北京航空航天大學
BEIHANG UNIVERSITY

Avionics Technology

B31353551

— Radio Navigation

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VI. Radio Navigation

（1）Some concepts

（2）Radio landing systems

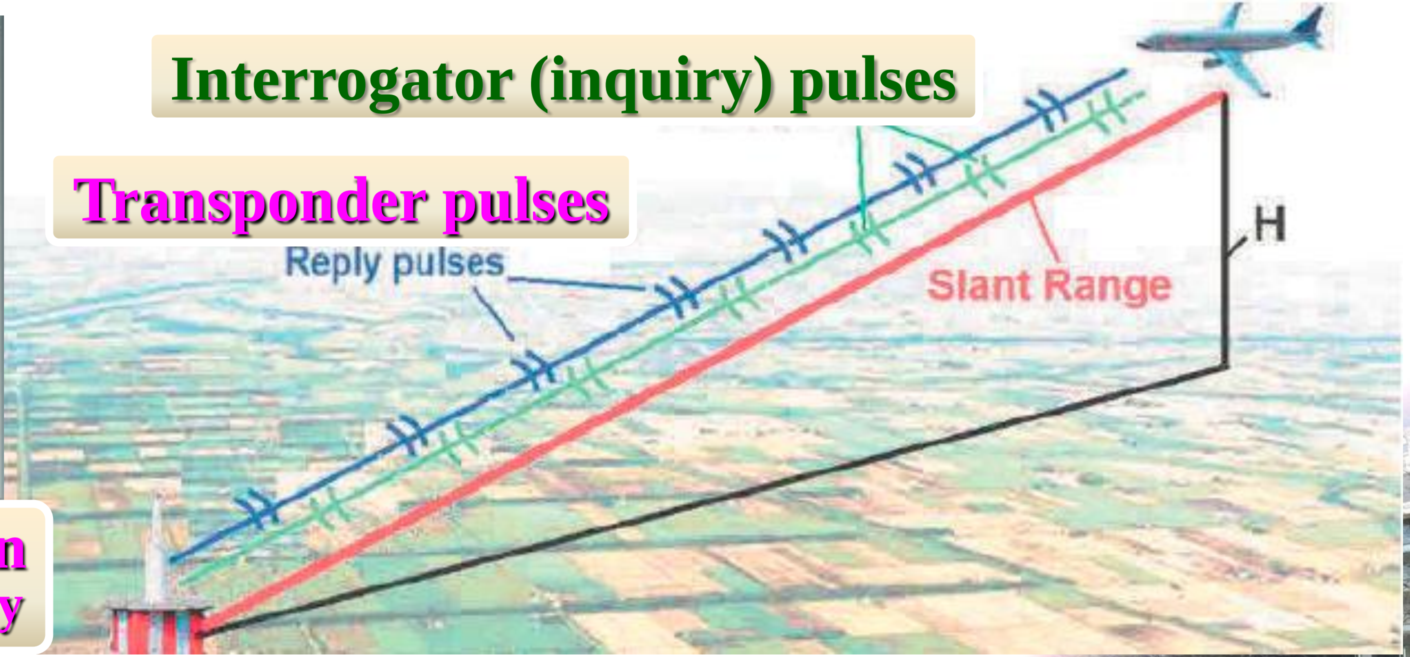
（3）Rho-theta navigation systems

（4）Satellite navigation systems

(3) ρ-θ navigation systems

- 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

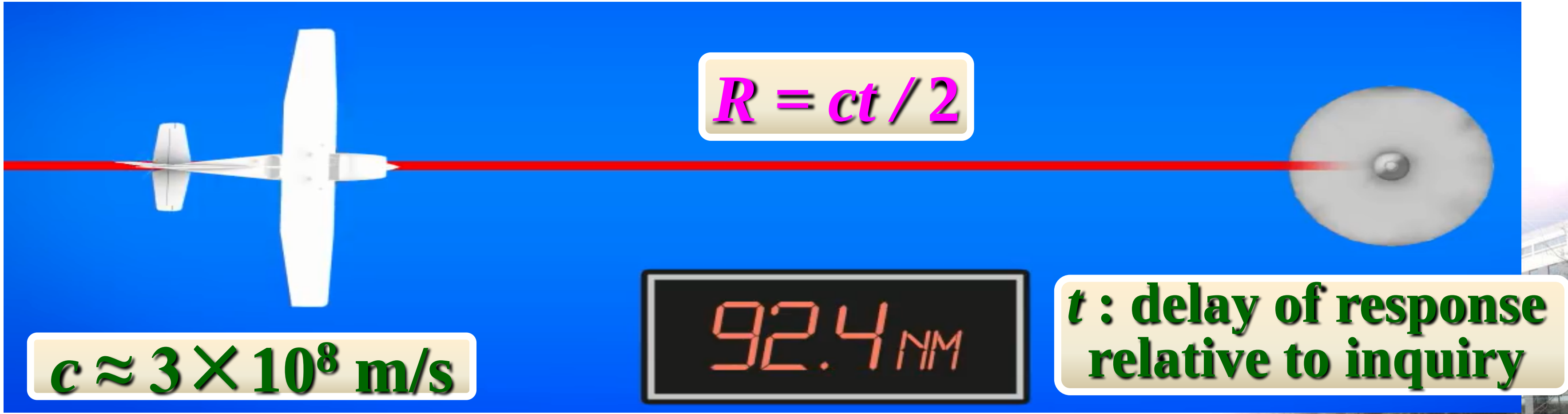


Interrogator (inquiry) pulses

Transponder pulses

(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

- Basic radar systems measure the range to objects by measuring the elapsed time between sending a pulse of radio energy and receiving a reflection of the object. And then the distance to the object is the elapsed time multiplied by the speed of light, divided by two (there and back).

Principle of pulsed radar

Surveillance radar (airport)

It rotates once every 4.8 seconds

(3) ρ-θ navigation systems

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- A delay τ between the time of radiating an interrogation signal and that of receiving a response (reply) signal is determined by $$\tau = 2R/c + t_{\mathrm{del}}$$

