MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent unit of MAHE, Manipal)

V SEMESTER B.TECH. (AERONAUTICAL ENGINEERING)

END SEMESTER EXAMINATIONS, DEC 2022

SUBJECT: AVIONICS AND NAVIGATION SYSTEMS [AAE -3156]

REVISED CREDIT SYSTEM

(01/12/2022)

Time: 3 Hours MAX. MARKS: 50

Instructions to Candidates:

- Answer **ALL** the questions.
- Missing data may be suitably assumed.

Q No	Question	Marks	CO attained	BT level
1A	Compare 5 types of electrical power generation techniques available in civil and military aircrafts. Give example of each.	02	CO4	L4

Ans

Select any 5 from below comparision table

Table 5.1 Recent civil & military aircraft power system developments

Generation type	*Civil application*		*Military application*	
IDG/CF [115 VAC / 400 Hz]	B777	2 × 120 kVA	Eurofighter Typhoon	
	A340	4 × 90 kVA		
	B737NG	2 × 90 kVA		
	MD-12	4 × 120 kVA		
	B747-X	4 × 120 kVA		
	B717	2 × 40 kVA		
	B767-400	2 × 120 kVA		
VSCF (Cycloconverter) [115 VAC / 400 Hz]			F-18C/D	2 × 40/45 kVA
			F-18E/F	2 × 60/65 kVA
VSCF (DC Link) [115 VAC / 400 Hz]	B777 (Backup)	2 × 20 kVA		
	MD-90	2 × 75 kVA		
VF [115 VAC / 380–760 Hz typical]	Global Ex	4 × 40 kVA	Boeing JSF [X-32A/B/C]	2 × 50 kVA
	Horizon kVA	2 × 20/25		
	A380	4 × 150 kVA		
VF 230 VAC	B787	4 × 250 kVA		
270 VDC			F-22 Raptor	2 × 70 kVA
			Lockheed-Martin F-35 – Under Review	

1B What is IMA? Explain the A-330 EFIS/ECAM architecture with neat diagram. **03** **CO1** **L2**

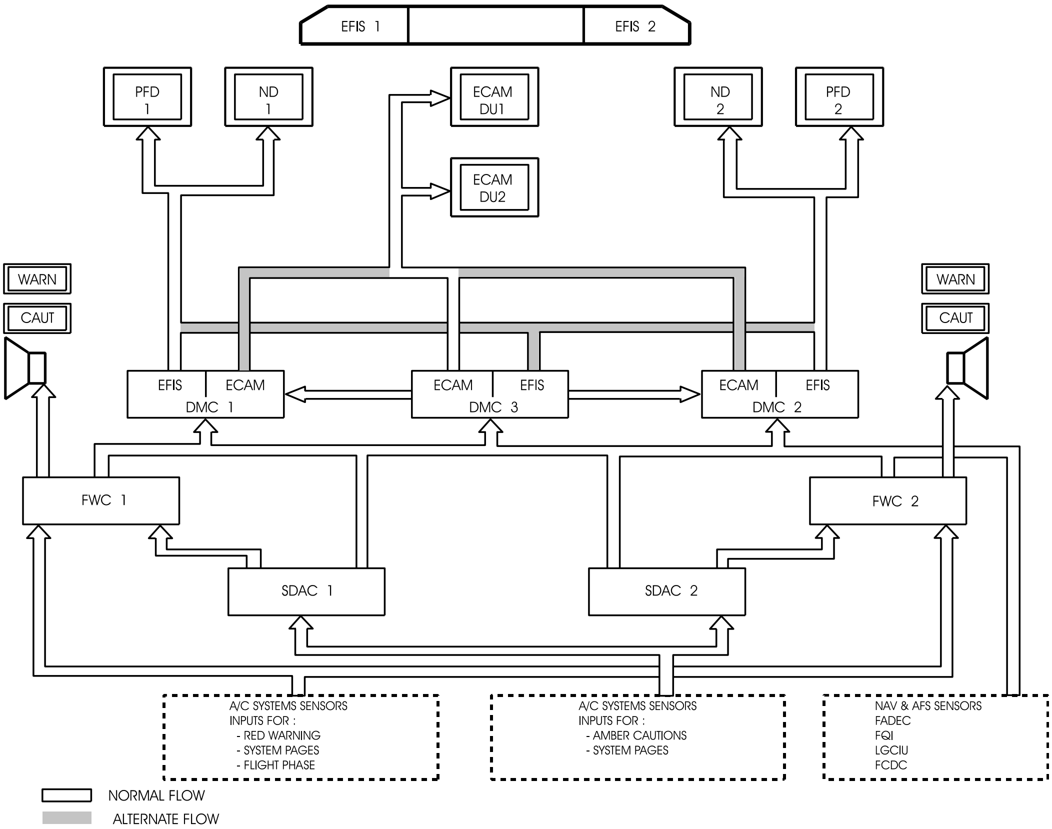
Ans The Integrated Modular Avionics (IMA) concept, which replaces numerous separate processors and line replaceable units (LRU) with fewer, more centralized processing units, is promising significant weight reduction and maintenance savings in the new generation of commercial airliners.
The AIRBUS IMA concept is based on “shared Modules”. A module- focused approached has been preferred compared with the previous concept of “Cabinet”. Its key features in A 380 are:

ARINC 600 IMA Module packaging connected to AFDX network
Robust partitioning in computing resource & communications
Determinism of application execution & data exchanges
Standardised Application Programming Interface (API) to avoid obsolescence impacts on applications
Conventional equipment’s mixable

EFIS / ECAM architecture

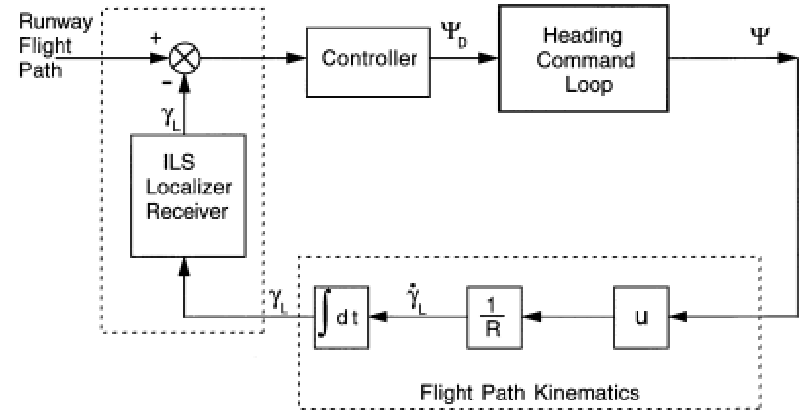
Components

- **DU** (Display Unit)
  - Six identical full-colour DUs
  - 7.25in x 7.25in case size
  - Symbol generator resident in DU
- **DMC** (Display Management Computer)
  - Three identical DMCs
  - Each DMC has two independent channels : EFIS/ECAM
  - Each DMC is able to drive all six DUs with four independent formats (PFD ; ND ; E/WD ; SD).
- **SDAC** (System Data Acquisition Concentrator)
  - Two identical SDACs
  - The SDCAs are connected to the DMCs and FWCs
- **FWC** (Flight Warning Computer)
  - Two identical FWCs
  - Each FWC is connected to all DMCs.



1C	Design an autopilot system to control the aircraft for the following cases during autonomous landing: (i) Localizer coupling loop, (ii) Glide path coupling loop and (iii) flare control loop.	**05**	**CO3**	**L6**

Ans



'ig. 8.9 Localiser coupling loop (φ is aircraft heading relative to runway centre line bearing).

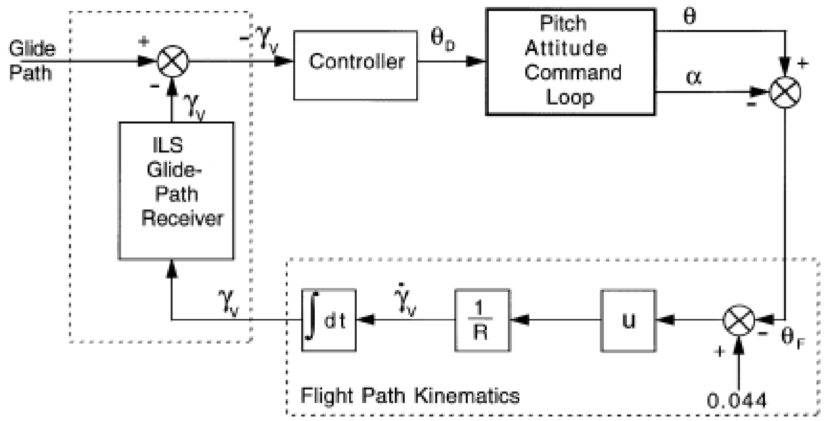


Fig. 8.10 Glide path coupling loop.

