Lesson 15

ANTENNAS

ACMA Syllabus February 2024 Chapters 1.5, 6.1 and 6.2

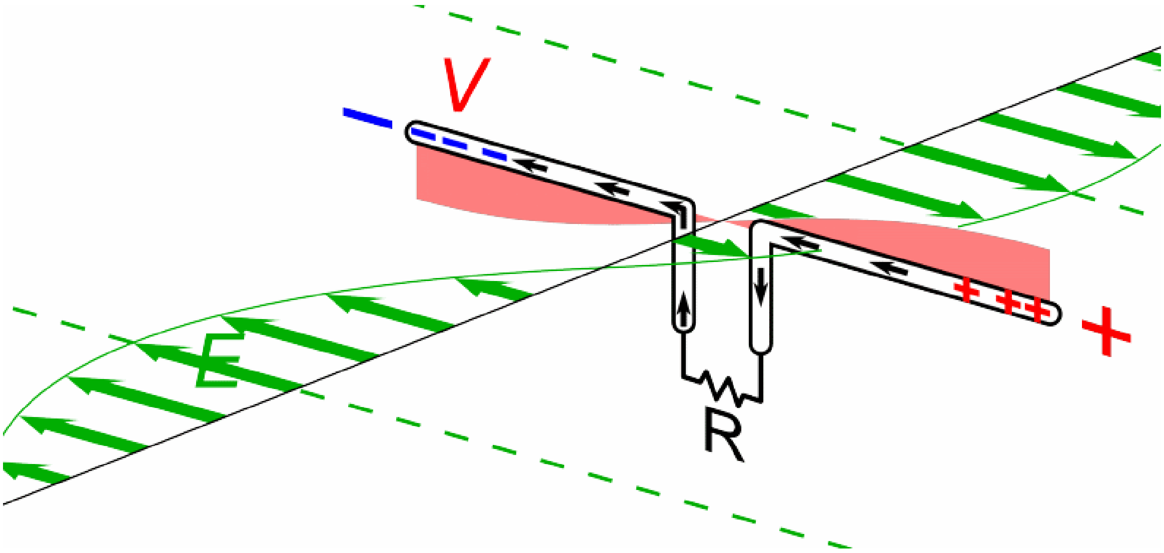
Contents

Antennas

Fields

An antenna converts alternating voltage electrical signals into electromagnetic fields for transmission and converts electromagnetic fields to alternating voltage electrical signals for reception.

There are two fields surrounding an active antenna. The E or (electric) and H (magnetic) fields. The E field in in the line of propagation and the H field it at right angles to the E field. The dipole below only shows the E field. The E field is the transmitted signal and defines the line of polarisation. A dipole is horizontally polarised.

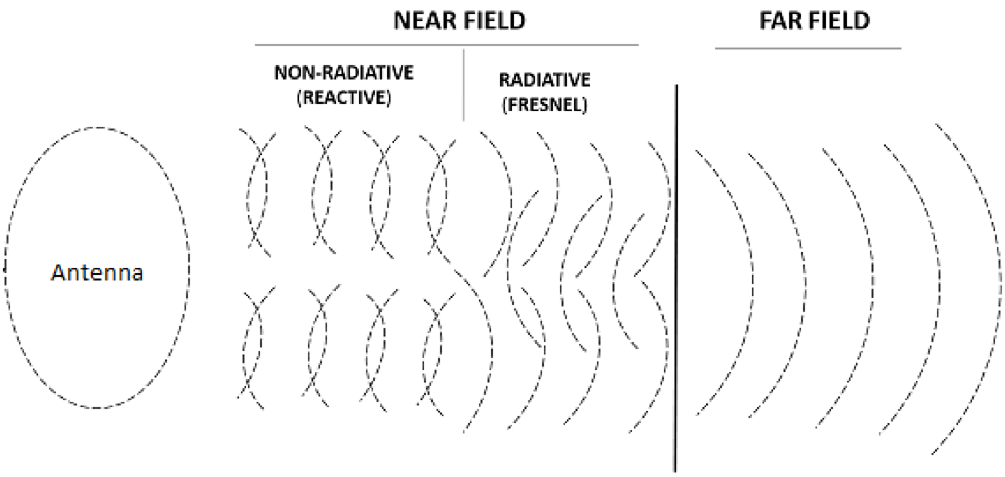


The concept of impedance matching, ZS, ZO and ZL, still apply for maximum signal transfer in both transmit and receive.

