HOMAviation Training Center

مرکز آموزش های هوایی هما

Radio navigation

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Chapter 1

Basic Principles

Cycle of a Periodical Process

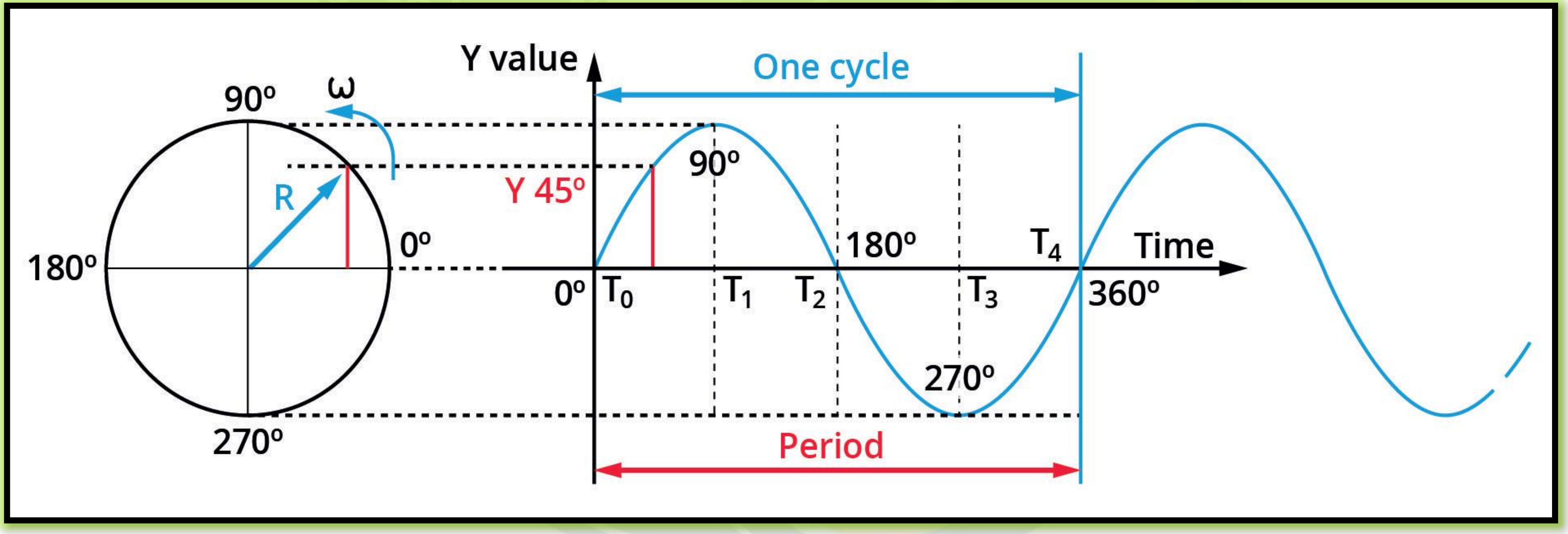
The **unit-vector** (R) rotates at a constant angular speed (ω) starting at 0 degree and passing 90 degrees ,180 degrees , 270 degrees , 360 degrees when it starts another revolution. The movement of the vector is projected on a 2-dimensional plane ,e.g. when the vector is at 45 degrees the projection is Y_{45} , at 90 degrees the projection is Y_{90} .

The value of the projection Y at any angle (a) is calculated by using the sine of the angle :

$$Y_a = R \times \sin a$$

The projection of a complete revolution of the unit-vector draws a sine curve, which includes all the angles from 0 degree to 180 degrees . A complete set of variable values is called a **cycle**.

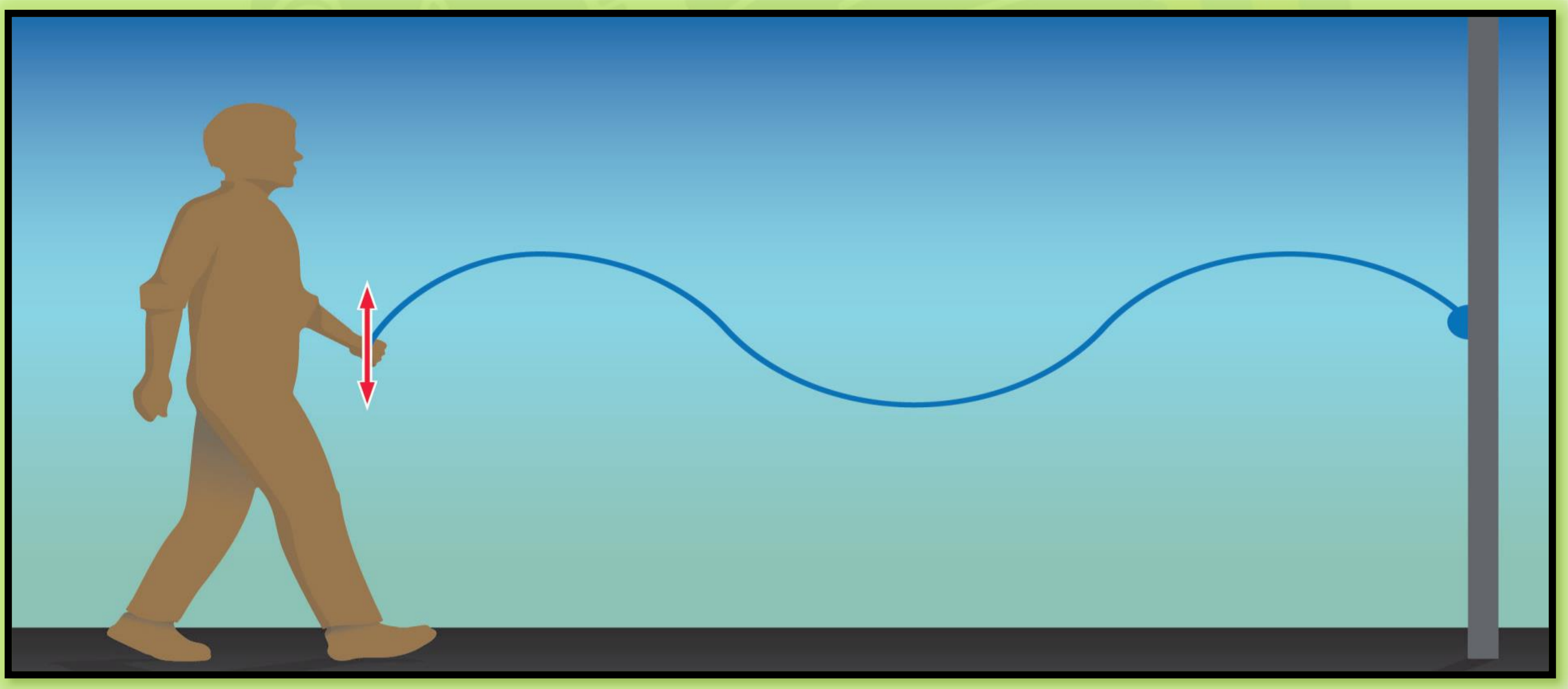
The time the vector takes to make a complete revolution (i.e., from T0 to T4) is called the **period**.



Waves

In physics, a **wave** is defined as a periodic disturbance of the particles of a substance which may be propagated without net movement of the particles, such as in the passage of undulating motion, heat, or sound.

When a long rope is oscillated at one end, an undulating motion called a **transverse wave .**

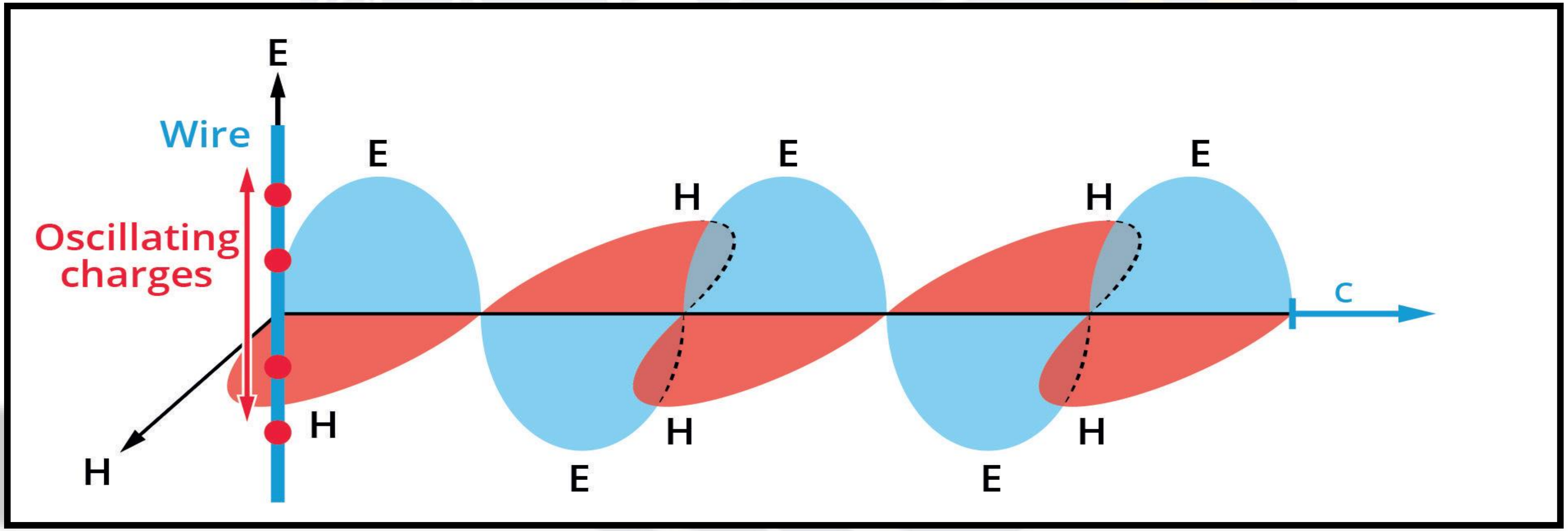


Vibrations created by a tuning fork compress the surrounding air and transmit a **soundwave**.

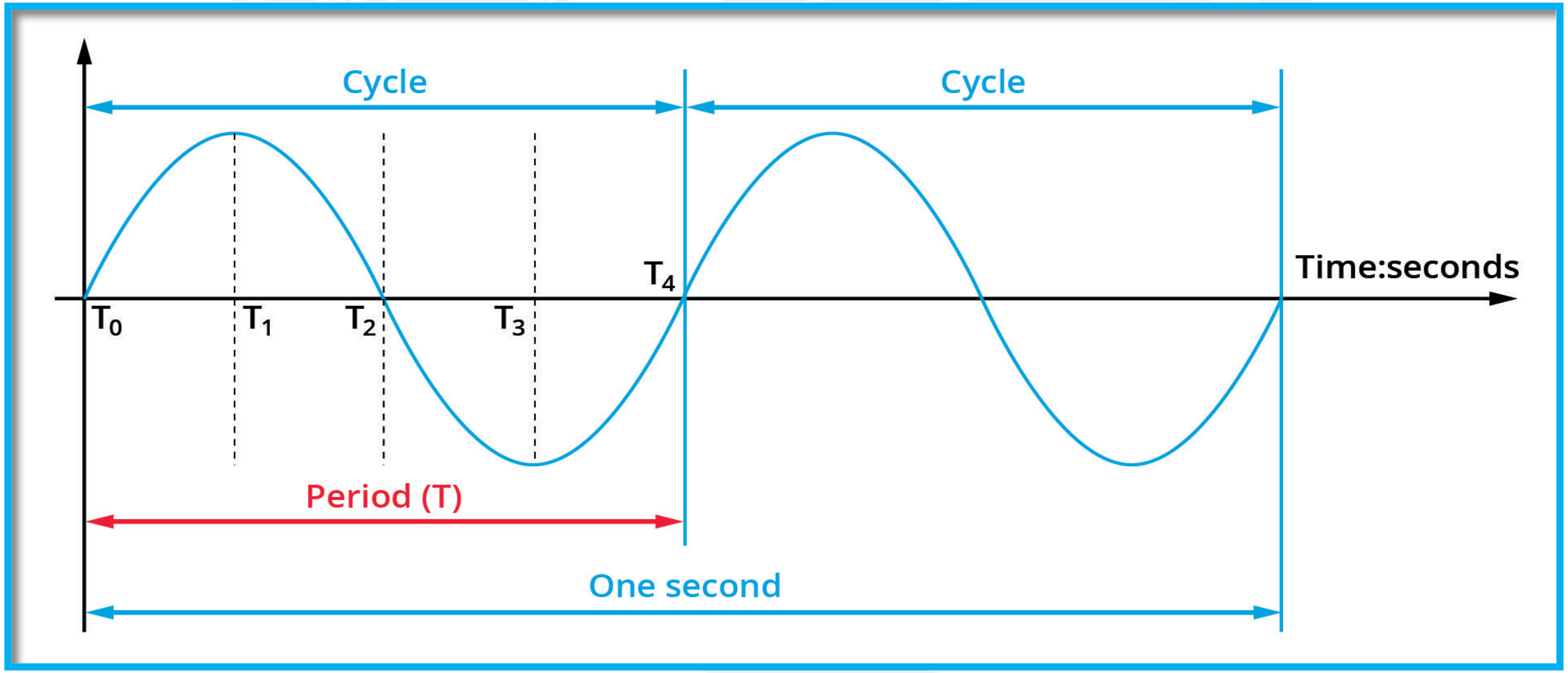
Electromagnetic Wave (EMW)

An oscillating electrical charge in a conductive wire radiates an electrical field (E) and a magnetic field (H). The fields oscillate in phase and are perpendicular to each other.

The combined electrical and magnetic field is an **electromagnetic wave (EMW)** which radiates in all directions from the wire at the speed (c).

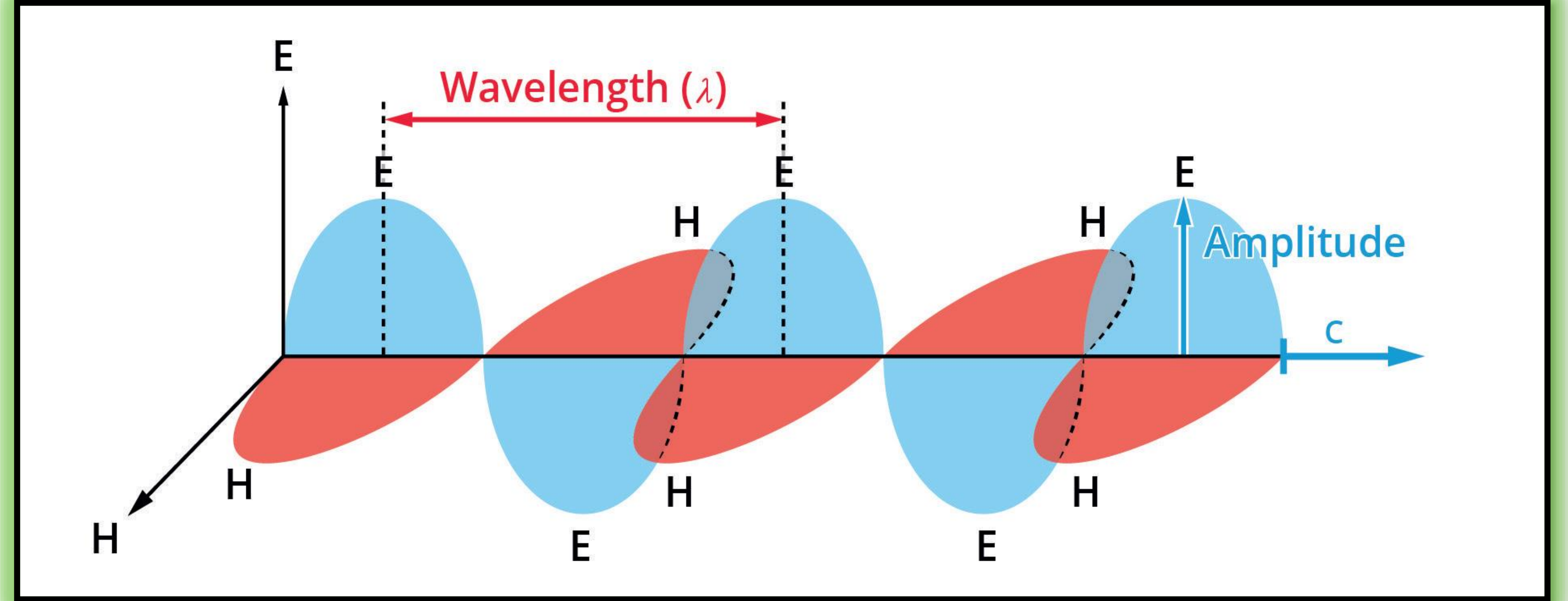


The **frequency** of a wave is the number of cycles per second expressed in hertz (Hz) and is an inverse function of the period (T) of a cycle; similarly the period is an inverse function of the frequency.



The **wavelength** (λ) is the physical distance a wave travels during a full cycle period.

The **amplitude** is the maximum value obtained during a cycle; it refers to the maximum strength of the radio wave.



Phase Angle

The phase is the relationship in time between the successive states of an oscillating or repeating system, e.g., an alternating electric current or a light or sound wave.

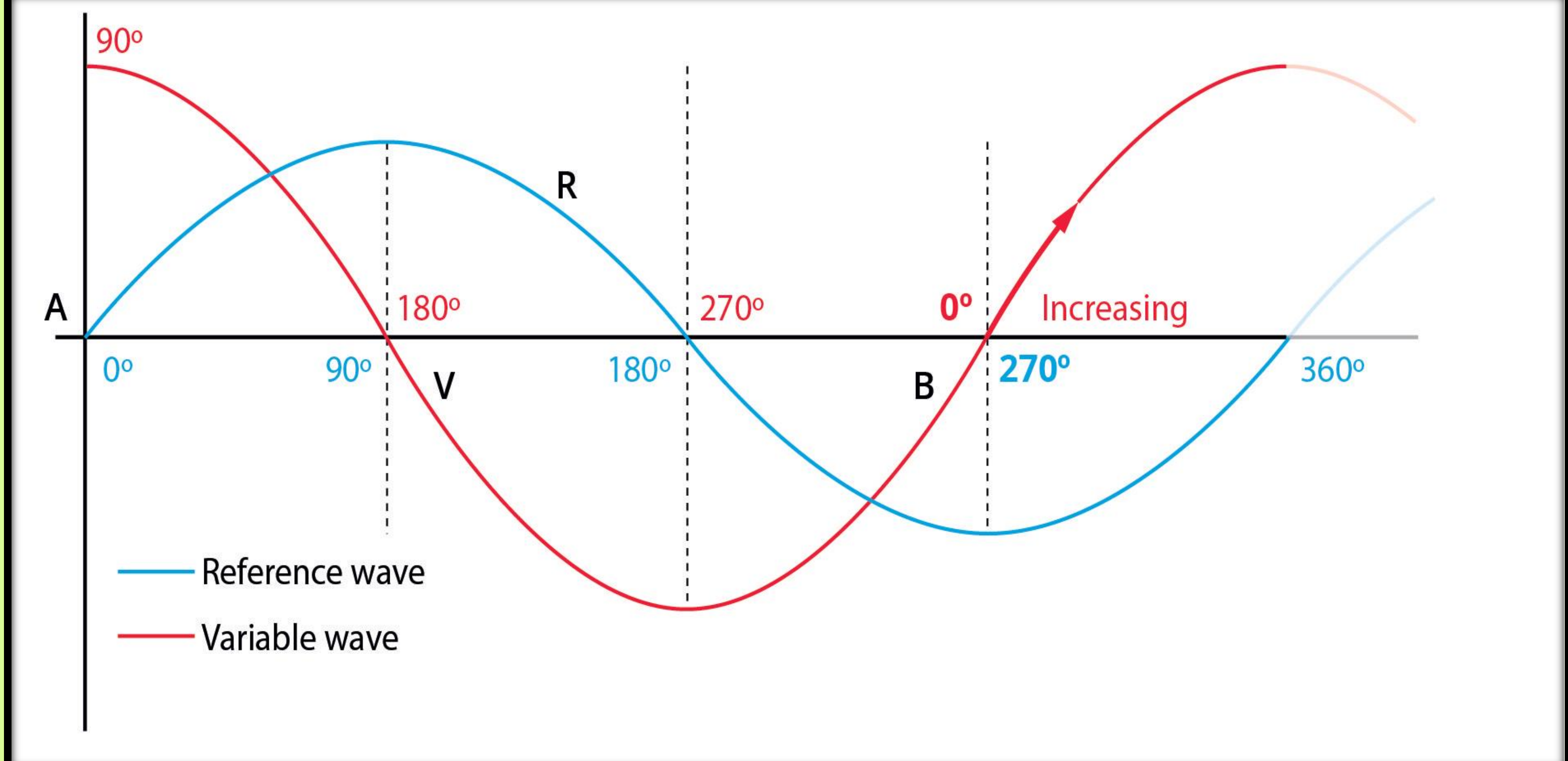
The phase angle is a point in the phase expressed as an angle360 degrees corresponding to one complete cycle.

phase angle difference

Some radio navigation systems (i.e., the VOR) use the comparison of phase between two signals to

define navigational information. To compare phases between two radio waves it needs the following:

- The two signals being compared must have the same frequency, otherwise any phase comparison would be meaningless.
- One signal will be designated the reference signal and the other a variable signal.
- The comparison must yield a positive result.


90º
R
A
180º
270º
0º
Increasing
0º
90º
V
180º
B
270º
360º
Reference wave
Variable wave

starting at zero phase on the reference wave (point A) , we observe that the reference wave has travelled through a phase angle of 270 degrees before zero phase is reached on the variable wave (point B) , hence the phase difference is 270 degrees .

The relationship can also be found mathematically. At the origin the phase of the reference wave is 0 (= 360 degrees) and the phase of the variable wave is 090 degrees . Subtracting the instantaneous phase of the variable wave from the instantaneous phase of the reference wave gives the same result, note the result must always be positive. Reference – variable = 360 degrees – 90 degrees = 270 degrees .

Frequency Bands

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Electromagnetic Spectrum

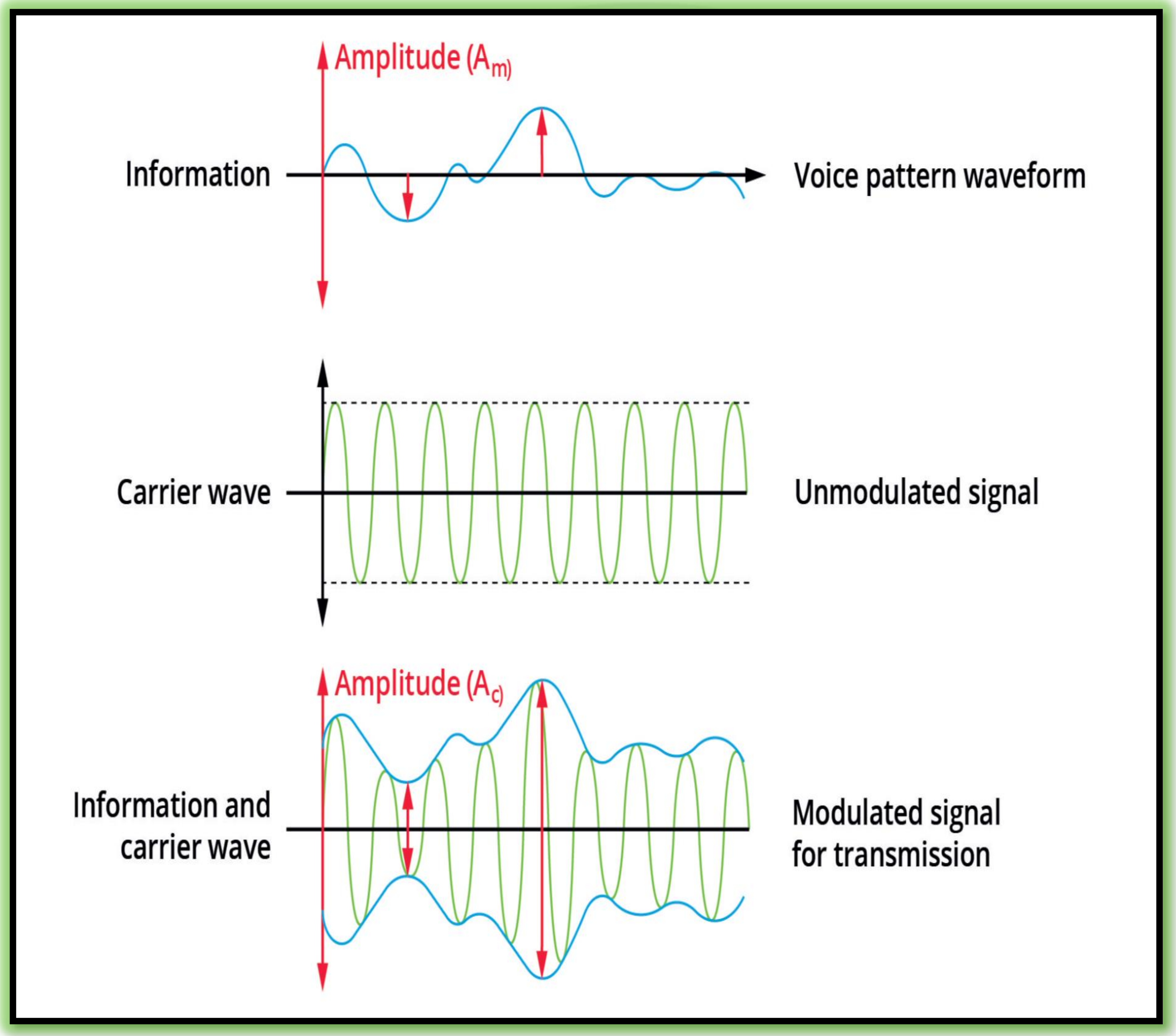
Frequency Bands			Wavelength Bands		
VLF	Very low frequency	3 kHz - 30 kHz	100 - 10 km	Myriametric	Radio, communication and navigation
LF	Low frequency	30 kHz - 300 kHz	10 - 1 km	Kilometric	
MF	Medium frequency	300 kHz - 3000 kHz	1000 - 100 m	Hectometric	
HF	High frequency	3 mHz - 30 mHz	100 - 10 m	Decametric	
VHF	Very high frequency	30 mHz - 300 mHz	10 - 1 m	Metric	
UHF	Ultra high frequency	300 mHz - 3000 mHz	100 - 10 cm	Decimetric	
SHF	Super high frequency	3 gHz - 30 gHz	10 - 1 cm	Centimetric	
EHF	Extremely high frequency	30 gHz - 300 gHz	10 - 1 mm	Millimetric	
IR	Infrared	300 gHz - 430 tHz	1 mm - 700 NM		Optical spectrum
ES	Visible light	430 tHz - 790 tHz	700 NM - 400 NM		
UV	Ultraviolet	790 tHz - 30 pHz	400 NM - 10 NM		
	X-ray	30 pHz - 30 eHz	10 NM - 0.01 NM		
	Gamma ray	More than 30 eHz	Less than 0.01 NM		
	Cosmic ray	More than 10^{21} Hz			

Radio waves are used to carry information, for example voice or digital data information, these radio waves, when carrying information, are called **carrier waves (CW)**

The frequencies LF , MF , VHF, UHF , SHF and EHF are used as carrier waves.

- LF and MF are used for ground-air transmissions over long distances.
- HF is used for ground- air and air - ground transmissions over long distances.
- For ground-air and air-ground transmissions over short distances VHF and UHF are used.
- Radar applications use frequencies from UHF to EHF.

The process to add information on a CW is called **modulation** .


Amplitude (A_m)
Information
Voice pattern waveform
Carrier wave
Unmodulated signal
Amplitude (A_c)
Information and carrier wave
Modulated signal for transmission

Kinds of Modulation

Amplitude Modulation (AM)

Amplitude modulation is when the amplitude (Am) of a lower frequency information signal, for example voice, modulates (i.e., varies) the amplitude (Ac) of a higher frequency carrier wave.

• In amplitude modulation the information is included in the carrier's amplitude variation.

Frequency Modulation (FM)

In frequency modulation, the amplitude of the information wave frequency modifies the frequency of the carrier wave.

The change in the carrier wave frequency is dependent on the rise and fall of the amplitude of the modulating wave frequency : the greater the amplitude, the greater the frequency deviation. The frequency of the modulating wave determines the rate of change of frequency within the modulated carrier wave.

Pulse Modulation

Pulse modulation is used extensively in radar systems and for data exchange in communications systems. An intermittent carrier wave is formed by the generation and transmission of a sequence of short period pulses.

Phase Modulation

In phase modulation the phase of the carrier wave is modified by the input signal. In binary phase shift keying (BPSK) a180 degrees phase shift represents a binary status change from 0 to 1 or 1 to 0 . This is the simplest case of phase modulation , which only allows low flow of information.

GPS uses binary phase shift keying

Antenna Placement

Each radio communication and navigation system have antennas. Some antennas are used to transmit and receive (VHF/HF comms , SSR, DME , weather radar) , others to only receive (LOC , GS,VOR , ADF, markers , GPS).

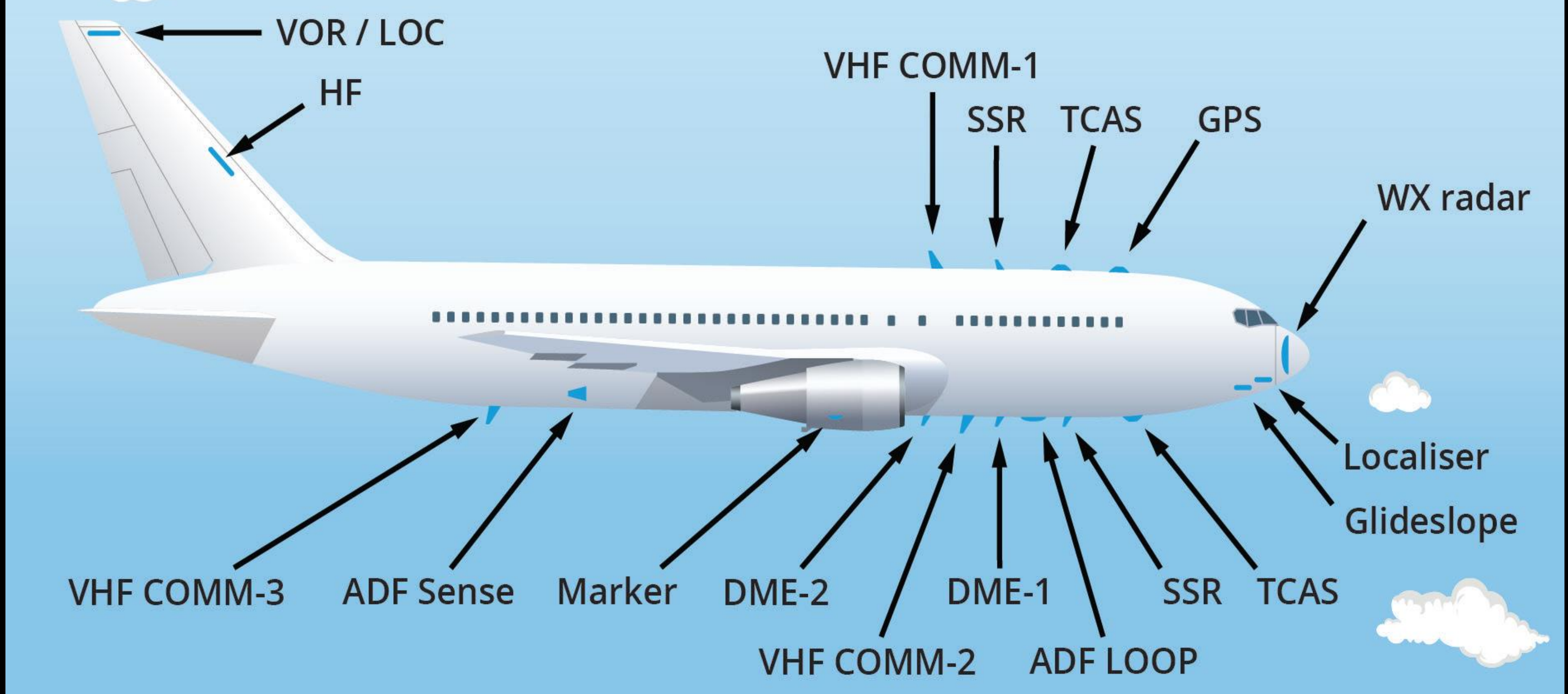
For safer operations , system redundancy requires at least two , or more systems , e.g. 2 VHF comms , 2 LOC and etc.

Most , but not all , aircraft antennas are located at the bottom of the fuselage on the aircraft's

longitudinal axis, as most radio stations are located on the ground. The weather radar is located

at the nose of the aircraft covered by a composite material dome called the **radome**.

Antennas - Locations



Polarisation

The polarisation of radio waves is defined as the plane of the electric field and is dependent on the plane of the antenna. A vertical aerial will emit radio waves with the electrical field in the vertical plane , and hence , produce a vertically polarised wave , and a horizontal aerial will produce a horizontally polarised wave.

