Avionics Technology

B31353551

— Radio Navigation

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VI. Radio Navigation

（1） Some concepts

（2） Radio landing systems

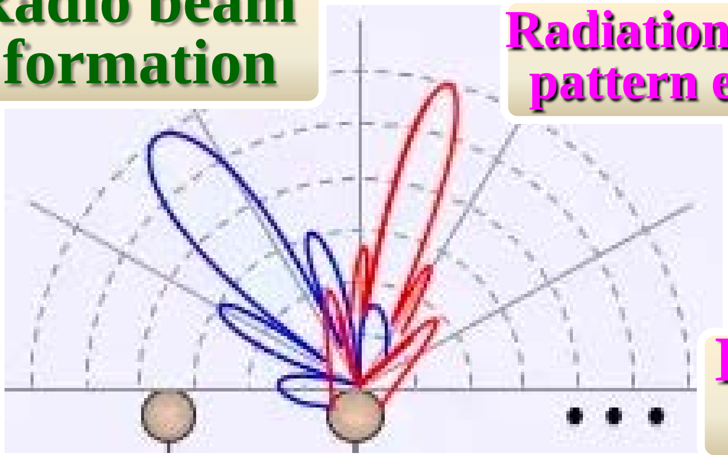
（3） Rho-theta navigation systems

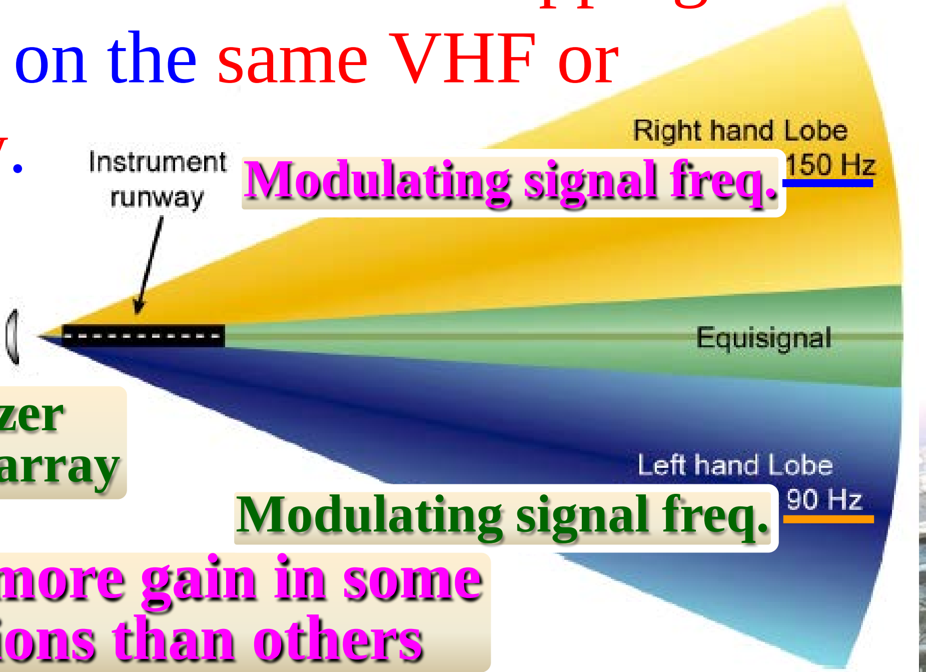
（4） Satellite navigation systems

(2) Radio landing systems

- The main method of determining the direction by means of localizers or 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

