北京航空航天大學
BEIHANG UNIVERSITY

Avionics Technology

B31353551

— *Radio Navigation*

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Spring Semester 2023 (11_May_T12)

VI. Radio Navigation

（1）Some concepts

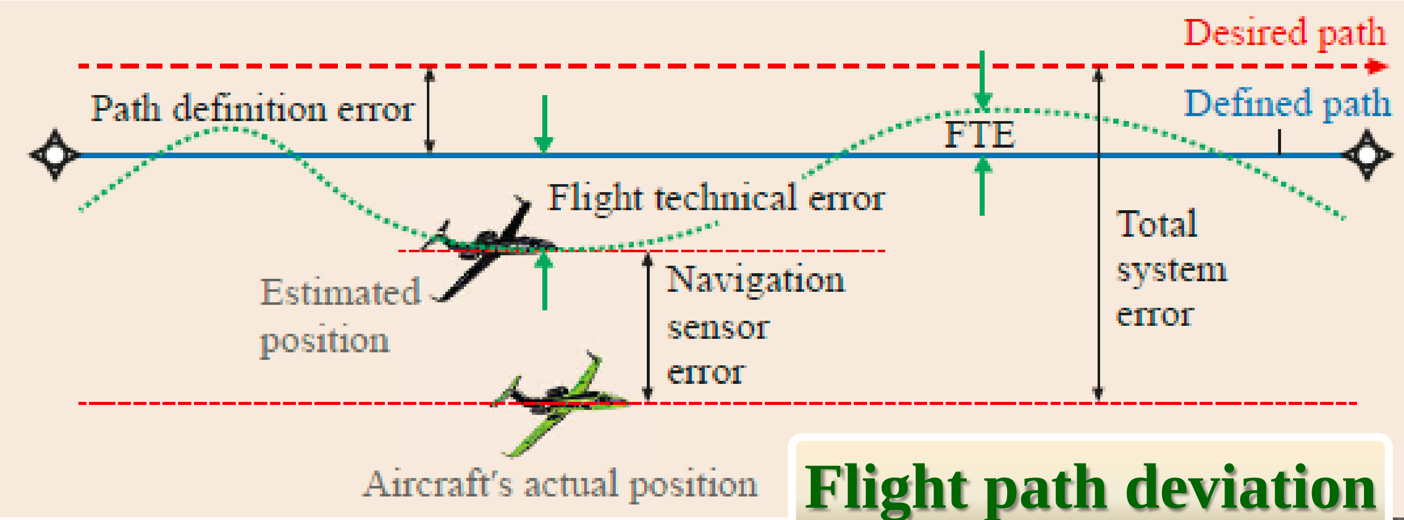
（2）Radio landing systems

（3）Rho-theta navigation systems

（4）Satellite navigation systems

(1) Some concepts

- Radio navigation systems consist of airborne and ground- or satellite-based navigation aids, including range- and direction-measuring radio navigation systems, radio-technical landing systems, short- and long-range systems, and satellite navigation systems.



Flight path deviation

(1) Some concepts

- Airborne equipment usually provides the radio navigation signal detection and its processing, and the ground- or satellite-based radio beacons — the forming of the radio signals of required structure and its emission. The systems based on radio waves conditions are exposed to radio interference and are not autonomous in most cases.

Airborne equipment: radio receiver

Radio beacon: radio transmitter

（1）Some concepts

- NDB (Non Directional Beacon) is simply just a ground-based AM radio transmitter which radiates radio waves in all directions (omnidirectional). In the aircraft, the receiving antenna was originally manually adjusted to find the signal bearing (azimuth angle), but very quickly became automated and is then called Automatic Direction Finding (ADF).

（1）Some concepts

- Each NDB is identified by a two- or three-letter Morse code call sign, which is the only (repeated) information modulated on radio signals radiated by the NDB transmitter. Amplitude shift keying (ASK) is used for audible distinction of signals from different NDBs.
- If incoming radio waves hit the ADF antenna loop in any direction other than directly perpendicular, a specific composite voltage *e* will be induced over the antenna, and the ADF can deduce down to the relative bearings to the beacon.