The signal from an antenna varies as a function of distance from the antenna. These distances are broadly divided into two regions, the near-field region, and the far field region.

The near field is unpredictable, and no measurements are usually made in this region.

In the Far Field the EM fields are dominated by radiating E and H-fields are at right angles to each other and in line with the direction of propagation.



Far Field. The regulation defines the far field of an antenna.

Near Field

The near field refers to places nearby the antenna where the emission of electromagnetic waves can be interfered with while the field lines remain electrically attached to the antenna. An example of this is an antenna over a tin roof. Here, the absorption of radiation in the near field by adjacent conducting objects detectably affects the loading on the transmitter.

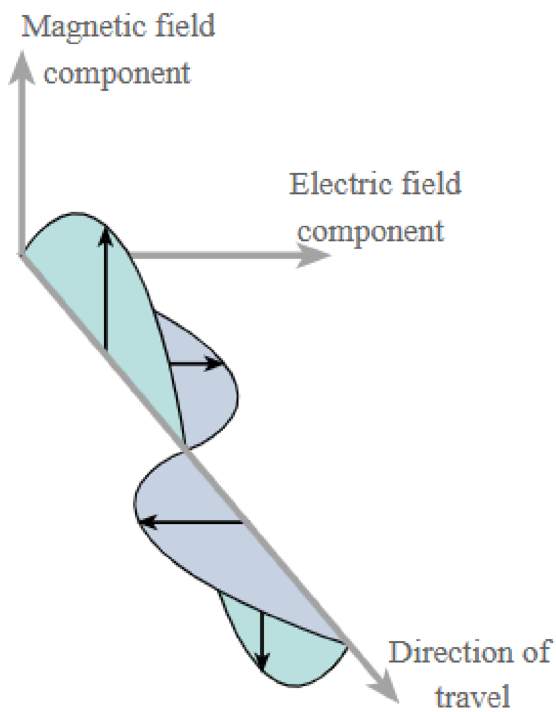
Far Field.

The far field is the region in which the field has settled into "normal" electromagnetic radiation. In this region, the field is dominated by transverse electric or magnetic fields with electric dipole characteristics. In the far-field region of an antenna, radiated power decreases as the square of distance, and absorption of the radiation does not feed back to the transmitter.

Measurements required for the Amateur Radio Class Licence Regulation are measured in the Far Field.

Polarisation

Polarization refers to the plane of the **E-field** (Voltage) looking at the wave from the transmitter.



There are three general antenna polarisations.

- Horizonal - the electric field will move sideways in a horizontal plane.
- Vertical - the electric field will oscillate up and down in a vertical plane.

Circular - the polarisation represented by the E-field rotates as the signal propagates. Signals rotating to the right are referred to as right-hand circular polarization (RHCP). Signals rotating to the left are referred to as left-hand circular polarization (LHCP)

Antenna Groups

The three main groupings of practical antennas.

1. Directional – This antenna can direct the signal in one direction e.g., Yagi.

2. Semi-directional - This antenna can direct the signal in two dominant directions e.g., dipole.
3. Omni-directional - This antenna is not able to direct the signal and radiates in all directions e.g., vertical whip.

The ideal antenna by which all antennas are compared, is called the isotropic antenna. The isotropic antenna is a theoretical antenna that radiates equally in all directions - horizontally and vertically with the same intensity. The antenna has a gain of 1 (0 dB) in the spherical space all around it and has an efficiency of 100%.