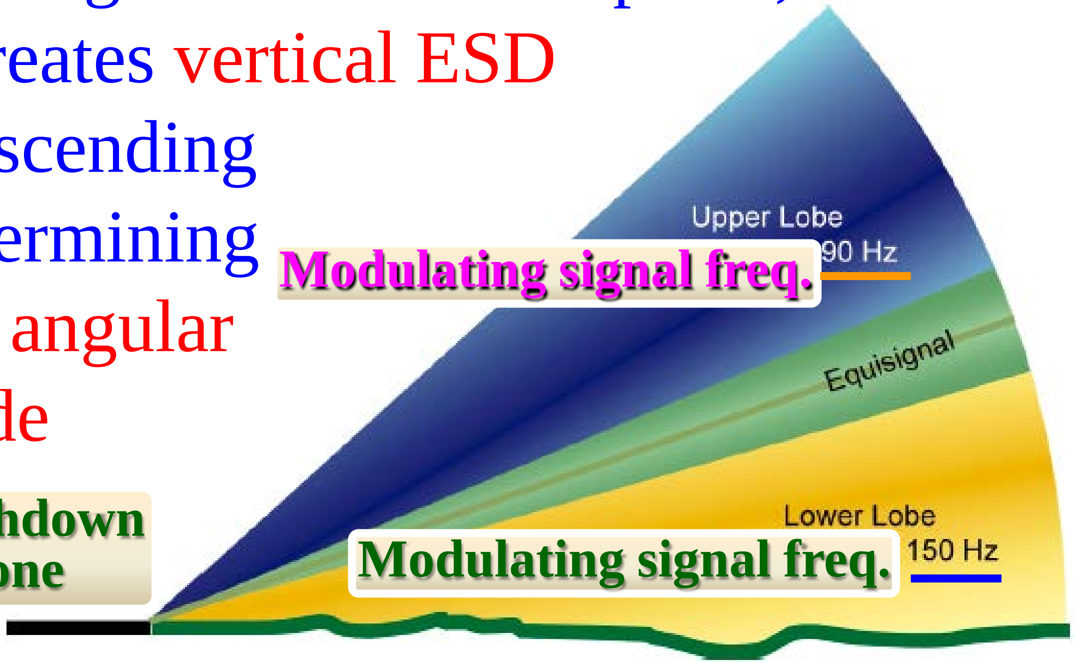




Having more gain in some directions than others

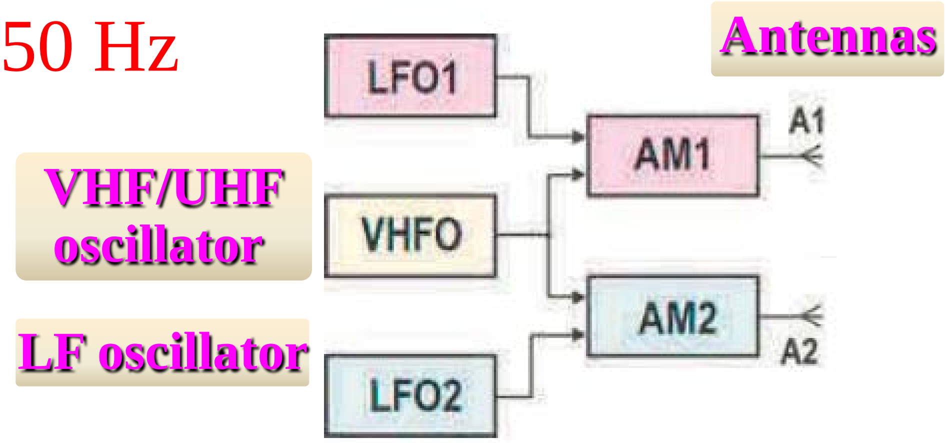
（2）Radio landing systems

- 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. For determining the lateral and vertical angular deviation, the amplitude modulation (AM) is employed.



(2) Radio landing systems

- The LOC and G/S implement the equi-signal method. VHF(108 ~ 122 MHz) or UHF(329.3 ~ 335 MHz) oscillator forms carrier oscillations. The oscillations are amplitude modulated in amplitude modulators AM1 and AM2 with low-frequency 150 Hz oscillation and with 90 Hz oscillation. AM signals are supplied to antennas A1 and A2 having overlapping antenna patterns.



LOC (G/S) transmitter schematic

(2) Radio landing systems

- The VHF or UHF transmitter at LOC or G/S generates and emits two amplitude-modulated (AM) 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 factor 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 150Hz or 90Hz; 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 150 Hz and 90 Hz is formed in space as:

$$e = e_1 + e_2 =$$

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

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

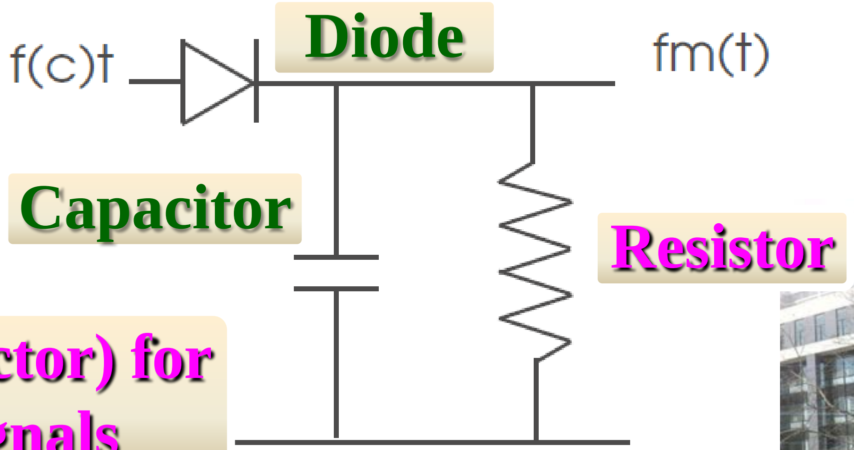
$M_1(\theta)$, $M_2(\theta)$ are known as *depths of space modulation* (DoSM)

