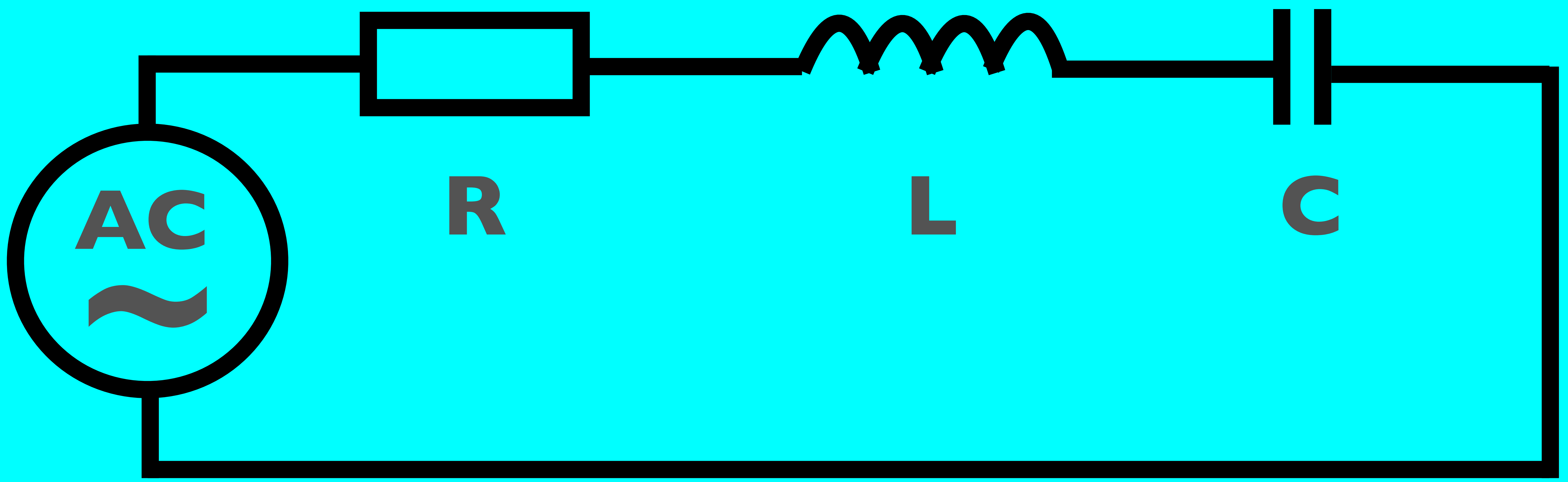
LORA / LORAWAN TUTORIAL 32

Resistor, Reactance, Impedance



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INTRO

- LoRa end nodes and gateways have antennas to transmit and receive the signals.
- In this tutorial I will explain why resistance, reactance and impedance plays an important role in antennas.
- Before I start with this tutorial please note the following:
  - I am not an antenna or electronics engineer.
  - My goal is to explain the most common used antenna terms to you in the simplest possible way.
  - This and subsequent tutorials are all related to antenna topics, because using the correct antenna is important when working with gateways and end nodes.

RESISTOR

- The main function of resistors in a circuit is to control the flow of current to other components.

- The resistor's (R) unit is Ohm (Ω). For example R=10kΩ

- In an electric circuit a resistor does not store any energy, it just dissipates some of the energy in the form of heat.

- In a Direct Current (DC) or Alternating Current (AC) circuit the resistor behaves the same. In an AC circuit the resistor's resistance is also called the ohmic resistance to differentiate between other forms of resistance.

CAPACITOR

- The main function of a capacitor in a circuit is to store energy and to give this energy back to the circuit when necessary.

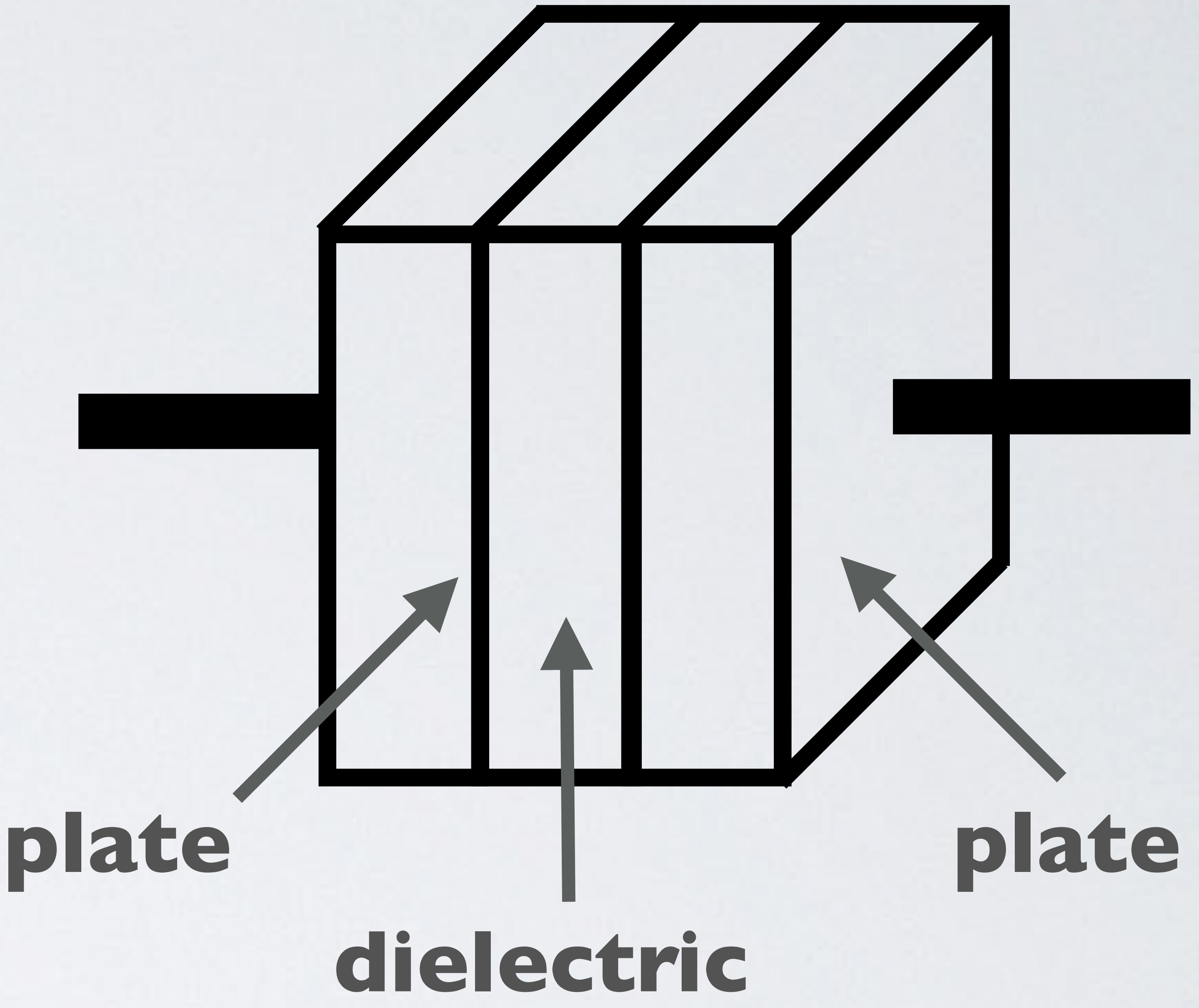
- The energy supplied to the capacitor is stored in the form of an **electric field** which is created between the plates of a capacitor.

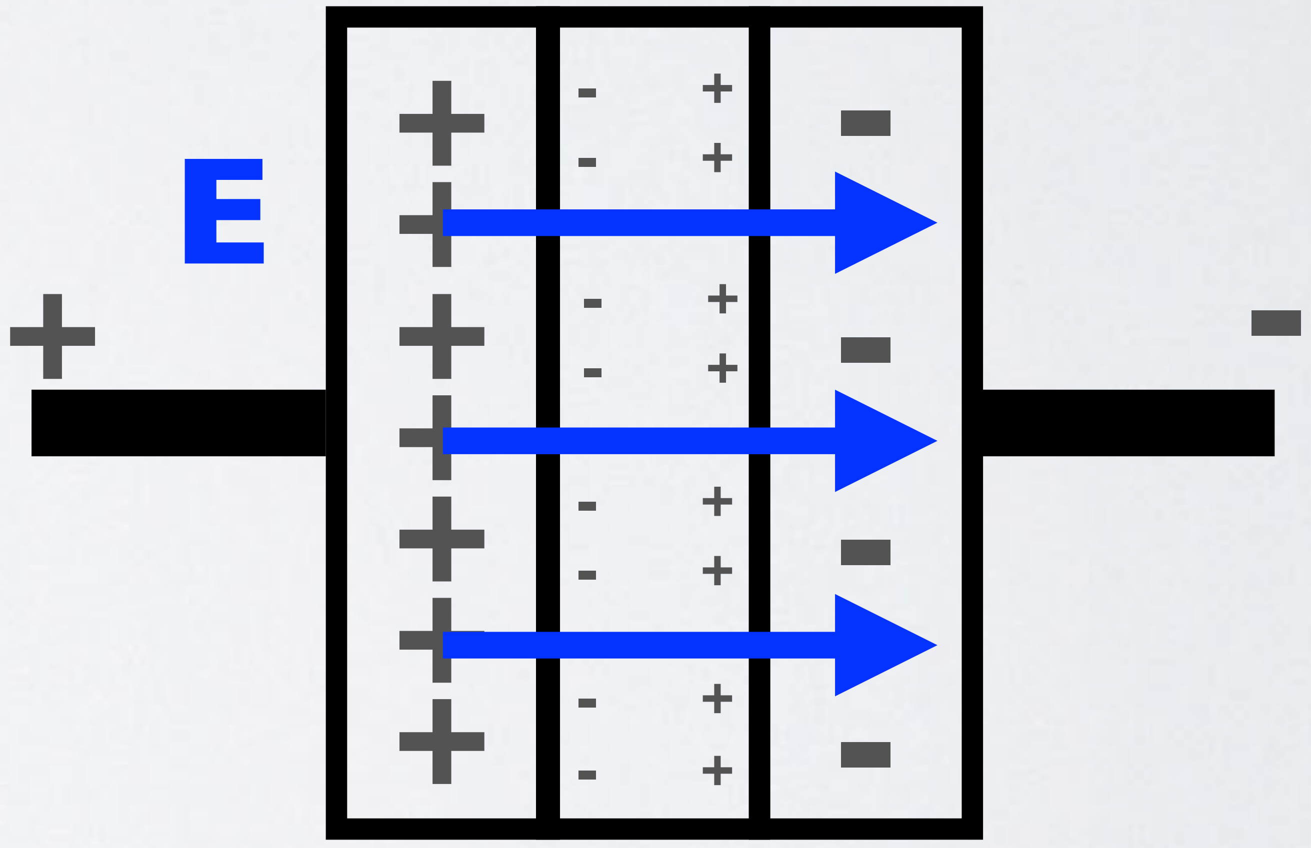
- The capacitor's (C) unit is Farad (F). For example C=220 μF.

