SB501 – NAVIGATION SYSTEMS

GEA Tianjin / 中国民航大学中欧航空工程师学院

1 – Radio Propagation Theory

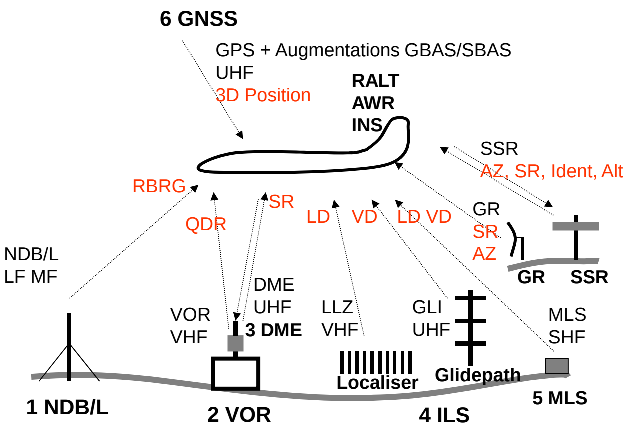
2 – Navaids NDB VOR DME

3 – Landing Systems ILS MLS

4 – Global Navigation GNSS

A. ROUGÉ – ENAC/TA/AVS

INTRODUCTION



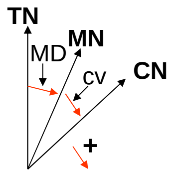
VLF: 3 KHz - 30 KHz
LF : 30 KHz - 300 KHz
MF : 300 KHz - 3 MHz
HF : 3 MHz - 30 MHz
VHF: 30 MHz - 300 MHz
UHF: 300 MHz - 3 GHz
SHF: 3 GHz - 30 GHz

NDB: Non Directional Beacon
L: Locator
VOR: VHF Omni Range
DME: Distance Measurement Equipment
ILS: Instrument Landing System
MLS: Microwave Landing System
GPS: Global Positioning System

GR: Ground Radar
SSR: Secondary Surveillance Radar

REFERENCE DIRECTIONS

TN True North
MN Magnetic North
CN Compass North



MD magnetic declination
cv compass variation (compass error)

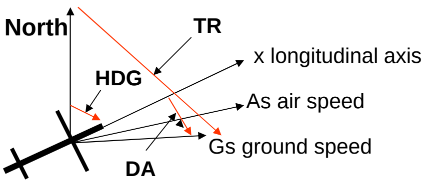
angles are measured clockwise.

TRUE NORTH (TN): Direction from a given location to the north geographic pole.
MAGNETIC NORTH (MN): Direction from a given location to north magnetic pole.
COMPASS NORTH (CN): Direction to north magnetic pole indicated on the compass.

MAGNETIC DECLINATION : angle between True North and Magnetic North. Positive declination if Magnetic North is on the East of the True North. Depends on place and time. Low in France -0°15' Paris 01/01/2012. TH = MH + d.

HEADING - TRACK – DRIFT

HDG Heading
TR Track
DA Drift angle



HEADING (HDG) : angle between North reference (true or magnetic) and aircraft axis. clockwise. TRUE HEADING and MAGNETIC HEADING.

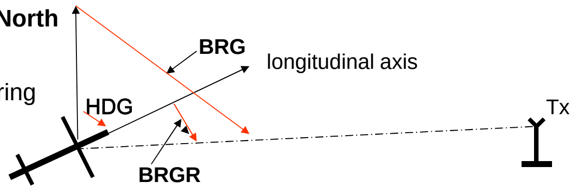
TRACK (TR): angle between North reference and the ground trajectory of an aircraft.

DRIFT ANGLE (DA) : angle between heading and track.

Track = Heading + DA

RELATIVE BEARING – BEARING

HDG Heading
BRGR Relative Bearing
BRG Bearing

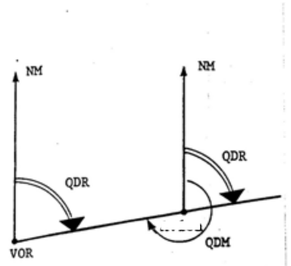


RELATIVE BEARING (BRGR) : angle between aircraft axis and the direction of the point to be measured.

BEARING (BRG) : angle between North reference (true or magnetic) and the direction of the point to be measured.

Bearing = Heading + Relative Bearing

BEARING TO – BEARING FROM



NM nautical mile unit of length
1 minute of arc of latitude
measured along a meridian.
1 **NM** = 1852m = 6076 **ft**
1 **ft** = 0.305 m
1 **kt** = 1 Nm/h = 0.5 m/s

QDM: magnetic bearing to the station
(QUJ: true bearing to the station**)**

QDR: magnetic bearing from the **station**
(QTE: true bearing from the station)

QDM # QDR +/- 180°
QDM = MH + RBRG

GREAT CIRCLE – RHUMB LINE

GREAT CIRCLE (ORTHODROME): shortest distance between two points on the Earth. It is an arc of great circle.
From Paris (Latitude 48°52' North) to Beijing (Latitude 39°54' North) common flight route over Baltic Sea.

RHUMB LINE (LOXODROME) : line on the earth's surface cutting all meridians at the same angle. It is a constant true track. It is not the shortest distance. A straight line on a Mercator chart.

NAVIGATION

NDB
NON DIRECTIONAL BEACON

VOR
VHF OMNI RANGE

DME
DISTANCE MEASUREMENT EQUIPMENT

LANDING

ILS
INSTRUMENT LANDING SYSTEM

LOCALIZER LLZ

GLIDE GLI

MLS
MICROWAVE LANDING SYSTEM

RADIO NAVIGATION

SURVEILLANCE

GR
PRIMARY RADAR

SSR
SECONDARY SURVEILLANCE RADAR

SUMMARY

NDB/L
NDB or Locator ground station beaming an unmodulated carrier.
On-board receiver (ADF Automatic Direction Finder) measuring the emission direction (direction finding) of the received signal. Relative bearing and bearing indicators. Accuracy depends on the conditions of use.

VOR
VOR ground station radiating QDR directly on the carrier.
On-board VOR receiver with bearing and deviation indicators.
Accuracy depends on the quality of the site (nearby obstacles).

DME
DME ground beacon.
On-board DME Interrogator measuring slant range Board / DME Beacon.
High Accuracy. Robust system.

SUMMARY

ILS
Materializes the glide path to the runway threshold.
Intersection of 2 radio planes radiated by 2 radio beacons (Localiser and Glidepath). On-board 2 needles deviation indicator.
Very accurate but narrow guiding sectors.
Sensitive to nearby obstacles.

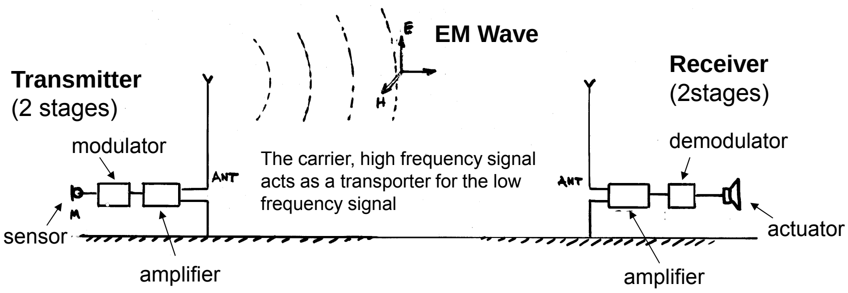
MLS
Designed to replace the ILS system.
Use of scanning beams.
Very accurate, robust but expensive. Very few facilities.

GPS/GNSS
Global and highly accurate coverage.
Variable precision, low integrity, availability and continuity low.
Need GBAS or SBAS augmentation.

RADIO PROPAGATION THEORY

1 – Signals
2 – Wave propagation
3 – Antennas

RADIO TRANSMISSION



Signals to be transmitted are often impossible to transmit directly as radiowaves due to their frequencies. **Modulation** is necessary to transmit the signal on a radio frequency called **carrier**. The information of the modulating signal is impressed onto the carrier. The carrier is modulated.

MODULATION

Modulation: periodic variation of the sinusoidal carrier by the modulating signal to be transmitted.The modulating signal is impressed onto the carrier.

- The process of Modulation is not neutral for the spectrum. The spectrum is **modified**. (a way to represent a signal amplitude of fundamental and harmonics function of frequency)
- The modulation of a carrier frequency generates a spectrum that must be taken into account for the bandwidth of circuits and interference protection.

KINDS OF MODULATION

- **Amplitude Modulation**: the information is impressed onto the carrier wave by **altering the amplitude** of the carrier.
- **Frequency Modulation**: the information is impressed onto the carrier wave by **altering the frequency** of the carrier.
- **Phase Modulation**: a modulation form used by GPS where the phase of the carrier is **reversed**. (Phase fraction of wavelength expressed in degrees)
- **Pulse Modulation**: A modulation form used in radar by transmitting **short pulses** followed by larger interruptions.

SPECTRUM

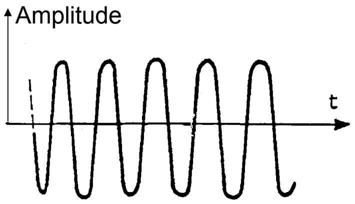
- Any periodic signal may be expressed as the **sum** of sinusoidal signals: **fundamental** signal of frequency f and **harmonic** signals of frequency 2f, 3f, … nf.
- It is then useful to know the **two inseparable representations** of a signal: amplitude as a function of time and amplitude of fundamental and harmonics as a function of their frequencies.
- A signal is capable of being transmitted if the number of its harmonic components is limited because the circuits that are physically executable carry only the frequencies of a certain interval: their bandwith is limited.

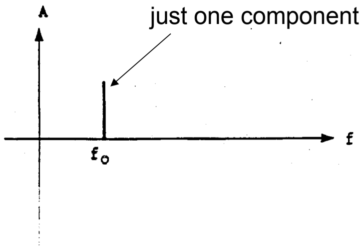
SPECTRUM

- Slow changing signal => narrow spectrum
- Fast changing signal => wide spectrum
- Periodic signal => spectrum of lines spaced 1/T apart
- Modulated signal => the spectrum is translated around the carrier
- Incoherent signal (noise or atmospheric interferences) => broad spectrum

SINE SIGNAL SPECTRUM

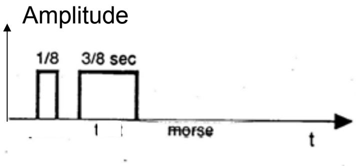
Collection of usual spectrums.

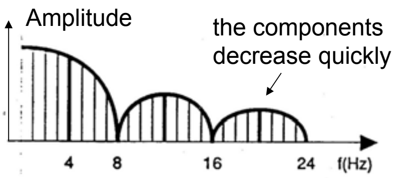




Pure sinusoidal signal. Also **CW** = continuous wave.
The decomposition is obvious, the spectrum is obvious.
A line at the f0 frequency.

MORSE CODE SPECTRUM

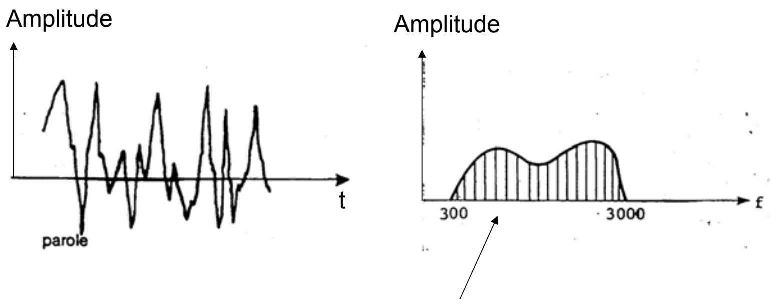




Morse code or **keying**: Interrupting the signal to break it into **dots** and **dashes**. Duration of dot 1/8 s duration of dash 3/8 s.

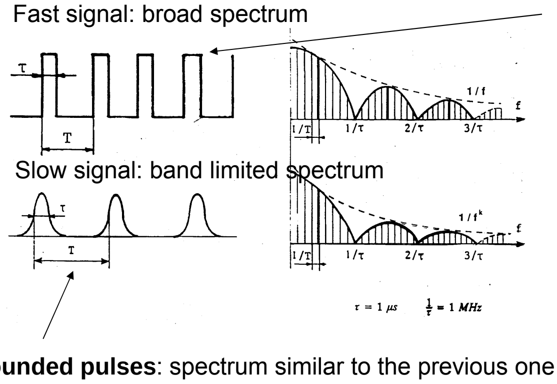
Morse code spectrum: the spectrum is theoritically infinite but the amplitudes decreases with the frequency and the useful spectrum maybe reduced to the lines of frequency lower than 30 hz

SPEECH SIGNAL SPECTRUM



The spectrum is **limited** with the 300hz 3000hz interval.
The line amplitude depends on the speaker and sound transmitted.

PULSE SIGNAL SPECTRUM



Periodic rectangular pulses: spectrum of lines spaced 1/T apart, the spectrum is theoritically infinite but the amplitudes decreases with the frequency and the useful spectrum maybe reduced to the lines of frequency lower than 2/tau.

Rounded pulses: spectrum similar to the previous one but the attenuation according to the frequency is faster.
This spectrum is most favorable in term of useful bandwith.

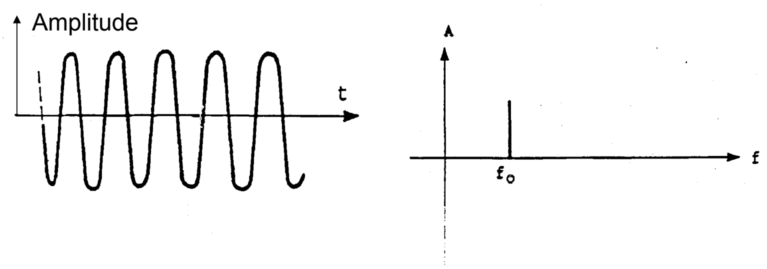
RADIO SIGNALS CLASSIFICATION

A radio signal may be classified by three symbol in accordance with the ITU radio regulation (International Telecommunication Union): Example: **A1A**

- First symbol indicates the type of modulation of the main carrier.
- Second symbol indicates the nature of the signal modulating the main carrier
- Third symbol indicates the nature of the information to be transmitted

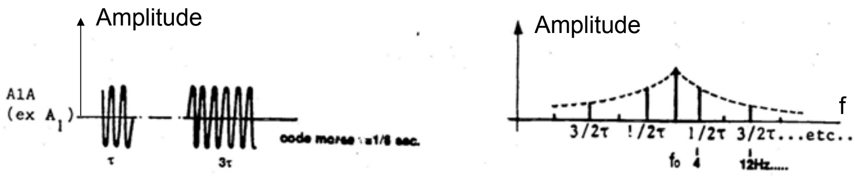
MODULATION NON

Collection of usual spectrums (modulated signals).



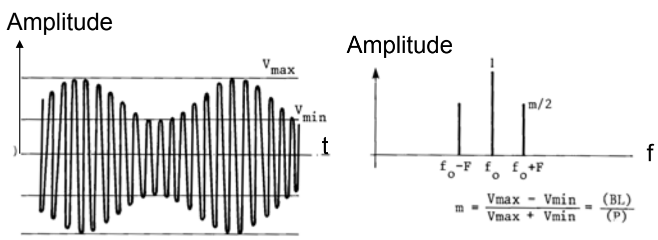
Pure sinusoidal signal. Also CW = continuous wave.
The spectrum is obvious.
None modulation: **NON**.

MODULATION A1A



A1A: Coded process. Signal interruption and restoration (according to the Morse code) (keying).
Interrupting the carrier wave to break it into dots and dashes.

MODULATION A2A



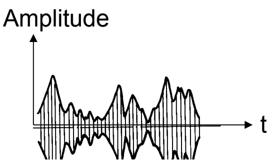
MODULATION **A2A** : **Sinusoidal Amplitude Modulation**.

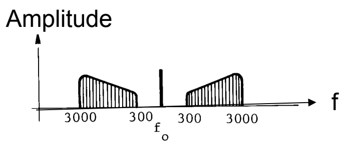
The amplitude of the carrier f0 varies according to a sine form at the rythm of the modulating signal F.

Spectrum: 2 side frequencies f0-F f0+F.

The modulation rate **m** shows how the carrier is dug (depth of modulation).

MODULATION A3E



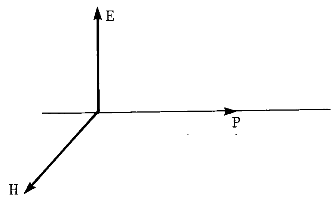


MODULATION **A3E**.

The amplitude of the carrier varies according to a speech signal.

Spectrum: 2 side bands.

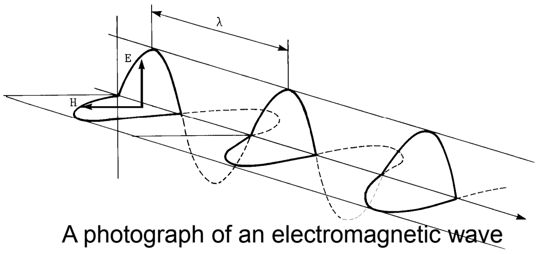
ELECTROMAGNETIC WAVE



ElectroMagnetic field: assembly of two alternating fields **E** and **H**, **perpendicular** to **each** other and **perpendicular** to the **direction** of propagation, vibrating in **phase**.

The theory of electromagnetic wave describes the remote effect of an alternating current flowing in a conductor. At long range this effect propagates at finite speed.It is depicted as the assembly of two fields, the electric and magnetic (E, H) fields and called the electromagnetic field.
E is expressed in **V/m** and **H** is expressed in **A/m**.

EM WAVE



Practical formula:
c = 300m/µs or 162000 Nm/s
(in free space only)
Practical formula:
lambda = 300/f
with lambda expressed in **km** and f expressed in **KHz** or lambda expressed in **m** and f expressed in **Mhz**.

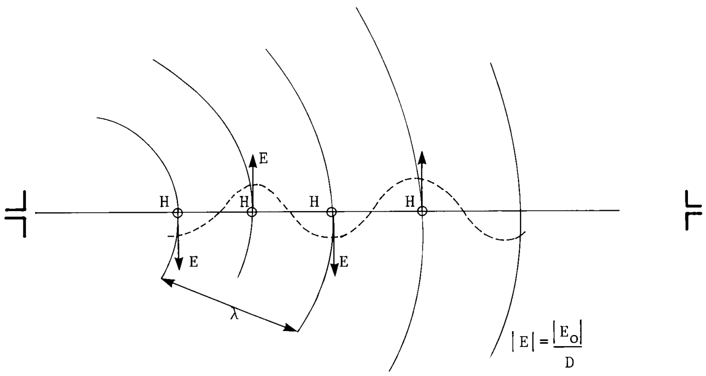
A photograph of an electromagnetic wave

1 - At a **given time** amplitudes are a sinusoidal function of distance with a period called **wavelength**. The wavelength is the distance travelled during a period of sinusoidal variation of the field.

The amplitude distribution follows the direction perpendicular to E and H, at the speed of light C.

2 - At a **given point** amplitude is a sinusoidal function of time.

PROPAGATION



SPACE ATTENUATION

As the transmitted power is distributed over wave surfaces that increase as the square of the distance, the power density decreases as 1/d*d and then the amplitude decreases as 1/d. (free space). It is called the **space attenuation**.

A highly variable attenuation may be added to this compulsory attenuation according to the properties of the environment.

POLARISATION

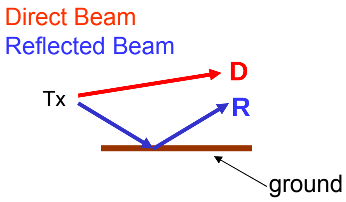
- The polarisation of EM wave describes the orientation of the plane of oscillation of the electrical component of the wave with regard to its direction of propagation.

- In free space the direction of fields E and H is fixed: fields propagate parallel to themselves in two perpenpendicular planes (rectilinear polarisation)

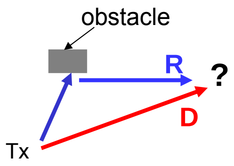
PHENOMENA RELATED TO PROPAGATION

1. Interference
2. Reflection
3. Diffusion
4. Refraction
5. Diffraction

INTERFERENCE



Useful for Elevation patterns and for directive transmissions from a group of antennas.

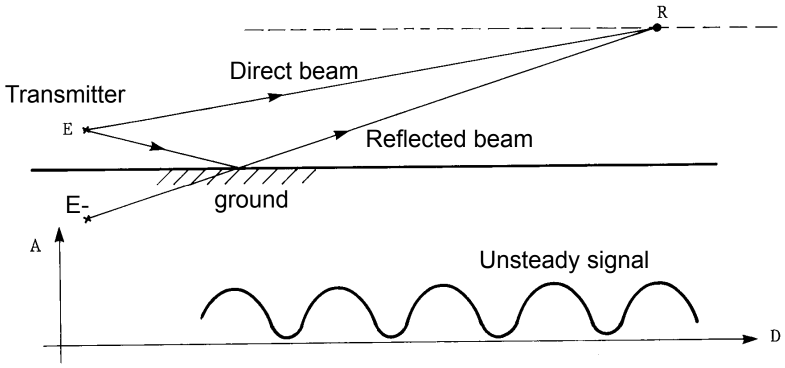


Very annoying -**Multipaths**.

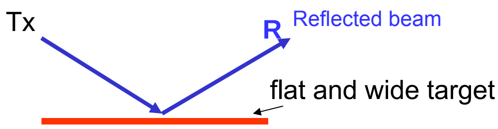
INTERFERENCE: Composition of 2 coherent fields (of same frequency and fixed relative phase). The direction of the resulting field may be variable over time.

