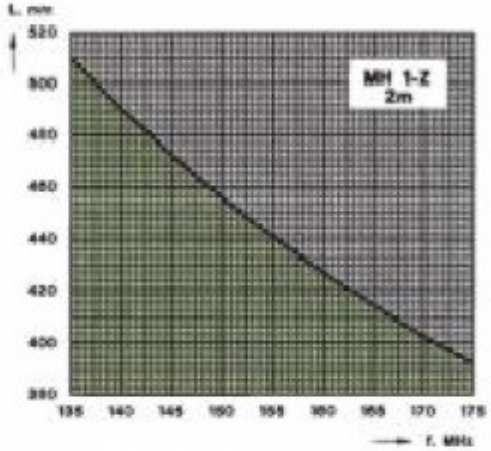
- Each VHF/UHF antenna has a certain frequency range
- Always read and follow the manufacturer's specifications for each VHF or UHF antenna that you use
- VHF and UHF antennas installed in a vehicle always need to be tuned (cut to the correct length) according to the frequency you use.

Handheld radio antennas

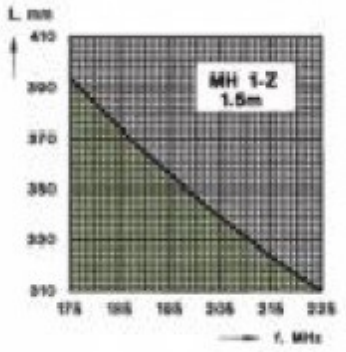




Mobile radio antennas



Higher/shorter



Mobile radio antennas

Example - antenna specifications (base/repeater)

S.M2E-160

AMPHENOL PROCOM

2-stack lightweight dipole array, 145-175 MHz

DESCRIPTION

The S.M2 is an array of phased centre fed folded dipoles mounted on an aluminium mast for PMR / Trunked radio applications. Each folded dipole balun assembly and associated harness junction is completely encapsulated in polyurethane resin, totally preventing moisture ingress. At VHF the antenna disassembles and flat packs for ease of shipping.
+ Former Skymasts brand product.

SPECIFICATIONS

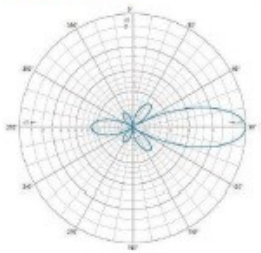
Electrical	
Frequency	145 - 175 MHz
3 dB Beamwidth, H-Plane	180 °
Polarisation	Vertical
3 dB Beamwidth, E-Plane	36 °
Impedance	50 Ω
Gain	5 dBd (7.2 dBi)
VSWR	< 1.5:1
Maximum Input Power	500 W
Front-To-Back Ratio	> 5.5 dB
Antistatic Protection	All metal parts DC-grounded (Connector shows a DC-short)

Mechanical		
Input Connection(s)	N(f) on RG213/U cable	
Materials	Main Boom, 48 mm dia., aluminium elements, 12.7 mm dia., aluminium balun, fully potted enclosure	
Dimensions	3400mm (h) x 590mm (w) (supplied in two sections)	
Wind Load	363 N (160km/h)	
Weight	8.5 kg / 18.74 lb	
Mounting Bracket	0300120/00 (Ordered Separately)	ETC-250 (ø50 to ø76mm) (Ordered Separately)
Alternate Mounting Bracket	2141.01.00.00 (up to ø120mm) (Ordered Separately)	

Environmental	
Operating Temperature Range	-40 to 70 °C
Ingress Protection	IP68

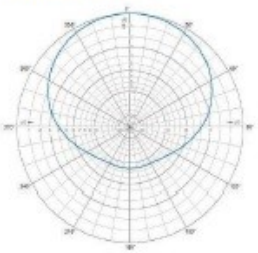
DIAGRAM

RADIATION PATTERNS



E-Plane | 160 MHz

RADIATION PATTERNS



H-Plane | 160 MHz

ORDERING

Type	Product No.	Frequency
2-stack lightweight dipole array, 145-175 MHz	S.M2E-160	145 - 175 MHz
Galvanised steel parallel bracket 32-60mm (PAIR)	0300120/00	
Galvanised steel parallel bracket 38-120mm (PAIR)	2141.01.00.00	
Extruded Parallel Tube Clamp, 50 - 76mm	ETC-250	

PROCOM CXL 1800-6LW

An Amphenol PRIVATE NETWORKS COMPANY

CXL 1800-6LW

6 dBd Omdirectional Base Station and Marine Antenna for the 1800

- Vertically polarized, omnidirectional base station and marine antenna.
- Approximately 6 dBd gain.

DESCRIPTION

- Provided with the sturdy "LW" mast mount – a lightweight, multipurpose, epoxy-coated mounting bracket made of non-corrosive aluminium.
- The accompanying U-bolts and fittings are made of stainless steel.
- To be mounted on vertical or horizontal mast tubes, 16 to 54 mm in outer diameter.
- The cable can be led either on the outside or along the inside of the mast tube.
- Large bandwidth with respect to both SWR and gain.
- Highly suitable for duplex operation with large spacing between the TX and the RX frequencies, e.g. the DCS-1800/PCN cellular system.
- The antenna element is sealed in a high-quality, conical glass fibre tube.
- All metal parts in the antenna are DC-grounded to reduce the noise caused by atmospherical discharge. Consequently, the antenna shows a DC-short across the coaxial cable.
- The CXL 1800-6LW is a vibration-proof, lightweight, slim-line, corrosion resistant, modern style base station and marine antenna.

ORDERING DESIGNATIONS

TYPE	PRODUCT NO.
CXL 1800-6LW	100000180

MECHANICAL	
TEMP. RANGE	-30°C ⇢ +70°C
CONNECTOR	N-female
WIND SURFACE	Approx. 0.04 m²
WIND LOAD	Approx. 51 N @ 160 km/h
COLOUR	White (RAL 9003)
MATERIALS	Shroud: Polyurethane-coated glass fibre Mounting bracket: Seawater resistant aluminium, epoxy-coated Clamps: Stainless steel
TOTAL HEIGHT	Approx. 1.2 m
DIA. IN TOP END	21 mm
DIA. IN BOTTOM END	23 mm
WEIGHT	Approx. 900 g
MOUNTING	On 16 to 54 mm dia. mast tube

SPECIFICATIONS

ELECTRICAL	
MODEL	CXL 1800-6LW
ANTENNA TYPE	Coaxial, collinear antenna, broad-banded
FREQUENCY	1700 – 1900 MHz
IMPEDANCE	Nom. 50 Ω
POLARIZATION	Vertical
GAIN	8 dBi 6 dBd
BAND WIDTH	≥ 200 MHz @ SWR ≤ 1.75
SWR	≤ 1.75, typ. ≤ 1.5
MAX. POWER	100 W
ANTISTATIC PROTECTION	All metal parts DC-grounded (Connector shows a DC-short)
HCM CODE	HCM000ND00, 007DE60

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Quiz #1

- Imagine that you build a dipole antenna. The measured frequency is 150MHz but your target frequency is 160MHz, you have to?