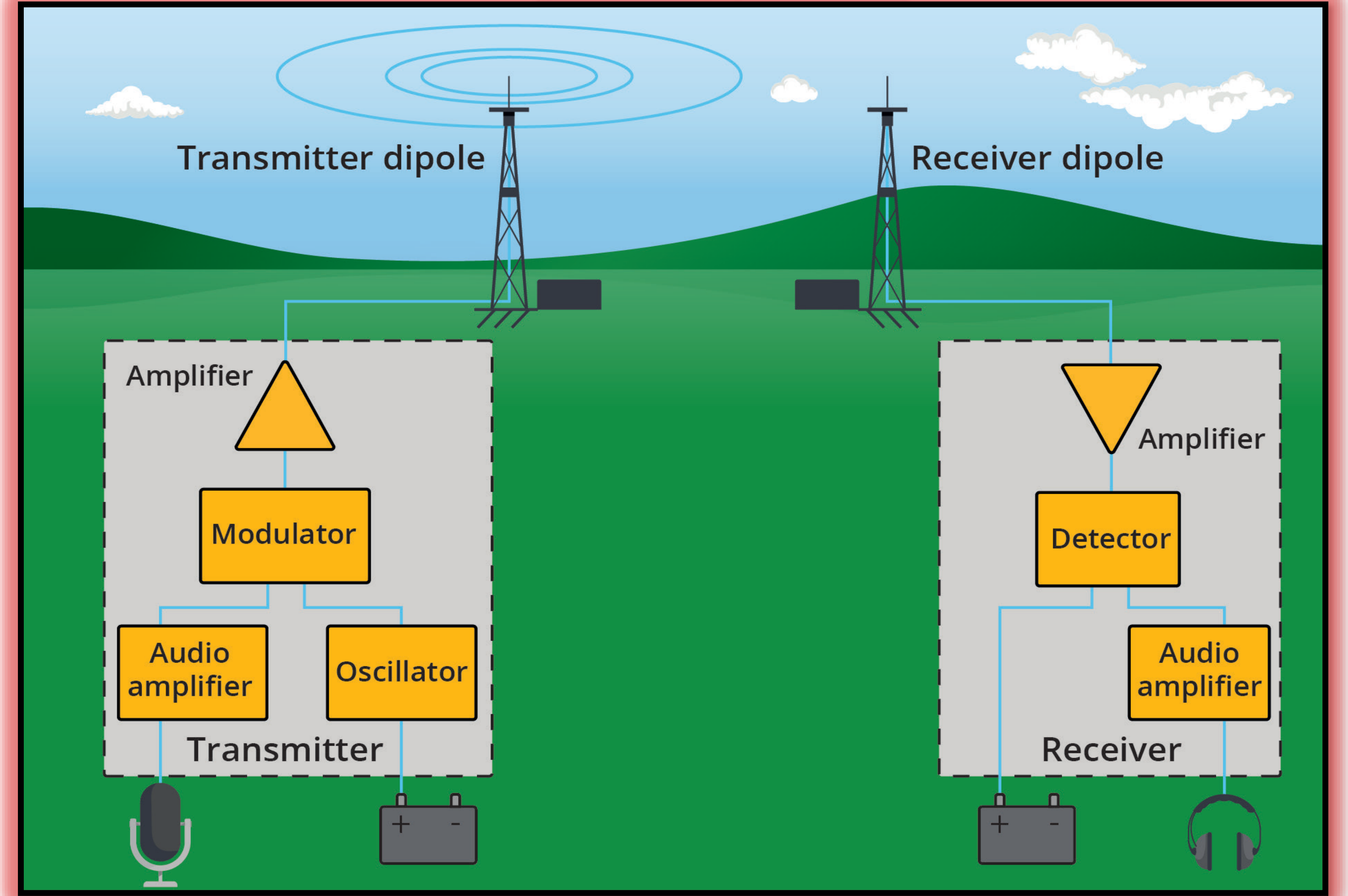
To receive maximum signal strength from an incoming radio wave, it is essential the receiving aerial is in the same plane as the polarisation of the wave, so a vertically polarised radio wave would require a vertical aerial. vertical and horizontal polarisations are used for radio communication and navigation systems

Circular polarisation can be produced in a variety of ways, one of which uses a helical antenna. In circular polarisation the electrical (and hence magnetic) field rotates at the frequency of the radio wave. The rotation may be right-handed or left-handed dependent on the orientation of the aerial array. Circular polarisation is used in satellite navigation systems.

Radio Transmission System

To transmit information wirelessly, a basic radio system is used and must include the following minimum equipment:

- At the transmission station: a transmitter and a transmitting antenna
- At the receiving station: a receiver and a receiving antenna
- Both antennas must have the same orientation (i.e., the same polarisation)


Transmitter dipole
Receiver dipole
Amplifier
Modulator
Audio amplifier
Oscillator
Transmitter
Amplifier
Detector
Audio amplifier
Receiver
+
-
+
-

Wave Propagation

The term **propagation** simply means how the radio waves travel through the atmosphere. Different frequency bands use different propagation paths through the atmosphere. The propagation path often determines the uses to which a particular frequency band can be put in either communication or navigation systems.

The different propagation paths associated with particular frequencies can also impose limitations on the use of those frequencies. Several factors affect the propagation of radio waves and need to be considered when discussing the propagation paths.

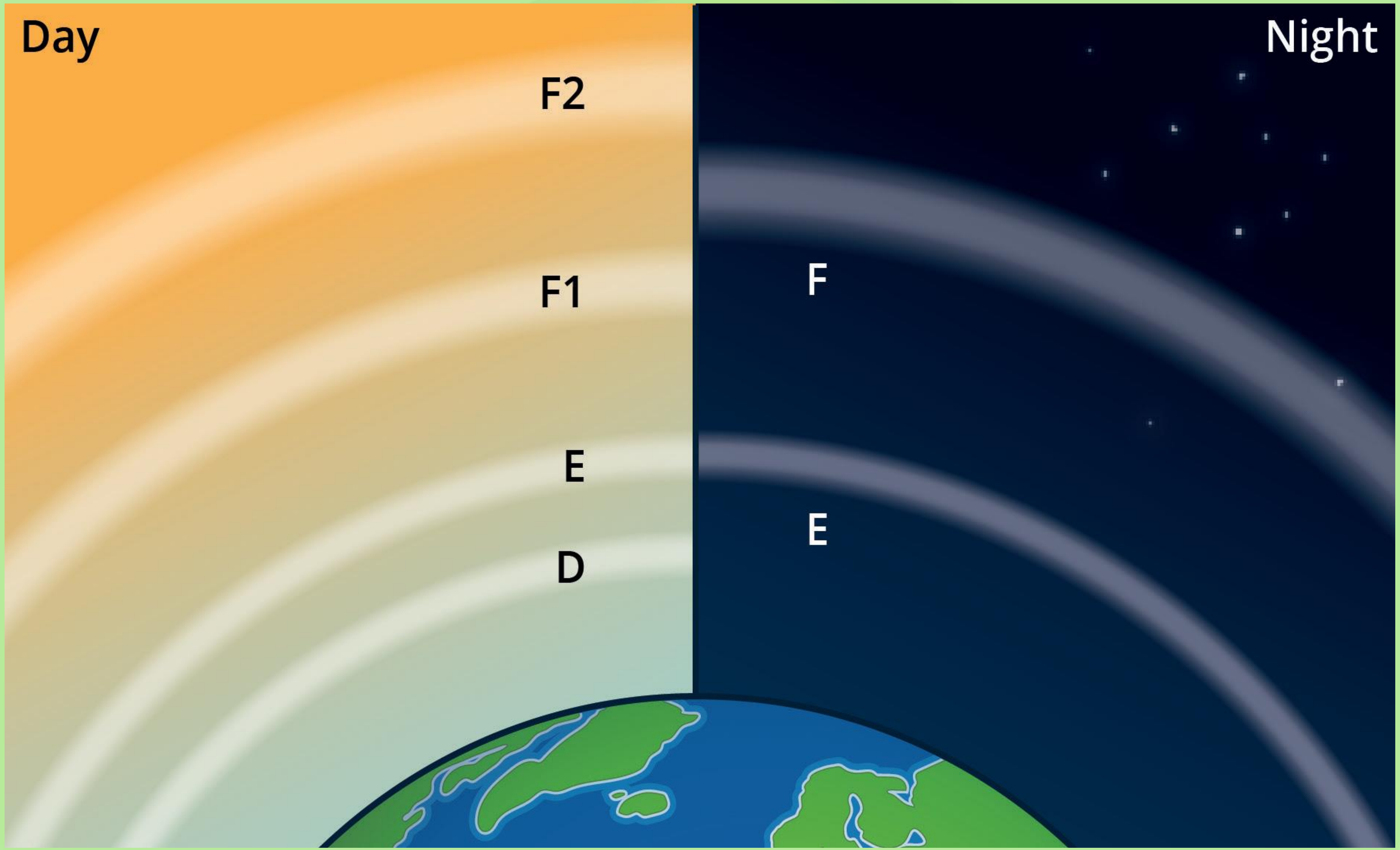
There are three propagation paths to be considered for aviation purposes :

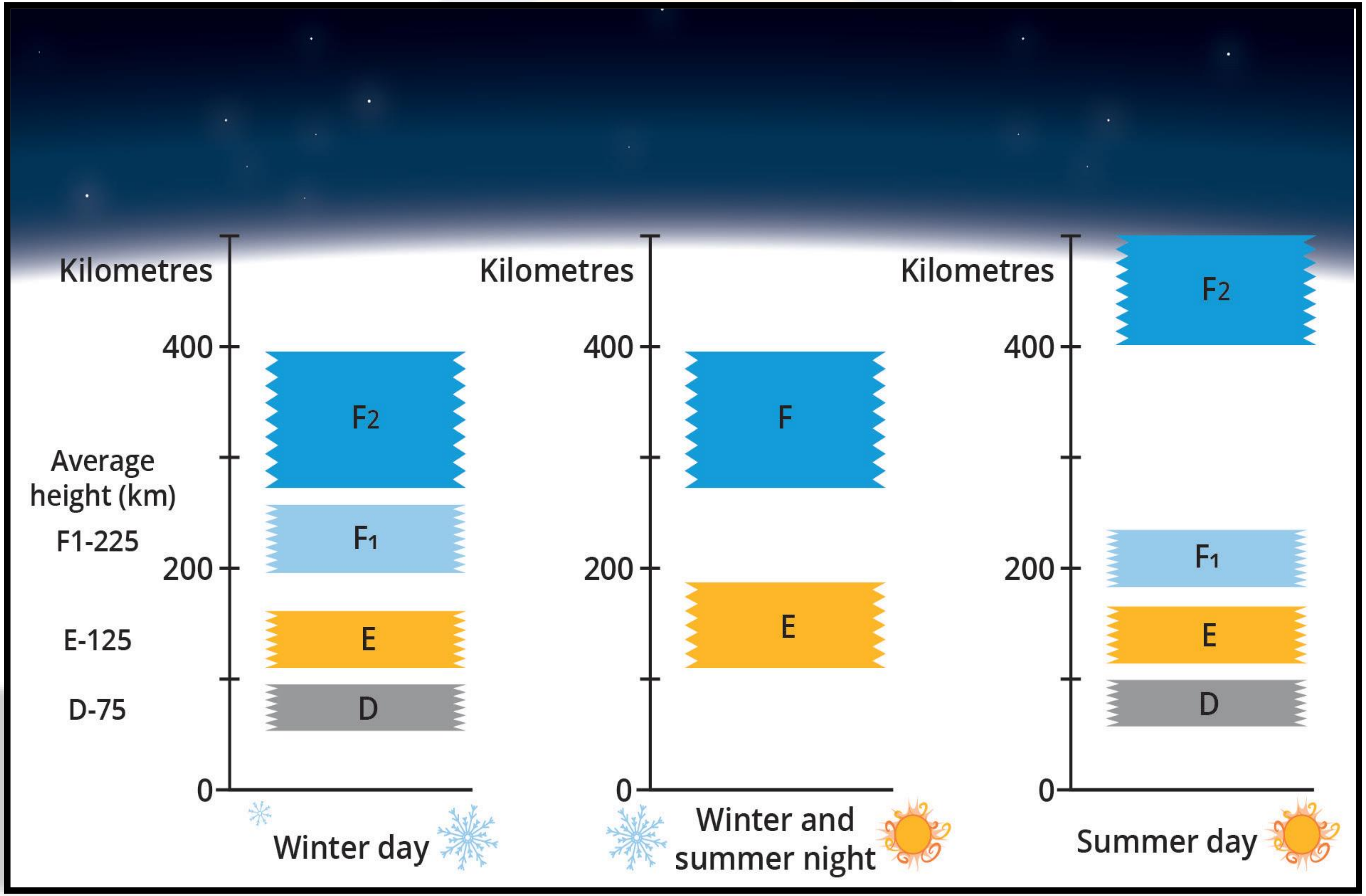
Propagation paths	Non-ionospheric	Ionospheric
	Surface waves 30 kHz - 2 MHz	Sky waves 3 MHz - 30 MHz
	Space waves > 30 MHz	

The Ionosphere

The **ionosphere** extends upwards from an altitude of about 60 km to 400 km. In this part of the atmosphere, the pressures are very low (at 60 km the atmospheric pressure is 0.22 hPa) and, hence, the gaseous atoms are widely dispersed. Within this region, incoming solar radiation (which varies in cycles of eleven years) at ultra-violet and shorter wavelengths interacts with the atoms raising their energy levels and causing electrons to be ejected from the shells of the atoms.

Since an atom is electrically neutral, the result is negatively charged electrons and positively charged particles known as **ions**.

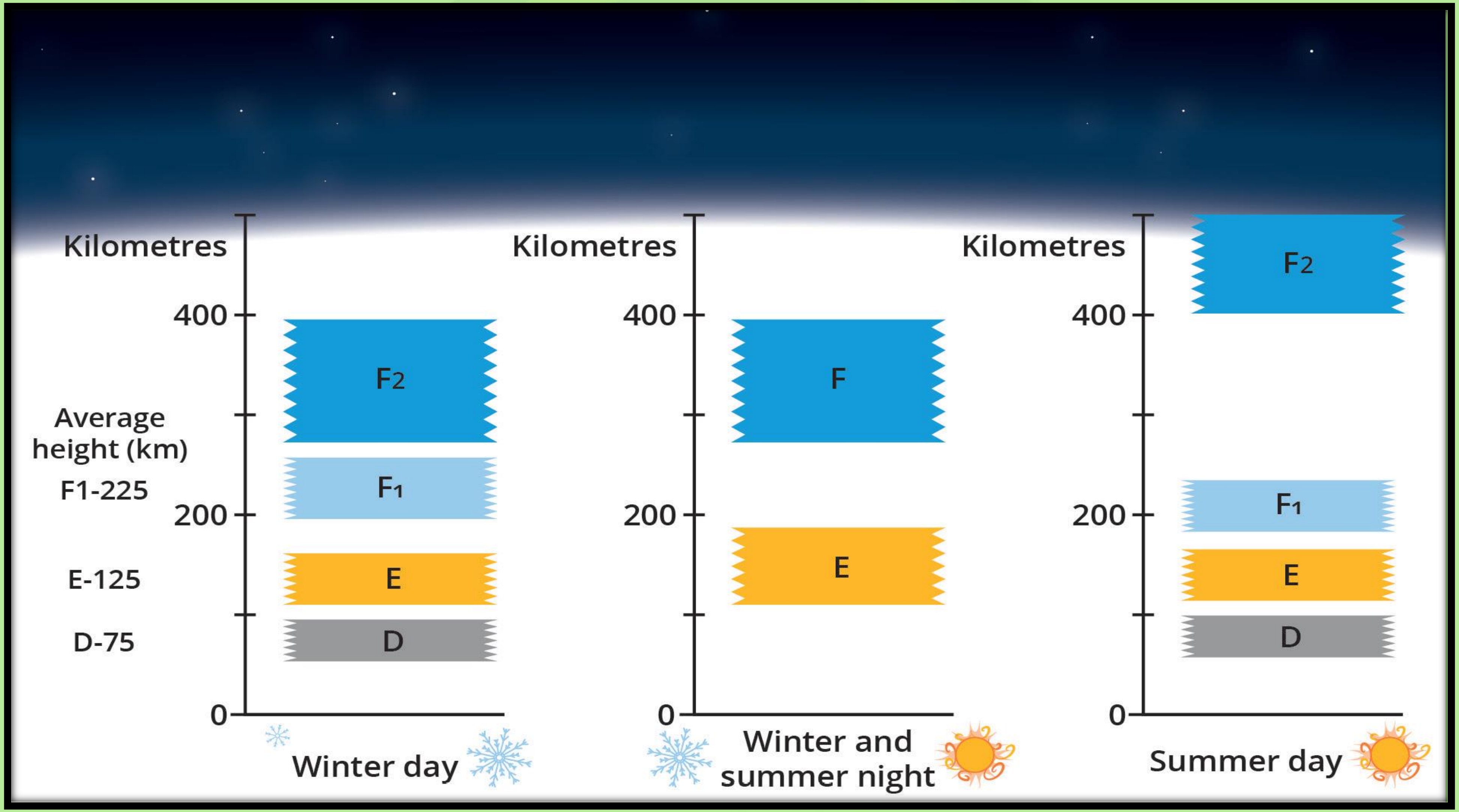

Day
F2
F1
E
D
Night
F
E


Kilometres
400
200
0
Average
height (km)
F1-225
E-125
D-75
F2
F1
E
D
Winter day
Kilometres
400
200
0
F
E
Winter and
summer night
Kilometres
400
200
0
F2
F1
E
D
Summer day

• The D-layer, the lowest of these layers, appears at an average altitude of 75 km. This is a fairly diffused area which , for practical purposes , forms at sunrise and disappears at sunset.

• The E-layer appears at an average altitude of 125 km and is present day and night. The E-layer reduces in altitude at sunrise and increases in altitude after sunset.

• The F-layer appears at an average altitude of 225 km. The F-layer splits into two at sunrise and re-joins at sunset, with the F1-layer reducing in altitude at sunrise and increasing in altitude after sunset. The behaviour of the F2-layer is dependent on the time of year. In summer, it increases in altitude and may reach altitudes in excess of 400 km, and in winter, it reduces in altitude.


Kilometres
400
200
0
Average
height (km)
F1-225
E-125
D-75
F2
F1
E
D
Winter day
Kilometres
400
200
0
F
E
Winter and
summer night
Kilometres
400
200
0
F2
F1
E
D
Summer day

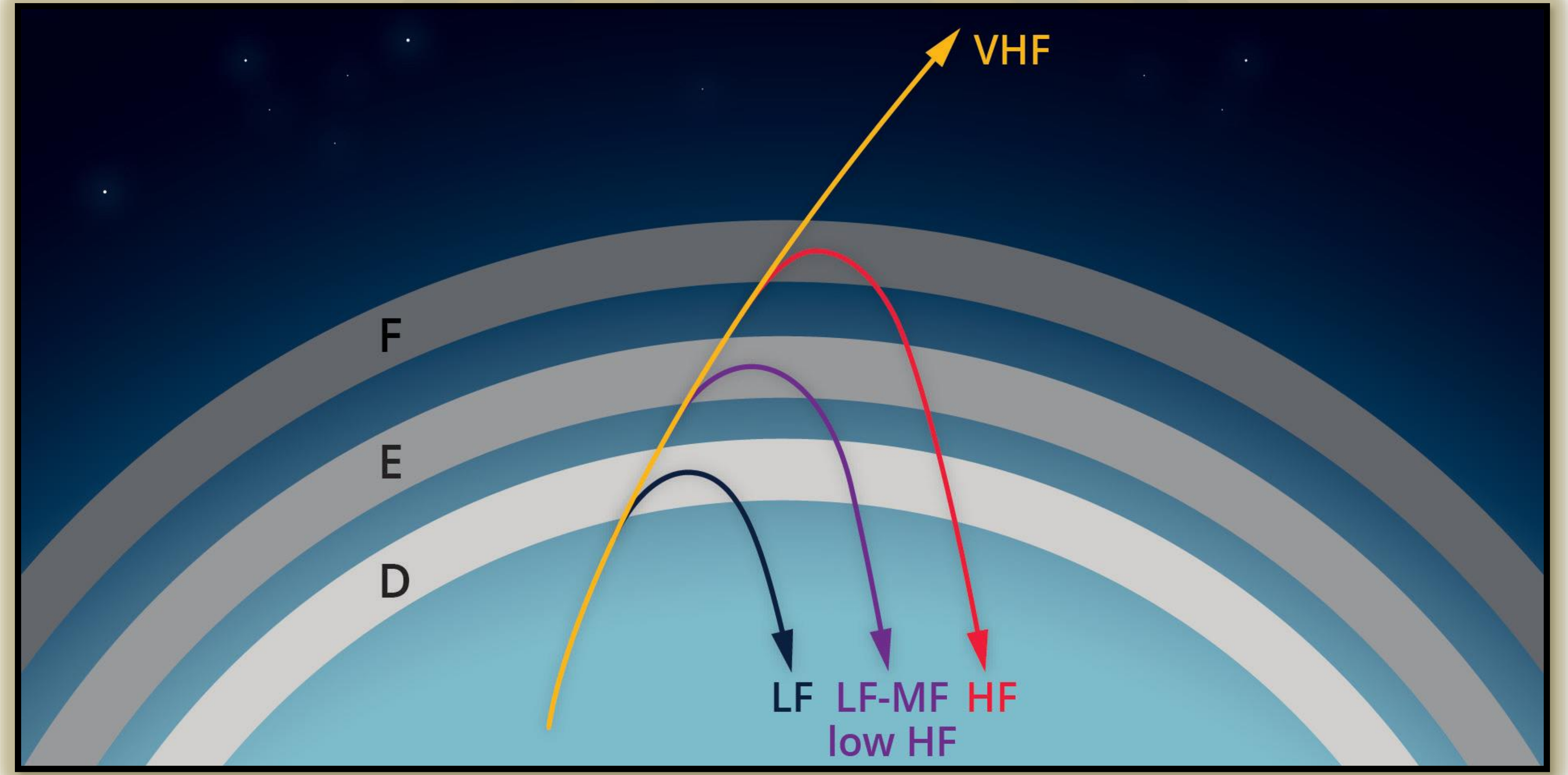
Sky Waves

The ionisation levels in the layers increase towards the centre of the layer. This means that as a radio wave transits a layer, it encounters an increasing density of ions as it moves to the centre of the layer and decreasing density as it moves out of the layer.

If the radio waves travel across the layer at right angles , they will be retarded but will maintain a straight path. However , if the waves penetrate the layer at an angle, they will be refracted away from the normal as they enter, then back towards the normal as they exit the layer. If the radio wave refracts to the earth horizontal before it reaches the centre of the layer , then it will continue to refract and will return to the surface of the earth as a **sky wave**.

sky waves are also defined as waves reflected from the ionosphere.

The amount of **refraction** experienced by the radio waves is dependent on both the frequency and the levels of ionisation.



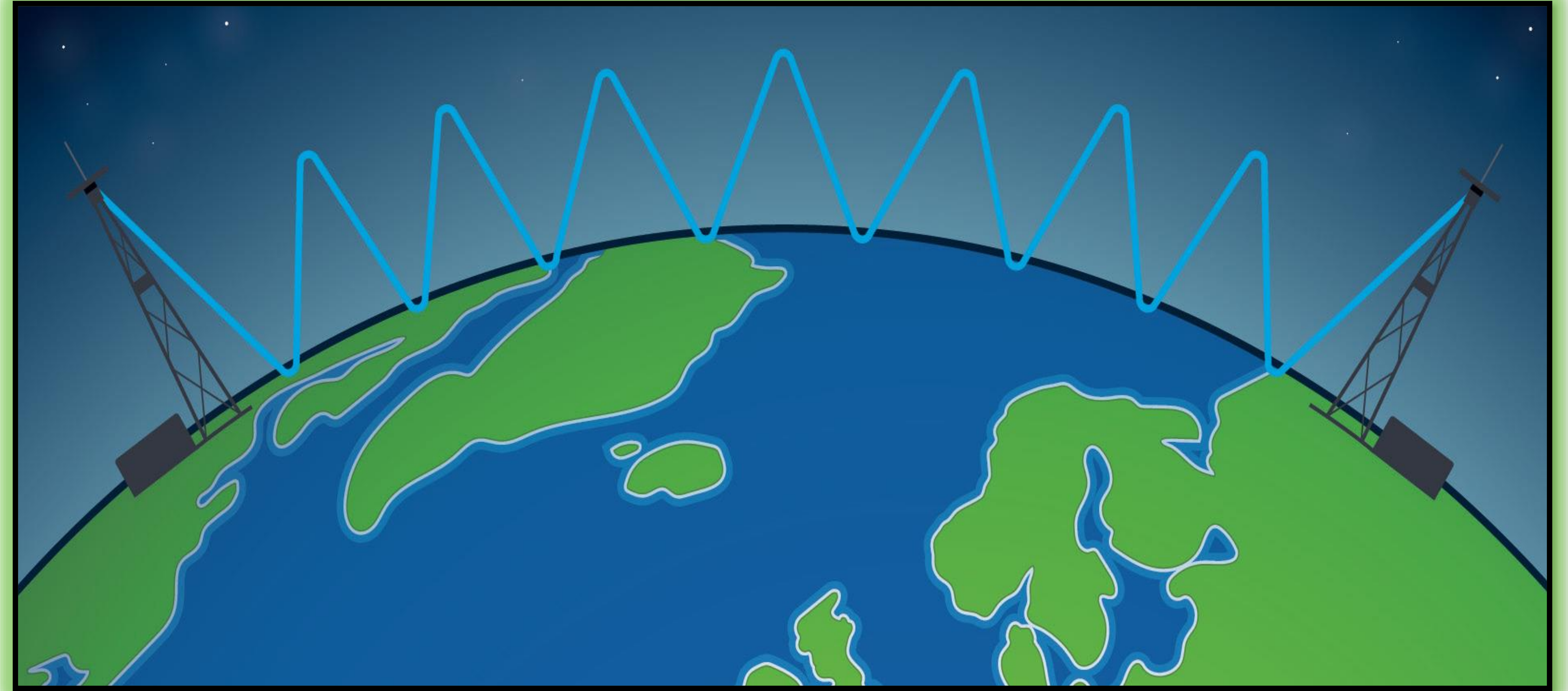
Ground Waves

Surface or **ground wave** propagation exists at frequencies from LF to HF bands. The portion of the wave in contact with the surface of the earth is retarded causing the wave to bend round the surface of the earth, a process known as **diffraction.**

The range achievable is dependent on several factors :

- The frequency
- The surface over which the wave is travelling
- The polarisation of the wave

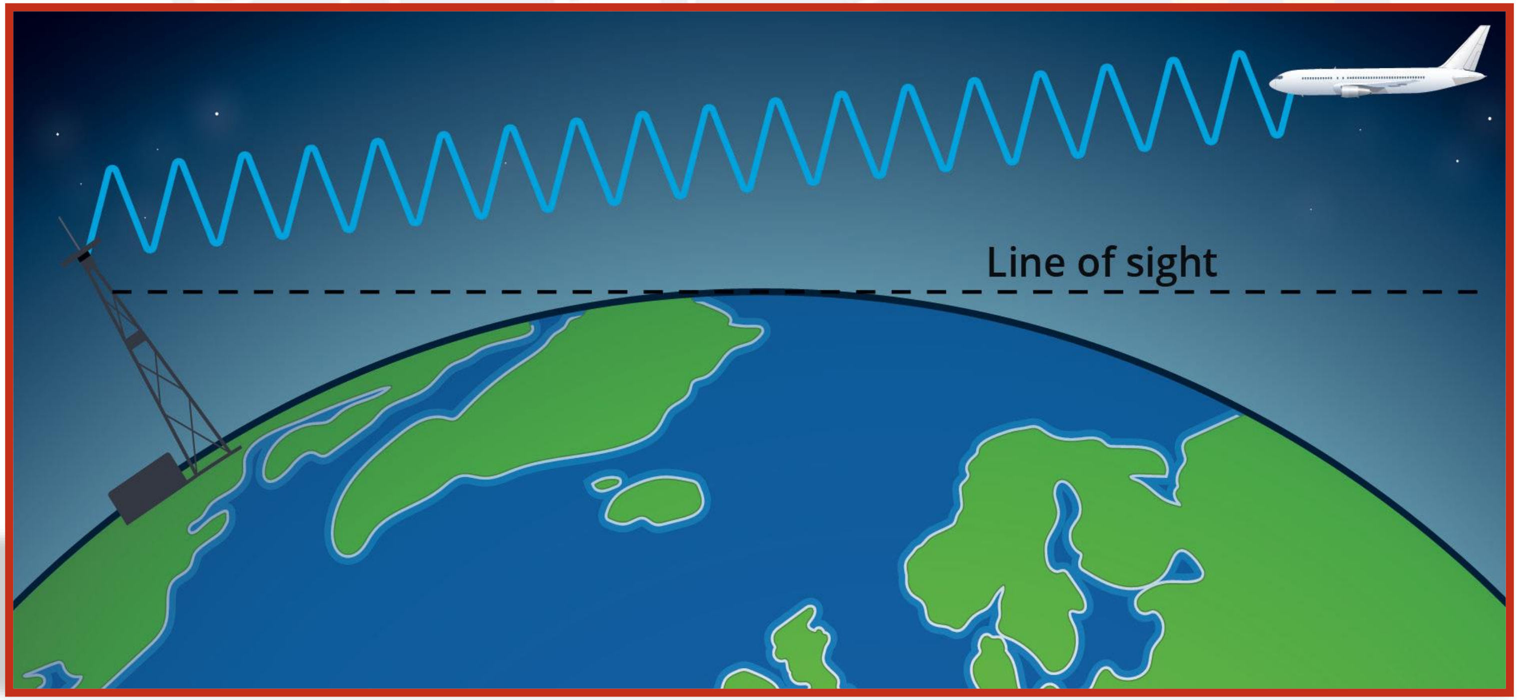
As the frequency increases, surface attenuation increases, the surface wave range decreases, and the range reachable with frequencies above HF is negligible.



Space Waves

Radio waves, which propagate in a straight line between a transmitter and a receiver, as visible light does, are called **space waves**. Space waves are available across the entire radio frequency bands but are the only propagation path for VHF band and above.

Space waves are limited in range by the line of sight (i.e, the radio horizon , which is slightly beyond the optical horizon due to some atmospheric refraction).



Frequency Band	Propagation Path
LF - MF	Ground waves (sky waves)
HF	Sky waves (surface waves)
VHF and above	Space waves

Doppler Effect

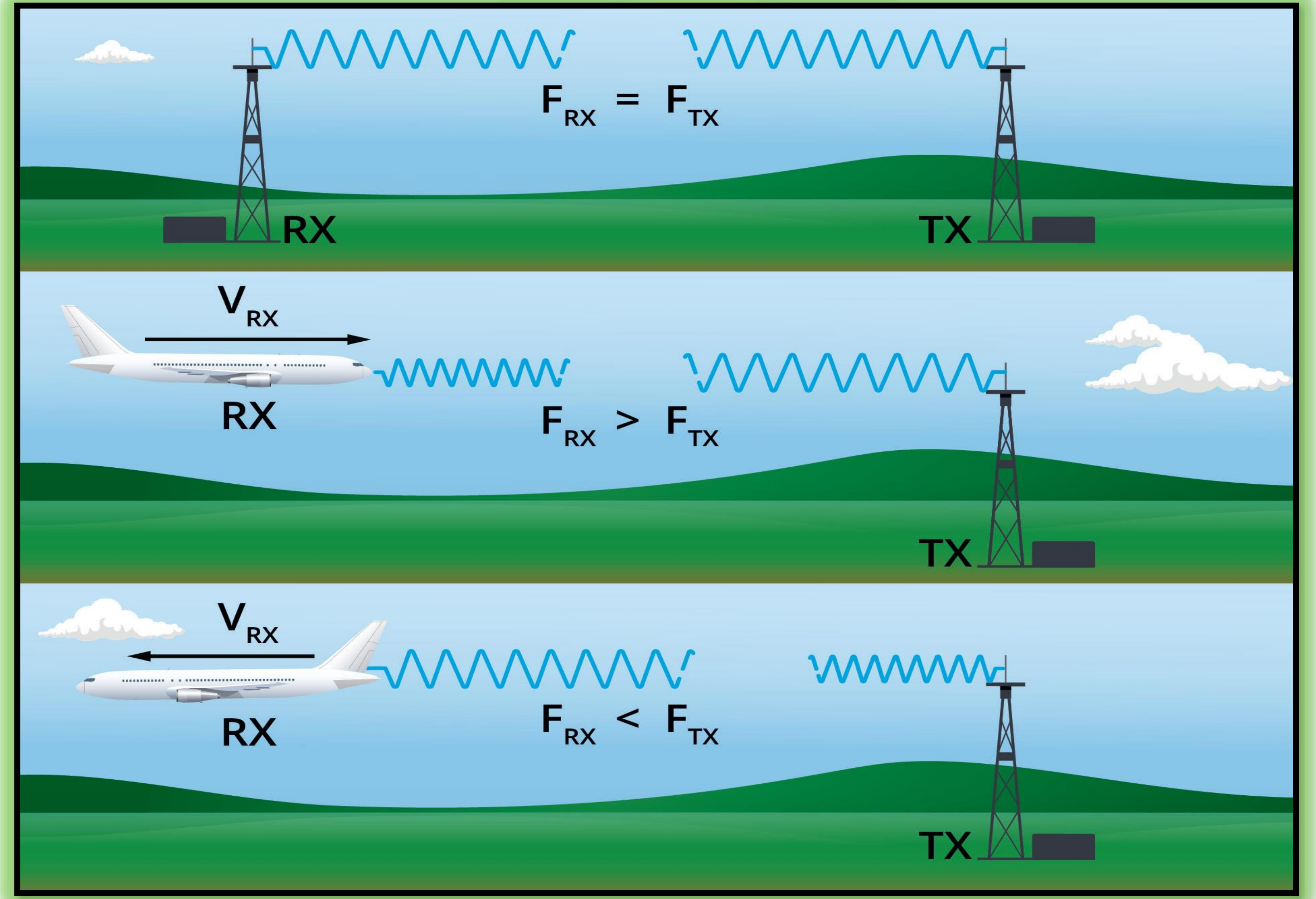
is the phenomenon where the frequency of a wave will increase or decrease if there is relative motion between the transmitter and the receiver.

Also an increase (or decrease) in the frequency of radio wave, sound, light, or other waves as the source (e.g. a transmitter-TX) and observer (e.g. a receiver RX) move towards (or away from) each other.’

The Doppler principle is used in navigation systems, such as Doppler VDF and Doppler VOR, to define a direction or radar to define motion speed.

