



HF radio

Guide for facilitators and community installers



with the support of:



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INTRODUCTION

The following guide is an outcome of a number of workshops conducted in 2020 in Puyo and Lago Agrio, Ecuador, by Rhizomatica, together with Kara Solar Foundation and the Confederation of Indigenous Nationalities of the Ecuadorian Amazon (CONFENIAE) in the context of the COVID-19 pandemic. These training workshops were attended by members of the Indigenous nationalities of the Ecuadorian Amazon: Sápara, Shiwiar, Waorani, Kofán, Achuar, Andwa, Shuar, Quijos, Kichwa and Siekopai.

From this effort, which is ongoing as of the publication of this manual, 40 solar-powered shortwave or high frequency (HF) radios have been deployed in different parts of the Ecuadorian Amazon. These radios were installed by Indigenous technicians and local people from beneficiary communities and nationalities, who were trained during three-day in-person workshops in the second half of 2020.

Who is this guide for and what is its purpose?

The purpose of this guide is to share the basics of installing a solar-powered HF radio station.

For some years now, Rhizomatica has been working to “modernize” HF technology, allowing the transmission and reception of digital information.¹ HF technology offers many advantages for autonomous communication in remote areas, and from our experience, it is possible and feasible to train people without much previous technical experience in the installation and use of solar-powered HF communication systems.

This guide is an attempt to share the learnings from on-the-ground experiences and interactions with communities, and to facilitate and support further training processes for the use and installation of HF-based communication networks.

The guide is aimed primarily at facilitators of training processes in HF radio and as reference material for people who have at least some prior knowledge of HF radio. In other words, it is not aimed at novices or people who are completely new to the subject.

1. www.rhizomatica.org/hermes/

A LITTLE THEORY BEFORE STARTING...

What is radio frequency (RF) and how is it different from electricity?

Radio frequency (RF) is composed of waves made up of electric and magnetic fields. This allows them to travel through space without needing a medium to propagate. Some electromagnetic waves originate naturally, such as sunlight and are visible, while others, such as radio waves, are generated by devices invented by humans, such as radio or TV transmitters.

The frequency of the oscillation of the waves is the mechanism used to classify them. Electromagnetic waves, grouped by their frequencies, is what we call the electromagnetic spectrum. A small segment of this spectrum, enables general radio communications such as television, radio, WiFi, and so on, forms the radio spectrum.

What is the HF band? Why is it used? What is it useful and not useful for?

High frequency (HF or shortwave)² refers to the band of the radio spectrum between 3 and 30 megahertz (MHz).

Shortwave or HF is a radio frequency band used by international radio stations to broadcast their programming to the world, aviation communication, and by amateur radio operators (ham radio). It is also very common to use these frequencies for communication between remote or distant points.

At these frequencies, between 3 and 30 MHz, electromagnetic waves propagate in a straight line, and bounce off the ionosphere³ at different altitudes (the higher the frequency, the higher the altitude). This allows signals to reach distant points and even circle the planet, with variations in propagation and signal quality depending on the season and time of day. Due to its ability to travel very far and without line-of-sight, HF radio has been used for decades for communication in remote places far away from urban areas.

2. These two terms refer to the same thing and can be used interchangeably.

3. The ionosphere is the part of the Earth's atmosphere that is permanently ionized due to solar radiation. It extends approximately between 80 km and 400 km above the surface of the Earth. The ionosphere reflects or refracts radio waves emitted from the Earth's surface, which makes it possible for these waves to travel up to thousands of kilometers via sky-wave propagation.



THE HF RADIO TRANSCEIVER

The radio transceiver (transmitter / receiver) is a device that can send and receive transmissions in the HF band. For our purposes, the terms 'radio' and 'transceiver' are used interchangeably in this manual and refer primarily to devices for sending and receiving analog voice.

There are many makes and models of HF radios or transceivers. A very common model is the ICOM-718, a transceiver with 100 watts⁴ of output power. There are many other brands offering similar transceivers with more or less the same features such as: Yaesu, Vertex, Alinco, Kenwood, etc. These devices are sometimes referred to as HF base stations.

In any case, an HF radio, regardless of the model, should have the following configurable functions:

- ▶ Reception volume
- ▶ Frequency selection
- ▶ SSB transmission mode (USB or LSB)
- ▶ Microphone gain
- ▶ Output power

The control and configuration of these functions are normally found on the front of the radio. On the back of the radio it is common to find the connectors for the 50 ohm⁵ coaxial cable coming from the antenna (connector type PL-259 / UHF) and another one for the power supply.



4. The watt is a unit used to express power, its symbol is W. In this case, watts are a useful measure of output power of the radio signal.

5. The ohm is a unit used to measure electrical resistance, its symbol is Ω (Omega). For the purposes of this manual, the devices, cables and antennas referred to are all 50 ohm.



Powering an HF radio

In terms of providing electricity to power the radio, most HF radio transceivers require 12V DC to 14V DC. This means that they can be powered by connecting directly to a 12V DC battery, common in solar and even car power systems.

If alternating current (energy from the public electrical grid) is to be used, an external power supply or transformer that converts alternating current (AC) into direct current (DC) is required. It is recommended to use a power supply rated for at least 25 amperes (for example, the 13.8V DC Astron SS-25⁶).

Programming transceiver settings

To configure the radio, some key parameters to consider are:

Transmit/Receive mode:

Most models offer different transmit modes such as AM, CW, SSB, etc. For listening to AM broadcast, the AM mode is used. For voice transmission and reception, Single Side Band (SSB) mode is used. This mode has two sub options: upper side band (USB) and lower side band (LSB).

