Electronics
Navigational Aids & Devices

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Table of Contents

I) History of Navigation
II) Radio Direction Finding
III) Radio Ranges
   a. LF / MF 4-course
   b. VHF Omni-directional Range (VOR)
   c. Doppler VOR
IV) Hyperbolic Systems of Navigation
   a. LORAN
V) Distance Measuring Equipment (DME) and Tactical Communications and Navigation (TACAN)
VI) Aids to Approach and Landing
   a. Visual Approach Slope Indicator / Precision Approach Path Indicator
   b. Instrument Landing System (ILS)
   c. Microwave Landing System (MLS)
VII) Radar and Sonar
VIII) Satellite Navigation
   a. Global Positioning System (GPS)
I) History of Navigation

Navigation
- Is the art and science of knowing where you are.
- Is the art of directing the movements of a craft from one point to another along a desired path, has an origin going back to pre-historic times.

4 Methods of Navigation:
1. Navigation by pilotage
   - The navigator fixes his position on a map by observing known visible landmarks.
   - Electronic – Pilotage – is possible with the aid of an air – borne radar.
2. Celestial Navigation
   - Is accomplished by measuring the angular position of celestial bodies.
3. Navigational by Dead-Reckoning
   - The position of the craft at any instant of time is calculated from the previously determined position, the speed of its motion with respect to earth along with the direction of its motion and the time elapsed.
   - Requires track angle and speed indicator.
4. Radio Navigation
   - Is based on the use of electromagnetic waves to find the position of the craft.

II) Radio Direction Finding

- The determination of the direction of arrival of electromagnetic waves at the receiving station. As electromagnetic waves travel along the great-circle path, direction-finding helps to locate the transmitter along a great circle.
- Can be used both air and sea-craft.

a. Loop Antenna

![Loop Antennas]

b. Radiation Pattern

![Radiation Pattern]
Errors in Direction – Finding
a. Errors due to abnormal polarization of the incoming wave (night effect and aeroplane effect).
b. Errors due to abnormal propagation.
c. Site errors, arising from re-radiation of energy from neighboring objects.
d. Instrumentation errors, arising from imperfections of the receiving apparatus.

Typical Aircraft System
1. instrument panels
2. center console
3. mid electrical service center
4. antenna locations

III) Radio Ranges
• Are navigational aids which are mainly used by aircraft.

Two types of radio ranges:

a. Low Frequency 4-course radio range:
   • Employs two antenna systems each of which has a polar diagram of the figure-of-eight type, these 2 bearing at right angles of each other.

SRA – Simultaneous Range Adcock
• Five antenna towers are used, 4 at the corners of a square and the fifth at the center.

Tx 5 - is different frequency among the 4 tx.
Spacing / distance between tx is 200 km.
Disadvantages:
1. Limited number of courses available
2. Poor signal / noise ratio
3. Fatigue caused by listening to the tones
4. Difficulty of identifying the course

b. VOR (VHF Omnidirectional Range)
- Is a short range navigation aid operating in the VHF band which provides the pilot with a track to steer to the VOR beacon and also deviation left or right of any selected track.

Two Categories of VOR:
1. Normal VOR beacon for en-route navigation – has a radio frequency carrier output of about 200 watts to provide a service range of up to 200 nautical miles. (Category A)
2. Terminal VOR – has a lower output of about 50 watts to provide the limited coverage (25 nautical miles) required for the approach and let down to an airport. (Category B)

Frequency Band:

Category A: 108.00 to 117.95 MHz
Channel Spacing = 50 kHz

Note:
0.1, 0.3, 0.5, 0.7 and 0.9 between 108 – 112 MHZ (ILS)

Category B: 108 – 112 MHz

Operation:
VOR Receiver Equipment:
1. Detects 2 AM (9960 Hz and 30 Hz)
2. Compares the Phase Difference

Maximum working range of a VOR beacon – 30 miles distance at 500 feet high to 200 miles distance at 20,000 feet high.
**For the Aircraft VOR:**
1. Flag Alarm System
   - Failure of power supplies
   - Insufficient amplitude of the reference phase or variable phase signals.
   - A substantial difference between the reading of the omni-bearing indicator and the actual bearing of the VOR.

**Doppler VOR**
- Offers greater accuracy and reliability and are compatible with existing VOR ground beacons.
- Comprises a 100 watts transmitter, 50 aerials sited in a circle approximately 50 feet in diameter and a single aerial in the center.