(1) Some concepts

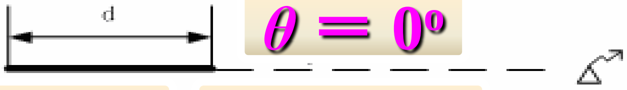
$$e = E\sin(\omega t+\varphi) - E\sin(\omega t-\varphi)$$
$$= 2E\sin\varphi\cdot\cos\omega t$$

$\sin\varphi \approx \varphi = \omega d/2c = \pi d/\lambda$ (d << λ due to λ is in the order of km)

Hence, $e \approx 2E(\pi d/\lambda)\cdot\cos\omega t$

If $\theta = 0^{o}$, then $e = e_{max}$

At other θ s , $e < e_{max}$



$\theta = 0^{o}$

$E\sin(\omega t-\varphi)$ $E\sin(\omega t+\varphi)$

Case *b*: point in the direction of NDB

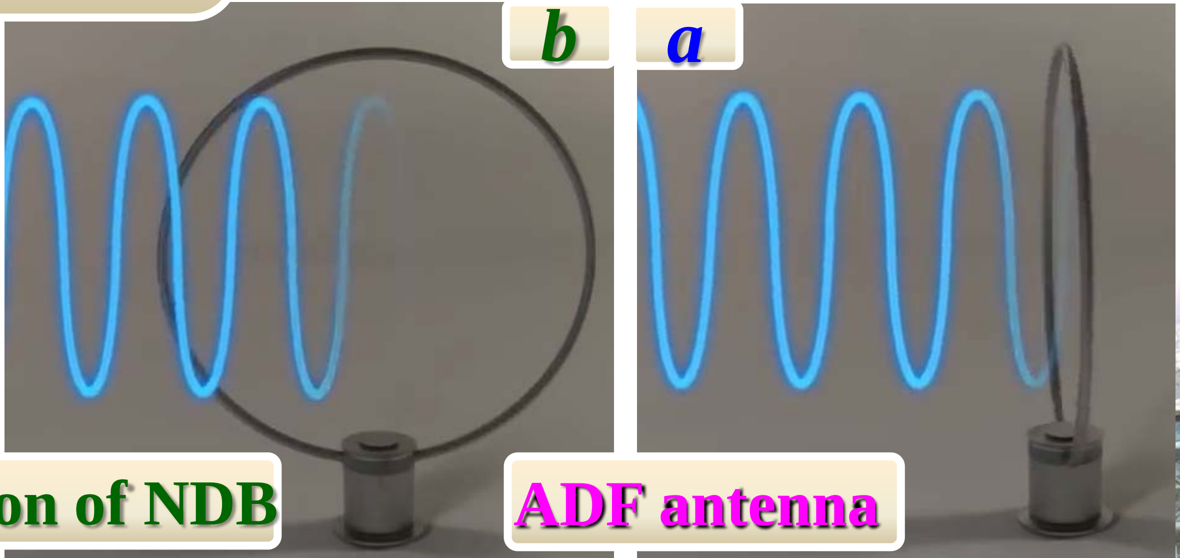
Case *a*: perpendicular direction

$E\sin\omega t$

$e = 0$

$\theta = 90^{o}$

$E\sin\omega t$



b *a*

ADF antenna

(1) Some concepts

- Today, NDB is considered the most basic navigation aid used in aviation operating on medium frequency (MF) band. Such a system has low accuracy of navigation that worsens with its departure from radio beacon, and serve as a backup for the more accurate systems.

Airborne ADF antenna

NDB station

(1) Some concepts

- Radio-technical methods of determining navigation parameters (distance, direction of signal arrival, etc.) use functional dependence between radio signals parameters (amplitude, frequency, phase and time of propagation along the radio path) and navigation parameters.