For historical reasons, for frequencies below 10.7 MHz it is customary to use lower sideband (LSB) mode, and above 10.7 MHz, upper sideband (USB). For communication between two stations or HF radio transceivers, it is important that both use the same transmission mode (LSB or USB).

Output power:

Output power is a parameter that can be set to define how many watts of output power the radio will use to transmit. It is often not necessary to use the full power of the radio to be heard hundreds of kilometers away. Using the radio at full power is fine, but it uses more energy, and if connected to alternative power systems, it may limit the functionality of the system by discharging the batteries.

An energy saving tip:

If the listener or receiver receives the transmission with 100 watts, set output power down to 60 watts or 40 watts of power and check if they are still copying.

Microphone gain:

This parameter is important because it influences the quality of audio heard by those receiving the transmission. If the microphone gain is low, it will be difficult to hear; and if it is too high, the audio will be very noisy, distorted and saturated.

6. <https://www.astroncorp.com/switching-desktop>

THE ANTENNA

An antenna is a device usually made of a metallic conductor, designed for the purpose of emitting and/or receiving electromagnetic waves into/from free space. A transmitting antenna transforms electrical energy into electromagnetic waves, and a receiving antenna performs the reverse function. In HF radio, the antenna we connect to the radio performs both functions: receiving and transmitting.

The characteristics and performance of an antenna depend on the relationship between its dimensions and the wavelength of the radio frequency signal transmitted or received. Also, in the case of HF, the height of the antenna above the ground affects the angle of incidence of the signal in the ionosphere. Hence, the closer the antenna is to the ground, the better the close coverage, the higher the antenna, the better the long distance coverage.

There is a great diversity of antenna types. In the case of HF radio, an easy antenna to make is a simple dipole. To make this antenna it is necessary to know the frequency on which it will transmit and receive. A simple dipole is only good for one frequency. If it is necessary to use multiple frequencies another type of antenna can be chosen: a multiband dipole (tuned to two or three frequencies) or a broadband antenna covering all HF frequencies from 3MHz to 30MHz.

What is a dipole antenna?

A simple dipole antenna receives the coaxial cable coming from the radio transceiver at its center, from which two radials emanate (one on each side). The length and thickness of the radials are determined by the type of use to be given to the antenna, especially the frequency it will use.

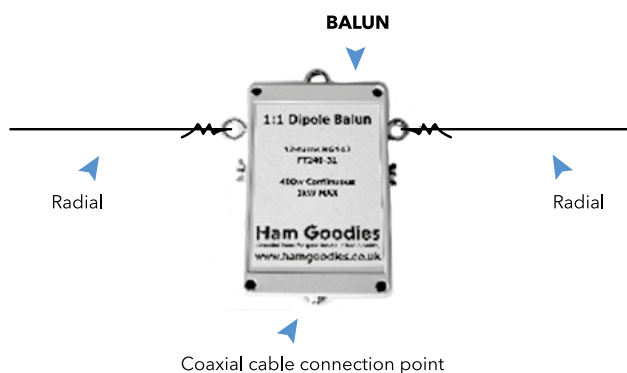
It is recommended to make the radials with 10 or 12 AWG (2 mm or 2.5 mm) copper electrical wire. In the center of the antenna it is common and recommended to put a 1:1 Balun, which helps to obtain better performance from the antenna, eliminating noise and other problems.

To calculate the length of each radial in meters (there are 2 in total), there is a simple equation:

**(143 ÷ the frequency)
and then the total ÷ 2**

For example, if the frequency is 7.5MHz, the length of each radial is 9.53 meters.

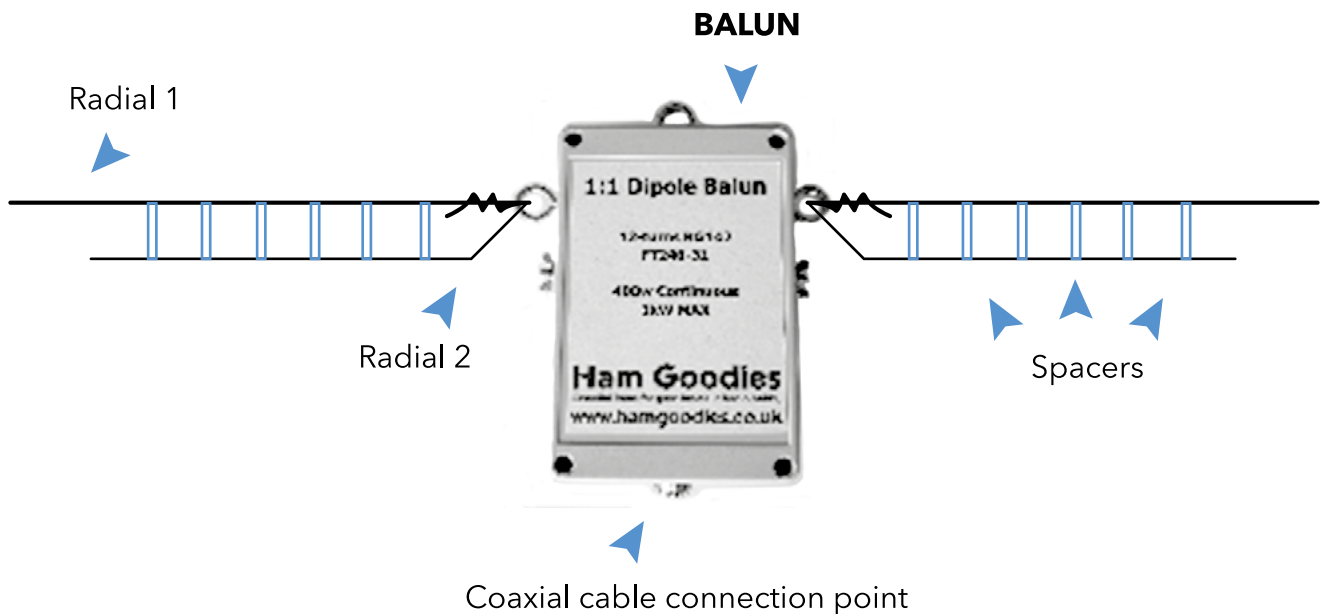
$$(143 \div 7.5) = 19.067 \div 2 = 9.53$$



A dipole antenna for multiple frequencies

If it is necessary to cover multiple frequencies with the same antenna, simply add another radial of the length corresponding to the frequency on each side of the antenna (with the Balun at the center).