- Cut a few centimetres at both ends of the antenna?
- Add a few centimetres at both ends of the antenna?
- Cut a few centimetres off the centre left side of the antenna?

Scan the QR code above or enter the quiz link in your browser: https://app.sli.do/event/dgjixnya

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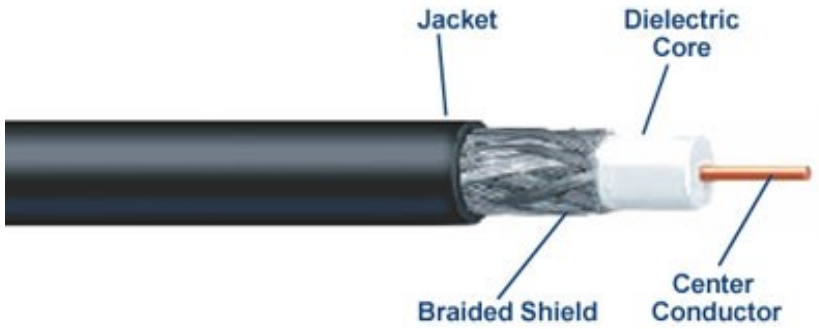
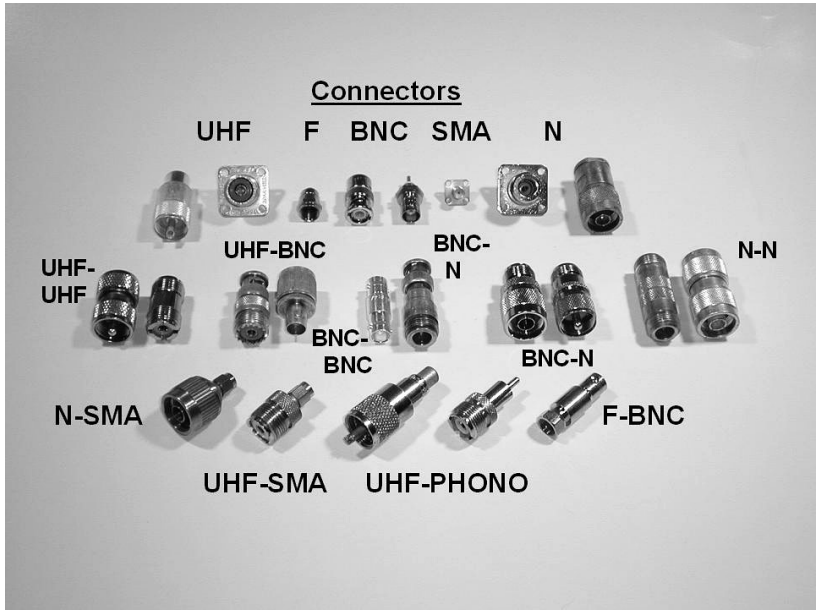
Cables and connectors

- Coaxial cables
- Connectors (BNC, N, PL,..)





Cables and connectors

- Every component between a transmitter and an antenna introduces a loss in transmission power.

Component	Loss (144 MHz @ 100m)
RG213 cable	9.2 dB
LMR600 cable	4.9 dB
N-connector	0.15 dB
Lightning arrestor	0.1 dB

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Losses

This is why it is very important to ensure the radio equipment and antennas are installed properly:

- Limit cable length in installations
- Don't bend cables or make nodes, keep them straight
- Make sure connectors are properly installed and water-proofed if outside
- Test all equipment after installation/deployment is complete

How can you measure the losses ?

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SWR (Standing Wave Ratio)

- SWR measures transmitter output power and reflected power from the antenna system
- Using an “SWR meter” installed between the antenna and the radio, we can measure the strength and quality of transmission.

Example of an SWR meter

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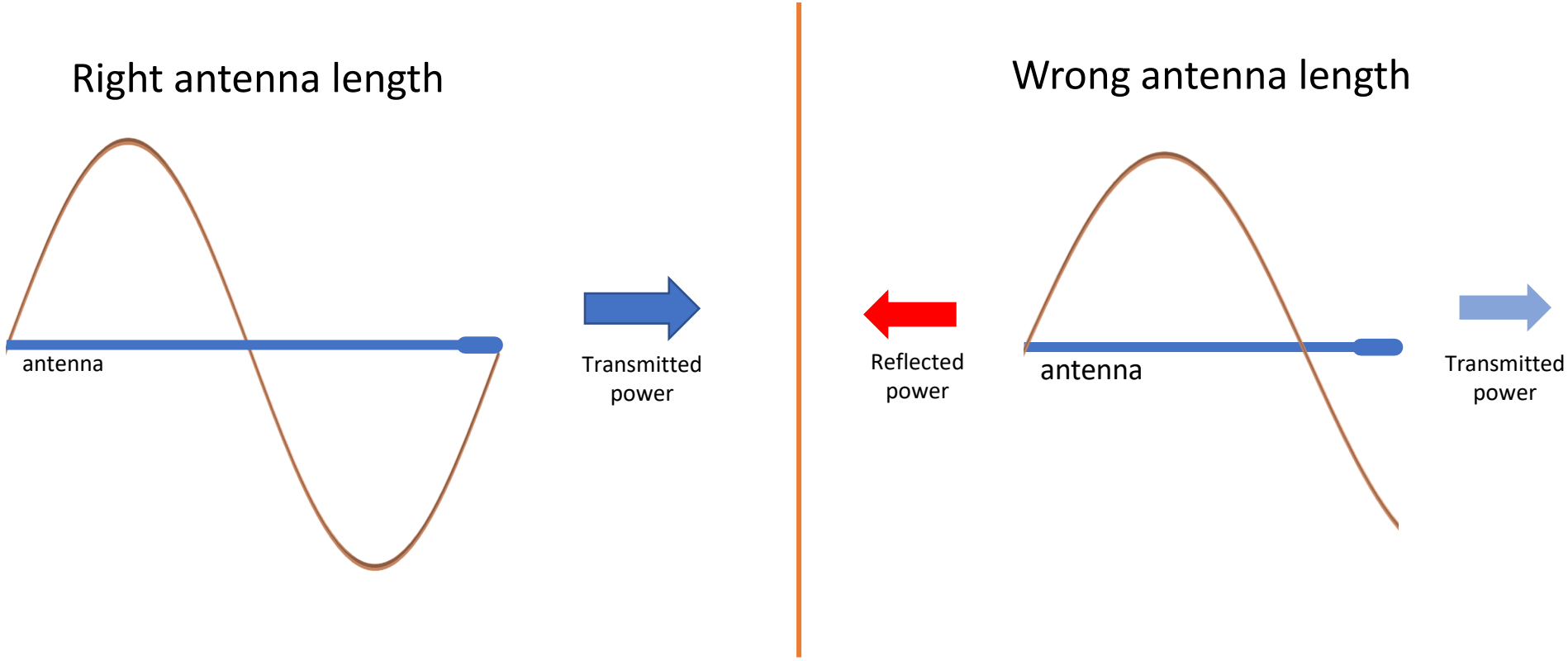
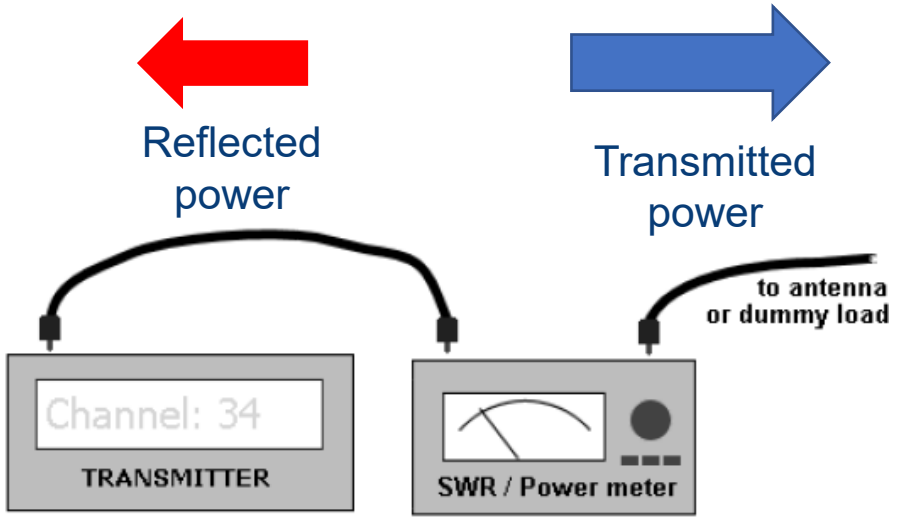
SWR and antennas