MULTI PATHS

Composition of 2 coherent fields.



REFLECTION

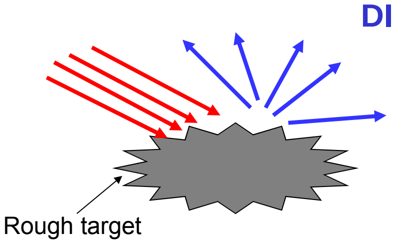


Wide target (span is high in comparison to the wavelength) **AND Flat** target (roughness is low in comparison to the wavelength)

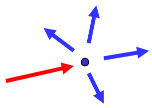
REFLECTION: At the boundary between two media with different dielectric constants, there is occurrence of a refracted beam and a reflected beam in compliance with laws similar to the laws of optics. However polarisation must be taken in account.

Over a flat obstacle of large dimension with regard to lambda: coherent reflection.

DIFFUSION



The roughness of the **target** is high regarding the wave length.



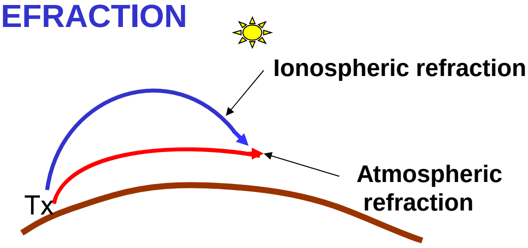
Hydrometeors: rain, hail, snow. (**Airborne Weather RADAR**)

Aircraft (**Primary RADAR**)

DIFFUSION: Over a rough obstacle (at the scale of lambda) DIFFUSION occurs: incoherent reflections to all the direction. (principle of radar).

REFRACTION

REFRACTION occurs when the radio path is bent.

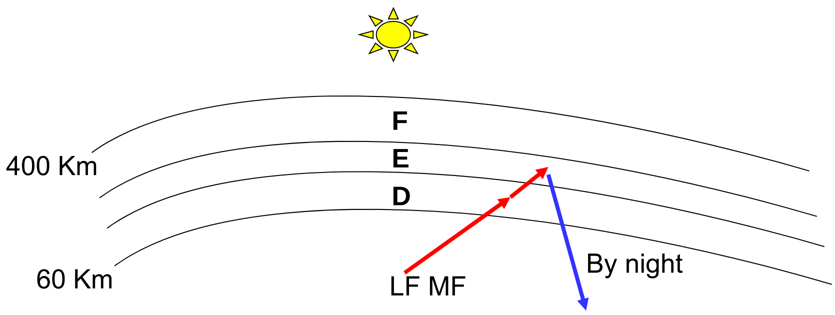


1 -The **Ionosphere** is the component of the earth's upper atmosphere from 60 to 400 km above the surface.

Under sun radiations the upper layers of the atmosphere are ionised and refracts some frequencies: propagation occurs between two points that may be beyond line of sight by total refraction at a height ranging from 60 to 400 Km. This ionospheric wave is called **SKY WAVE**.(f < 30 Mhz)

2 -There's also a refraction in the lower layer of the atmosphere.

IONOSPHERE



The **Ionosphere** is the component of the earth's upper atmosphere from 60 to 400 km above the surface.The layers are named **D,E,F** and their depth varies with time. Under sun radiations these upper layers of the atmosphere are ionised and refracts some frequencies

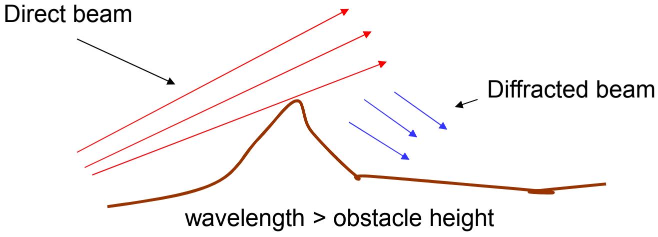
STRUCTURE OF IONOSPHERE

The IONOSPHERE is the ionized component of the Earth's upper atmosphere from 60 to 400 km above the surface.

The layers in the IONOSPHERE are named D, E and F layers and their depth varies with time.

Electromagnetic waves refracted from the E and F layers of the IONOSPHERE are called SKY waves.

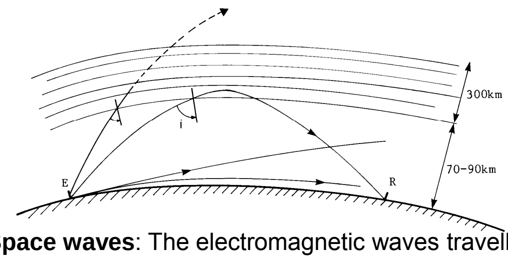
DIFFRACTION



DIFFRACTION: Any point of a wavefront is the source of a spherical wave (Huyghen's principle).

The wave by-pass opaque obstacle: attenuation is high but it leaves however an exploitable field (**GROUND WAVE**) if the frequency is lower than 3 Mhz.

PROPAGATION PATHS



Space waves: The electromagnetic waves travelling through the air directly from the transmitter to the receiver.

Ground or **Surface Waves**: The electromagnetic waves travelling along the surface of the earth.

Sky waves: The electromagnetic waves refracted from the D and E layers of the ionosphere.

SPACE WAVE

Direct wave between two point within radio line-of-sight characterized in the atmosphere by:

- Great field stability
- Fixed polarisation
- Reduced attenuation (close to 1/D)

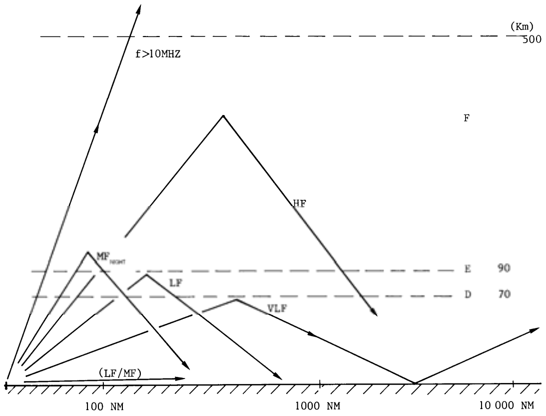
The radio line-of-sight is slighty greater than the optical visibility due to the atmospheric refraction. Above a spherical earth it is related to the altitude of the transmitting and receiving antennas.

SKY WAVE

Under sun radiations the upper layers of the atmosphere are ionised and refracts some frequencies: propagation accurs between two points that may be beyond line of sight by total refraction at a height ranging from 60 to 400 Km. This ionospheric wave is called Sky wave.(f < 30 Mhz).

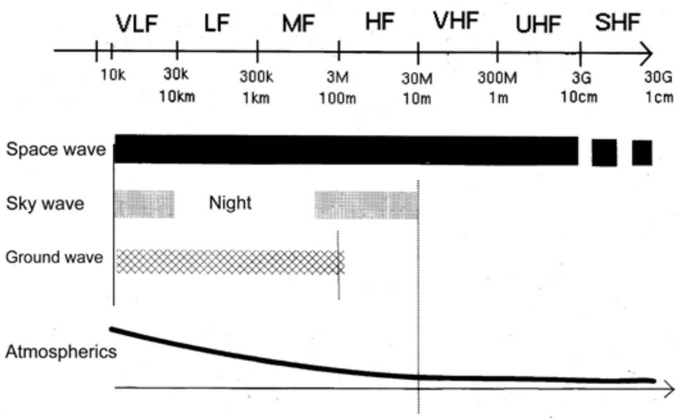
The equivalent reflection depends on frequency (easier at the lower freqencies impossible above 30 Mhz), ionisation (hour, day, season, latitude) and angle of incidence (impossible if the angle is too small hence there is a skip zone (zone of silence) for the sky wave around the transmitter.

SKY AND GROUND WAVES



PROPAG-33

PROPAGATION TABLE



PROPAG-34

RADIO NOISE

We call radio noises the spurious signals, generally with broad spectrum, that superimpose to any useful signal received.
The noise is coming from:

- Internal noise coming from thermal agitation
- External noise coming from atmospheric electrical discharges
- Electrical noises onboard the aircraft
- Jammers

The **SNR** signal noise ratio determines the efficiency of a radio link.

ATMOSPHERIC NOISE

The atmospheric interferences prevail at low frequencies and they are broad spectrum noises.

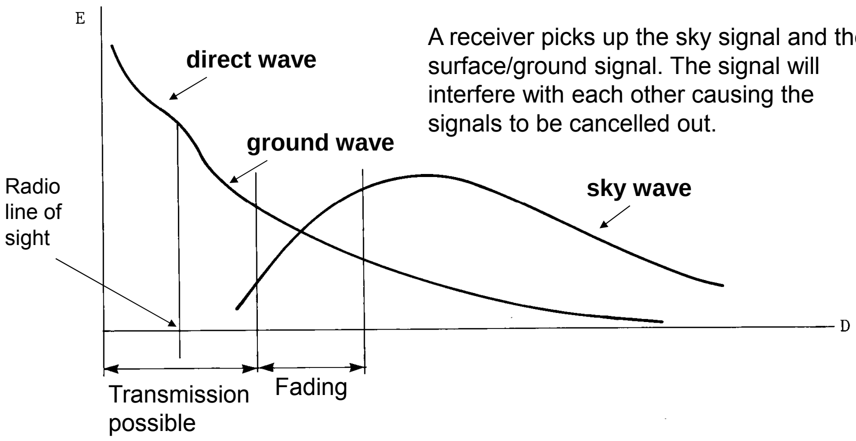
The noise power is almost negligible above 30 MHz, stronger at night than during the day (due to ionospheric propagation), stronger in equatorial area than in temperate area.

FACTORS AFFECTING PROPAGATION

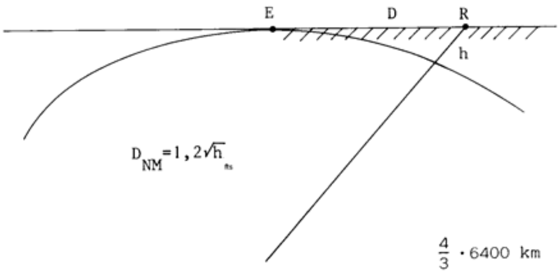
- Skip Distance: the distance between the transmitter and the point on the surface of the earth where the first sky return arrives.
- Skip Zone / Dead Space: the distance between the limit of the surface wave and the sky wave.
- Fading: Interference sky wave and ground wave.

FADING

A receiver picks up the sky signal and the surface/ground signal. The signal will interfere with each other causing the signals to be cancelled out.



RANGE OF DIRECT WAVE



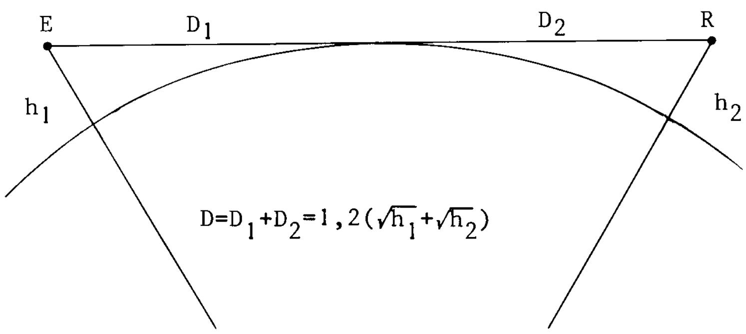
The radio line of sight (range of direct wave) is slightly **greater** than the optical visibility due to the atmospheric refraction.

Above a spherical earth it is related to the the altitude of the transmitting and receiving antennas.

The propagation is not straight (atmospheric refraction).
Slight curvature.

Practical formula:
D = 1.23 * sqrt(h)
D expressed in Nm and h expressed in feet

RANGE OF DIRECT WAVE



RANGE OF DIRECT WAVE

The radio line of sight (range of direct wave) is slightly **greater** than the optical visibility due to the atmospheric refraction.

Exemple1: Transmitter placed at the top of Eiffel tower.

D = 1.23 * √ (1000)
D = 39 Nm

Exemple 2: Airliner. FL 330 long-haul aircraft , FL 290 Paris Toulouse.
FL 400 executive jet.

D = 1.23 * √ (40000)
D = 240 Nm

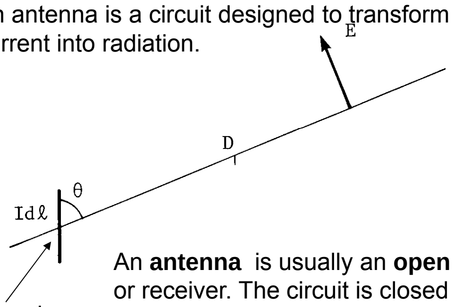
Exemple 3: VOR located at 2500 ft and aircraft flying at 10000 Ft.

D = 1.23 * √ (2500) + 1.23 * √ (10000)
D = 184 Nm

RADIO NAVIGATION

RADIATION OF AN ELEMENT OF CURRENT

An antenna is a circuit designed to transform electrical energy of a high freq current into radiation.



$$|E| = k \frac{I d\ell \sin\theta}{\lambda D}$$

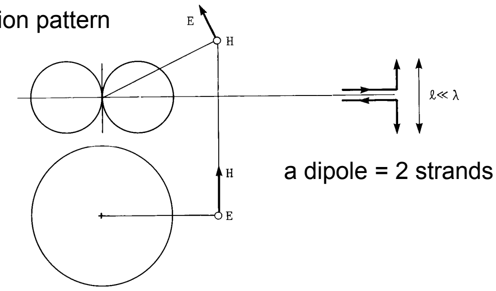
$$\left|\frac{E}{E_o}\right| = k' |\sin\theta|$$

A strand (an element of current, a tiny copper wire)

An **antenna** is usually an **open circuit** connected to a transmitter or receiver. The circuit is closed by the EW.
The circuit has finite dimensions and the field radiated to space is the combination of elementary fields coming from the different sections of the circuit where the amplitude of the alternating current is known.
As a result the radiation of actual antennas is never isotropic.

RADIATION PATTERN OF A DIPOLE

ELevation pattern

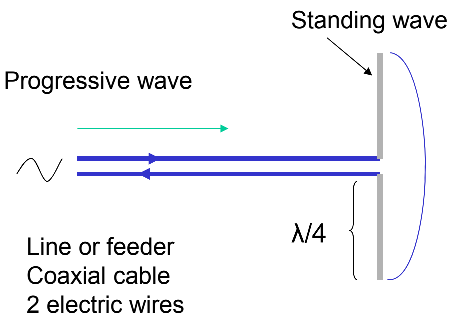


AZimuth pattern

Dipole of length very low compared to lambda. The radiation pattern is a torus of revolution whose axis is the dipole. Its cross-section is bicircular and describes the field amplitudes at a given distance.

Radiation pattern : the amplitude distribution of the E Field is plotted versus the direction. Electric modulus as a function of the direction.
The pattern is considered in vertical plane (**EL** pattern) and in the horizontal plane (**AZ** pattern), plotted in polar coordinates.

HALF WAVE DIPOLE ANTENNA

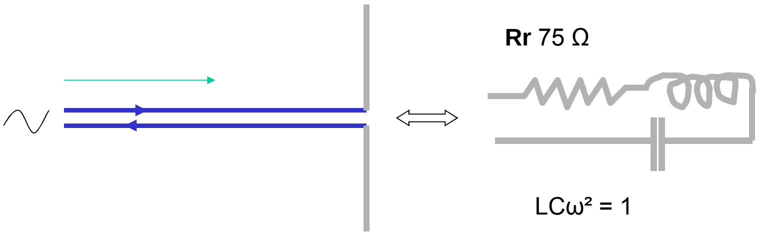


Tuned antenna:
It is intesting to generate in the antenna a state of standing current waves to **increase** the radiation.

The antenna is the tuned and its yield is maximal.

An half wave dipole antenna consists of two quater wavelength radiators.
The current and the voltage are 90° out of phase.

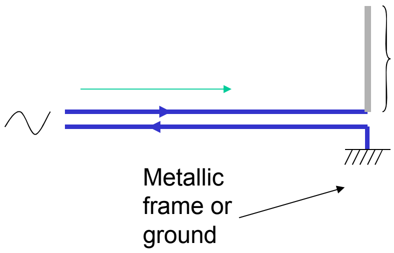
RADIATION RESISTANCE



A tuned antenna is equivalent to a RLC circuit, resistor coil and capacitor.
The radiated energy seems to be dissipated in a virtual resistance called radiation resistance Rr.

RADIO NAVIGATION

MONOPOLE ANTENNA

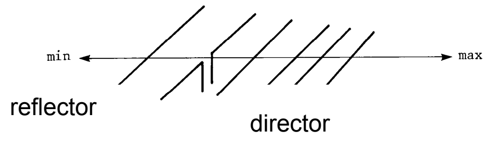


With a metallic frame or ground it is possible to remove the lower strand. **Monopole** antenna (quater wave antenna).

ANTENNA WITH WIRE REFLECTOR

An insulated wire acts as reflector and increase directivity.

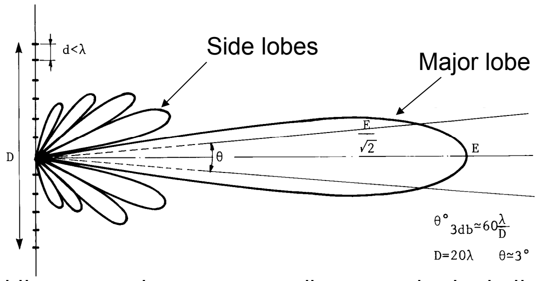
Insulated wire in the vicinity of a radiation wire, excited by coupling and its radiation is combined with dipole.



YAGI Antenna.

ALIGNED ANTENNAS ARRAY

Aligned antennas **array**. It is constituted of antennas arranged along a line and powered by defined amplitudes and phases so as to create patterns with strong **directivity**.



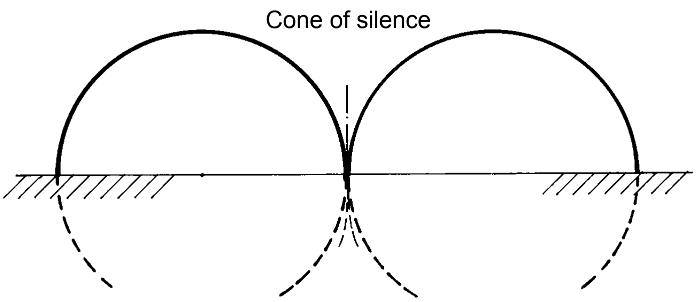
The direction of the maximal gain is generally perpendicular to the array.
The gain decreases quickly with azimuth, the pattern presents a **major lobe**.
Relative maxima are obtained by less favourable recombination of the fields **side lobes.**

KINDS OF DIRECTIONAL ANTENNAS

It is also possible to make a directional antennas whitout an array. It depends on frequency.

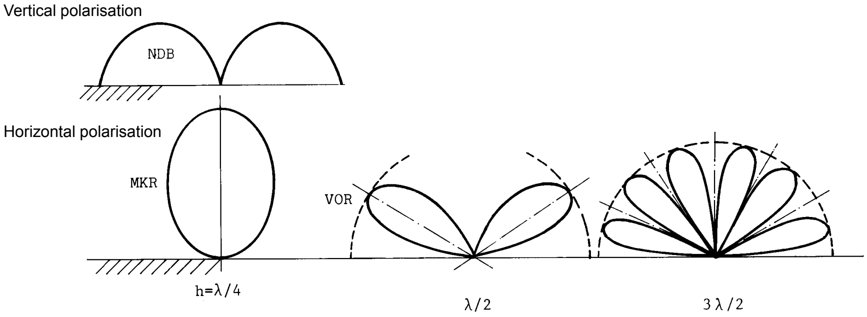
- Loop antenna used in ADF receivers
- Parabolic Antenna used in primary radars and weather radars (solid reflector)
- Slotted planar array used in modern weather radars
- Helical antenna used in GPS transmitters (shape of helix, it radiates circulary polarized radio wave)

MONOPOLE WITH GROUND



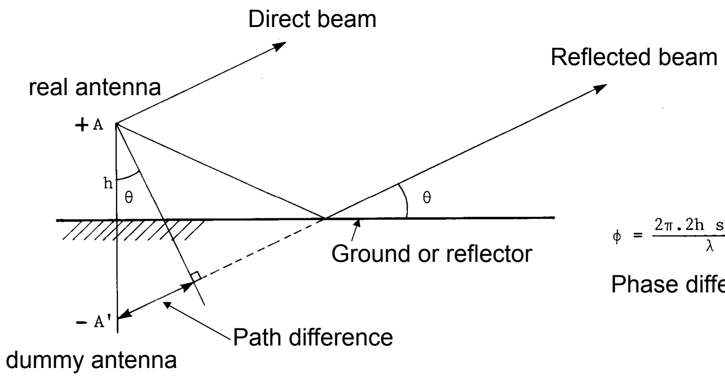
The radiation pattern is **half** a **torus** of revolution whose axis is the monopole antenna. Its cross-section is **semi bicircular** and describes the field amplitudes at a given distance.

RADIATION PATTERN WITH GROUND



Raising the antenna above the ground generates the **foliation** of **EL**evation patterns. This effect is exploited in radionavigation to obtain patterns that favour low elevation angles: reduced radiation with regard to obstacles. Many lobes in the pattern.