The difference between the transmitted frequency (Ftx) and the received frequency (Fxr) is called the **Doppler shift** or **Doppler frequency** (Fd), which varies with the relative speed (V) between the transmitter and the receiver and is also a function of the transmitter frequency (Ftx).

The Doppler frequency Fd is positive when the transmitter and/or the receiver is/are moving towards each other and is negative when moving away from each other.


RX
TX
$F_{RX} = F_{TX}$
V_{RX}
RX
TX
$F_{RX} > F_{TX}$
V_{RX}
RX
TX
$F_{RX} < F_{TX}$

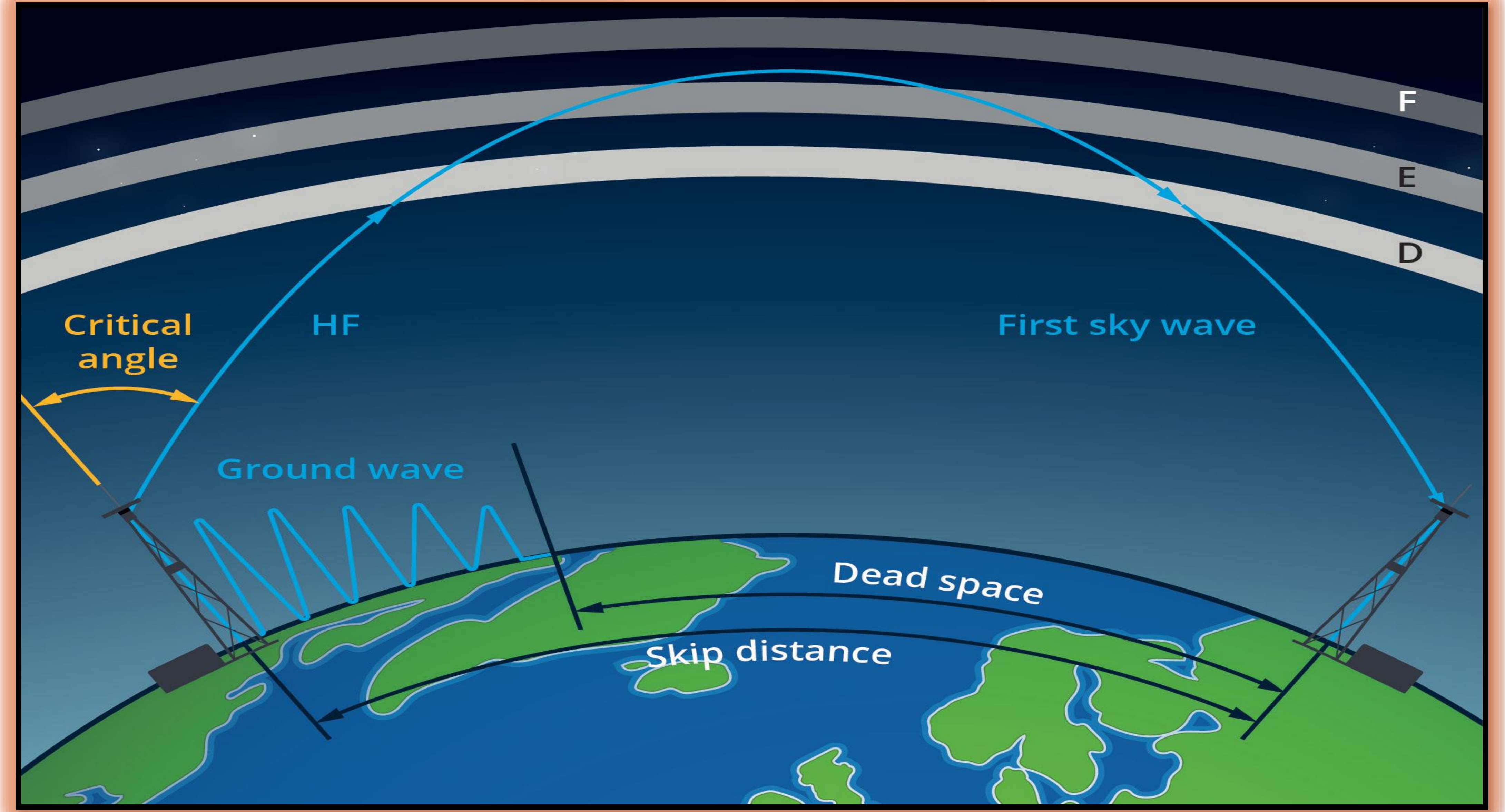
Chapter 2

Factors Affecting Propagation

The **skip distance** is the distance between the transmitter and the first sky wave return , which varies with the frequency, the time of the day, and the ionospheric status. The attainable range may be from 1,300 to 2,300 NM.

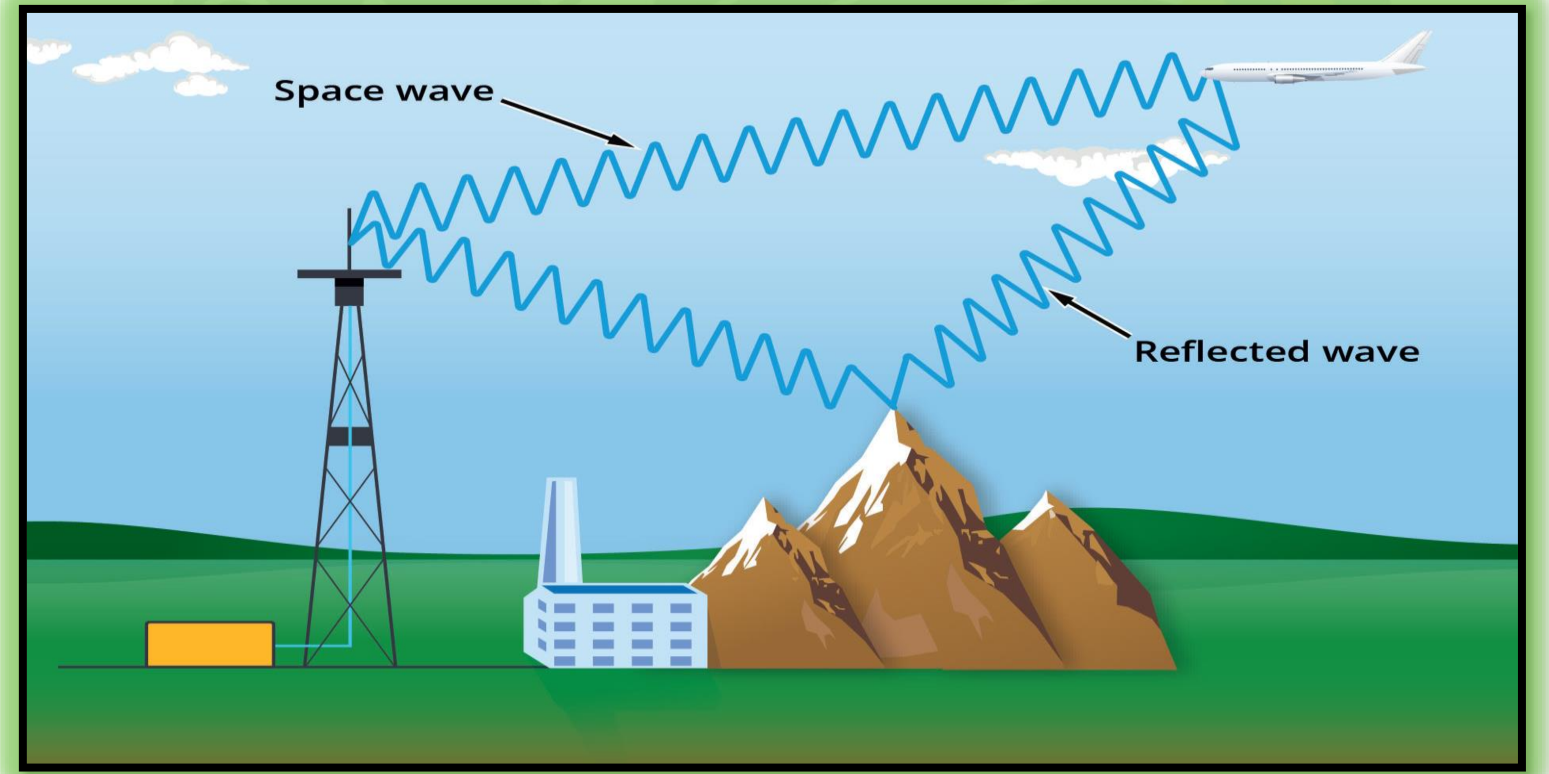
The **dead space** is the distance between the point where the ground waves are completely attenuated to the first sky wave.

HF radio waves which are reflected by the ionosphere (due to ionospheric refraction) return to the Earth surface, which happens when the angle between the wave and the normal at the transmitter is equal to the critical angle. The critical angle is dependent on the frequency (the higher the frequency, the larger the angle) and the ionisation level of the ionosphere (the higher the ionisation , the smaller the angle). HF radio also propagates ground waves useable within a limited range (about 50NM to 150 NM).

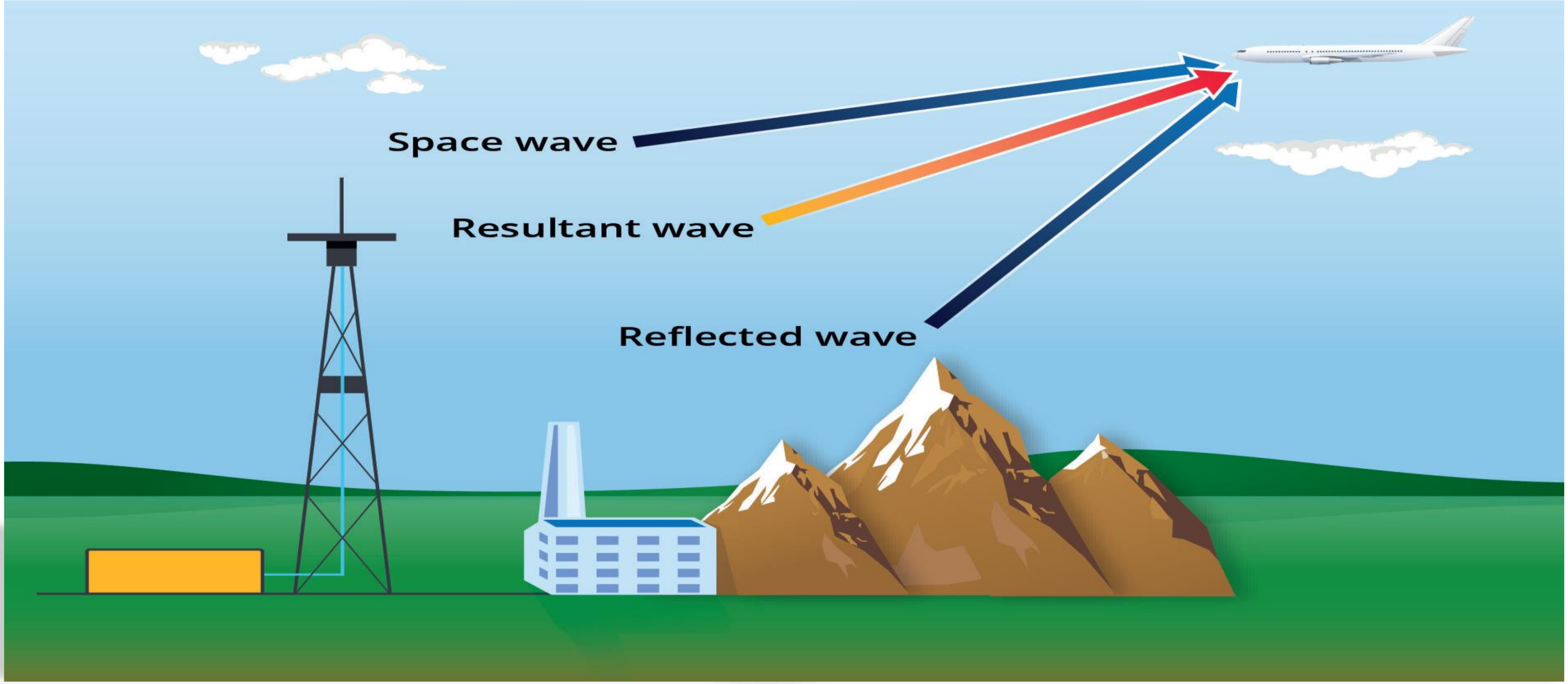

F
E
D
Critical angle
HF
First sky wave
Ground wave
Dead space
Skip distance

Fading

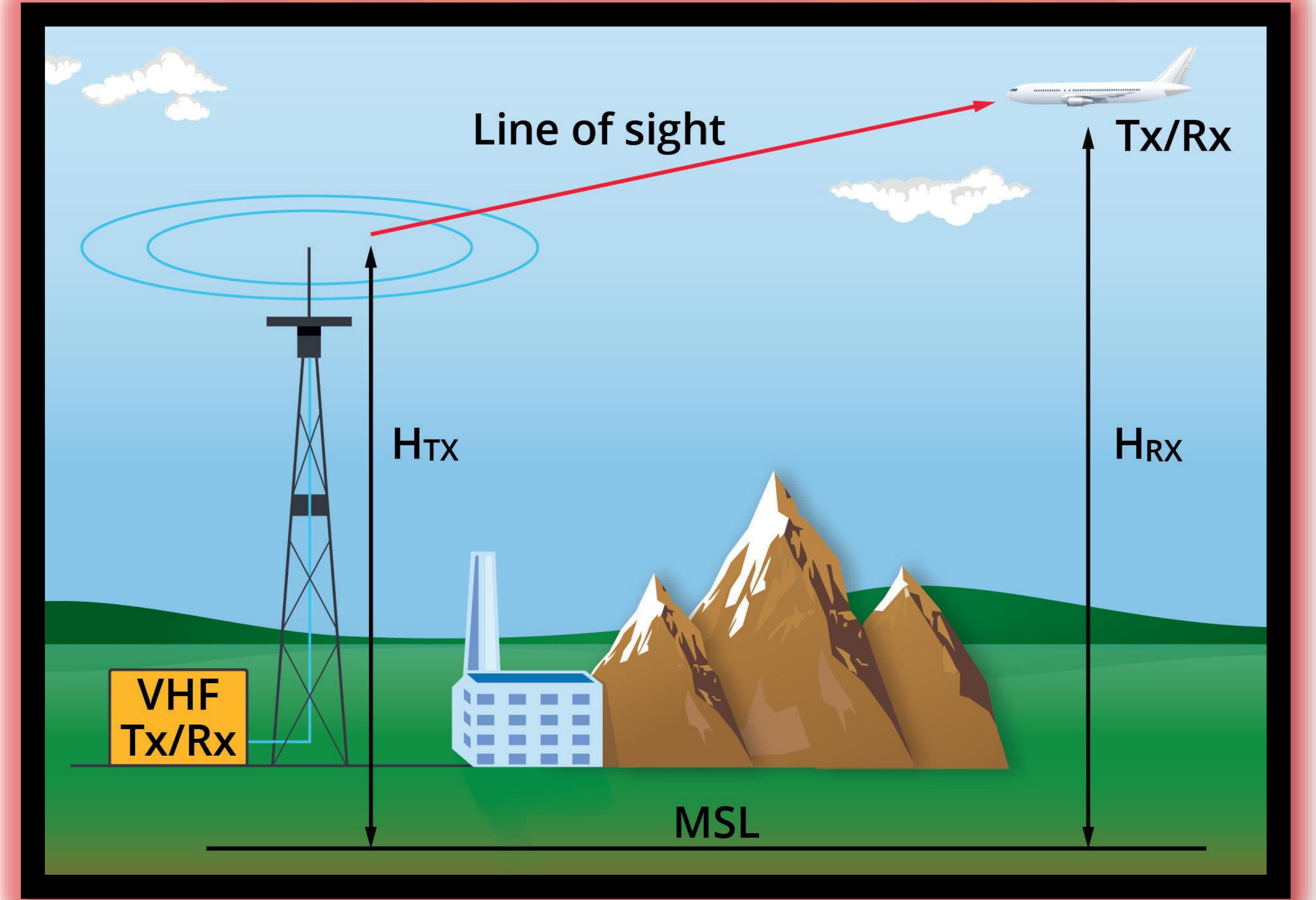
Transmissions following different Paths can occur for a number of reasons , e.g. reflections , and can arrive at a receiver simultaneously. However , the two signals will not necessarily be in Phase. In extreme cases, the two signals will be in anti-phase and will cancel each other out. Signals going in and out of phase are indicated by alternate fading (i.e., gradually become weak) and strengthening of the received signal.



The combination of the space and reflected waves at the receiver antenna is a resultant wave , which may be stronger or weaker depending on the phase difference, if any.



Space waves are limited in range by the line of sight as the frequencies are too high for surface waves and sky waves. The range is dependent on the height of the transmitter and the height of the receiver.



The range (R) from the receiver to the transmitter is calculated as follows :

$$R = 1.23 \times (\sqrt{HTX} + \sqrt{HRX})$$

R is given in in nautical miles (NM)

H is the height above mean see level (MSL) in feet

Example

What is the minimum altitude at which an airplane can receive a signal from a VHF transmitter at a range of 160 NM if the transmitter is located at 324 ft MSL ?

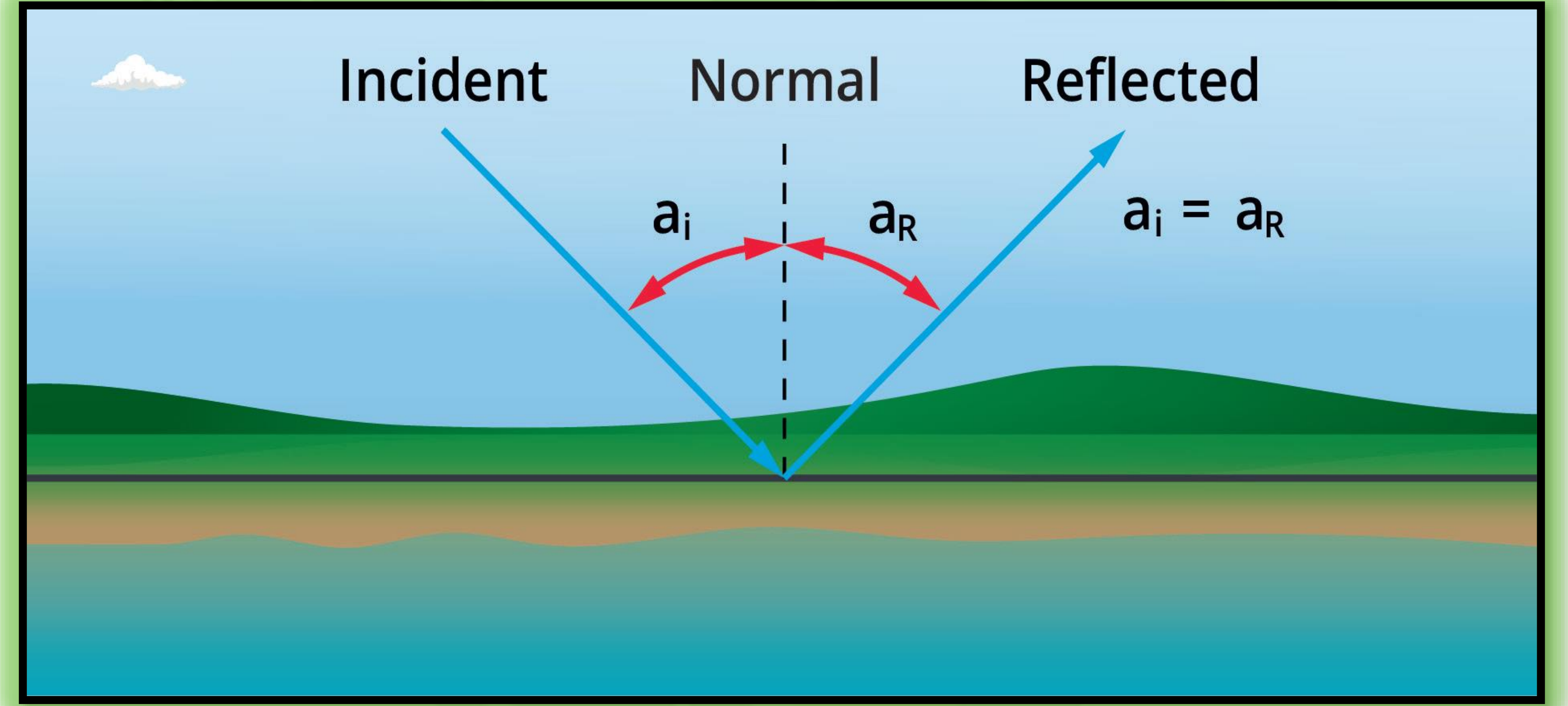
$160\ NM = 1.23 \times (\sqrt{324} + \sqrt{HRX})$

$HRX = (\ (160-1.23\times18)/\ 1.23\ )2$

$HRX \cong 12{,}560\ ft$

Reflection

In physics, **reflection** is the throwing back by a body or surface of light, heat, sound, and electromagnetic waves (EMW). It depends on the nature and the size of the obstacle , the wavelength and the incidence angle (a_i).



The reflection of an EMW by an obstacle or the ground changes the phase of the wave and in some conditions of incidence angle varies the polarisation. Efficient reflection from an object depends upon its size in relation to the wavelength :

- Shorter wavelengths are reflected more efficiently.
- Smaller (larger) objects reflect shorter (longer) wavelength.

A typical system which uses the reflection properties is the primary radar.

But reflection properties may create multipaths and lead to errors, i.e. , reflected waves and space or ground waves combine resulting in interferences (e.g., fading).

Refraction

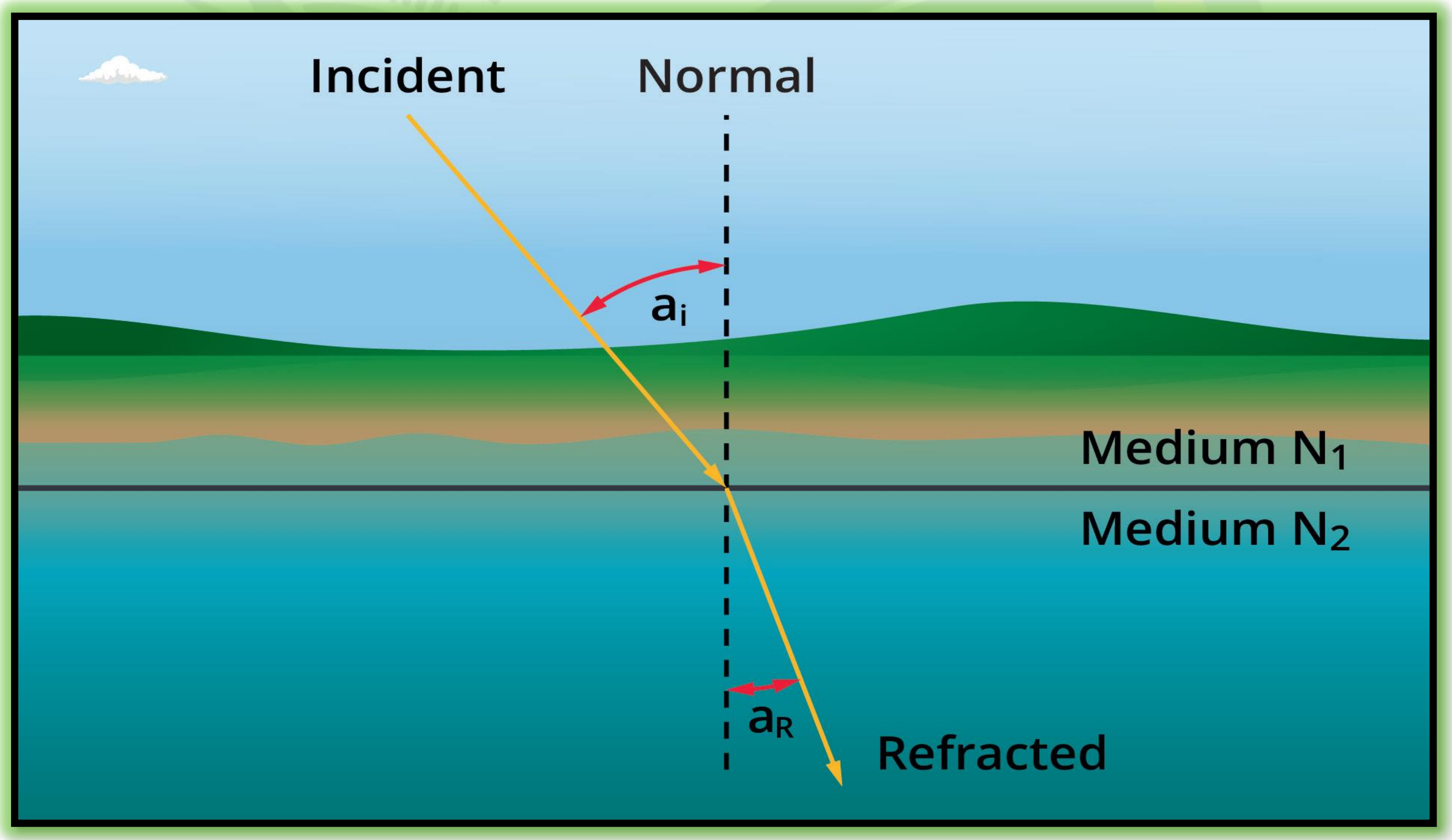
In physics, **refraction** is the fact or phenomenon of light or radio waves changing direction when passing obliquely through the interface between one medium (N1) and another (N2) or through a medium of varying density. Each substance is given a coefficient , the refractive index , to enable calculations to be performed.

The direction of the refracted wave depends on :

- The medium of the incident wave (N1) and the medium of the refracted waves (N2)
- The angle of incidence (ai)
- If the incident wave is normal with the surface there is no refraction

Refraction is a function of frequency :

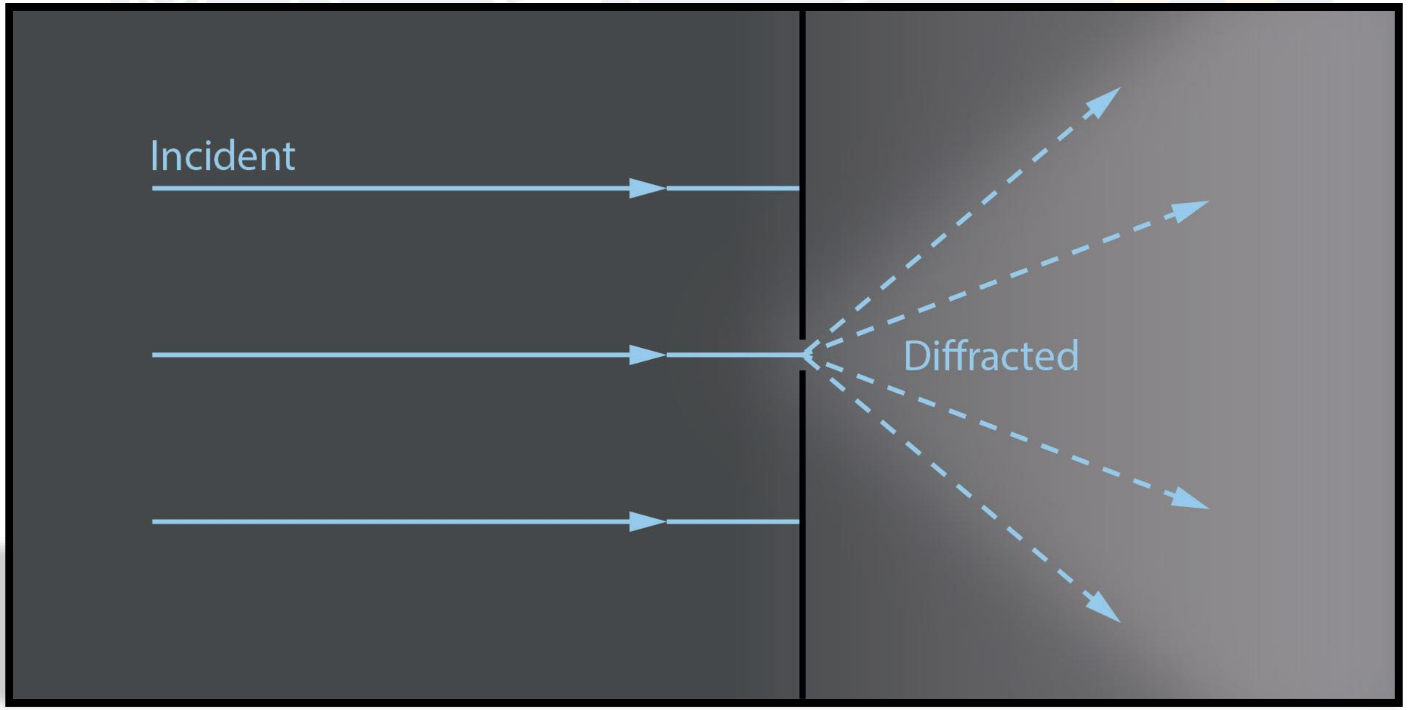
- Lower frequencies refract the most
- Refraction is negligible with VHF frequencies and above



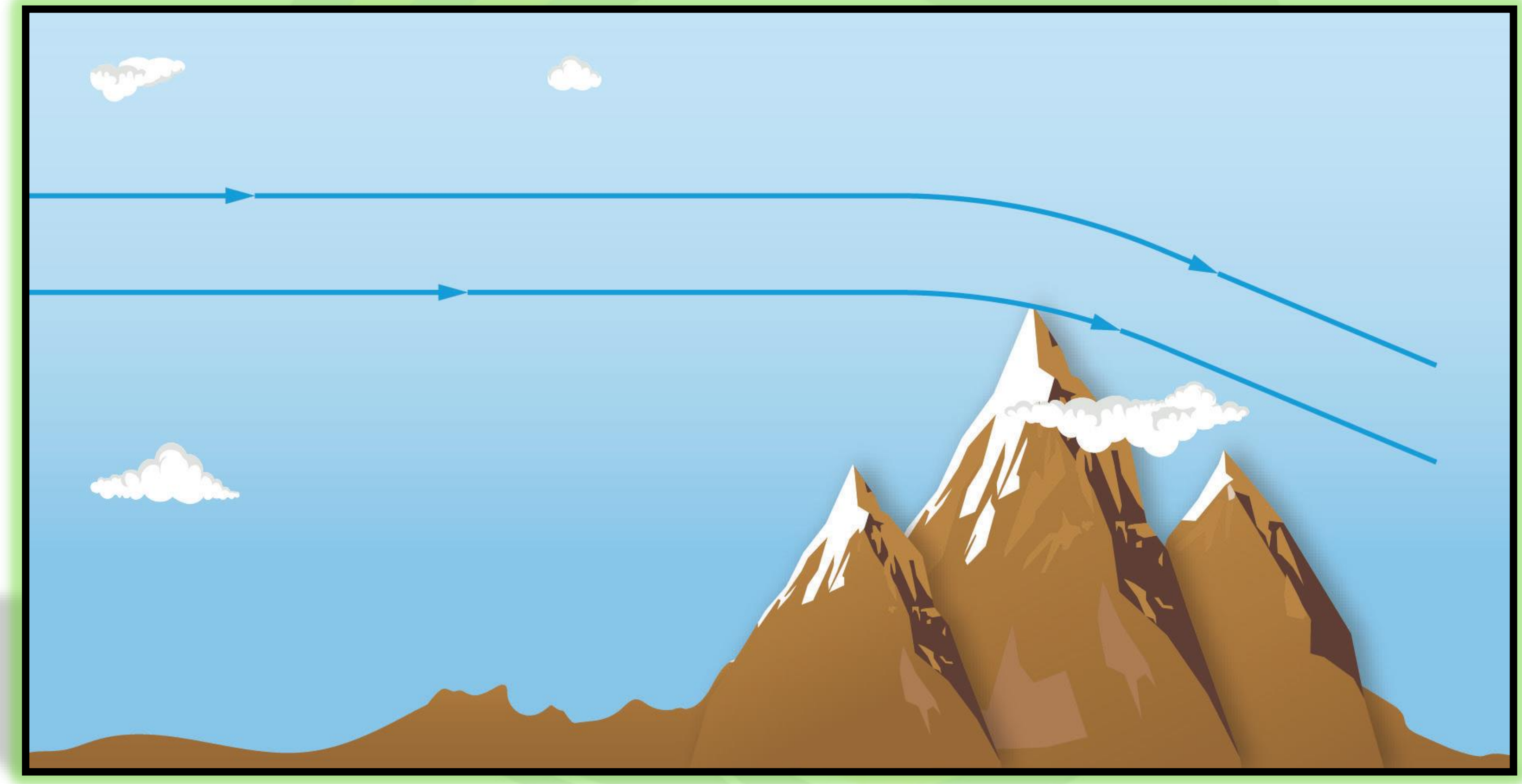
Diffraction

In physics, **diffraction** is the process by which a beam of light or an electromagnetic wave is spread out as a result of passing through a narrow aperture or across an edge. Diffraction is a function of frequency :

- Lower frequencies diffract the most.
- Diffraction is negligible with VHF frequencies and above.



This phenomenon allows EMW which propagate over edges of objects (e.g., hills and mountain peaks), with dimensions equal to or lower than the wavelength, to bend towards the ground (i.e., ground waves).



Attenuation

Attenuation is the term given to the loss of signal strength in a radio wave, due to **absorption** and the inverse square law as it travels outward from the transmitter.

Absorption

As the radio wave travels outwards from a transmitter the energy is absorbed and scattered by the molecules of air and water vapour, dust particles, water droplets, vegetation, the surface of the earth and the ionosphere. The effects of this **absorption** are the following :

- **Atmospheric absorption:** Increases as frequency increases and is a very significant

factor above about 1 GHz.

- **Surface absorption:** Increases as frequency increases, a part of the energy is refracted into the ground. The propagation is better over sea than over land.
- **Ionospheric absorption:** Decreases as frequency increases.