- A capacitor consists of two plates and between those two plates there is an isolator called dielectric.

DIELECTRIC

- A dielectric is an electrical insulator.
  It is a very poor conductor of electric current.
- When a dielectric is placed in an electric field (E), practically no current will flow thru the dielectric.
- The dielectric can be polarised by the applied electric field.
- Dielectric materials are used in capacitors and in the construction of radio frequency transmission lines aka coaxial cables.





CAPACITOR

- In a ***Direct Current*** (DC) circuit a capacitor acts as an open circuit and does not permit current to pass, it has an infinite resistance.

- But in an ***Alternating Current*** (AC) circuit the capacitor has a resistance.
  The capacitor's resistance is called capacitive reactance ($\mathbf{X_c}$).

CAPACITIVE REACTANCE

- The capacitive reactance (X_c) is calculated as follows:

$$X_c = \frac{1}{2 \times \pi \times f \times C}$$

The capacitive reactance (X_c) can also be written as:

$$X_c = \frac{1}{\omega \times C}$$

where:

$$\omega = 2 \times \pi \times f$$

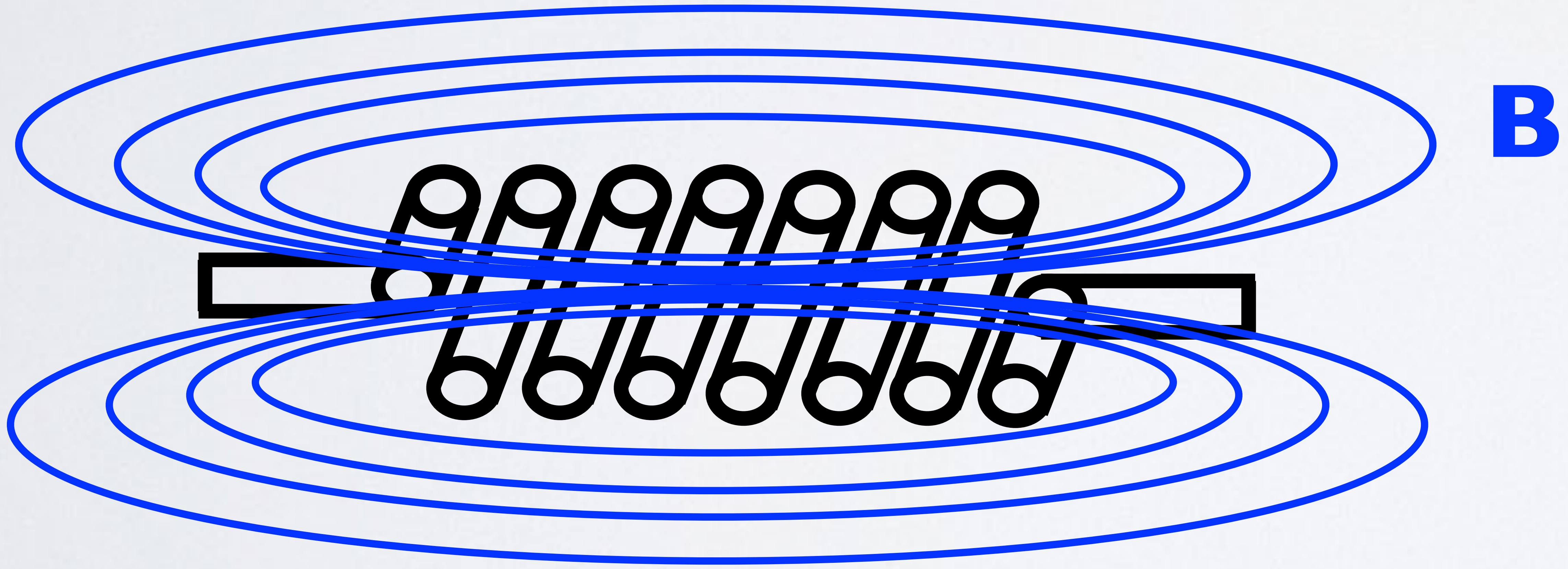
X_C is the capacitive reactance in Ohm [Ω]
f is the frequency in Hertz [Hz]
C is the capacitance in Farad [F]

In an AC circuit the frequency plays an important role.

INDUCTOR

- The main function of an inductor in a circuit is to store energy and to give this energy back to the circuit when necessary.

- The energy supplied to the inductor is stored in the form of a **magnetic field** which is created by the coil. The more windings the coil has the stronger the generated magnetic field. If a metal core is put inside the coil the magnetic field is increased which means more energy can be stored.



INDUCTOR

- The inductor's (L) unit is Henry (H). For example L=4.7 μH

- In a ***Direct Current*** (DC) circuit an inductor acts as an short circuit and allows the current to pass, it has zero resistance.

- But in an ***Alternating Current*** (AC) circuit the inductor has a resistance.
  The inductor's resistance is called inductive reactance (**X_L**).

INDUCTIVE REACTANCE

- The inductive reactance (X_L) is calculated as follows:

$X_L = 2 \times \pi \times f \times L$

In an AC circuit the frequency plays an important role.

The inductive reactance (X_L) can also be written as:

$X_L = \omega \times L$

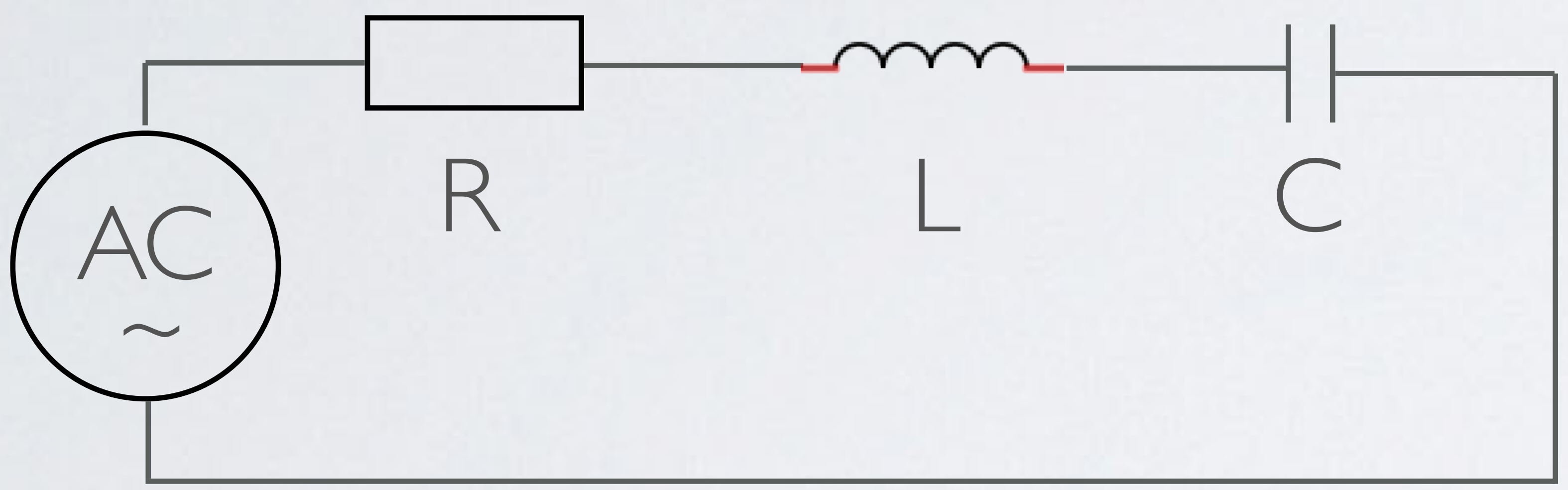
where:

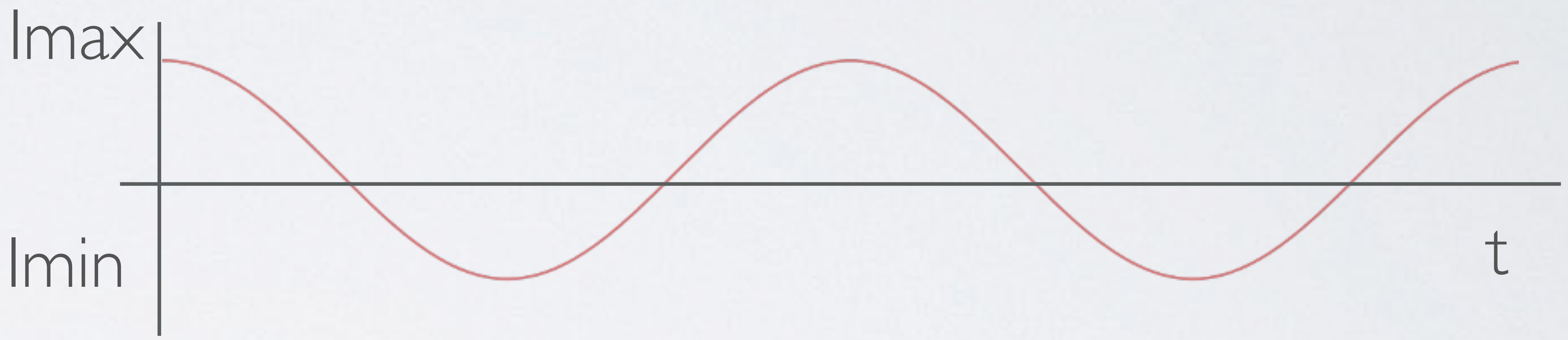
$\omega = 2 \times \pi \times f$

X_L is the inductive reactance in Ohm [Ω]
f is the frequency in Hertz [Hz]
L is the inductance in Henry [H]