ANTENNA AND REFLECTOR



$$\phi = \frac{2\pi . 2h \sin \theta}{\lambda}$$

Phase difference

NAVAIDS

1 – NDB/L

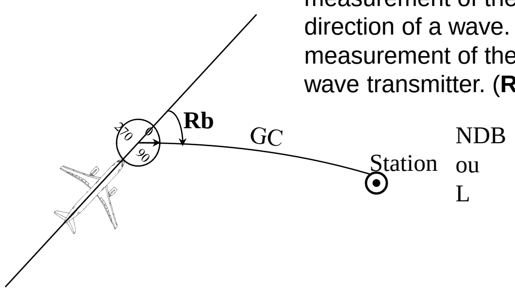
2 – VOR

3 – DME

DIRECTION FINDING

Goniometry: angle measurement

Direction finding is the radio measurement of the propagation direction of a wave. Actually, it is the measurement of the azimuth of the wave transmitter. (**Rb**)

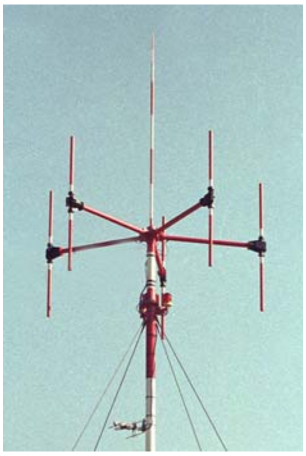


AERONAUTICAL GONIOMETRY

2 type of goniometry:

1 - **Ground** direction finding of aircraft transmitting VHF signals usings **VDF**s (VHF Direction Finder). The measurement read by the TWR operator is transmitted to the pilot in VHF.
2 - On **board** direction finding of MF radio beacons using the airborne **ADF** (Automatic Direction Finder) (obsolete ?).

VDF



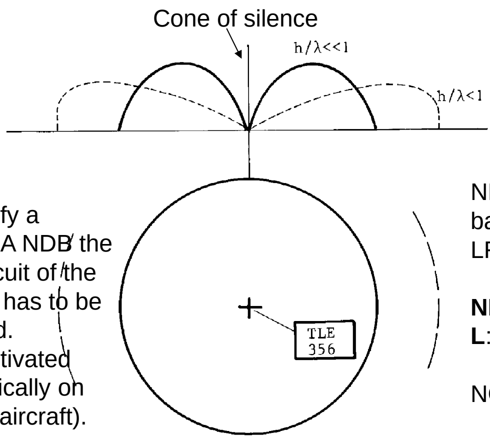
82 vdf in France
Reduction 50%

VDF

According to ICAO Annex 10:

- Class A . Accurate to within +/- 2°
- Class B: Accurate to within +/- 5°
- Class C: Accurate to within +/- 10°
- Class D: Accurate to less than class C

NDB RADIATION PATTERN



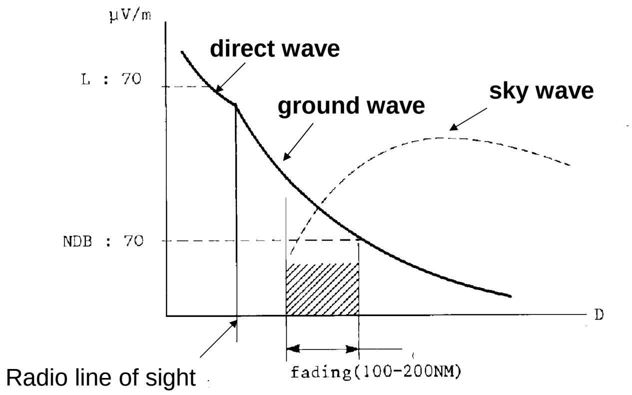
To identify a NON/A1A NDB the BFO circuit of the receiver has to be activated.
(BFO activated automatically on modern aircraft).

NDB/L operates in LF and MF band in vertical polarisation.
LF MF: 190 – 1750 Khz

NDB: 100W/1kW **>100Nm**
L: 10W/100W **10/25 NM**

NON/A1A or NON/A2A

NDB COVERAGE RANGE



NIGHT EFFECT

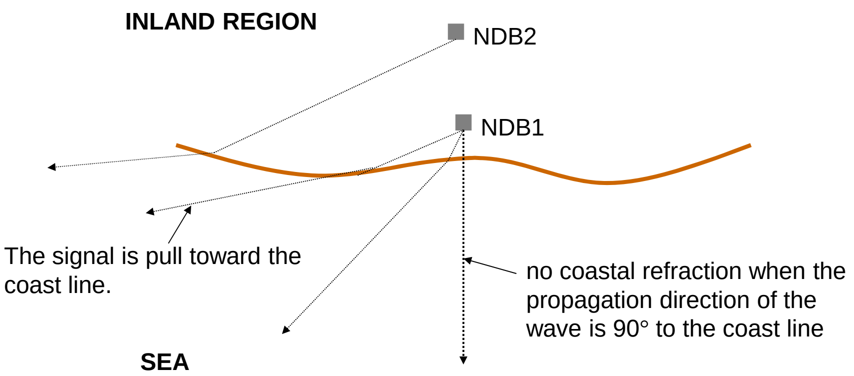
- By day, D region absorbs LF MF signal
- At night D region disappears allowing sky wave
- Interference between sky wave and ground wave (FADING) at 70/100 Nm

COASTAL REFRACTION

- Radio waves speed up over water and it induces refraction .
- The propagation path is pull towards the coast
- Refraction negligible at 90° to the coast

There is no coastal refraction when the propagation direction of the wave Is 90° to the coast line or when the NDB is sited on the coast line. Coastal refraction error increases with increased incidence.

COASTAL REFRACTION



RADIO NAVIGATION

NDB/L

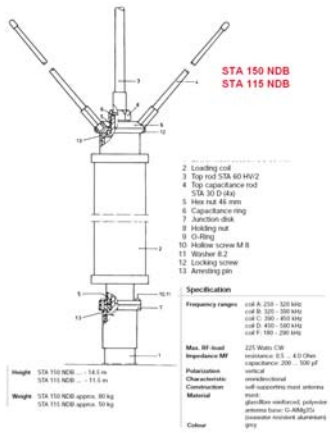
Daisy antenna with capacitive hat to increase yield.

166 NDB/L in France.
Reduction 50%.

NAVAIDS-11

RADIO NAVIGATION

NDB/L

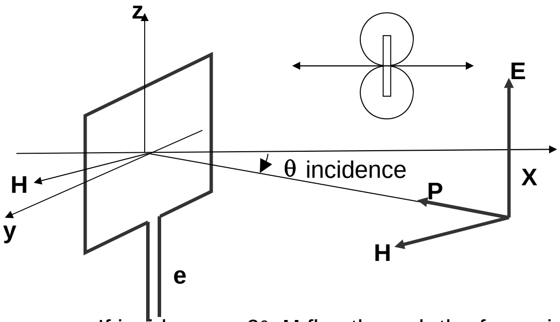


NAVAIDS-12

NDB/L

FRAME ANTENNA

Frame Antenna: It is constitued of a solenoid coiling of horizontal axis.
The design of this antenna is based on the voltage induced by the component H of the EM field polarized vertically and which propagates horizontally.



In the horizontal plane the reception pattern is a **double circle** with 2 fading directions along the frame axis. The old slaved rotating frame was replaced
by a set of **two fixed frames** at right angle.
Measurement is ambiguous. We need a **reference** antenna.

If incidence = 0° **H** flux through the frame is 0.
If incidence = 90° **H** flux through the frame is max.

RBI Relative Bearing Indicator

Relative Bearing Indicator
Only used in light aircraft.
The rotation angle of the diametral needle is equal to the relative bearing.
The needles indicates direction to the beacon.

1- **Fixed Card**

2- **Movable Card**.
In the case of Movable Card:
manually rotation of the card with the HDG knob and the head of needle indicates QDM.
Bearing = Heading + relative Bearing.

RMI Radio Magnetic Indicator

Radio Magnetic Indicator

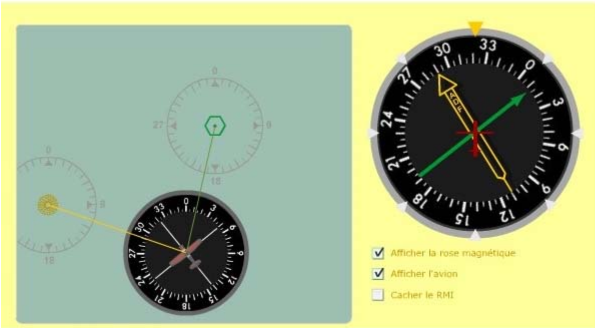
It 's a compass card which indicates the aircraft 's compass heading with needles which indicate direction to the beacon.

The **head** of needle indicates **QDM**.
The **tail** of the needle indicates **QDM+/- 180**°.

The compass card is enslaved to the aircraft's heading.

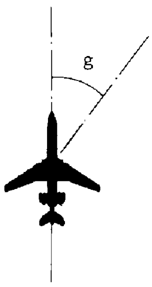
Bearing = Heading + relative Bearing
BRG = HDG +BRGr
MB = MH + RB

RMI Radio Magnetic Indicator

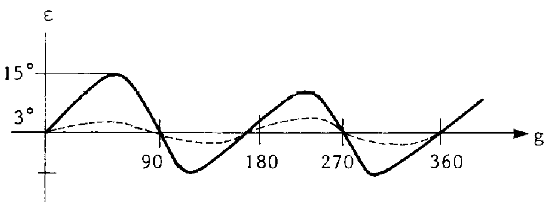


RMI ANIMATION.

QUADRANTAL ERROR



Distorsion of the incoming signal from the NDB by **reradiation** from the airplane. This is corrected during installation of the antenna.



ERRORS

- The accuracy of the NDB/ADF chain is +/- 5 degrees within the designated operational coverage BY DAY ONLY. (SNR > 3)
- Error incresase: Thunderstorms, Night, Coastal refraction, Station interference at night from other NDB stations on the same frequency may occurs at night due to sky wave contamination.

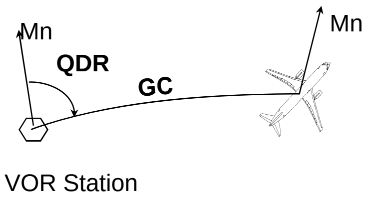
CONCLUSION

- Advantages: Simple infrastructure. Low implementation constraints. reduced cost. Long range by day even at very low altitude.
- Disadvantages: range depends on weather conditions. maximum range limited by night. Severe errors with sky waves.

SUMMARY

- Ground transmitter in LF or MF band (190 Khz 175O KHZ)
- NDB 100w/1KW > 100 Nm
- LOCATOR 10W/100W 10/25 NM
- 2 types of emission: NON/A1A or NON/A2A
- BFO required for NON/A1A modulation
- RMI or RBI
- Accuracy +/- 5 degrees

VOR INTRODUCTION



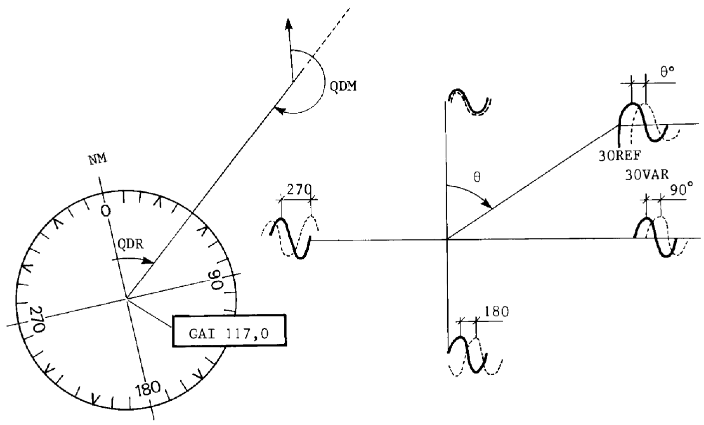
VHF

QDR

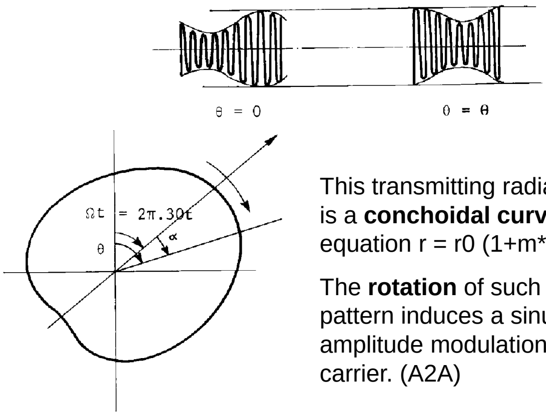
VOR RADIO PRINCIPLE

- Vor radiates a VHF carrier modulated by 2 low frequency signals at 30 Hz:
- A reference signal (30REF) whose phase is identical whatever the azimuth of the transmision
- A variable signal (30VAR) whose phase-shift is proportional to azimuth

VOR RADIO PRINCIPLE



30 VAR

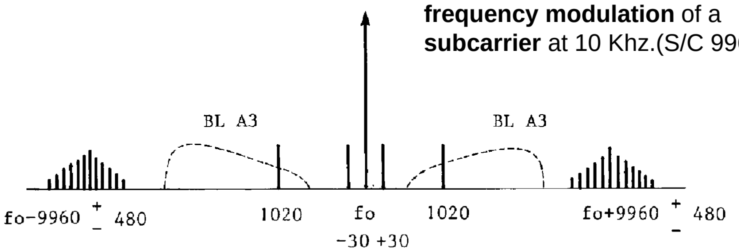


This transmitting radiation pattern is a **conchoidal curve** of polar equation r = r0 (1+m*cos(a))

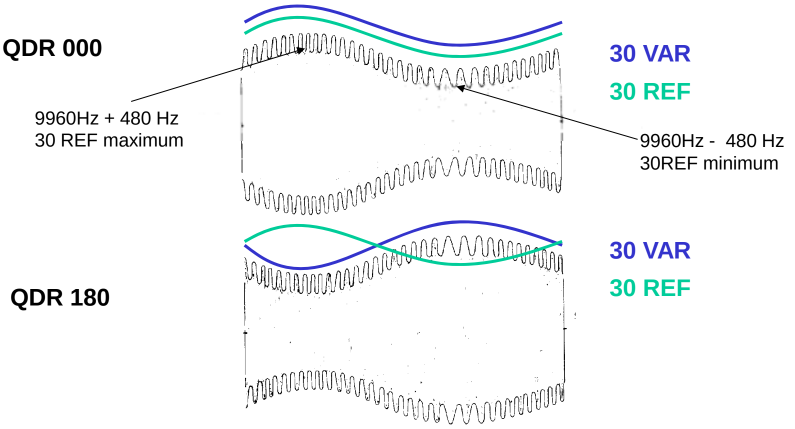
The **rotation** of such a radiation pattern induces a sinusoidal amplitude modulation of the carrier. (A2A)

30 REF

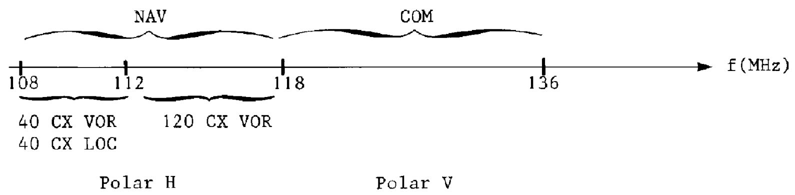
Transmitting the 3O REF: By **frequency modulation** of a **subcarrier** at 10 Khz.(S/C 9960Hz)



VOR SIGNALS



VHF NAV



2 x 40 channels within 108-112 Mhz and 120 channels within 112-117.95 Mhz

If first decimal place is an odd number→ LOC
If first decimal place is an even number→ VOR

40 cx VOR 108.0 108.05 108.20 108.25 108.40 108.45 → 111.85 MHz
40 cx LOC 108.1 108.15 108.30 108.35 108.50 108.55→ 111.95 MHz
120 cx VOR 112.0 112.05 112.1 112.15 → 117.95 MHz

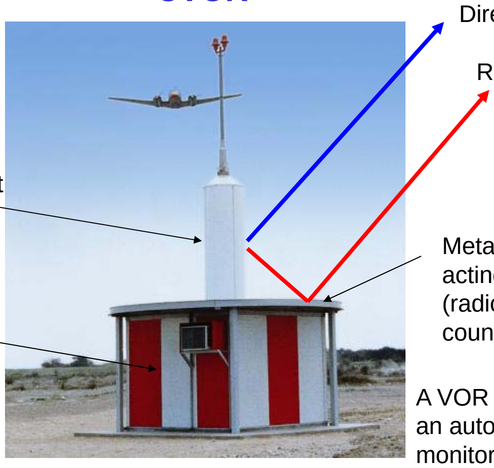
CVOR

Conventional VOR
First generation of VOR.

Antenna at the center of the roof protected against climatic variations by a radome.

VOR shelter

87 VOR in France.
Reduction 50%.



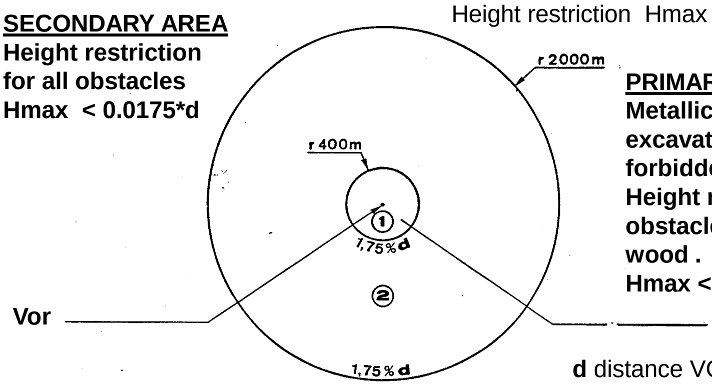
Metallic circular roof acting as a reflector. (radioelectric counterweight)

A VOR station has an automatic ground monitoring system

GROUND FACILITY IMPLEMENTATION CONSTRAINTS

SECONDARY AREA
Height restriction for all obstacles
Hmax < 0.0175*d

Height restriction Hmax < 0.0175 * d



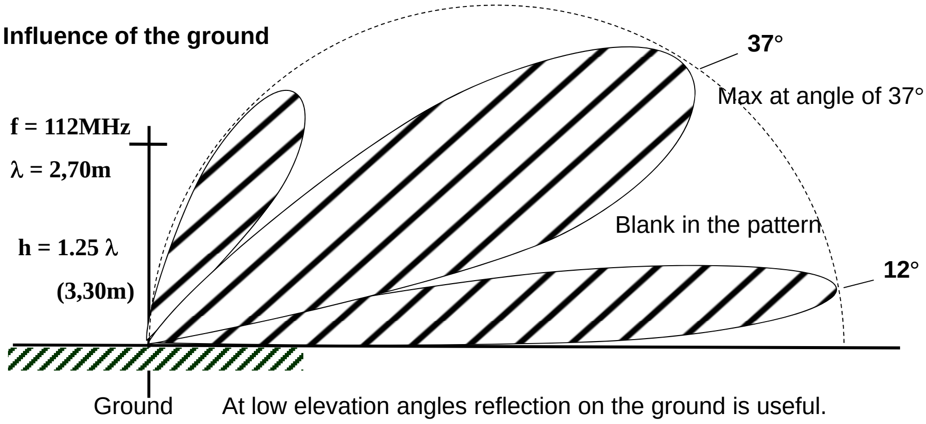
PRIMARY AREA
Metallic obstacles and excavations are forbidden.
Height restriction for obstacles made of wood .
Hmax < 0.0175*d

d distance VOR obstacle.

The implementation constraint of the VOR are critical.

RADIO NAVIGATION

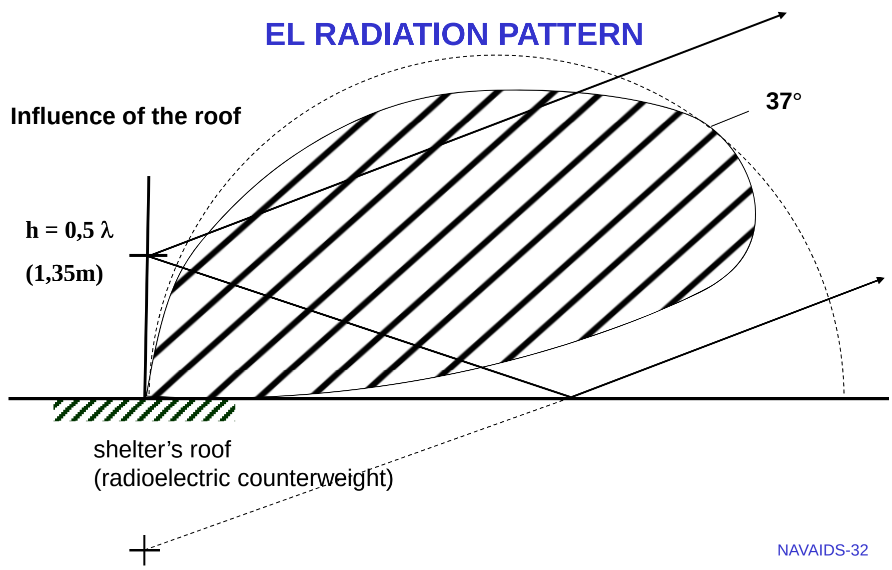
EL RADIATION PATTERN



NAVAIDS-31

RADIO NAVIGATION

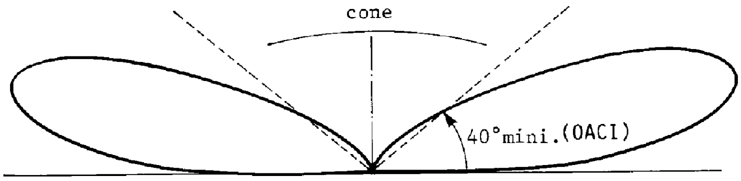
EL RADIATION PATTERN



NAVAIDS-32

CONE OF AMBIGUITY

Cone of silence. The OFF flag may appear momentaly.
Vor provides signals up to a minimal elevation angle of 40°.



tg(40°)= H/R=0.8 => R=1.2*H
=> R(Nm) = 0.2*H (1000 Fts)

DVOR

- Second generation of VOR **Doppler VOR**.
- **DVOR** is more robust and accurate than CVOR. **DVOR** is less sensitive to site error than CVOR. It overcomes siting error.
- DVOR: 30 VAR and 30 REF are inverted.The REF signal is an AM signal. The Variable Phase signal is frequency modulated.
- 48 antennas on a circle, pseudo-rotation : one antenna activated alternately.
- Pseudo-rotation induces a doppler modulation of the carrier.
- The same airborne equipment can be used with CVOR or DVOR.