- Remember the reflected power when an antenna does not have the proper length.

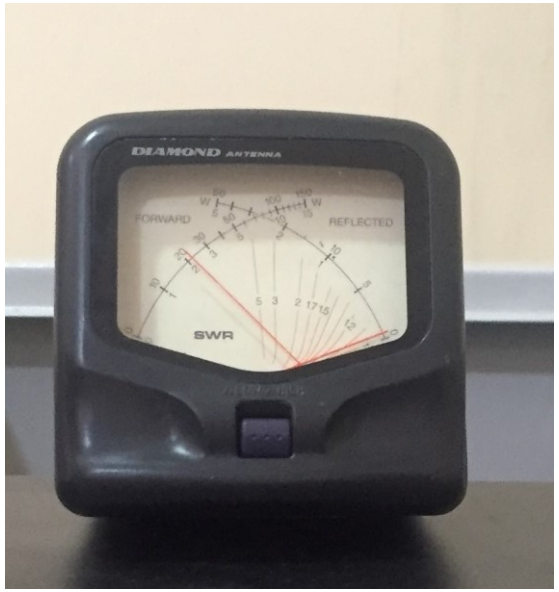


Radio basics - SWR

- When a signal is transmitted from a transmitter to the antenna, not all of the signal might be transmitted by the antenna due to various reasons, such as:
  - Antenna is not correct for the frequency used (or is damaged)
  - Open or short circuit in the cable
  - Impedance mismatch between the transmitter, cable and antenna

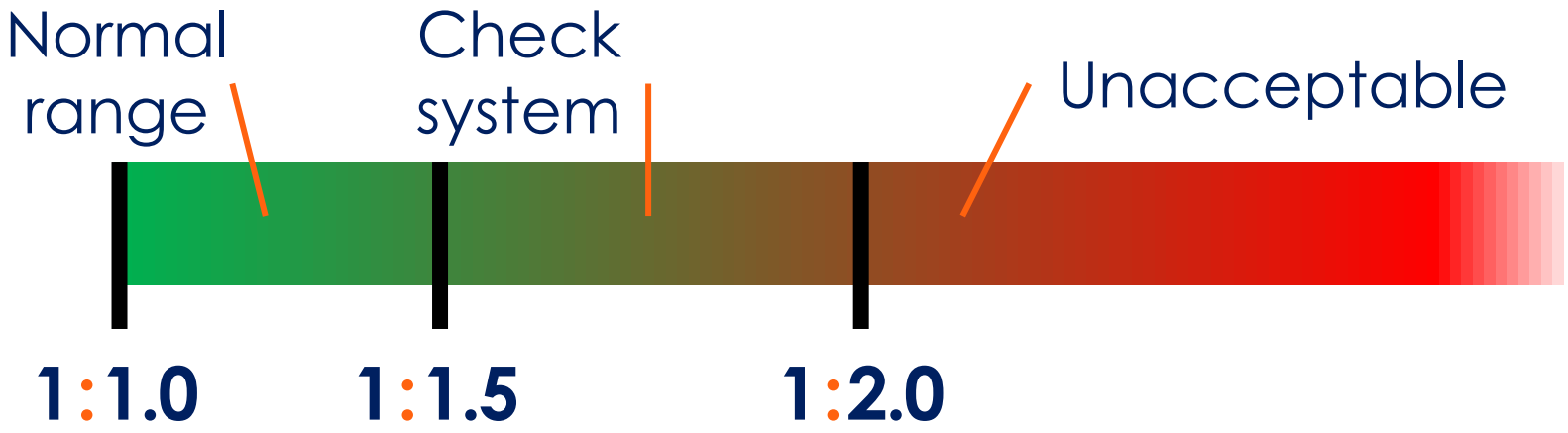


Connecting an SWR meter



SWR reading

- When none of the signal is reflected, the ratio is 1:1 (perfect reading)
- When some of the signal is reflected, the ratio is between 1:1.5 and 1:2.0 (the system can still work with this SWR but should be checked)
- Anything beyond this is unacceptable and should be rectified before using the radio



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SWR is important!

High SWR values means we don’t transmit all energy coming from the transmitter, this results in reduced coverage and can seriously damage the equipment.

Always test SWR after installing or maintaining a radio system. When troubleshooting you can measure the SWR at different points of the antenna chain to find the issue.