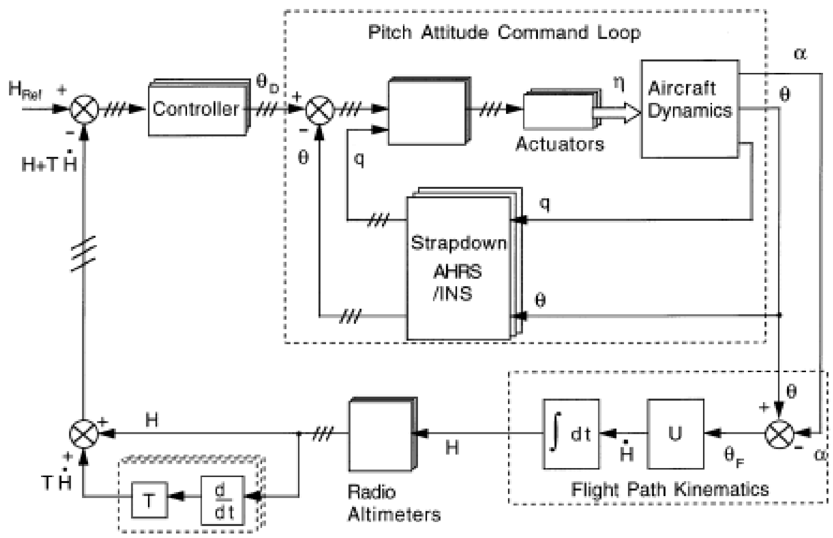
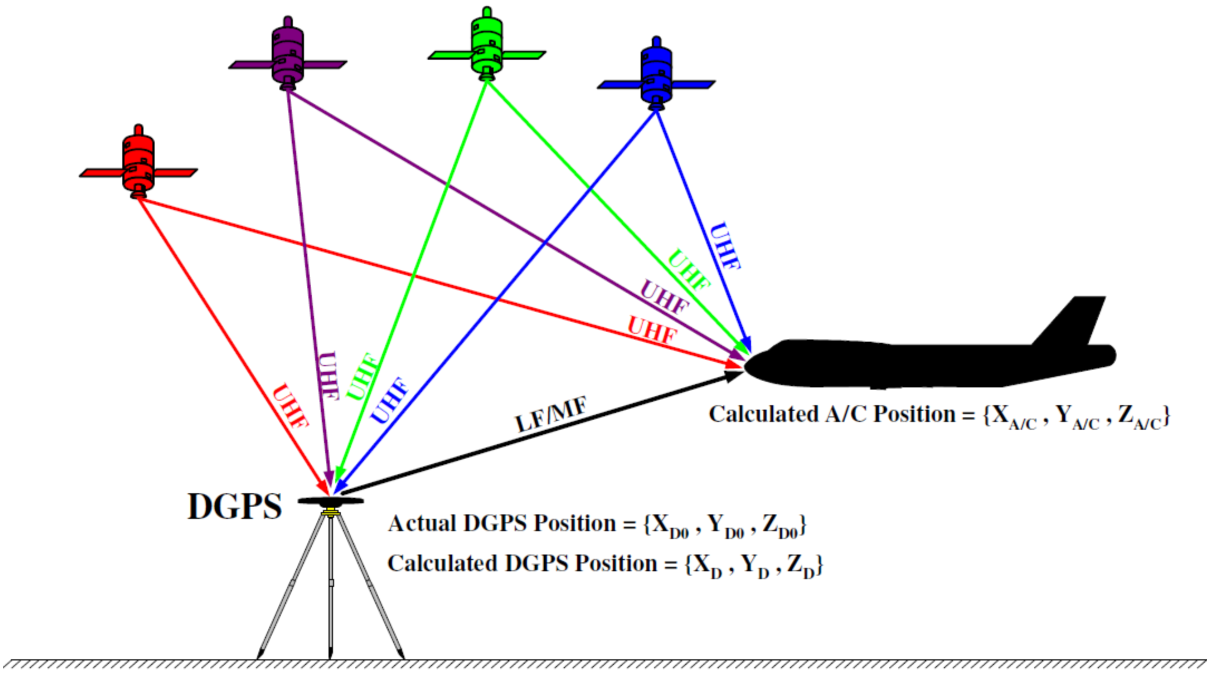


Fig. 8.12 Automatic flare control loop.

2A Derive the position of aircraft with correction of DGPS signal installed within 100 km range. Explain the working principle of it in SBAS. **03** **CO3** **L3**

Ans



DGPS used to correct A/C position fix

- **On the GND:**

1) Rx-Tx: DGPS system.

2) Frequency:

- Rx: UHF [used to calculate DGPS position fix]
- Tx: LF/MF 283.5 – 325 kHz [used to transmit correction signal to A/C]

3) The DGPS is stationary, therefore its actual {LATD0, LOND0, ALTD0} is well known. Then It can be transform to {XD0, YD0, ZD0}.

4) 4-SATs to obtain a 3D position fix for the DGPS. This calculated position is identified as {XD, YD, ZD}.

5) The DGPS then takes the difference that exists between the actual known position and the calculated position obtained using GPS SATs.