VHF Carrier AM by the 9960 Hz Sub-Carrier at ±480 Hz shift due to the aerial switching is carried out 30 times a second, which occurs at 30 Hz.

**Tabulation**

<table>
<thead>
<tr>
<th>Detected Rx Signals</th>
<th>Conventional VOR</th>
<th>Doppler VOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Hz AM or VHF Carrier</td>
<td>Variable Phase (space modulated)</td>
<td>Reference Phase</td>
</tr>
<tr>
<td>30 Hz FM of 9960 Hz Sub-carrier</td>
<td>Reference Phase</td>
<td>Variable Phase (Doppler Frequency Shift)</td>
</tr>
</tbody>
</table>

**Typical Aircraft VOR System**
1. Antenna
2. Preamplifier
3. Receivers
4. VHF NAV Accessory Unit
5. VHF NAV Control Panels

**VOR System Provides:**
1. VOR station audio ID signal to the audio distribution unit.
2. VOR bearing signal and warning flag signal to the radio digital distance magnetic indicator (RDDMI).
3. To-from (station heading) information, VOR deviation (right – left) and warning flag signals to the horizontal situations indicator and the computers.

**Flag Alarm System:**
1. Failure of power supplies
2. Insufficient amplitude of the reference phase or variable phase signals.
3. A substantial difference between the reading of the omni-bearing indicator and the actual bearing of the VOR.
IV) Hyperbolic Systems of Navigation

- Are based on the measurement of the differences in the time of arrival of electromagnetic waves from two transmitters to the receiver in the craft.

LORAN – Long Range Navigational Aid

- Was developed during World War II, at ranges up to 800 to 1000 miles. It is now used in many recreational boats and aircraft, due to the decreased cost and increased simplicity of the required electronic circuitry. The basic principle of LORAN is the have the ship or aircraft receive specially coded signals from pairs of powerful, shore-based transmitters at known locations, in the a from of hyperbolic pattern. It is also based on the difference in time required for pulsed radio signals to arrive from a pair of synchronized transmitters.
Note:

Two transmitter mainly used, unless there will be an uncertainty, the transmitter 3 will resolved the conflict.

Theory:

To determine the time delay:

\[ t_d = \frac{AP - BP}{C} \]

where:

\[ C = \text{speed of light} \]

\[ AP = \sqrt{(x + d)^2 + y^2} \]
\[ BP = \sqrt{(x - d)^2 + y^2} \]
\[ AP - BP = \sqrt{(x + d)^2 + y^2} - \sqrt{(x - d)^2 + y^2} = L \]

Note:

\[ d, a, b, L \text{ = are constants} \]
\[ x + y \text{ = variables} \]

From eqtn (1) and (2), it yields:

\[ a = \frac{L}{2} \quad ; \quad b = \sqrt{d^2 - a^2} \]
Operations:

Carrier frequency is 100 kHz at multimegawatt power. Master station transmits first, followed by the secondary stations in a specific order in an overall signal sequence called GRI (group repetition interval). The master station transmits 8-pulses spaced 1-ms apart, followed by 9th pulse 2-ms later. Each secondary station in the chain follows after a prescribed delay and transmits 8 pulses spaced at the 1-ms interval. Phase Modulations are used to distinguish master station pulses from secondary station pulses at the receiver.

V) Distance Measurement Equipment (DME) and Tactical Air Navigation (TACAN)

A) Distance Measurement Equipment (DME)

It is a system combining ground – based and airborne equipment to measure the distance of the aircraft from a ground facility. It is primarily used for position fixing, enroute separation, approach to an airport, avoiding protected airspace, holding at a given position or calculating ground speeds.

1) Airborne DME consists:
   a. Transceiver
   b. Control unit
   c. Distance indicator
   d. Antenna

2) Ground – Based DME consists: - operates only on a single frequency.
   a. Receiver – transmitter
   b. Antenna
**Operation:**

Airborne DME transmits interrogation pulses to the ground station. The ground station receives these interrogation and after a fixed delay (50µs), transmits reply pulses. It computes the slant range to the ground station from the amount of time elapsed between transmitting and receiving the pulse pairs.

**Slant Range** – is the distance measurement taken by the equipment from air to ground.
Interrogation:
- 1025 – 1150 MHz at 1MHz increment for 126 Channels.

Reply:
- 962 – 1213 MHz at 1MHz increment at 63MHz below from carrier frequency for 256 Channels.