RESISTOR, CAPACITOR AND INDUCTOR

- A field generator generates an Alternating Current (AC) and in an AC circuit a capacitor (C) and an inductor (L) both acts like a resistor. Lets assume the following circuit:





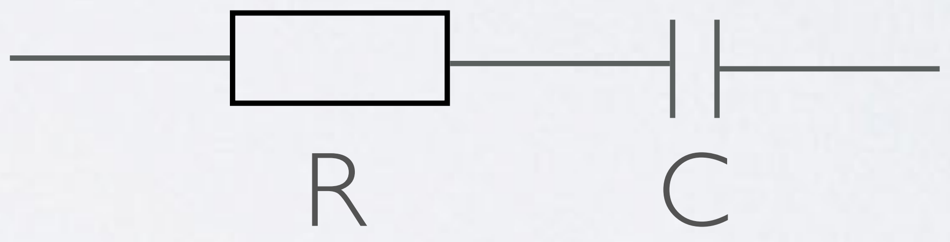
- The resistor *opposes the flow of* ***electrons***.
- The capacitor *opposes the change in* ***voltage*** by dropping or supplying the current.
- The inductor *opposes the change in* ***current*** by dropping or supplying the voltage.

IMPEDANCE

- **Impedance (Z), measured in ohms, is the combined effect of all the ohmic resistance, capacitive reactance and inductive reactance.**

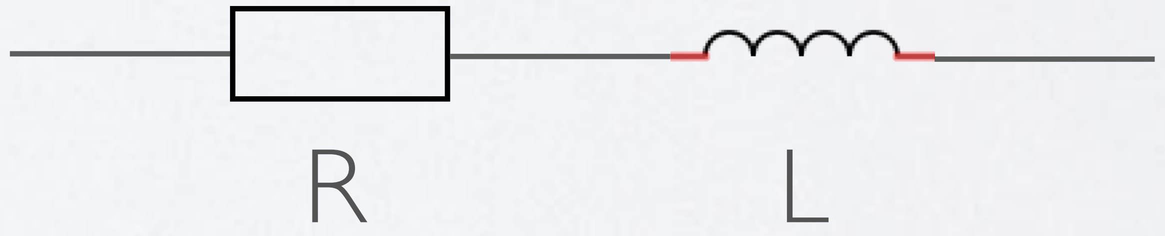
- If an AC circuit has only an ohmic resistor and capacitor in series the impedance is:

$$Z = \sqrt{R^2 + Xc^2} = \sqrt{R^2 + \left(\frac{1}{\omega \times C}\right)^2}$$



- If an AC circuit has only an ohmic resistor and inductor in series the impedance is:

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + (\omega \times L)^2}$$



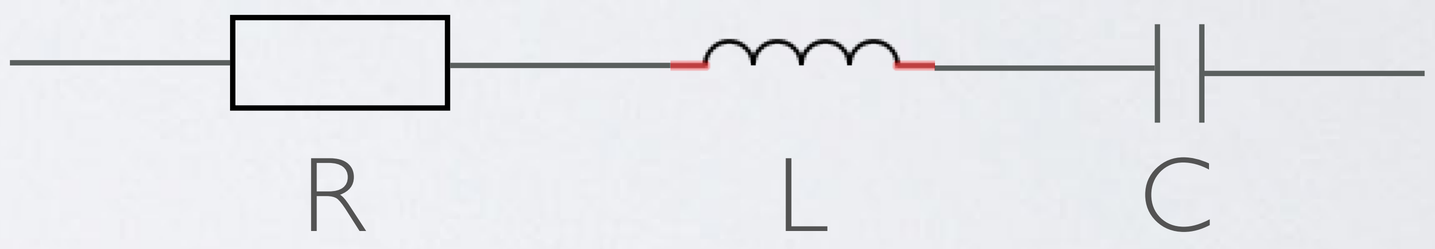
IMPEDANCE

- If an AC circuit has an ohmic resistor, inductor and capacitor in series the impedance is:

$$\mathbf{Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left((\omega \times L) - \left(\frac{1}{\omega \times C}\right)\right)^2}}$$

where:

$$\mathbf{\omega = 2 \times \pi \times f}$$

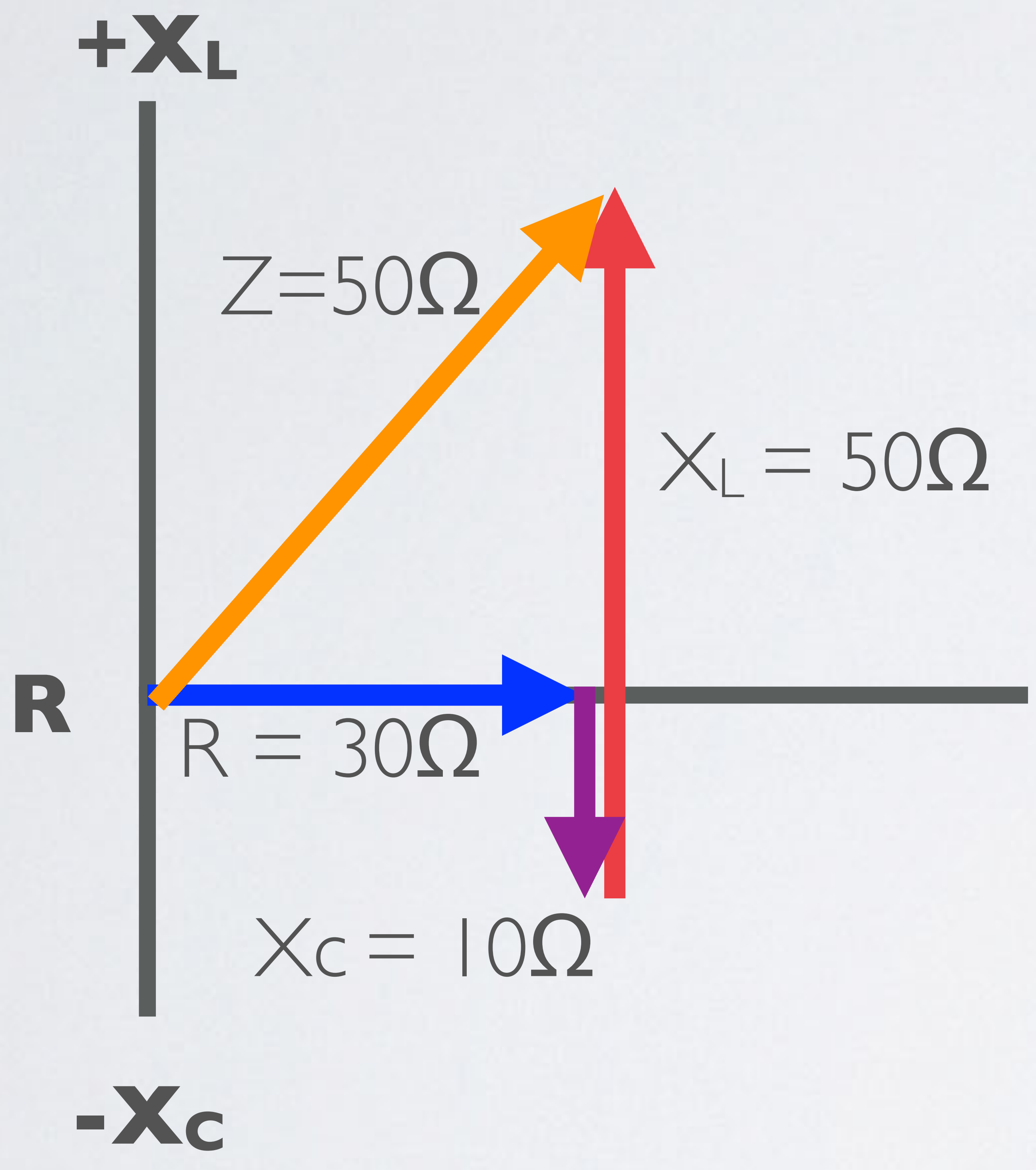


Z is the impedance in Ohm [Ω]
R is the ohmic resistance in Ohm [Ω]
X_L is the inductive reactance in Ohm [Ω]
X_c is the capacitive reactance in Ohm [Ω]

f is the frequency in Hertz [Hz]
C is the capacitance in Farad [F]
L is the inductance in Henry [H]

RESISTANCE, REACTANCE AND IMPEDANCE

- Impedance (Z) is the combination of ohmic resistance (R) and reactance (X_c and X_L) which defines the total opposition to the current flow.



The ohmic resistance is drawn on the X-axis and the reactance is drawn on the Y-axis.

The capacitive reactance (X_C) is considered a negative number. The vector is drawn downwards.