Radio navigation signal

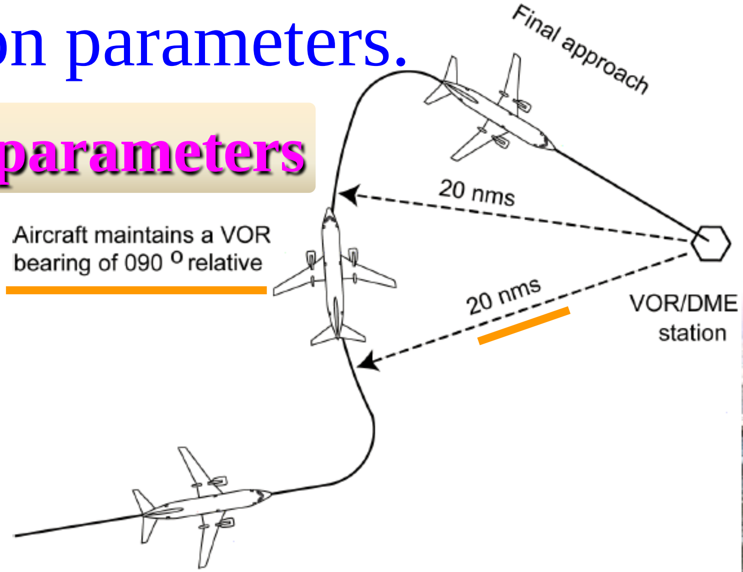
$$e(t) = A\cos(2\pi f_c t + \varphi)$$

Amplitude

Frequency

Phase

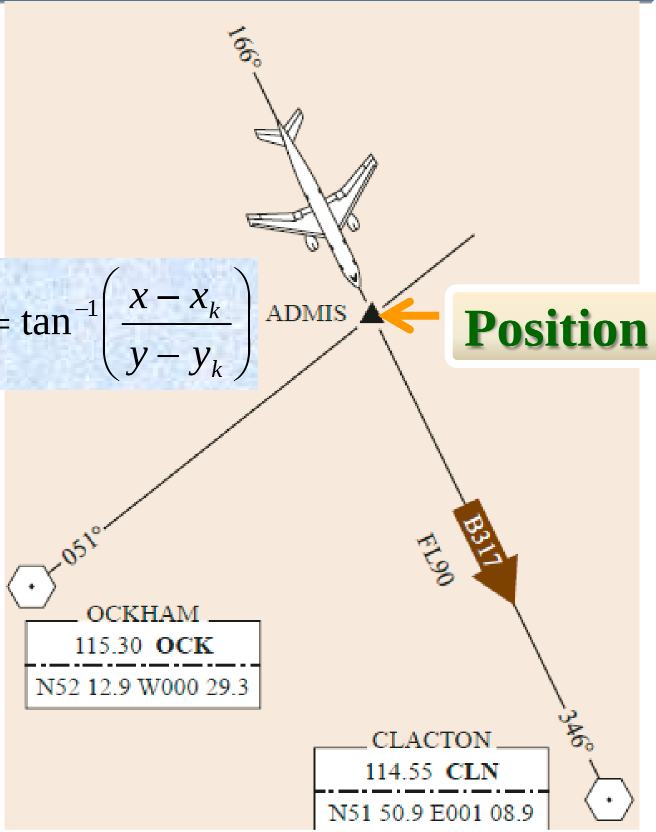
Navigation parameters



(1) Some concepts

- The aircraft's position determination is based on the *intercept or LOP* (lines of position) *method*. Line of position is the geometric locus on a plane, where each point has the constant navigation parameter value. Two or more lines of position intersection (crossing) is a result of navigation parameter measurement. LOP can be straight lines of specific bearing's values (azimuth), circle lines of equivalent distances, a circle line of equivalent distance and a straight line of specific bearing value (azimuth).