To separate the radials on the same side, 30 cm lengths of one inch (25 mm) or one and a half inch (38 mm) diameter PVC pipe can be used. Holes are drilled at each end to allow the radial cable to pass through. It is recommended to place the radial spacers every 2 meters.



A dipole antenna for all HF frequencies

If it is necessary to be able to switch frequencies and use the entire HF band from 3MHz to 30MHz, there are "broadband" antennas that can be purchased or built. These are more expensive and complex to make than simple dipole antennas as they require specialized parts.

It is important to know that using such an antenna has its pros and cons. Obviously, one advantage is to be able to use any frequency in the entire HF band. However, this could cause legal or administrative problems when using frequencies for which you do not have permission. From a technical point of view, a broadband HF antenna absorbs quite a bit of power instead of radiating it out, which could limit the range of the station.



MULTI-BAND ANTENNA AT THE CONFENIAE HEADQUARTERS, PHOTO: KARA SOLAR.

How can I build my own antenna?

Tools:

- ▶ Soldering iron and solder, pliers, cutting pliers, tape measure, drill and drill bits, knife or cutter, small adjustable wrench and electrical tape.

Materials to make a simple single frequency band dipole antenna:

- ▶ Copper wire - AWG 10 or 12. It is important to do the math to know how much to purchase for the radials and to have at least 20% more on hand (see page 7).
- ▶ Balun 1:1 - This can be purchased or can be made. MFJ-918 and Radiowavz B11F are relatively easy to find models available from electronics stores or radio equipment suppliers.
- ▶ PVC pipe - 1 meter of 1.5 inch (38 mm) diameter.
- ▶ Rope or steel cable for hanging/attaching the antenna.

Materials to make a multiband dipole antenna

- ▶ Balun 1:1
- ▶ Rope or steel cable to hang/attach the antenna.
- ▶ PVC pipe - 1.5 inch (38 mm) diameter, lengths of 30 cm, to separate the radials every 1.5 or 2 meters.
- ▶ Enough copper wire for all the radials, which can be 4 (2 frequencies), 6 (3 frequencies) or more.

Remember that each frequency has a corresponding radial length.

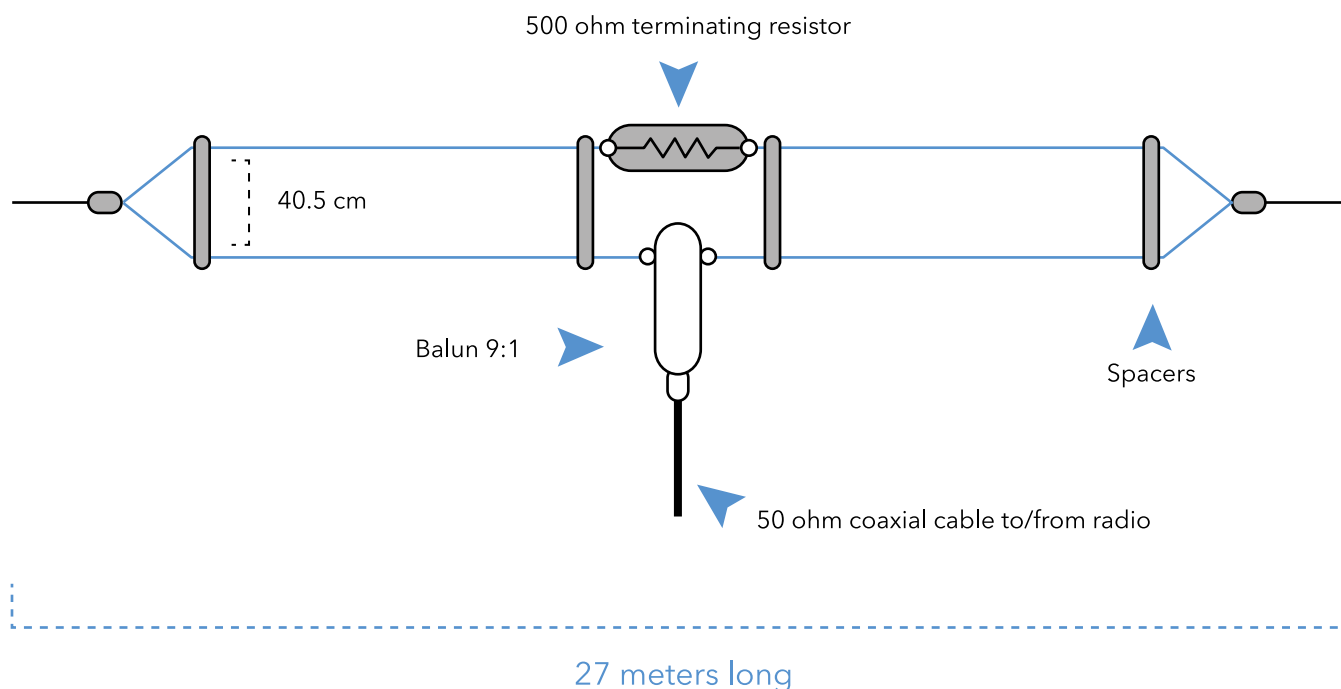
Materials to make an all band or broadband antenna - T2FD type

- ▶ Balun 9:1⁷
- ▶ 500 ohm terminating resistor⁸
- ▶ PVC pipe - 1.5 inch (38 mm) diameter, lengths of 40.5 cm, to separate the radials every 1.5 or 2 meters.
- ▶ 57 meters of AWG-10 cable cut in half (2 lengths of 28.5 meters).