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Troubleshooting SWR issues

- High SWR values could be related to:
  - Loss of power to the antenna
  - Radio interference
  - Loose connector
  - Cut or damaged cable

Quiz #2

- What does a very high SWR reading mean? Select one of the following options:

1. The transmitter is putting out more power than normal.
2. The antenna is the wrong length, or there may be an open or shorted connection somewhere in the feed line.
3. There is a large amount of solar radiation which means poor radio conditions.
4. The signals coming from the antenna are unusually strong.

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Overview of two-way VHF/UHF communications

Read more about {TESS+}: www.wfp.org/telecommunications-security-standards
Email: TESS@wfp.org

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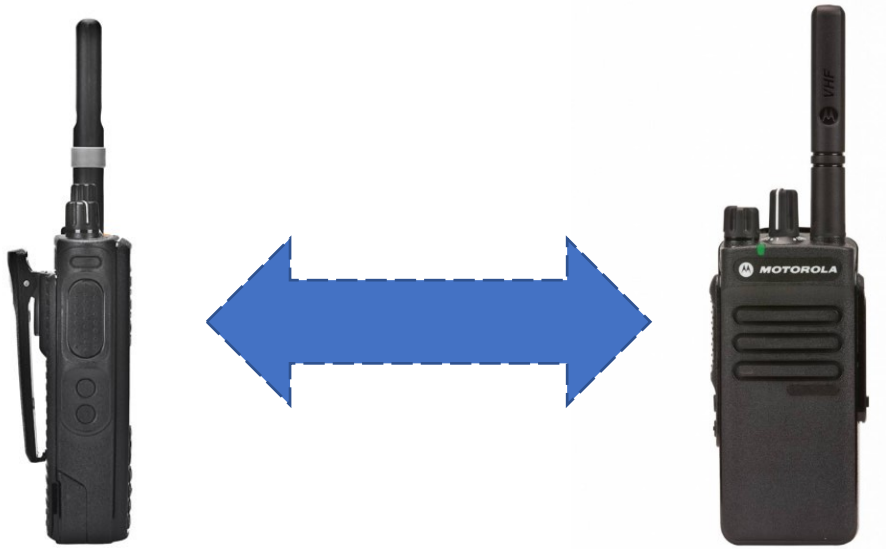
Two-way radio communications

- Two-way radio communication is a form of communication where both parties are involved in the transmission of information.
- Push-to-talk (PTT) is used in two-way radio comms. A PTT button activates the transmitter. When the button is released the radio switches to receive mode only.

Two-way radio communications - advantages

- Advantages of a well-planned two-way radio system in analogue mode:
  - Instant communication (PTT)
  - Network independence
  - Call broadcast
  - Open standard (e.g iCOM, Motorola or other brands)
  - Emergency feature built in the device



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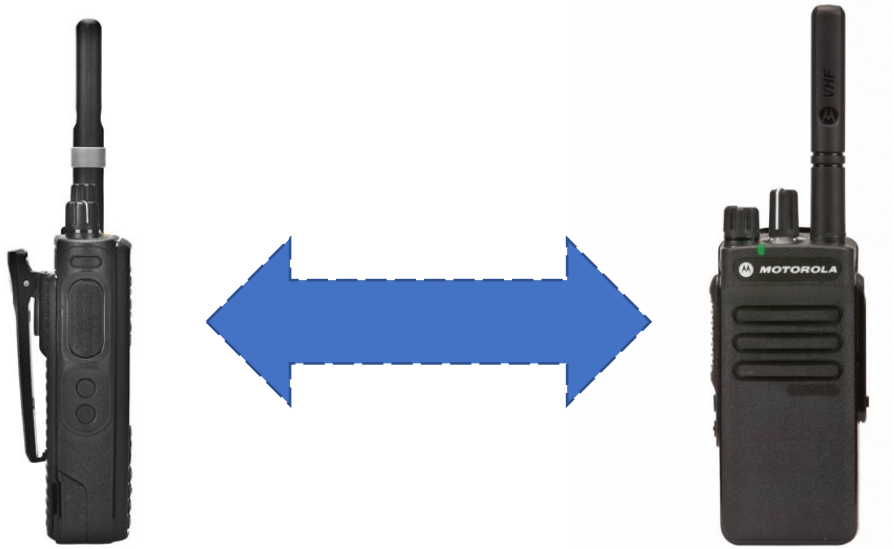
Two-way radio communications - disadvantages

- Disadvantages of a two-way radio system in analogue mode:
  - Coverage
  - No private call



VHF/UHF UN SCS network standards

The UN standard SCS (Security Communication System) VHF/UHF network is implemented with **analogue** user access and includes two basic user features:

- Basic PTT (push-to-talk).
- Sel-V ID (caller ID, stun/un-stun, emergency)

VHF and UHF comms

- Frequencies in the VHF and UHF band use “line-of-sight” (LOS), meaning that they are blocked by hills and mountains.
- To a certain degree the signal can penetrate buildings and walls, but this will weaken the signal.

Two-way radio communications - simplex vs duplex

- A channel with the same frequency for both transmitting and receiving is called a **simplex channel.**
- A channel with different frequencies, one for transmitting and one for receiving is called a **duplex channel.**

Two-way radios can operate in two modes: simplex and duplex

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Two-way radio communications - simplex

1. **Simplex** mode:
   - Uses line of sight and depends on radio output power
   - Radio stations communicate with each other directly, on the same frequency
   - No repeater or other device in between

Handheld radio range (simplex): approx. 5 – 7 km
Mobile radio range (simplex): approx. 10 – 12 km

Two-way radio communications - simplex

Simplex mode:

Receive (Rx)

and Transmit (TX)

155.000 MHz

Receive (Rx)

and Transmit (TX)