DVOR

VOR BOARD INDICATORS

2 chains of measurement :

• **Automatic** chain (no pilot action, continuous display)
→ **RMI** Radio Magnetic Indicator

• **Manual** chain (the pilot chooses a reference radial)

→ **CDI** Course Deviation Indicator
→ **HSI** Horizontal Situation Indicator

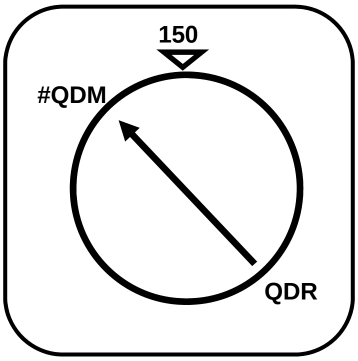
RMI

RMI has a remote reading compass repeater which indicates the aircraft's Magnetic heading.

A pointer indicates on the compass card the aircraft's QDM to the beacon.

The tail end of the needle indicates the QDR.

The arrow head of the needle shows the #QDM.



RMI

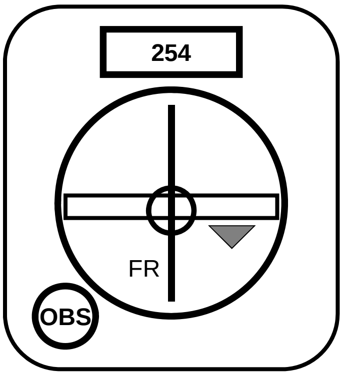
- It 's a compass card which indicates the aircraft 's compass heading with needles whish indicate direction to the beacon

CDI

Zero centered galvanometer
(L/R deviation bar) with:
• radial selector
(OBS Omni Bearing Selector)
• TO/FROM binary indicator

Omni Bearing Selector 254
FROM

Deviation scale +/- 10°



CDI

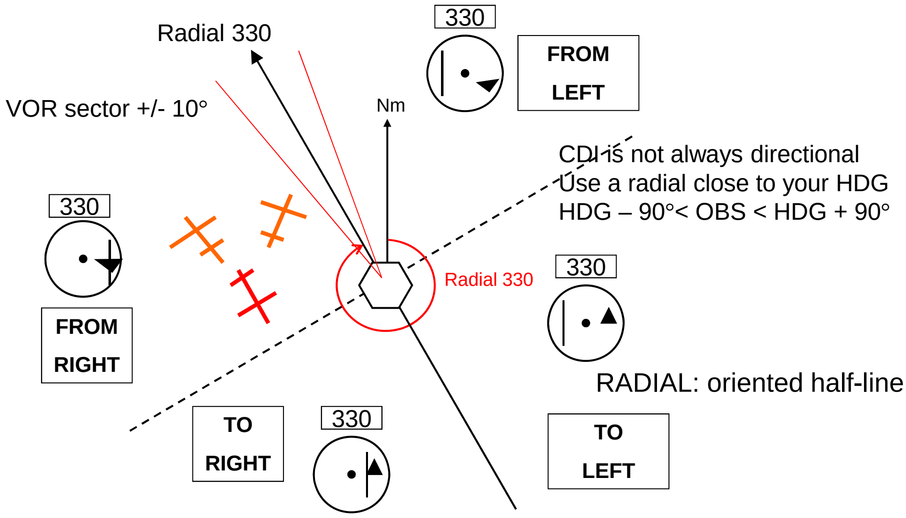
Zero centered galvanometer
(L/R deviation bar) with:
• radial selector
(OBS Omni Bearing Selector)
• TO/FROM binary indicator

2 possible uses:
• measuring an azimuth by centering the deviation bar
• measuring a deviation according to a choosen radial.

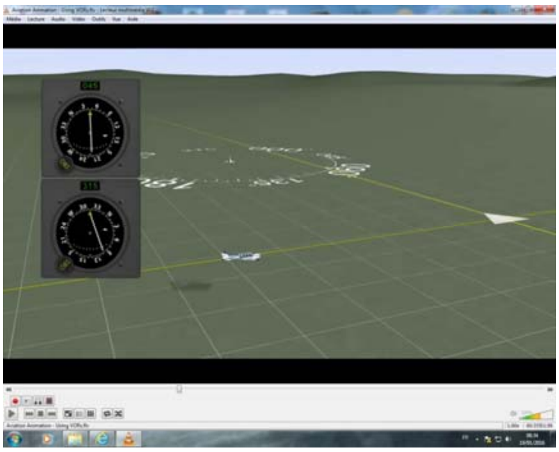
Deviation scale +/- 10°

The heading of the aircraft does not affect the display.
CDI is not always directional.
CDI is widely used in light aircraft only.

Omni Bearing Selector 254
FROM



CDI



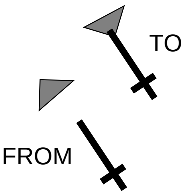
CDI VOR ANIMATION.

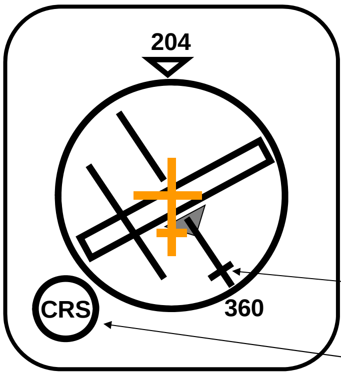
HSI

L/R deviation bar, To/From indicator and CRS selector.

HSI is a CDI « inside » a compass card.

The internal CDI rotates when selecting a radial with the CRS (Course)





Le HSI VOR is always directional.

HDG 204
CRS 360
Sector TO
RIGHT

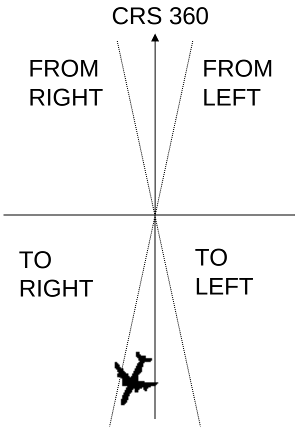
crs pointer

CRS selector

HSI

HSI VOR ANIMATION.

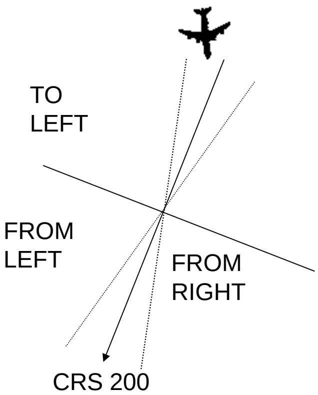
HSI BENDIX KING



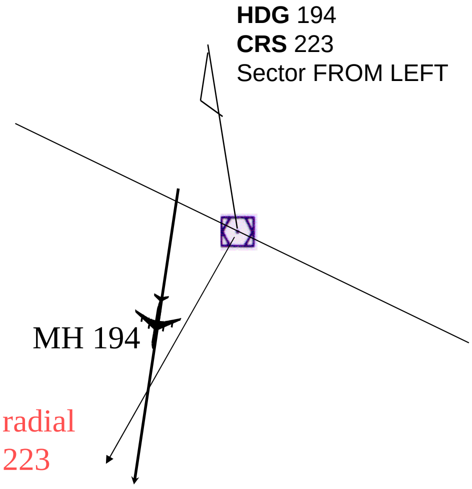
HDG 204
CRS 360
Sector TO RIGHT

HSI

HDG 175 **CRS** 200
Sector TO LEFT



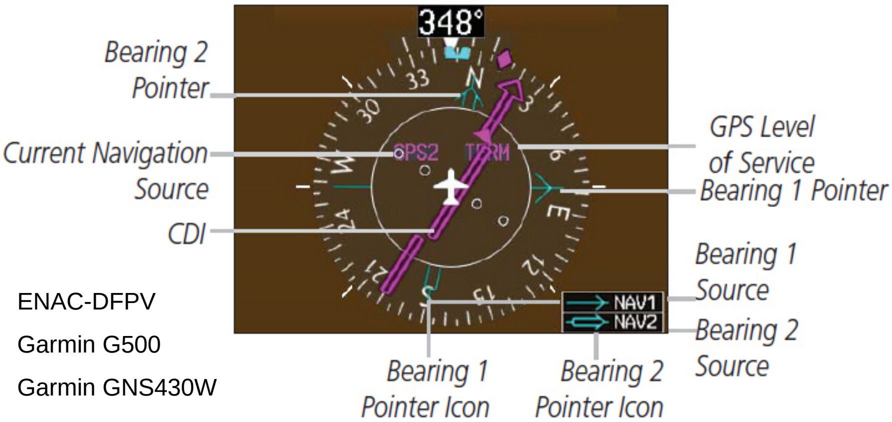
VOR HSI



A319/A320/A321 EIS - ND : ROSE / VOR mode

STL 945.7136/97 12.7

GARMIN G500



ENAC-DFPV

Garmin G500

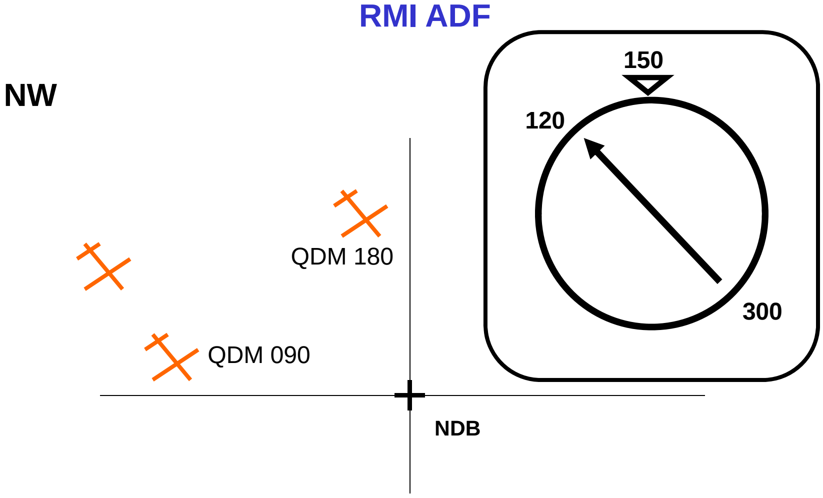
Garmin GNS430W

MCQ RMI

- An aircraft is located on the NW of a NDB station. What is the RMI indicator?

- A >> MH 150, needle 060
- B >> MH 150, needle 330
- C >> MH 150, needle 240
- D >> MH 150, needle 120

RMI ADF

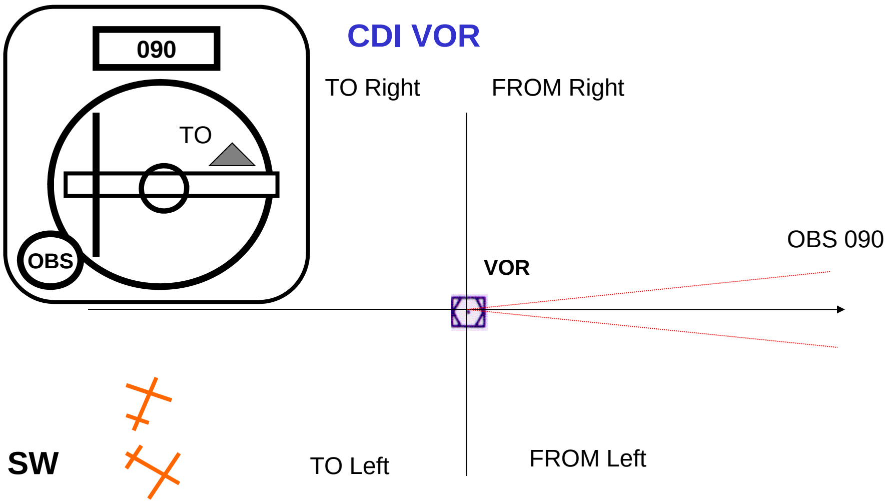


MCQ CDI

- An aircraft is located on the SW of a VOR station. What is the CDI indicator ?

- A >> OBS 090, FROM, Right Deviation
- B >> OBS 090, FROM, Left Deviation
- C >> OBS 090, TO, Right Deviation
- D >> OBS 090, TO, Left Deviation

CDI VOR

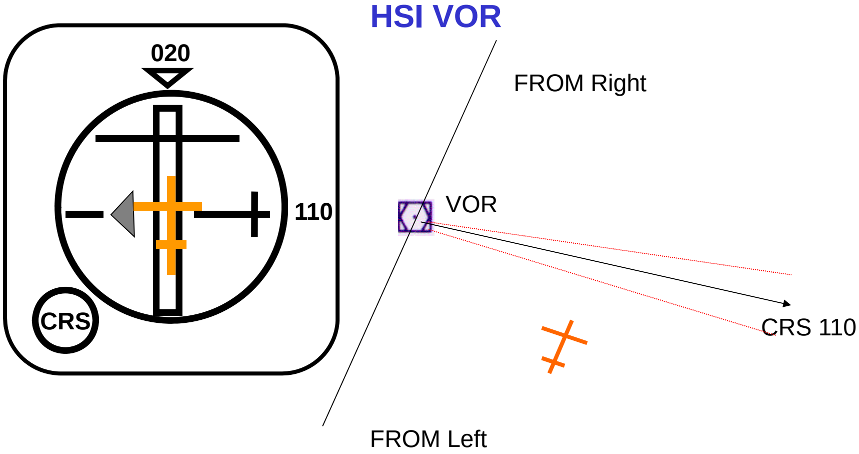


MCQ HSI

An aircraft is on the SE of a VOR station.What is the HSI indicator (MH 020):

- A >> CRS 110, deviation bar up, TF indicator and CRS pointer opposed
- B >> CRS 290, deviation bar up, TF indicator and CRS pointer opposed
- C >> CRS 110, deviation bar down, TF indicator and CRS pointer opposed
- D >> CRS 110, deviation bar down, TF indicator and CRS pointer same side

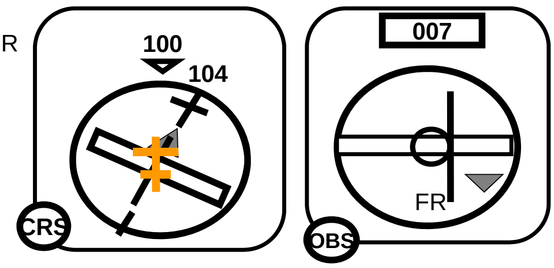
HSI VOR



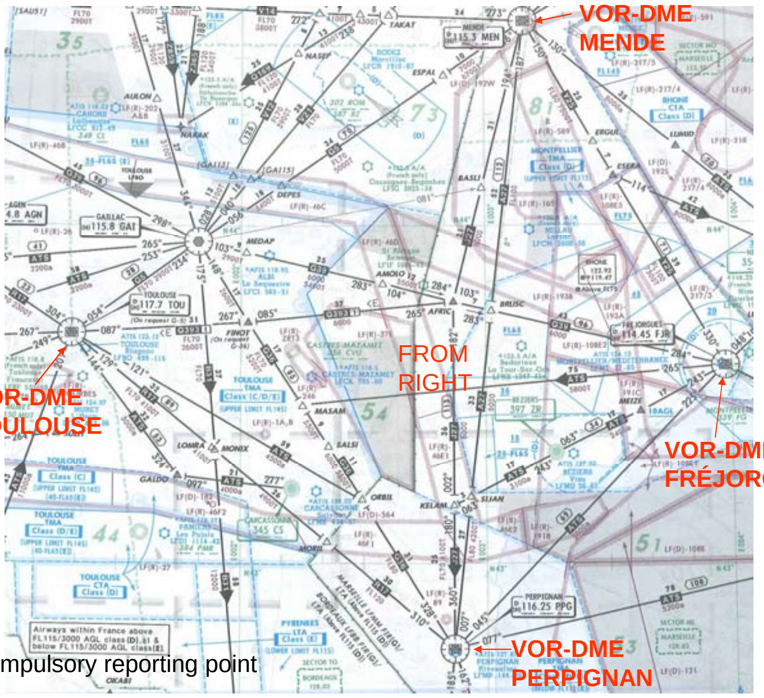
CLASSICAL INSTRUMENTATION - SITUATION

An aircraft makes the trip **Toulouse** – **AFRIC** – **BRUSC** – **Montpellier** (see map) .
It has an **ADF** receiver and 2 **VOR** receivers (1 et 2).
VOR1 is operated on **HSI** and **RMI** (single needle).
VOR2 is operated on **CDI** and **RMI** (double needle).
The pilot has selected frequency 114.45 (**FJR**) on VOR1 and frequency 116.25 (**PPG**) on VOR2 :

HSI VOR1 FJR
Radial 104
TO
Deviation 0°
HDG 100



CDI VOR2 PPG
Radial 007
FROM RIGHT
Deviation 2°



CLASSICAL INSTRUMENTATION - QUESTIONS

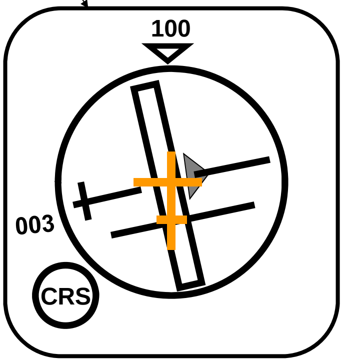
Q1 - At this moment, Marseille control asks if he has passed the point BRUSC. What does the pilot?

- A >> I arrive in 1 minute
- B >> I'm vertically point BRUSC
- C >> I just spent BRUSC
- D >> I do not know !

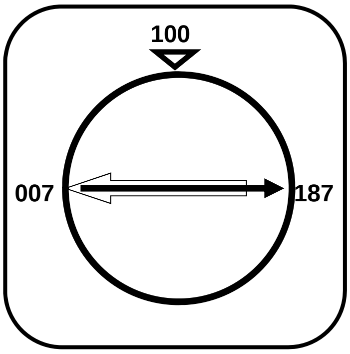
Q2 - A vertical BRUSC point, the driver selects **116.25 PPG** on **VOR1** and **115.3 MEN** on **VOR2**.
Representing the HSI at that position (selected course **003**) and **RMI-VOR** (single needle on PPG 116.25, double needle on MEN 115.3)

CLASSICAL INSTRUMENTATION - RESPONSES

Q1 : A >> I arrive in 1 minute
Q2 : HSI and RMI vertical point BRUSC



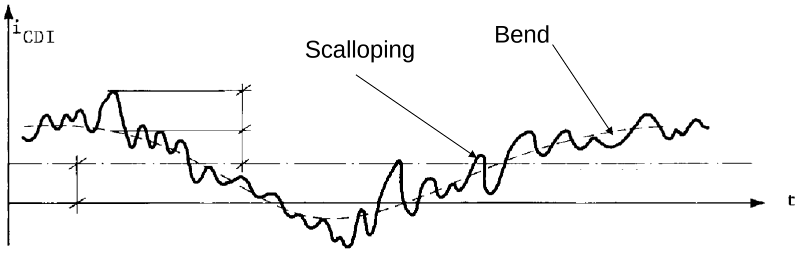
HSI VOR1 PPG
Radial 003
FROM Gauche
Deviation 4°



Single needle on PPG 116.25
Double needle on MEN 115.3

VOR ERRORS

Bad quality of the vor radial is due to multipaths (interference).
The result of interference depends on phase relation thus on the path difference which vary according to the plane motion.
High frequency component Scalloping, Low frequency component Bend.



Pseudo periodicity of the error and maximum error for obstacles at 90° or 270° from the selected radial.

ERROR BUDGET

- Station error (Site error) +/- 0,5° or +/- 2°
- Propagation error +/- 3°
- Aircraft Equipment +/- 3°

- Quadratic mean -→ 3° to 5°

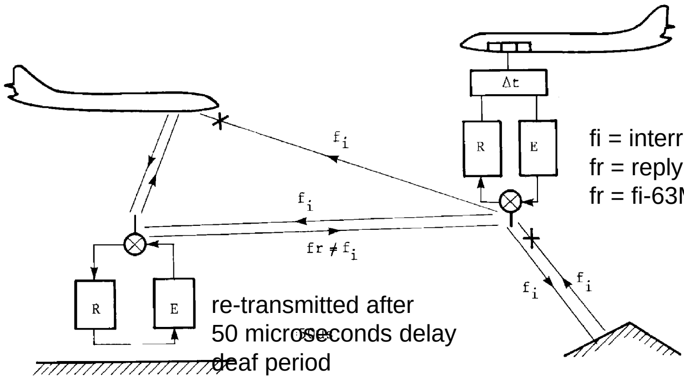
SUMMARY

- Vor radiates QDR.
- Phase comparison of two 30 HZ signals.
- 108 to 117.95 Mhz 160 channels.
- CVOR DVOR TVOR.
- Accuracy: 5° CVOR 3° DVOR.