- Even if DGPS is located on the GND, it still has a height for its antenna and therefore, we consider a 3D = {LAT, LON, ALT} position rather than a 2D = {LAT, LON} position.

$$\Delta = Calculated\ Position - Actual\ Position$$

$$\Delta = \underbrace{\begin{pmatrix} X_D \\ Y_D \\ Z_D \end{pmatrix}}_{\text{Calculated DGPS Position}} - \underbrace{\begin{pmatrix} X_{D0} \\ Y_{D0} \\ Z_{D0} \end{pmatrix}}_{\text{Actual DGPS Position}}$$

6) Ideally, Δ should be roughly zero; however, most of the time this is not the case, and therefore the Δ information is transmitted to the airborne GPS-Rx in the form of a correction signal.

❑ **In the A/C:**

1) Rx: GPS-Rx system.

2) Frequency:

- Rx: UHF [used to calculate A/C position fix]
- Rx: LF/MF [used to observe correction signal from DGPS]

3) Range of Operation 370 km

4) Again, the A/C obtains its 3D position fix using the 4-SATs.

5) Then, the GPS-Rx detects the correction signal that contains the information and performs the following correction:

$$Actual\ Position = Calculated\ Position - \Delta$$

$$Actual\ A/C\ Position = \overbrace{\begin{pmatrix} X_{A/C} \\ Y_{A/C} \\ Z_{A/C} \end{pmatrix}}^{Calculated\ A/C\ Position} - \Delta$$

- Range of Operation- In other words, the maximum distance that separates the GND DGPS and the airborne GPS-Rx cannot exceed 370 km.

DGPS correction can assist in SBAS to provide error correction onboard. SBAS works as below with ground validated error correction

SBAS incorporates a modular architecture, similar to GPS, comprised of a Ground Segment, Space Segment, and User Segment:

- The Ground Segment includes reference stations, processing centers, a communication network, and Navigation Land Earth Stations (NELS)
- The Space Segment includes geostationary satellites (For example, EGNOS uses Inmarsat transponders)
- The user segment consists of the user equipment, such as an SXBlue II GPS receiver and antenna

SBAS uses a state-based approach in its software architecture. This means that a separate correction is made available for each error source rather than the sum effect of errors on the user equipment's range measurements. This more effectively manages the issue of spatial decorrelation than some other techniques, resulting in a more consistent system performance regardless of geographic location with respect to reference stations. Specifically, SBAS calculates separate errors for the following:

- The ionospheric error
- GPS satellite timing errors
- GPS satellite orbit errors

2B	With neat diagram, explain the word format, message format and transmission media used in MIL-STD-1553 communication protocol to transmit information from AHRS to Primary Flight Display (PFD).	**04**	**CO5**	**L2**

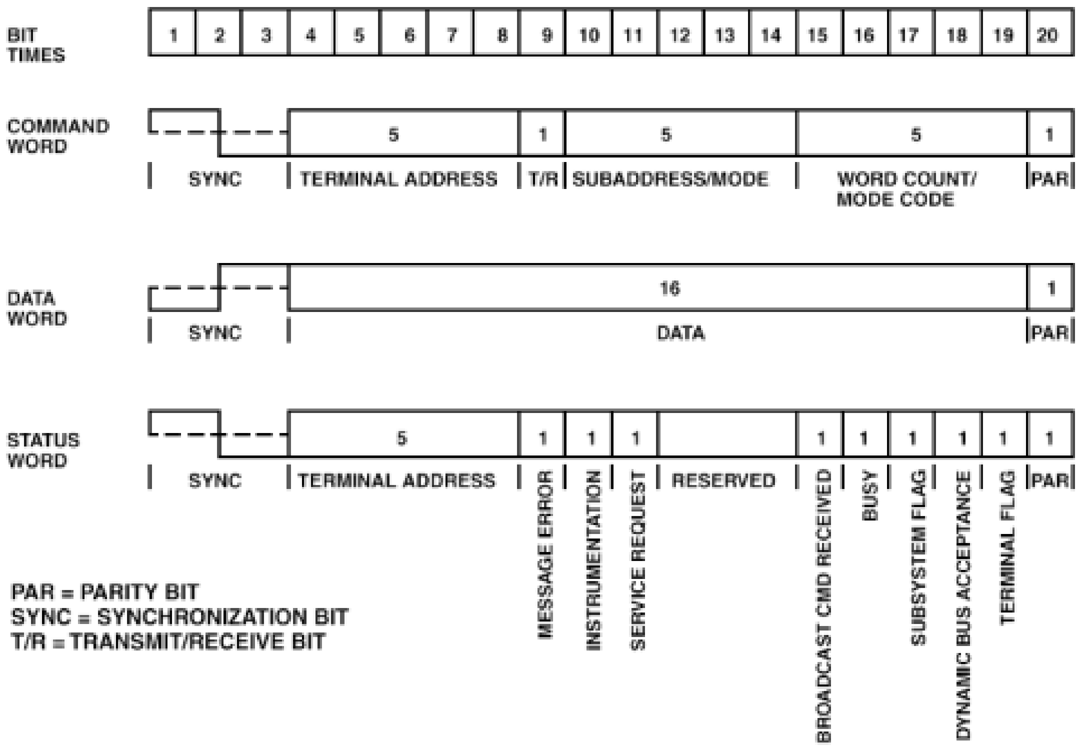
Ans AHRS send the attitude-pitch roll and heading angle to the primary flight display. This information will be shared through MIL STD 1553 B from AHRS to PFD and symbology generated will be displayed over PFD screen. Communication protocols of MIL STD 1553 is below:

Three distinct word types are defined by the standard. These are command words, data words, and status words. Each word type has a unique format yet all three maintain a common structure. Each word is 20 bits in length. The first three bits are used as a synchronization field, thereby allowing the decode clock to re-sync at the beginning of each new word. The following 16 bits are the information field and differ among the three word types. The last bit is the parity bit. Parity is based on odd parity for the single word.

Bit encoding for all words is based on bi-phase Manchester II format. The Manchester II format provides a self-clocking waveform in which the bit sequence is independent. The positive and negative voltage levels of the Manchester waveform is DC balanced (same amount of positive signal as there is negative signal) and as such is well suited for transformer coupling. A transition of the signal occurs at the center of the bit time. A logic “0” is a signal that transitions from a negative level to a positive level. A logic “1” is a signal that transitions from a positive level to a negative level. The terminal’s hardware is responsible for the Manchester encoding and decoding of the word types. The interface that the subsystem sees is the 16-bit information field of all words.

The sync and parity fields are not provided directly. However, for received messages, the decoder hardware provides a signal to the protocol logic as to the sync type the word was and as to whether parity was valid or not. For transmitted messages, there is an input to the encoder as to what sync type to place at the beginning of the word, and parity is automatically calculated by the encoder.

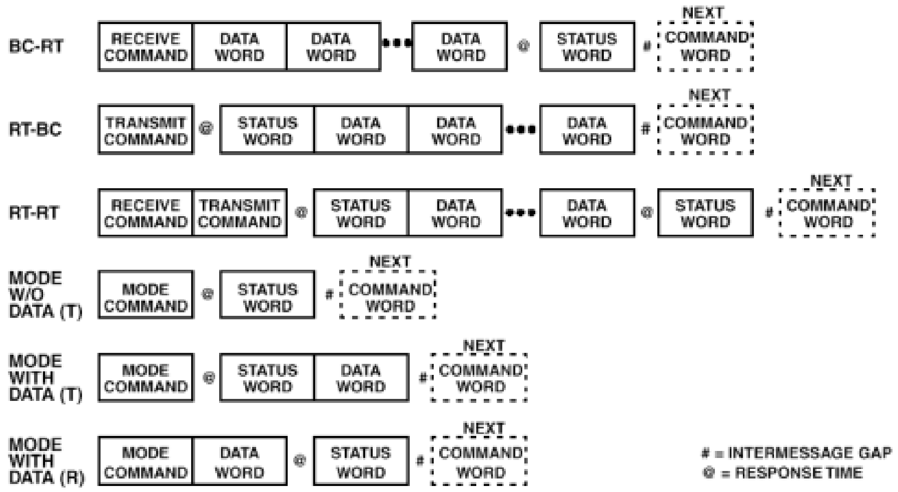
Word Format:



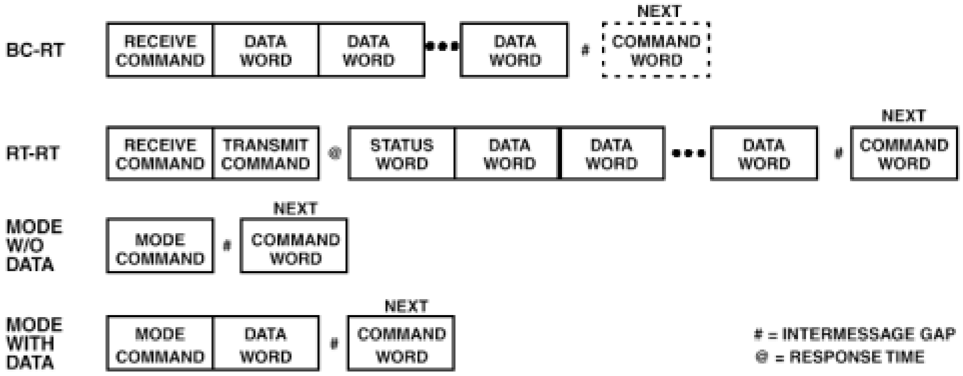
URE 1.5 Word formats.