(2) Radio landing systems

- The airborne ILS equipment extracts the modulation envelopes of 150 Hz and 90 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:

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



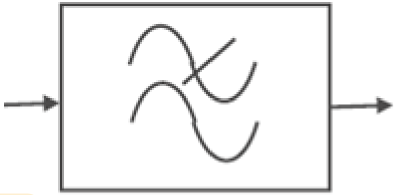
Envelope detector (extractor) for demodulating AM signals

(2) Radio landing systems

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

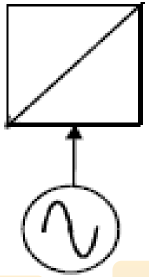
Combining baseband signal

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



150 /90Hz filter

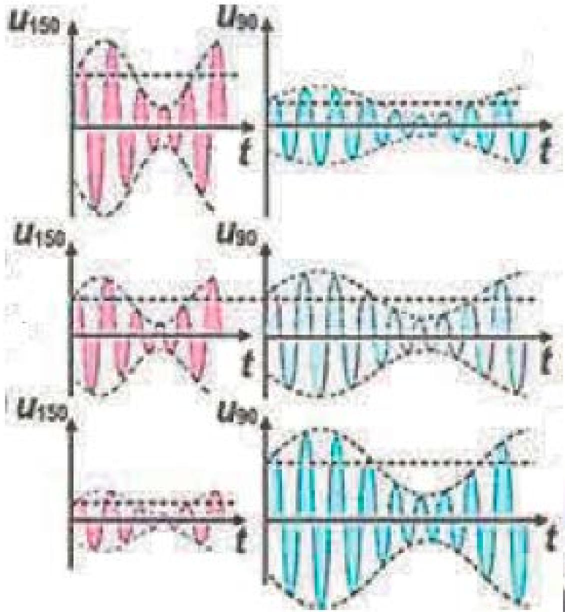
$M_1(\theta)\cos \Omega_1 t / M_2(\theta)\cos \Omega_2 t$



AM demodulator

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

Comparer input



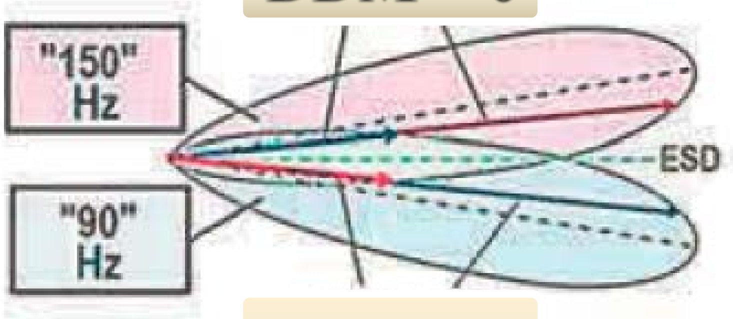
Baseband signal with freq. of 150Hz

Baseband signal with freq. of 90Hz

（2）Radio landing systems

- The amplitudes of spectral components of the resultant radiation field depend on the depths of space modulation which in their turn depend on deviation of the aircraft from the ESD. If aircraft deviates left or right (up or down) from the ESD, the amplitude of the component of 90 Hz(150Hz) frequency increases (decreases) or decreases (increases), and then DDM < 0 or DDM > 0 will be detected on the aircraft.