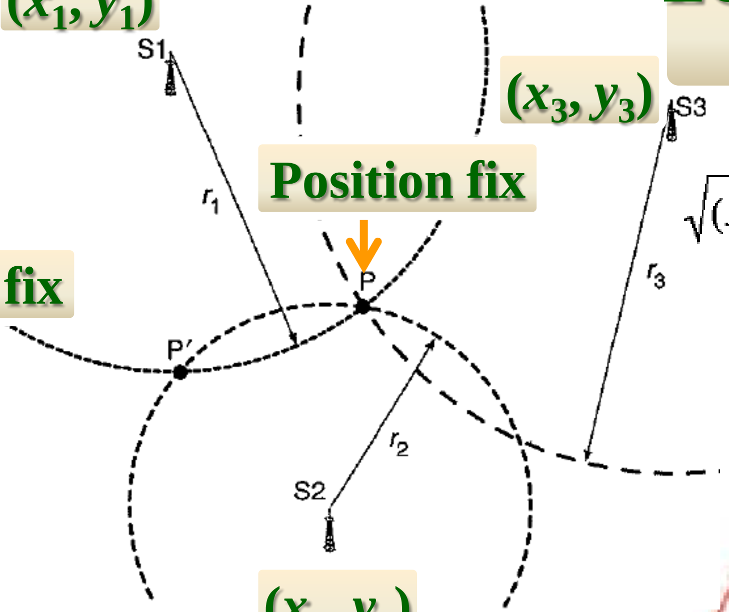
(1) Some concepts



$$\Theta_k = \tan^{-1}\left(\frac{x-x_k}{y-y_k}\right)$$

Position fix

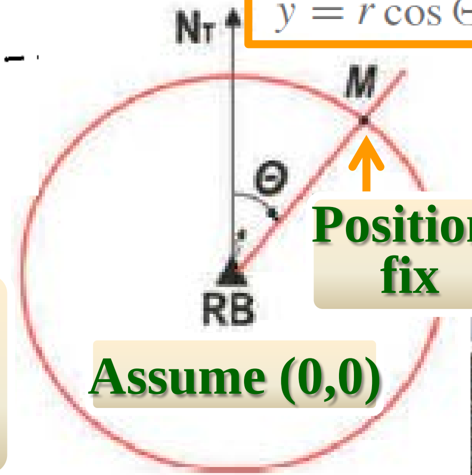
LOP of specific bearings



LOP of equivalent distances

$$\sqrt{(x_k - x)^2 + (y_k - y)^2} = r_k$$

$$x = r \sin\Theta$$
$$y = r\cos\Theta$$



Assume (0,0)

LOP of specific bearing and equivalent distance based on single station

（2）Radio landing systems

- Landing is the most complicated stage (phase) of flight at the end of which an aircraft should be taken to the set point on the runway (RW) surface. Radio-technical landing systems are thus able to provide a precise control of the flight path during the final approach of aircraft in all weather conditions.

Poor visibility landing condition

(2) Radio landing systems

- Landing is greatly influenced by meteorological factors, density and intensity of air traffic in the vicinity of Airports. Aircrafts are guided to be lined up for intercepting ILS signal.

Radar screen at ATC center for landing instructions

(2) Radio landing systems

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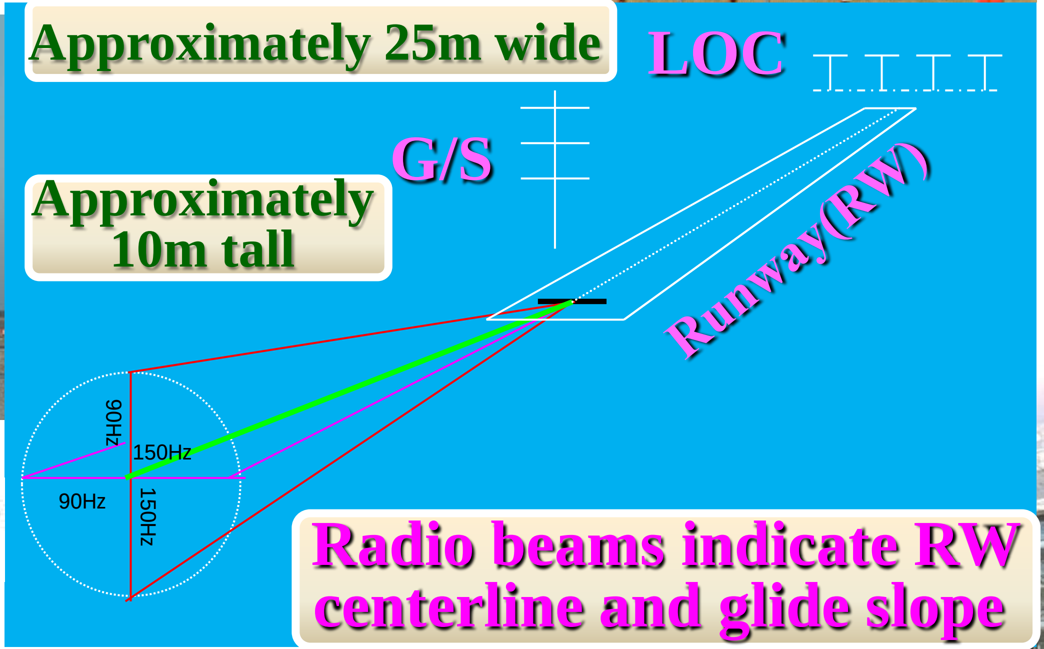
- ILS (*Instrument landing system*) is a approach guidance system installed at major airports and airfields which provides guidance in poor visibility conditions during the approach to the runway. A small number of airports are also equipped with MLS (*Microwave landing system*) which is more accurate. However, it will still be a long time before ILS is completely replaced by MLS.