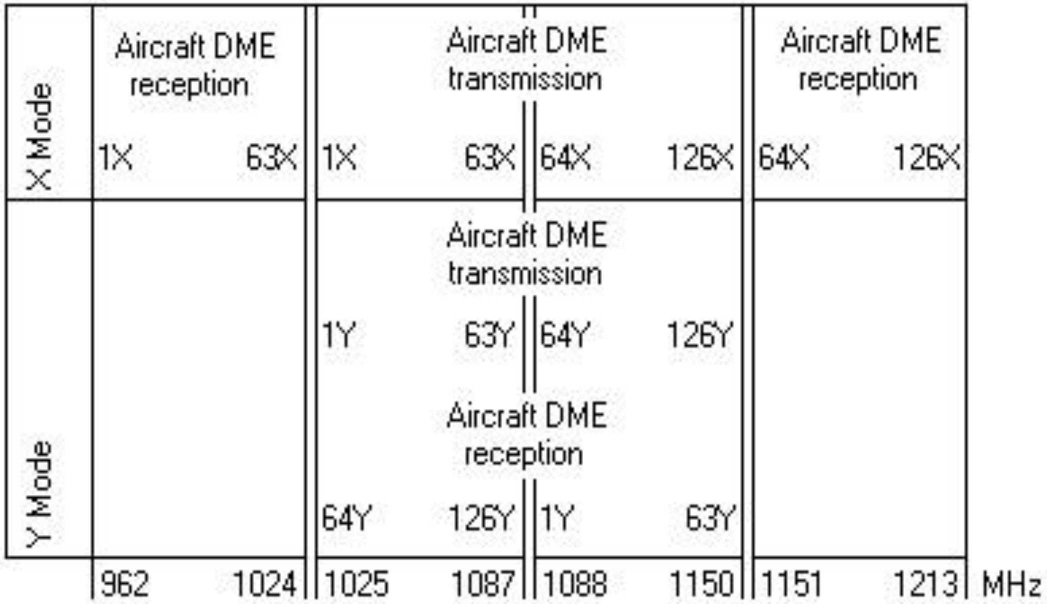
  where R is a distance between the interrogator and transponder, t_{del} is a signal delay in the transponder equipment which is formed from the time needed for processing the interrogation signal received. Then, the measured range is determined as

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

t_{del} : an intentionally introduced time delay

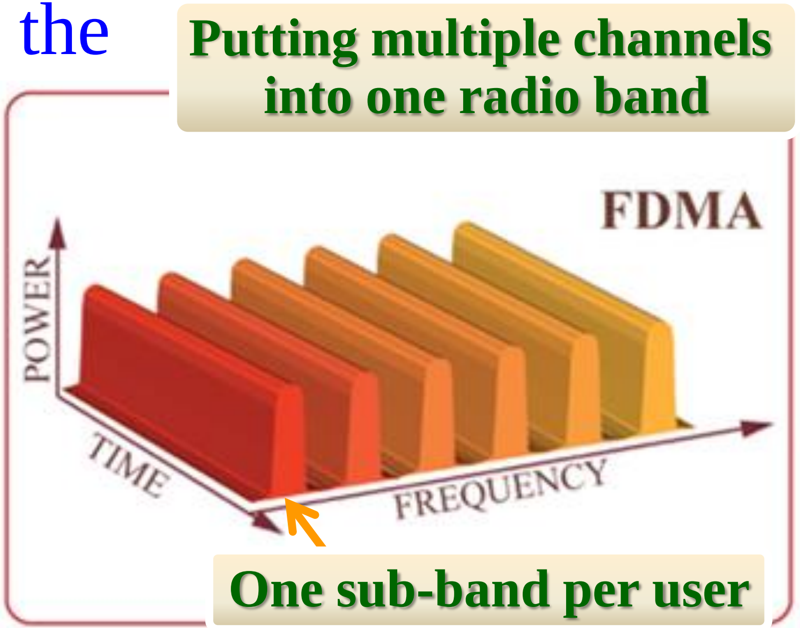
(3) ρ-θ navigation systems

- 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.



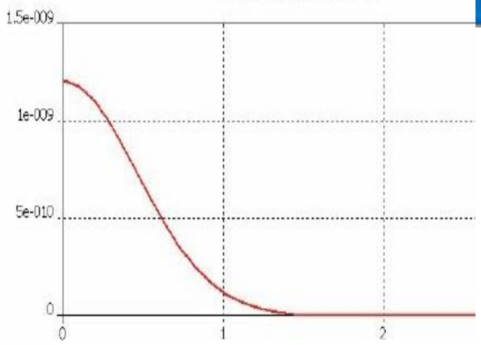
(3) ρ-θ navigation systems

- 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 (1151 ~ 1213MHz, transponder).

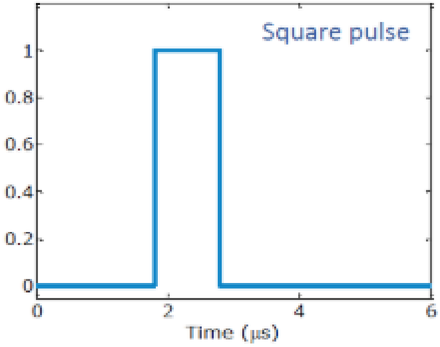


（3）ρ-θ navigation systems

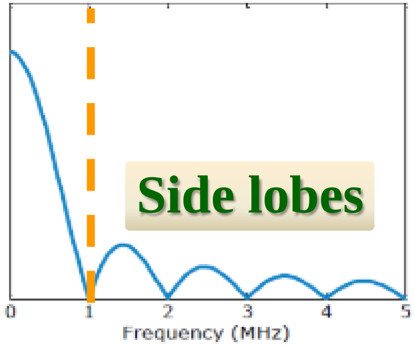
- To eliminate an influence of side lobes of the pulse signal spectrum on adjacent frequency channels, DME uses pulse signals having a special bell(Gaussian)-like shape.