DME PRINCIPLE

Slant Range
Aircraft component: the interrogator
Ground component: the transponder

Pulse Technique: stream of pulse on a UHF carrier



fi = interrogation freq.
fr = reply freq.
fr = fi-63Mhz

re-transmitted after
50 microseconds delay
deaf period

DME PRINCIPLE

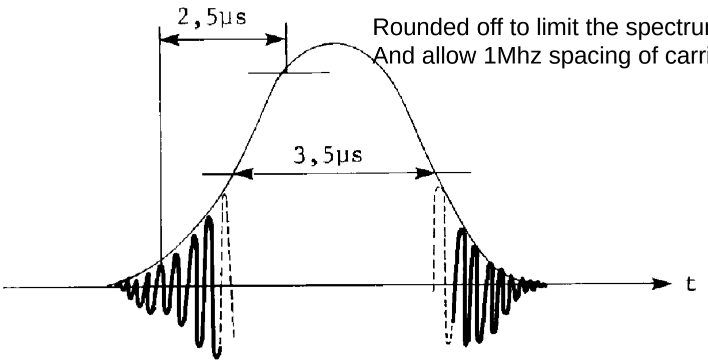
- Measurement of propagation time on double path.
- 2 * SR = 300m/µs * (T_propagation – 50µs)

DME PULSE

Freq: 960 to 1215 Mhz
Re-transmitted at fi-63Mhz

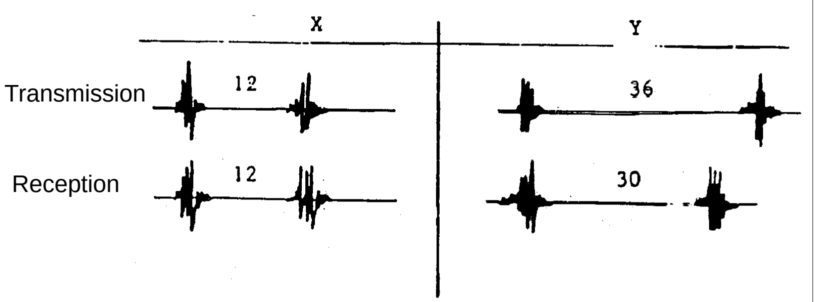
width = 3.5 us
rise time = 2.5 us

Rounded off to limit the spectrum
And allow 1Mhz spacing of carrier freq.



PULSE PAIRS

Pulses are transmitted in pairs: the spacing between the 2 pulses constitutes a coding. The spacing between the individual pulses of a pair is 12 µS for Xchannel and 36 µs for Y channel.



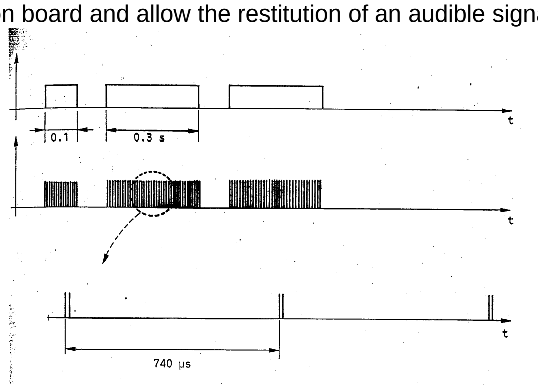
To eliminates isolated spurious pulse and to doubles the number of channels

DME CHANNELS

- Channels are numbered 1 to 126X and 1 to 126Y : 252 channels operating between 962 and 1215 Mhz. Spacing: 1 Mhz.
- 63 MHZ between the interrogation and transponding frequencies.
- DME channels are paired with VOR or ILS Localiser frequencies.(200 ch VOR/LOC)

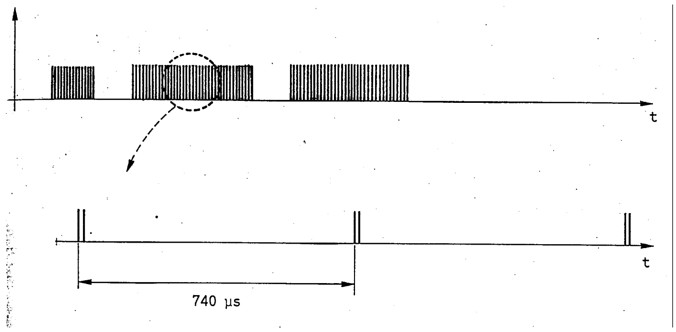
STATION IDENTIFICATION

Call sign transmitted in Morse code every 40 sec as pulse trains grouped in double pair.
Transmitted at a fixed rate spacing 740 µs.
Decoded on board and allow the restitution of an audible signal of 1350 Hz.



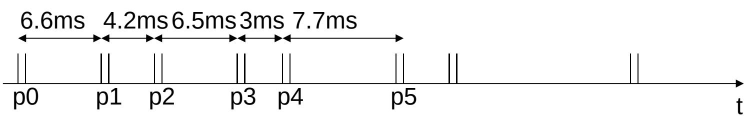
IDENTIFICATION SIGNAL

Range info is not available during ident period.
The yield ratio number of replies / number of interrogations is not 100%.



TRANSMISSION OF PAIRED PULSES AT RANDOM INTERVALS

Each interrogator is programmed to transmit its paired pulses at random intervals. The transmission sequence of pulses is irregular this differentiates its pulses from all the others.
Average recurrence **150 paired pulses per seconde**. (**150 pps**)



It is possible to **pick out** (select) synchronous replies by **correlation**.
Correlation : the received sequence is written in memory then comparison with the radiated sequence.

SEARCH AND TRACKING MODES

2 stages:

- Search Mode: To achieve a rapid lock-on the DME Interrogator radiates 150 pps for 100 s maximum. It takes 5 seconds on modern DME.
- Tracking mode: After lock-on the system operates at 25 pps (low bit rate).

DME INDICATOR

DME readout device

DME-speed is computed from the rate of change of slant range.

An aircraft circling a DME will have An indicated airspeed of 0.

Error < 1.5% if D(Nm) > H(1000fts)

TACAN

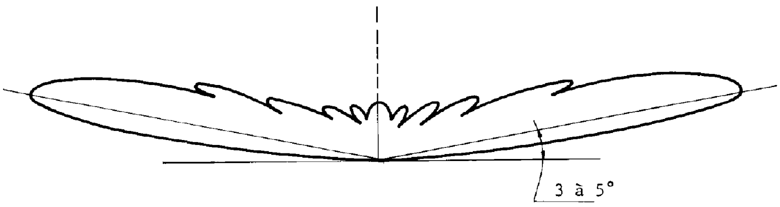
- The DME is derived from the military radi aids TACAN (TACtical Air Nav) but it has kept only the distance measurement sub-assemby: then the DME and TACAN systems are compatible.
- TACAN provides range and bearing.
- Civil aircraft can obtain range from DME or TACAN.

ACCURACY AND COVERAGE

ACCURACY: +/- 0.25 Nm + 1.25 % measured distance

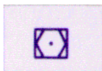
Ground station can be saturated : 2700 pulses pairs per second

Capacity: 100 (200 ?) aircraft using the DME at same time.



DME STAND ALONE

VOR and DME are often co-located.



65 DME in France.

DME and GLIDE

DME and GLIDE

VORTAC

SUMMARY

- The distance measured by DME is slant range.
- 50 microseconds delay time and pulse pairs.
- DME operates in UHF band beetween 960-1215MHZ.
- search mode, tracking mode.
- 100 aircraft.
- Accuracy: +/- 0.25 Nm +1.25 % measured distance. Line of sight.

LANDING SYSTEMS

1 – ILS

2 – MLS

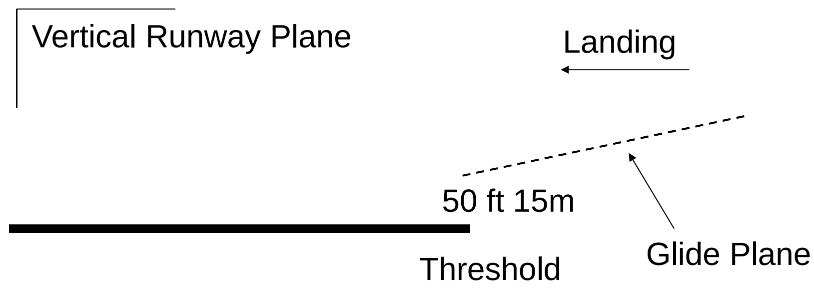
ILS INTRODUCTION

- Purpose of ILS: to provide the pilot guidance signals on the glide path to the runway.
- The guidance trajectory is rectilinear in the vertical runway plane at an angle of about 3°.The extension of the guidance trajectory crosses the runway 300m beyond the threshold.

ILS INTRODUCTION

- ILS is a precision approach guidance system because it gives guidance in both horizontal and vertical plane.
- ILS provides the pilot visual guidance in cockpit to enable the pilot to fly to his Decision Height. At decision height the pilot decides to land or decides to go around.

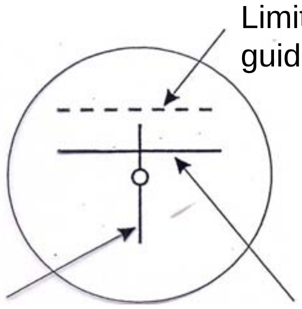
ILS INTRODUCTION



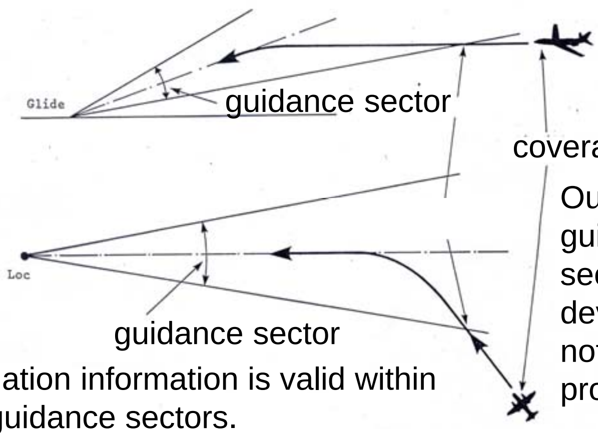
The guidance trajectory is the intersection of the vertical runway plane and the slant plane perpendicular to the previous.

ILS INDICATOR

ILS CDI
2 needles CDI.
2 zero centered galvanometers mounted in opposition.

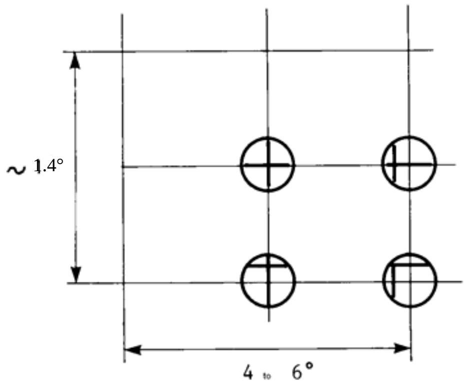


ILS INTRODUCTION



The deviation information is valid within narrow guidance sectors.

ILS INDICATOR



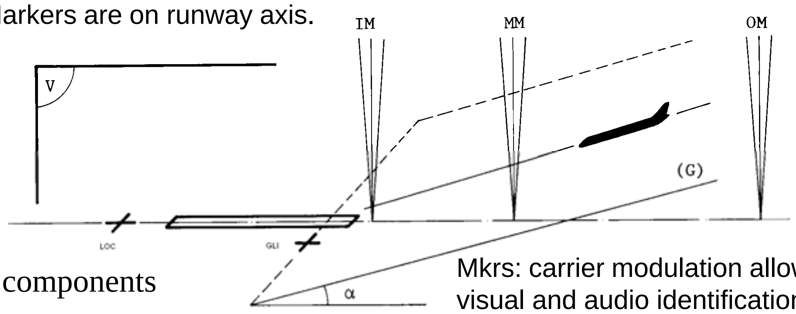
CDI deviation and guidance sectors.

The intersection of the 2 guidance sectors is a pyramid of guidance to the threshold.

5° for most runways

ILS COMPONENTS

The LOCALIZER (LOC or LLZ) is located 300m from the end of the runway. LLZ transmits in VHF.
The Glide Path (GP) is located 300m from the threshold and about 120m from the runway edge.GP transmits in UHF.
Markers are on runway axis.



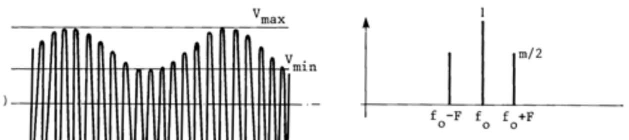
3 components

Mkrs: carrier modulation allows visual and audio identification.

RADIO PRINCIPLE

- A VHF or UHF ground transmitter radiates 2 half carriers with two patterns. The modulation is 150Hz for the right pattern, 90 Hz for the left pattern.
- The 2 half carriers are synchronized and the receivers sees just one carrier modulated with 90Hz and 150Hz.
- The DDM (Difference in Depth of Modulation) is proportional to the angular deviation.

MODULATION A2A



$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

m = depth of modulation

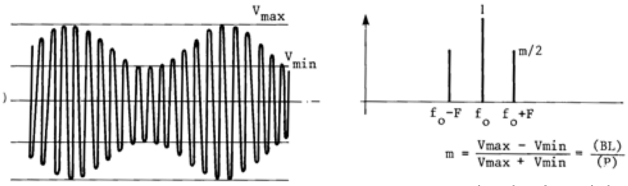
MODULATION A2A : Sinusoidal Amplitude Modulation.

The amplitude of the carrier f0 varies according to a sine form at the rythm of the modulating signal F.

Spectrum: 2 side frequencies f0-F f0+F.

The modulation rate m shows how the carrier is dug.

DDM and SDM



m = depth of modulation

Depth of modulation 90Hz
m_90Hz = (Vmax_90Hz – Vmin_90Hz) / (Vmax_90Hz + Vmin_90Hz)

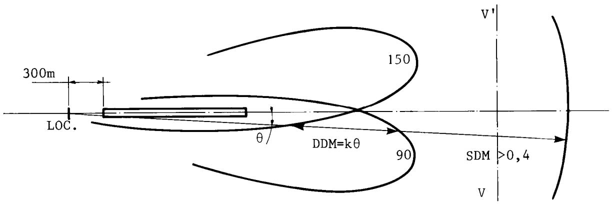
Depth of modulation 150 Hz
m_150Hz = (Vmax_150Hz – Vmin_150Hz) / (Vmax_150Hz + Vmin_150Hz)

Difference in Depth of Modulation
DDM = m_150Hz – m_90Hz

Sum in Depth of Modulation
SDM = m_150Hz + m_90Hz

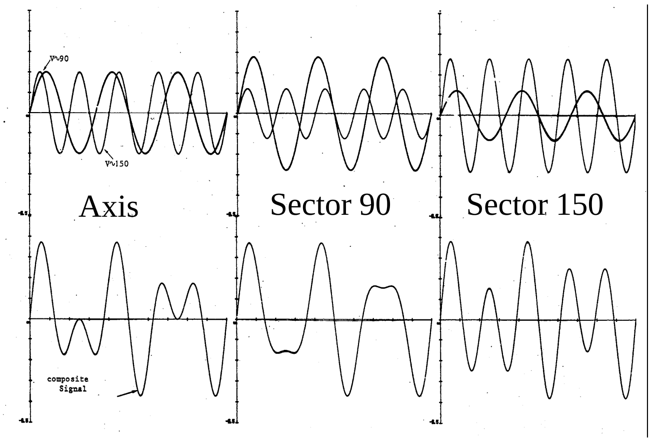
LOC : RADIO PRINCIPLE

2 strictly synchronous VHF carriers are transmitted according 2 directive radiation patterns.
The 2 radiation patterns point slightly away from the centerline.



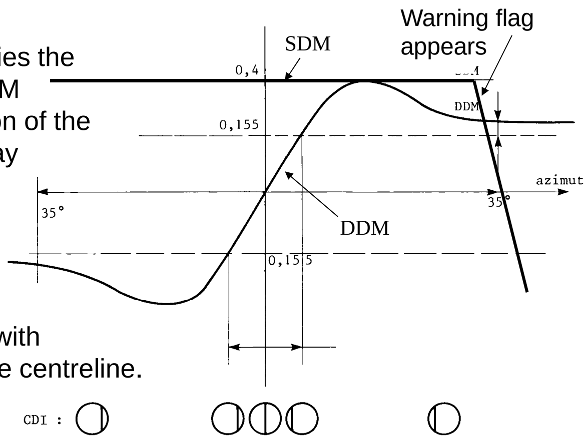
The right pattern radiates an half carrier modulated at 150Hz and the left pattern radiates an half carrier modulated at 90Hz.The DDM increases with displacement from the centerline.

ILS SIGNALS



LOC : ICAO STANDARD

This standard specifies the laws of the DDM/SDM variation as a function of the azimuth to the runway centreline.



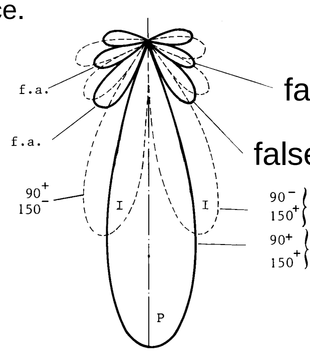
The DDM increases with displacement from the centreline.

LOC : DIRECTIVE RADIATION PATTERN

Real patterns are symetrical because it's advantageous in term of execution and performance.

P: even pattern with the peak on the axis.

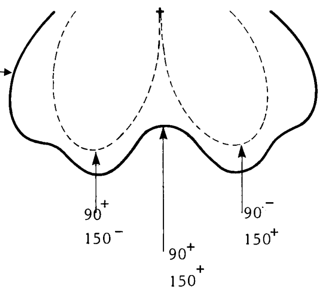
I: odd pattern with the null on the axis.



LLZ antenna radiate side lobes which could give rise to false centerline.

LOC : COVERAGE RADIATION PATTERN

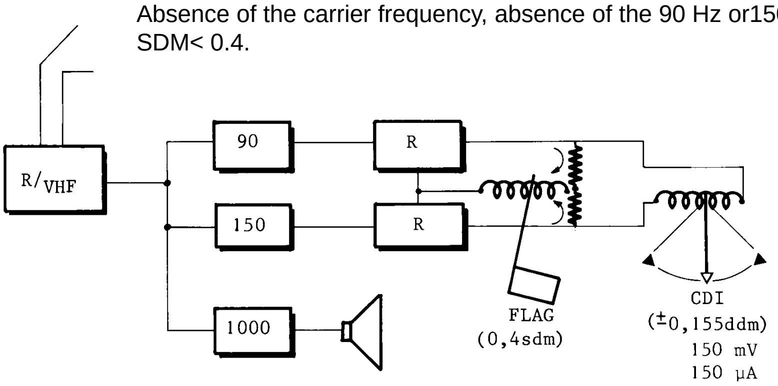
Directive array reduce spurious reflexion but to hide side lobe we need an additional signal: coverage radiation pattern.



When the frequency of the coverage transmission is drift of a few Khz (to stay within the receiver bandwith), the receiver receives the strongest signal (capture effect).

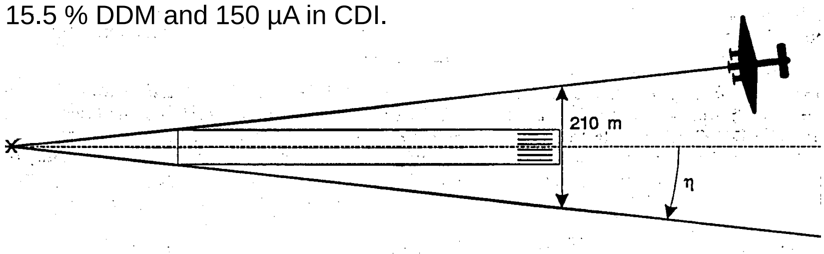
ILS RECEIVER BLOCK SCHEMATIC

Warning flags will appear for both LLZ and GP:
Absence of the carrier frequency, absence of the 90 Hz or150Hz, SDM< 0.4.



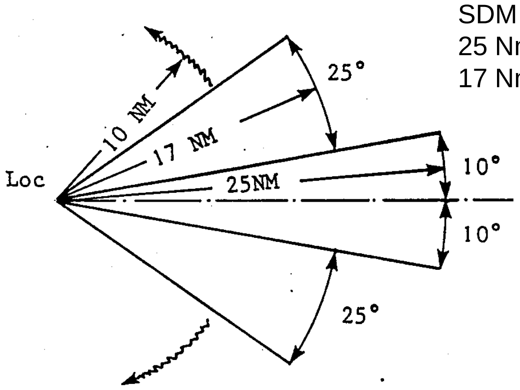
LOC : GUIDANCE SECTOR

Guidance sector: 700 feet intercepted at threshold
15.5 % DDM and 150 µA in CDI.



Angular sector defined by the length 210 m intercepted at the runway threshold.

LOC : AZ COVERAGE SECTOR



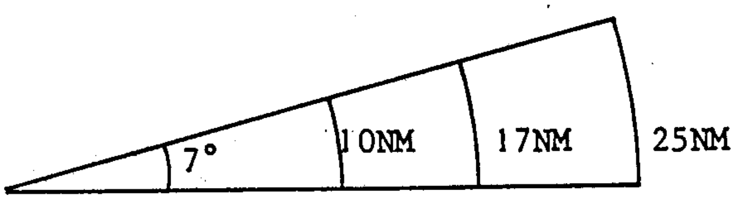
SDM > 0.4.
25 Nm on the axis up to +/- 10°.
17 Nm up to +/- 35°.

LLZ coverage is 10° on either side of the centerline to a distance of 25 Nm AND 35° on either side of the centerline to a distance of 17 Nm.