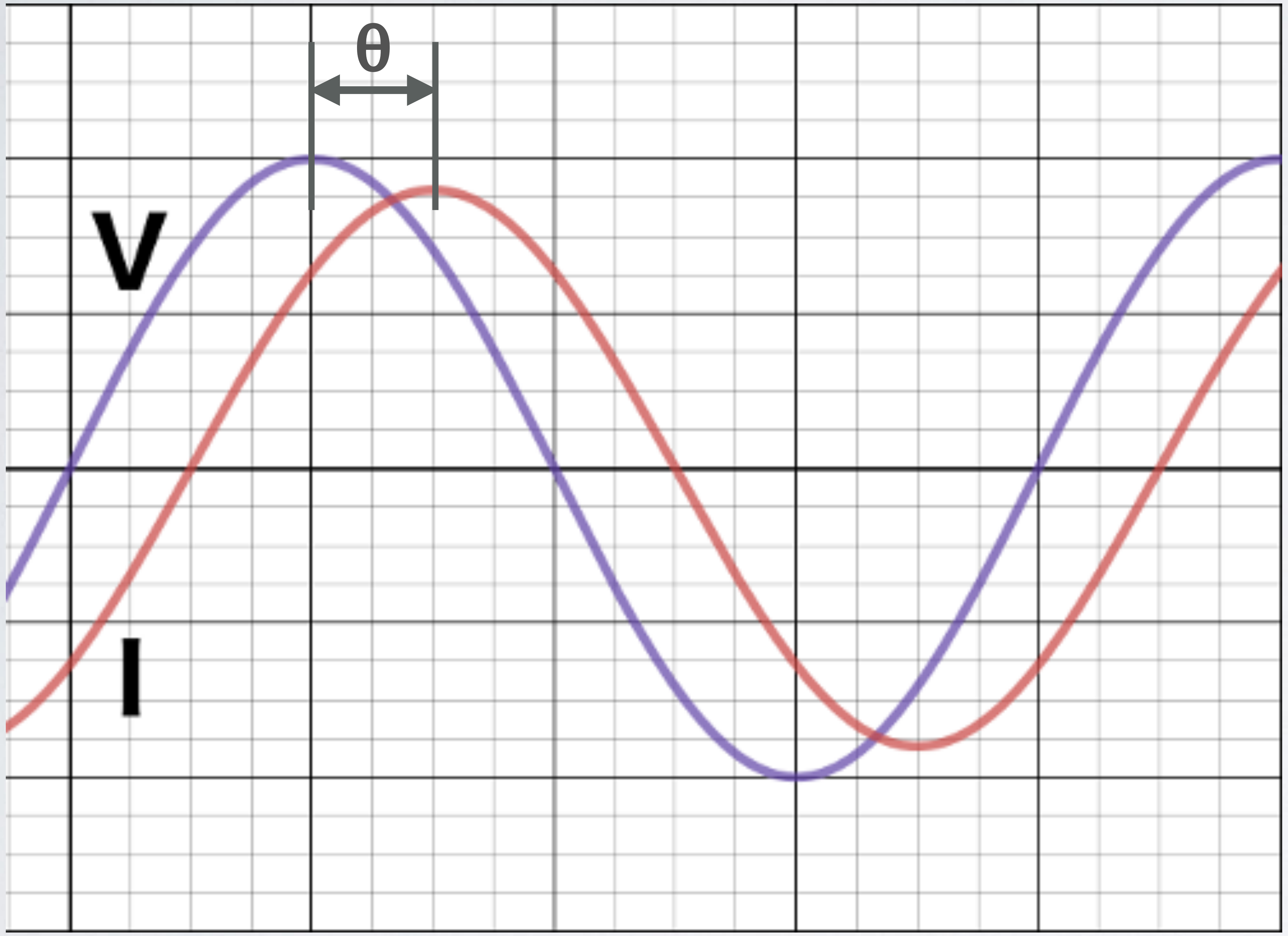
The inductive reactance (X_L) is considered a positive number. The vector is drawn upwards.

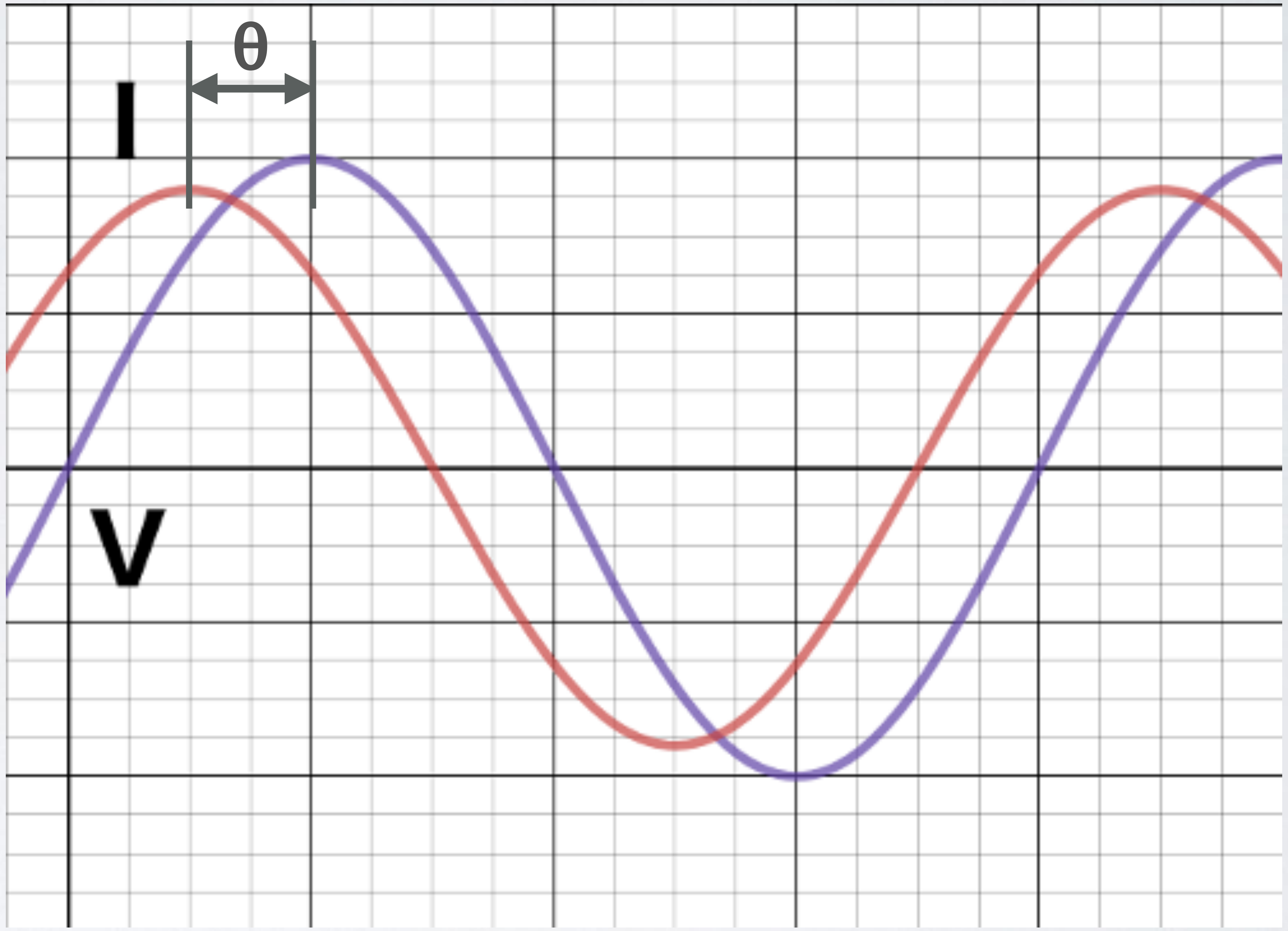
The length of the hypotenuse is the total impedance (Z).

CAPACITORS AND INDUCTORS PHASE RELATIONSHIP

- In an AC circuit, when using capacitors or inductors, the current and voltage do not peak at the same time.
- There is a phase difference between the voltage and current indicated by the angle θ. The phase difference is <= 90 degrees.
- If the voltage leads the current the phase is positive.
- For inductive circuits the voltage leads the current. The phase is positive.
  For capacitive circuits the current leads the voltage. The phase is negative.
- Handy mnemonic: **ELI** THE **ICE**MAN
  ELI = For inductive circuits (**L**) the voltage (**E**) leads the current (**I**)
  ICE = For capacitive circuits (**C**) the current (**I**) leads the voltage (**E**)