155.000 MHz

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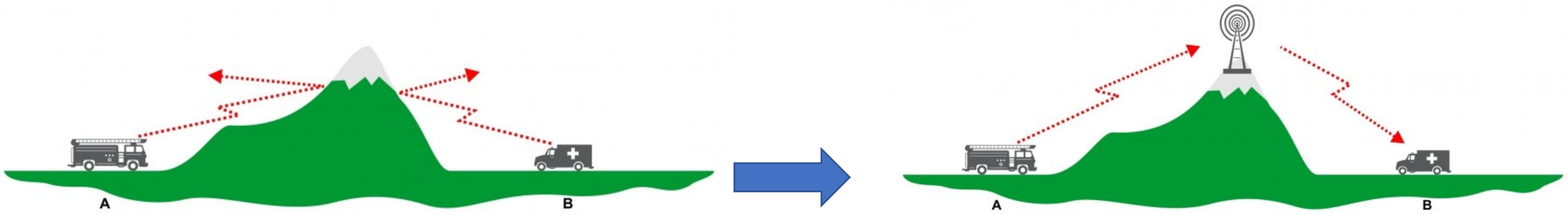
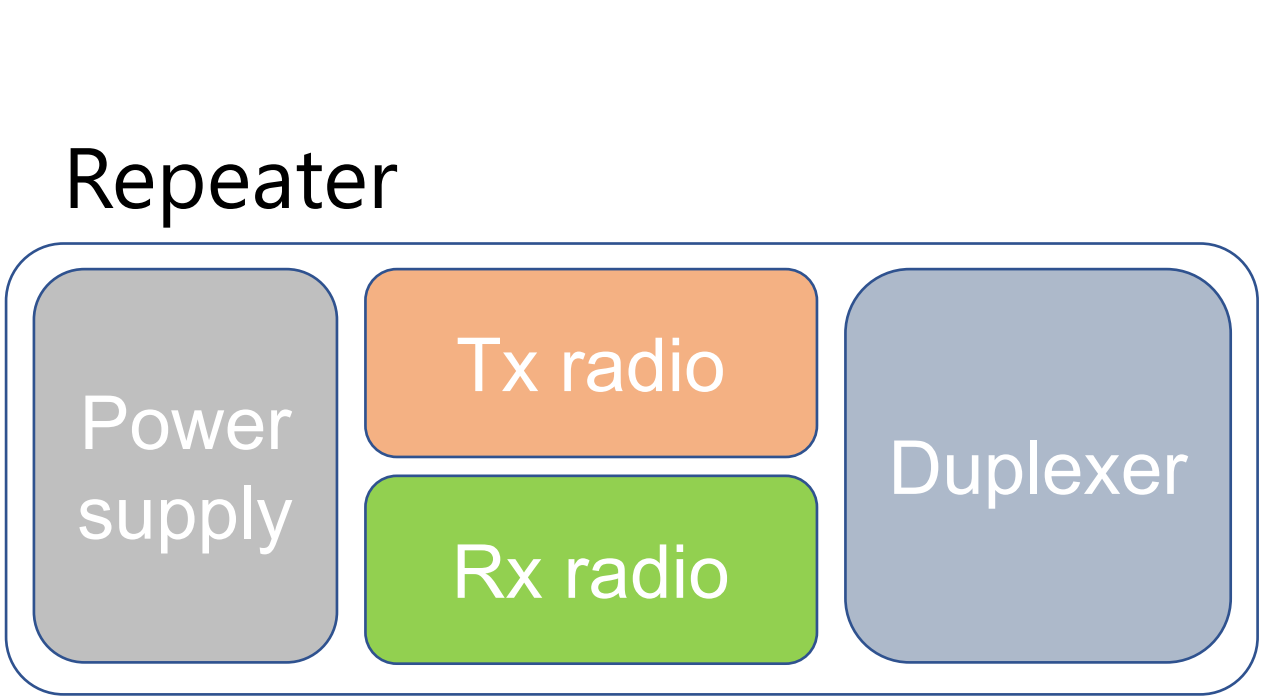
Two-way radio communications - duplex

2. **Duplex** mode:

   – Used when there is no line of sight
   – Radio station transmits on one frequency and receives on a different frequency
   – Repeater extends the radio coverage



Basic components of a VHF/UHF repeater station



Repeater

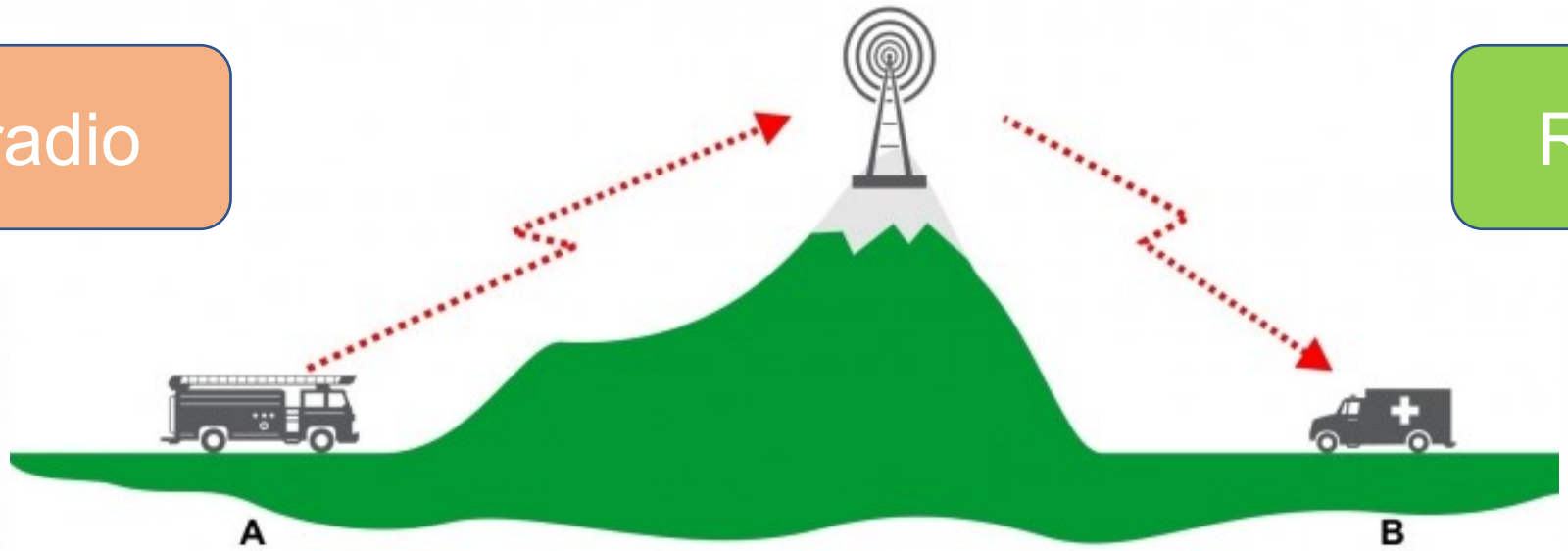
Two-way radio communications (repeater)