Message Formats, Validation, and Timing

The primary purpose of the data bus is to provide a common medium for the exchange of data between systems. The exchange of data is based upon message transmissions. The standard defines 10 types of message transmission formats. All of these formats are based upon the three word types just defined. The 10 message formats are shown in Figures below. The message formats have been divided into two groups. These are referred to within the standard as the “information transfer formats” (Figure 1.6) and the “broadcast information transfer formats”. The information transfer formats are based upon the command/response philosophy that all error free transmissions received by a remote terminal be followed by the transmission of a status word from the terminal to the bus controller. This handshaking principle validates the receipt of the message by the remote terminal.



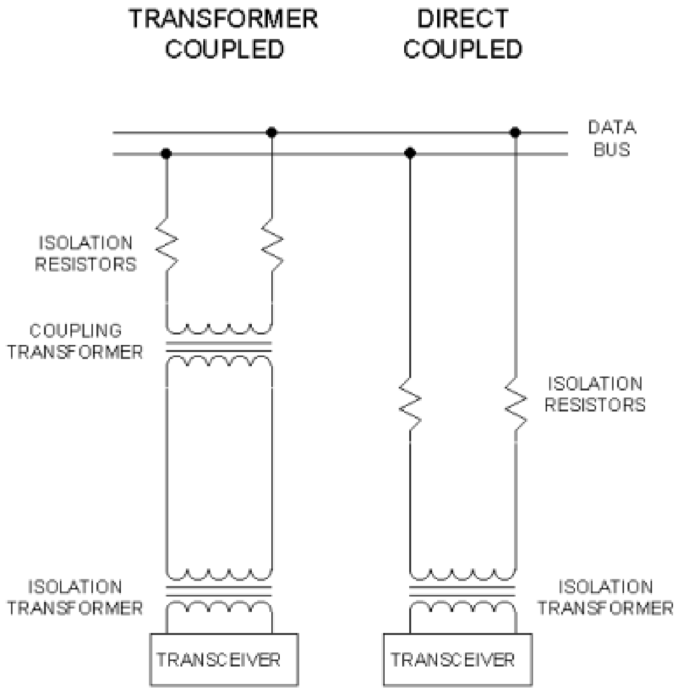
IGURE 1.6 Information transfer formats.



URE 1.7 Broadcast information transfer formats.

Transmission Media

The transmission media, or data bus, is defined as a twisted shielded pair transmission line consisting of the main bus and a number of stubs. There is one stub for each terminal (system) connected to the bus. The main data bus is terminated at each end with a resistance equal to the cable’s characteristic impedance. This termination makes the data bus behave electrically like an infinite transmission line. Stubs, which are added to the main bus in order to connect the terminals, provide “local” loads, and produce an impedance mismatch where added. This mismatch, if not properly controlled, produces electrical reflections and degrades the performance of the main bus. Therefore, the characteristics of both the main bus and the stubs are specified within the standard. Table 1.2 is a summary of the transmission media characteristics. The standard specifies two stub methods: direct and transformer coupled. This refers to the method in which a terminal is connected to the main bus. Figure 1.2 shows the two methods, the primary difference between the two being that the transformer coupled method utilizes an isolation transformer for connecting the stub cable to the main bus cable.



Terminal connection methods.

2C	During approach, what is the function of ADF, VOR and DME? Highlight the function of onboard equipment installed in the aircraft in this scenario.	**03**	**CO2**	**L2**

Ans During approach ADF and VOR guide the aircraft to approach a particular bearing angle to reach airport runway. DME always guide the distance left between aircraft and runway nearby installed DME Tx.

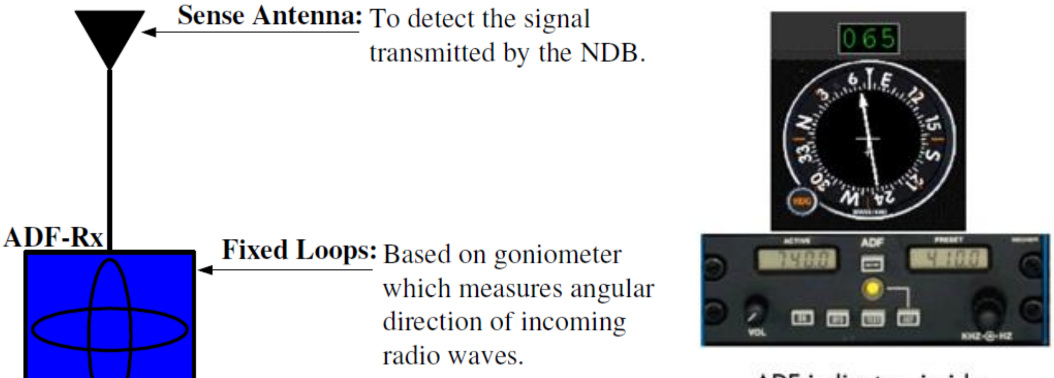
Bearing as well as distance between aircraft and runway give precision guidance to approach runway and TDP.