Propagation Velocity

Waves travel through a medium at a specific speed. The wave propagation speed defines how fast the wave travels.

$$v = f \ x \ \lambda$$

v = Speed of the wave in metres per second (m/s)

f = The frequency in hertz.

λ = The wavelength in meters (m)

Example: What is the speed of a radio was at the frequency of 145MHz?

$$v = f \ x \ \lambda$$

v = 145,000,000 x 2.067

v = 299,715,000 metres per second

Speed of light in a vacuum is 299,792,458 m / s. So, this signal is just under the speed of light or 99.97% the speed of light.

Balanced and Unbalanced

Antennas can be balanced or unbalanced. A balanced antenna is symmetrical about the feed point (e.g., a dipole) whereas an unbalanced antenna is not symmetrical about the feed point (e.g., a long wire)

Reactance

Antennas will present a reactance either side of their centre frequency (fc). As the frequency decreases below fc, the antenna is too short and will present capacitive reactance Xc. As the frequency increases above fc, the antenna is too long and will present inductive reactance Xl.

- Antenna too short: capacitive. Xc
- Antenna too long: inductive. Xl

Antenna Types

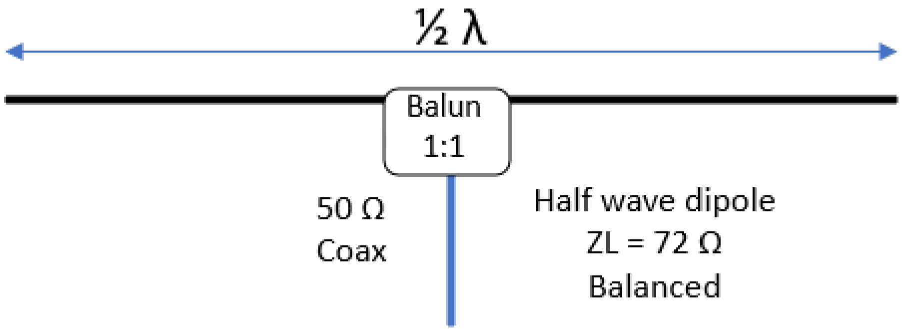
Dipole

The dipole is one of the most common antennas and it has a theoretical antenna impedance of 72 Ohm. The dipole often hangs too close to the ground, causing the impedance to drop towards the 50 Ohm. Ideally, the dipole should be half the wavelength above the ground.

A dipole has two legs each a quarter wavelength long. As the dipole is a balanced antenna with a ZL of 72 Ω, a 1:1 balun is recommended to match to the unbalanced coaxial cable. Wavelength is calculated by Wavelength (λ) = c / f.

Example: What is the overall length of a dipole for 14.2 MHz.

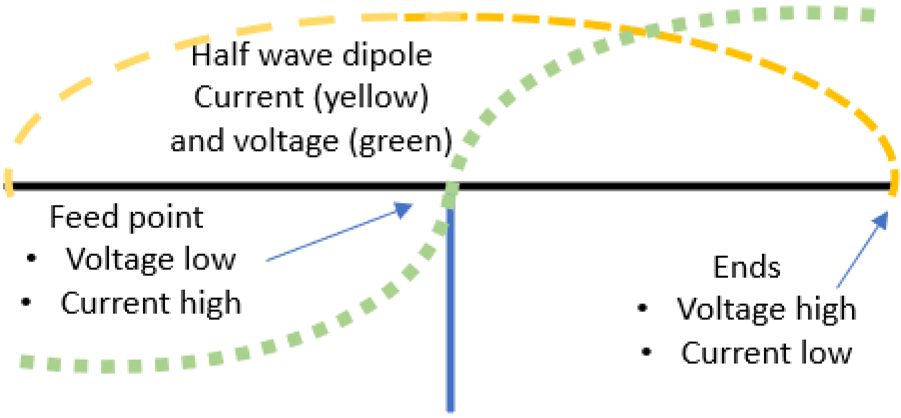
300 / 14.2 = 21.21 metres so for half wave the dipole is 10.1 metres long.