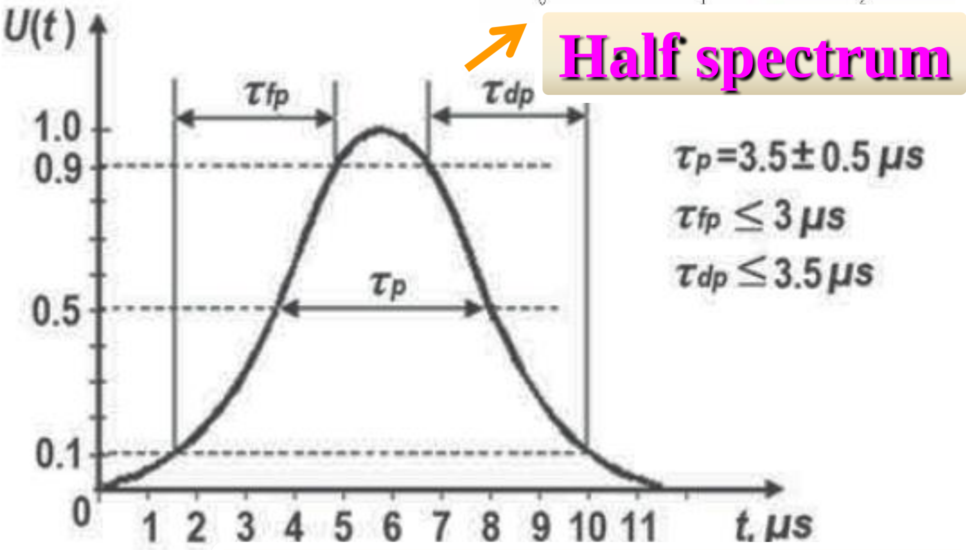
Half spectrum



Commonly used square pulse



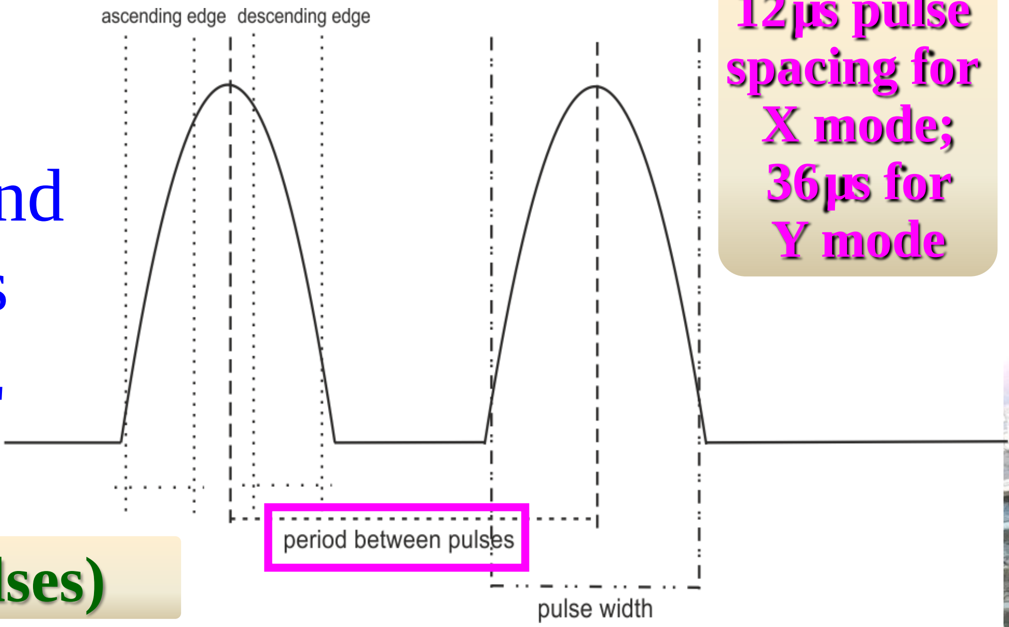
Half spectrum



Envelope of a DME pulse

(3) ρ-θ navigation systems

- The pulse signals in the case of DME are in a pair or 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.



12μs pulse spacing for X mode; 36μs for Y mode

DME pulse pair (coded pulses)

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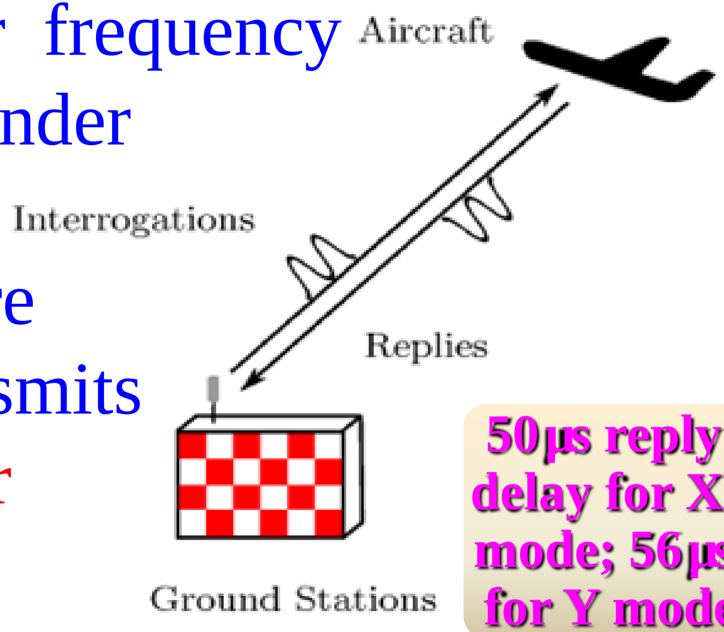
- DME ground beacon receives a double-pulse, adds delay of 50 or 56 μs (t_{del}) depending on X or Y mode and sends the response (i.e. the received double-pulse) back to the interrogator. And the carrier frequency of the interrogator and the transponder are shifted 63 MHz up or down depending on mode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



50μs reply delay for X mode; 56μs for Y mode

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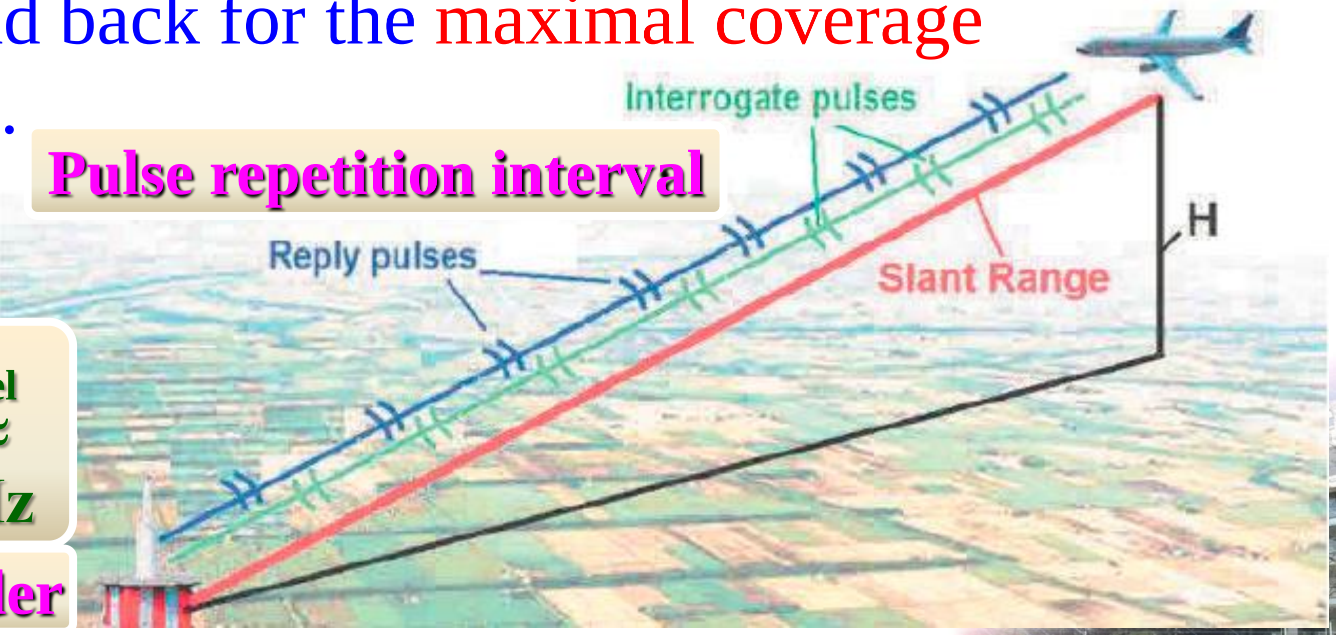
- The period of repetition of interrogation pulses T_{rep} should exceed the maximal total delay when propagating a signal from the interrogator to the transponder and back for the maximal coverage range $R_{\max}$, i.e.