DDM > 0



DDM < 0

In ESD, DDM = 0 or $F_1(\theta) = F_2(\theta)$

(3) ρ-θ navigation systems

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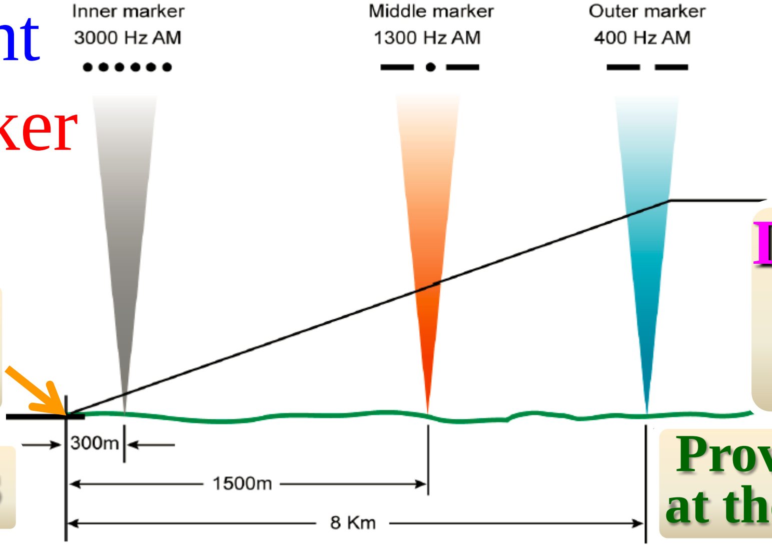
- For the ILS, the guidance of an approaching aircraft position relative to the touchdown zone can also be provided with the use of the continuous signals of a DME system in replacement of the marker beacons.



Touchdown point

Marker beacons

DME station near an airfield

Providing a 0 reading at the touchdown point

（3）ρ-θ navigation systems

- The information displayed on aircraft:
  - ✓ Distance in NM between aircraft and DME station
  - ✓ Speed of the aircraft
  - ✓ Time to reach the station

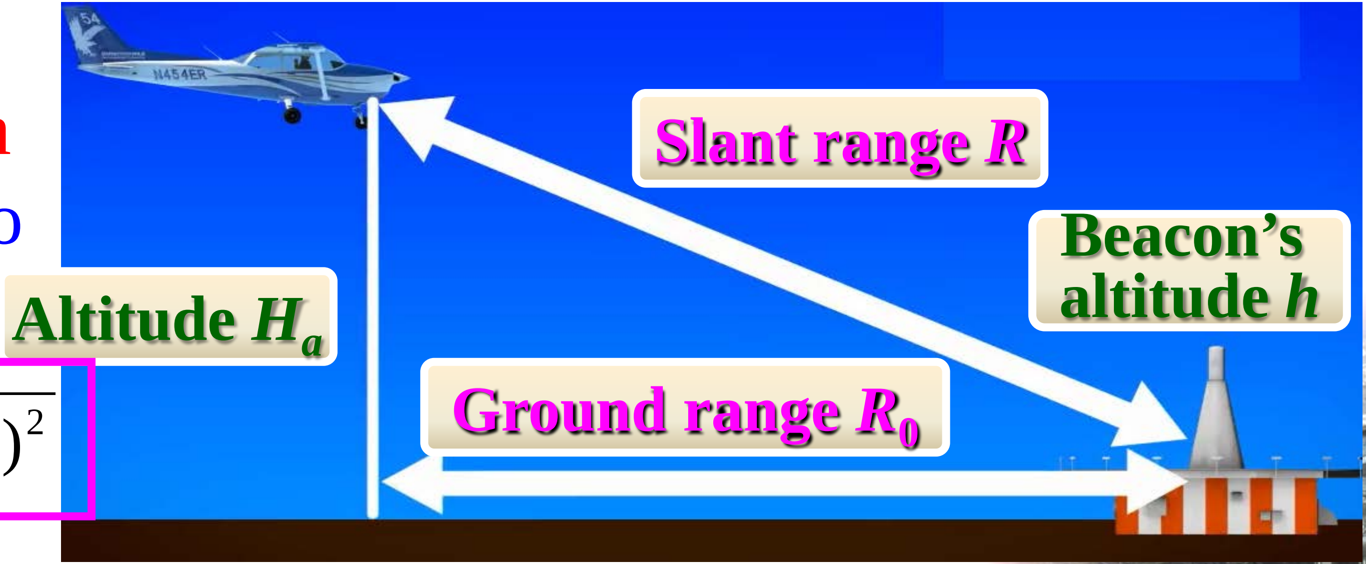
Airborne DME equipment

Station identifier (Morse code: MOU)

DME/VOR station on aviation chart

(3) ρ-θ navigation systems

- *Distance-measuring equipment* (DME) is designed to determine a slant range of an aircraft relative to a ground-based radio beacon, which is intended to determine the aircrafts' position at a distance of not more than 400 ~ 500 km from the radio beacon.



$$\boxed{R_0 = \sqrt{R^2 - (H_a - h)^2}}$$

（3）ρ-θ navigation systems

- The DME measures an aircraft’s distance in a straight line (LOS) to the ground beacon (slant range), not the distance from a point on the ground vertically below it (i.e. ground range).