Chapter 3

Radio Aids

Ground Direction Finding (DF)

The use of the **VHF ground direction finding (VDF)** provides a means of determining the aircraft bearing from a ground station, which is able to measure the direction (i.e., the bearing) of a received radio transmission from an aircraft.

The service operates on VHF frequencies from 118 to 137 MHZ , which is the frequency band of aircraft communication radio.

Military airfields provide direction-finding service in the UHF band , so-called UDF.

Use of VDF

The pilot uses VDF to request from the ATC controller a magnetic (or true) bearing to or from the station , and the request is transmitted only using the VHF voice communication on the listed frequencies.

The ground station uses bearings from incoming VHF calls to survey the traffic in uncontrolled airspace.

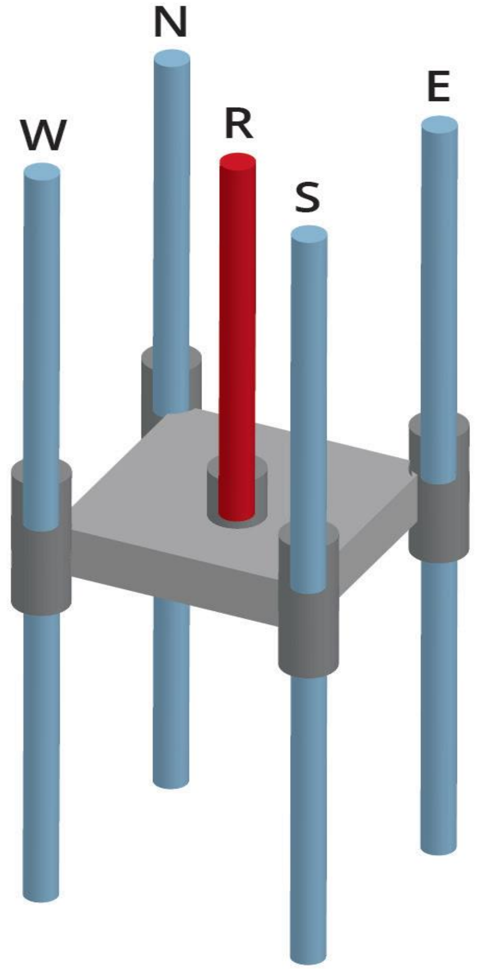
The principle of operation is based on a VHF Comm ground receiver combined with a directional antenna system. The antenna is either :

• a set of two pairs of dipoles perpendicular to each one in conjunction with a single omnidirectional aerial, known as an **Adcock aerial**, or

• a set of dipoles placed in a circle, known as a phase, or a **Doppler VDF antenna.**

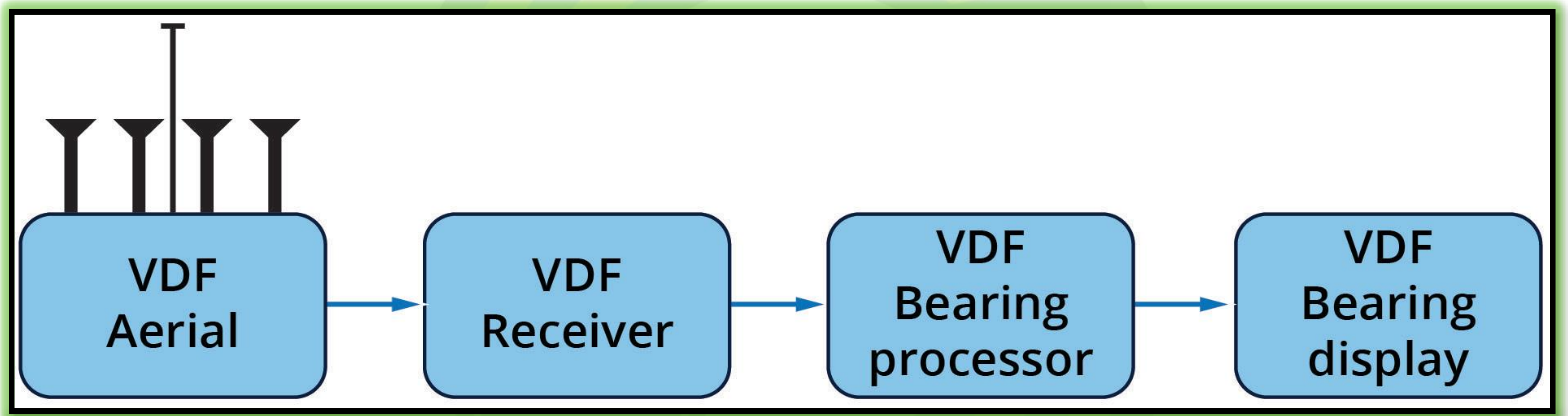
The equipment required on board the aircraft is a VHF Comm transmitter/receiver.

- Due to VHF space wave propagation the available range is limited by line of sight.



VDF Adcock
aerial

VDF Doppler
aerial


VDF
Aerial
VDF
Receiver
VDF
Bearing
processor
VDF
Bearing
display

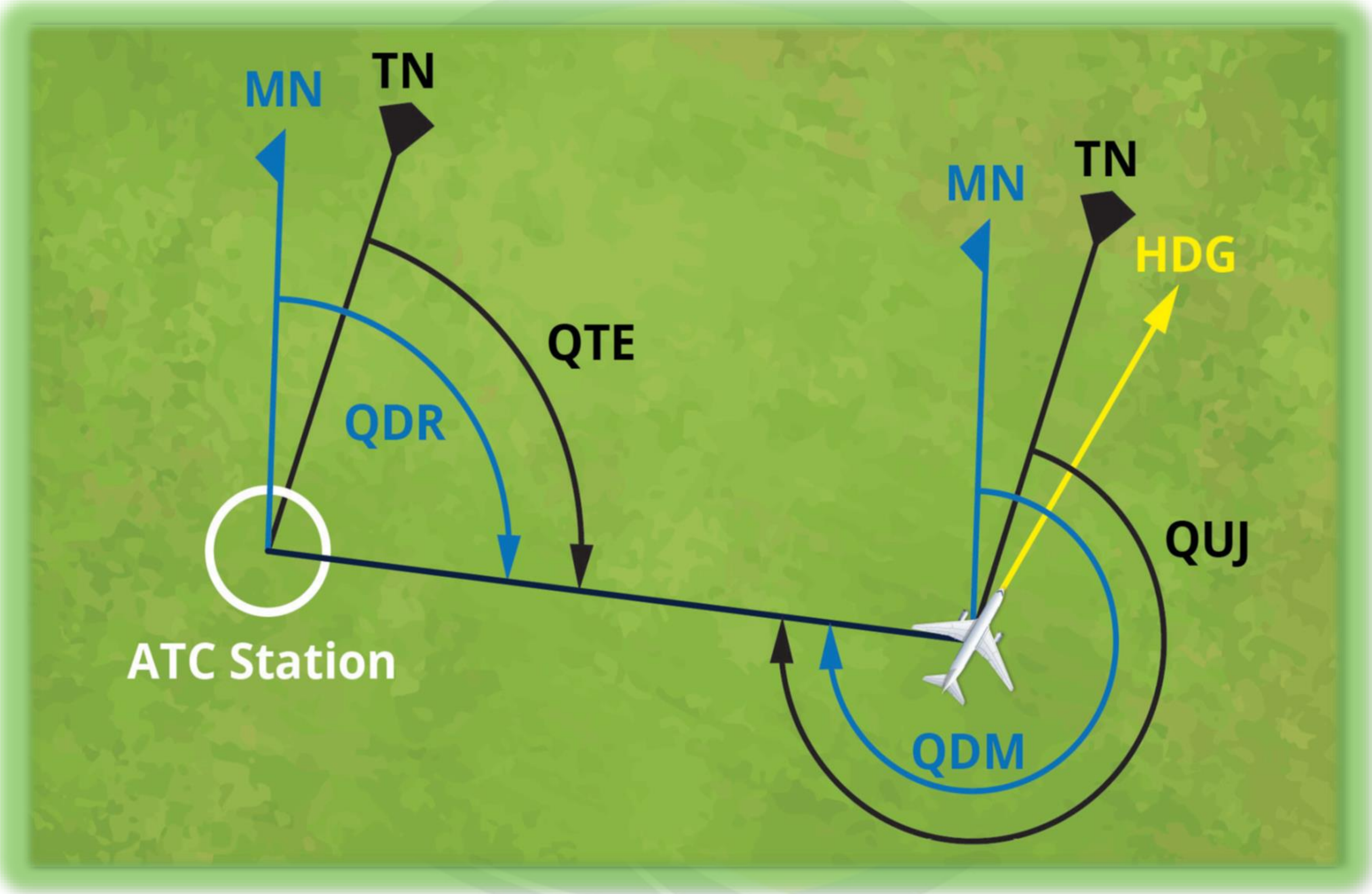
QDM and QDR

- The **QDM** is the magnetic bearing TO the station from the aircraft (i.e. the aircraft's magnetic heading to steer (assuming no wind) to reach the VDF station) used mainly for station homing and/or let-downs using published procedures.

- The **QDR** is the magnetic bearing FROM the station to the aircraft, also called radial.

- The **QUJ** is the true bearing TO the station from the aircraft.

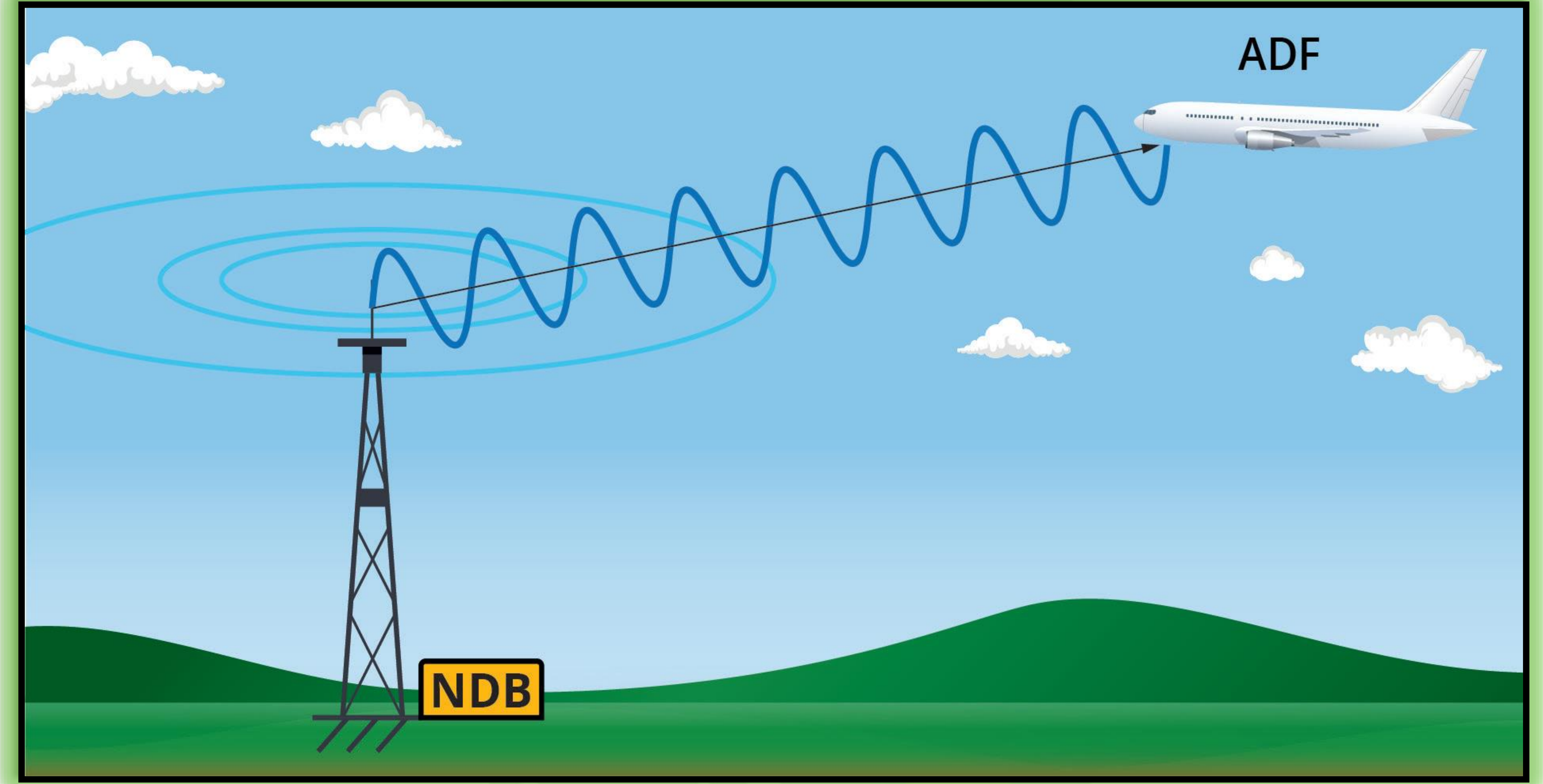
- The **QTE** is the true bearing FROM the station to the aircraft.


MN
TN
QTE
QDR
ATC Station
MN
TN
HDG
QUJ
QDM

Non-Directional Radio Beacon (NDB)/Automatic Direction Finding (ADF)

The NDB is the ground station , which transmits an **omnidirectional** radio signal in the LF and MF band to provide an aid for navigation and non-precision approaches to airports.

The ADF is the equipment on board the aircraft , which automatically finds the direction of the transmitted NDB signal.


ADF
NDB

The NDBs transmit at the allocated frequencies 190 kHZ (upper LF band) -1,750 kHZ (MF band) a vertically polarised signal , which propagate as surface waves. There are two types of NDBs :

En-route NDBs: These have an average radius of rated coverage (i.e., a range) of 50 NM or more , up to several hundred NM.

Locator (L or Lctr): Is a low powered NDB used as an aid for final approach procedures. The locator has an average radius of rated coverage between 10 and 25 NM.

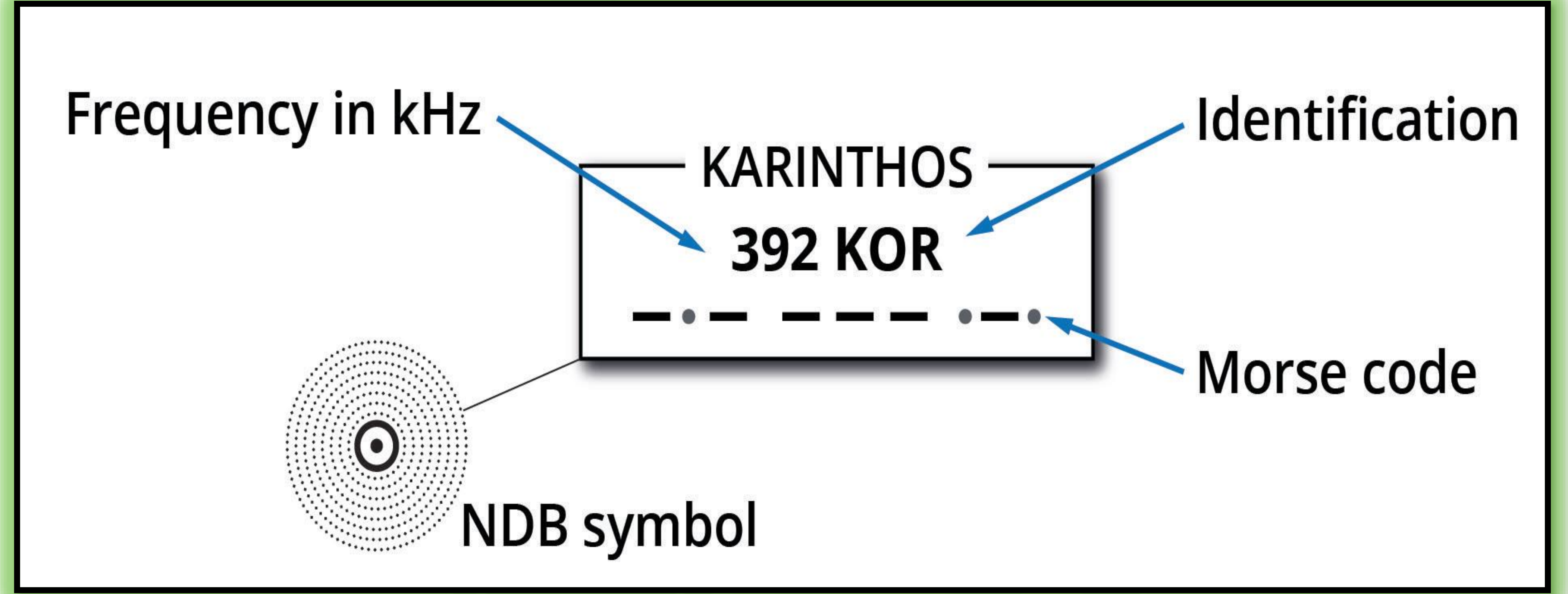
Use of NDBs

En-route NDBs are used for homing , holding fix , terminal and airway navigation. Locators are used for runway approach procedures (i.e, let-down procedures) ,holding fix , missed approach procedures, and may be used as a supplement to the ILS outer and middle marker beacons , called **locator outer marker (LO or LOM)** and **locator middle marker (LM or LMM).**

NDB identification

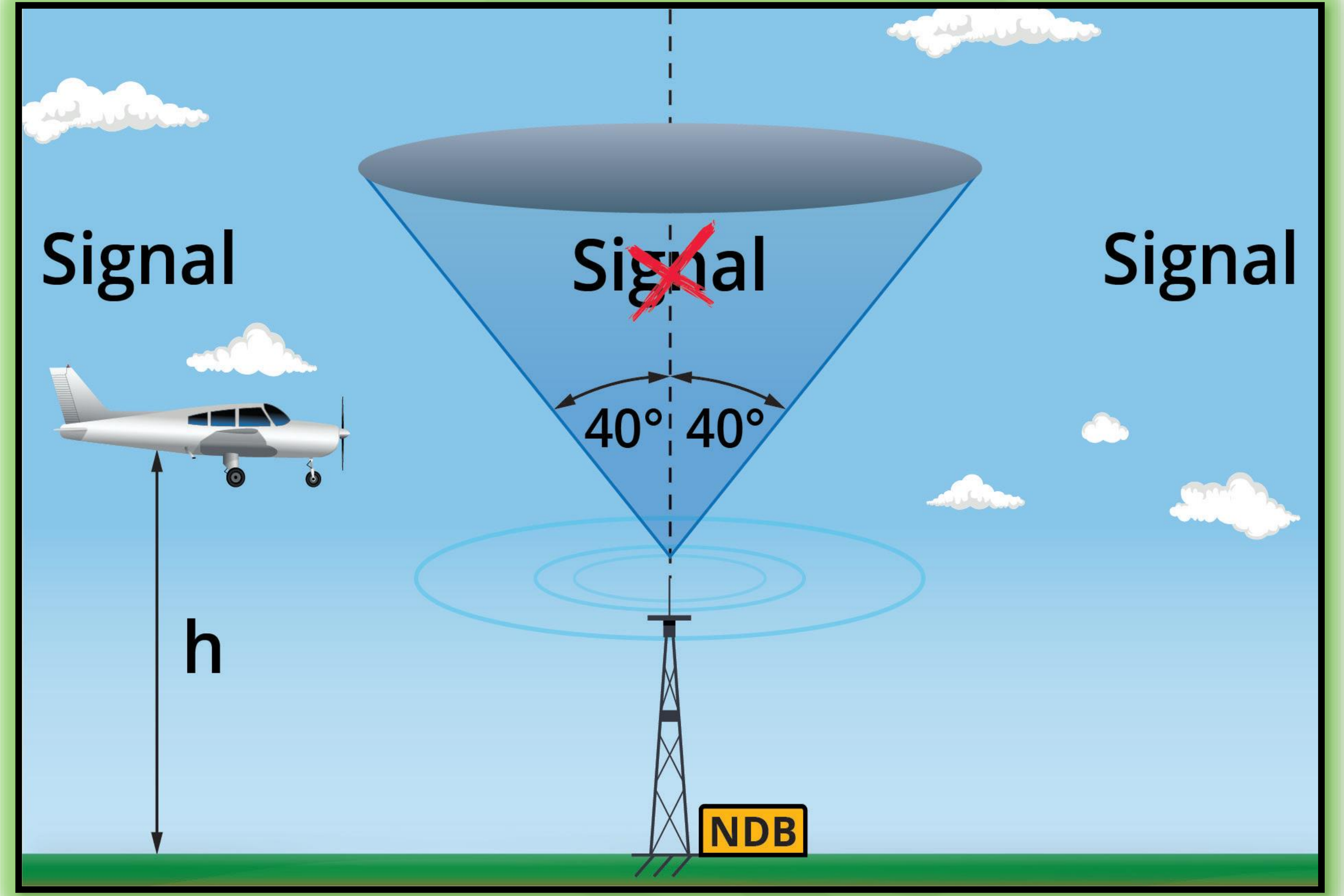
Each NDB is individually identified by a two or three-letter international morse code group , transmitted at a rate corresponding to approximately 7 words per minute.

For NDBs with an average radius of rated coverage 50 NM or less , that are primarily approach and holding aids in the vicinity of an aerodrome , the identification shall be transmitted at least three times each 30 seconds, spaced equally within that time period.


Frequency in kHz
KARINTHOS
392 KOR
Identification
Morse code
NDB symbol

Cone of Confusion

A **cone of confusion** (or cone of ambiguity) extending at an angle of 40 degrees either side of the NDB exists overhead the NDB transmitter during which the aircraft does not receive any signals. The diameter of the cone increases with aircraft height (h).


Signal
Signal
Signal
40°
40°
h
NDB

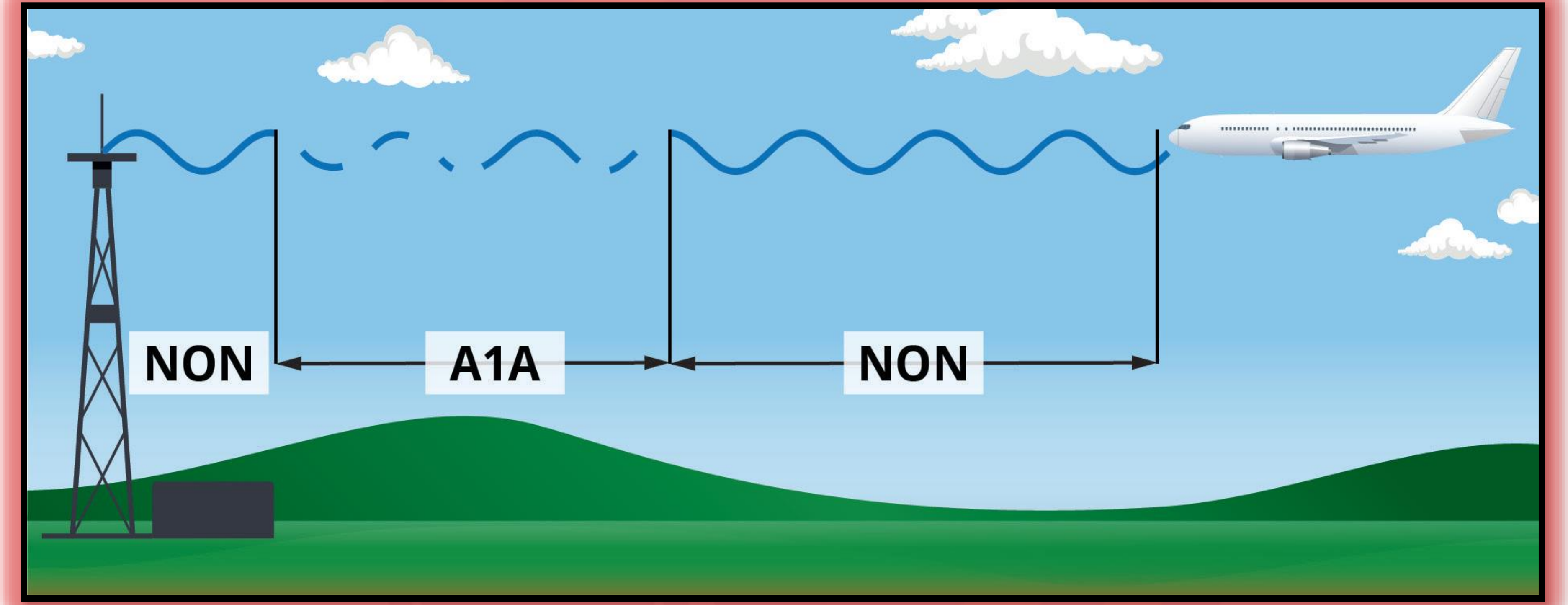
NDB Types of Emission

There are two types of emission :

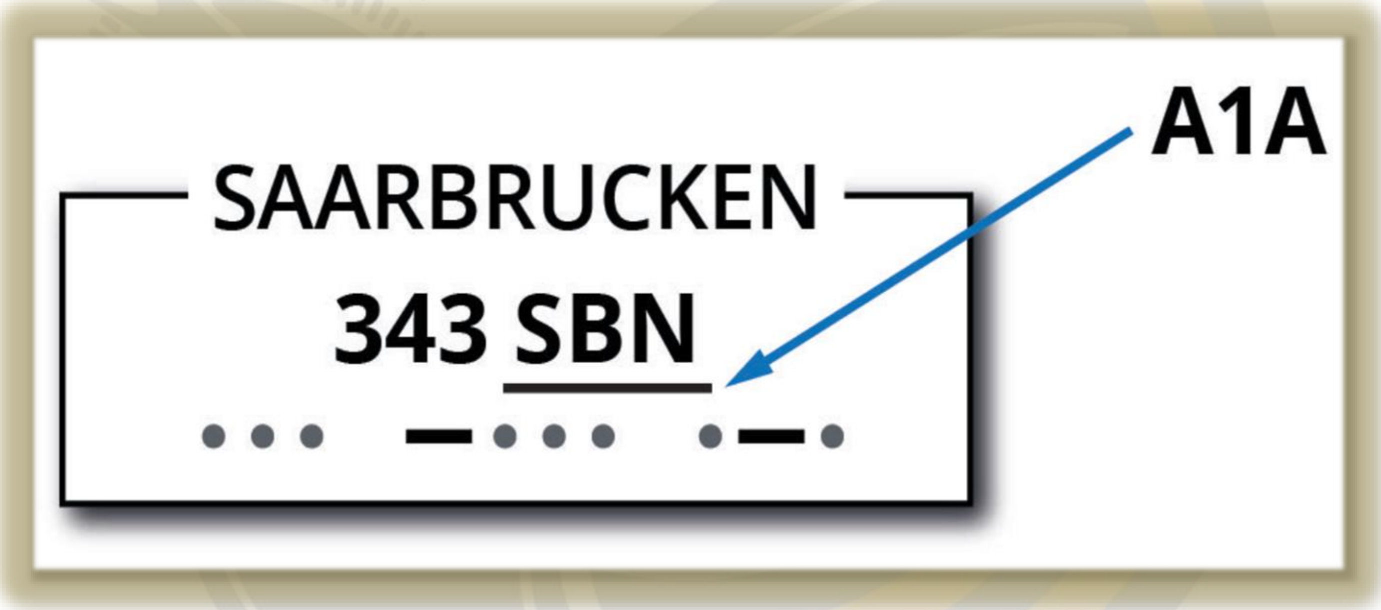
- Unmodulated emission **N0N A1A**
- Modulated emission **N0N A2A**

The NON part is the transmission of an unmodulated carrier wave.

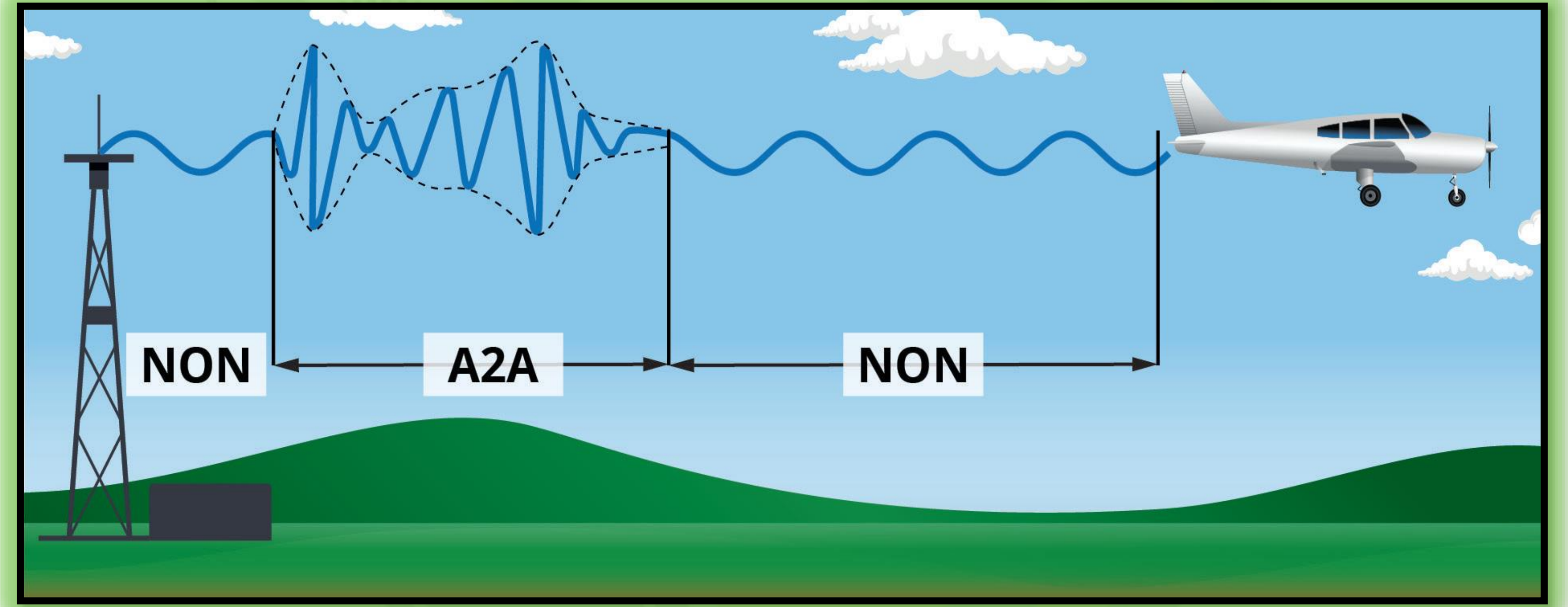
The A1A part is the emission of an interrupted unmodulated carrier wave.


NON
A1A
NON

An NDB is recognised as a NON A1A when its published identification is underlined.



The A2A part is the emission of an amplitude modulated carrier wave.



Beat Frequency Oscillator - BFO

The identification of the modulated NDB consist of modulating the carrier wave in amplitude (A2A) with a tone of 400 or 1,020 Hz in order to give the morse code.

The identification of the unmodulated NDB (A1A) consists of the momentary interruption of the carrier wave in a short sequence , which forms the morse code.

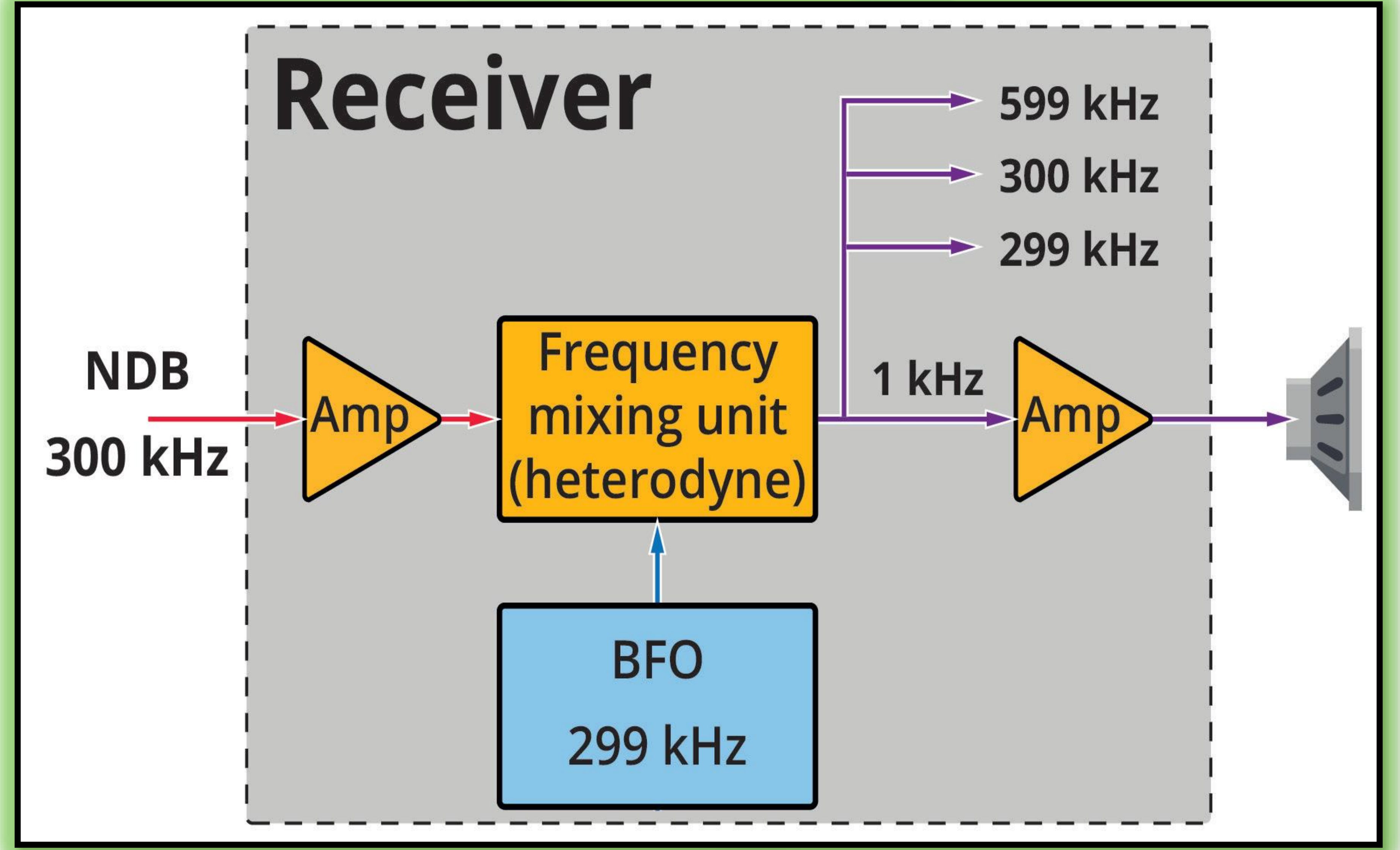
But there is a problem:

the frequency of the carrier wave (usually between 200 and 500 kHZ) is too high to be audible by human ear , which has an audible range of 20 to 20,000 HZ.

