062 Radio Navigation

062-01 Basic Radio Propagation Theory

062-01-01 Basic Principles

C = 300,000,000 m/s $\lambda_m = \frac{300}{f_{MHz}}$ $Range_{nm} = 1.23 \times (\sqrt{H1_{ft}} + \sqrt{H2_{ft}})$

VoLuMe High Very USEful

V	Very Low Frequency (VLF)	3-30 kHz	-
L	Low Frequency (LF)	30-300 kHz	NDB, LORAN C
M	Medium Frequency (MF)	300-3000 kHz	NDB, long range communications
H	High Frequency (HF)	3-30 MHz	long range communications
V	Very High Frequency (VHF)	30-300MHz	short range, VDF, VOR, ILS, marker beacons
U	Ultra High Frequency (UHF)	300-3000 MHz	ILS GS, DME, SSR, SatCom, GNSS, INMARSAT
S	Super high Frequency (SHF)	3-30 GHz	RADALT, MLS, radar
E	Extremely High Frequency (EHF)	30-300 GHz	-

062-01-02 Antenna

dipole antenna: ½ of wave length

SSB Single Sideband (used in HF two-way)

062-01-03 Wave Propagation

HF	sky waves, ground wave range is small
VHF	space waves only

062-02 Radio Aids

062-02-01 Ground D/F

VDF is accurate ±2°

062-02-02 NDB/ADF

accuracy ±5°

static interference	TS or precip, needle deflected towards CB
night effect	D-Layer disappears, sky waves interfere with ground waves, bearing errors & fading, range increases
station interference	when two signals are received
coastal effect	increases as angle between signal and coastline decreases (no effect at 90°)
mountain effect	random reflection at steep slopes, big bearing errors
bank angle	bearing error (dip error)
quadrantal errors	signal bending by aircraft metallic surfaces

BFO makes carrier wave audible (N0N A1A ident transmissions), locator beacon range: 10-25 nm

ICAO NDB Frequencies: 190-1750 kHz

$Water: Range_{nm} = 3 \times \sqrt{Power_W}$

$Land: Range_{nm} = 2 \times \sqrt{Power_W}$

062-02-03 VOR and Doppler-VOR

108-117.975 Mhz, TVORs are even decimals, ILS Locs are odd decimals

062-02-04 DME

960-1215 Mhz (63 Mhz between req & reply)

50 µs fixed delay, 12.36 µs „radar mile“

search mode	150 pps, then 60 pps after 100 s
tracking mode	5-25 pps
memory mode	10 s

ground station: max 2700 pps (100 aircraft)

dme ident: every 30 seconds

accurracy:

- DME-N: ±0.25 nm + 1.25% of distance
- DME-P: 0.2 nm

associated VOR/DME:

- 100 ft apart when in terminal area
- 2000 ft apart when not used in terminal area

TACAN can provide DME

062-02-05 ILS

loc

- 1 dot loc = 0.5° (full deflection 2.5°)
- ±10° within 25 nm (18 nm for steep GP)
- ±35° within 17 nm (10 nm for steep GP)
- 7° above loc horizontal plane
- loc antenna 300 m after runway end

GP

- 1 dot GP= 0.14° (full deflection 0.7°)
- 0.45 θ to 1.75 θ (θ … GPangle)
- ±8° within 10 nm
- GP antenna 300 m beyond threshold

mark	color	pattern	tone	distance
inner	white	6 dots	3000 Hz	75-450 m
mid	amber	2 dash/6 dots	1300 Hz	1050 m
outer	blue	2 dashes	400 Hz	3.5-6 nm

DDM, ILS Lobes:

- 90 Hz (high, left)
- 150 Hz (low, right)

loc freq 108.1 – 111.95 Mhz, odd first decimals

normal ils intercept: 3-10 nm, false glidepath above!

$$ROD = \frac{glideslope_{\circ} \times GS \times 100}{60}$$

062-02-06 Microwave Landing System MLS

5.03 – 5.09 Ghz (SHF), 300 kHz spacing, 200 available channels, ±40° of centerline, 20 nm

062-03 Radar

062-03-01 Pulse Techniques and Associated Terms

$$Range_{nm} = \sqrt[4]{Power_{watts}}$$

$$Range_{km} = \frac{300000}{PRF \times 2}$$

max range: prf (also pulse width & frequency)

min range: pulse length

062-03-02 Ground Radar

Long Range Surveillance Radar 200-300 nm

062-03-03 Airborne Weather Radar

map: cosecant beam, wx: pencil-beam (3-5°)