LOS: line of sight

Ground range as a function of altitude and slant Range

Altitude (FT)	Ground Range (NM) Slant Range (NM)						
	0.5	1	2	3	4	5	10
0	0.5	1.0	2.0	3.0	4.0	5.0	10.0
1000	0.5	1.0	2.0	3.0	4.0	5.0	10.0
2000	0.4	0.9	2.0	3.0	4.0	5.0	10.0
3000	0.1	0.9	1.9	3.0	4.0	5.0	10.0
4000	-	0.8	1.9	2.9	4.0	5.0	10.0
5000	-	0.6	1.8	2.9	3.9	4.9	10.0
10000	-	-	1.1	2.5	3.7	4.7	9.9
15000	-	-	-	1.7	3.2	4.4	9.7
20000	-	-	-	-	2.3	3.8	9.4

(3) ρ-θ navigation systems

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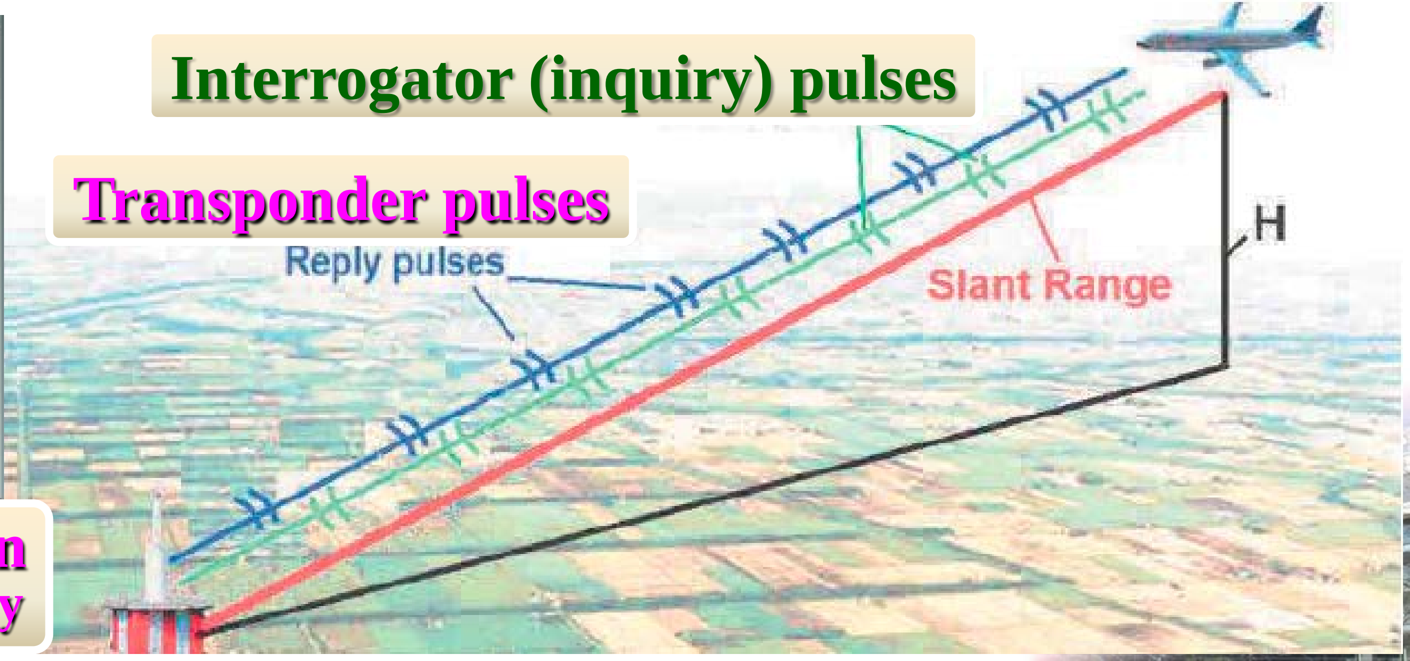
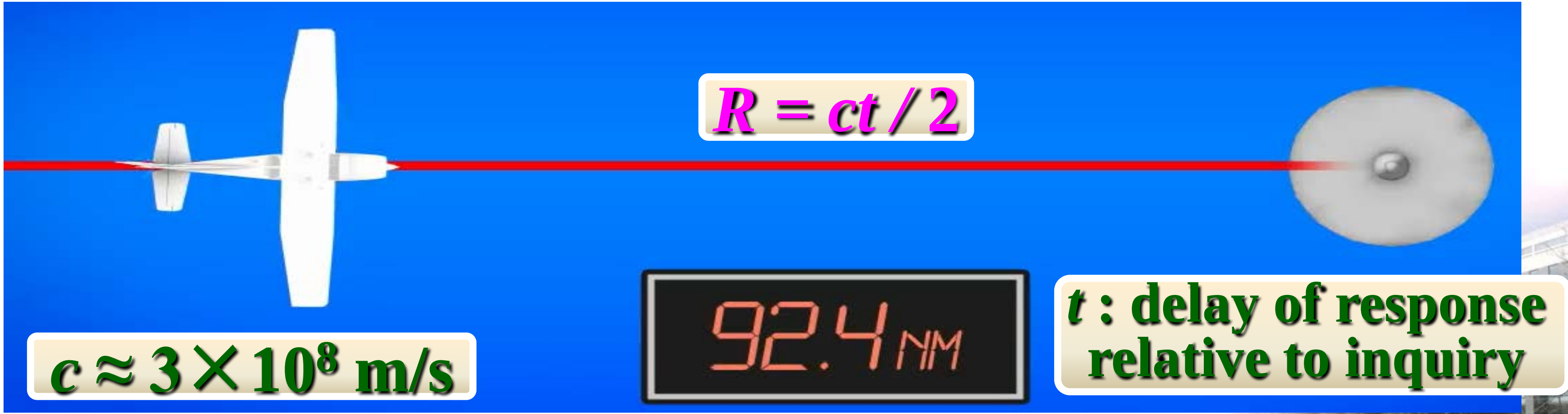
- DME provides distance information using the pulse signals, which includes a ground-based radio beacon (a transponder) and onboard equipment (an interrogator).