Note:
 a) X – Channel Frequency
   962 – 1024 MHz
   1151 – 1213 MHz

 b) Y – Channel Frequency
    1025 – 1150 MHz

c) DME should be paired with the VOR / ILS for simultaneous selection of bearing and distance measuring facilities at one controller.

Frequency Pairing:
X – Channel with VHF
- Even numbers of 50 kHz increments

Y – Channel
- Odd number of 50 kHz increments.

Pulse Separation:
X – Channel
- 12µsec separation on both interrogation and reply.

Y – Channel
- 36 µsec for interrogation pulses intervals
- 30 µsec for reply pulses intervals
B) TACAN (Tactical Air Navigation)

- is an air navigation system which provides a properly equipped aircraft with bearing and distance from a shipboard or ground radio beacon selected by the pilot. The distance from the ground beacon is visually displayed in the aircraft on a meter calibrated in nautical miles and the direction in degrees with respect to magnetic north.

Operation’s Theory:

TACAN are based on the time required for a radio pulse signal to travel to a given point and return. The radio beacon periodically transmits its identifying call in International Morse Code. The characters of the code consists of a train of pulse pairs generated at a fixed rate of 1350 Hz. Identification call signals have priority over the distance information signals. The pulses of each pair are spaced 12 µsec apart.

The time delay of the distance interrogation pulse pair to the corresponding distance reply pulse pair in the radio beacon is adjusted to exactly 50 µsec.

![TACAN Block Diagram](image-url)
VI) Aids to Approach and Landing:

A) VASI – Visual Approach Slope Indicator
   - designed to give visual indicators of the desired approach slope.
1. No light – NL
2. Red – R
3. White – W
4. Transition from Red to White
5. Transition from White to Red
PAPI (Precision Approach Path Indicator)

The PAPI system comprises a four unit wing bar located in a line at right angles to the runway. The unit nearest the runway is set higher than the required approach angle with progressive reduction in the setting of the units farther. The normal difference between the setting angles is 20 minutes of arc.
B) Instrument Landing System (ILS)
- is a radio system enabling an aircraft to locate the selected runway, adopt the correct glide-slope and approach in all weather conditions by providing lateral, vertical and distance to the threshold information.

3 Elements of ILS:

1. VHF Localizer – which gives left / right (lateral) guidance on to the extended runway centre line.

2. UHF Glide Path – which gives up/down (vertical) guidance with respect to a suitable descent path at an angle of about 3 degrees above the horizontal.
3. VHF Marker Beacons – to indicate predetermined distances to the runway threshold.
Marker Beacon
Radiation Pattern

At the center has no signal
(cone of silence)

Ground System Localizer

Carrier Frequency = 108.1 - 111.9 MHz
- horizontal polarization
- 109.9 MHz Mactan Airport

Usable Range
**Glideslope: Glide Path**
- UHF Channels: 329.3 MHz and 335.0 MHz

**C) Microwave Landing System (MLS)**
- is an air derived data system in which the airborne unit obtains precision azimuth angle, elevation angle and range data referenced to the runway. The system is capable of transmitting auxiliary data such as runway identity, equipment status, weather data and sitting constants to airborne units.

**Basic Functions of MLS System:**
1. a basic C – Band elevation and azimuth guidance element.
2. a DME operating in a separate portion of C – Band.
3. an elevation guidance element for flare out guidance to touchdown operating in the Ku – Band.
4. a black course azimuth (and optional elevation) guidance.
VII) RADAR and SONAR

A) RADAR (Radio Detection and Ranging)
- To detect reflecting objects by using echo principle.
- Provide range information.

\[
\text{Distance} = \text{(speed of light)} \times \text{(time)}
\]

\[
\text{Range} = \frac{ct}{2}
\]

where:
- \(c\) – speed of light
- \(t\) - time

Type of Pulse Radar:

1. ASR (Airport Surveillance Radars) – are used primarily to survey aircraft operating in relatively close proximity to air terminals.

2. ARSR (Air Route Surveillance Radars) – are used to determine the location of aircraft in transit along air routes. It is a high powered long range device (200 miles). It is sometimes associated with Radar Microwave Link.