To listen to the identification of a NON A1A NDB , a system called the **beat frequency oscillator (BFO),** must be switched on by the Pilot to identify the NDB and remains on as long as the beacon is used to navigate. Modern airplanes select the BFO automatically.

The BFO may be momentarily selected on when a A2A NDB is used to listen to a tone , which confirms a received signal.

The BFO generates a low frequency of 299 kHZ which is mixed with the NDB carrier wave (CW) frequency (e.g.300 kHZ). This process is called a **heterodyne mixing**, and the results are the Sum , the CW , the 299 KHZ and finally the difference of the two signals , which is filtered out to the audio system.

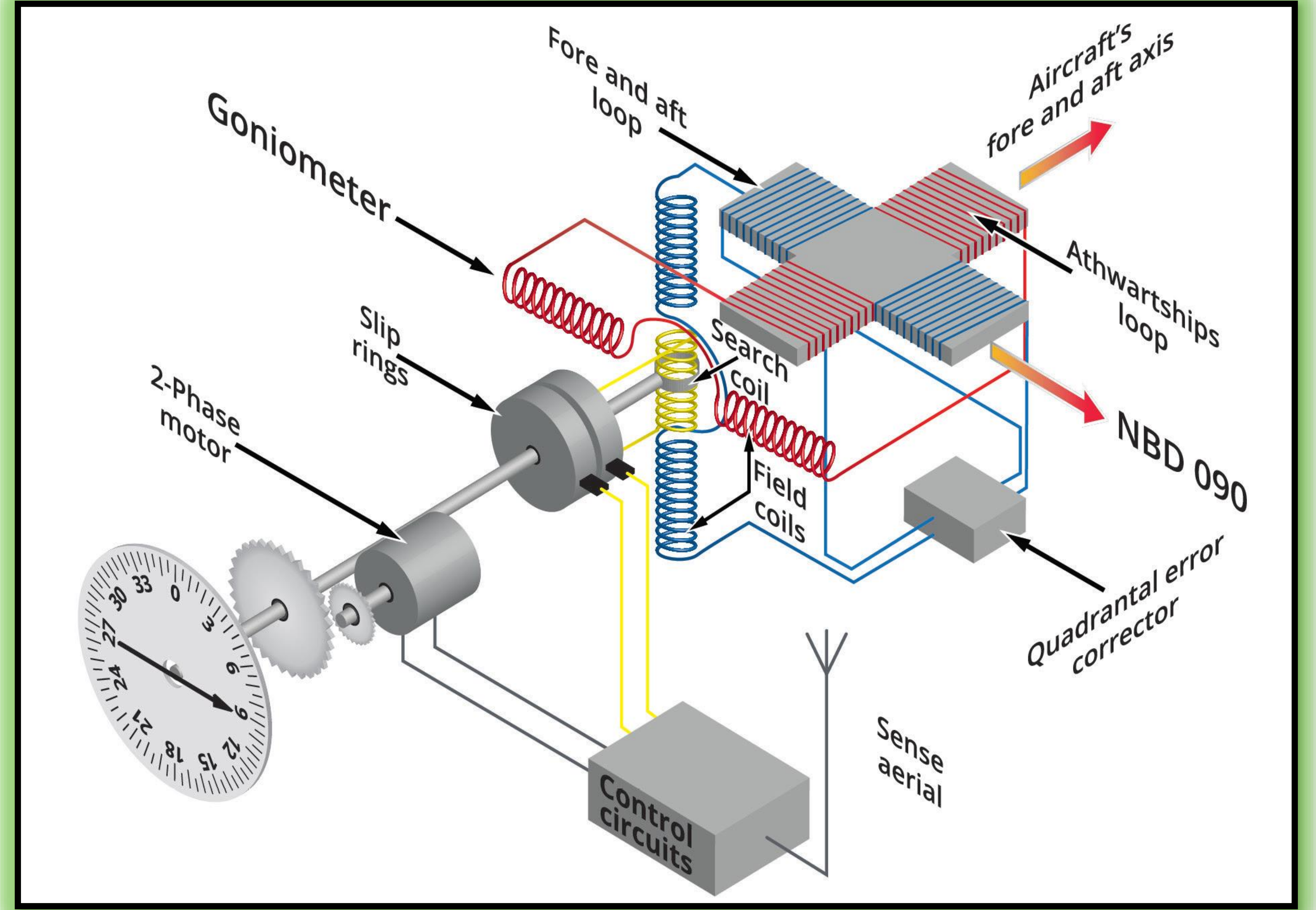

Receiver
NDB
300 kHz
Amp
Frequency mixing unit (heterodyne)
599 kHz
300 kHz
299 kHz
1 kHz
Amp
BFO
299 kHz

The Automatic Direction Finder - ADF

The ADF system on board the aircraft consists of :

- An antenna system
- A receiver
- Indicators

The antenna system includes a combination of a directional loop antenna and an omnidirectional sense antenna. Both antennas capture the vertically polarised signal transmitted by an NDB.


Fore and aft loop
Aircraft's fore and aft axis
Goniometer
Athwartships loop
Slip rings
Search coil
2-Phase motor
NBD 090
Field coils
Quadrantal error corrector
Sense aerial
Control circuits
33
0
3
6
9
12
15
18
21
24
27
30

The receiver is controlled by the ADF control panel , which is used to tune the NDB frequency.

The control panel has a mode selector with usually three modes: OFF , ADF and ANT .

ADF must be selected for navigation and NDB identification.

ANT (for antenna) selection allows to listen to the NDB identification tone or vocal broadcast.

The tuned receiver amplifies the signal from the antennas and transmits the direction and sense information to the indicators.


1
2
TONE
ADF
ANT
399.5
ADF
ANT
375.0
ADF
TEST
TEST
ADF
ANT
OFF

Type of Indicators

The ADF information may be presented on analogue instruments :

- Fixed card relative bearing indicator (RBI)
- Moving-card RBI
- Radio magnetic indicator (RMI)

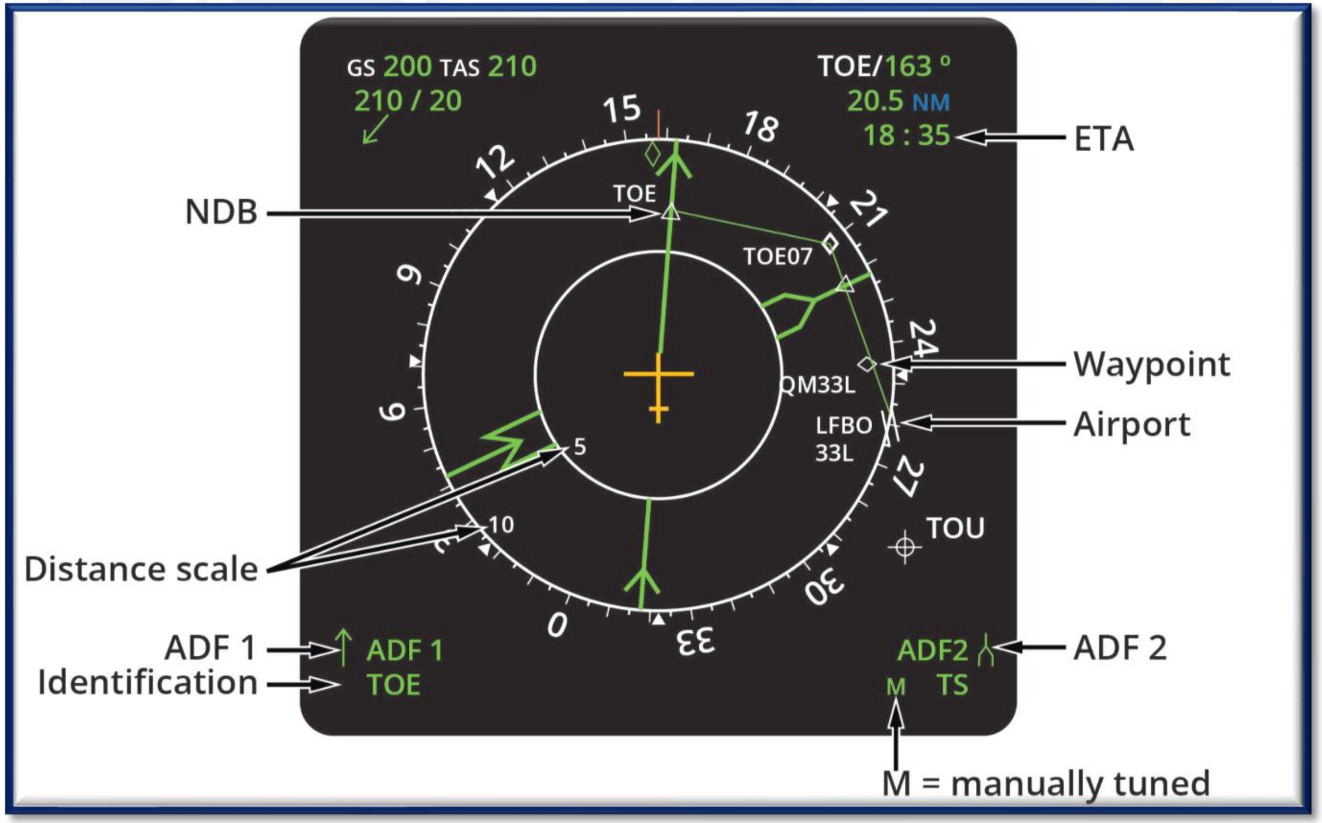
Fixed card RBI

Moving card RBI

RMI

The ADF information may be presented on digital instruments :

- Navigation display (ND)
- Electronic horizontal situation indicator (EHSI)



In ADF indication, the needle always points to the beacon, and it shows the relative direction to the NDB seen from the aircraft.

This direction is called the **relative bearing (RB)** and is measured in degrees (0 to 360 positive values) from the aircraft's nose clockwise to the station's bearing (needle's Pointer).

On a moving-card indicator , the magnetic heading of the aircraft is set by rotating the HDG knob to the value of the direct reading compass compensated for any deviation. The readings are the relative bearing (RB) and the QDM (Pointer)/QDR (tail) ,if the heading is set correctly.

The **radio magnetic indicator (RMI)** is continuously synchronised with the aircraft magnetic heading source (i.e. compass system , INS or IRS).

Two needles are usually displayed to show the ADF 1 and ADF 2 navigational information :

- Relative bearings 1 and 2
- Magnetic bearing to stations 1 and 2, i.e., **QDM** 1 and 2
- Magnetic bearing from stations 1 and 2, i.e., **QDR** 1 and 2

Note that if the heading source is lost or erratic , the only correct information is the relative bearing and the QDM / QDR are unreliable.

$$QDM = HDG + RB$$

or

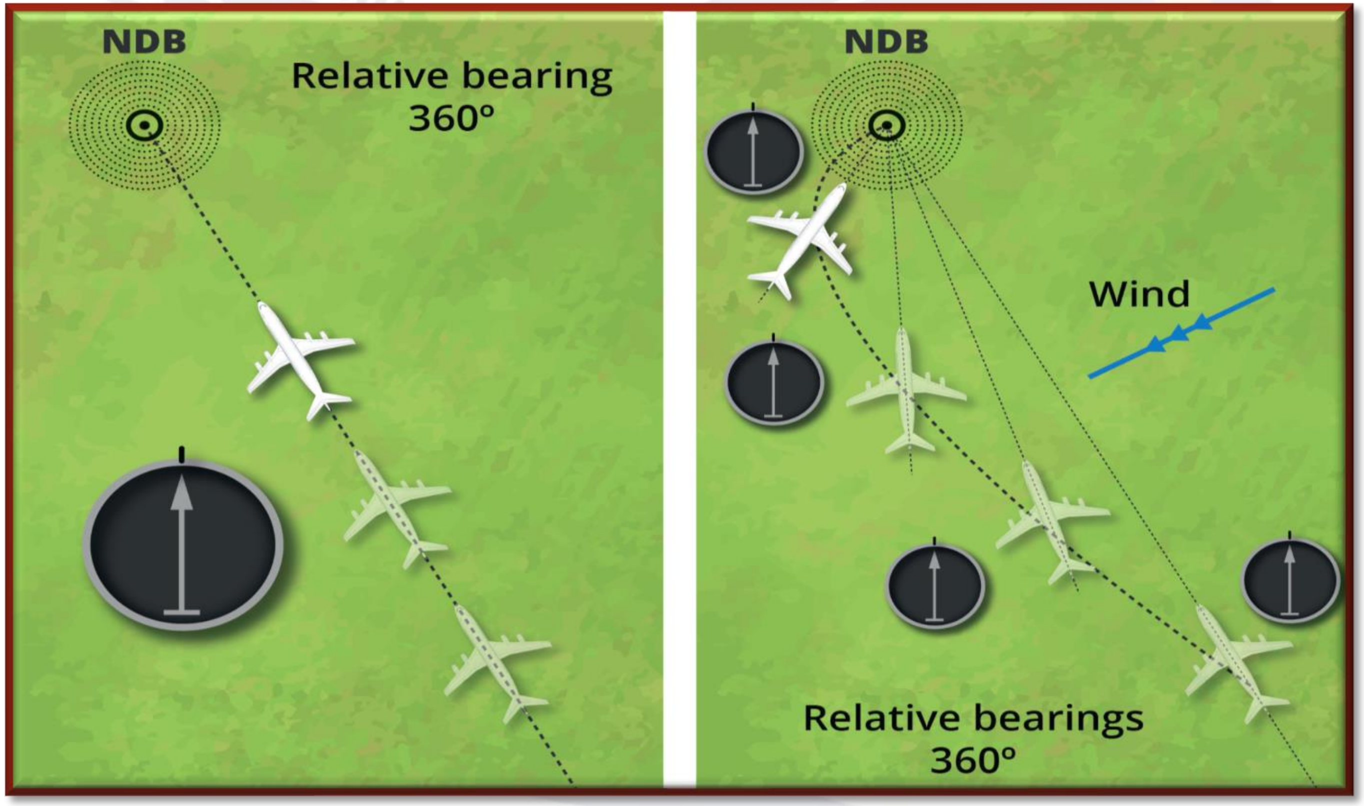
$$RB = QDM - HDG$$

The aircraft magnetic heading is 330 and ADF1 needle indicates a QDM of 090. The relative bearing RB is :

090 – 330 = 240 (+360) = 120 as RB is given as a positive value.

Homing

To home to an NDB , fly direct to the beacon maintaining the relative bearing (RB) 360 even in case of crosswind, which results in following a curved track.



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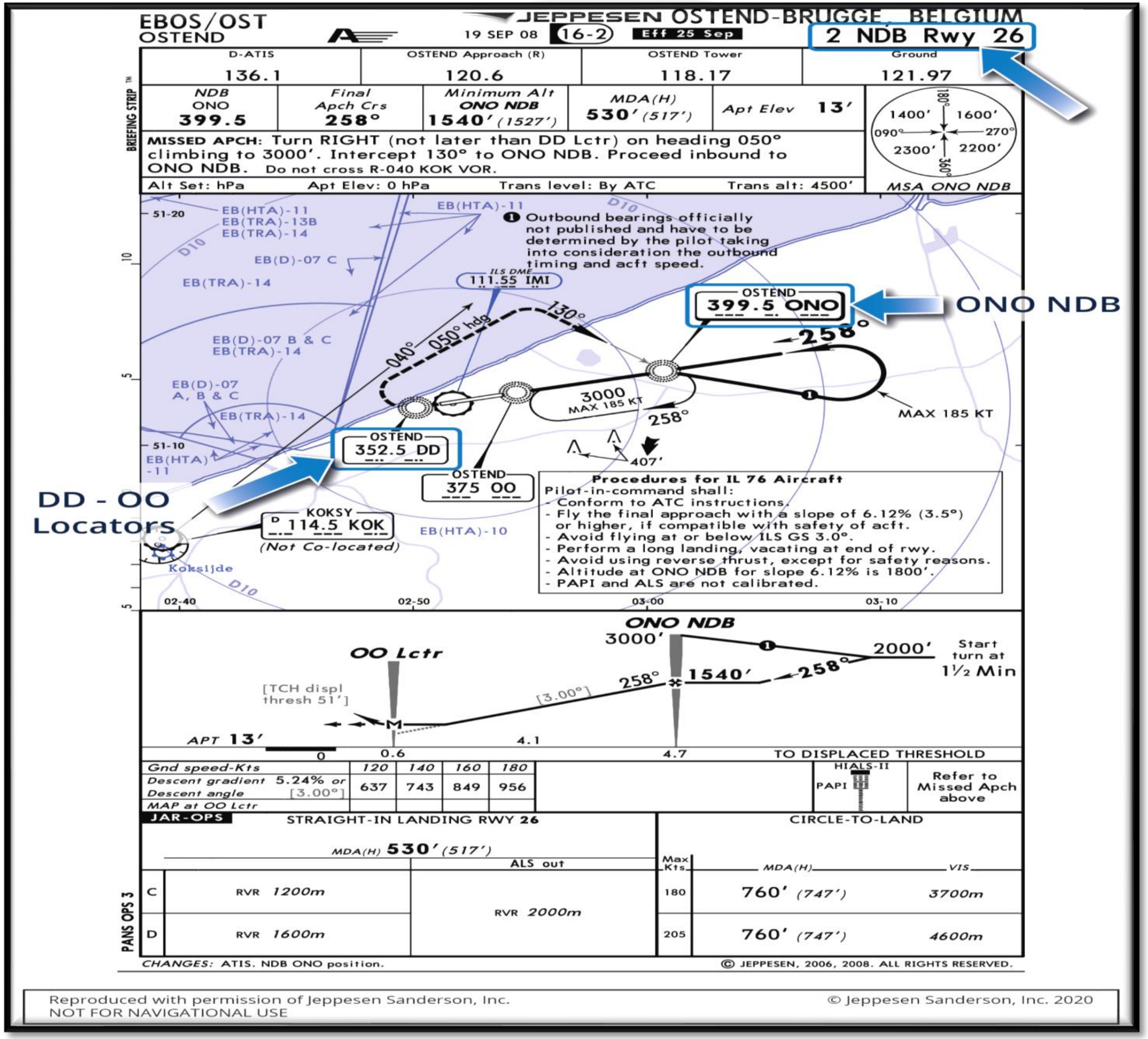


EBOS AD 2.19 Radio Navigation and Landing Aids

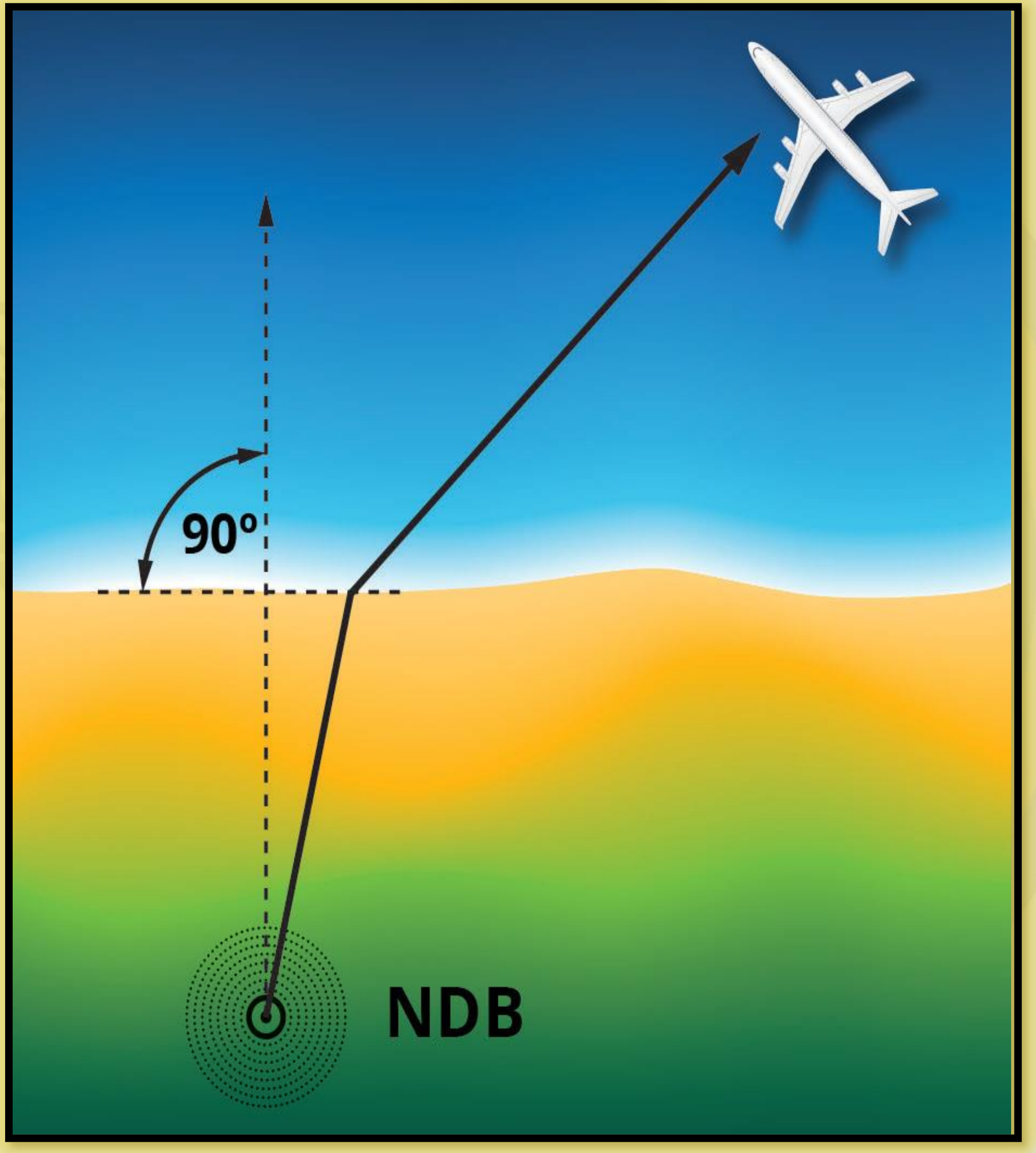
Type of aid MAG VAR	ID	FREQ	Hours of operation	Position of transmitting antenna	DME antenna elevation	RMK
1	2	3	4	5	6	7
NDB	ONO	399.5 kHz	H24	511313.1N 0030041.8E		Coverage: 50 NM Collocated with OM ILS 26
L	DD	352.5 kHz	H24	511138.1N 0025006.1E		257° GEO / 0.85 NM from THR 08 Coverage: 25 NM
L	OO	375 kHz	H24	511216.6N 0025426.1E		Coverage: 25 NM Collocated with MM ILS 26

Errors and Accuracy

Coastal Refraction

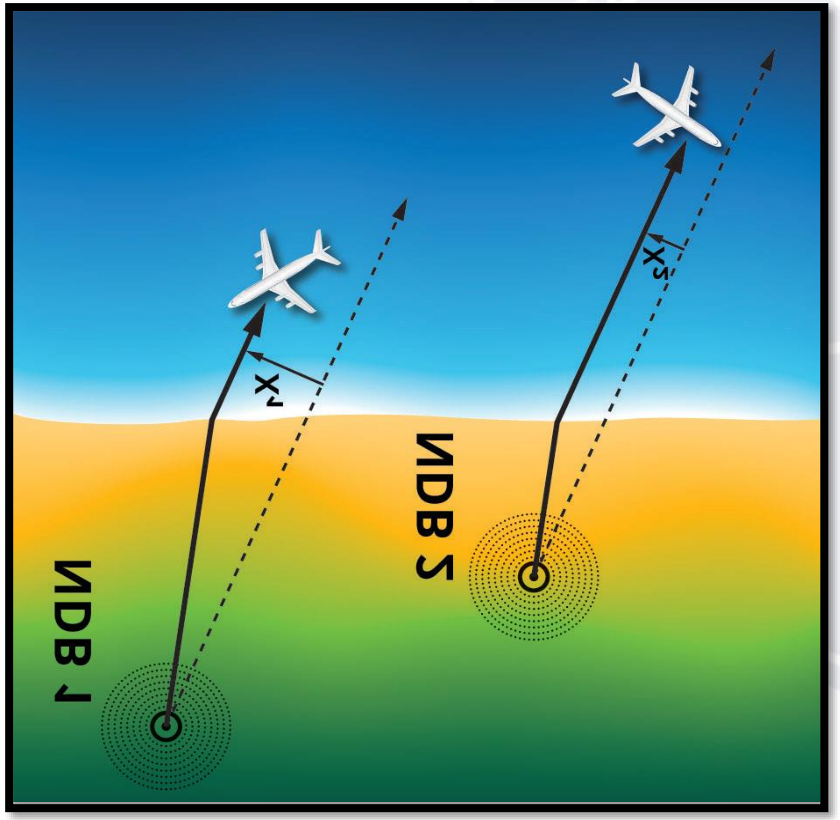
Radio waves speed up over water due to the reduced absorption of energy (attenuation) compared to that which occurs over land.

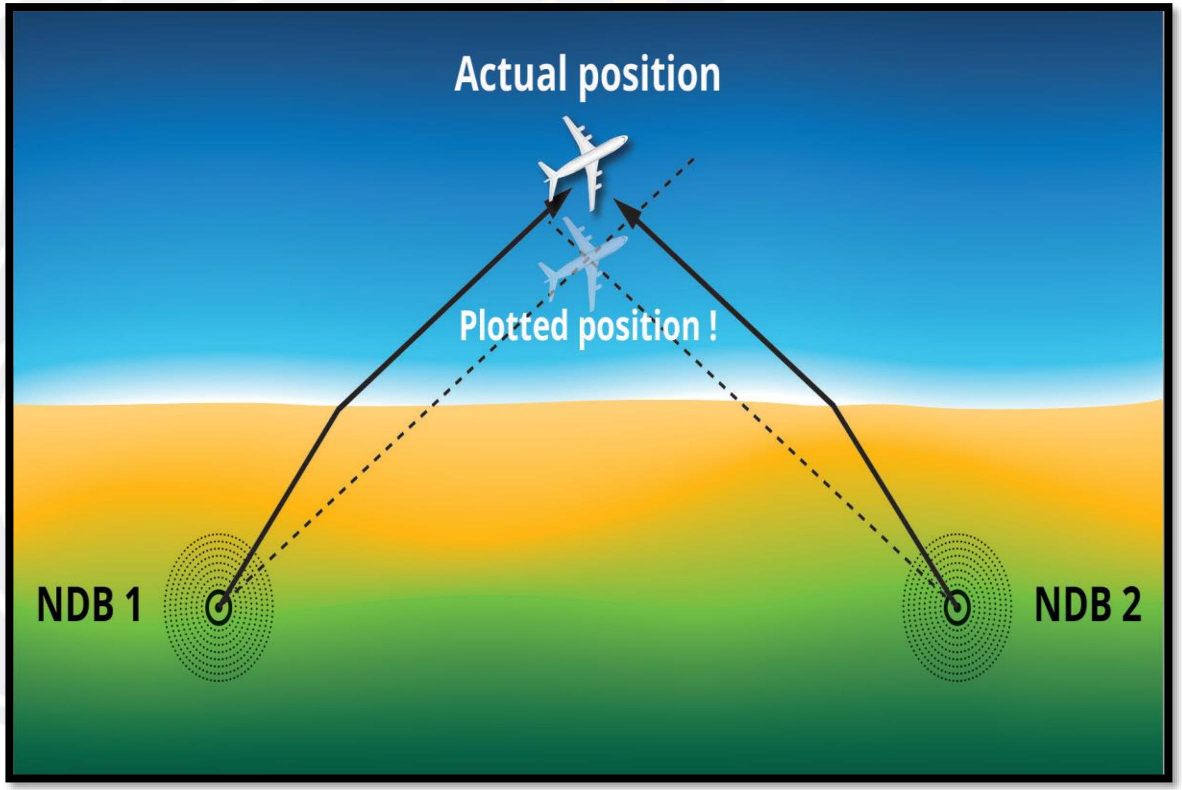
This speeding up causes the wave front to bend (refract) away from its normal path and pull it towards the coast. Refraction is negligible at 90 degrees to the coast but increases as the angle of incidence increases.


90°
NDB

The effect can be minimised by :

- Using NDBs on or near to the coast
- Flying higher
- Using signals that cross the coast at or near to 90 degrees .





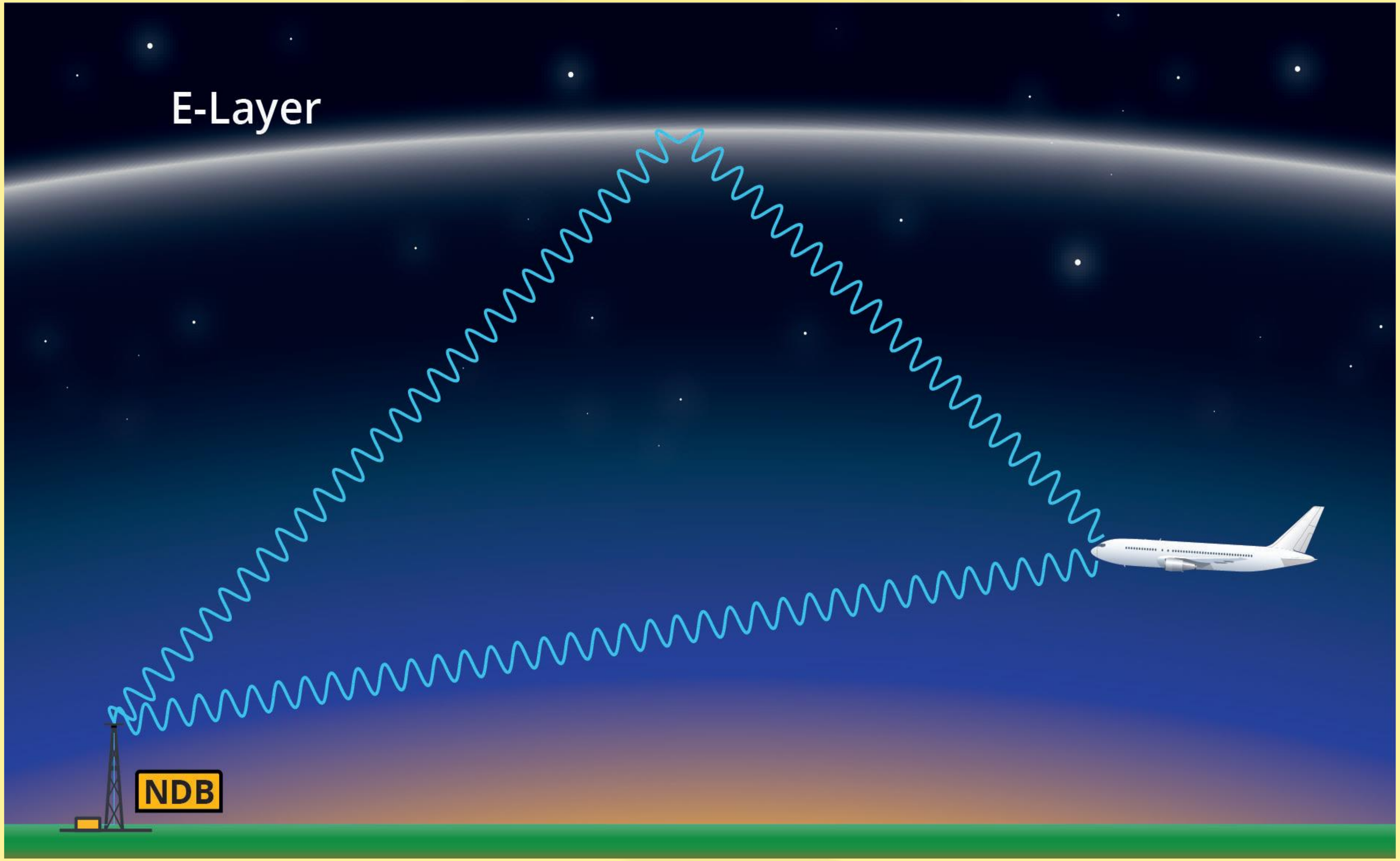
Night Effect

By day, the D-region absorbs signals in the LF and MF bands. At night, the D-region disappears, allowing sky wave contamination of the surface wave being used. This arises for two reasons :

Phase interference of the sky wave with the surface wave because of the different paths and the induction of currents in the horizontal elements of the loop aerial.

The effect first becomes significant at 70 -100 NM from the NDB. The effect is manifested by fading of the audio signal and the needle ‘hunting’ and is worst around dawn and dusk , when the ionosphere is in transition.