DME indication on primary flight display



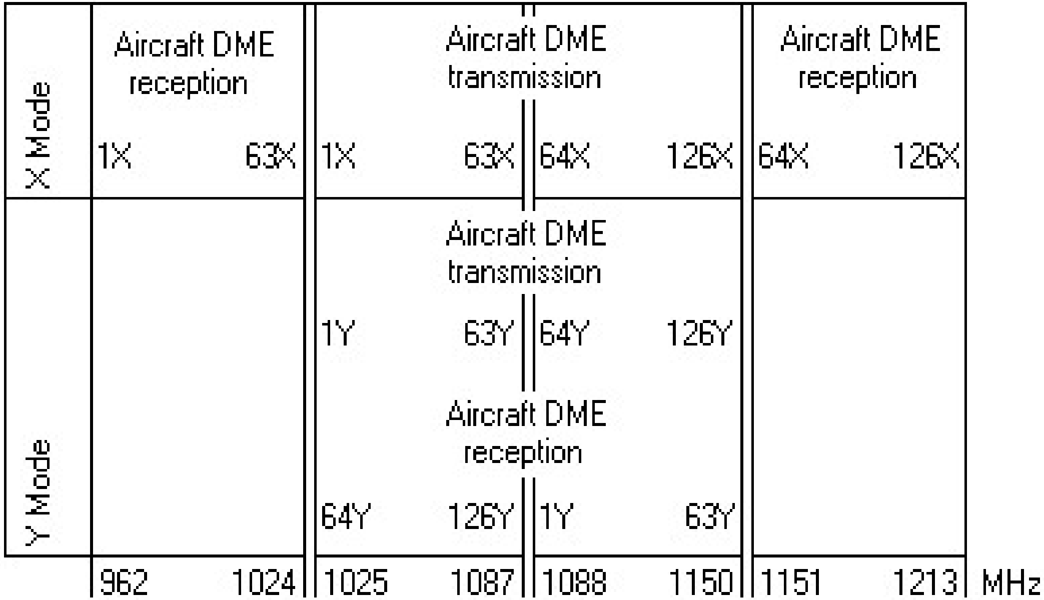
(3) ρ-θ navigation systems

- The onboard interrogator can calculate the time to reach ground beacon. Pilot sets the VHF DME frequency on the interrogator, which is paired with the frequency of DME ground transponder (UHF band), and waits for a response to the inquiry which can derive the slant range.