7. <https://palomar-engineers.com/antenna-products/Bullet-50-450-9-1-HF-Balun-1-8-61-MHz-500-1500-Watts-T2FD-BBTD-ALE-p133084125>

8. <https://palomar-engineers.com/antenna-products/Termination-Resistor-500-Ohm-Non-Inductive-for-T2FD-BBTD-Rhombic-1-61-MHz-375-Watts-p136240953>

Tilted Terminated Folded Dipole Antenna (T2FD)



How do I test and tune the antenna?

To evaluate whether an antenna is correctly tuned to the desired frequency, it is recommended to use a wattmeter with forward and reflected power measurements or an antenna meter/analyzer.

A wattmeter measures the power radiating from the antenna (forward) and the power reflected from the antenna back to the radio. The less the reflected power, the better.

The logarithmic ratio between the outgoing and reflected power is called the Standing Wave Ratio (SWR). The SWR starts at 1 (no reflection) and is identified on the wattmeter at the junction between the two wattmeter needles.

Up to 1.4 SWR is a good value for the antenna (2.8% power return). Above 2.0 SWR is detrimental (11.1% of the power returned), and above 3.0 (25.0% of the power returned), operations should stop, and antenna maintenance or adjustment should be performed.

In case it is necessary to use an unmatched antenna (with high SWR), an antenna tuner is required. Manual antenna tuners have knobs that are turned and adjusted until a low SWR is achieved. Typically antenna tuners are also wattmeters, as shown below:



◀ WATTMETER

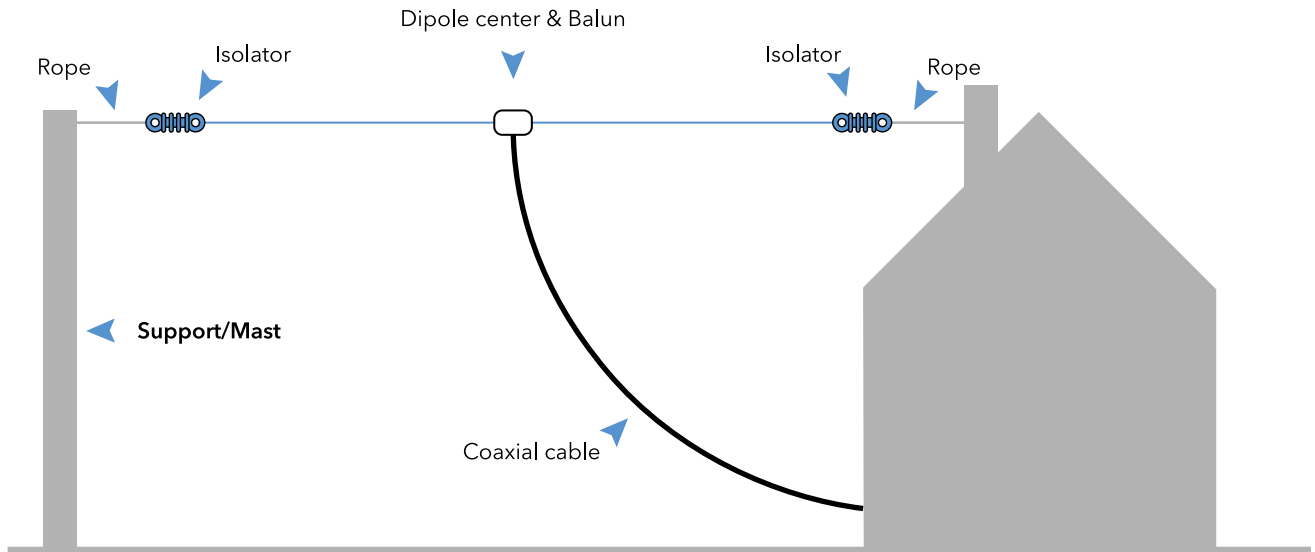


◀ ANTENNA TUNER

How to install an HF antenna

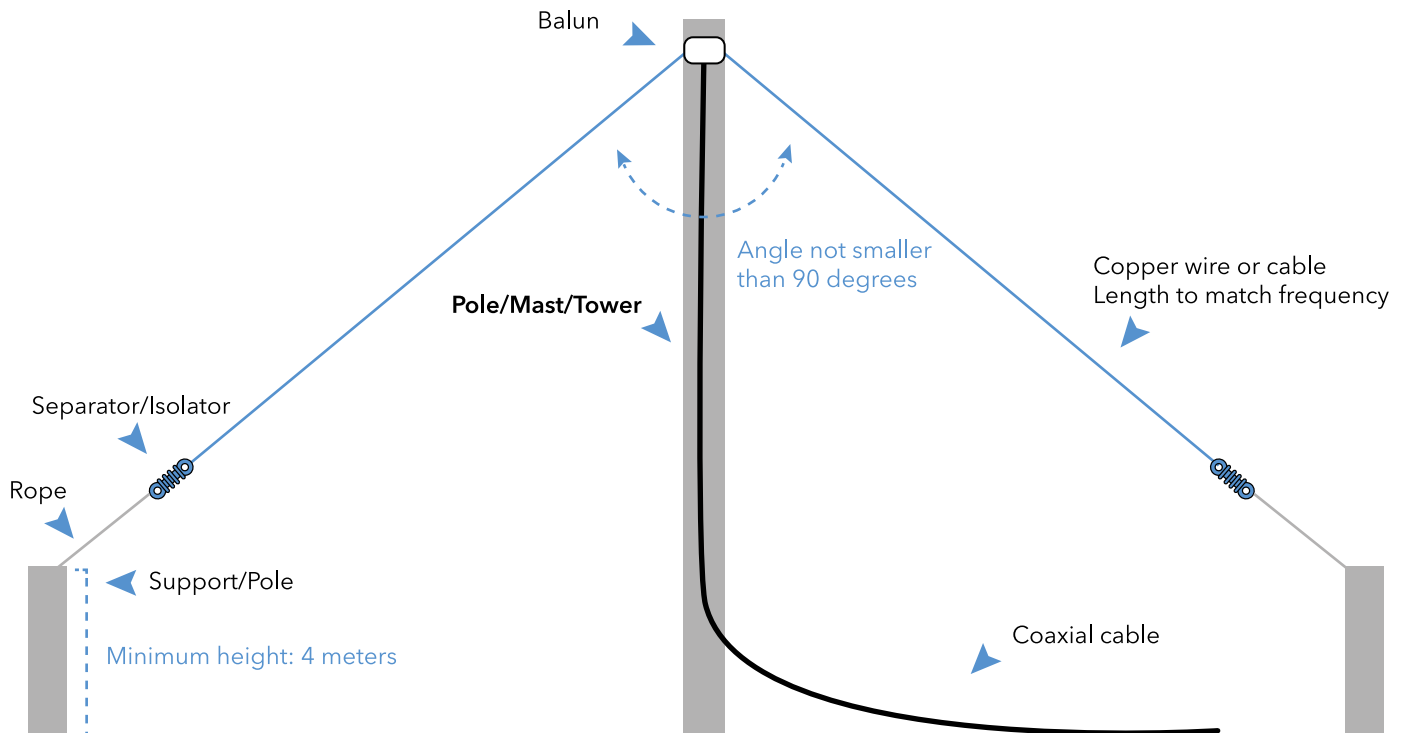
First off, it is important to consider that, due to the length of HF waves, most HF antennas are large and take up a lot of space. A dipole HF antenna can occupy from 5 meters (30MHz) to 48 linear meters (for 3MHz), depending on the frequency. This is key at the time of installation because the antenna must be installed parallel to the ground (horizontal).

It is recommended to look for an open space, without trees or buildings blocking the view of the sky, but close enough to where the radio transceiver is located, so that the radio can be connected to the antenna by a cable (it is recommended not to exceed 50 meters of cable). In many cases the antenna can be installed on a roof or in an open field using poles to raise it off the ground.



Another way to install a dipole antenna is as an "inverted V", which will be supported in the center with the ends lower than the center. Viewed from the side, it looks like an inverted or upside down "V". The advantage of this mode is to save linear space, making it ideal for rooftops.

INVERTED V DIPOLE ANTENNA



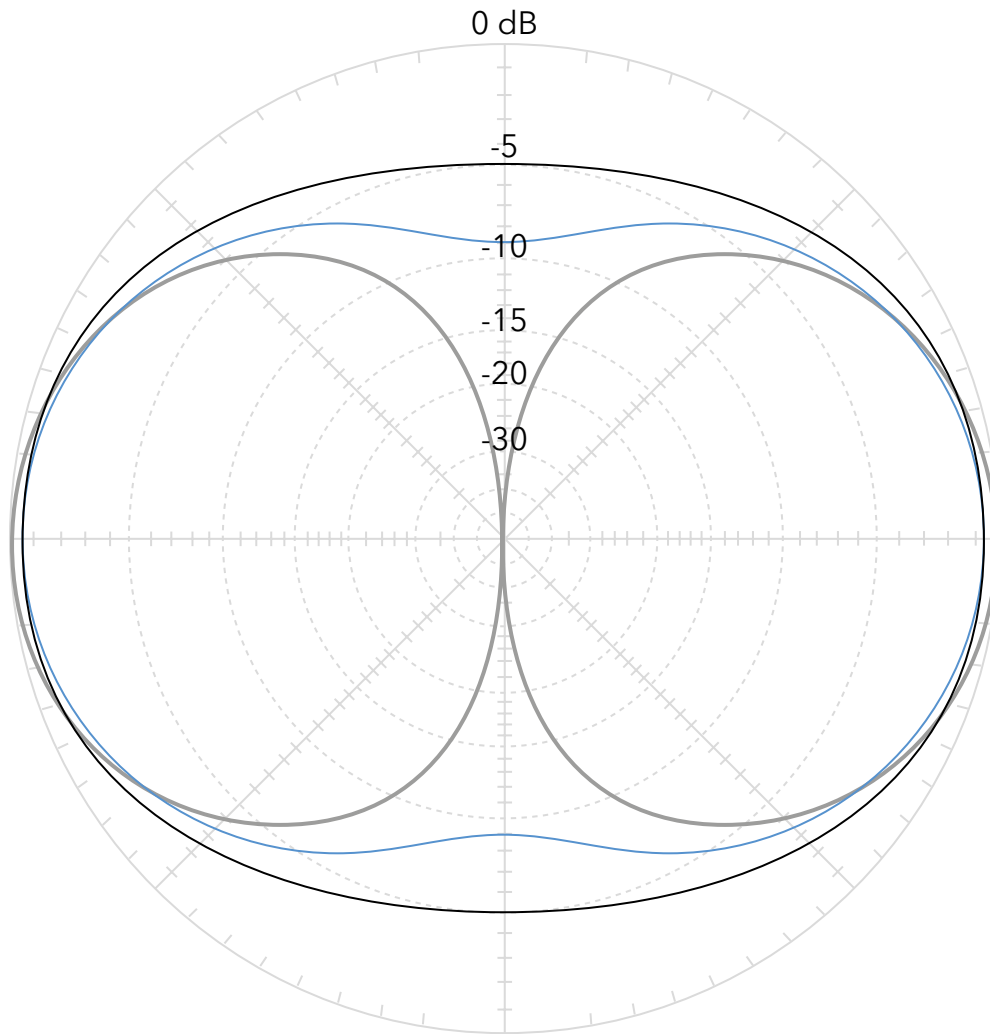


SAPARA TECHNICIANS CONNECTING A CHARGE CONTROLLER, PHOTO: KARA SOLAR.