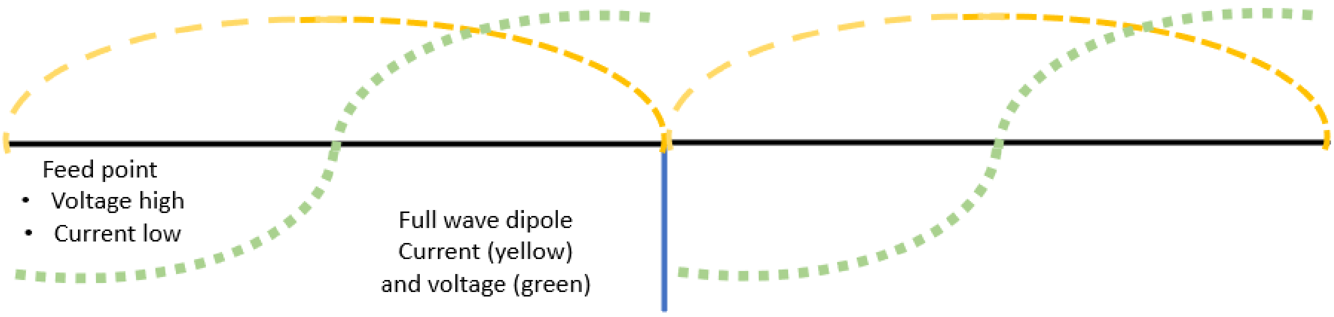


If a full wavelength dipole is used, the ZL is very high at around 2500 Ω.

Dipole Current and voltage

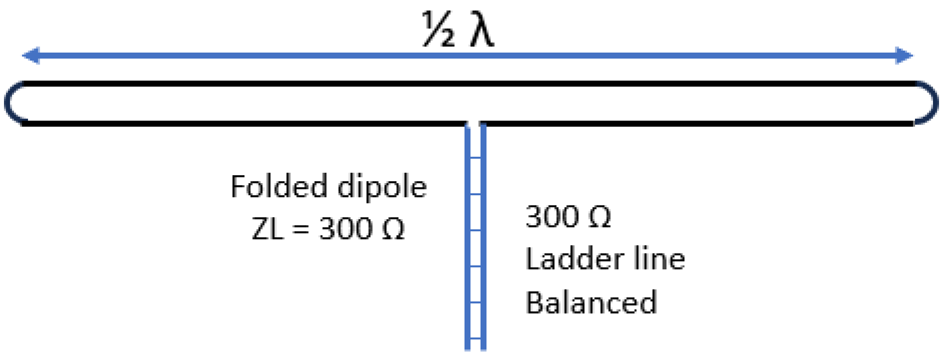
A dipole has maximum current at the feed point and maximum voltages at the ends. If the transmitter is sending 100 W to the antenna, current is over 1 ampere and the voltage at the ends is over 70 V. So be careful, the ends can bite.





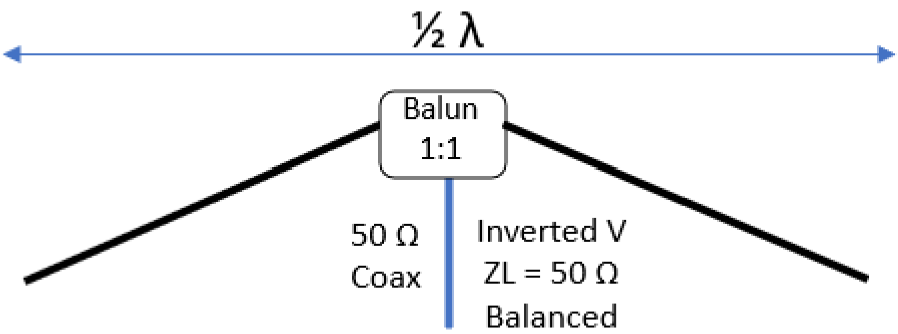
Folded Dipole

A folded dipole has a theoretical impedance of 300 Ω so is ideally fed with a ladder line of the same impedance. If the folded dipole is used with the unbalanced coaxial cable, a balun is needed to match the impedance.