(3) ρ-θ navigation systems

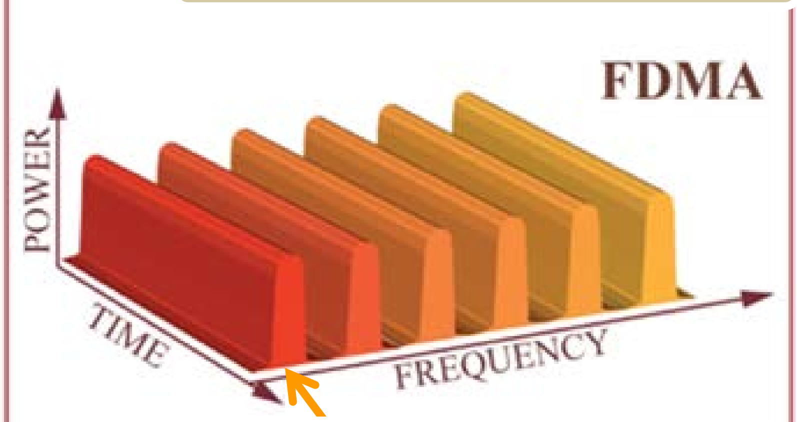
- DME works in the frequency range of 962~1,213 MHz at 1 MHz spacing, which provides 252 frequency channels. The channels are numbered 1~126X and 1~126Y. The frequencies on which the DME are divided to the frequency for interrogation which are paired to response frequency.



(3) ρ-θ navigation systems

- If the DME is in X mode and the interrogator frequency is in the range from 1025 ~ 1087 MHz, 63 MHz is deducted from the frequency of interrogation (the transponder frequency will be in the range from 962 ~ 1024 MHz). However, if the interrogator frequency is between 1088 and 1150 MHz, the 63 MHz is added to the interrogator frequency (i.e. 1151 ~ 1213MHz).

Putting multiple channels into one radio band



One sub-band per user

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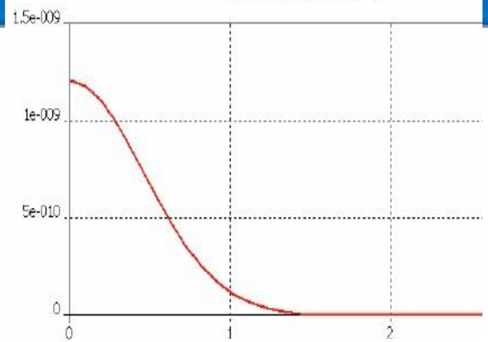
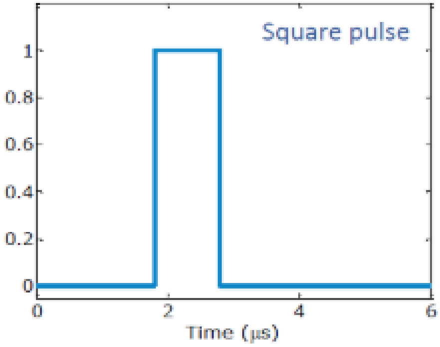
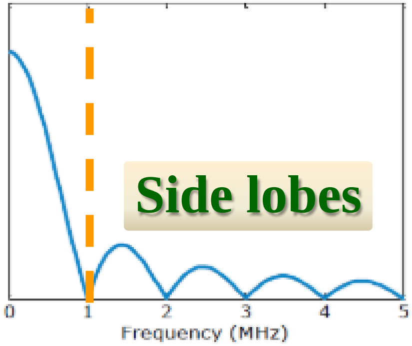
- To eliminate an influence of side lobes of the pulse signal spectrum on adjacent frequency channels, DME uses pulse signals having a special bell(Gaussian)-like shape.