Rx radio

Tx radio

Tx radio

Rx radio



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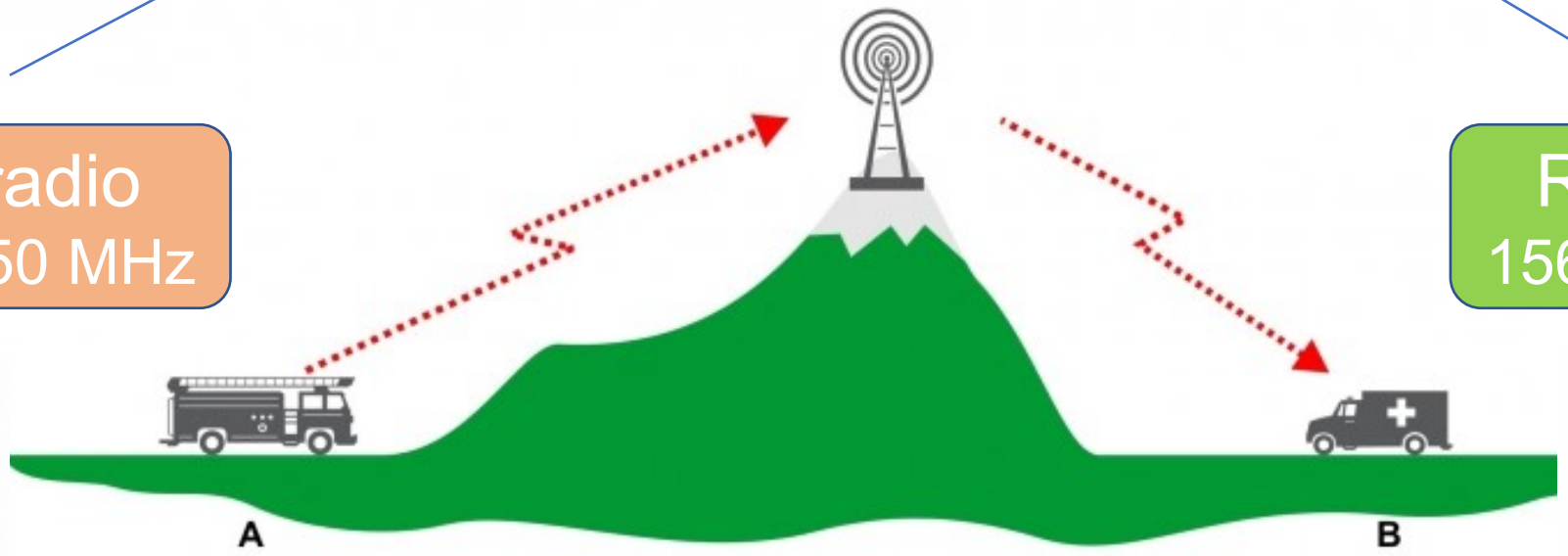
Two-way radio communications (repeater)

Rx radio
151.550 MHz

Tx radio
156.550 MHz

Tx radio
151.550 MHz

Rx radio
156.550 MHz



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Quiz #3

One VHF repeater is programmed with the frequencies:

- Tx: 155.150 MHz / Rx: 160.150 MHz

Which **Tx** frequency should be programmed in the user equipment e.g. handheld and mobile radios?

1. 155.150 MHz
2. 157.150 MHz
3. 160.150 MHz

Scan the QR code above or enter the quiz link in your browser: https://app.sli.do/event/dgjixnya

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Answer

Receive (Rx):

160.150 MHz

Repeater

Transmit (Tx):

155.150 MHz

Transmit (Tx):

160.150 MHz

User equipment

Receive (Rx):