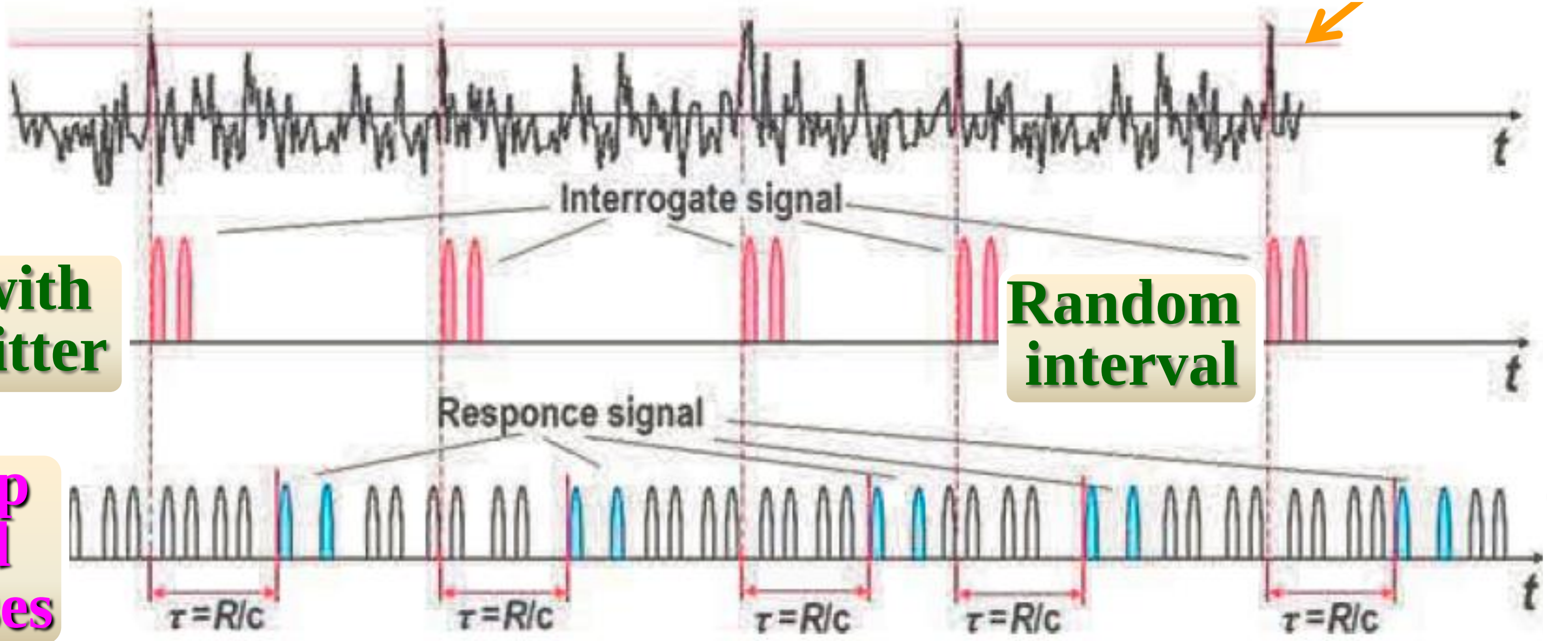
$$T_{\mathrm{rep}} \geq \frac{2R_{\max}}{c} + t_{\mathrm{del}}$$

If $R_{\max}$= 450km, t_{del} = 50μs, then T_{rep} ≈ 3ms or F_{rep} ≈ 330Hz



(3) ρ-θ navigation systems

- DME interrogation and reply signals are pulse pairs radiated at random intervals, i.e., the transmission sequence of pulses is irregular or jittered.

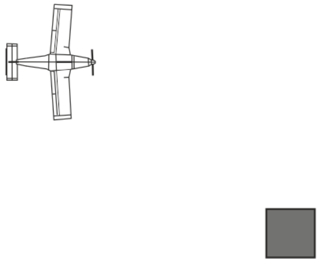


(3) ρ-θ navigation systems

- The aircraft transmits interrogations with randomly selected frequency- the *jitter*, waiting for the responses. The ground-based beacon/transponder is responding with the same jitter frequency. Onboard interrogator predicts when answers to its requests should come and seeks responses using time gating that have the same frequency as his original interrogations. The aircraft then distinguishes and correctly matches interrogations and responses from more aircrafts come into the beacon's range.

(3) ρ-θ navigation systems

- While the interrogator is searching for its right replies, in the so-called search mode, the interrogator sends 150 ppps (pulse pairs per second). After the replies being found (a definite number of reply pulse pairs fall within the gate), the interrogator goes into track mode, which only keeps communication with the beacon by sending 30 ppps.

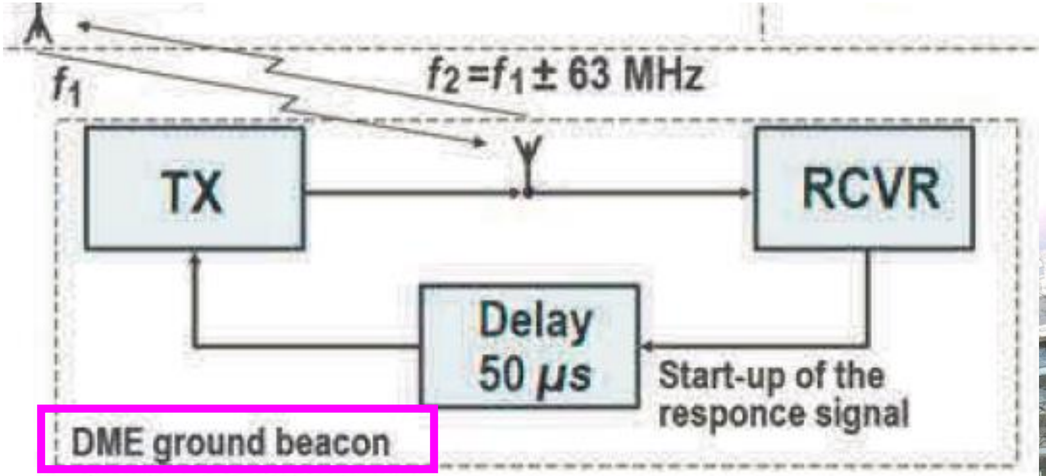


(3) ρ-θ navigation systems

- The peculiarity of DME operation is also that the beacon generates reply signals regardless of the presence or absence of interrogation signals from onboard. The mean power of the beacon transmitter depends on the frequency of generating reply signals and changes in its output power has an adverse impact on the operation of its output. In order to avoid quick changes in the number of transmitted replies (power), the beacon automatically generates *squitter* pulses (SP), at least 700 ppps when there are no interrogation signals.