An inverted-V dipole antenna has a more or less omnidirectional radiation pattern towards the Earth's surface, while a horizontally oriented dipole antenna has radiation nulls in the direction of the antenna elements, as shown below. In this schematic, the black line shows the radiation pattern of the horizontal dipole and the blue line shows the inverted-V radiation pattern.

AZIMUTH PLANE FREE SPACE RADIATION PATTERN

14,15 MHz

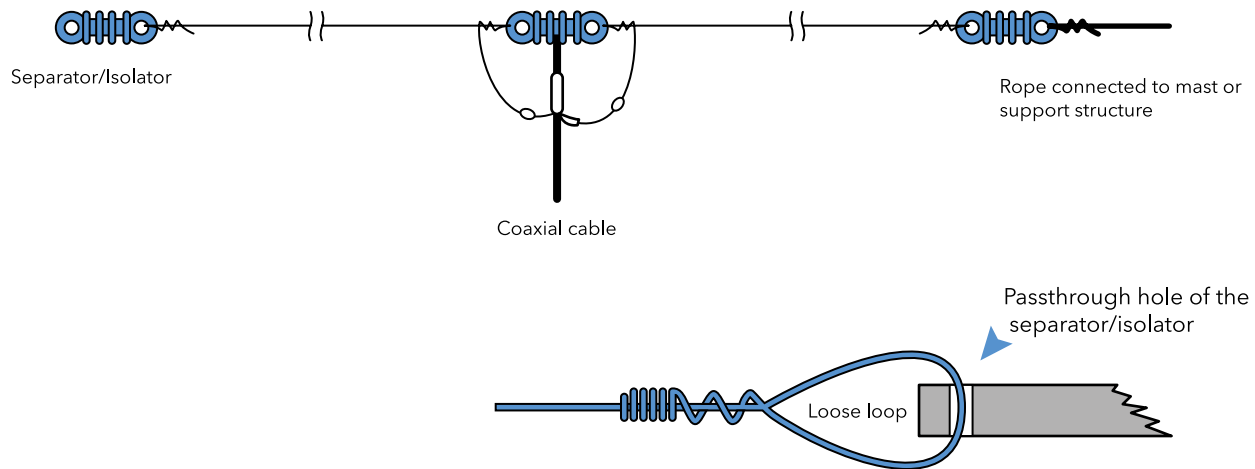


Black: Inverted U
Blue: Inverted V
Gray: Dipole

Securing the antenna radials

To fix the ends of the antenna (in this case, the tip of the radials) it is necessary to separate or electrically isolate the radial/antenna and the thing or place where it is going to be affixed (tree, pole, tower, building, etc.). There are commercial separators available, but in reality a piece of PVC pipe of 1" or 1.5" diameter (25 or 38 mm) and 6" (15 cm) long is sufficient for the task.

A STANDARD DIPOLE ANTENNA SETUP



RF CABLE AND CONNECTORS

The coaxial or RF cable is the transmission path between the radio and the antenna.

In HF systems, the length of this cable is not so important, but it is recommended to avoid very long lengths (more than 50 meters) in order not to lose transmission power. The radio emits a certain amount of power and if the cable is too long, not all the power reaches the antenna to be emitted, due to attenuation of the signal in the cable. Similarly, a very long cable can also affect the reception of weaker signals and, therefore, the usefulness of the system for communication. For example, on a 30 meter RG-8 coaxial cable with a 100 watt HF radio on the 6MHz frequency, there is a loss of 10 watts between the radio and the antenna. With 50 meters of cable, the loss is 15 watts.

What is coaxial cable?

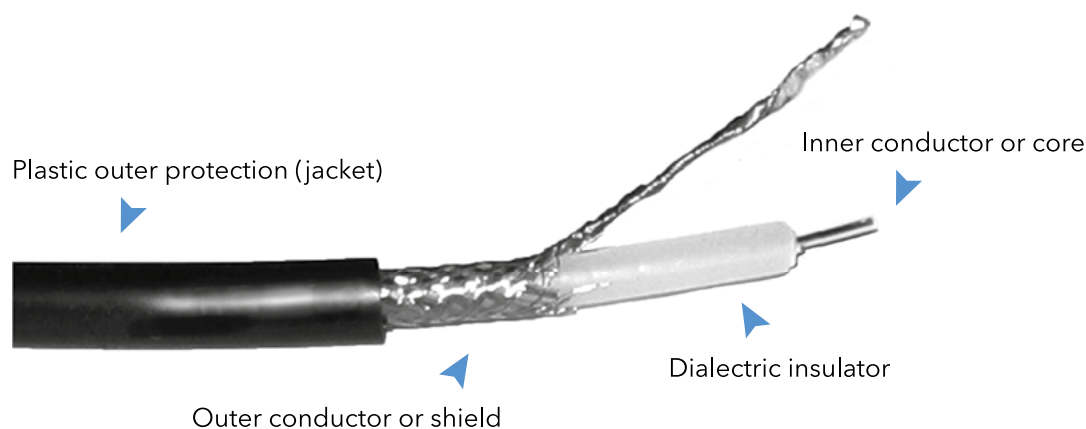
It is a cable used to carry high-frequency electrical signals and has two concentric conductors:

- ▶ A central one, called the core, which carries the signal / information.
- ▶ An outer one, tubular in appearance, called the shield, shielding or braid, which serves as a ground reference and current return.