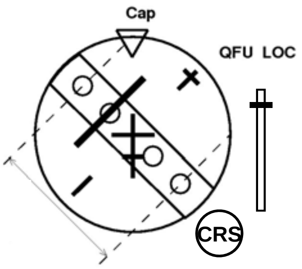
LLZ HORIZONTAL COVERAGE

LOC : EL COVERAGE SECTOR

LLZ VERTICAL COVERAGE



LOC : HSI



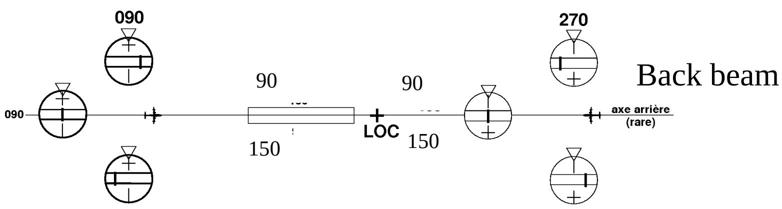
Full scale deflection of the CDI needle corresponds to approximately 2.5° displacement from the ILS centre line.

Full scale deflection on the GP corresponds to approximately 0.7° from the ILS GP centre line.

HSI and LLZ : No TO-FROM, deviation independent of the course pointer setting, course pointer = QFU for directional left/right bar in approach.

LOC : FRONT AND BACK BEAM APPROACH

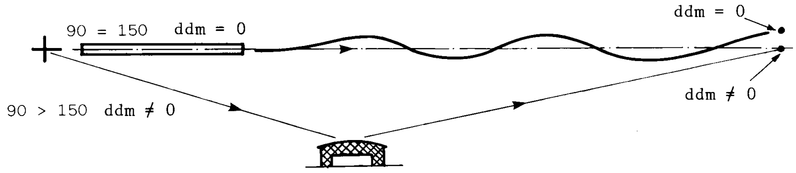
Back course approach are allowed in some countries.
This enables aircraft to make non precision approach on the back beam of the LOC.



Same setting of the course pointer for front beam and back beam approach.

LOC MULTIPATHS

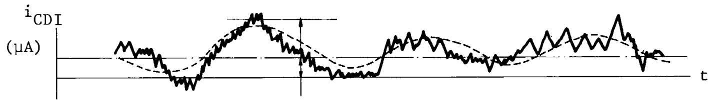
Multipath interference: reflections from large objects within the ILS coverage.



After interference of the direct and reflected signals the DDM is no longer zero on the theoritical axis, it depends on phase relations thus on the path difference which vary according to the plane motion. There's a pseudo periodicity of the error.

LOC ERRORS AND ACCURACY

Necessity of flight test to classify LLZ performance category.



The recording of the CDI electric current on board an aircraft maintained on the theoritical axis reveals the quality of the axis.

LOC PERFORMANCE CATEGORY

The quality of a LLZ axis is determined by its threshold average offset and the amplitude of its bends.Accuracy requirements are progressively higher for CAT1 CAT2 CAT3.

- **CAT1** : +/- 10.5m threshold average offset and 0.3° to 0.6° amplitudes of the bends.
- **CAT2** : +/- 7.5m threshold average offset and 0.1° to 0.6° amplitudes of the bends.
- **CAT3** : +/- 3M threshold average offset and 0.1° to 0.6° amplitudes of the bends.

ILS : CRITICAL AND SENSITIVE AREA

ILS critical area:
An area of defined dimensions about the LLZ and GP antennas where vehicles, including aircraft, are excluded during all ILS operations.

ILS sensitive area:
An area extending beyond the critical area where parking and/or movement of vehicles, including aircraft, is controlled to prevent the possibility of unacceptable interference to the ILS signal during ILS operations.

LOCALIZER

Dipole Antennas.

150 ILS in France
Reduction 30%

LOCALIZER

Log Periodic Dipole Array.

Wide band and high gain.

GLIDE INTRODUCTION

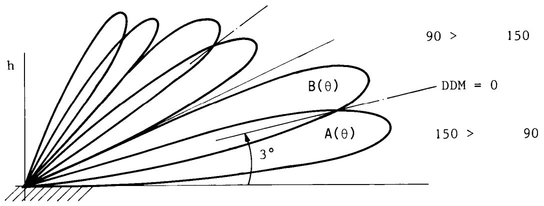
- Purpose: To materialize the glide slope according to an elevation angle of 3° and 15 m above the threshold.
- The radio principle is similar to the LLZ principle but applied in the vertical plane where the elevation angles replaces the azimuth angles.

GLIDE RADIO PRINCIPLE

- An UHF ground transmitter radiates 2 half carriers with two patterns. The modulation is 150Hz for the lower pattern, 90 Hz for the upper pattern.
- The 2 half carriers are synchronized and the receivers sees just one carrier modulated with 90Hz and 150Hz.
- The DDM (Difference in Depth of Modulation) is proportional to the angular deviation.
- The GP frequency is paired with the localiser and selection of the frequency is automatic.

GP RADIO PRINCIPLE

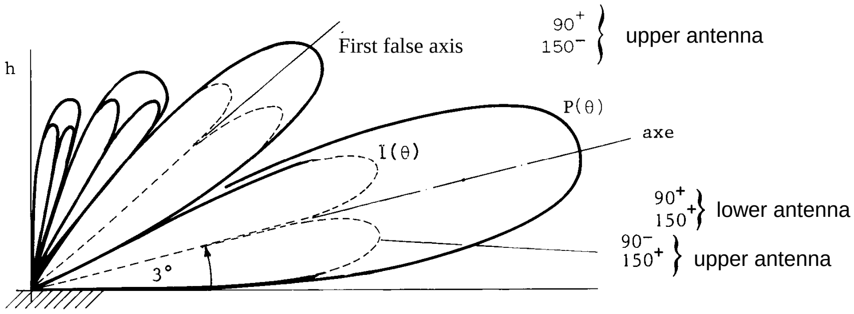
GP antenna radiates side lobe (false beams) which could rise to false glide path indication.



The first false glideslope occurs at twice the glide path angle.
It should not be a danger but pilot should be aware of that.

GP : EL RADIATION PATTERN

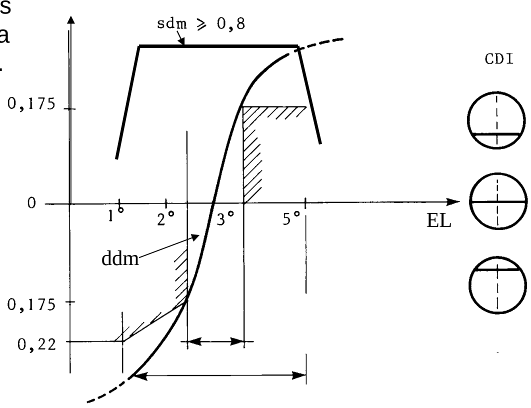
Real patterns are symetrical because it’s advantageous in term of execution and performance.



GP : ICAO STANDARD

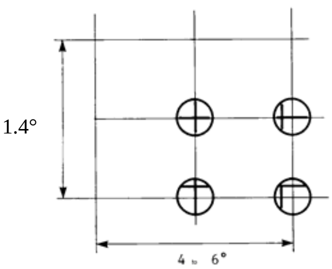
This standard specifies the laws of the DDM/SDM variation as a function of the elevation angle.

The DDM increases with displacement from the glide path



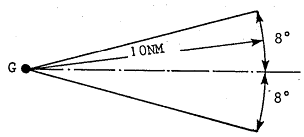
GP: GUIDANCE SECTOR

- Guidance sector = +/- 0.24 * angle_of_descent



Full scale deviation indicates that the aircraft is approximately 0.7° above or below the glide path.

GP : AZ COVERAGE SECTOR

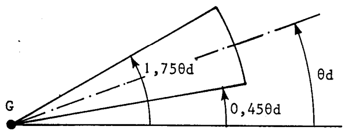


The glide path coverage extends from the transmitter to a distance of 10 Nm in sectors of 8° in AZ on each side of the centreline.

GP coverage are is 8° on either side of the centreline to a distance of 10 Nm from the runway.

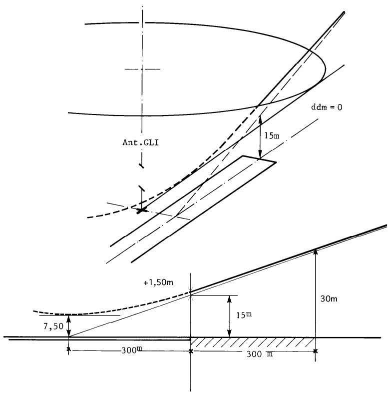
GP : EL COVERAGE SECTOR

The vertical coverage is provided from 0.45*angle_of_descent to 1.75*angle_of_descent



θd	1,75 θd	0,45 θd
2,5°	4,375°	1,125°
3,75°	6,56°	1,70°
5°	8,75°	2,25°

GP TRAJECTORY



The place of DDM=0 is in fact a revolution cone.

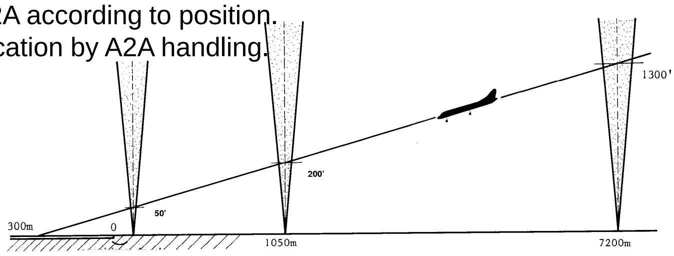
The descent plane is then a portion of conical surface whose intersection with the vertical runway plane is a hyperbole branch whose lower point is located 7.50m above the runway 300m downstream the threshold.

Unsteady needle after the threshold.

GLIDE

MARKERS

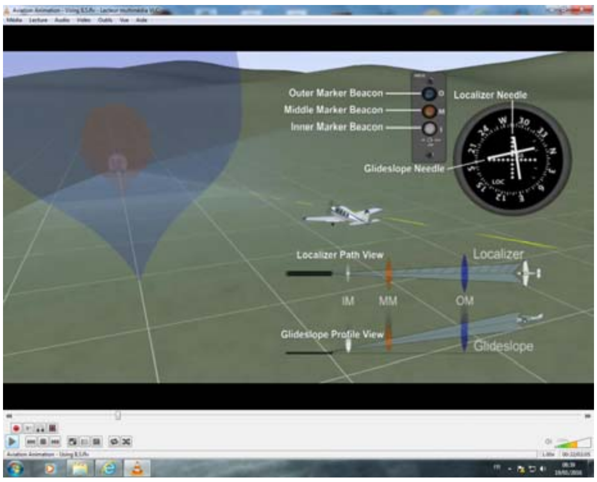
Single VHF freq of 75 Mhz. Horizontal polarisation.
Modulation A2A according to position.
Morse identification by A2A handling.



Coverage corresponding to a field of 1.5 mV/m

white amber blue

MARKERS



ILS ANIMATION.

SUMMARY

- LLZ: 40cx VHF 108 to 111.95 Mhz, located 300m after the runway end. Measurement of DDM.
- GP: 40cx paired (329 to 335Mhz), located 300m after the threshold. Measurement of DDM.
- Mkrs: 75 Mhz. IM MM OMM. Fan shaped vertical radiation.

MLS INTRODUCTION

- Important growth of traffic during 80s.
- We need an improved landing system.
- FAA changes its mind.

ILS PROBLEMS

- Single descent path
- Narrow guidance sectors, capture problems.
- Large antennas, difficult to implement
- High sensitivity to spurious reflections and interferences.
- Difficult to monitor, problem od signal integrity
- Saturation of the VHF band. 40 Cx only.

MLS - SPECIFICATIONS

Broad coverage / guidance sectors.
Possibility (in theory) to build a wide range of approach procedures to increase runway efficiency.

Possibility to choose a reference AZ (offset regarding RVP) and a reference EL (offset regarding GP) and to observe deviation regarding these 2 references on a 2 needles CDI. Theoritical possibility to make segmented approaches.

The DME/P or Precision DME is needed.
Pulse with lower rise time than classic DME.
Better accuracy (x10) at low range (7 NM).
DME Interrogator P-mode compliant.

MLS

- 200 Channels.
- AZ coverage sector is at least +/- 40° from the runway centre-line.
- EL coverage sector is from 0.9° to 15°.

MLS PRINCIPLE

- C BAND (5 Ghz).
- TRSB : Time Referenced Scanning Beam
- TDM : Time Division Multiplexing (AZ, EL, FL, DATA)

C BAND ADVANTAGES

- MLS frequencies are far away from FM Band
- Small size of antennas
- No ground plane needed

C BAND DISADVANTAGES

- Space Attenuation (rain, snow)
- Attenuation if the runway is not flat (convex runway)
- Specific Tools

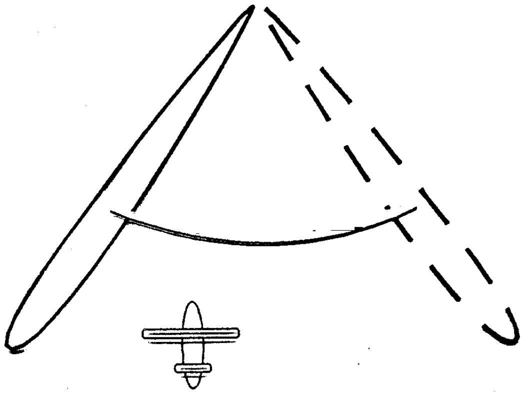
TRSB ADVANTAGES

- Critical zones are smaller than ILS.
- More robust (multipaths)

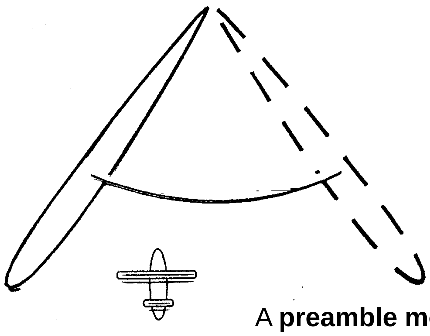
TDM ADVANTAGES

- Receivers are simpler
- 4 functions on the same frequency → Low bandwith

MLS TRSB



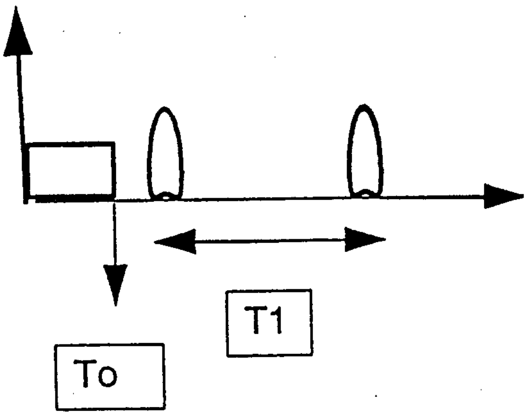
MLS TRSB



Two fine beams move at constant speed in AZ and EL, within the coverage sectors: then , we receive onboard two pulses by round trip scanning: the time interval between these pulses is proportional, within a constant, to the AZ (or EL) angle.

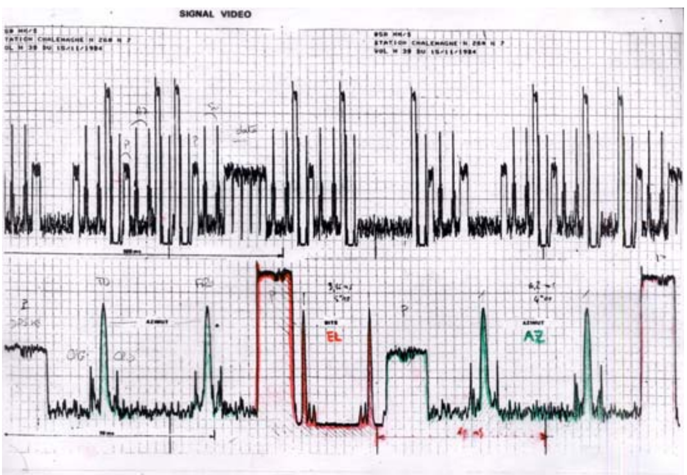
A **preamble message** is radiated before the **TRSB** on an omnidirectional pattern. Binary phase modulation of the carrier.

TO/FROM SCAN



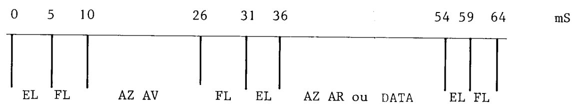
We receive onboard two pulses by round trip scanning: the time T1 interval between these pulses is proportional, within a constant, to the AZ (or EL) angle.

TRSB

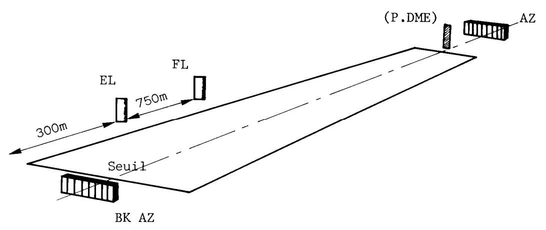


TDM

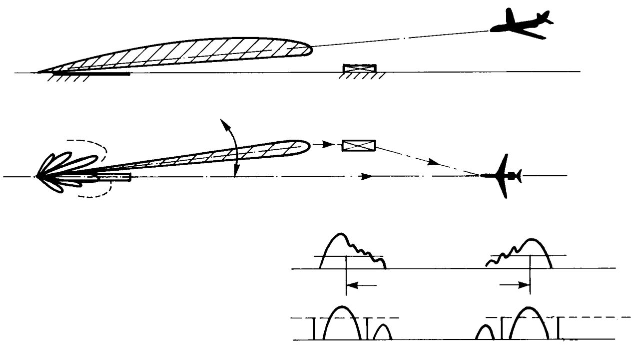
Time Division Multiplexing: stations transmit during slots.



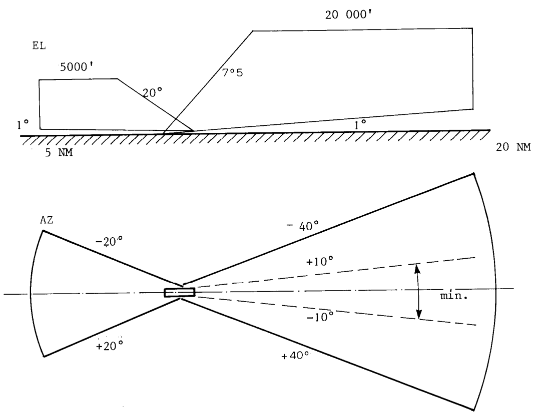
MLS COMPONENTS



MULTI-PATHS



MLS COVERAGE



INTERNATIONAL CONTEXT

- Continue ILS operations when possible
- Install MLS where economically possible
- MMR receivers
- Studies on GNSS2 for landing

MLS

MLS

SUMMARY

- 5 Ghz, 300Khz spacing, 200 channels.
- TRSB and TDM.
- Preamble message: binary phase modulation of the carrier.
- AZ coverage sector +/- 40 °.

GNSS GLOBAL NAVIGATION SATELLITE SYSTEM

1 – GNSS introduction

2 – GPS

3 – SBAS GBAS augmentations

GNSS

FANS (Future Air Navigation Systems), a committee of experts of the International Civil Aviation Organization (ICAO), proposed technical solutions for future navigational aids in 1983. The FANS committee demonstrated that navigation, communication and surveillance would be linked in the years ahead and thus introduced the theoretical concept of **CNS/ATM** (Communication Navigation Surveillance / Air Traffic Management).

The **CNS/ATM** concept, adopted by ICAO in 1991, is a response to the lack of consistency in ATM and the limitations of conventional radio. It concerns deploying new resources to handle the growth of air traffic.

The **CNS/ATM** concept includes a worldwide positioning and time measurement system known as the Global Navigation Satellite System (**GNSS**).

GNSS

GNSS is based on one or more **existing** satellite constellations augmented with related systems.

These **augmentations** are required to achieve levels of accuracy, integrity, availability and continuity that respond to the requirements of the civil aviation community.

ACCURACY INTEGRITY AVAILABILITY

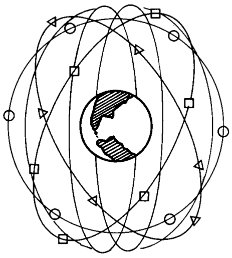
A navigation system's **accuracy** is a statistical expression of the level of conformity between the measured position and the actual position (for example, 100 m on the horizontal plane in 95% of cases).

A navigation system's **integrity** is its ability to detect a degradation in precision beyond a threshold and to warn the user of this degradation without exceeding a warning period. Threshold and warning period are specified depending on flight phase.

A navigation system's **availability** is its ability to provide positioning and nominal integrity services <u>at the start</u> of the flight phase considered.

A navigation system's service **continuity** is its ability to provide positioning and nominal integrity services <u>during</u> the flight phase considered.

GPS INTRODUCTION



Global Positioning System.

2 services provided:

SPS Standard Positioning Service for civilian users.
h : 100 m 95% equator v: 150m 95 % equator.

PPS Precision Positioning Service for authorised users.

And timing service for PPS and SPS.