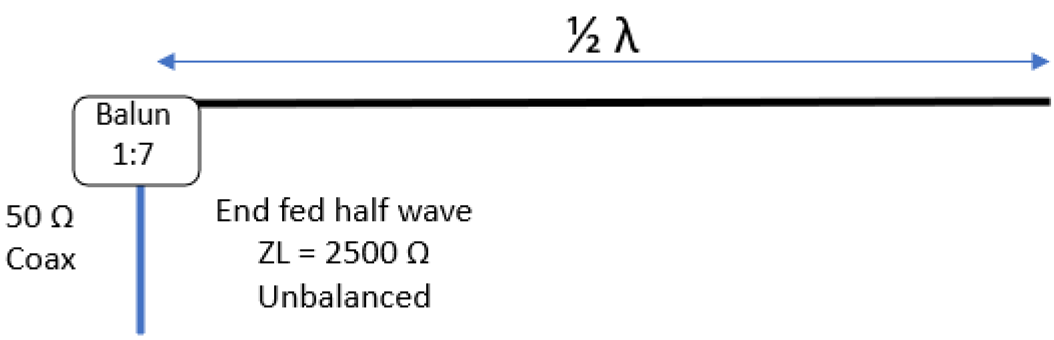
Inverted V

An inverted V antenna is a dipole with the ends dropped. The impedance is close to 50 Ohm, which makes the antenna very popular with amateurs. Ensure the ends are a few meters above the ground.



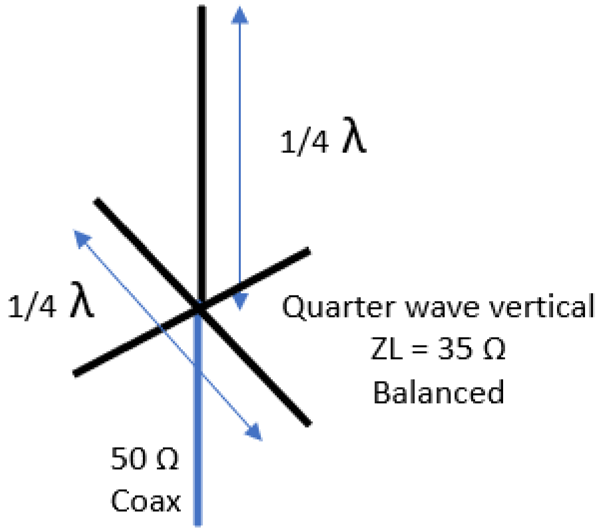
End fed half-wave antenna.

Many amateurs find this very practical because there is no long transmission line needed. The downside is that a large impedance transition is required.



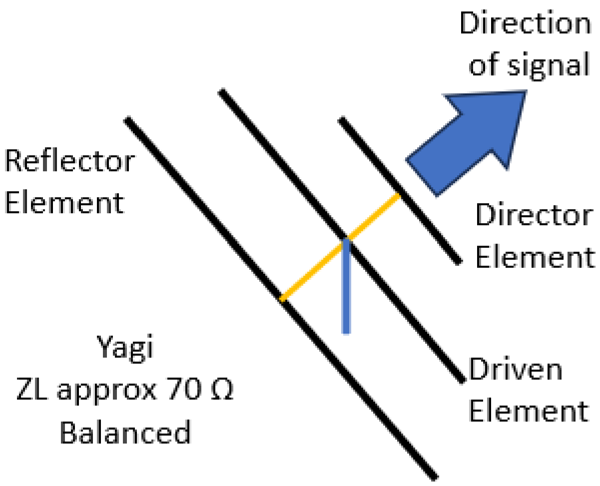
Quarter-wave vertical antenna [ground plane]

A quarter wave vertical can be compared to a vertical half wave dipole. Half the dipole is standing vertically, and the other half of the dipole are radials. A good earth is very important. This reduces the antenna impedance.