Between the two conductors is a dielectric insulating layer, the characteristics of which mainly determine the quality of the cable. The whole assembly is usually protected by an exterior insulating material, also called a jacket.

Most common radio frequency systems, such as HF, use 50 ohm coaxial cable. RG-8 is a very common type of coaxial cable, reasonably priced and durable. Another good option is RG-58, which is cheaper and lighter, but less efficient, i.e. there is more loss in long runs.

PARTS OF THE COAXIAL CABLE



What connectors does coaxial cable use?

It is necessary to attach a PL-259 type RF connector (commonly called UHF connector) on both ends of the coaxial cable. This connector allows connection to the HF radio and antenna.

There are two models of this connector, one is for crimping with a special tool and the other is for soldering.

PL-259 connectors also have to be chosen depending on the type of coaxial cable used (RG-8 vs. RG-58, for example), as they are of different thicknesses.



It is possible to buy cables with the connectors already in place. It is also possible to attach the connectors yourself, although some tools are required.

How to connect a PL-259 connector to RG-8 coaxial cable (solder type)

The following tools are needed:

- Knife or cutting blade
- Soldering iron and solder wire
- Multimeter
- Cutting pliers

There are videos online that offer a good starting point with step-by-step instructions.⁹

9. <https://youtu.be/uJKRcxKQlyM>



MEASURING THE PROPERTIES OF AN ANTENNA, PHOTO: KARA SOLAR

POWERING THE SYSTEM

Most HF radios require between 12 and 14 volts of direct current (DC) electricity, which means that they can be powered directly from a 12V battery that is common in photovoltaic (solar power) systems, or even from a car battery in case of emergency.

For each installation, it is necessary to define what or how the power supply of the radio will be. Here we will consider two options: grid and solar power.

Using grid electricity to power the HF radio equipment requires a power supply to transform the 110V or 220V AC power coming from the wall socket to the 12V DC (ideally 13.8V DC) that the radio uses.

There are many options for these power supplies, and it is recommended to use a minimum 25 ampere solid state power supply, such as the Astron RS-35A. A switching power supply is also an option, but it is important that it be of good quality, such as the Astron SS-25 or SS-30.

In the case of **using renewable energy**, such as a photovoltaic or solar system, there are many options, but the minimum requirements are:

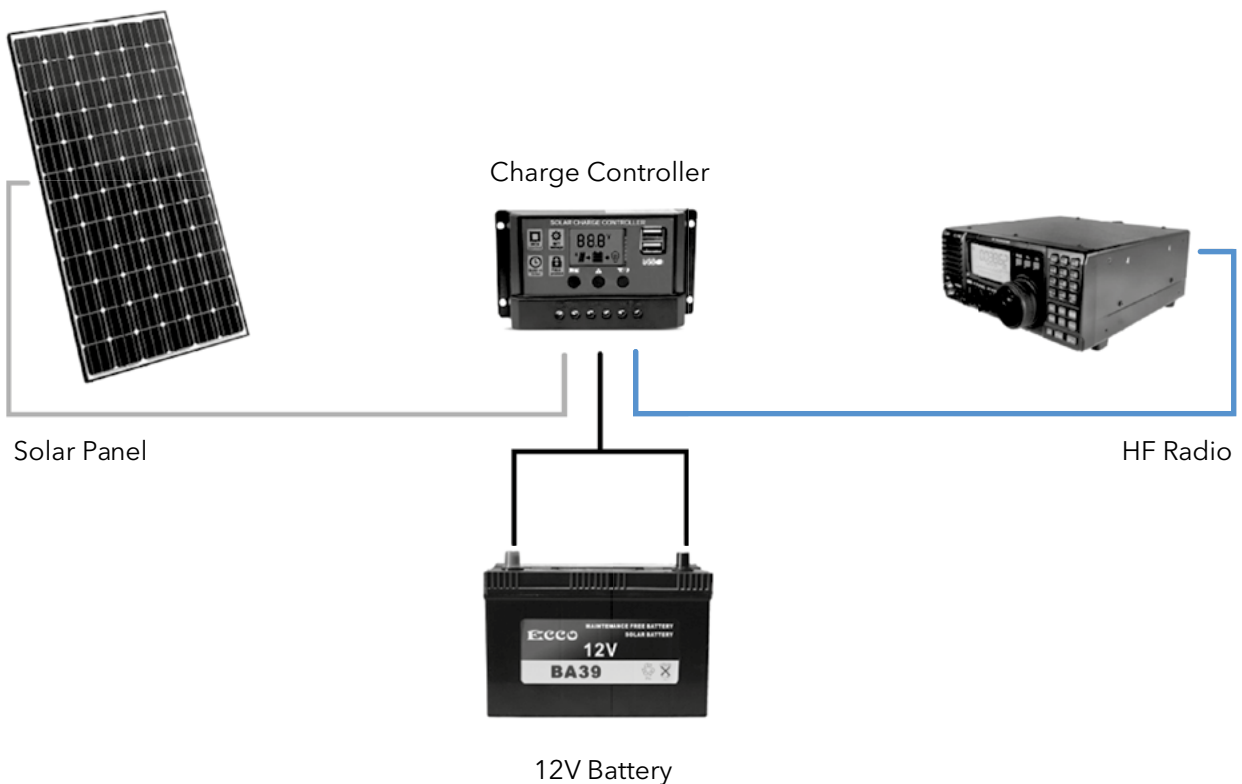
- ▶ A 12V **battery** suitable for solar systems. It is not recommended to use a 12V car battery because its lifetime in this application would be very limited, due to the fact that the battery will be charged and discharged frequently. A 100Ah battery is recommended, with 150Ah being an even better option.
- ▶ One or multiple **solar panels**. Preferably 150 or 200 watts and 12 volt output.
- ▶ A solar **charge controller** (preferably PWM type) rated for 12 volts and 30 or 40 amps. The charge controller is a device that regulates the voltage coming out of the solar panel and distributes the power to charge the battery and to be used by the HF radio. The battery, panel and radio are connected to the controller, each with its positive and negative cables in the assigned spaces.
- ▶ Black and red **stranded copper electrical wire**, AWG-10 thickness.