(3) ρ-θ navigation systems

- When receiving interrogation signals, the beacon generates squitter pulses and replies to requests of aircrafts. The maximal frequency of generating such summarized reply signals must be at least 2,700 ppps. The higher the frequency of entering the interrogation signals is, the lower the frequency of generating the SP replies is, i.e. the beacon can suppress squitter automatically.



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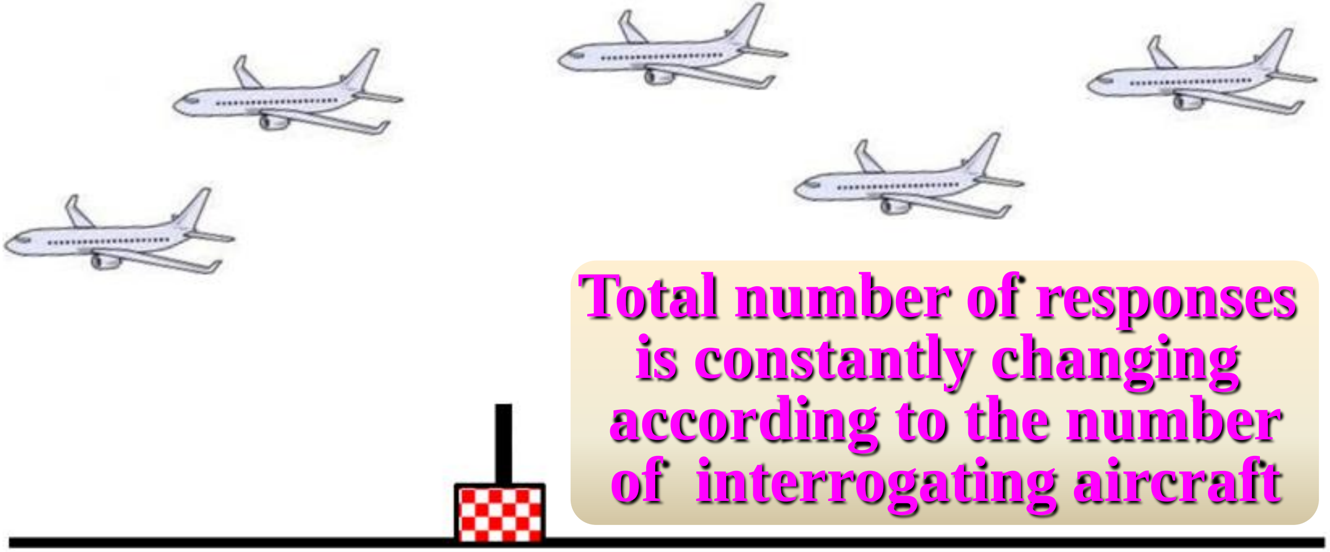
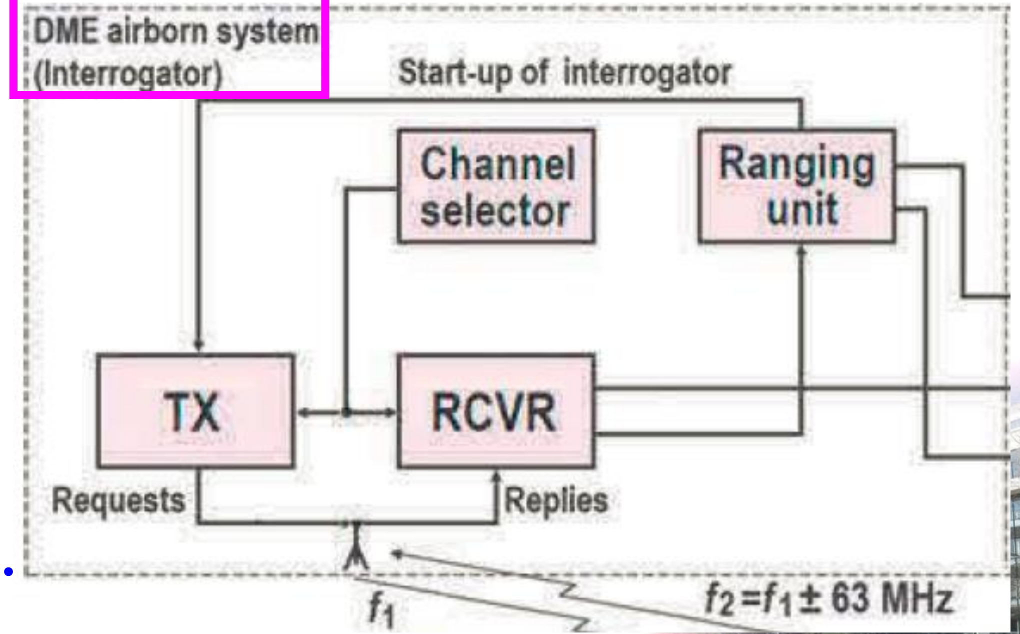
- For DME, the system capacity is 100 aircraft per second with reply efficiency (the ratio of replies to incoming interrogations) $K_{rep} = 0.9$. If the nominal number of responses ($K_{rep} > 0.9$) reaches, DME automatically reduces sensitivity and those aircraft that are the most distant are not served.



(3) ρ-θ navigation systems

- After receiving an SP of the beacon, the airborne DME starts to generate interrogation signals in the form of coded pulse pairs for the beacon. And the transponder receiver gets blocked for a so-called dead time (usually not less than 60 μs) after receiving interrogation pulses, which can eliminate the influence of echo signals.



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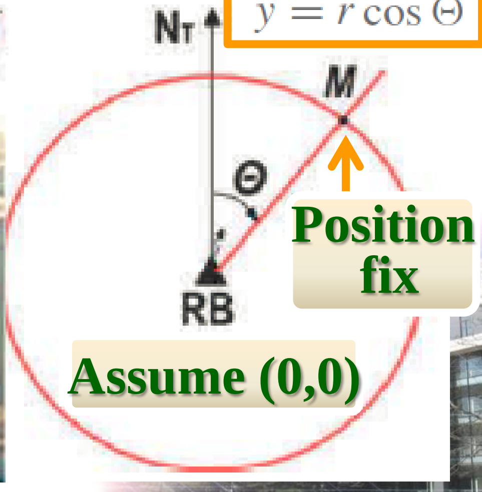
- DME/N and DME/P systems are distinguished. DME/N is a standard DME system used for navigation en route, and ground-based DME/N beacons are usually installed as a collocation to VOR. VOR/DME short-range navigation system is then formed. Originally, DME/P (P refers to “precision”) was developed for MLS landing system. Nowadays, DME/P radio beacons are used in ILS system as well, and installed in the typical range of 100 km to the airport area.

(3) ρ-θ navigation systems

- Aircraft's position is determined by LOP (lines of position) method. For this, the information is required about either the distances to two range radio beacons or about azimuths to two azimuth radio beacons or about the azimuth and distance to one ρ-θ radio beacon.