9.3 Ghz, stabilized in roll & pitch

062-03-04 SSR & Transponder

P1 pulse: frame

P2 pulse: eliminate side-lobe replies

P3 pulse: frame („control pulse“)

P4 pulse: short – AC, long – A/C/S

up 1030 Mhz, down 1090 Mhz

4096 codes

fruiting/garbling

ident: SPI (Special Position Identification)

pulse after normal response (20s)

elementary: callsign/identity, current altitude, capability report of transponder, status (ground or flight)

enhanced: MH, IAS, TAS, Mach, VS, roll angle, track angle rate, true track angle, GS, selected alt

062-05 Area Navigation Systems and RNAV or FMS

062-05-01 General Philosophy and Definitions

accuracy (best -> worst):

DME/DME, DME/VOR, DME/LOC, LOC

nav-db: airport data, company routes, nav aid freqs (but not atc freqs!)

062-05-02 Simple 2D RNAV

2-dot HSI RNAV in ENR mode: 2nm per dot

rho (ρ): distance, theta (θ): bearing

062-05-03 4D RNAV

input	**output**
DME	distance to waypoints
radials	ETO
TAS & ALT from ADC	GS & TS
heading	true wind
	track error

062-05-04 FMS and General Terms

multiple DME non-precision approach: 0.3 nm

B737-400: DME/DME

062-06 GNSS (Global Navigation Satellite Systems)

062-06-01 GPS/GLONASS/GALILEO

	GPS	**GLONASS**	**GALILEO**
satellites	24	24	30
oribtal planes	6 (55° incl)	3	3 (56° incl)
orbit duration		11¼ h	14 h
orbit height	20200 km	19100 km	23200 km
clocks	4		rubidium passive hydrogen maser
coordinate system	WGS84	PZ-90	
frequencies	1575 MHz (L1, C/A & P, civil) 1227 MHz (L2, P, mil)		1164-1215 MHz 1260-1300 MHz 1559-1591 MHz

RAIM: 6 sats, 5 when using baro-input (AAIM), 4 sats for 3D pos, 3 sats for 2D pos

„all in view“ - tracking all sats in view (more than required)

„searching the sky“ – receiver startup without sat data

ICAO acurracy requirement: 9 (old: 13) m horizontal, 15 m vertical 95% of the time

galileo: 3 sections (timing, signal generation, transmit)

galileo: monitoring similar to gps/glonass but also by spread-spectrum monitoring (ground)

navigation message: almanac, ephemeris, satclock correction, ionospheric model, sat health

062-06-02 Ground, Satellite and Airborne Based Augmentation Systems

LAAS (usally 30-40km around airports)

GBAS: 35° apart final at 15 nm from threshold, 10° apart at 15-20 nm

WAAS, EGNOS, MSAS, GAGAN

GBAS Frequencies: VHF (ILS/VOR)

062-07 PBN

062-07-01 PBN Concept (as described in ICAO Doc 9613)

3 components: nav aid infrastructure, nav spec, nav application

062-07-02 Navigation Specifications

RNAV10, RNP 4	oceanic/remote
RNAV5	enroute, arrival
RNAV2, RNP2	under development, arrival, departure, enroute, oceanic/remote
RNAV1, RNP1	arrival, departure (SIDs & STARs)
RNP APCH	approach
RNP AR APCH	authorization required (0.1 nm)
RNP 0.3	all phases, except oceanic/remote & final approach, primarily for helicopters
A-RNP	includes RNAV1, RNAV2, RNAV5, RNP1, RNP2 & RNP APCH
B-RNAV	RNP-5
P-RNAV	RNP-1

062-07-03 Use of PBN

IF	Initial Fix
TF	Track to Fix
CF	Course to Fix
DF	Direct to Fix
FA	Fix to an Altitude
CA	Course to an Altitude
RF	Radius to Fix
FRT	Fixed Radius Transition

data processing: accuracy, resolution & integrity

062-07-04 PBN Operations

Path Definition Error (PDE) – rnav system

Flight Technical Error (FTE) - pilot/autopilot

Navigation System Error (NSE) – accuracy

062-07-05 Reqs of RNAV and RNP Specs

accuracy, integrity, continuity