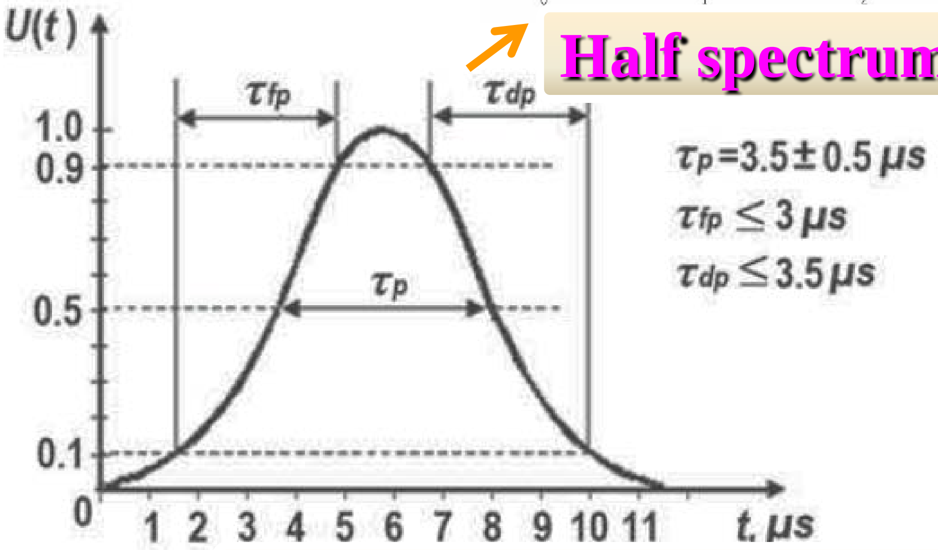
Half spectrum



Commonly used square pulse



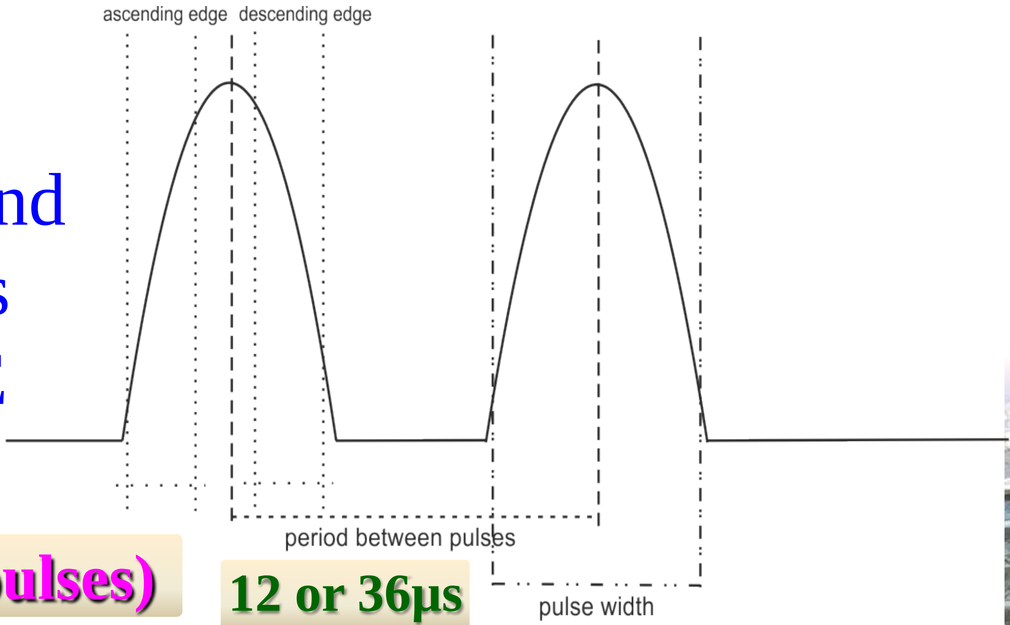
Half spectrum



Envelope of a DME pulse

（3）ρ-θ navigation systems

- The pulse signals in the case of DME are in a pair and called double-pulses. Double pulses have specific characteristics : pulse width (3.5±0.5μs), length of leading and descending edges (≤ 3μs), amplitude, period between pulses. And the period between pulses determines whether DME operates in X or Y mode.



12 or 36μs

DME double pulses (coded pulses)

(3) ρ-θ navigation systems

- A delay τ between the time of radiating an interrogation signal and that of receiving a response (reply) signal is determined by

$$\tau = 2R/c + t_{\text{del}}$$

where R is a distance between the interrogator and transponder, t_{del} is a signal delay in the transponder equipment which is formed from the time needed for processing the interrogation signal received. Then, the measured range is determined as

$$R = \frac{c}{2}(\tau - t_{\text{del}})$$

- DME ground beacon receives a double-pulse, adds delay of 50 or 56 μs depending on X or Y mode and sends the response (i.e. the received double-pulse) back to the interrogator. And the carrier frequency of the interrogator and the transponder are shifted 63 MHz up or down depending on mode X or Y. Before this, the onboard interrogator transmits the double-pulse with 12 (X) or 36 μs (Y) period between pulses.