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

One ρ-θ radio beacon



- VOR (VHF Omnidirectional Range) system is created for determining the aircraft's azimuth toward the ground radio beacon—an angle between the direction of North magnetic passing through the beacon and the direction to the aircraft.

Airborne VOR indicator

VOR/DME ground-based beacon

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- VOR uses frequencies in the VHF band from 108.0 to 117.95 MHz with 50 kHz spacing, and the first 4 MHz is shared with the ILS band. The VOR radio beacon emits 360 radio beams (lines of position or radials) that are divided by 1^{o} intervals which enables pilot to know on which radial he is flying To or From the VOR beacon.

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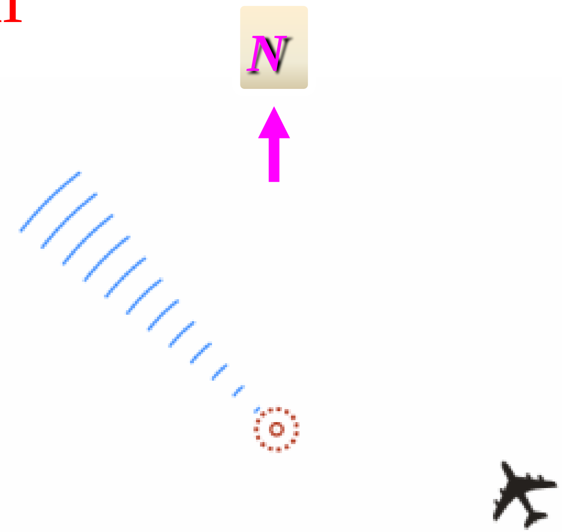
- A VOR radio beacon sends out an omnidirectional master signal, and a highly directional secondary signal is propagated by a phased antenna array and rotates clockwise in space 30 times a second. This signal is timed so that the signal phase varies as the secondary signal rotates, i.e. so-called "spinning" signal.



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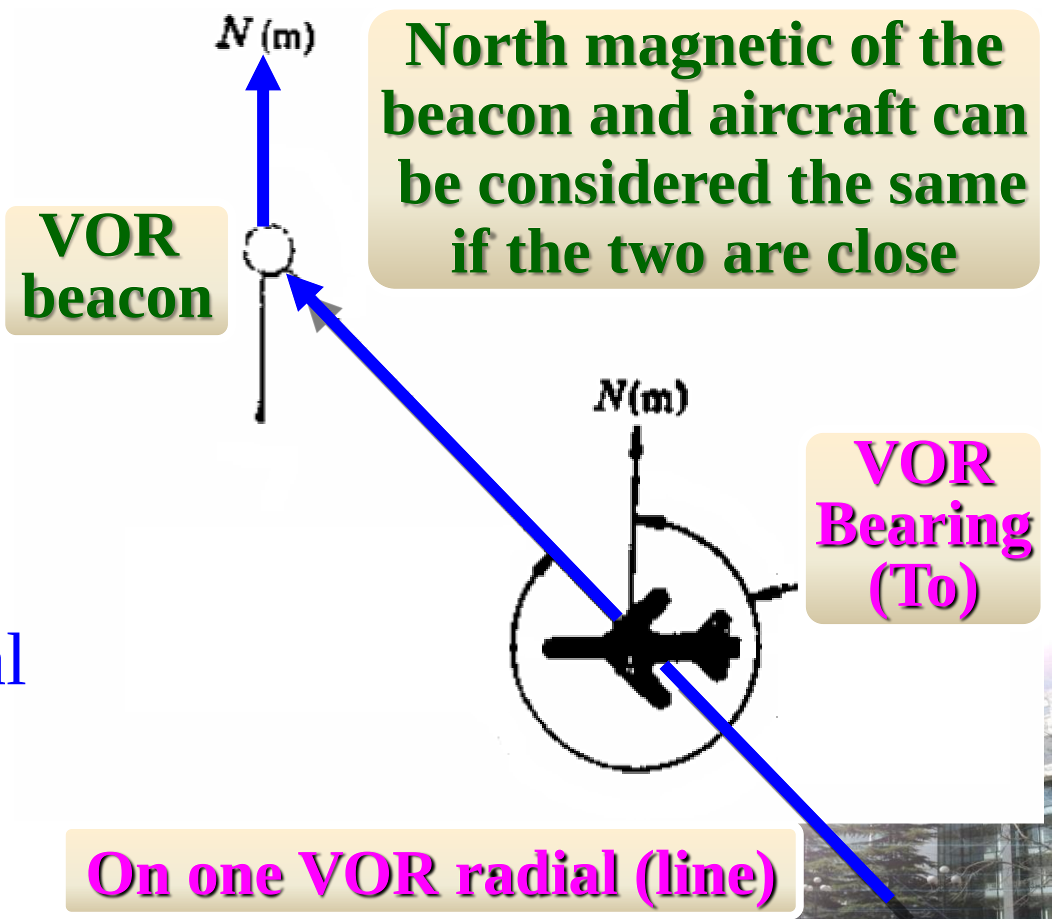
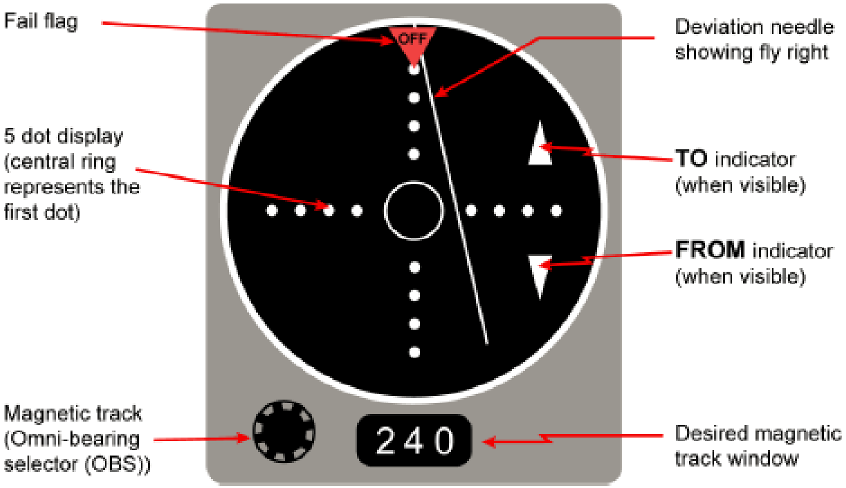
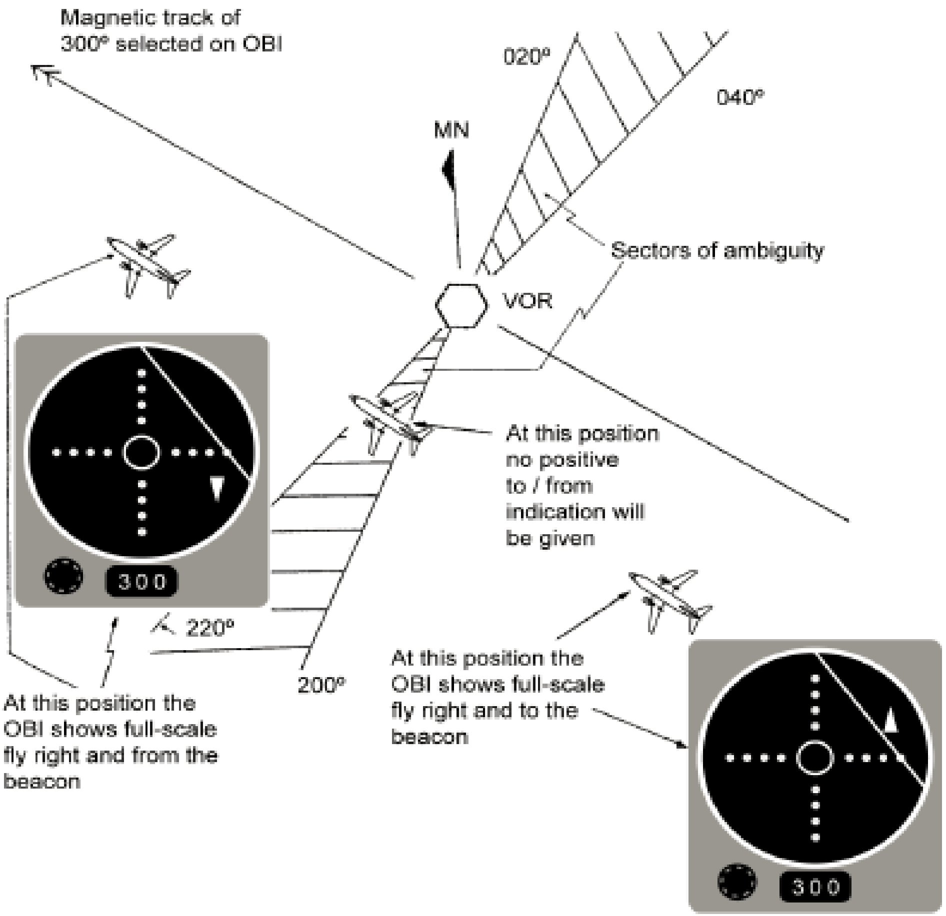
- VOR beacon transmits two VHF radio signals from the same facility. One is omnidirectional and radiates from the ground station in a circular pattern, provid-ing the secondary signal with a phase reference for comparison.