Airport equipped with MLS

(2) Radio landing systems

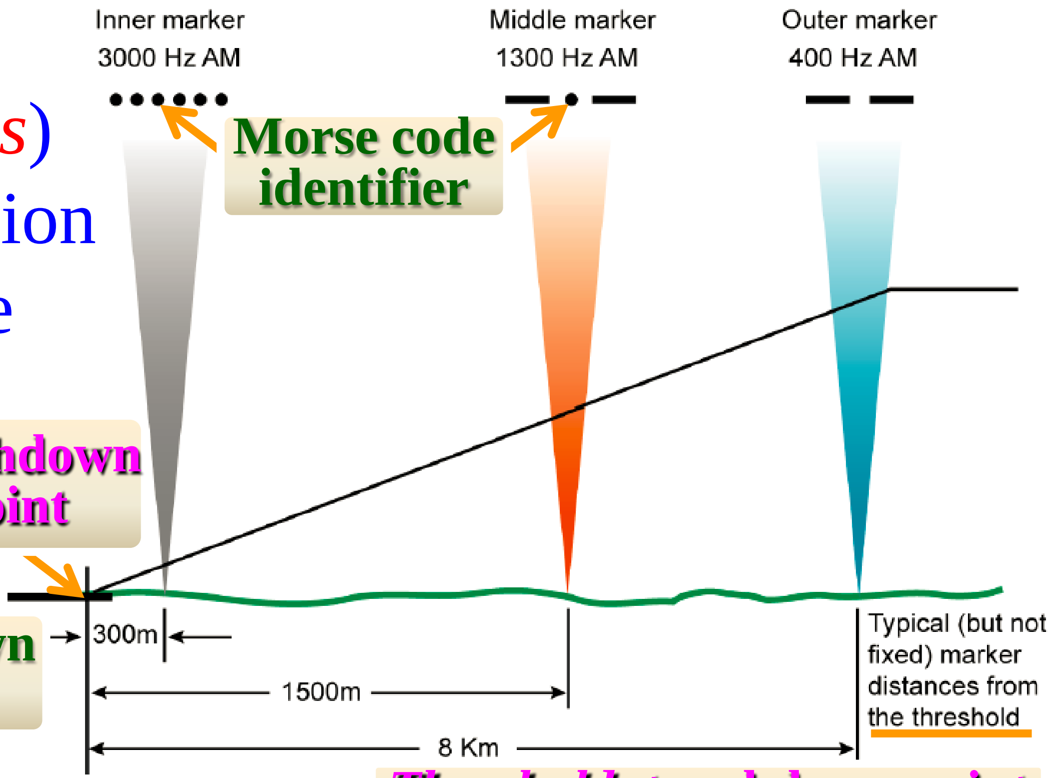
- The ILS system basically comprises a *localizer* (LOC) transmitter situated at the end of the runway and a *glide slope* (G/S) transmitter situated at the edge of the runway.



Following the glide path with the aid of ILS

(2) Radio landing systems

- The ILS also determines the moments of passing three points on the glide path (namely *marker beacons*) situated along an extension of the runway centerline at a certain distance relative to the runway threshold.