CAPACITORS AND INDUCTORS PHASE RELATIONSHIP

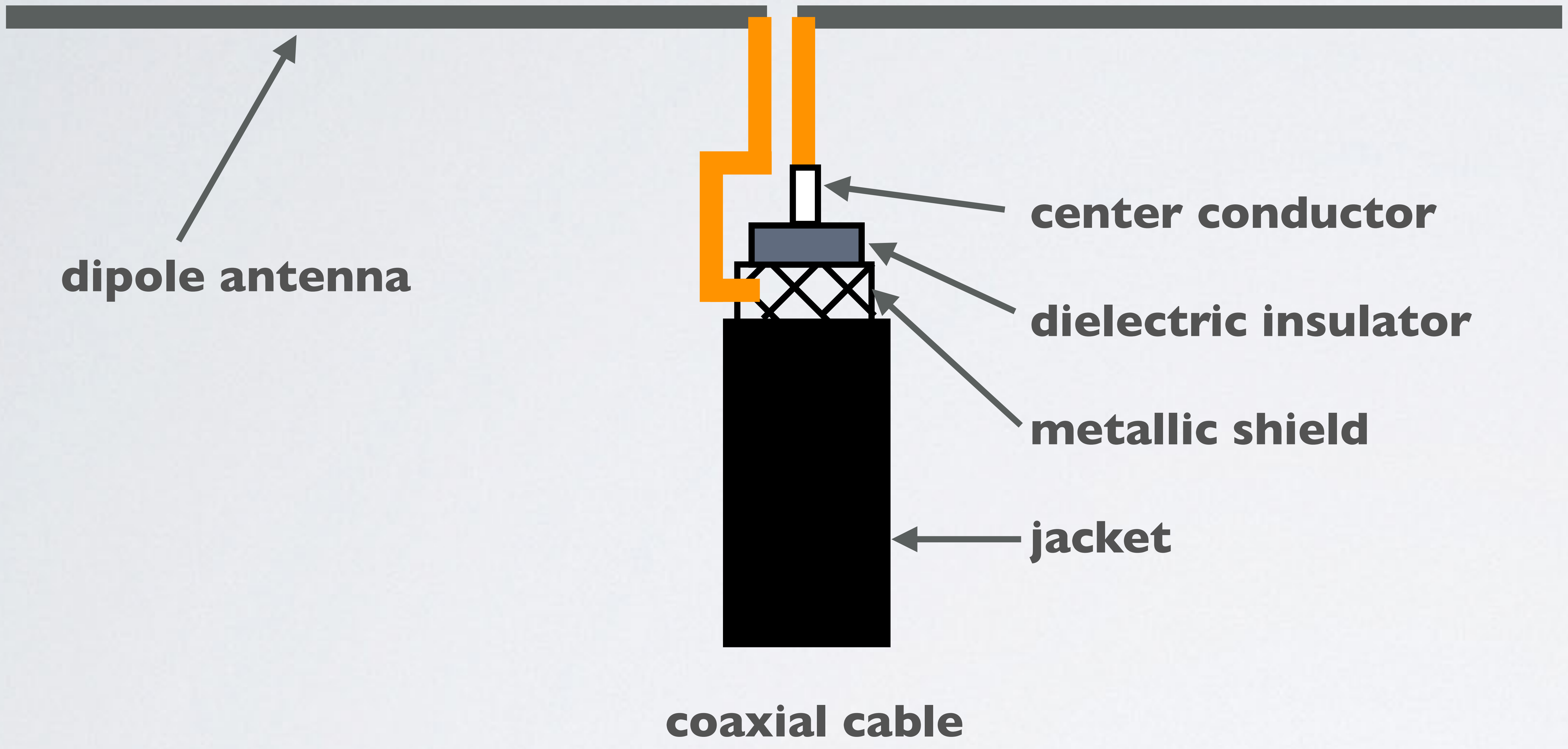




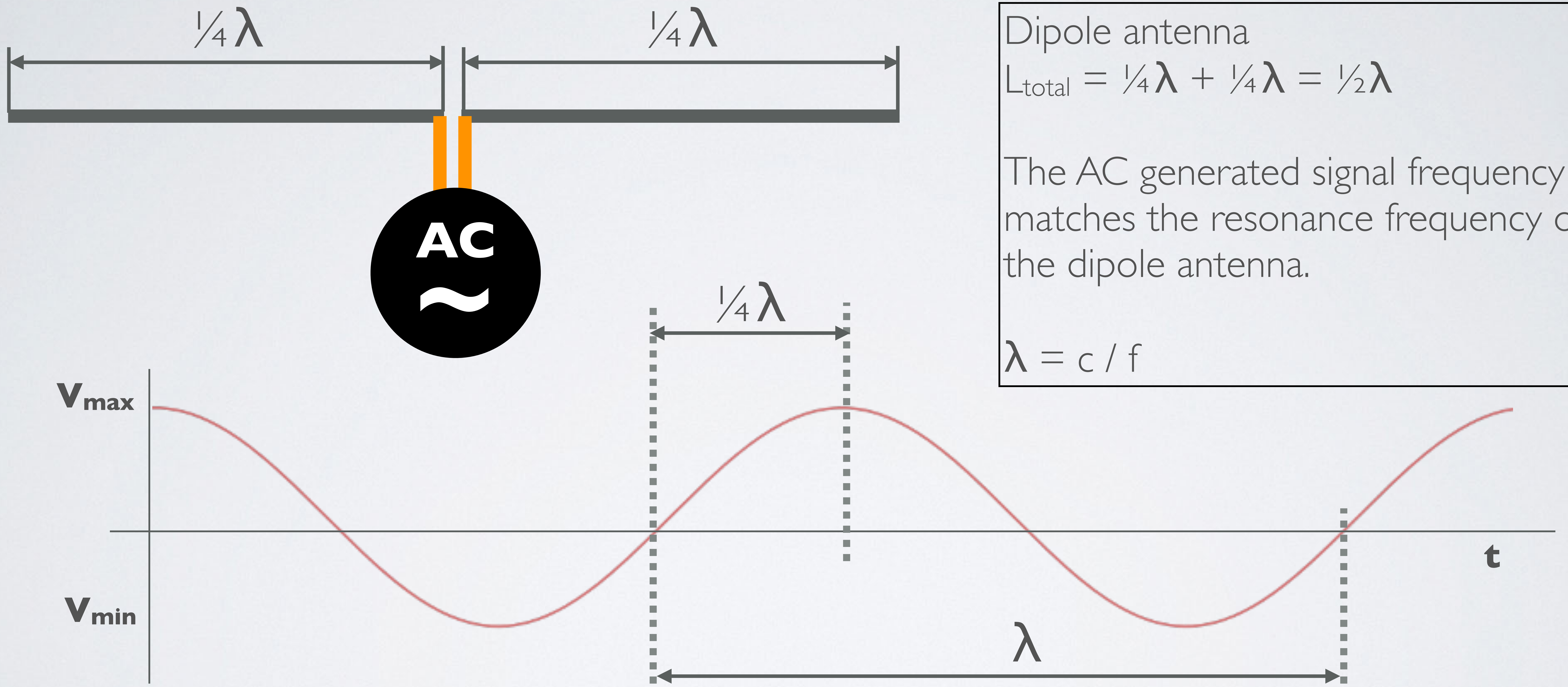
Inductive circuits (ELI):
Voltage leads the current.
Phase (θ) is positive.

Conductive circuits (ICE):
Current leads the voltage.
Phase (θ) is negative.

DIPOLE ANTENNA



DIPOLE ANTENNA



Dipole antenna
$L_{total} = ¼λ + ¼λ = ½λ$

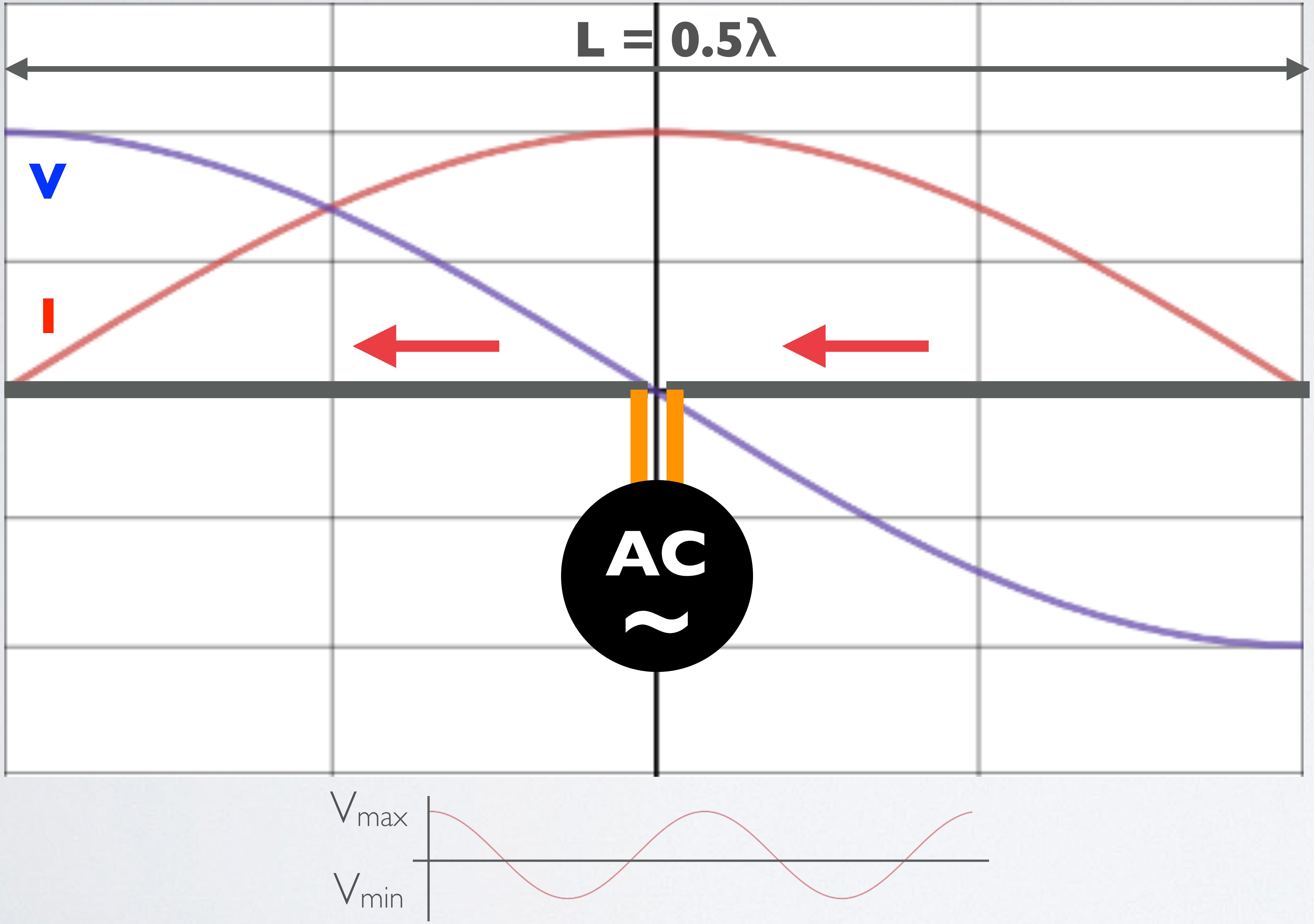
The AC generated signal frequency matches the resonance frequency of the dipole antenna.