Charge controller installation

The charge controller has a very specific installation order that must be followed each time it is installed or connected. It is important to always follow this connection sequence:

- 1.** Connect the battery to the charge controller, positive (+) pole first and then negative (-) pole. To avoid voltage in the wiring, first connect the cable to the controller and then to the battery.
- 2.** Connect the solar panel to the charge controller, positive pole first and then negative pole.
- 3.** Connect the radio to the charge controller, positive pole first and then negative pole. First connect the wires to the charge controller, then to the radio.

To uninstall the system, follow the procedure in reverse: start by disconnecting the radio, then the panel and finally the battery.



Important tips for installing photovoltaic electrical systems

The entire installation depends on where the radio and antenna will be placed. Once that is defined, the task is to analyze where and how to place the solar panel in an area where it will receive direct sunlight most of the day, which is usually the roof of the same building or structure where the radio is installed. It is also important to remember that the radio installation site should not be so far away (less than 50 meters) from the open area (roof, field) where the HF antenna will be placed.

It is crucial to connect the cables coming out of the battery correctly (positive to positive and negative to negative), never interchange them. One way to identify the cables is by color (black or blue will always be negative, red or white will always be positive). The solar panel also has two wires, one positive (red) and one negative (black). If both wires are the same color, look for the + and – symbols

Finally, it is important to keep the solar panel(s) clean and out of the shade.



TESTING THE HERMES SYSTEM, PHOTO: KARA SOLAR

IMPORTANT TIPS FOR THE INSTALLATION OF AN HF RADIO SYSTEM

- ▶ **NEVER EVER** connect the radio to a power source or turn it on without first connecting it to an antenna.
- ▶ Install in a location where the radio can be protected from the elements and where there is not a lot of foot traffic to avoid accidental disconnection.
- ▶ Remember that the RF coaxial cables that connect the radio to the antenna should not be longer than about 50 meters in length. The longer the distance, the better the cable to be used (RG58: short, RG8: medium, RGC213: long) to avoid power loss. Care should be taken in choosing the place to install the antenna so the coaxial cable can easily reach the radio without strain on the cable and connectors.

Antenna installation

- ▶ The antenna should be installed in an open location, with no trees or buildings around it to block its full view of the sky.
- ▶ The antenna should be installed horizontally parallel to the ground or in an inverted V-shape. It may be necessary to put a pole in the center where the antenna connects to the RF cable connector and the Balun to make this possible.
- ▶ In a multi-band antenna, the radials should be oriented on top of each other. It may be necessary to put a pole in the center where the antenna connects to the RF cable connector and the Balun to make this possible.
- ▶ The antenna has to be installed at least 4 meters above the ground, to transmit better and to avoid accidents with people walking or living nearby.
- ▶ Any cable should always be well secured and placed in a way that it does not hinder the transit of people or can be easily mistreated (stepped on, used to hang things on, etc.).
- ▶ If there is a thunderstorm, it is good practice to disconnect the antenna and power supply cable to avoid damage to the radio from lightning.
- ▶ **CAUTION**, never connect the radio to its power source or turn it on without an antenna connected. Ensure both ends of the coaxial RF cable are connected, one end to the radio and the other to the antenna.

Sealing the cable/connector

- ▶ Before raising the antenna, the coaxial cable must be connected to the antenna connector or Balun.
- ▶ To prevent water from entering the cable, it is important to seal the connection between the cable and the Balun or antenna connector. To do this, it is recommended to first use a layer of black electrical tape or outdoor insulation tape (e.g. Scotch 33+), then a layer of self-fusing tape (e.g. Scotch 23), and finally another layer of electrical tape.

To make the layers, the cable is wrapped starting just below the connector until the connector is completely covered so that no water can enter from the Balun or antenna connector.

In this [link](#) you can find a video tutorial on how to seal the cable and the connector.¹⁰

HF radio installation and use

- ▶ Check the fuse in the red power cable of the radio (if applicable) and of the radio itself (if applicable).
- ▶ Connect the coaxial cable coming from the antenna to the back of the radio, tighten by hand only and do not use a wrench to avoid damage. Ensure the cable is also attached to the antenna.
- ▶ Connect the power wires from the radio to the charge controller or power supply, respecting positive (red) and negative (black). Inverted polarity can destroy the radio.
- ▶ Connect the microphone.
- ▶ Turn on the radio with the PWR button.
- ▶ Check the volume and make sure that there is sound coming out of the radio, even if it is white noise.
- ▶ Tune to the desired frequency and use the MODE button to select USB or LSB (ICOM-718).
- ▶ Test the microphone and transmission by pressing the microphone button. This should cause the radio to go silent and a change from Rx to Tx on the left side of the display (ICOM-718)
- ▶ With the SET button, check RF POWER (transmit power) and MIC GAIN (microphone level) (ICOM-718).
 - ▶ RF POWER at 99 or H is ideal to start.
 - ▶ MIC GAIN between 65 and 85 is fine.

10. <https://www.youtube.com/watch?v=CcHiHCw0lsY>