3. PAR (Precision Approach Radars) – are very accurate, short range radars used as aids to instrument landings.

4. ASDE (Airport Surface Detection Equipment) – is a primarily radar system used for control of traffic on the found at large airports.
Table of Radar Frequency and Applications

<table>
<thead>
<tr>
<th>Freq. Band</th>
<th>Center Freq.</th>
<th>Center λ</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>300 MHz</td>
<td>100 cm</td>
<td>Early warning radar ARSR, DME, TACAN, ASDE, ASR, Airborne Search Radar, PAR, RML.</td>
</tr>
<tr>
<td>L</td>
<td>1,000 MHz</td>
<td>30 cm</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>3,000 MHz</td>
<td>10 cm</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>10,000 MHz</td>
<td>3 cm</td>
<td></td>
</tr>
</tbody>
</table>

**Pulse Width and Pulse Interval Relationship:**

\[
\begin{align*}
t_p &= \text{pulse width} \\
T &= \text{pulse interval} \\
P_t &= \text{peak power} \\
P_{\text{ave}} &= \text{average power}
\end{align*}
\]

Duty Ratio = \( \frac{t_p}{T} = \frac{P_{\text{ave}}}{P_t} \)

PRF (pulse repetition frequency) = \( \frac{1}{T} \)

---

**Radar Block Diagram**

- Transmitter
- Duplexer
- Modulator
- Receiver
- Indicator
- Data Link
- Antenna
- Timer
**Minimum Range:**

\[ R_{\min} = \frac{t_p \mu \text{sec}}{12.36 \mu \text{sec/mile}} \]

**Hit per Scan:**

1. For 360° Radar

\[ N_s = \frac{(PRF)\beta}{(RPS)360^\circ} \]

2. For Sector Scanning Radar

\[ N = \frac{(PRF)\beta(t)}{\phi} \]

**Bearing Resolution:**
simplify and rearrange the equation, yield:

\[
\frac{D}{R} = \sin\left(\frac{\beta}{2}\right)
\]

where:

- \(D\) = distance between the 2 aircraft
- \(\beta\) = beamwidth
- \(R\) = range between radar and aircraft

**Receiver Sensitivity** – a radar receiver’s ability to separate desired echo signals from undesirable noise.

\[
P_{\text{noise}} = P_N = kT_K\Delta f
\]

where:

- \(k\) = Boltzmann’s Constant \((1.38 \times 10^{-23} \text{ joules / } ^0\text{K})\)
- \(T_K\) = Absolute temperature in space in \(^0\text{K}\)
- \(\Delta f\) = receiver bandwidth in Hz.

**Receiver Noise Figure**

\[
F = \frac{P_r}{P_N} = FKP_N = FKTK\Delta f\text{ at } R = R_{\text{max}}; (P_r = P_{r(\text{min})})
\]

\[
P_{r(\text{min})} = FKP_K\Delta f
\]

† receiver sensitivity

**Free Space Maximum Range Equation**

\[
\phi = \frac{P_r G_t}{4\pi r^2} \text{ watt / m}^2
\]

Power Density at a distance \(r\) from the antenna:
Power intercepted by the target at distance $r$:

$$P = \Phi A_0 = \frac{P_t G_r}{4 \pi r^2} A_0 \text{ watts}$$

Power density of the returning echo at range $r$:

$$\Phi = \frac{P_t G_r A_0}{4 \pi r^2} = \frac{P_t G_r A_0}{16 \pi^2 r^4} \text{ W/m}^2$$

Echo power received by the radar antenna with antenna aperture: $A_a$

$$P_r = \frac{P_t G_r A_0 A_a}{16 \pi^2 r^4} \text{ watts}$$

$$P_r = P_r(\text{min}) = \frac{P_t G_r A_0 A_a}{16 \pi^2 (R_{\text{max}})^4}$$

$$R_{\text{max}} = \frac{\sqrt[4]{P_t G_r A_0 A_a}}{16 \pi^2 P_r(\text{min})}$$

where:

$$G_r = \frac{4\pi A_a}{\lambda^2}$$

thus,

$$R_{\text{max}} = \frac{\sqrt[4]{P_t A_0 A_a^2}}{4\pi^2 FkT_k \Delta f}$$

**Second Time around Targets:**

$${t_p}$$

| Pulse 1 | Pulse 2 |

$${T_1}$$  $${T_2}$$

Indicated T or range  actual T
Example:

\[ R_{\text{max}} = 1.23 \left( \sqrt{ha} + \sqrt{ht} \right) \text{ Nautical Mile} \]

where:
- \( ha \) = antenna height in ft.
- \( ht \) = target altitude in ft.