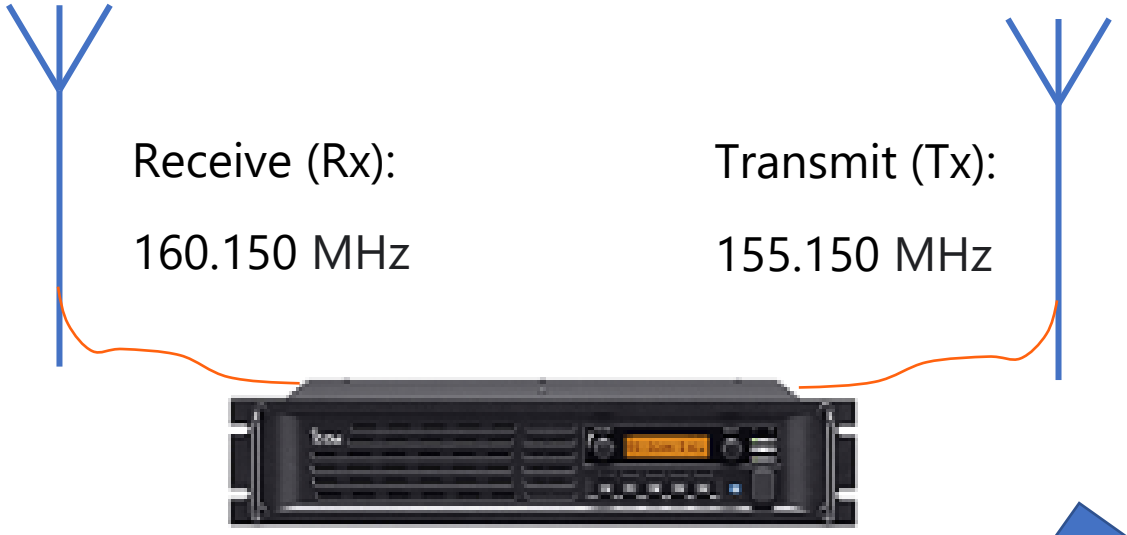
155.150 MHz

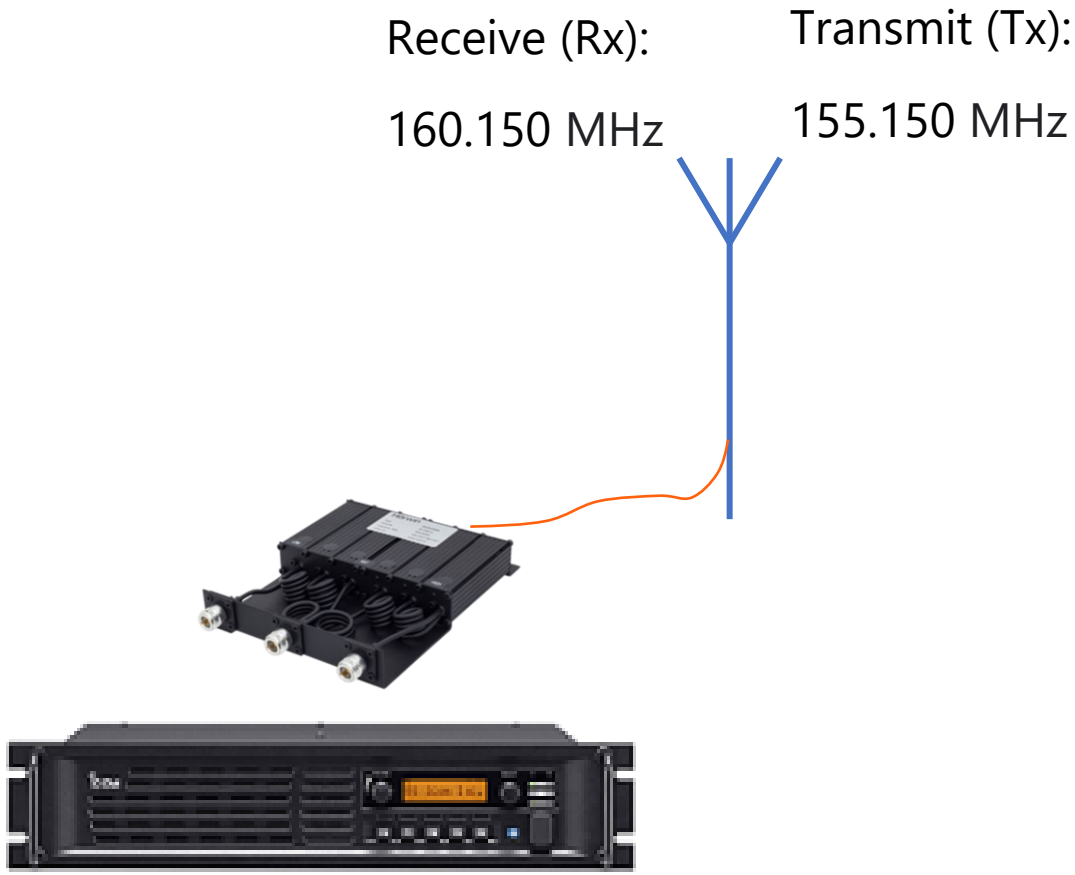
User equipment

Duplexer

- A duplexer is a passive device used in radio communication to connect a receiver (Rx) and a transmitter (Tx) with different frequencies to a single antenna
- A duplexer needs to be “tuned” to the correct frequencies.

Duplexer


Receive (Rx):
160.150 MHz
Transmit (Tx):
155.150 MHz


Receive (Rx):
160.150 MHz
Transmit (Tx):
155.150 MHz

Quiz #4

You are given the task to install a VHF repeater, but you have noticed that the repeater does not have a duplexer. Could you install the repeater?

Select one of the following options:

1. No
2. Yes, but two antennas are needed. The antennas should be installed close to each other.
3. Yes, but two antennas are needed. The antennas should be installed with a reasonable separation from each other.

Scan the QR code above or enter the quiz link in your browser: https://app.sli.do/event/dgjixnya

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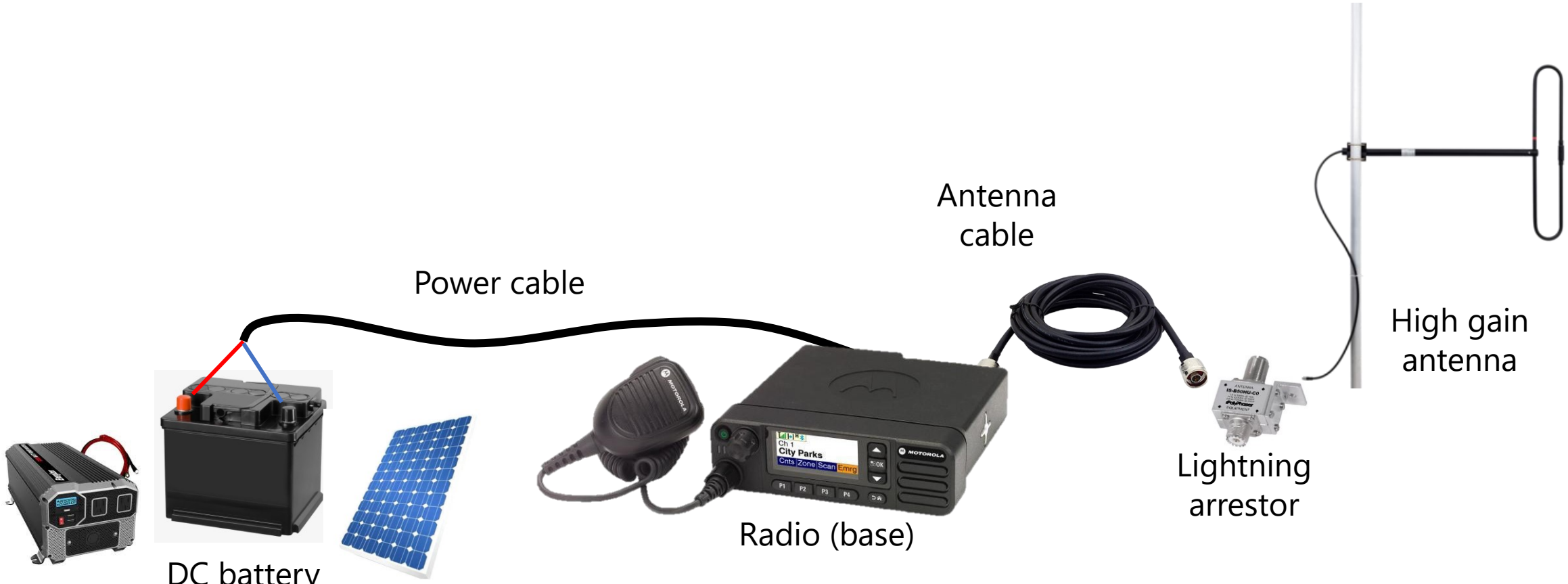
Answer

- 3. Antennas need to be installed with separation from each other.

Basically, this is the function of the duplexer. The duplexer separates the Tx from the Rx, to be able to share one antenna.

Basic components of VHF/UHF base radio station



Basic components of VHF/UHF mobile radio station

Output power radio equipment

Device	Max. transmit power
Handheld radio	5 W
Mobile / Base radio	25 W
Repeater	50 W

Reminders

- Handheld radios should ideally be used outside. When inside, radios should be used close to a window to give the antenna as much line of sight as possible to the repeater.
- A badly tuned vehicle antenna will decrease the reception from the repeater.