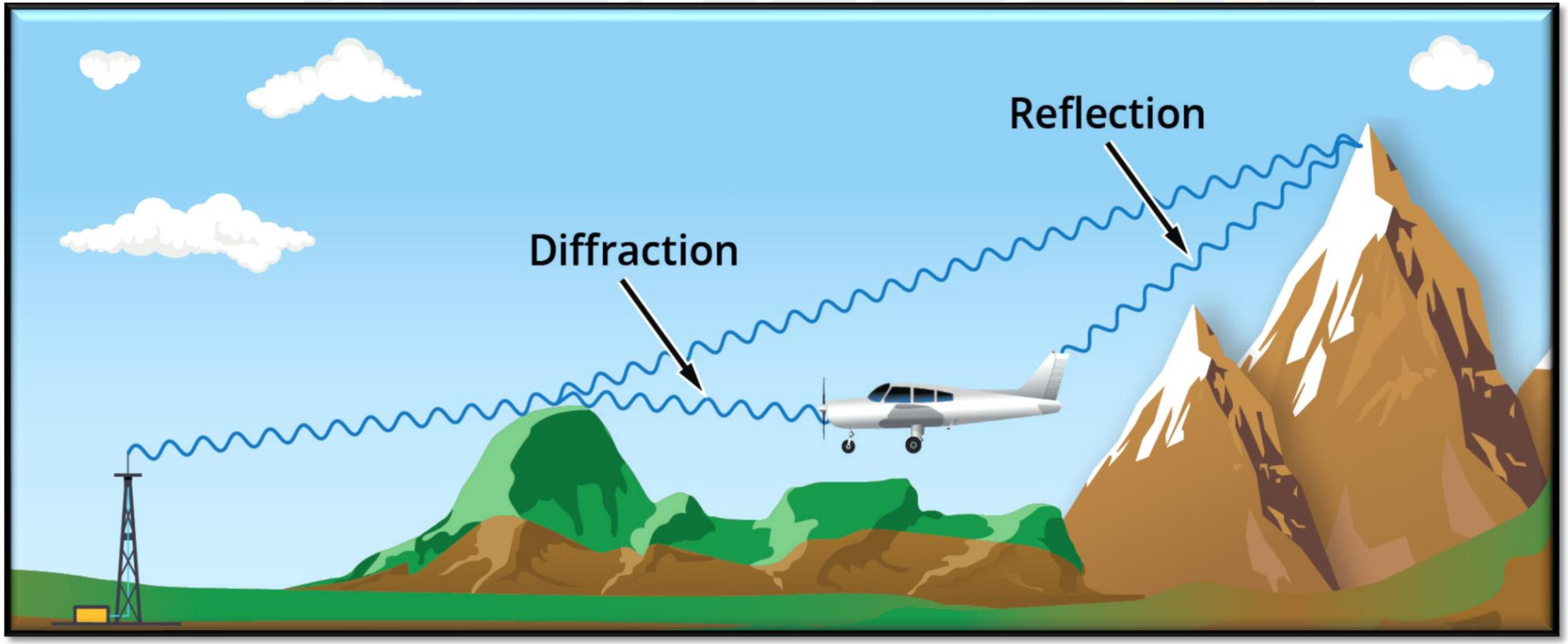
Other stations transmitting on the same frequency may interfere the signal of the in-use NDB due to sky wave contamination.


E-Layer
NDB

Mountain Effect

Mountainous areas can cause reflections and diffraction of the transmitted radio waves to produce errors in ADF systems.

These errors will increase at low altitude and can be minimised by flying higher.



Precipitation

Is generated by the collision of water droplets and ice crystals with the aircraft. It causes a reduction in the signal/noise ratio , which affects the accuracy of the bearings and can, in extreme circumstances, completely mask the incoming signal. The indications on the RMI/RBI will be a wandering needle, and the audio will have a background hiss.

Thunderstorms:

Have very powerful discharges of static electricity across the electromagnetic spectrum, including LF and MF. These discharges cause bearing errors in the ADF. A static discharge in a cumulonimbus cloud (CB) will be heard as a loud crackle on the audio, and the needle will move rapidly to point to the CB. When there are several active cells close together, it is possible for the needle to point to them for prolonged periods.

Care must be taken in the use of ADF when thunderstorm activity is forecast. It has been said that during a thunderstorm , the only sensible use of the ADF is to indicate where the active cells are.

Dip Error

A loop aerial is designed to use vertically polarised waves for direction finding. If the incoming wave has significant horizontal component of polarization , it may momentarily downgrade the ADF accuracy leading to bearing errors during a turn with significant angle of bank , which is referred to as a dip error.

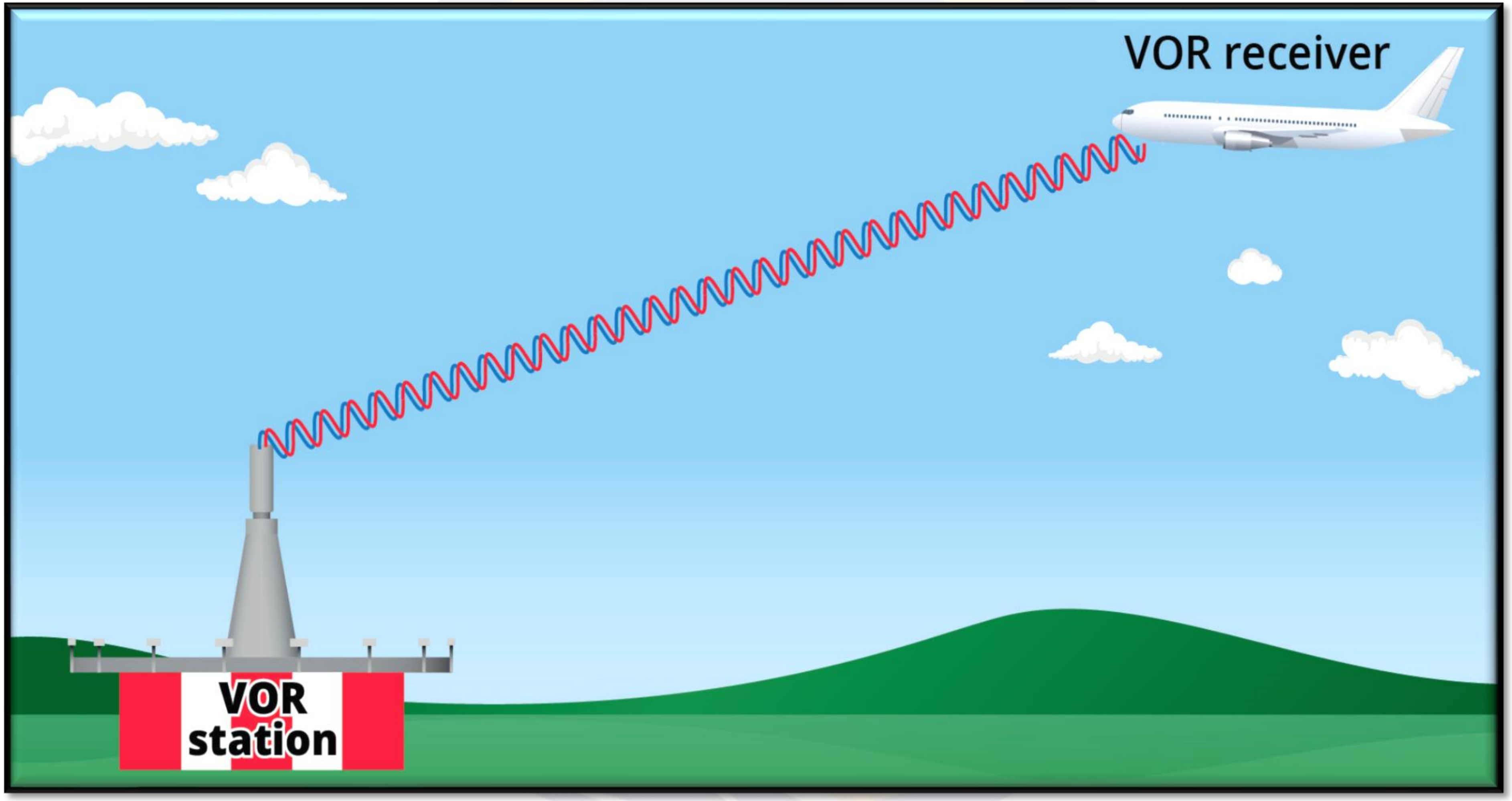
VHF Omnidirectional Radio Range (VOR)

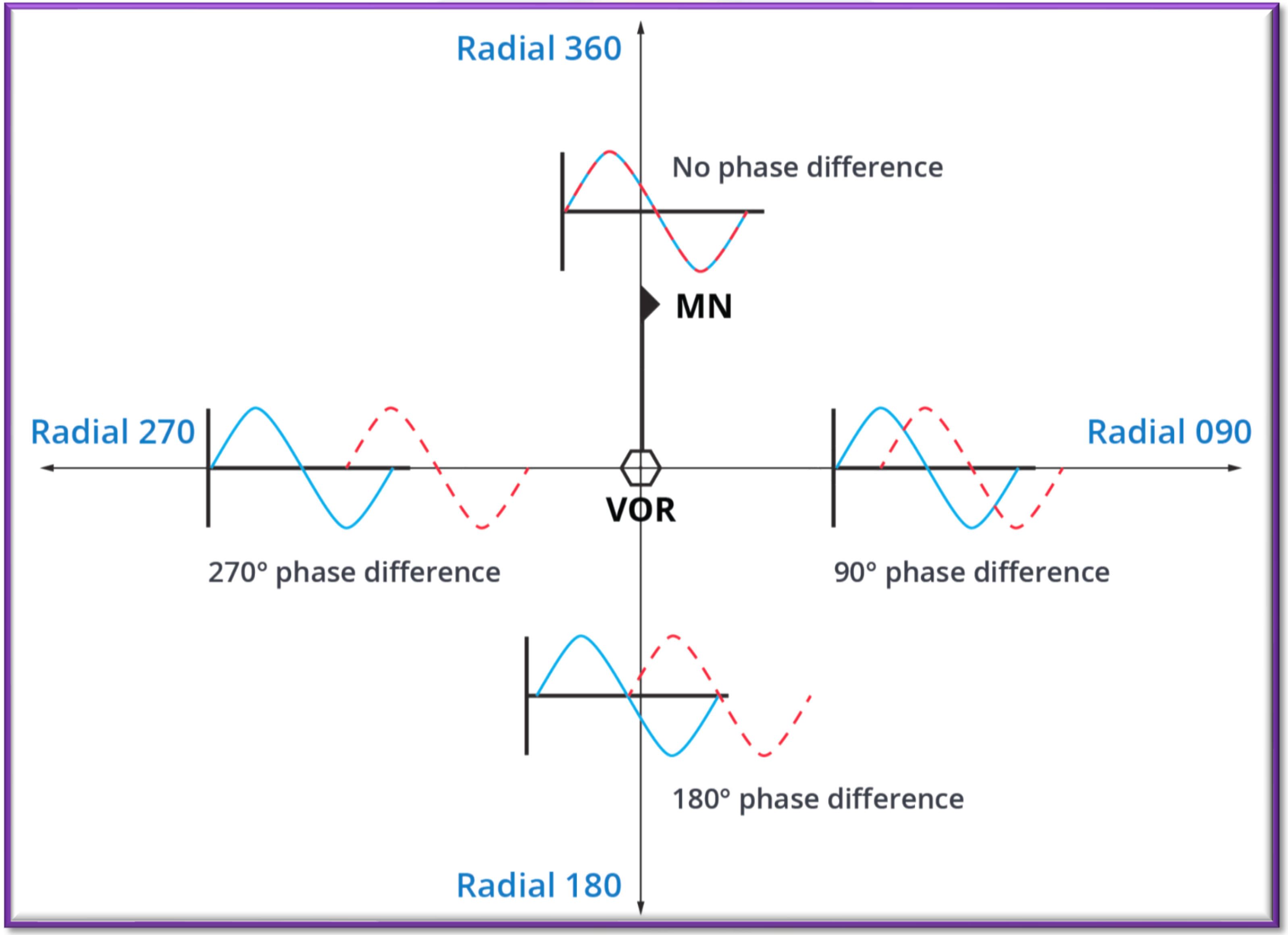
The VHF omni-directional range (VOR) produces bearing information usually aligned with magnetic north at the VOR location. It is practically free from static interference and is not affected by sky waves , which enables it to be used day and night. VOR has the following uses :

- Marking the beginning, the end, and centre line of airways or sections of airways
- As a let-down aid at airfields using published procedures
- As a holding point for aircraft
- As a source of en-route navigational position lines

There are two VOR stations in use :

- **Conventional VOR (CVOR)**
- **Doppler VOR (DVOR)**


VOR receiver
VOR
station


Radial 360
No phase difference
MN
Radial 270
Radial 090
VOR
270° phase difference
90° phase difference
180° phase difference
Radial 180

VOR Transmission Frequencies

VOR beacons operate , according to ICAO Annex 10 within the VHF band between 108.0 and 117.975 MHz as follows :

• 40 channels between 108-112 MHz , which are shared with the instrument landing system (ILS) , but only those with even decimals and even decimals plus 0.05 MHz are VOR frequencies :

•108.0 , 108.05 , 108.20 , 108.25 , 108.40 , 108.45 , … , 111.975 MHz . These channels are

normally used by short range VORs and terminal VORs (TVOR).

And

• 120 channels ,112-117.95

All the channels are separated by 50 kHz.

CVOR and DVOR

Terminal VOR (TVOR) station transmits at low power with shorter range , is used at major airfields for departure and approach procedures.

Test VOR (VOT) is found at certain airfields and broadcasts a fixed omnidirectional signal for a 360 degrees test radial.

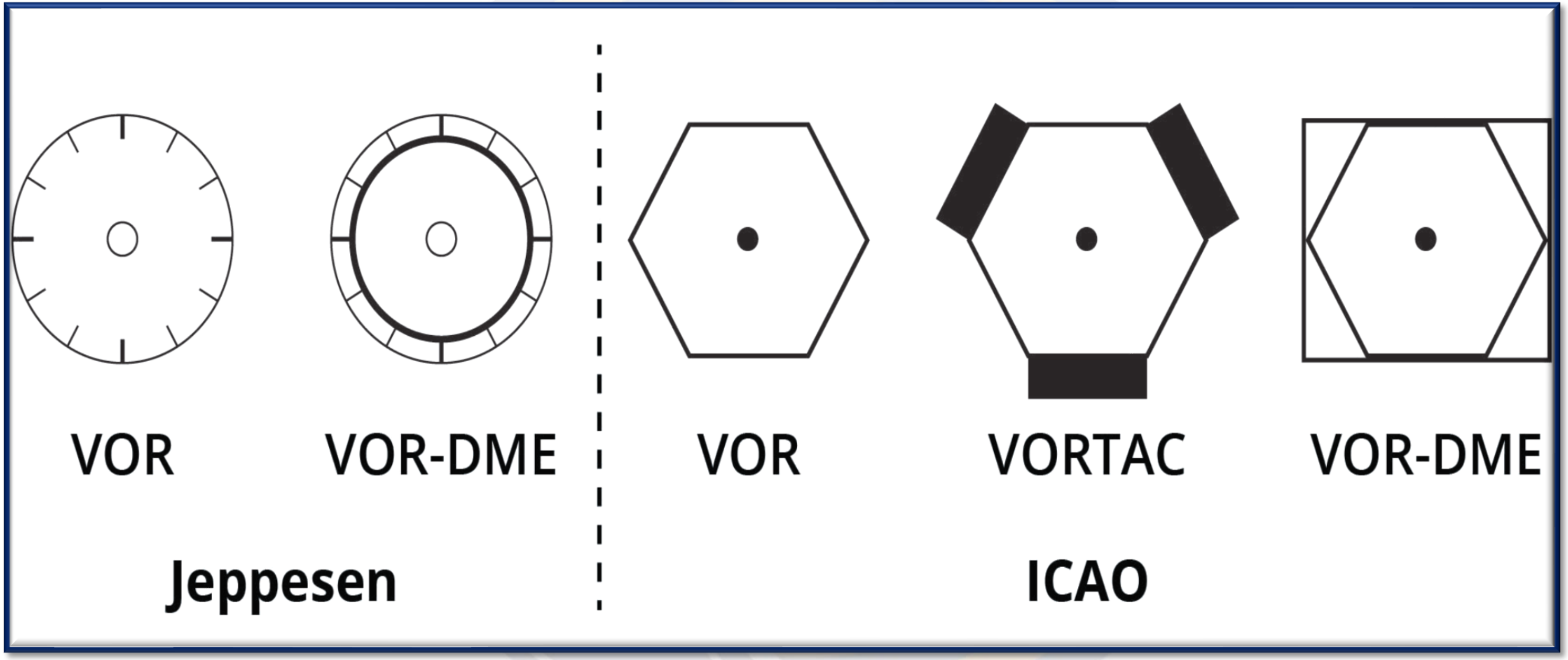
C/DVOR, TVOT may transmit an automatic terminal information service (ATIS) on the carrier wave in amplitude modulation.

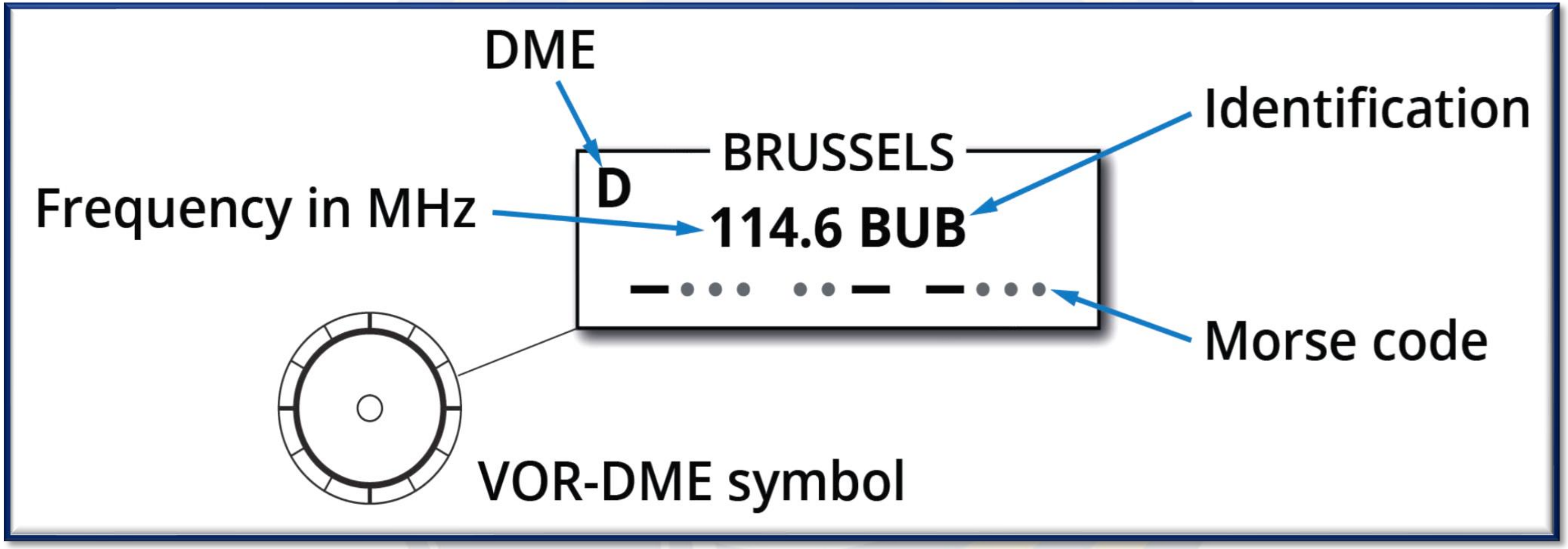
VOR Aircraft Equipment

The equipment consists of :

- Antenna(s)
- Receiver(s)
- Indicators

On large aircrafts (CS-25), two VOR sets, VOR 1 and VOR 2, are installed for fail-safe operations.


VOR
VOR-DME
VOR
VORTAC
VOR-DME
Jeppesen
ICAO


DME
Identification
BRUSSELS
D
Frequency in MHz
114.6 BUB
Morse code
VOR-DME symbol

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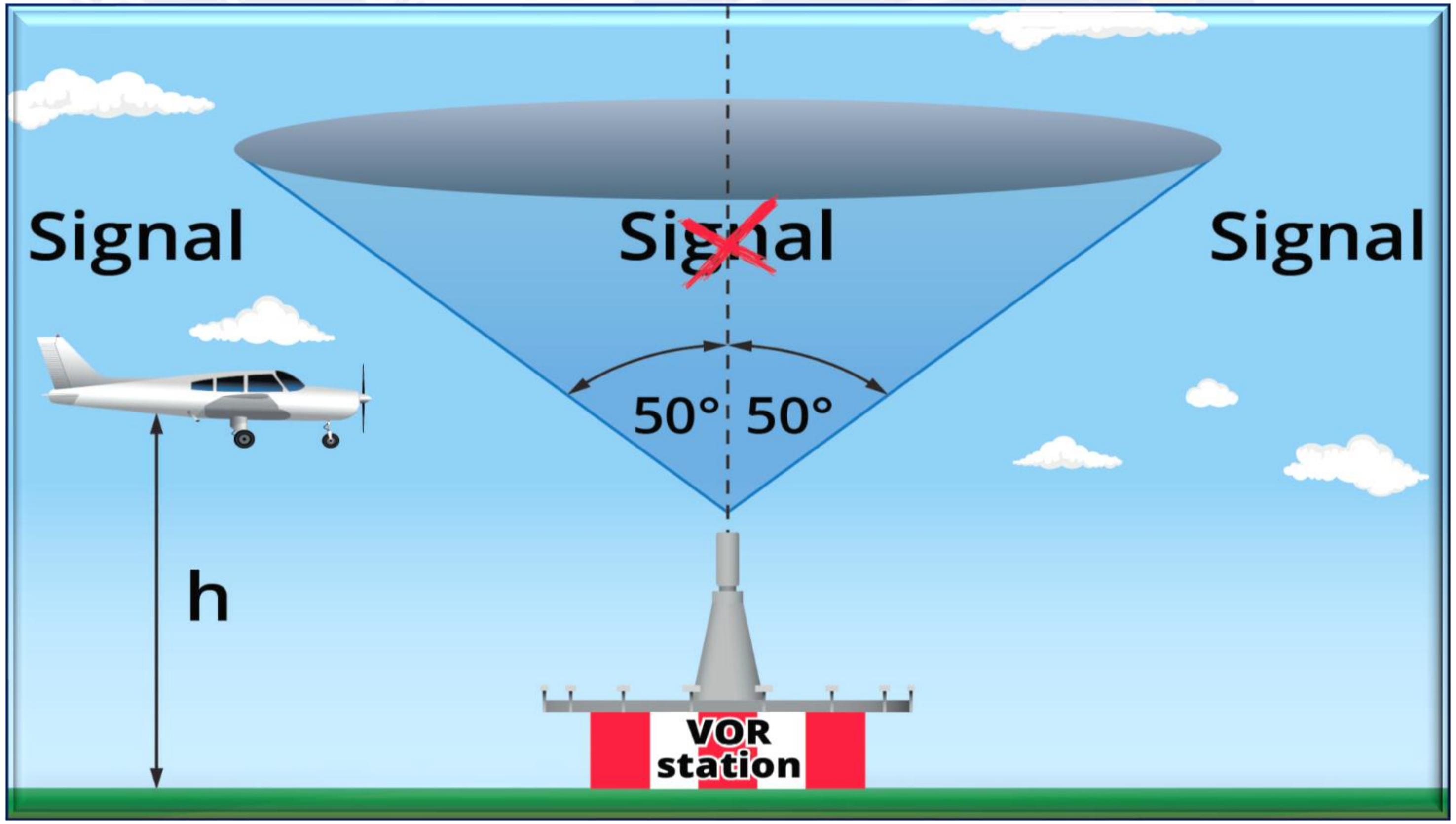
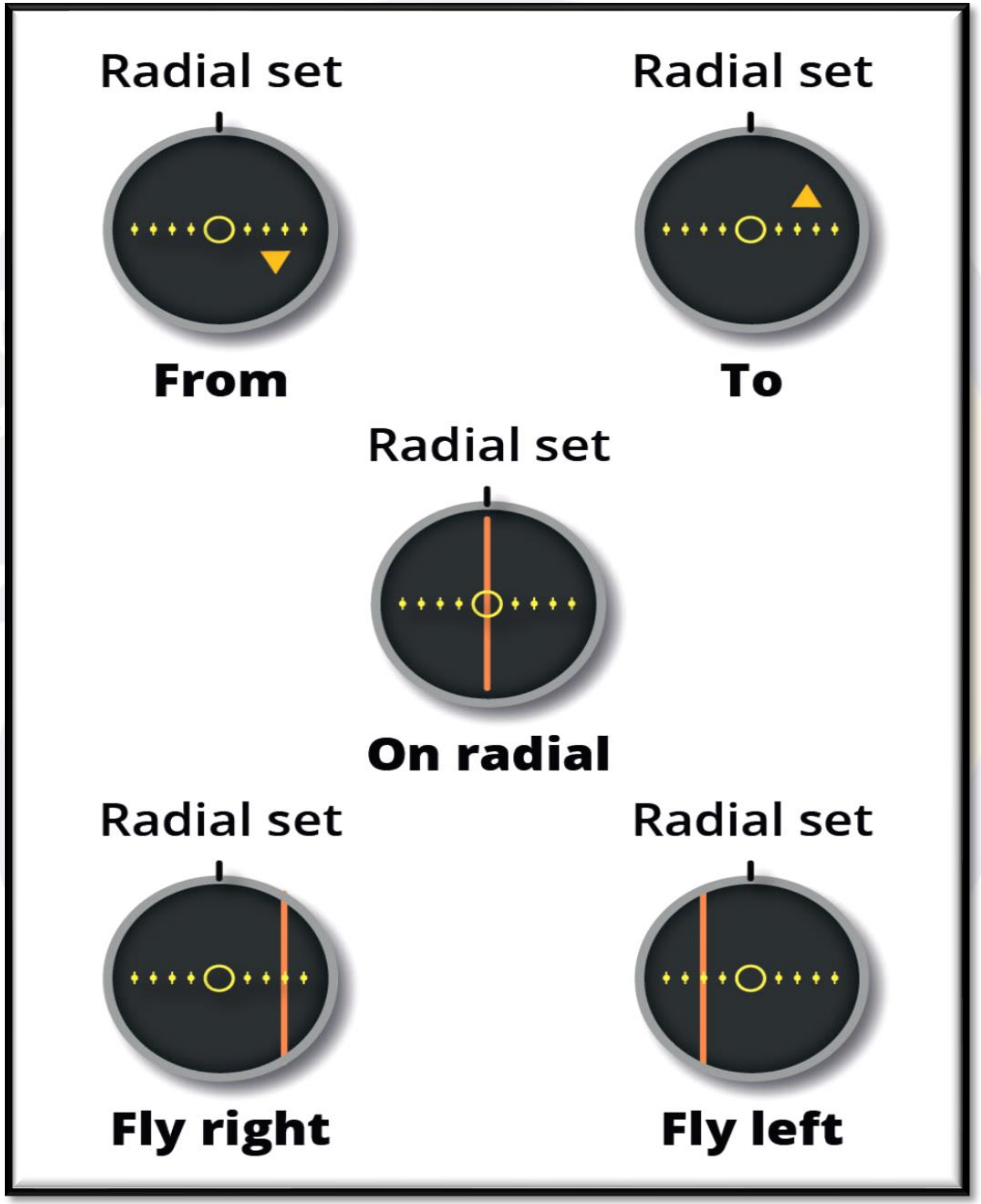
Cone of Confusion

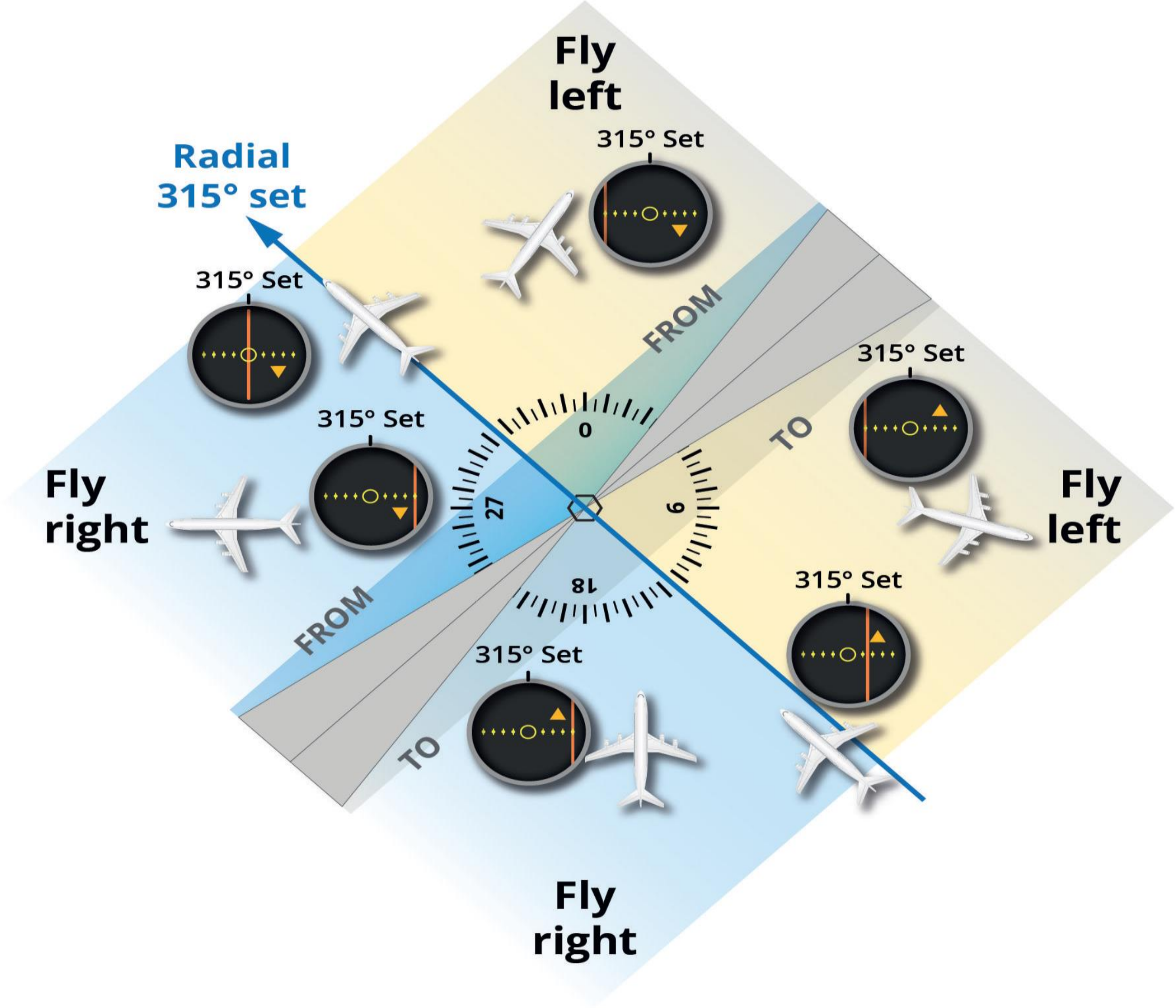
A **cone of confusion** (or cone of ambiguity) extending at an angle of 50 degrees either side of the VOR exists overhead the VOR transmitter during which the aircraft does not receive any signals. The diameter of the cone increases with aircraft height (h).

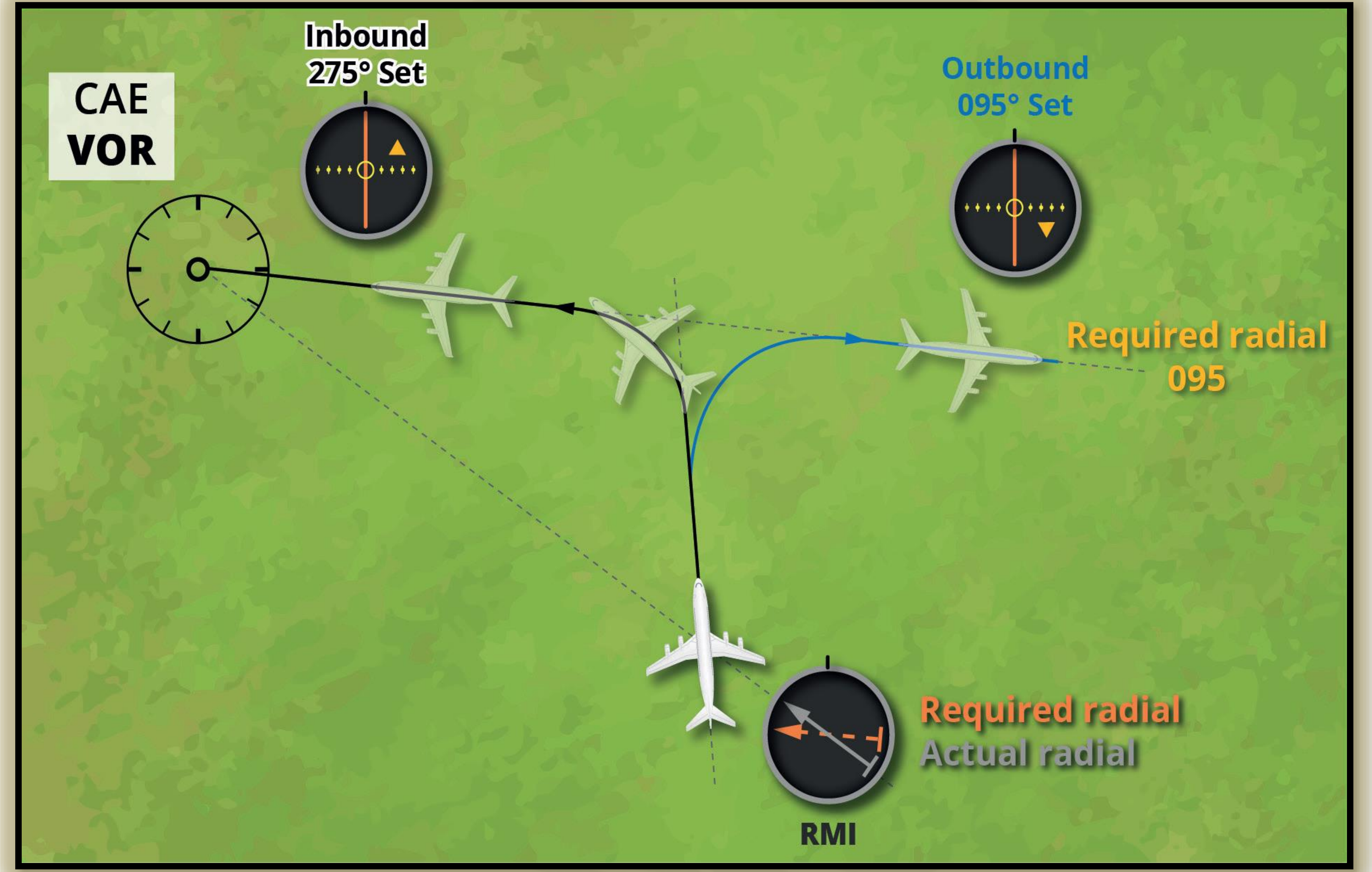


Radial 330 set

OBI


Radial set
From
Radial set
To
Radial set
On radial
Radial set
Fly right
Radial set
Fly left


Fly
left
315° Set
Radial
315° set
315° Set
FROM
315° Set
315° Set
0
TO
Fly
right
27
9
Fly
left
18
315° Set
FROM
315° Set
TO
Fly
right


Inbound
275° Set
CAE
VOR
Outbound
095° Set
Required radial
095
Required radial
Actual radial
RMI

The Horizontal Situation Indicator - HSI

The HSI is continuously synchronised with the aircraft magnetic heading source. The arrowhead shows the required course, set by the pilot.