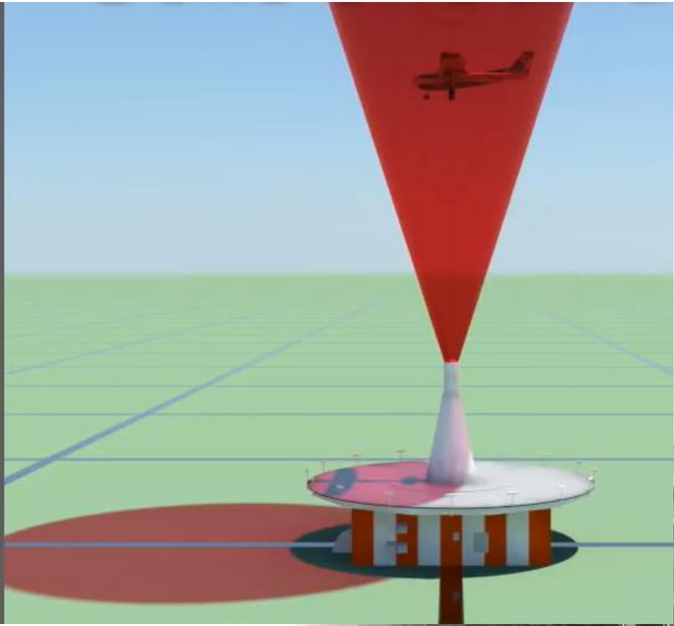
Omni Bearing Indicator (OBI) is often designed to serve a dual function as both VOR bearing indicator and ILS meter (the glide-path needle is omitted)





(3) ρ-θ navigation systems

- At the installation on the routes, the cone of ambiguity (confusion) over the radio beacon is taken into consideration, the period during which an aircraft will not receive usable signals will increase as altitude increased, i.e. depending on flight height.



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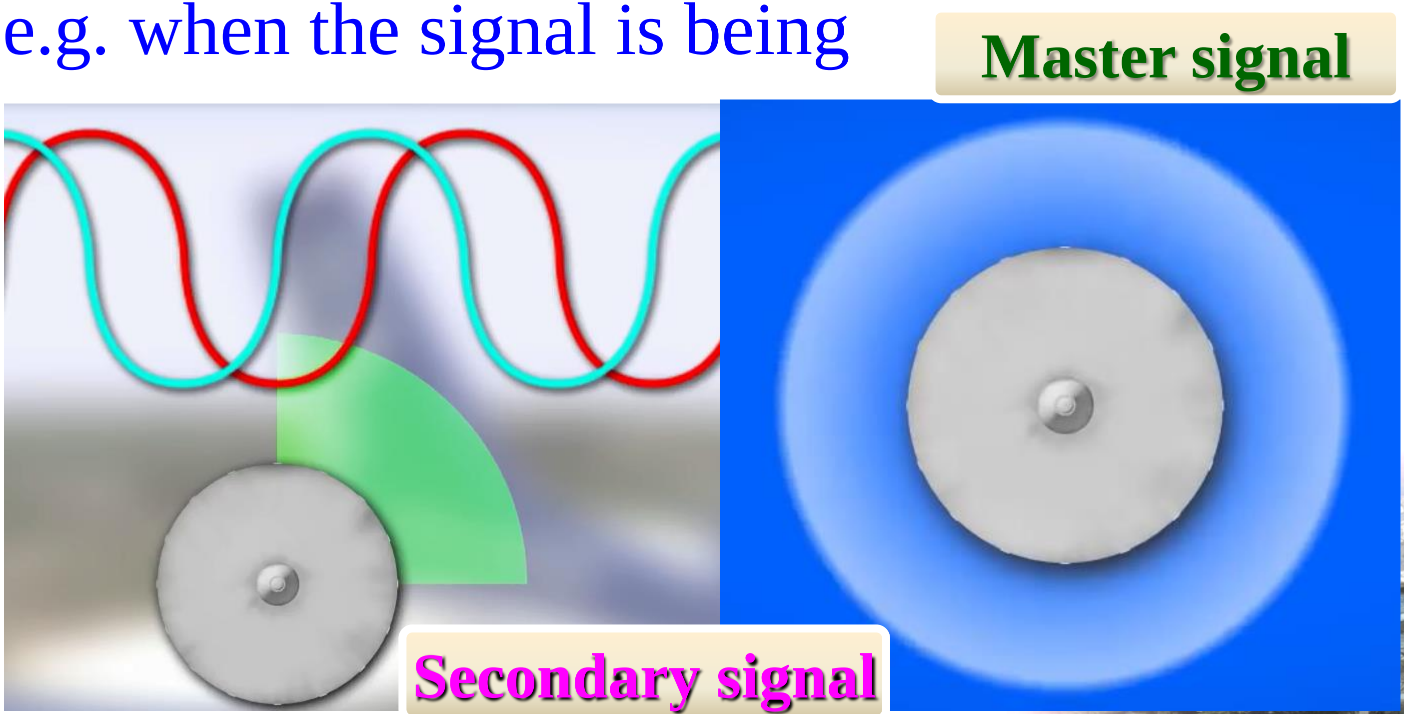
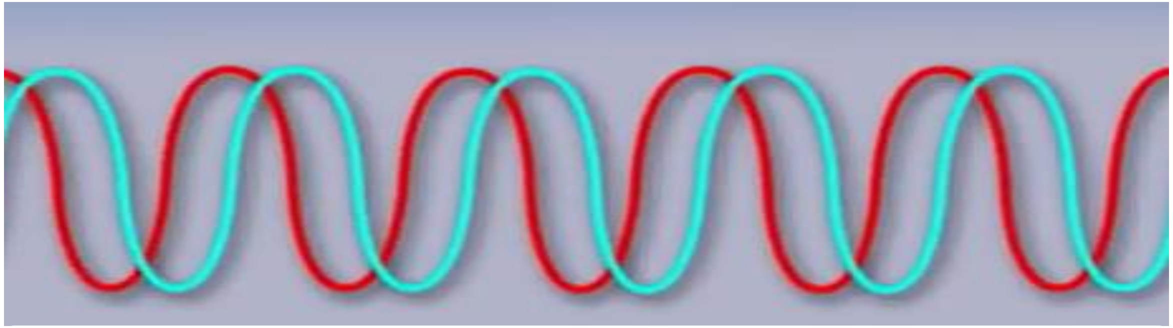
- The secondary signal phase difference compared to the master is the same as the angular direction of the spinning radio beam, e.g. when the signal is being sent 90° clockwise from North, the signal is 90° out of phase with the master.