Solution:

\[ R = \frac{T}{12.36} + 60 \text{NM} \]

\[ R = 141 \text{NM} \]

Radar Horizon:

Required:
1. \( R_{\text{max}} \) at \( ha = 30 \text{ ft} \) and \( ht = 2000 \text{ ft} \)
2. \( ht \) at \( ha = 30 \text{ ft} \) and \( R_{\text{max}} = 200 \text{ NM} \)

Solution:

Typical Data of Aircraft for the Radar to detect:

<table>
<thead>
<tr>
<th>Type of Aircraft</th>
<th>Radar Cross-section in ( \text{ft}^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>B – 17</td>
<td>800</td>
</tr>
<tr>
<td>AT – 11</td>
<td>200</td>
</tr>
<tr>
<td>PBY</td>
<td>500</td>
</tr>
<tr>
<td>Taylorcraft</td>
<td>170</td>
</tr>
<tr>
<td>T – 33</td>
<td>25</td>
</tr>
<tr>
<td>B – 29</td>
<td>1200</td>
</tr>
<tr>
<td>C – 54</td>
<td>240</td>
</tr>
<tr>
<td>F – 86D without tank</td>
<td>16</td>
</tr>
</tbody>
</table>
B) SONAR (Sound Navigation and Ranging)

- are used ships for sonic and ultrasonic, underwater detection, ranging, sounding and communications.

Two types of SONAR:

1. **Active SONAR (echo ranging type)** – is a target seeking system. It is capable of transmitting underwater sounds that strike targets and are returned in the form of echoes. The returned echoes indicate the range and bearing of the target.

   **Two classification of Active Sonar:**
   a. Searchlight SONAR – transmits the energy pulse at only one bearing at a time, and the transducer is held at that bearing to listen for a returning echo.
   b. Scanning SONAR – provides audible and visual indications of all underwater objects around the ship. It has a capability to scan 360° direction.

2. **Passive SONAR** – provide an underwater sound listening system capable of long – range search and tracking of noise sources. It used **hydrophone**.

   **Two types of hydrophone:**
   a. Electrostrictive – utilizes barium titanate and operates on the piezoelectric effect to convert acoustic energy to electrical energy.
   b. Magnetestrictive – utilizes magnetestrictive alloys and operates the same principle as electrostrictive.

Problem:

1. A radar transmitter has a peak pulse power of 400 kW, a PRF of 1500 pps and a pulse width of 0.8 µsec. Calculate:
   a. The maximum unambiguous range (100km)
   b. The average transmitted power (480W)
   c. Duty cycle (0.12%)

2. The radar is to have a maximum range of 60 km. What is the allowable PRF for unambiguous reception? (2500 pps)
VIII) Satellite Navigation

- GPS (Global Positioning System)
- NAVSTAR (Navigation System using Timing and Ranging)

System consists:
1. ground stations
2. orbiting satellites
3. special receivers

The whole system consists of 18 satellites to cover virtually on the globe and another 24 satellites to provide redundancy and a way to cross-check results.

Note:
Three satellites provide position coordinates \((x, y, z)\) but the fourth satellite will take care the error correction for the clock.

User’s latitude \(\theta = \cos^{-1} \sqrt{\frac{U_x^2 + U_y^2}{|U|}}\)

User’s longitude \(\beta = \tan^{-1} \frac{U_x}{U_y}\)
The complete GPS system has 3 segments:

1. Control segment – with master control stations (ground stations) which assures the overall system performance and accuracy.

2. Space segment – consisting of the satellites themselves, transmitting time codes and orbital position information to the users.

3. User segment – the actual user electronic circuitry which must receive signals from the 4 satellites, compute the time differences and determine position.

Note:
No limits to the number of receivers since data are broadcast to all.

GPS Satellites
- Not geostationary but have an average height of 9476 miles and approx. 12 hrs. to complete one orbit. Satellite orbits have an inclination of 55° to the equator. It operates a L – Band from 1.57542 and 1.2276 GHz.
- It uses ASCII characters for the data (prone to noise corruption). A pseudorandom sequence (PRSQ) is used, just to counteract the noise.
- It utilized two unique pseudorandom patterns.
  1. P pattern – is very long, sent at 10.23 Mbps which more precise timing.
  2. C/A pattern is sent at 1.023 Mbps which accuracy is sufficient.

GPS Receiver
- First function is to act as a front end for signal reception of the two GPS frequencies and to recover P and C/A pseudorandom bit streams that have been modulated onto the carrier.