Touchdown point

Touchdown zone

2 ~ 4° approach slope to RW plane

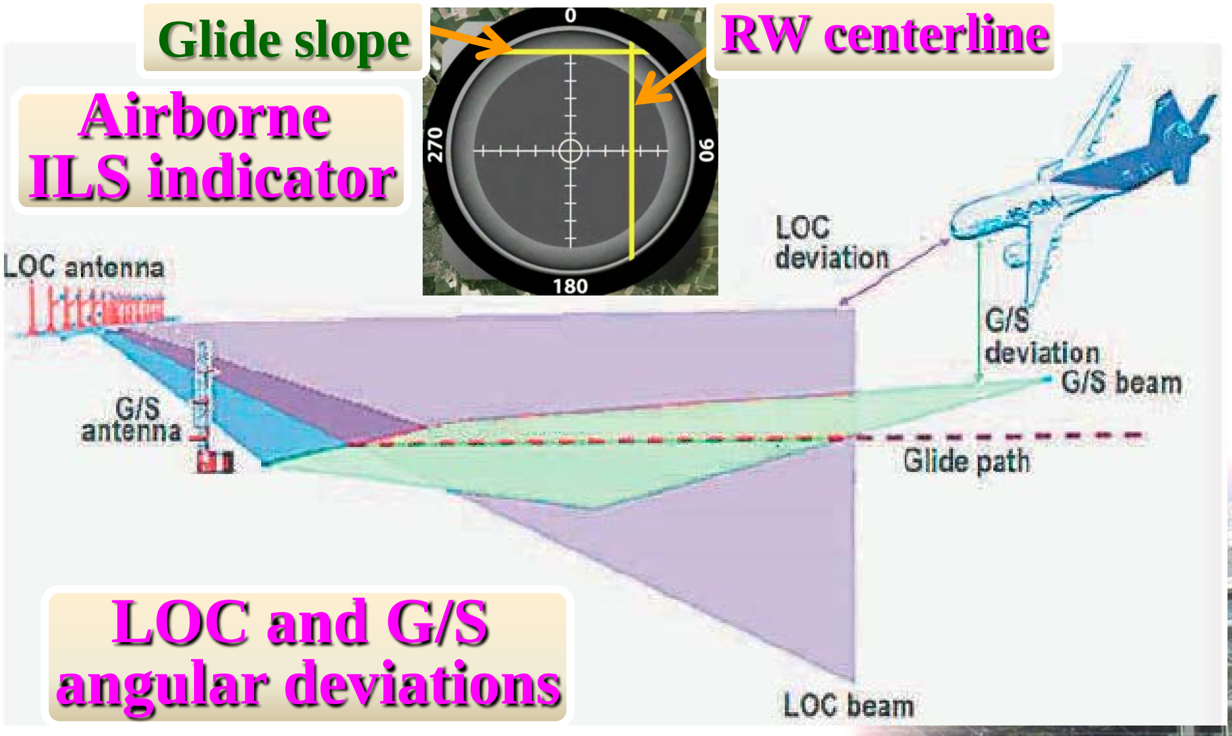
***Threshold*: touchdown point**

(2) Radio landing systems

- The landing system aids the aircraft to fly along a specified trajectory, i.e. a glide path, and can be considered as a guidance to a region of admissible lateral and vertical deviations from the ideal descent path.

Flying along the ideal descent path

- LOC and G/S radio beacons form radiation fields defining a course plane (a vertical plane passing through the runway centerline) and a descending/gliding plane (a plane sloped to the ground plane at an angle of approximately 3º.



(2) Radio landing systems

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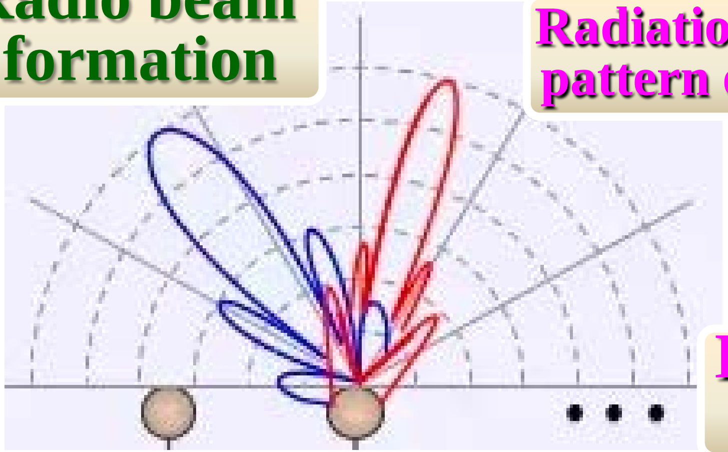
- The main method of determining the direction by means of localizers and glide slope beacons is an *equi-signal* method. The LOC or G/S transmits two overlapping radio beams of equal energy on the same VHF or UHF carrier wave frequency.