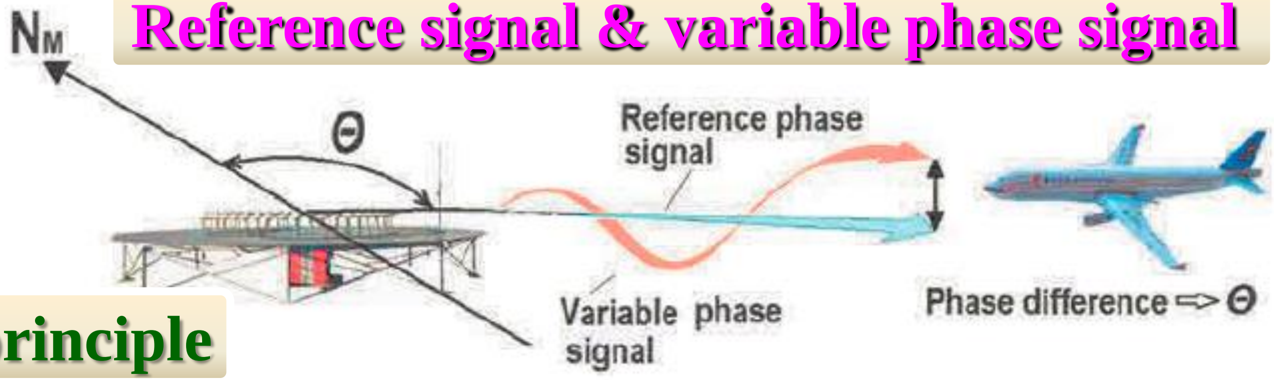


(3) ρ-θ navigation systems

- The VOR beacon emits the signal of reference phase as well as the signal, which phase of carrier depends on the azimuth, i.e. azimuth signal. Onboard equipment processes signals and measures phase difference proportional to azimuth.



Reference signal & variable phase signal



VOR principle

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$$r(t) = m_r \cos(\Omega_n t + \frac{\Delta\Omega_n}{\Omega} \sin \Omega t)$$

Signal of reference phase

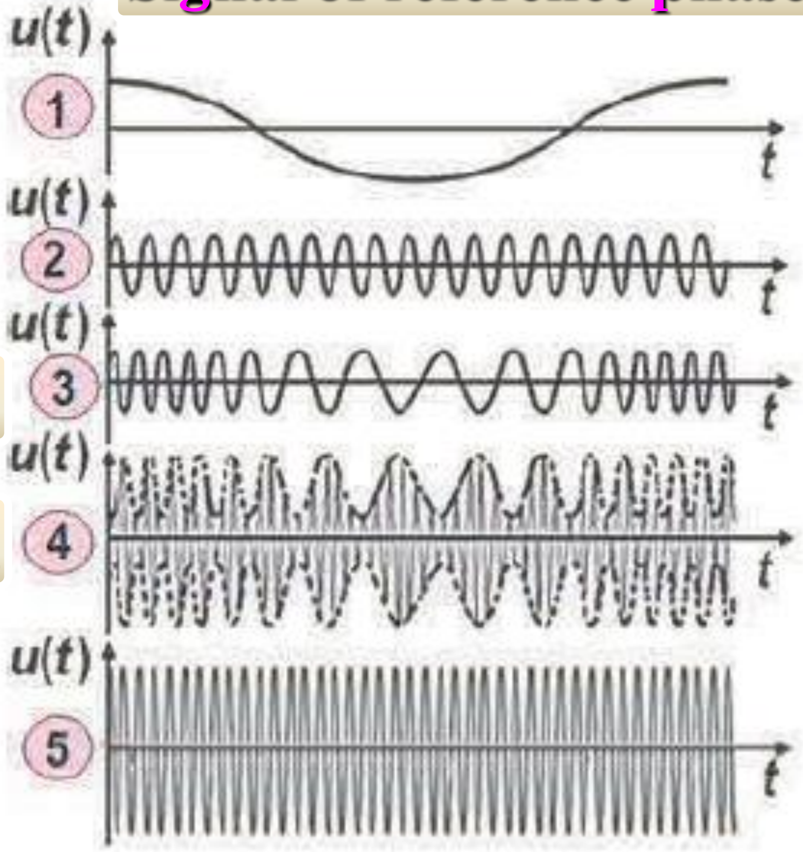
Signal of subcarrier

FM signal of subcarrier

Composite signal

Signal emitted by rotating antenna

$$v(\theta, t) = A\cos(\Omega t - \theta)\cos \omega_c t$$



(3) ρ-θ navigation systems

$$e(\theta,t) = E_m[1 + A\cos(\Omega t - \theta) + m_r\cos(\Omega_n t + \Delta\Omega_n/\Omega\sin\Omega t)]\cos\omega_c t$$

Signal in space

Received signal onboard

Signal of subcarrier onboard

Reference signal after filtering

Signal of variable phase after filtering