$λ = c / f$

DIPOLE ANTENNA VOLTAGE DISTRIBUTION

- A nice animation where you can see the voltage distribution and how the current flows thru the dipole antenna: https://en.wikipedia.org/wiki/Dipole_antenna

DIPOLE CURRENT AND VOLTAGE DISTRIBUTION



What is the purpose of this picture?

Just like capacitors and inductors there is a phase difference between the voltage (V) and the current (I).

Simply said an antenna has resistor, capacitor and inductor characteristics.

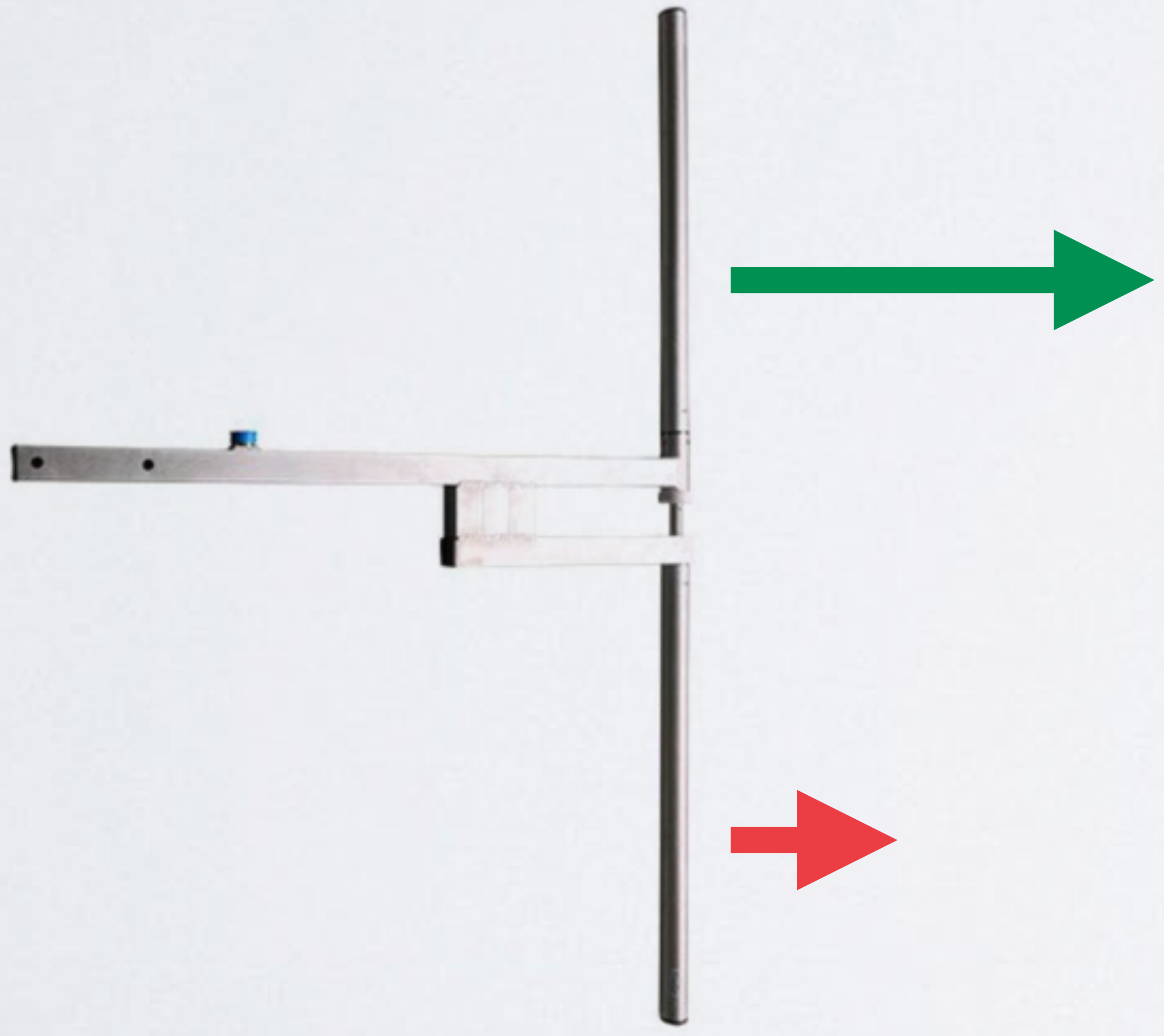
This means an antenna has:
- Resistance R,
- Capacitive reactance X_C
- and Inductive reactance X_L

Thus an antenna has impedance (Z).

RADIATION AND OHMIC RESISTANCE

- In the previous slide I mentioned that an antenna has a resistance R.
  In fact an antenna has two types of resistance:

  - A radiation resistance (R_{rad}), which converts electrical power into EM radiation.
  - And an ohmic resistance, which is loss on the antenna's structure that converts electrical power into heat radiation (R_{loss}).

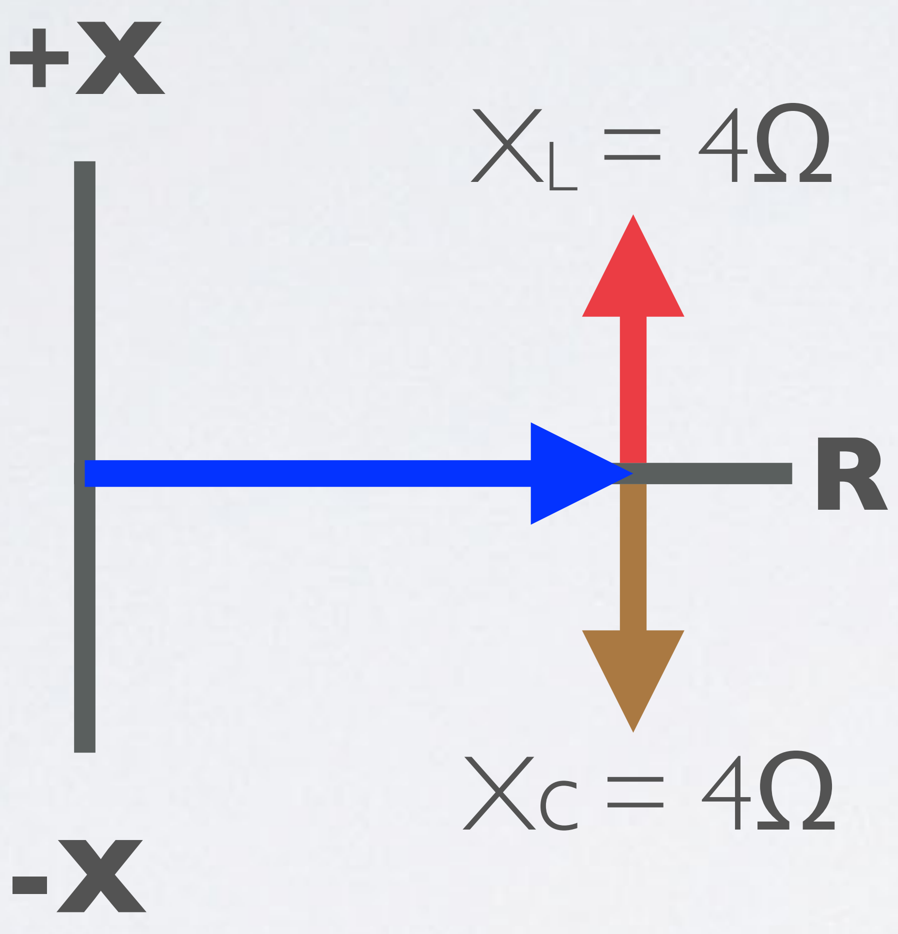


Radiation resistance creates Electro Magnetic radiation.
This is what we want.

Ohmic resistance creates heat.
We do not want this.

RESONANT ANTENNA

- An antenna is called resonant when the capacitive (X_C) and inductive (X_L) reactances cancel each other out.



- In a resonant antenna:
  - The reactance (X) is zero, the antenna is purely resistive ($= R_{rad} + R_{loss}$) which means that the voltage and current are in phase at the antenna feed point.
  - A maximum of current will flow thru the antenna.
  - The VSWR is close to 1. In the next tutorial I will explain what VSWR is.