Yagi

The Yagi is a directional antenna concentrating the signal through the director element direction. The element lengths and spacing need to be calculated. Yagi calculators available on the internet.

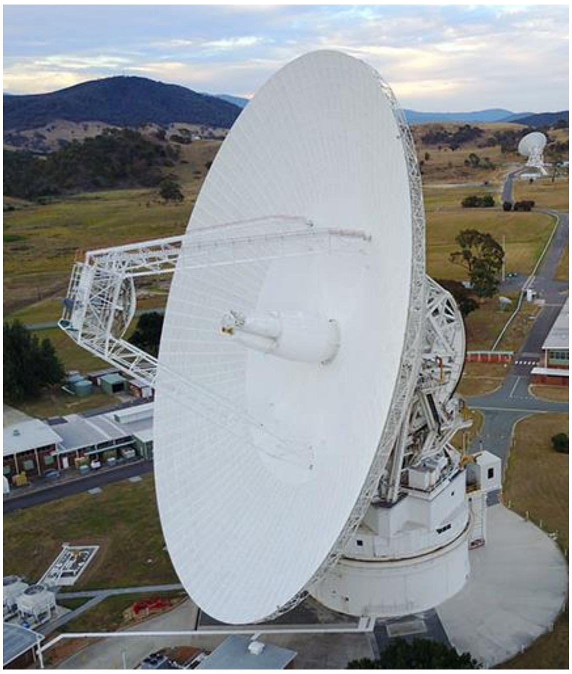


Aperture antennas

An antenna with an aperture at the end is known as an Aperture antenna. Good examples of this are waveguides and the aperture may be square, cone, rectangular or circular.

Horn Antenna

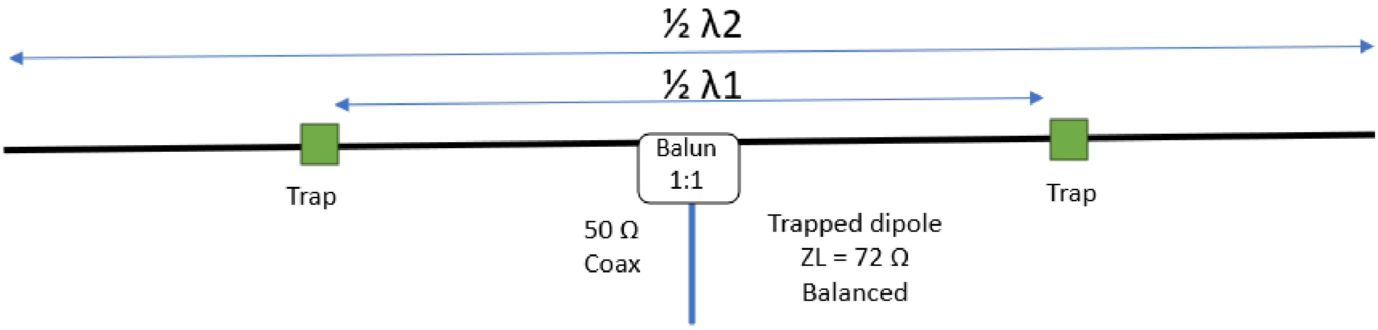
The aperture antenna usually is placed within a parabolic reflector to concentrate the signal direction. This concentration works for transmission and reception. These reflectors vary in size from small TV reception to the example below of the Tidbinbilla tracing station antenna.



Trapped dipole.

A trapped dipole is a multiband dipole. The traps (parallel tuned circuits) allow the antenna to be lengthened for the designated frequencies.