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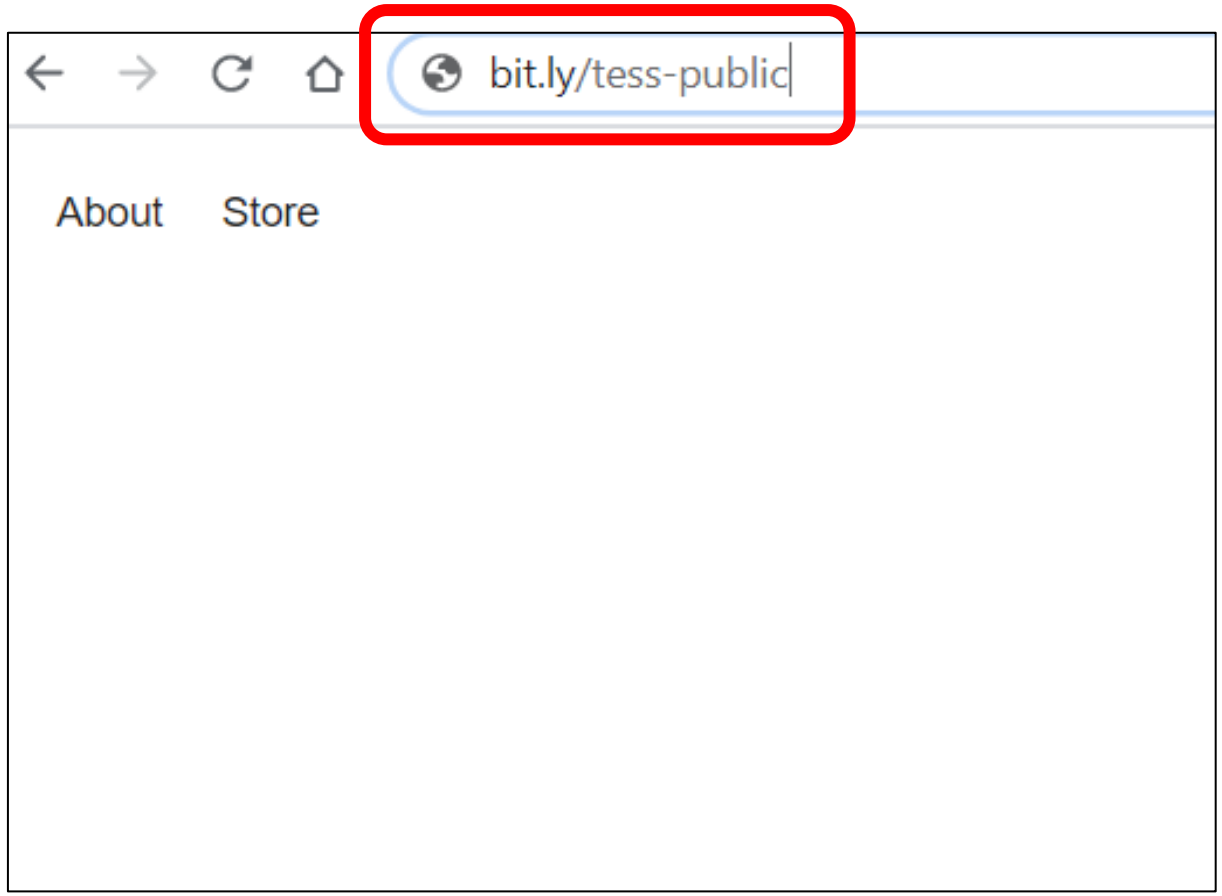
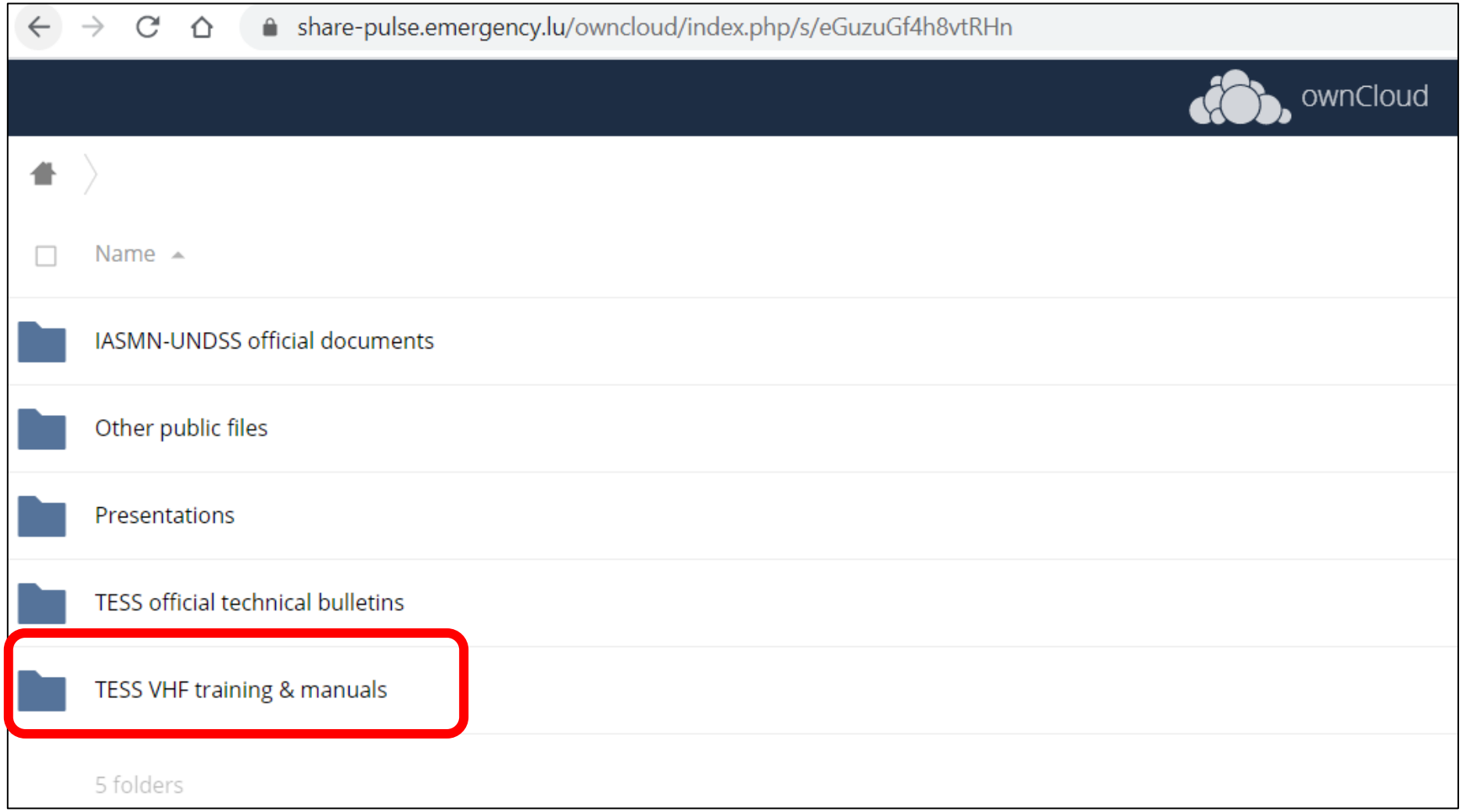
{TESS+} – where to find resources

- Go to the {**TESS+} public library** by entering this URL in your browser: http://bit.ly/tess-public



{TESS+} - Navigate to the VHF training directory

- Click on the "**TESS VHF training & manuals**" folder to access the {TESS+} VHF training package:



Questions and discussion

- We invite you to join the **{TESS+} Online Community** to receive updates about {TESS+} including invitations to future webinars.
  - Simply email tess@wfp.org and ask to be added.