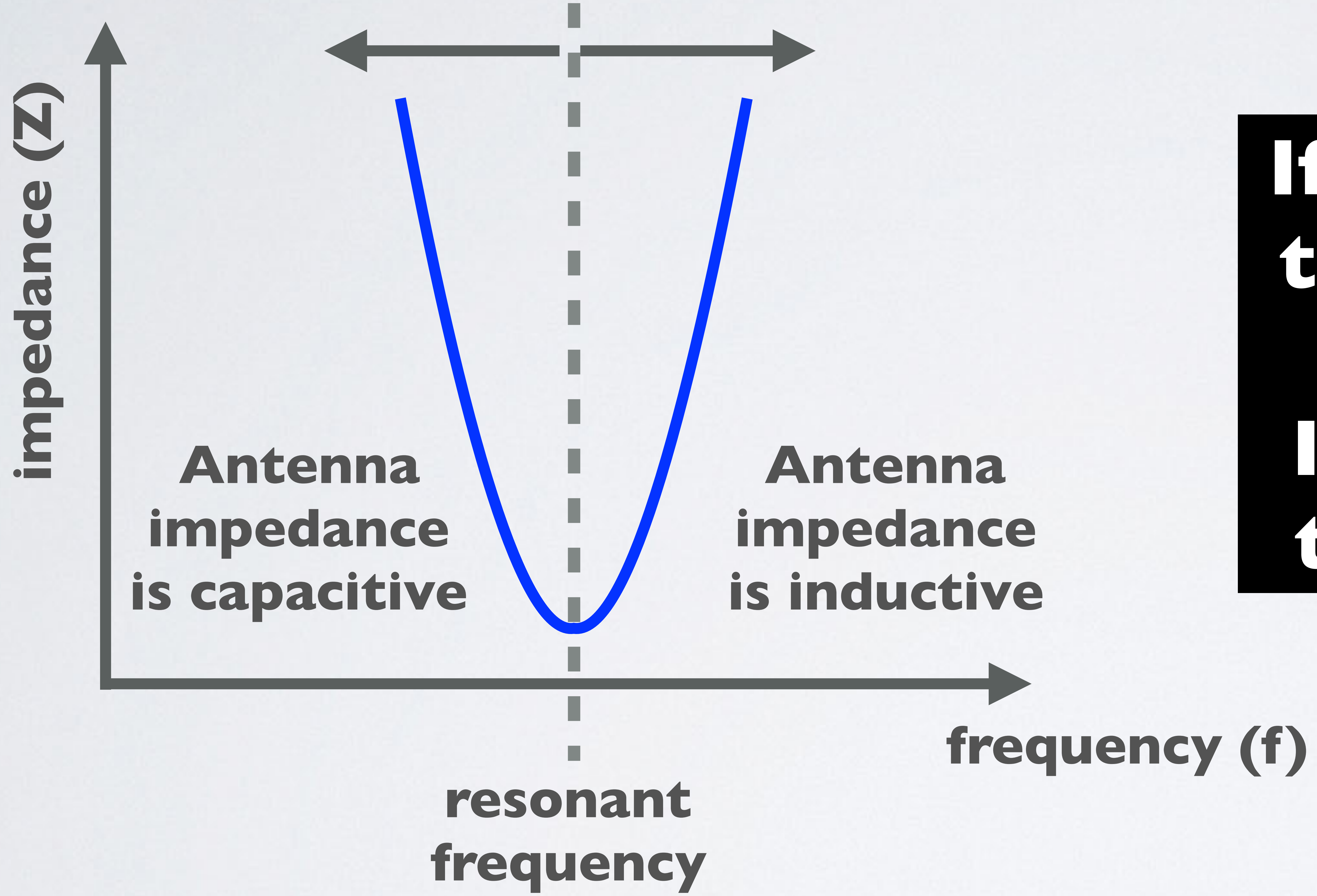
RESONANT ANTENNA

- For a **resonant antenna**, the antenna efficiency is calculated as follows:

$$\textbf{Antenna efficiency} = \frac{R_{rad}}{R_{rad} + R_{loss}}$$

- The radiation resistance should be much higher than ohmic resistance otherwise the antenna is not efficient.

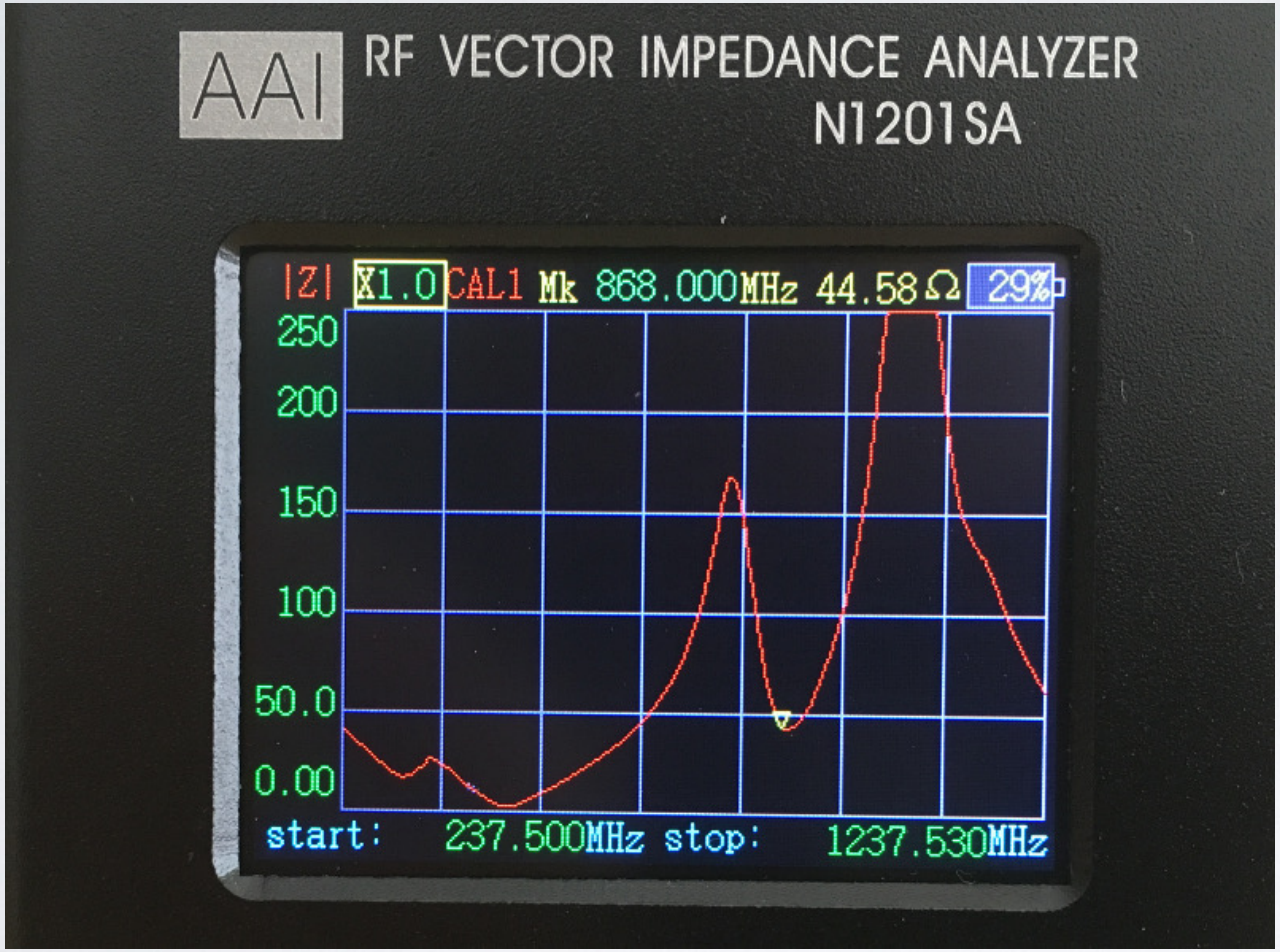
VARIATION OF ANTENNA IMPEDANCE WITH FREQS



If an antenna is too short, the antenna is capacitive.

If an antenna is too long, the antenna is inductive.

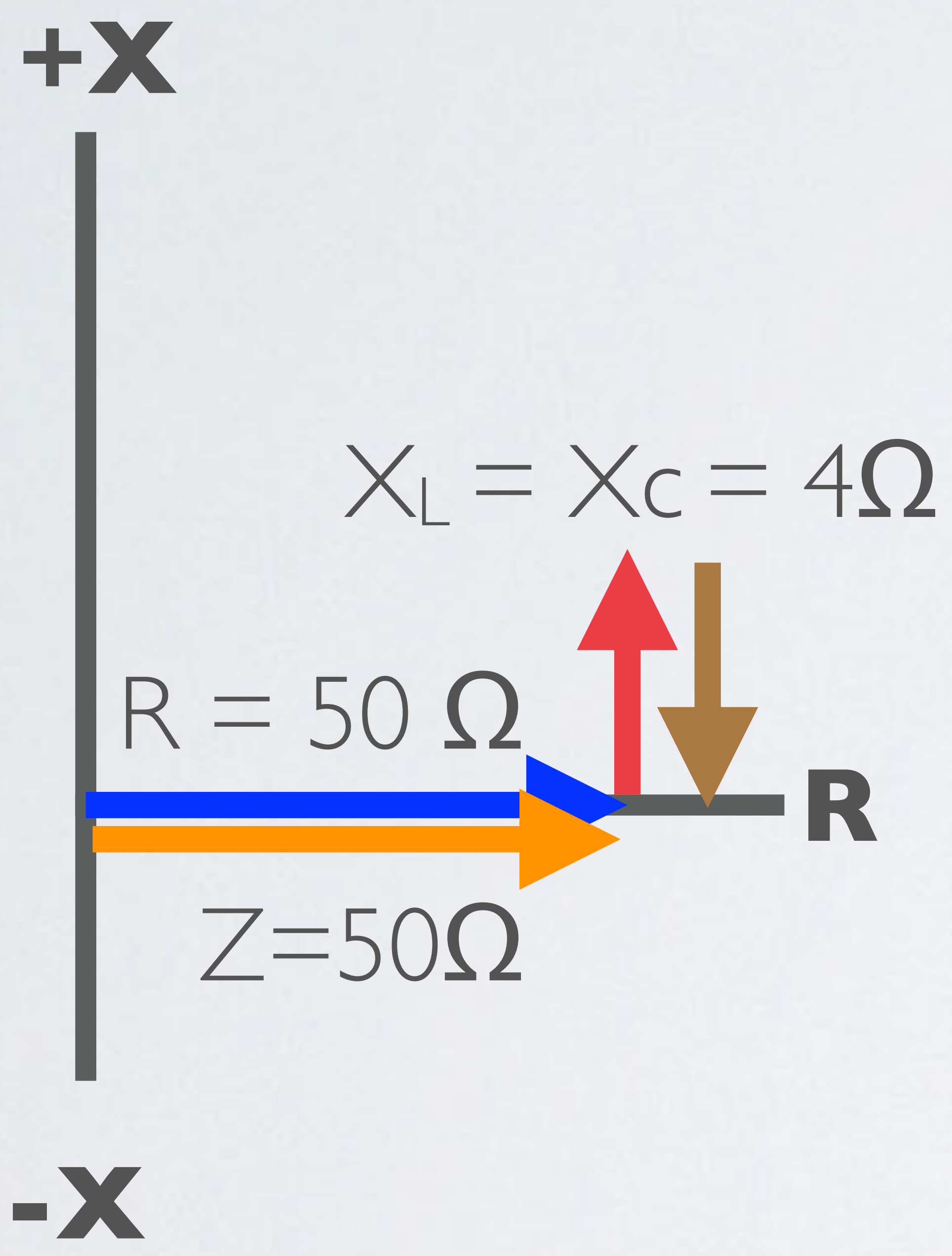
VARIATION OF ANTENNA IMPEDANCE WITH FREQS



Resonant freq. = 868 MHz

ANTENNA EFFICIENCY

- The radiation resistance (R_{rad}) is needed for converting electrical power into EM radiation and that is what we want, all the rest are "losses" which hurt the antenna efficiency.