The first dipole, λ1, is cut to the desired frequency. The traps are parallel tuned circuits designed to resonate at λ1 frequency. When the transmitter is tuned to λ2 frequency, the taps will not block the signal, and the dipole will resonate at λ2. The traps do impact on the final length of each dipole so careful tuning is needed.



Non-resonant antenna

If an antenna resonates at a frequency higher than the desired frequency, the antenna is too short and behaves **capacitively.**

If an antenna resonates at a frequency lower than the desired frequency, the antenna is too long and behaves **inductively.**

Read the article on Smith Charts **HERE**.

Antenna Factors

Height and Take Off Angle

Through propagation via the F2 layer the maximum distance reachable in a single hop is around the 2500 km. There are two factors which change the distance in our favour. One is the height of the layer and second the take-off angle (the lower angle the better it is for far DX)

The F2 layer is not controlled by us but the antenna height is controllable.

Comparing the different take-off angles of vertical and horizontal antennas, a horizontal antenna (with the same gain) will outperform the vertical.

Placing the horizontal antenna as high as possible above ground give the antenna the lowest take of angle. If the antenna is placed 1 metre above the ground, the take of angle is 44 degrees. Placing the antenna 10 meters up gives 14-degree angle. At 40 metres up, the angle is down to 4 degrees.

Antenna Terms

Directivity - Directivity of an antenna is that the contraction of the radio waves is in one direction.

Gain – The gain of an antenna is the ratio of the radiation intensity compared to the radiation intensity if the antenna were an isotropic antenna. Gain is defined by the letter G and is a unitless measure that combines an antenna's radiation efficiency and directivity.

Efficiency - The efficiency of an antenna is determined by estimating the total loss of energy at the input terminals of the antenna. This includes mismatch losses and the dielectric/conduction losses.

Capacitance Hat - Where short masts must be used, a capacitive top load (also known as top hat or capacitance hat) is sometimes added at the top of the mast to increase the radiated power. Since the top load acts electrically like an additional length of mast, this is called "electrically lengthening" the antenna.

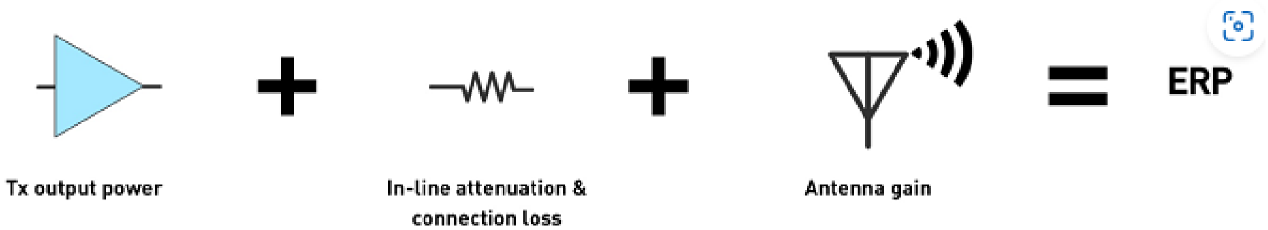
Capture area - The capture area or aperture of the antenna, is the area of the antenna in correct orientation to the direction of the incoming electromagnetic wave.

Front-to-back ratio - The term front-to-back ratio, AKA front-to-rear ratio, is the ratio of power gain between the front and rear of a directional antenna.

Power

Effective Radiated Power (ERP)

ERP measures the combination of the power emitted by the transmitter and the ability of the antenna to direct that power in a given direction. It is equal to the input power to the antenna multiplied by the gain of the antenna.



ERP, in watts, is determined by:

1. The transmitter power at the antenna outlet – watts.

2. Combine the losses of all devices between the transmitter and antenna - dBs

3. The gain of the antenna - dBs

Transmitter power and ERP are both measured in Watts. Items 2-3 are measured in dB and all measurements must be converted into the same scale. Convert Watts to dBW then back again.