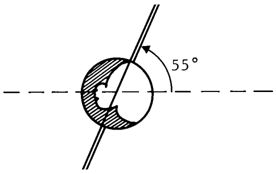
Worldwide coverage and high accuracy but:
- Unsteady **Accuracy**
- Unsteady **Availability**
- Low **Integrity**

RADIO NAVIGATION

GNSS ACRONYMS

- **GNSS**: Global Navigation Satellite System.
- **GPS**: Global Positioning System. GLONASS: GLObal Navigation Satellite System.
- **DOD**: Dept Of Defense.
- **SPS**: Standard Positioning Service.
- **PPS**: Precision Positioning Service.
- **PRN**: Pseudo Random Noise.
- **C/A** code: Coarse Acquisition Code.
- **P code**: Precision code. **AS**: Anti spoofing
- **GDOP**: Geometric Dilution Of Precision.
- **SA**: Selective Availability.
- **SBAS**: Space Based Augmentation System.(WAAS EGNOS MSAS)
- **GBAS**: Ground Based Augmentation System.
- **ABAS**: Airborne Based Augmentation System.
- **RAIM**: Receiver Autonomous Integrity Monitoring.
- **IPD**: Ionospheric Propagation Delay.
- **SV:** space vehicle (satellite)

GPS SPACE SEGMENT

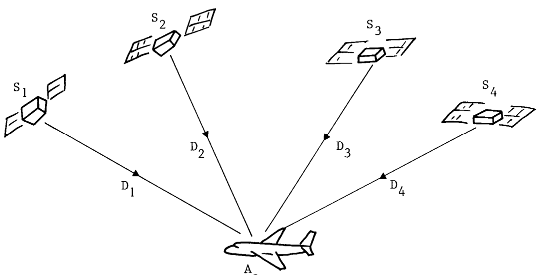


- constellation of **24** SVs.
- **6** orbit planes, inclination of **55°** to the plane of equator, **60°** spaced in long, **4** SVs by orbit planes.
- average orbit altitude **20 180** km.
- period of **12** hours.
- **4** atomic clocks by SV 1 ns accuracy (2 caesium 2 rubidium).

SVs transmit on 2 frequencies: **L2** (military frequency) **1227.6** Mhz and **L1** (civilian frequency) **1575.42** Mhz.

SVs broadcast 2 pseudo-random noise code (**PRN**)(**ranging code**). Each SV has its own code. Each code is unique and provides the mechanism to identify each satellite. A navigational data message is also provided (**Navigation Message**).
C/A code (Coarse acquisition code): 1023 elts, chip code: 1µs, length: 1ms.
P code (Precision code): chip code: 0.1 µs, length: 7days.

GPS PRINCIPLE



Measurement of the propagation time between the **SV** and the **receiver**.

The distance calculated is called **pseudo-range** because the difference between the **receiver time** and the **SV time** create an **erroneous range** (at least initially).

4 SVs are needed to determine a 3D position.
3 SVs are needed to determine a 2D position.

GPS SIGNALS

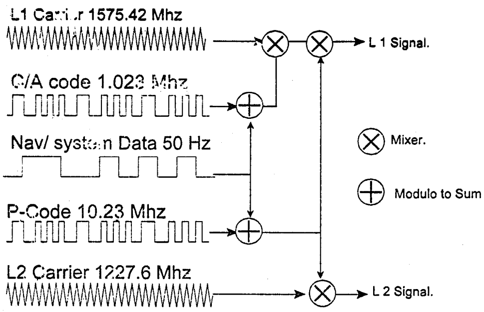
FREQ	MHz	CODE P	CODE C/A		SIGNAL P	SIGNAL C/A
L_1	1575,42	10,23 Mb/s	1,023 Mb/s	50 bps	- 163 dBW	-160 dBW
L_2	1227,60	10,23 Mb/s	N/A	50 bps	- 166 dBW	N / A

P code and **C/A code** are pseudo random noise (**PRN**) sequence.
For each satellite the **C/A** and **P** code are unique.
C/A and **P code** provide the mechanism to **identify** each satellite.

C/A code (Coarse acquisition code): **1023** elts, chip code: **1µs**, length:**1ms**.
P code (Precision code): chip code: **0.1 µs**, length: **7days**.

Chip code = duration of an element of code.

GPS TRANSMITTER



C/A and **P** codes are transmitted on **L1** but **P** code is not used by **SPS**.

P code is transmitted on **L2**.

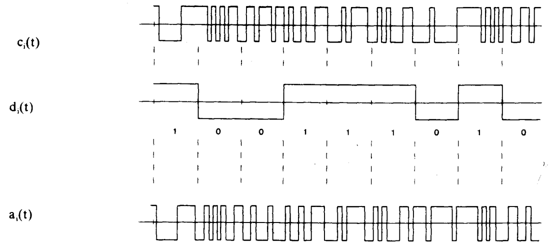
The **Navigation Message** is transmitted on **L1** and **L2**.

PPS uses both frequencies **L1** and **L2**.

L1 civilian frequency, **L2** military frequency.

CODE AND DATAS

Code AND **data** are mixed on the carrier.
The navigation message is superimposed on PRN codes with modulo addition of code and data.
Modulation of the carrier is Binary Phase Shift Keying (**BPSK**) modulation at two phase states (0° and 180°).



GPS NAVIGATION MESSAGE

This is a data message sent at a speed of **50 bits/second**. It contains data specific to the satellite that emits it (**ephemeris** and **clock correction**), data on the **entire** constellation (**almanac**) and parameters relating to **ionospheric propagation**.

GPS **ephemeris** is the table for predicting the position of the satellite being considered. GPS **almanac** includes the set of 24 ephemeris.

The navigation message is composed of frames that are **1500** bits long and last **30** seconds. Each frame is divided into five subframes that are **300** bits long and last **6** seconds.

Transmission time for the entire navigation message requires **25** frames, or **12** minutes and **30** seconds.

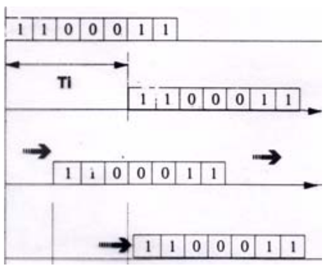
GPS NAVIGATION MESSAGE

Navigation Message contains:
- sv position time prediction: almanac and ephemeris data.
- sv clock time correction.
- ionospheric model.
- sv health data.

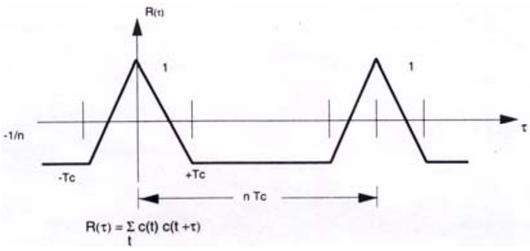
The **almanac** contains the orbital data about ALL the satellites in the GPS constellation.
The **ephemeris** contains data used to correct the orbital data of the satellites due to small disturbances.
The **clock correction parameters** are data for correction of the satellite time.
Ionospheric model is used to calculate time delay of the signal travelling through the ionosphere.
The **GPS health message** is used to exclude unhealthy satellites from the position solution.

CORRELATION

The measurement principle consists of correlating two identical sequences; the code received and the same code generated locally.

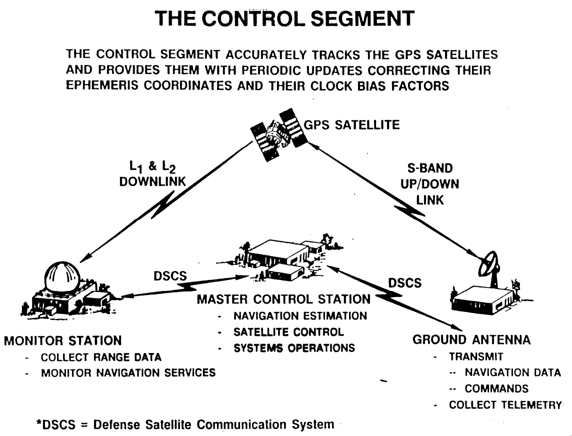


CORRELATION FUNCTION



The autocorrelation function (bit by bit sum of products) is periodic and causes well-defined maximums to appear.

GPS CONTROL SEGMENT

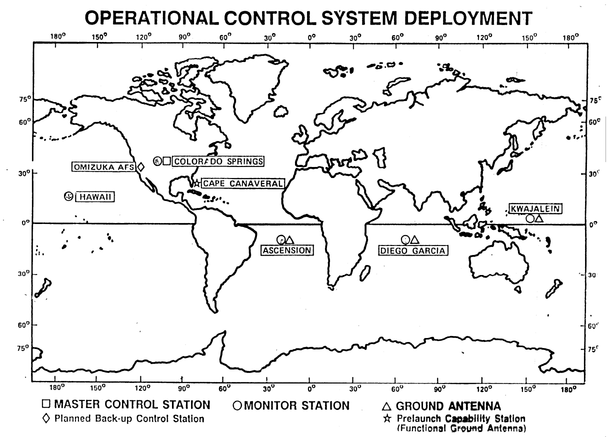


The **control segment** comprises: a **master control station**, **ground antenna** and **monitoring stations**.

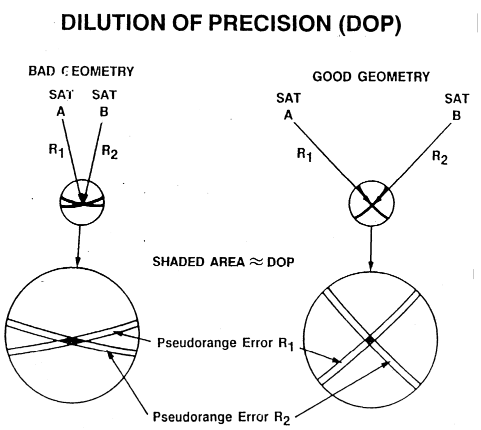
The MCS is responsible for all aspects of the constellation command and control: navigation data **upload** and **monitoring** of the satellites.

The monitoring stations check SVs computed positions and clock time every 12 h.

CONTROL SEGMENT DEPLOYMENT



DILUTION OF PRECISION



The concept of **DOP** can be illustrated by reasoning in two dimensions. If the angle at which the LOPs cross is **small**, precision is greatly **diluted**.

If the LOPs cross at **90°,** the position error is proportional to the distance error.

In three dimensions dilution will be minimal if three SATs are observed **120°** apart just above the horizon and a SAT is directly **overhead**.

GPS ERRORS

Most significant factors affecting accuracy:

- Ionospheric propagation delay **IPD**.
- **Dilution** of position.
- Satellite **clock error**.
- Satellite orbital **variations**.
- Multipaths

IPD is the most significant error.
In PPS receivers IPD can almost be **eliminated** by using two frequencies (L1 and L2).
In SPS receivers IPD is currently reduced by 50 % by using the ionospheric model from the navigation message.

Errors in satellite orbits are due to solar wind, gravitation of the sun, moon, planets.

GPS ERRORS

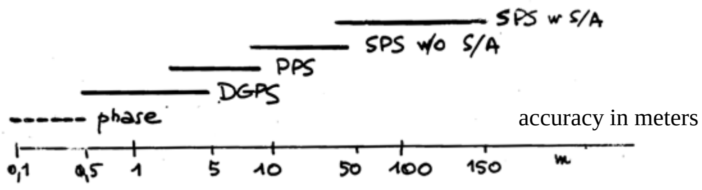
UERE (**USER EQUIVALENT RANGE ERROR**) represents the sum of errors for **1 pseudo range**:

SV clock error	1.5m
Ephemeris errors	2.5m
Ionospheric propag error	5.0m
Tropospheric propagation error	0.5m
Receiver noise error	0.3m
Multi-path reception	0.6m
==== >	**UERE** : 8 m

Final localisation precision may be expressed as the product of UERE and a degradation factor from the Geometric Dilution Of Precision (GDOP).
POSITION ERROR = **UERE** x **GDOP**.

In three dimensions this degradation or dilution factor is called Position Dilution Of Position (PDOP).

GPS ACCURACY



The precision of non-augmented GPS, i.e. without additions, is **variable**. It **depend**s on the service used (PPS or SPS), presence of **SA**, **differential correction data** and lastly **receiver dynamics** ("static" receivers in civil engineering used a phase tracking technique to improve precision).
The requirements of the civil aviation community are quite **high**: **highly dynamic** receivers, **integrity** and **availability.**

GPS INTEGRITY : RAIM

RAIM stands for Receiver Autonomous Integrity Monitoring. It is a technique whereby a receiver processor determines the integrity of the navigation signals.

RAIM is achieved by consistency check among pseudo range measurements.

Basic RAIM requires 5 satellites.

GLONASS

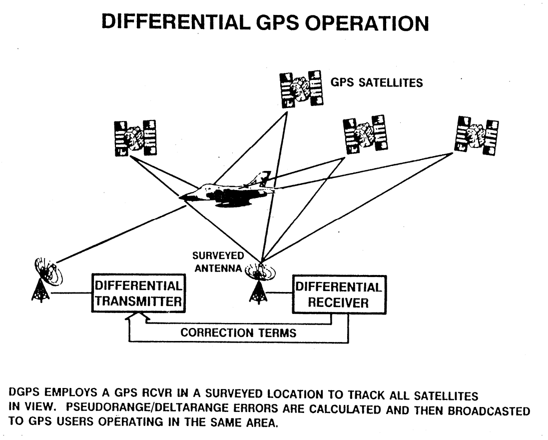
GLONASS stands for **GL**Obal **N**avigation **S**atellite **S**ystem. It is a russian constellation:

- 24 SVs
- Near circular orbit at 19 100 km at an inclination of 64.8° to the equator.
- Each orbit is completed in 11 hours 15 minutes.
- Each SV transmits navigation signals on 2 L-Band frequencies, L1 1.6 Ghz and L2 1.2 Ghz.
- L1 is a standard accuracy signal designed for civil user and L2 is a high accuracy signal for authorised user only.
- Navigation message has a duration of 2 seconds and contains 'immediate' data which relates to the actual satellite and 'non immediate' data which relates to all other satellites within the constellation.

GALILEO

- 30 satellites in 3 planes inclined at 56° to the plane of the equator. 9 SVs + 1 spare replacement by plane.
- Near circular orbit at an altitude of 23222 km. Each orbit will take 14 hours.
- Signals will be transmitted in two bands 1164-1215 Mhz and 1559-1591 Mhz. (1559-1591 Mhz will be shared with GPS on a non-interference basis).
- Timing section with 2 clocks: Rubidium standard clock and more precise Passive Hydrogen Maser clock.
- signals consist of a ranging code identifier and a navigation message.

DIFFERENTIAL GPS



GBAS : GROUND BASED AUGMENTATION SYSTEMS

Principle of a **GBAS** : to mesure on ground the signal errors transmitted by **GNSS** satellites and relay the mesured errors to the user for correction. **GBAS** based on **GPS** is sometimes called **LAAS** (Local Area Augmentation System).

ICAO GBAS standard uses a data link in the VHF band of ILS-VOR (108-118 Mhz).
GBAS station coverage is about 30 km. **GBAS** systems **locally** augment **GPS** and **GLONASS.**

ICAO GBAS standard provides the possibility to interconnect **GBAS** stations to form a network broadcasting large scale differential corrections. Such system is identified as **GRAS** (Ground Regional Augmentation System).

GBAS Coverage: 15 NM from the landing threshold point within 35° apart the final approach path and 10° aprt between 15 and 20 NM.

SBAS : SATELLITE BASED AUGMENTATION SYSTEMS

Principle of **SBAS** : to measure on the ground the signal errors transmitted by **GNSS** satellites and transmit differential corrections and integrity messages for navigation satellites.

Use of geostationary satellites enables messages to be broadcast over very wide areas. **SBAS** systems **regionally** augment **GPS** and **GLONASS.**

SBAS consists of 3 elements : ground infrastructure (monitoring and processing stations), SBAS satellites, SBAS airborne receivers.

SBAS station network measures pseudo range between the ranging source and an SBAS receiver at the known locations and provides corrections for ranging source ephemeris errors, clock errors and ionospheric errors.

SBAS : **EGNOS** (European Geostationary Navigation Overlay Service) in Western Europe and the Mediterranean, **WAAS** (Wide Area Augmentation System) in USA, **MSAS** in JAPAN, **GAGAN** in India.

EGNOS

EGNOS stands for **E**uropean **G**eostationary **N**avigation **O**verlay **S**ervice.

- It consists of **3 geostationary** Inmarsat satellites which broadcast GPS look-alike signals.
- **Accuracy** improved to 1-2m horizontally and 3-5m vertically.
- **Integrity** Alarm delay : 6 secondes! (up to 3 hours for a GPS alone)

ABAS : AIRBORNE BASED AUGMENTATION SYSTEMS

Principle of **ABAS** : to use redundant elements within the GPS constellation or the combination of GNSS measurements with those of other navigation sensors (inertial systems) to develop integrity control.

Unlike **GBAS** and **SBAS, ABAS** does not improve positioning accuracy.

RAIM (Receiver Autonomous Integrity Monitoring) is an **ABAS** system using only GNSS information.

An **ABAS** system using information from additional on board sensors is named **AAIM** (Aircraft Autonomous Integrity Monitoring).

Global Navigation Satellite System (GNSS)

Course Notes

A.ROUGÉ

1

GNSS

FANS (Future Air Navigation Systems), a committee of experts of the International Civil Aviation Organization (ICAO), proposed technical solutions for future navigational aids in 1983. The FANS committee demonstrated that navigation, communication and surveillance would be linked in the years ahead and thus introduced the theoretical concept of **CNS/ATM** (Communication Navigation Surveillance / Air Traffic Management).

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> A navigation system's <u>precision</u> is a statistical expression of the level of conformity between the measured position and the actual position (for example, 100 m on the horizontal plane in 95% of cases).
>
> A navigation system's <u>integrity</u> is its ability to detect a degradation in precision beyond a threshold and to warn the user of this degradation without exceeding a warning period. Threshold and warning period are specified depending on flight phase.
>
> A navigation system's <u>availability</u> is its ability to provide positioning and nominal integrity services <u>at the start</u> of the flight phase considered.
>
> A navigation system's service <u>continuity</u> is its ability to provide positioning and nominal integrity services <u>during</u> the flight phase considered.

A navigation resource that satisfies these four criteria for a flight phase constitutes a <u>unique resource</u> for this flight phase.

A navigation resouce that satisfies the criteria for precision and integrity but does not satisfy the availability/continuity criteria is termed a supplementary resource for this flight phase. The lack of availability/continuity requires installation of a unique resource. Since the supplementary resource is integral, the unique resource may be inactive as long as the supplementary resource is available.

It is possible to define restrictive operational procedures with prediction for availability before the flight phase. In this case installation of a unique resource is not required and the navigation resource is qualified as primary resource for navigation.

In 2011 two global positioning systems (GPS) are operational, the American **NAVSTAR-GPS** and the Russian **GLONASS** (GLObal Navigation Satellite System).

The European **GALILEO** system is in development and will be operational in 2014.

1.1 GPS Introduction

GPS is a system for navigation using satellites developed by the United States Department of Defense (**DOD**) for military purposes.

The system provides two services:

1. Precision Positioning Service (**PPS**) for authorized users (American military, NATO, etc),
2. Standard Positioning Service (**SPS**) for civilian users and thus can be used as part of **GNSS.**

The precision of **SPS** (at the equator and in 95% of cases) is 100 meters on the horizontal plane and 150 meters on the vertical plane.

SPS precision has noticeably improved since the voluntary degradation of precision called Selective Availability (**SA**) was deactivated.

Augmentations or additions to GPS are necessary for GNSS because limitations remain, including

- variable precision,
- variable availability,
- low integrity.

GPS uses trilateration to perform position calculations. From a geometry standpoint, trilateration requires 3 distances at 3 reference points (known positions) to calculate a position in a three-dimensional (3-D) space. In reality GPS requires four distance measurements to find a 3-D position. This additional measurement is necessary to estimate the bias relating to the time reference of the GPS receiver when calculating a 3-D point.

The four distances are obtained by measuring four propagation times on a simple trajectory (satellites / GPS receiver) using a globally synchronised infrastructure. The propagation time measurements on a simple trajectory require close synchronisation between the satellite time reference and the receiver time reference.

1.2 GPS space segment

The space segment is composed of 24 satellites (SATs) or space vehicles (SVs) in near-circular orbits at an average altitude of 20,180 km. The orbital period is 12 hours. SATs are located on six planes inclined by 55° with respect to the equatorial plane and spaced apart by 60° in longitude. There are four SATs per plane.

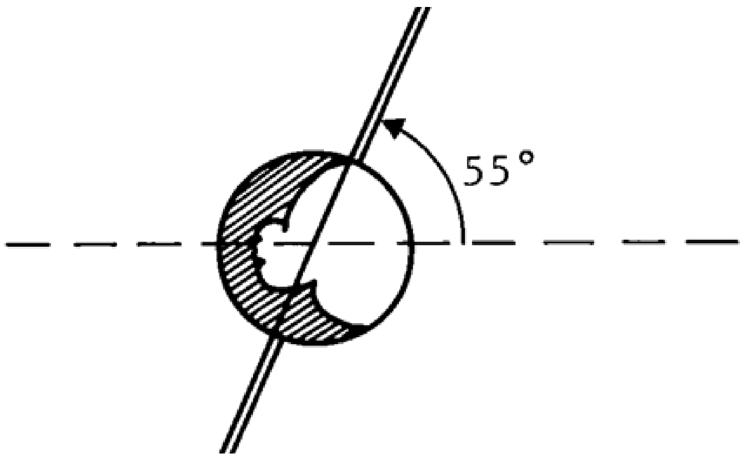

Figure 1.1: Space segment

The choice of this geometry is necessary for global coverage. The principle for calculating the solution to 3-D navigation requires that, *at any point on the globe and any moment*, any receiver can be viewed by at least four SATs. In reality, specific constraints on the visible SATs/receiver group, service continuity and the level of integrity require that this number be increased.

The SATs are equipped with four clocks (two caesium, two rubidium) whose reliability over a week is on the order of 10 to the power of -13 (class 10 power -13). They are reset daily by the control segment. The quality of the clocks, a critical point in the programme, defines GPS time.