Calculate the antenna efficiency for an resonant antenna:

$R_{rad} = 37\Omega$, $R_{loss} = 13\Omega$, $X_L = 4\Omega$, $X_C = 4\Omega$

$$\textbf{Antenna efficiency} = \frac{R_{rad}}{R_{rad} + R_{loss}}$$

$$\textbf{Antenna efficiency} = \frac{37}{37 + 13}$$

Antenna efficiency = 0.74

ANTENNA IMPEDANCE

- In this picture a sleeve antenna is analysed.
  The analyser measures:
  Resistance R (= R_{rad} + R_{loss})= 50.20Ω
  Total reactance X (=X_C + X_L) = 4.798 Ω

- The antenna impedance Z is:

$$\mathbf{Z = \sqrt{R^2 + X^2}}$$

$$\mathbf{Z = \sqrt{50.20^2 + 4.798^2}}$$

$$\mathbf{Z = 50.43\ \Omega}$$

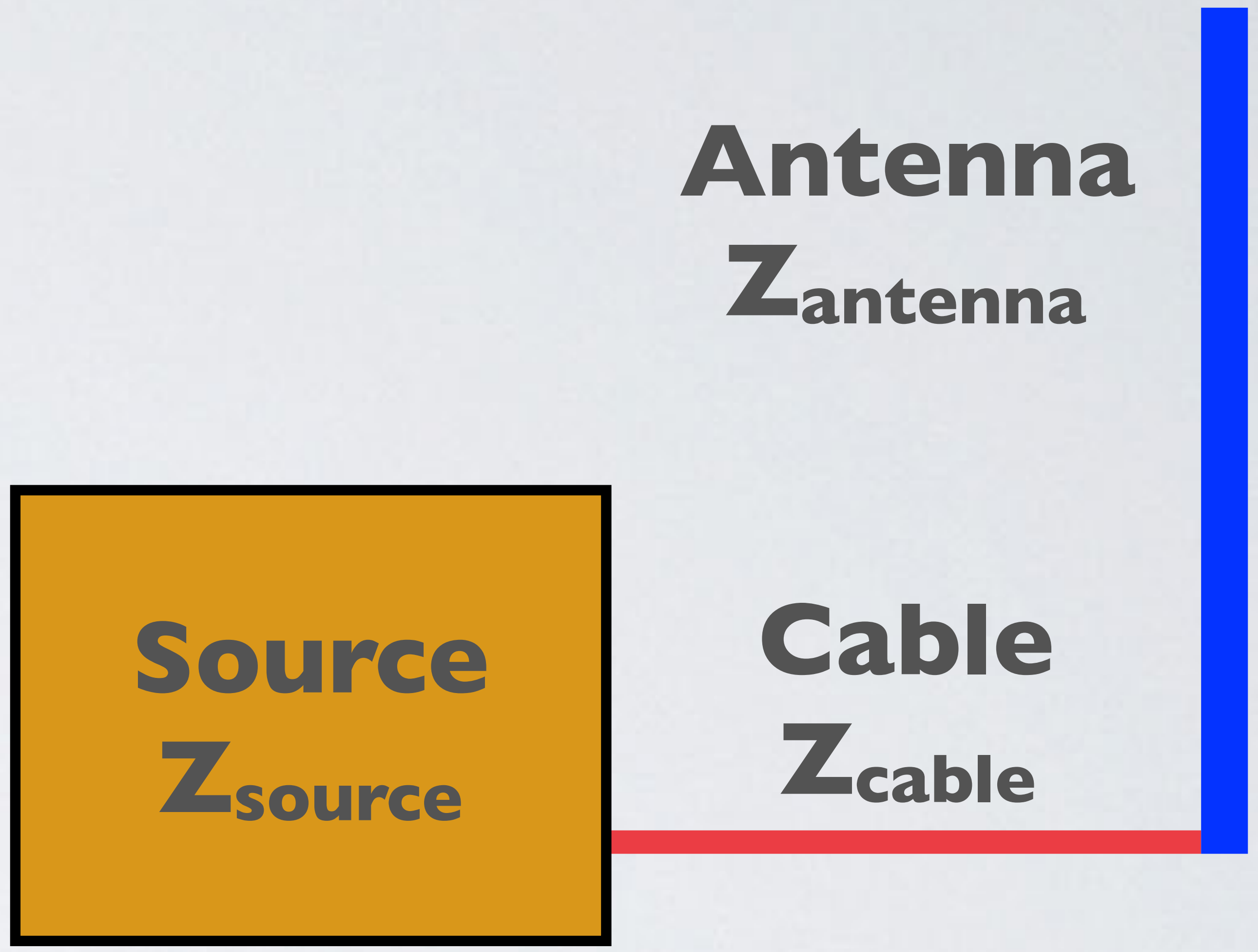
- Why do we want the antenna impedance (Z) to be 50Ω?

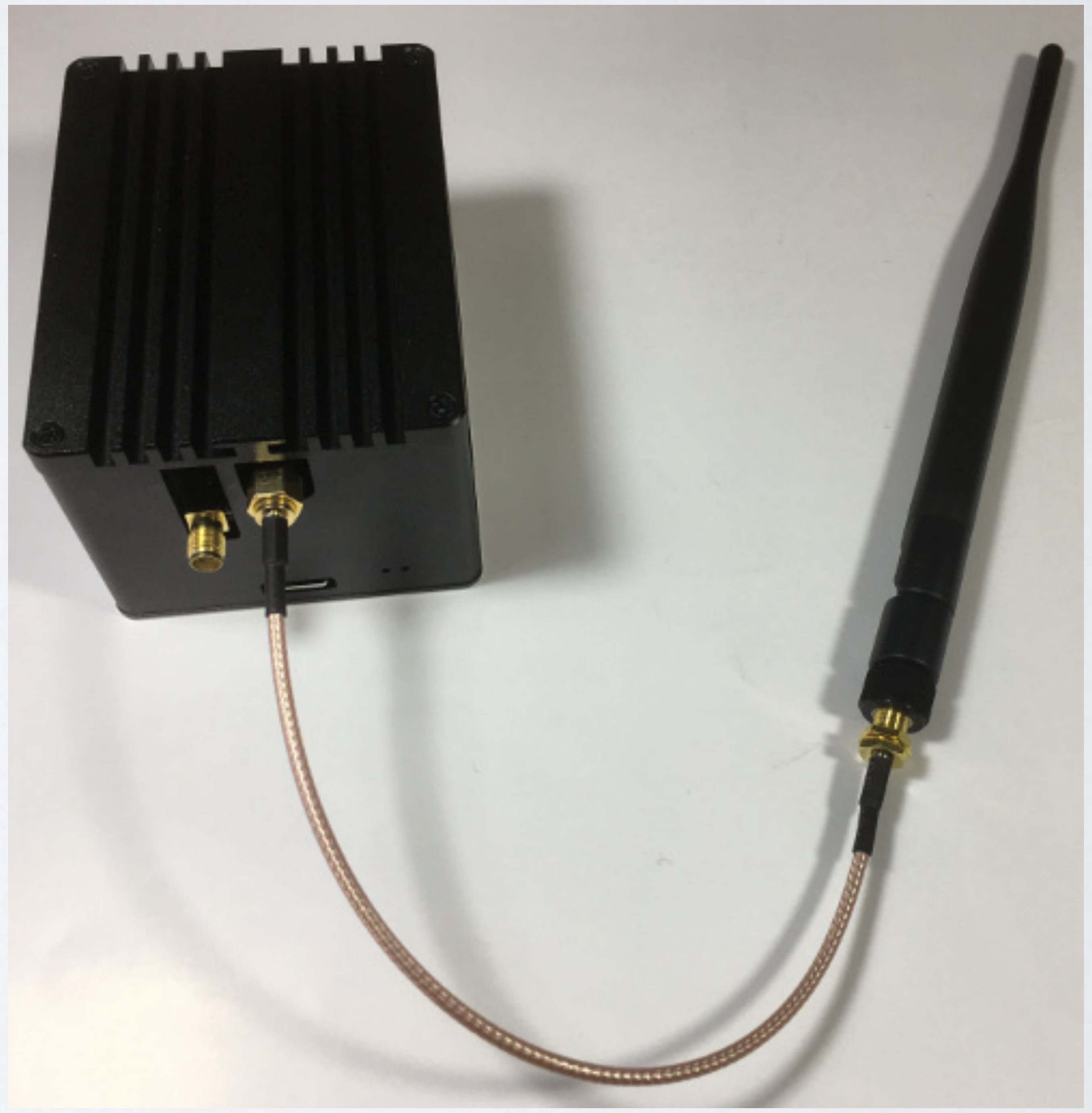
IMPEDANCE MATCHING

- The source, cable and antenna must have the same impedance.
  If not this will impact the signal.

- If $Z_{antenna} > Z_{cable}$, the signal is reflected.
  If $Z_{antenna} < Z_{cable}$, the signal strength is reduced.
  If $Z_{antenna} = Z_{cable}$, the signal strength is maximum.

- In general 50 Ω coax cables are used for data communications (LoRa, WiFi, etc.) or amateur radio.





IMPEDANCE MATCHING

- In the gateway documentation you may find the following line:
  "*The antenna port is well matched to standard 50 Ohm impedance.*" or
  "*RF interface optimised to 50 Ohm.*"

- In the coax cable and antenna specification you may find the line:
  "*Impendance: 50Ω*"

- In an ideal situation: $Z_{source} = Z_{cable} = Z_{antenna} = 50\ \Omega$