Example: What is the ERP of the follow configuration?

TX Power: 100 W
Connecting devices: - 3dB
Antenna gain: 5dB
ERP = 100W output + a drop of 3dB then a gain of 5dB.

What is a drop of 3dB from 100W?

-3dB = 10 Log (x / 100)

-3/10 = log x / 100

-0.3 = log x / 100

Antilog -0.3 = x / 100

0.5011 = x / 100

100 x 0.5011 = x

50 W = x

So, 50 W are lost in the connections.

Now the antenna gives a gain of 5db on the 50 W from the connections.

5 dB = 10 Log x / 50

0.5 = Log x / 50

Antilog 0.5 = x / 50

3.1622 = x / 50
3.1623 X 50 = x

X = 158.115 W

ERP = 158.115 W

Effective Isotropic Radiated Power (EIRP) – EIRP is the hypothetical power that would have to be radiated by an isotropic antenna to give the same signal strength as the actual source antenna in the direction of the antenna's strongest beam.

Converting EIRP and ERP

Watts

The isotropic antenna has a gain of 1.64 over the dipole.

EIRP (W) = 1.64 x ERP(W)

In the previous example, the power was calculated at 158.115W. The equivalent power needed to be radiated by an isotropic antenna can be calculated.

Example: EIRP = 1.64 x 158.115 W

EIRP = 259.30 W

dBs

ERP is always 2.15 dB less than EIRP. The ideal dipole antenna could be further replaced by an isotropic radiator (a purely mathematical device which cannot exist in the real world).

The isotropic antenna has a gain of 2.15 dB over the dipole.

EIRP (dB) = ERP (dB) + 2.15

In the previous example, the ERP was 158.115W with an input of 100 W. Calculate the ERP (dB).

ERP (dB) = 10 Log (power out / power in)

= 10 Log (158.115 / 100)

= 10 Log 1.58

= 10 x 0.1986

= 1.986 dB

EIRP (dB) = ERP (dB) + 2.15

= 1.986 + 2.15

= 4.136 dB

Electromagnetic Radiation (EMR) Safety

Radiofrequency (RF) Electromagnetic Radiation (EMR) is non-ionising radiation and ranges between 3 kilohertz (kHz) to 300 gigahertz (GHz). Ionising radiation, Gamma rays and X rays, has more energy than non-ionising radiation and can cause damage to living tissue. Not usually experienced in a normal radio shack.

Exposure to high levels of RF EMR can heat biological tissue and potentially cause tissue damage. The amount of environmental RF EMR routinely encountered by the public is too low to produce significant heating or increased body temperature.

When working with antennas and transmitters, apply safety standards and safe work practices. Minimise or eliminate EMR exposures.

As antennas are located above ground, the additional risk is falls from working at heights. In 2020-2021, 42% of hospitalised injury cases and 40% of accidental injury deaths in Australia were due to falls. Falls resulted in 243,000 hospitalisation cases in Australia in the same period. This means that around 950 people per 100,000 population were hospitalised due to falls. 26 Apr 2023

A 12 minute video in Wikipedia on antennas can be seen **HERE**. Bit dry but worth a look.

Antenna SWR Plot

An important action for a new antenna is to plot the SWR of the antenna across the operating band. This plot is essential to check later if the SWR has changed and to ensure the antenna ids operating in the correct portion of the band. Go to the link and plot the SWR for your antenna.

Antenna SWR Plot

Special Note

Australian Building Regulations 2018

97 Masts, poles etc.

(1) a mast, pole, aerial, antenna, chimney, flue or service pipe—

(a) when attached to a building, must not exceed a height of 3 m above the highest point of the roof of the building; or

(b) when not attached to a building, must not exceed 8 m above the ground level.

(2) The report and consent of the relevant council must be obtained to an application for a building permit in relation to a design that does not comply with this regulation.

Go to Lesson 15 Questions.