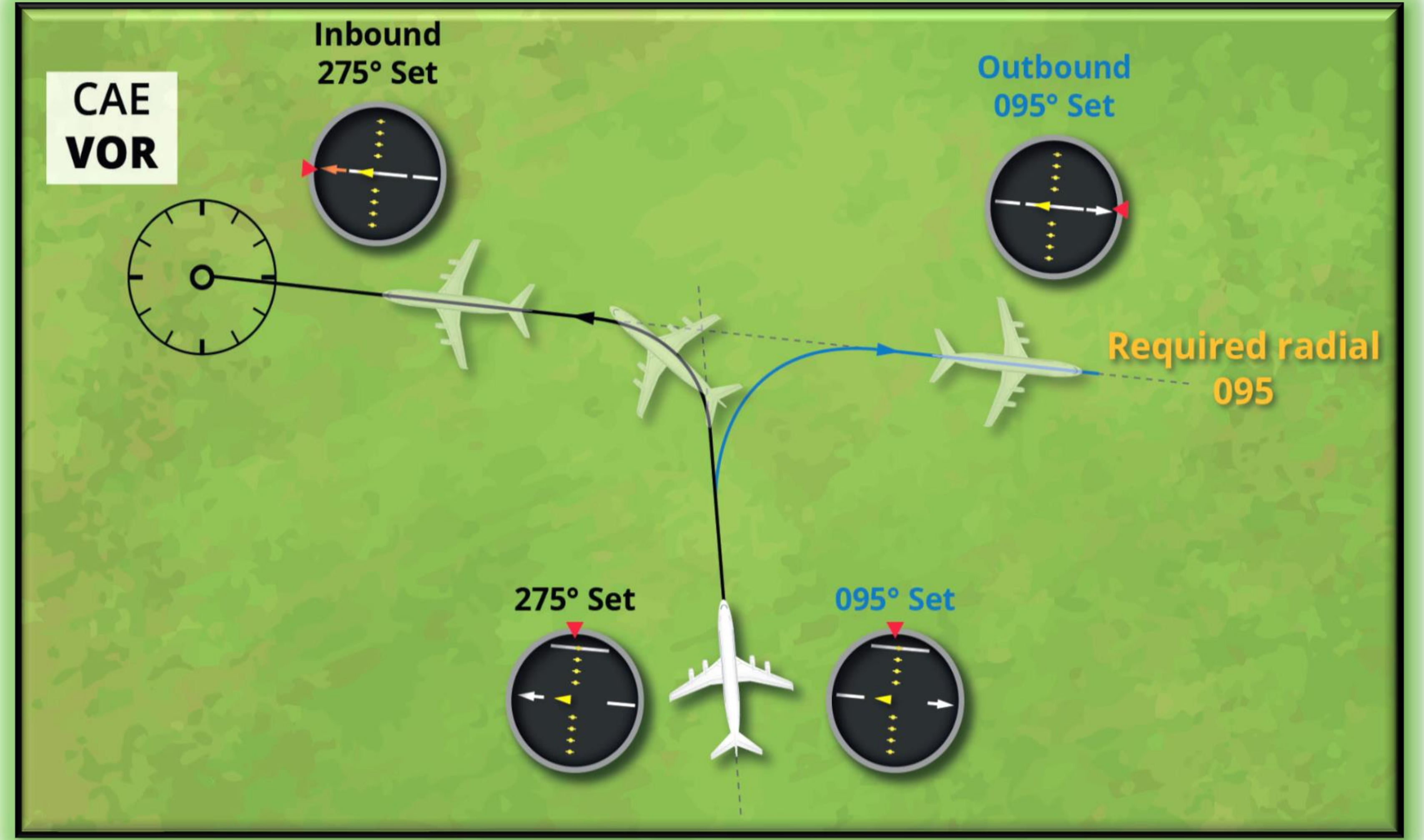
The TO/FROM indicator will be decided by the instrument.

- If the actual radial , which the aircraft is on , is within 90 degrees of the course set , then FROM will be shown.
- If the actual radial is more than 90 degrees from the course set , then TO will be shown.

The course deviation indicator (CDI) shows the angular difference between the required course and the actual VOR Radial the aircraft is on.

Radial 030 set

HSI


Inbound
275° Set
CAE
VOR
Outbound
095° Set
Required radial
095
275° Set
095° Set

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EBAW/ANR
DEURNE

JEPPESEN
17 APR 20 (13-2) CAT A, B & C
Eff 23 Apr

ANTWERP, BELGIUM
VOR Rwy 29

BRIEFING STRIP ™

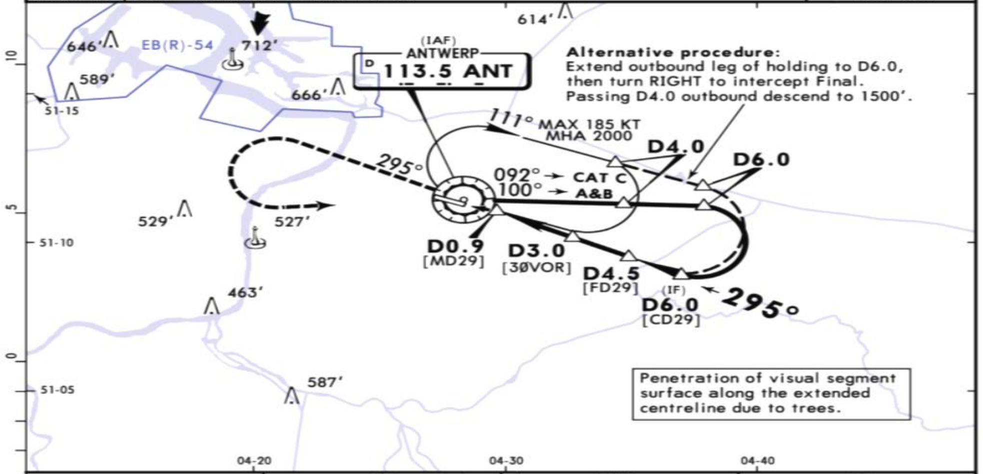
D-ATIS	*ANTWERP Tower	*Ground
124.205	135.205	121.905

VOR ANT	Final Apch Crs	D4.5	DA/MDA(H) (CONDITIONAL)	Apt Elev 31'
113.5	295°	1500' (1469')	440' (409')	

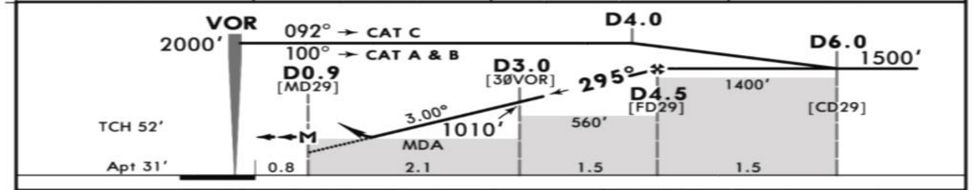
MSA ANT VOR: 090° – 270°; 1700; 2200

MISSED APCH: Climb STRAIGHT AHEAD to VOR. Continue climb on R-295. At 1500' turn LEFT (MAX 160 KT) direct to VOR. Climb and maintain 2000'. No turn before the MAPT.

Alt Set: hPa Apt Elev: 1 hPa Trans level: By ATC Trans alt: 4500'
1. DME required. 2. Base turn MAX 185 KT.



ANT DME	2.0	3.0	4.0
ALTITUDE	690'	1010'	1330'



Gnd speed-Kts	70	90	100	120	140	160
Descent Angle 3.00°	372	478	531	637	743	849
MAP at D0.9						

HIALS PAPI — ANT 113.5 — 1500' — ANT 113.5 on R-295

Standard

STRAIGHT-IN LANDING RWY 29

	With D3.0 CDFA DA/MDA(H) 440' (409')		W/o D3.0 CDFA DA/MDA(H) 560' (529')	
		ALS out		ALS out
A	RVR 1500m		RVR 1500m	
B	RVR 1500m		RVR 1500m	
C	RVR 1500m	RVR 1900m	RVR 2000m	RVR 2400m
D	NOT APPLICABLE			

CIRCLE-TO-LAND

	Max Kts	MDA(H)	VIS
A	100	590' (559')	1500m
B	135	720' (689')	1600m
C	180	1060' (1029')	2400m
D		NOT APPLICABLE	

PANS OPS

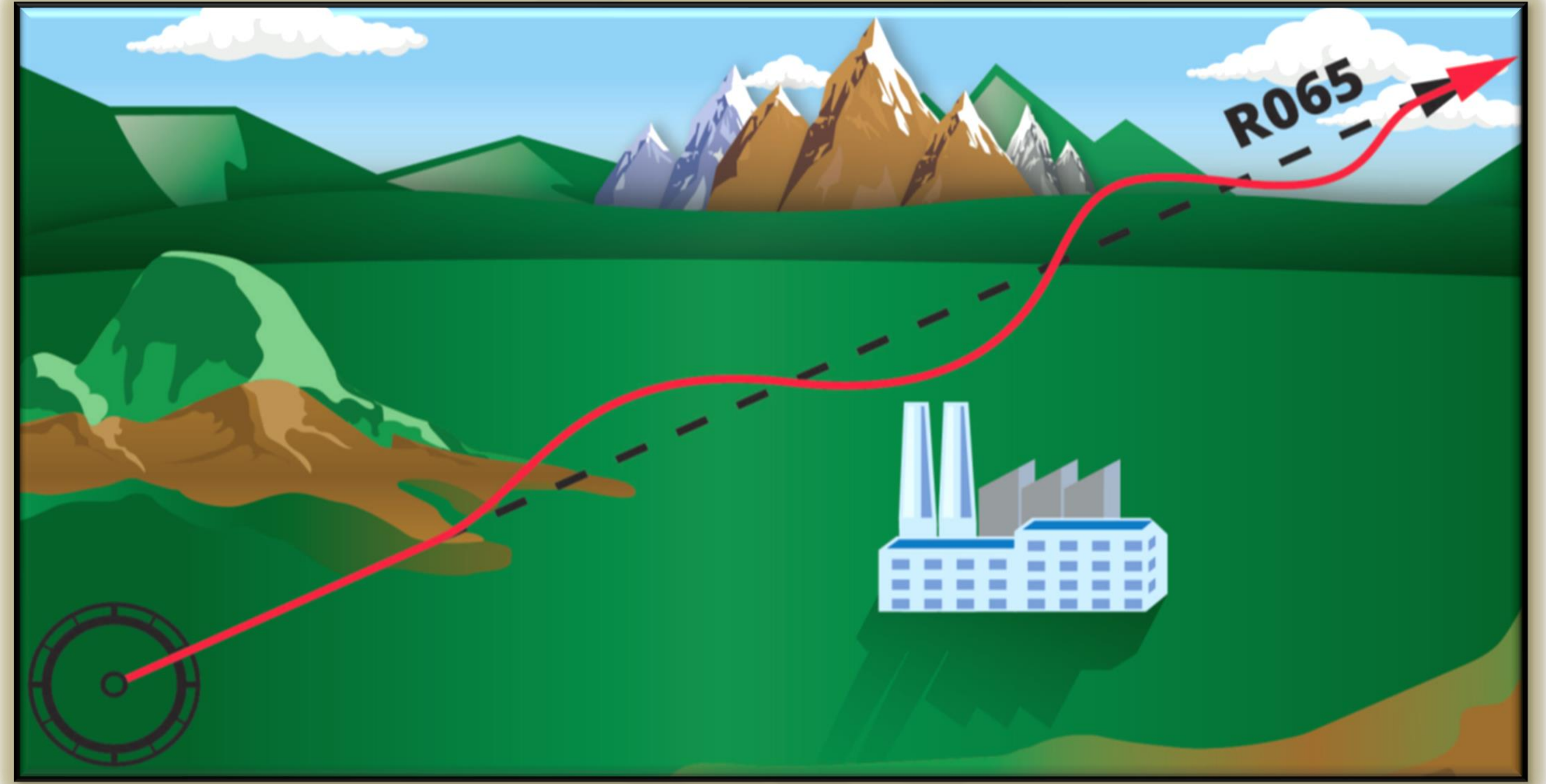
CHANGES: Apt elevation. Altitudes. SMA. Minimums.

Errors and Accuracy

Site errors and propagation errors

caused by the fact that , having left the VOR site with +- 1 degree Accuracy , the transmissions are further affected by terrain and distance. At considerable range from the VOR bends or scalloping can occur.

VOR scalloping is defined as an imperfection or deviation in the received VOR signal. It causes the signal to bend as a result of reflections from buildings or terrain, and it causes the CDI to slowly or rapidly shift from side to side.

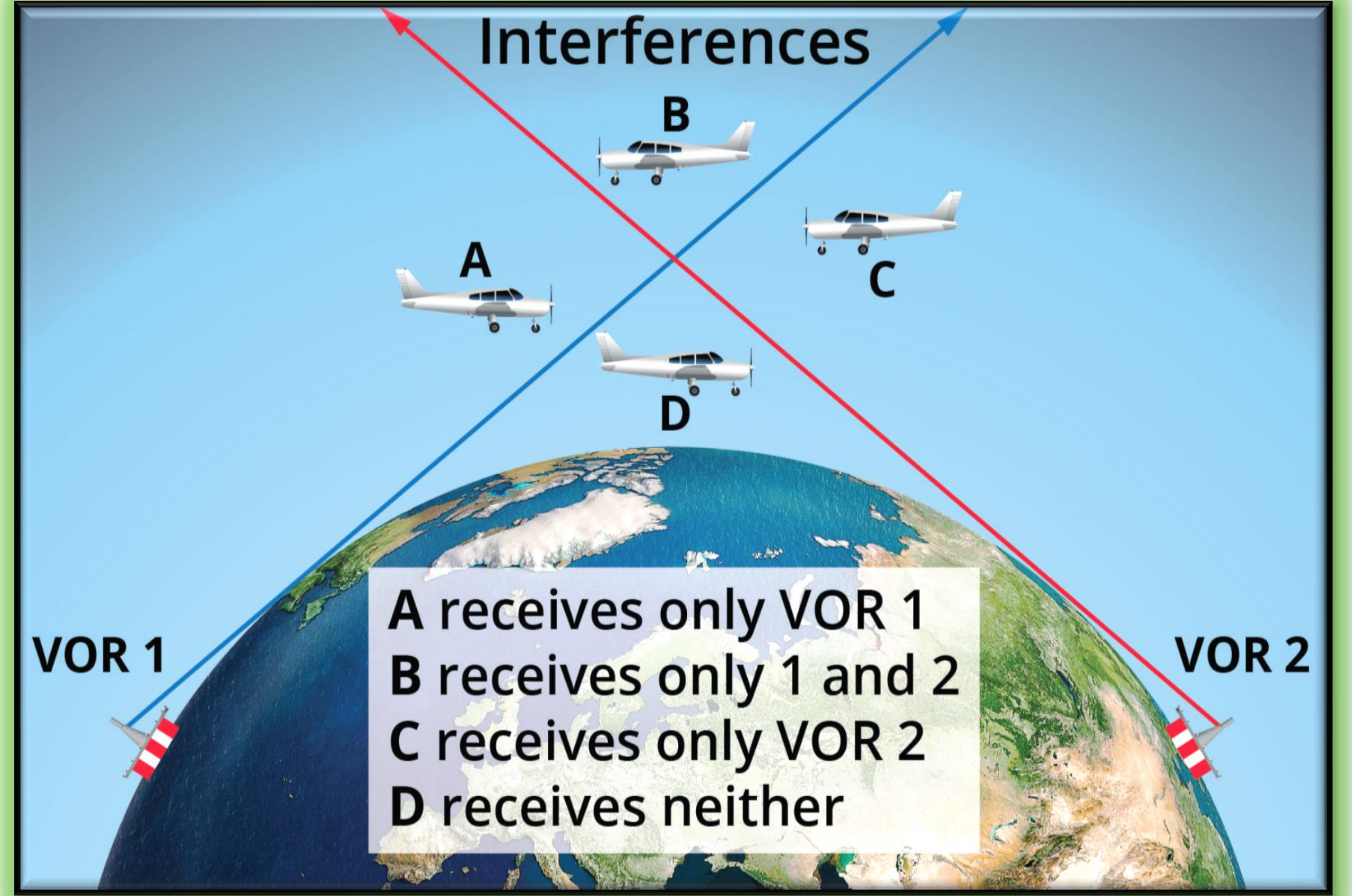

R065

NOTE

Airborne equipment errors are caused by aircraft equipment assessing and converting the phase differences to 1 degree of bearing , maximum aircraft equipment error should be +- 4 degrees .

VOR Accuracy

The above errors are aggregated to give a total error of +- 5 degrees . The pilot has to fly the required radial within one half -full scale deviation to be established on the VOR track.


Interferences
B
A
C
D
VOR 1
VOR 2
A receives only VOR 1
B receives only 1 and 2
C receives only VOR 2
D receives neither

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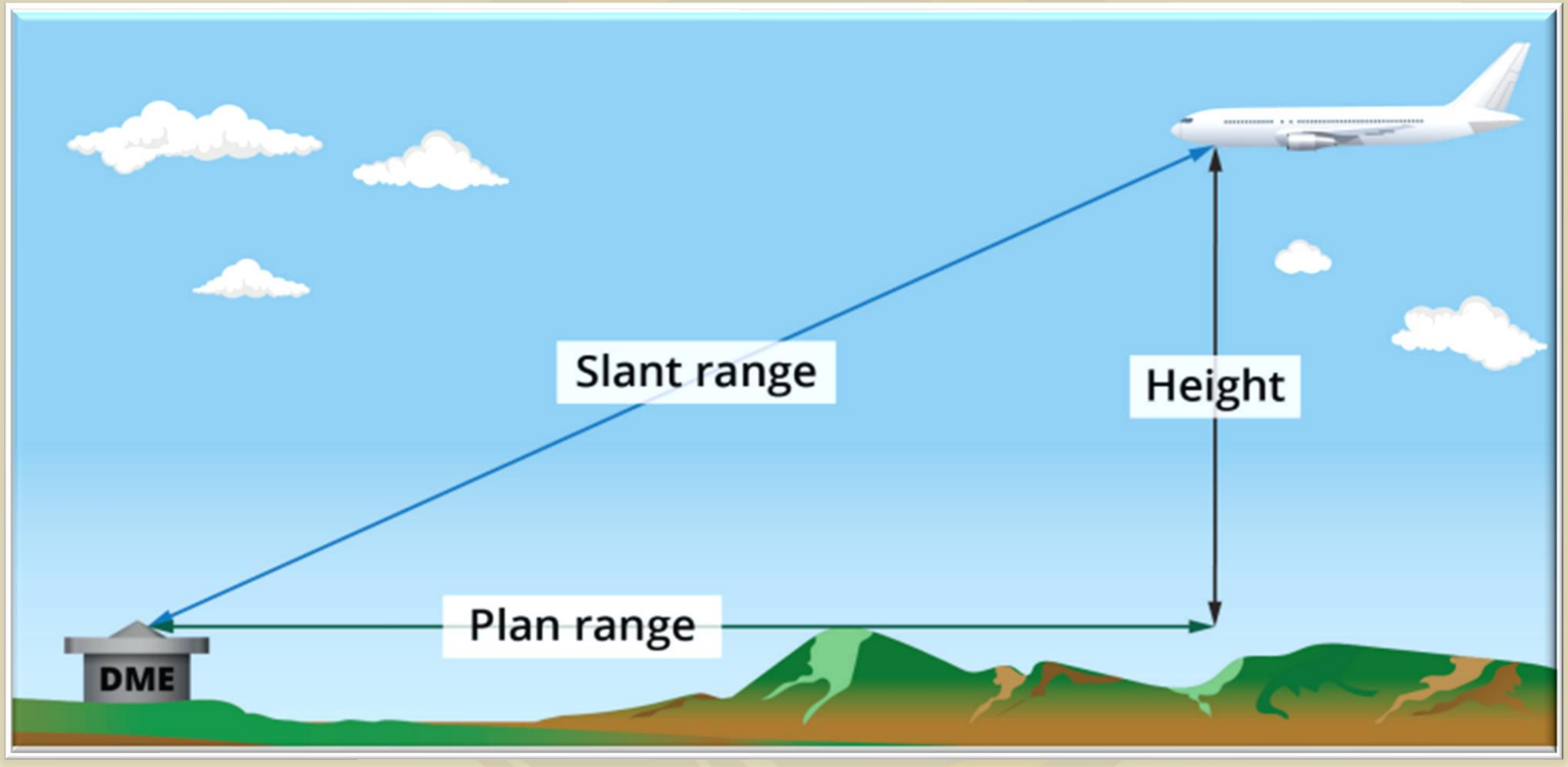
ENR 4.1 Radio Navigation Aids - En-Route

Name of station (MAG VAR/year)	ID	Frequency (CH)	Hours of operation	Co-ordinates	DME antenna ELEV	Remarks
AFFLIGEM DVOR/DME (1°W/2005)	AFI	114,900 MHz (CH 96X)	H24	505428N 0040820E	291 ft AMSL	DOC: 40 NM - FL 250 Sector E: 90 NM - FL 250
ANTWERPEN DVOR/DME (1°W/2005)	ANT	113,500 MHz (CH 82X)	H24	511126N 0042821E	74 ft AMSL	DOC: 40 NM - FL 250
BEAUVECHAIN TACAN	BBE	(CH 107X)	H24	504523N 0044605E		DOC: 100 NM - FL 250 OPR: Belgian air component
KLEINE-BROGEL TACAN	BBL	(CH 33X)	H24	511013N 0052759E		DOC: 40 NM - FL 250 OPR: Belgian air component
FLORENNES TACAN	BFS	(CH 52X)	H24	501429N 0043911E		DOC: 100 NM - FL 600 Sector SE: 200 NM - FL 600 OPR: Belgian air component
BRUSSELS DVOR/DME (1°W/2005)	BUB	114,600 MHz (CH 93X)	H24	505408N 0043217E	178 ft AMSL	DOC: 100 NM - FL 500
BRUNO DVOR/DME (1°W/2005)	BUN	110,600 MHz (CH 43X)	H24	510707N 0045032E	86 ft AMSL	DOC: 40 NM - FL 250
CHIÈVRES DVOR/TACAN (1°W/2005)	CIV	113,200 MHz (CH 79X)	H24	503426N 0034958E	214 ft AMSL	DOC: 60 NM - FL 500 CIV DVOR is located 800m from CIV TACAN. Both aids can therefore not be considered as collocated. TACAN unreliable: 056°-234° and 315°-326° beyond 30 NM BLW 3,000 ft COORD TACAN: 503420N - 0034918E OPR TACAN: USAF
COSTA DVOR/DME (1°W/2005)	COA	110,500 MHz (CH 37Y)	H24	512053N 0032119E	42 ft AMSL	DOC: 60 NM - FL 500
DIEKIRK DVOR/DME/NDB (0°W/2005)	DIK	114,400 MHz (CH 91X) 307.000 kHz	H24	495141N 0060747E	1109 ft AMSL	DOC: 70 NM - FL 500 Sector NW: 100 NM - FL 500 DOC NDB: 50 NM

Distance Measuring Equipment (DME)

At localities where for operational reasons or because of air traffic control reasons such as air traffic density or proximity of route there is a need for more precise navigation service than that provided by VOR, distance measurement equipment (DME) shall be installed and maintained in operation as a complement to VOR.

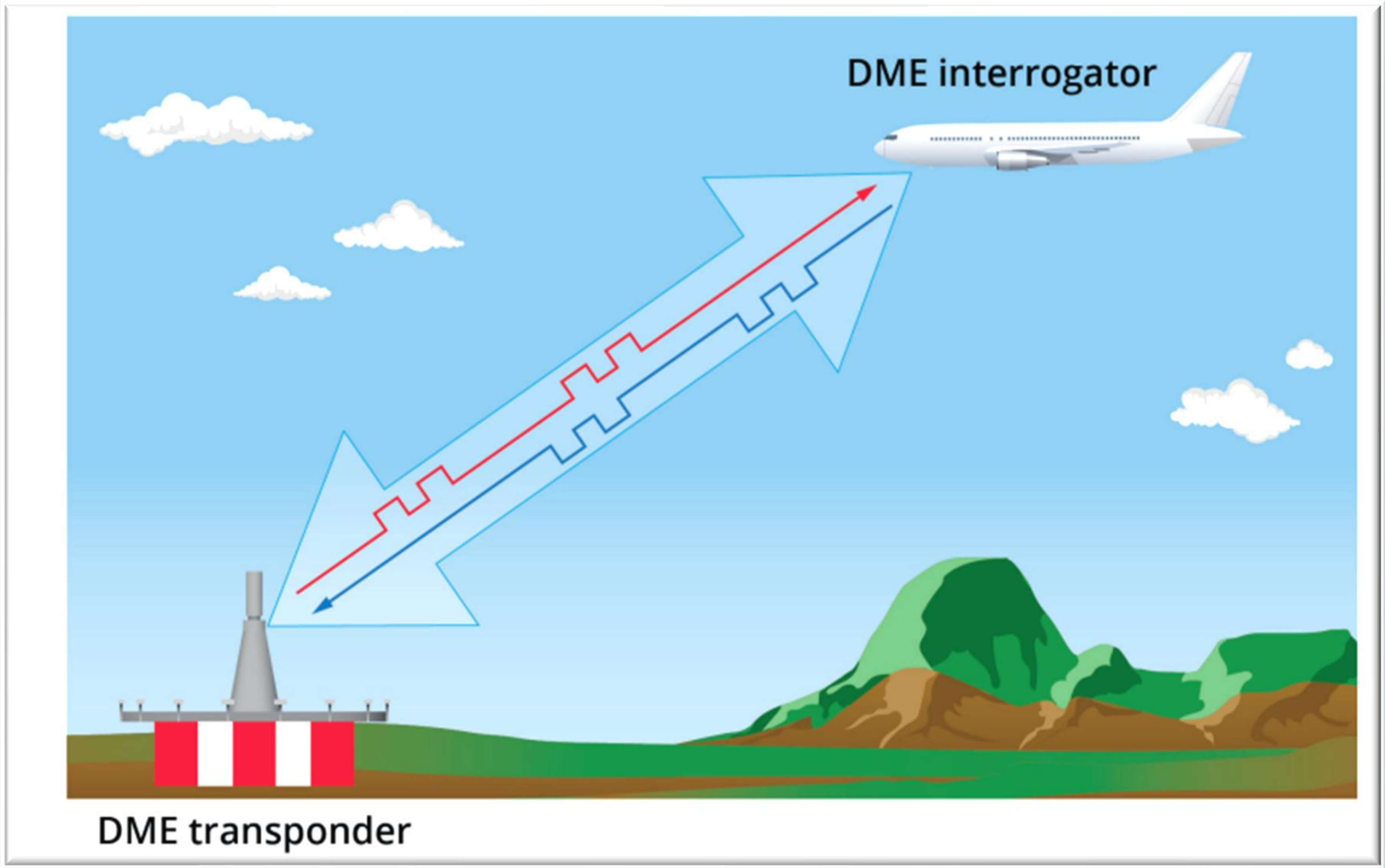
Distance measuring equipment (DME) is a secondary radar system that enables an aircraft to establish its range from a ground station. A pilot obtains accurate magnetic bearings from a VOR beacon and accurate slant ranges from a DME.


Slant range
Height
Plan range
DME

Secondary Radar System

The secondary radar system is a two-way data communication system, which consists of two main components :

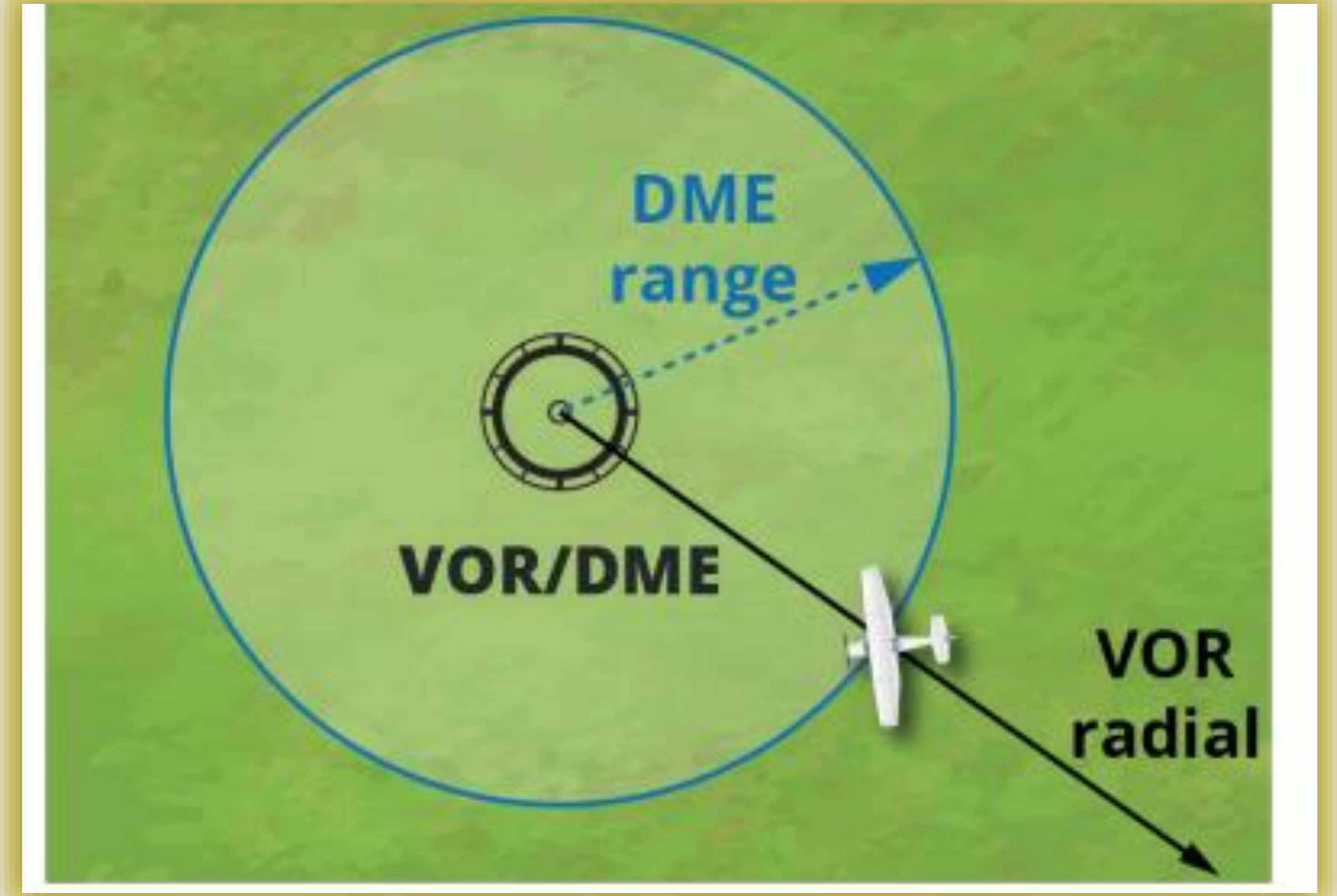
- An interrogator, which transmits interrogation pulses and receives replies from the transponder.
- A transponder, which receives the interrogation pulses and replies to the interrogator with data information pulses.