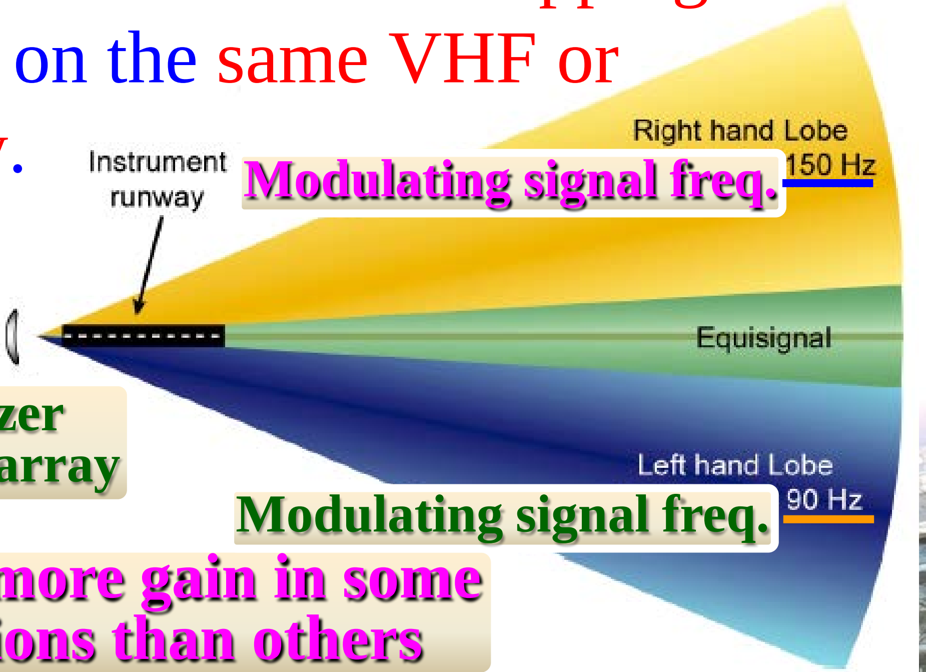
Radio beam formation



Radiation power pattern envelope

Having more gain in some directions than others

Localizer antenna array

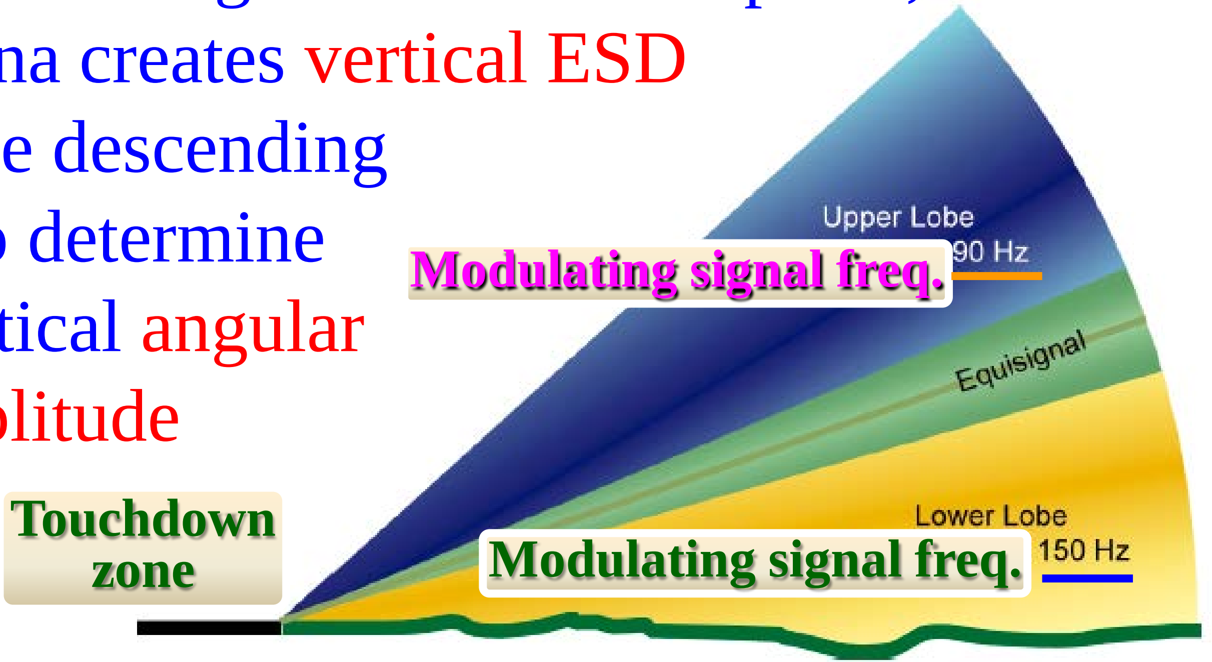


Modulating signal freq.

Modulating signal freq.

(2) Radio landing systems

- The center of the overlap area defines the ILS equi-signal direction (ESD). The LOC antenna creates horizontal ESD coinciding with the course plane, and the G/S antenna creates vertical ESD coinciding with the descending / gliding plane. To determine the lateral and vertical angular deviation, the amplitude modulation (AM) is employed.



(2) Radio landing systems

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- The VHF transmitter at LOC or G/S generates and emits two amplitude-modulated signals:

$$e_1 = E_m F_1(\theta)(1+m\cos \Omega_1 t) \cos\omega t$$
$$e_2 = E_m F_2(\theta)(1+m\cos \Omega_2 t) \cos\omega t$$

E_m are amplitudes at antenna outputs assumed to be equal

$F_1(\theta)$ or $F_2(\theta)$ is the directivity of antenna, a function of direction (azimuth or elevation angle θ) of the beam pattern

m are indexes of amplitude modulation(amplitude sensitivity)

Ω_1/Ω_2 equals to 90Hz or 150Hz; ω are frequencies of carriers

(2) Radio landing systems

- When combining the radiation fields produced by the transmitting antennas, a resultant amplitude-modulated field e with modulating frequencies of 90 Hz and 150 Hz is formed in space as:

$$e = e_1 + e_2 =$$

$$E_m[F_1(\theta)+F_2(\theta)][1+M_1(\theta)\cos\Omega_1 t+M_2(\theta)\cos\Omega_2 t]\cos\omega t$$

$$M_1(\theta) = \frac{mF_1(\theta)}{F_1(\theta)+F_2(\theta)} \quad M_2(\theta) = \frac{mF_2(\theta)}{F_1(\theta)+F_2(\theta)}$$