The GPS receiver cannot include a clock of such quality. It thus uses a pseudo-synchronised reference (simple electronic quartz) whose bias in relation to GPS time will be considered as a fourth variable in addition to the three localisation variables.

1.3 GPS Principle

The position of the GPS receiver is obtained by measuring the distances to the satellites. The GPS receiver is located at the intersection of a certain number of lines of position (LOP). The LOPs (geometric position of points such that the measurement aboard is constant) are spheres centred on the position of each satellite.

The measured distances are called pseudo-distances; they contain an error because the SAT and user clocks are not perfectly synchronised.

The receiver measures pseudo-distances by estimating the delay between two identical codes, one sent by the satellite, the other generated locally.

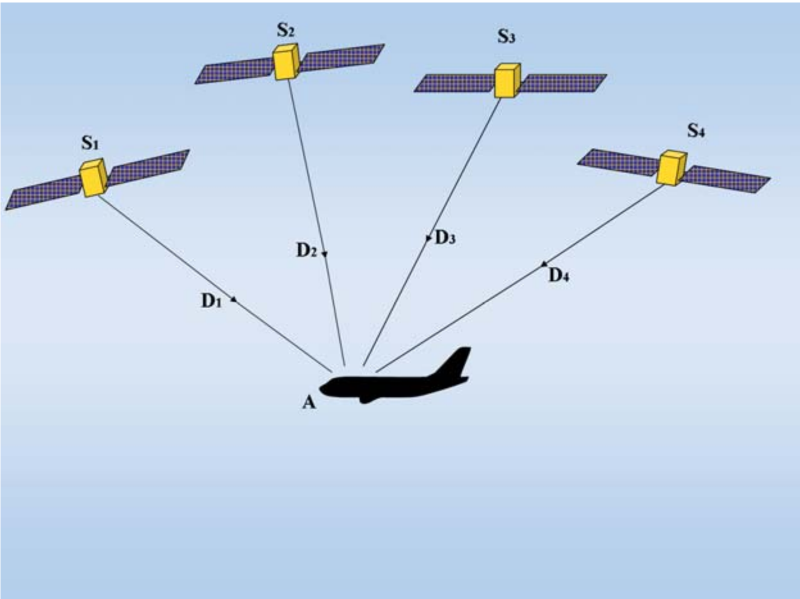

Figure 1.2: Principle

In summary, to calculate a GPS position, four propagation times are measured on a simple trajectory using a globally synchronised infrastructure.

1.4 GPS Signals

Each satellite in the GPS constellation sends two carrier frequencies called L2 (1227.60 Mhz) and L1 (1575.42 Mhz). L2 is a military frequency and L1 a civilian frequency. The two carrier frequencies are modulated by pseudo-random **codes** and a navigation **message**.

A pseudo-random code or pseudo random noise (**PRN**) is a sequence of binary code (0 or 1) that appears random. In actuality, the sequence repeats itself after every N pieces of data. Each element of code is also called a chip. A PRN code does not contain data but is used to recognise the satellite and perform the calculation for SAT/receiver distance.

Each SAT emits its own unique coarse acquisition (C/A) code and precision code (P-code). The C/A or civilian code is short (1,023 elements, duration of code chip of 1 microsecond, and 1 ms in length). The P- or military code is long (duration of code chip is 0.1 microsecond with a length of 7 days).

A navigational message is a binary sequence (data) that gives the satellite's position and other parameters.

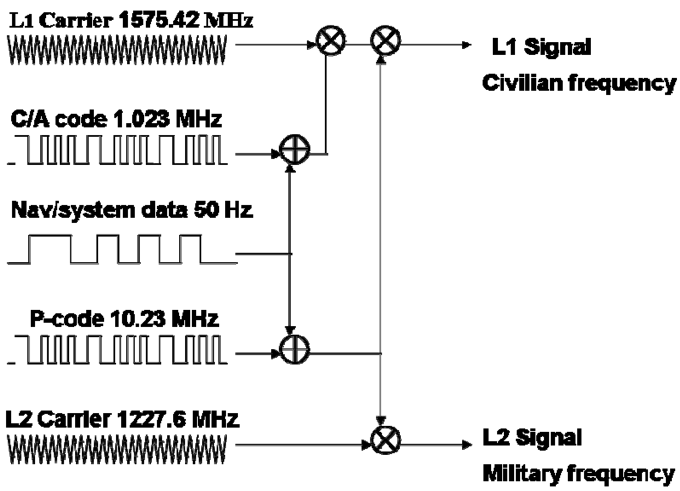

Figure 1.3: GPS Signals

The civilian **L1** carrier is triply modulated (**C/A** code, P-code, navigation message) but the P-code will not be used for **SPS** ("civilian" receiver).

The **L2** carrier is modulated by the P-code and navigation message. **PPS** (military receiver) uses P-code on two frequencies to evaluate propagation conditions.

The navigation message is superimposed on PRN codes with modulo addition of code and data. Modulation of the carrier is Binary Phase Shift Keying (**BPSK**) modulation at two phase states (0° and 180°).

1.5 GPS Navigation Message

This is a data message sent at a speed of 50 bits/second. It contains data specific to the satellite that emits it (ephemeris and clock correction), data on the entire constellation (almanac) and parameters relating to ionospheric propagation.

GPS ephemeris is the table for predicting the position of the satellite being considered. GPS almanac includes the set of 24 ephemeris.

The navigation message is composed of frames that are 1500 bits long and last 30 seconds. Each frame is divided into five subframes that are 300 bits long and last 6 seconds.

Transmission time for the entire navigation message requires 25 frames, or 12 minutes and 30 seconds.

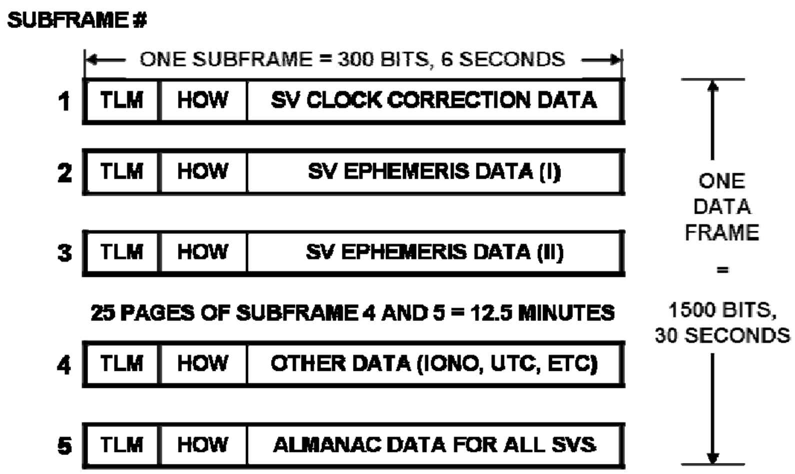

Figure 1.4: GPS Navigation Message

The SAT stores the data, which is updated by the control segment.

During the first measurement, if the receiver is not initialised with an approximate time and position, the receiver operates in full search mode: this is called Search the Sky. In this case, it will require nearly ten minutes to locate its position.

1.6 GPS Code correlation

The GPS uses Code Division Multiple Access (CDMA). All 24 SATS simultaneously emit on the same frequencies (L2 and L1). A GPS receiver receives all signals from the visible constellation. Potential interference is resolved because the receiver recognises the double signature (C/A and P-codes) of each satellite.

Codes must have the following properties:

- possibility of filtering some in relation to others, or null intercorrelation,
- possible identification using a delayed version of itself, auto correlation presenting a marked peak.

The measurement principle consists of correlating two identical sequences; the code received and the same code generated locally.

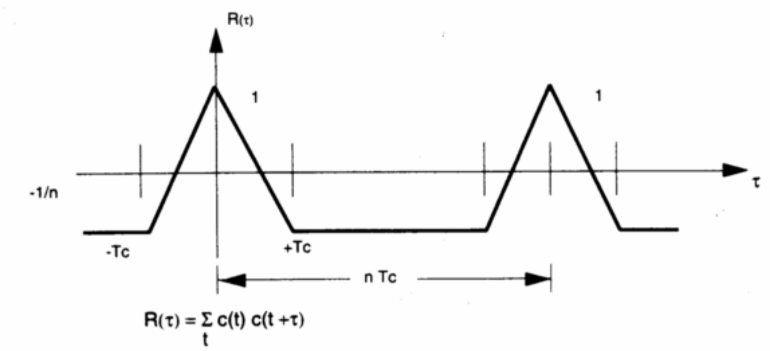

Figure 1.5: Correlation function

For this, local code is switched with received code to calculate the autocorrelation function.

The autocorrelation function (bit by bit sum of products) is periodic and causes well-defined maximums to appear.

1.7 GPS Control Segment

The American military is responsible for the control segment and maintaining the entire space segment. It is composed of **5 stations** on the ground at the following sites:

- Colorado Springs master control station and monitor station
- Hawaii monitor station
- Ascension Island monitor station and ground antenna
- Diego Garcia monitor station and ground antenna
- Kwajalein monitor station and ground antenna

The monitor stations verify satellite status, reporting to the master station which determines the corrections to be made to the orbital parameters, time data, etc. Corrections are sent to the satellite concerned.

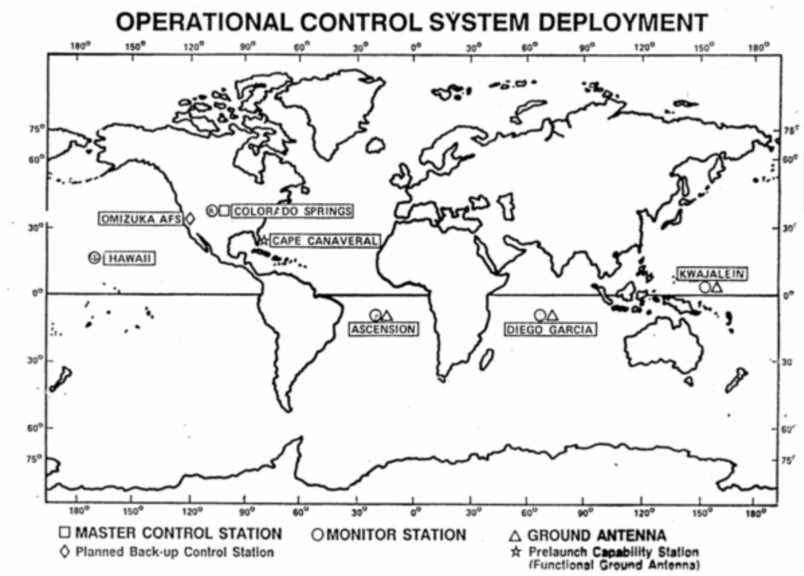

Figure 1.6: Control segment

This segment is also responsible for intentionally degrading the precision of the navigation solution for SPS by introducing errors in the position (erroneous data introduced in the ephemeris section of the data message, known as ephemeris overcoding) and time data (time dither) of each satellite. This voluntary degradation is called selective availability (SA) and has not been used since 2000.

1.8 GPS User Segment

It is composed of all receivers able to receive GPS signals. Civilian receivers are distinct from military receivers. High dynamic users (civil aviation) can be distinguished from low dynamic users (geodesy). Lastly, the receivers are single (L1) or dual frequency (L1 and L2), single or multi-channel and may include such special features as autonomous integrity monitoring or augmentation access.

1.9 GPS Precision

By principe (measurement of four pseudo-distances), precision of the solution of navigation depends on the geometry with which the receiver sees the constellation. Precision varies in time and space. Navigation service can thus be greatly degraded and even unavailable in certain cases. The degradation (or dilution) of the precision in position is inversely proportional to the volume of the tetrahedron created by the receiver and the four SATs used. At each moment, the receiver must choose from all SATs received at an elevation angle of at least 5°, the group of four SATS resulting in minimal dilution of precision (DOP).

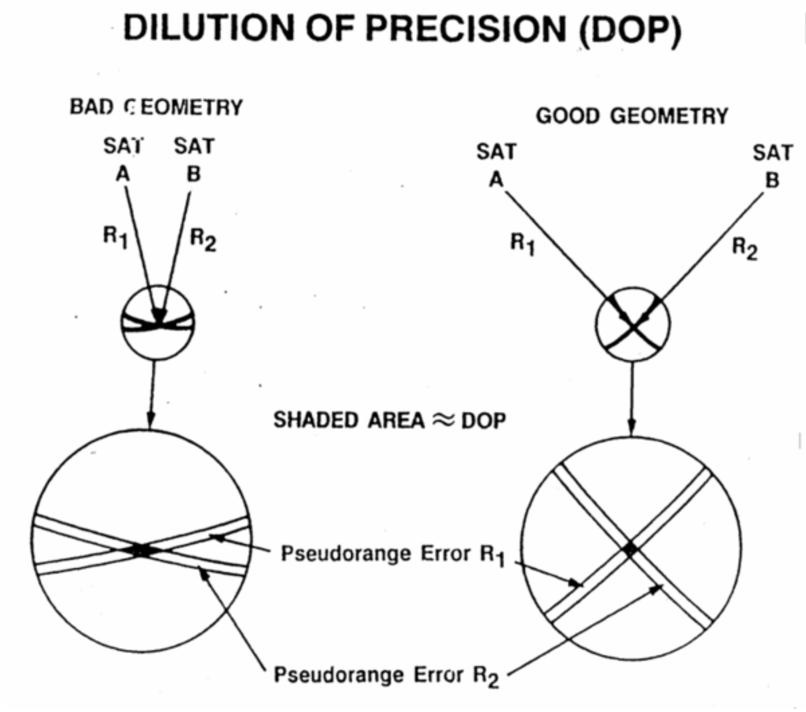

Figure 1.7: Dilution Of Precision

The concept of DOP can be illustrated by reasoning in two dimensions. If the angle at which the LOPs cross is small, precision is greatly diluted. If the LOPs cross at 90°, the position error is proportional to the distance error. In three dimensions dilution will be minimal if three SATs are observed 120° apart just above the horizon and a SAT is directly overhead.

The measurement of the propagation time for the descendant SAT/receiver signal is affected by several factors:

- ionospheric propagation delay (IPD) (most significant factor)
- satellite position (ephemeris)
- synchronisation (satellite clock)
- receiver noise
- multi-trajectory.

These factors introduce an equivalent error on the SAT/receiver distance measurement, known as User Equivalent Ranging Error (UERE).

Final localisation precision may be expressed as the product of UERE and a degradation factor from the Geometric Dilution Of Precision (GDOP). POSITION ERROR = UERE x GDOP.

In three dimensions this degradation or dilution factor is called Position Dilution Of Position (PDOP).

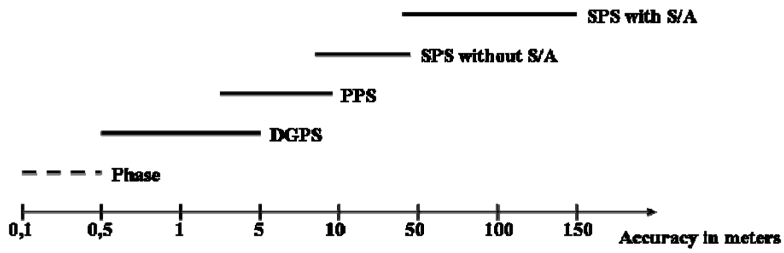

Figure 1.8: Errors

The precision of non-augmented GPS, i.e. without additions, is variable. It depends on the service used (PPS or SPS), presence of SA, differential correction data and lastly receiver dynamics ("static" receivers in civil engineering used a phase tracking technique to improve precision). The requirements of the civil aviation community are quite high: highly dynamic receivers, integrity and availability.

1.10 Ground Based Augmentation System (GBAS)

The **GBAS** is a local augmentation of GPS and GLONASS based on the concept of local differential.

The technique of local differential assumes a spatial correlation in the errors. Two receivers located fairly closely together (< 30 km) take the same measurements that have the same errors. A ground or differential receiver, whose exact position is known, helps provide corrective terms for an embedded GPS receiver nearby.

The ICAO **GBAS** uses a data connection on VHF band ILS-VOR (108–118 Mhz) to send corrections. The data connection is known as VHF Data Broadcast (VDB).

The range of a GBAS station is on the order of 30 km. Coverage is from 35° Azimuth up to 15 nautical miles of the threshold and 10° Azimuth between 15 nautical miles and 20 nautical miles from the threshold.

The ICAO GBAS can interconnect the GBAS stations to create a large-scale differential correction network, which is called a Ground Regional Augmentation System (**GRAS**).

The GBAS is sometimes referred to as the Local Area Augmentation System (LAAS).

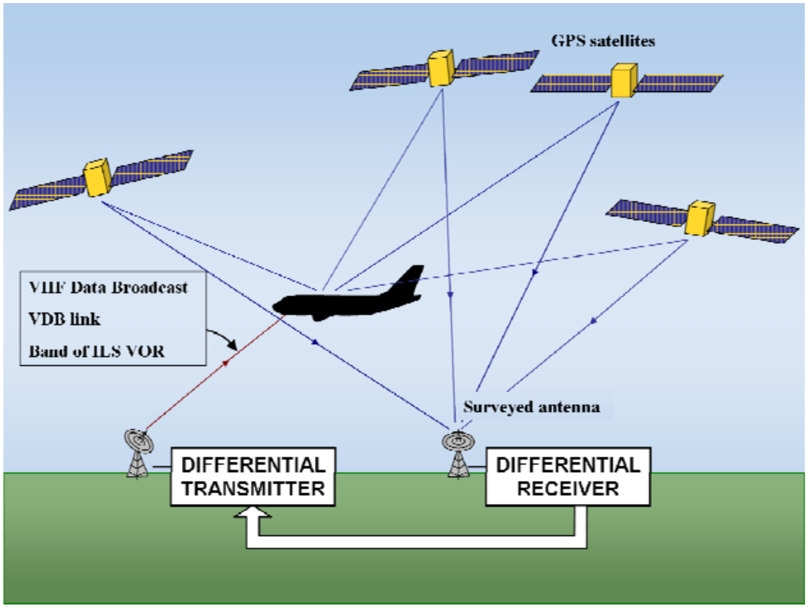

Figure 1.9: GPS Differential

1.11 Satellite Based Augmentation System (SBAS) – European Geostationary Navigation Overlay Service (EGNOS)

An **SBAS** is a regional augmentation (at the continental level) of **GPS/GLONASS**. An **SBAS** has three sub-sections:

- a ground infrastructure of **GPS/GLONASS** signal control stations
- one or more geostationary **SBAS satellites**
- **SBAS** receivers (augmented GPS/GLONASS receivers).

The station network monitors the GPS/GLONASS signals and emits a correction signal to the geostationary **SBAS satellites.** Correction data is then emitted over a large area to the **SBAS** receivers.

Various SBAS have been developed, including Wide Area Augmentation System (**WAAS**) for the USA, European Geostationary Navigation Overlay Service (**EGNOS**) for Europe, **MSAS** for Japan and **GAGAN** in India.

EGNOS, the European augmentation to **GPS,** has been operational and available for air navigation since March 2011. It relies on a network of 40 ground stations and three geostationary INMARSAT satellites emitting corrections and GPS pseudo-signals.

EGNOS monitors, corrects and assures signals provided by **GPS** and gives Europe a positioning precision on the order of 1 to 2 metres on the horizontal plane and 3 to 5 metres on the vertical plane.

It significantly augments integrity and reduces the warning delay to only six seconds (compared with two to three hours for GPS alone).

1.12 Airborne Based Augmentation System (ABAS)

ABAS is an augmentation to GPS that uses airborne data to improve integrity.

Unlike **GBAS** and **SBAS**, **ABAS** does not improve precision.

A GPS receiver equipped with Receiver Autonomous Integrity Monitoring (**RAIM**) includes technology that improves GPS integrity. To locate a position, a user must access four satellites with good geometry (i.e., PDOP<6 and elevation angle greater than 5°). RAIM requires redundant data and thus additional satellites. Five satellites are required to detect a faulty satellite. Six satellites are required to detect and isolate the faulty satellite. RAIM is an ABAS technology that uses only GNSS data.

Aircraft Autonomous Integrity Monitoring (**AAIM**) uses data from onboard sensors (inertia and pressure-altitude).

1.13 GLONASS

GLONASS is the satellite navigation system of the Russian Federation. It has been in operation since January 1996.

GLONASS specifications:

- 24 satellites, 3 orbital planes, 8 SATs per plane
- Quasi-circular orbits at 19,100 km inclined at 64.8° relative to the equator
- Period of 11 hours and 15 minutes

- Each satellite emits two signals on Band L, an L1 carrier at 1.6 Ghz and an L2 carrier at 1.2 Ghz
- L1 for standard navigation service and L2 for precise navigation service (authorised users only)

1.14 GALILEO

GALILEO is the future European satellite navigation system, which will become operational in 2014.

GALILEO specifications:

- 30 satellites, 3 orbital planes inclined at 56° relative to the equator. Nine SATs +1 spare per plane.
- Quasi-circular orbits at an altitude of 23,222 km.
- Period of 14 hours
- Each satellite emits two signals (two frequency bands 1164–1215 Mhz and 1559–1591Mhz)

1.15 GPS Acronyms

GNSS

Global Navigation Satellite System

GPS

Global Positioning System

GLONASS

GLOBal Navigation Satellite System

DOD

Dept Of Defense

SPS

Standard Positioning Service

PPS

Precision Positioning Service

PRN

Pseudo Random Noise

C/A code

Coarse acquisition code

P-code

Precision code

GDOP

Geometric Dilution of precision

SA

Selective Availability

SBAS

Space Based Augmentation System

GBAS

Ground Based Augmentation System

ABAS

Airborne Based Augmentation System

RAIM

Receiver Autonomous Integrity Monitoring

IPD

Ionospheric Propagation Delay