DME interrogator
DME transponder

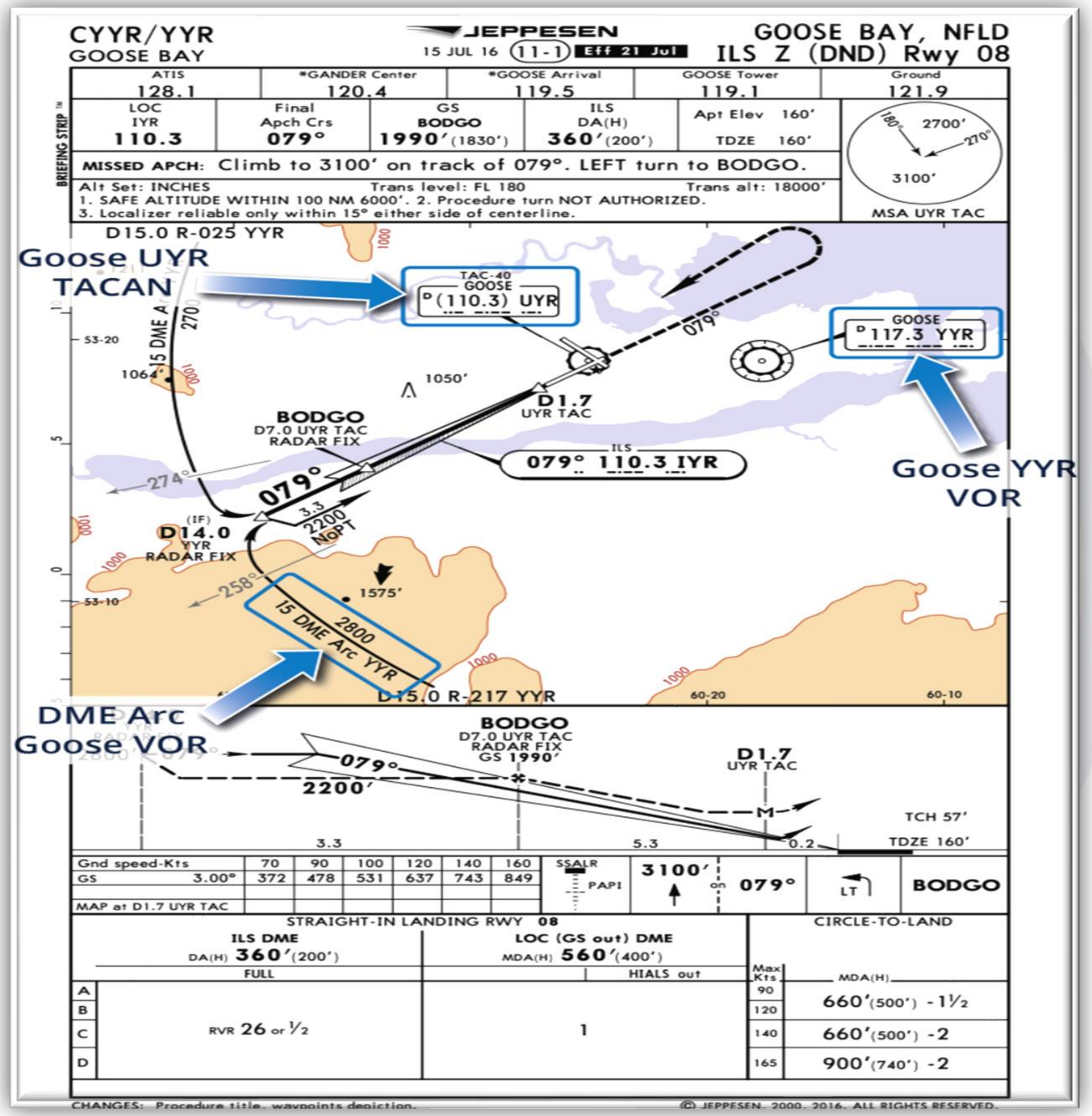
DME and TACAN

A channel number is selected by the pilot of a tactical air navigation (TACAN) equipped military aircraft, and this equipment provides the pilot with range and bearing.

Civil aircraft have the VOR/DME equipment and select the appropriate paired VHF frequency to obtain range from either a DME station or military TACA1 distance measurement facility which is compatible with civil DME interrogators. A TACAN co-located with a VOR station is called VORTAC.


DME
range
VOR/DME
VOR
radial

HOMAviation Training Center
مرکز آموزش هــای هوایی همـــا



Instrument Landing System (ILS)

The instrument landing system (ILS) has been in existence for over 40 years. The system provides pilots with an accurate means of carrying out an instrument approach to a runway, giving guidance both in the horizontal and the vertical planes.

It even enables aircraft to carry out automatic landings. ILS is a precision approach system because it gives guidance in both the horizontal and the vertical plane.

ILS provides the pilot with visual instructions in the cockpit to enable him to fly the aircraft down a predetermined glide path and extended runway center line (localiser) to his decision height (DH).

At decision height the pilot decides to land (if he has the required visual references and sufficient room to maneuver the aircraft for a safe touchdown) or he goes around and carries out the published missed approach procedure .

ILS Components

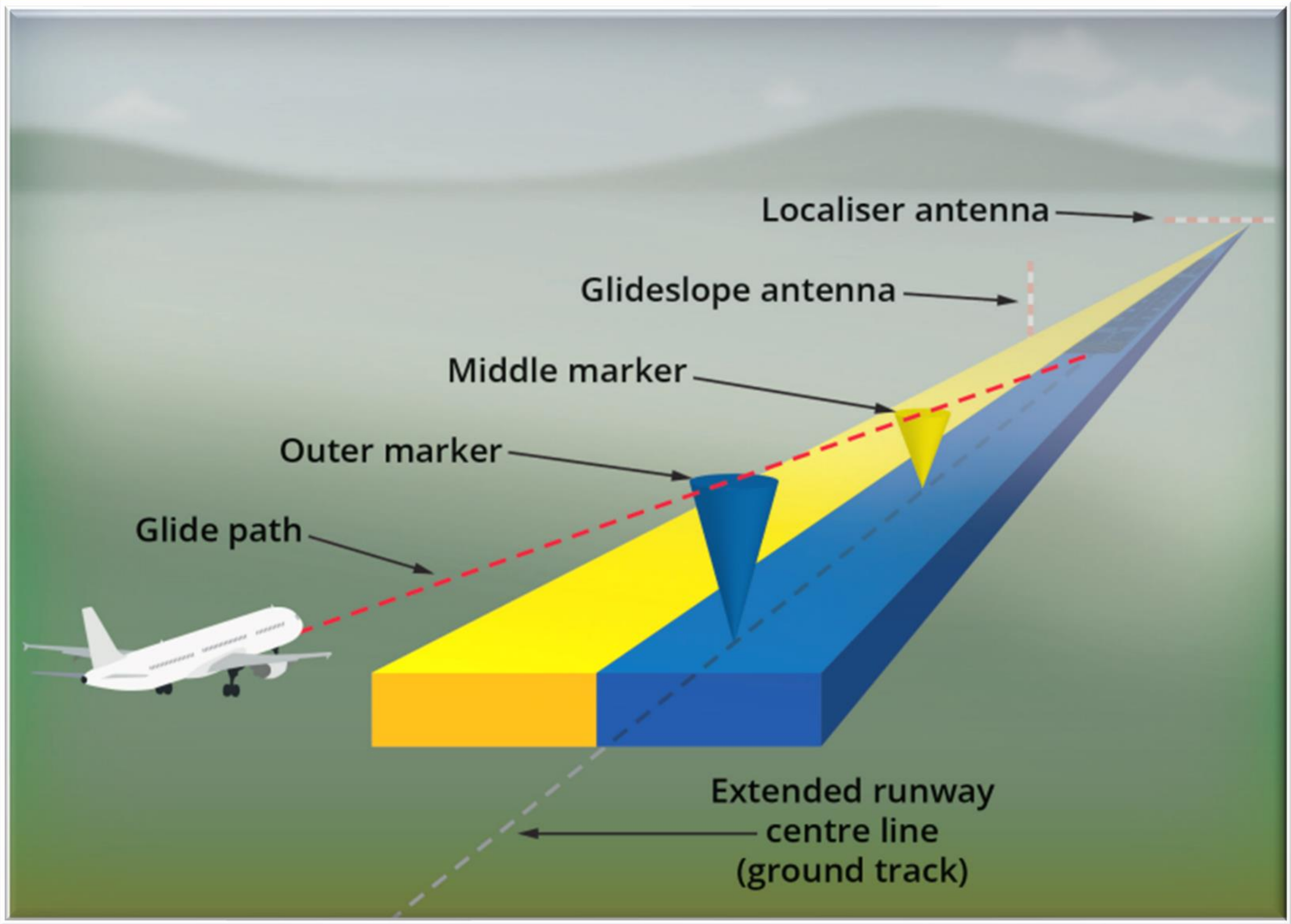
The system requires a suitable ground installation and airborne equipment. The ground installation has three distinct components, namely localiser, glide path, and marker beacons.

A. The localiser (LOC) transmits in the VHF band and is located about 300m from the up-wind end of the runway.

B. The glide path (GP) transmitter operates in the VHF band and is frequency paired with the localiser. It is located 300 m in from the threshold and about 200 m from the runway edge abeam the touchdown point.

C. Marker beacons transmit at 75 MHz in the VHF band. These include the outer marker (OM), the middle marker (MM), and possibly an inner marker (IM). They are provided to enable the pilot to crosscheck the aircraft's height against ranges and timing to the runway threshold.

D. Distance measuring equipment (DME) that is frequency paired with the ILS frequencies are now increasingly provided to supplement or replace the range information provided by marker beacons.


Localiser antenna
Glideslope antenna
Middle marker
Outer marker
Glide path
Extended runway
centre line
(ground track)

ILS Frequencies

The localiser operates in the :

•VHF band between 108 and 111.975 MHz

The glide path operates in the :

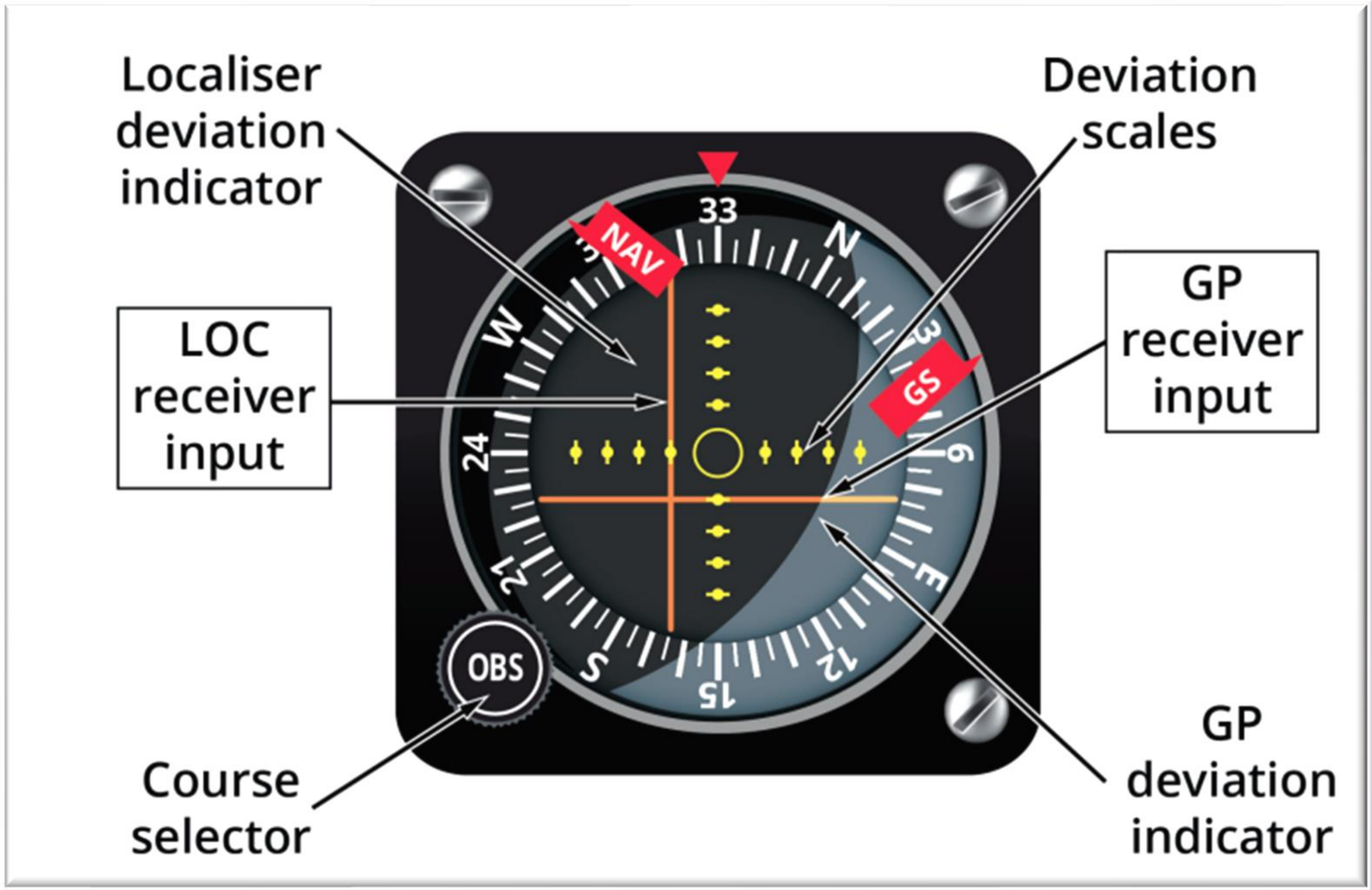
•UHF band between 329.15 and 335 MHz

VHF carrier frequency: 75 Hz

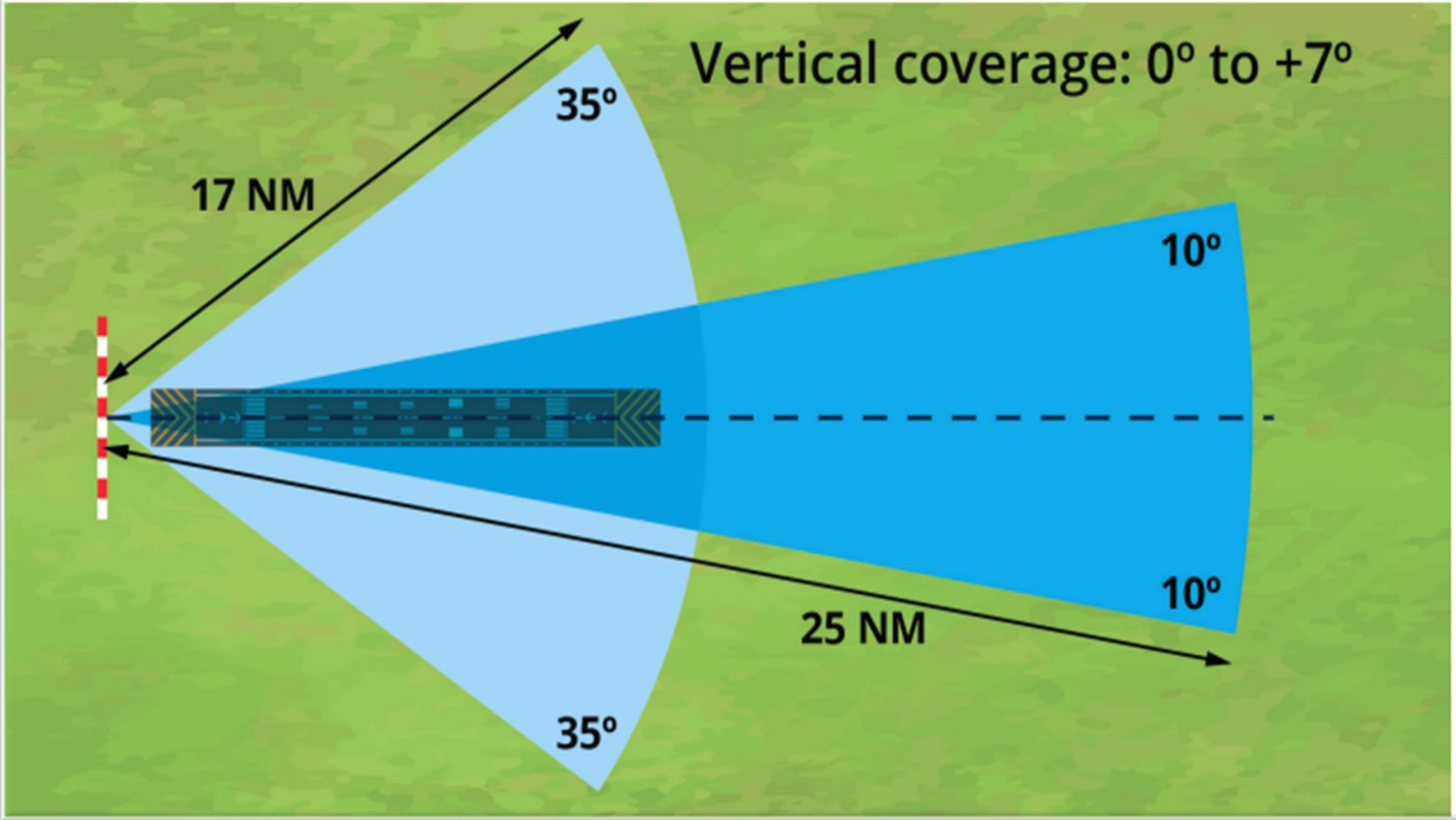
400 Hz - Low pitch
Dashes, two dashes per second continuously
Flashing blue light
Final approach fix, check range versus alt

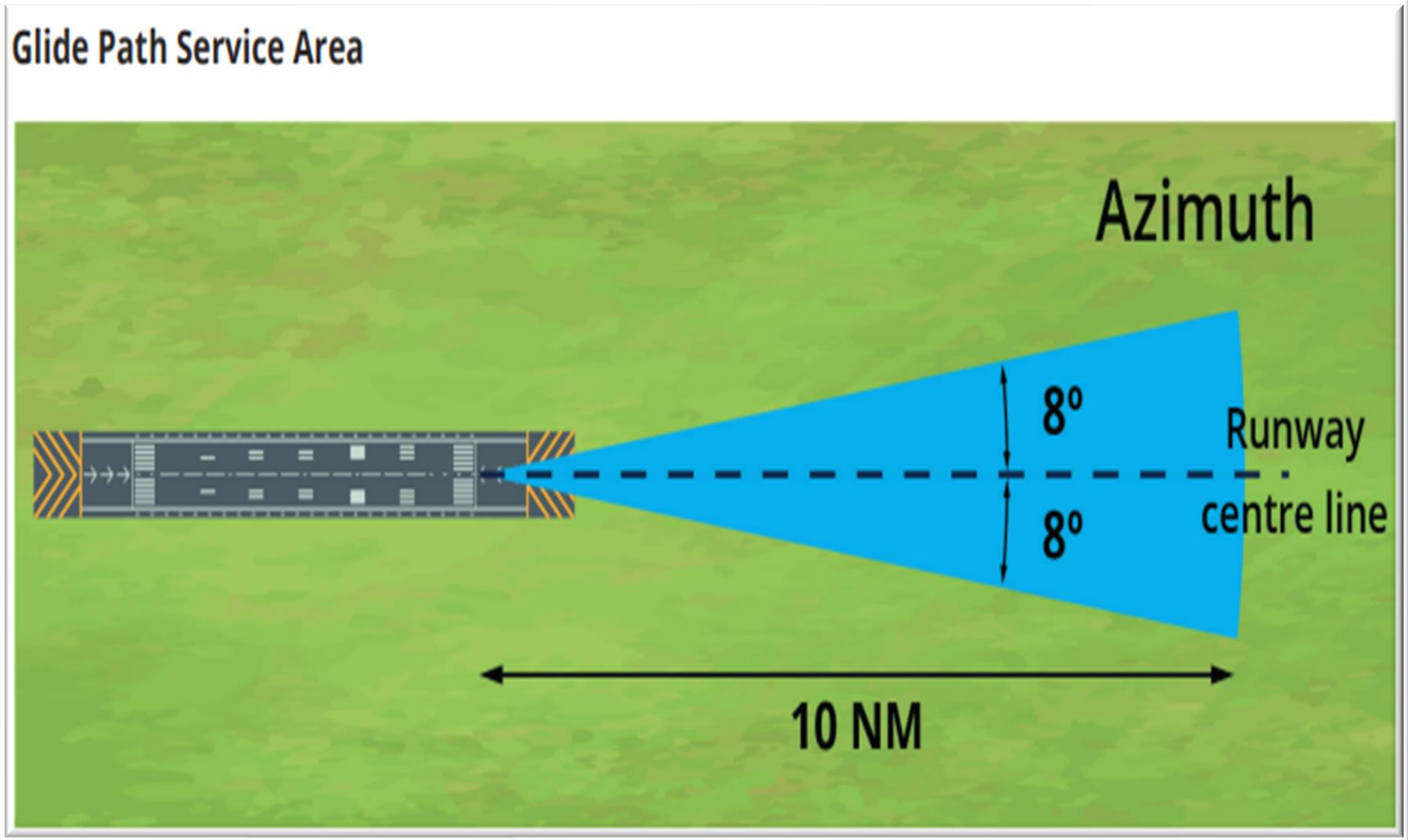
1,300 Hz - Medium pitch
Alternate dots and dashes
Flashing amber light
CAT 1 decision height

3,000 Hz - High pitch
Dots, six dots per second continuously
Flashing white light
CAT 2 decision height


Localiser deviation indicator
Deviation scales
LOC receiver input
GP receiver input
Course selector
GP deviation indicator
33
N
W
24
21
S
15
12
E
6
3
NAV
GS
OBS

Localiser Service Area




Glide Path Service Area
Azimuth
8°
8°
Runway
centre line
10 NM

ILS Facility Performance Categories

Category I (Cat I)

A category I ILS is one which provides guidance information from the coverage limit of the ILS to the point at which the localiser course line intersects the ILS glide path at a height of 200 ft or less above the horizontal plane containing the threshold.

Category II(Cat II)

An ILS which provides guidance information from the coverage limit of the ILS to the point at which the localiser course line intersects the ILS glide path at a height of 50 ft or less above the horizontal plane containing the threshold.

Category III (Cat III)

An ILS, which provides guidance information from coverage limit of the facility to, and along, the runway surface.

Category I

- A decision height (DH) not lower than 200 ft pressure altimeter and
- A runway visual range (RVR) not less than 550 m.

Category II

- A DH lower than ft but not lower than 100 ft radio altimeter and
- A RVR not less than 300 m.

Category III A

- A DH lower than 100 ft radio altimeter or no DH and
- A RVR not less than 200 m.

Category III B

- A DH lower than 50 ft radio altimeter or no DH and
- A RVR less than 200 m but not less than 75 m.

Category III C

No DH and no RVR limitations


SPEED
ALT
HDG
LOC
BARO 550
AP1
1FD2
A/THR
220
200
180
160
139
10
10
10
10
GP
LOC
ILS or MLS
LOT
109.50
10 NM
QNH 1010
16 17 18 19
227

Chapter 4

RADAR

Radio Detection and Ranging

A primary radar uses pulses of radio energy reflected from a target i.e. it uses one frequency throughout.

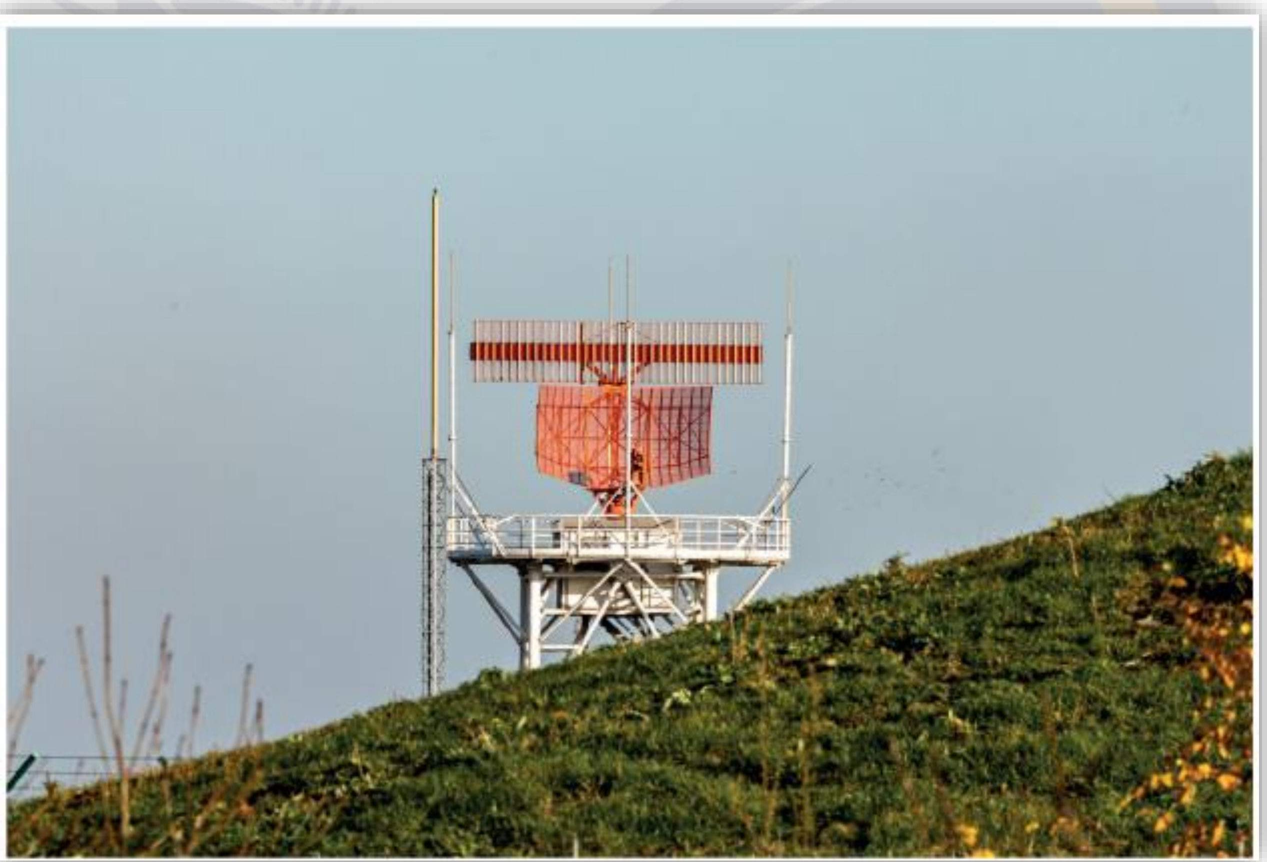
Figure 3.1.1 The primary radar antenna

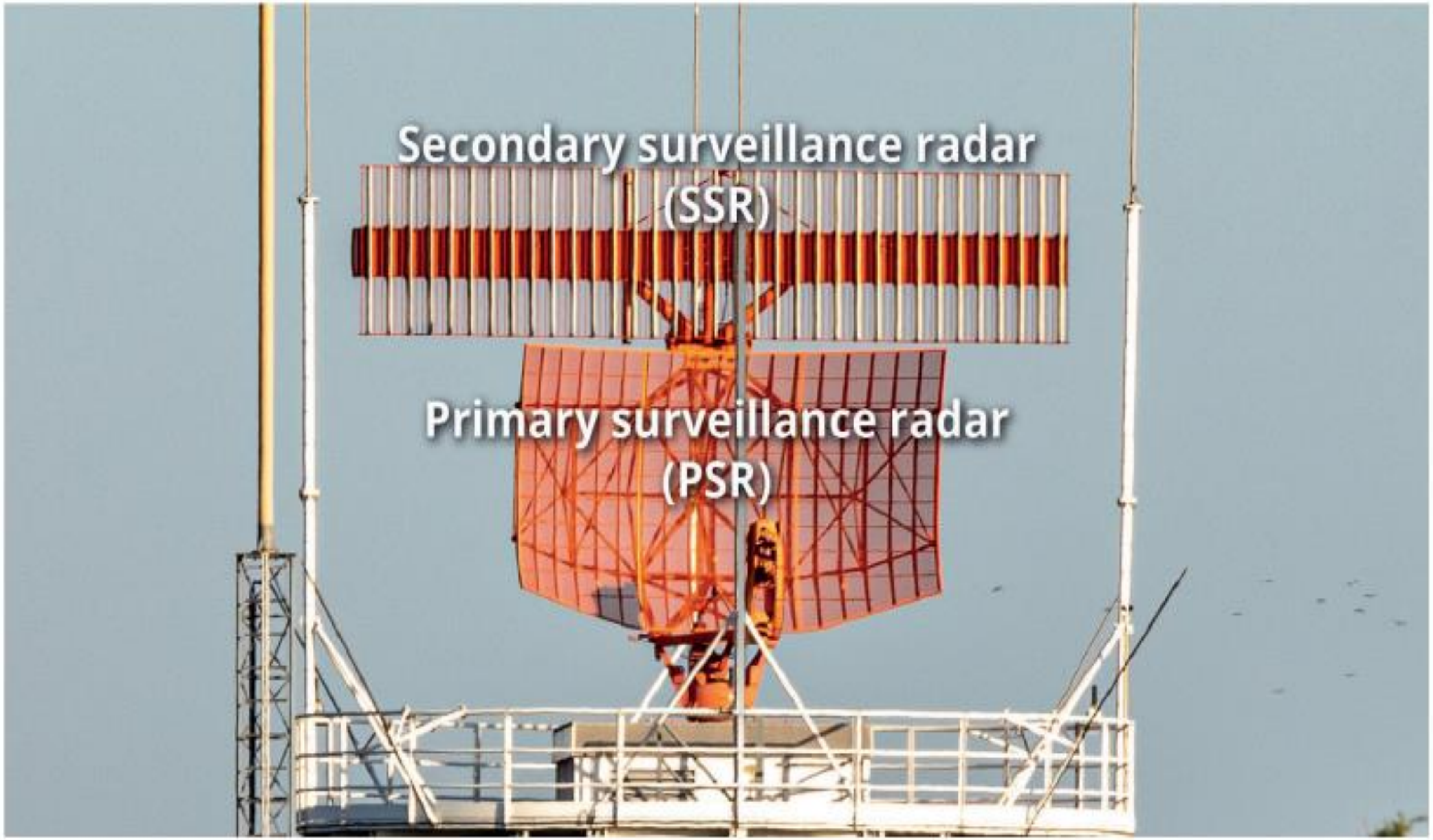
A secondary radar transmits pulses on one frequency but receives on a different frequency i.e., the object transmits its own energy. It is a system utilising an interrogator and transponder.

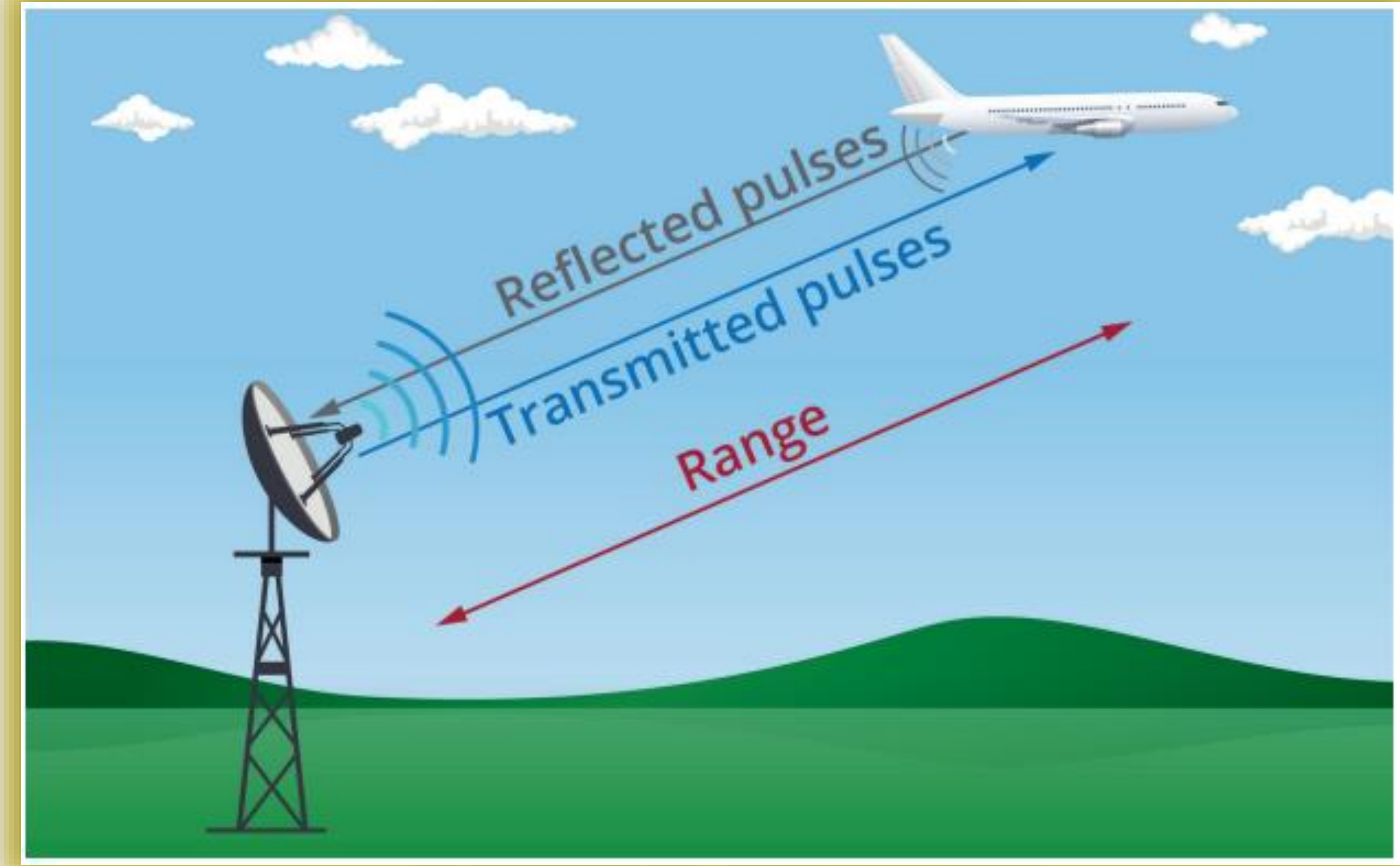
The transponder can be located in the aircraft (secondary surveillance radar) or on the ground (DME)

Air traffic control (ATC) services use ground radars extensively to serve a large number of requirements and users.

They employ both primary radar and secondary radar techniques. Primary radar is used to detect aircraft not equipped with a secondary radar. The services that can be offered by ATC are information surveillance or guidance.




Secondary surveillance radar
(SSR)
Primary surveillance radar
(PSR)


Reflected pulses
Transmitted pulses
Range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