$M_1(\theta)$, $M_2(\theta)$ are depths of space modulation (DoSM)

(2) Radio landing systems

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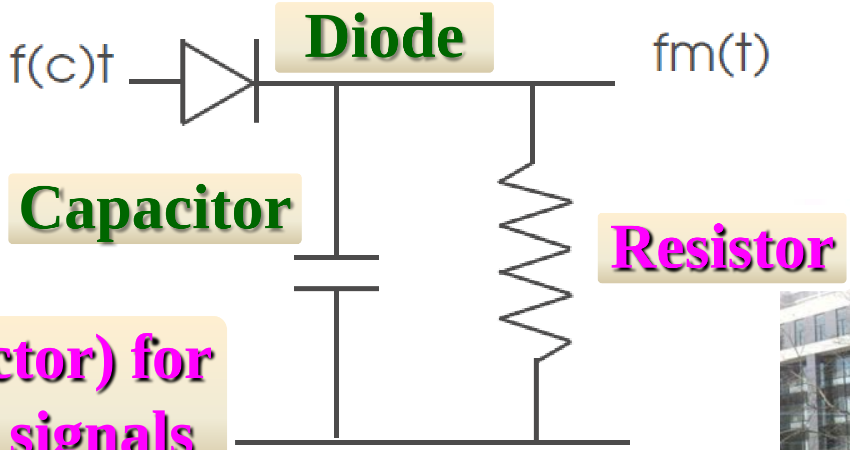
- The airborne ILS equipment extracts the modulation envelopes of 90 Hz and 150 Hz, and determines the difference in modulation envelope amplitudes which is proportional to the difference in depth of modulation (DDM). If the aircraft flies in the ESD, then DDM = 0.

Modulating (baseband) signal:

$$\boxed{M_1(\theta)\cos\Omega_1 t + M_2(\theta)\cos\Omega_2 t}$$



Envelope detector (extractor) for demodulating DSB-AM signals

(2) Radio landing systems

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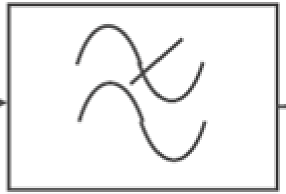
- The difference in depth of modulation (DDM) is finally derived from a comparer: DDM $= M_1(\theta) - M_2(\theta)$ $= m[F_1(\theta) - F_2(\theta)]/ [F_1(\theta) + F_2(\theta)]$

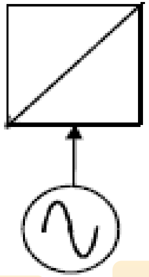
Combining baseband signal



$M_1(\theta)\cos \Omega_1 t/$
$M_2(\theta)\cos \Omega_2 t$

$M_1(\theta)\cos \Omega_1 t$
$+M_2(\theta)\cos \Omega_2 t$

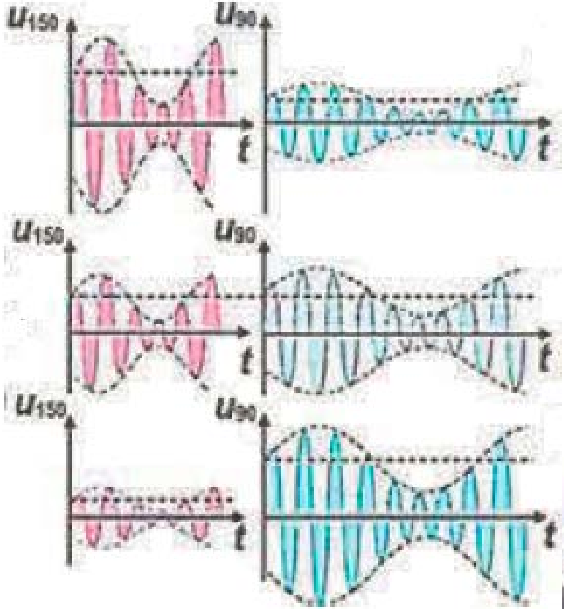
90 /150Hz filter



Comparer input

$M_1(\theta)/M_2(\theta)$

Coherent detector



Baseband signal with freq. of 150Hz

Baseband signal with freq. of 90Hz