Below is the onboard working principle of ADF, VOR and DME to guide the pilot to approach the aircraft to runway.

ADF

In the A/C:

1) Rx: ADF-Rx system.
2) Frequency: MF 550 – 1750 kHz (commercial AM band)
3) ADF bearing needle points only to the tuned NDB.
4) When A/C flies toward an NDB the ADF bearing pointer indicates 000°.
5) When A/C flies above an NDB the ADF bearing pointer indicates 180°.

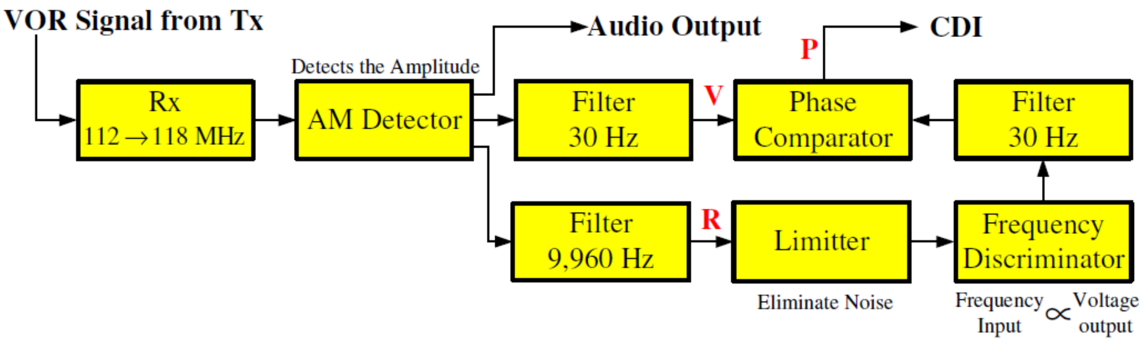


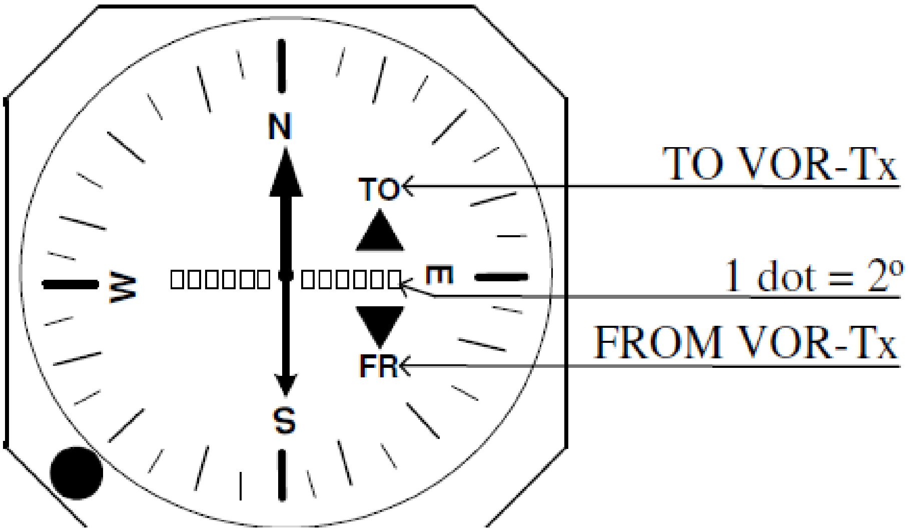
ADF indicator inside the cockpit

VOR:

In the A/C:

1) Rx: VOR-Rx system.
2) Frequency: VHF
3) The phase difference P between R & V is calculated.
4) A/C CDI shows the VOR radial reading. If CDI becomes defective a red flag will appear.





DME

In the A/C:

1) *Rx-Tx: DME system also known as (a.k.a) the Interrogator.*

2) *Frequency: UHF*

3) Range of Operation: 150 – 200 miles 240 – 320 km

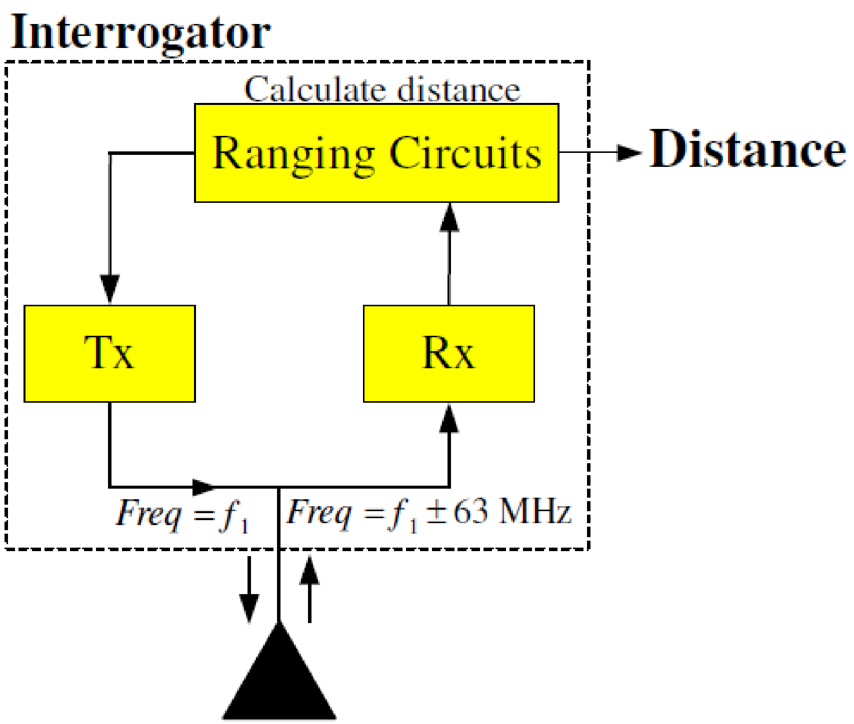
4) A/C DME displays:

Distance in: nm

GS in: kts

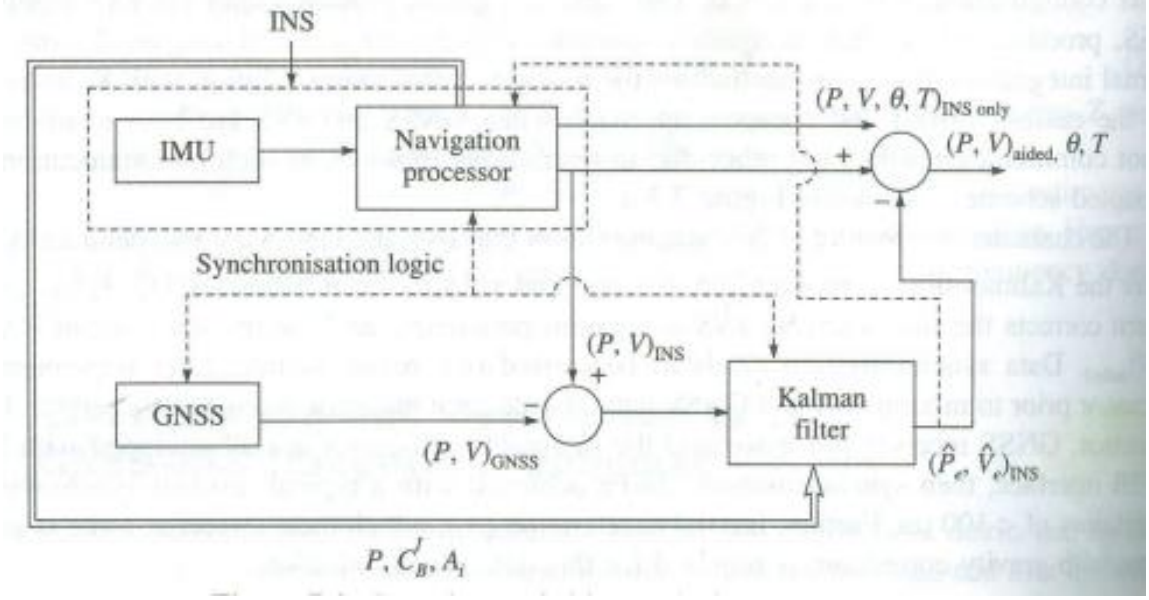
Remaining time to get to

GND station in: minutes



3A	Defend the synchronization logic and requirement of sensor data in single coordinate frame and algorithm in the GNSS-INS integration scheme. Explain with neat diagram.	**02**	**CO2**	**L5**

Ans In the GNSS-INS integration scheme the INS data will be calibrated when GPS is available. Since AHRS/INS sensors and GPS Receiver sensor works at different frequency or data rate so it is require to process the Kalman filter at same frequency to calculate the best error hidden in information. This error requires to correct the INS information in position and velocity with time. Without synchronization at same time or frequency processing of algorithm is not possible in this. One of the schemes is shown as below.



Here, INS, GNSS and Kalman filter algorithm synchorized at same time so data available from each sensor before processing the algorithms at every instant of time.

3B	Design a redundant and reconfigurable primary and secondary control surface actuation system in modern airbus aircraft. Sketch and highlight energy driven, symmetrical design of control surfaces and explain the quadruplex redundancy.	**05**	**CO3**	**L6**
Ans	Airbus modern aircraft available is A 380. Flight control redundancy and reconfigurable systems is required to keep as back up in case of failure of one lane or energy driven actuators.			

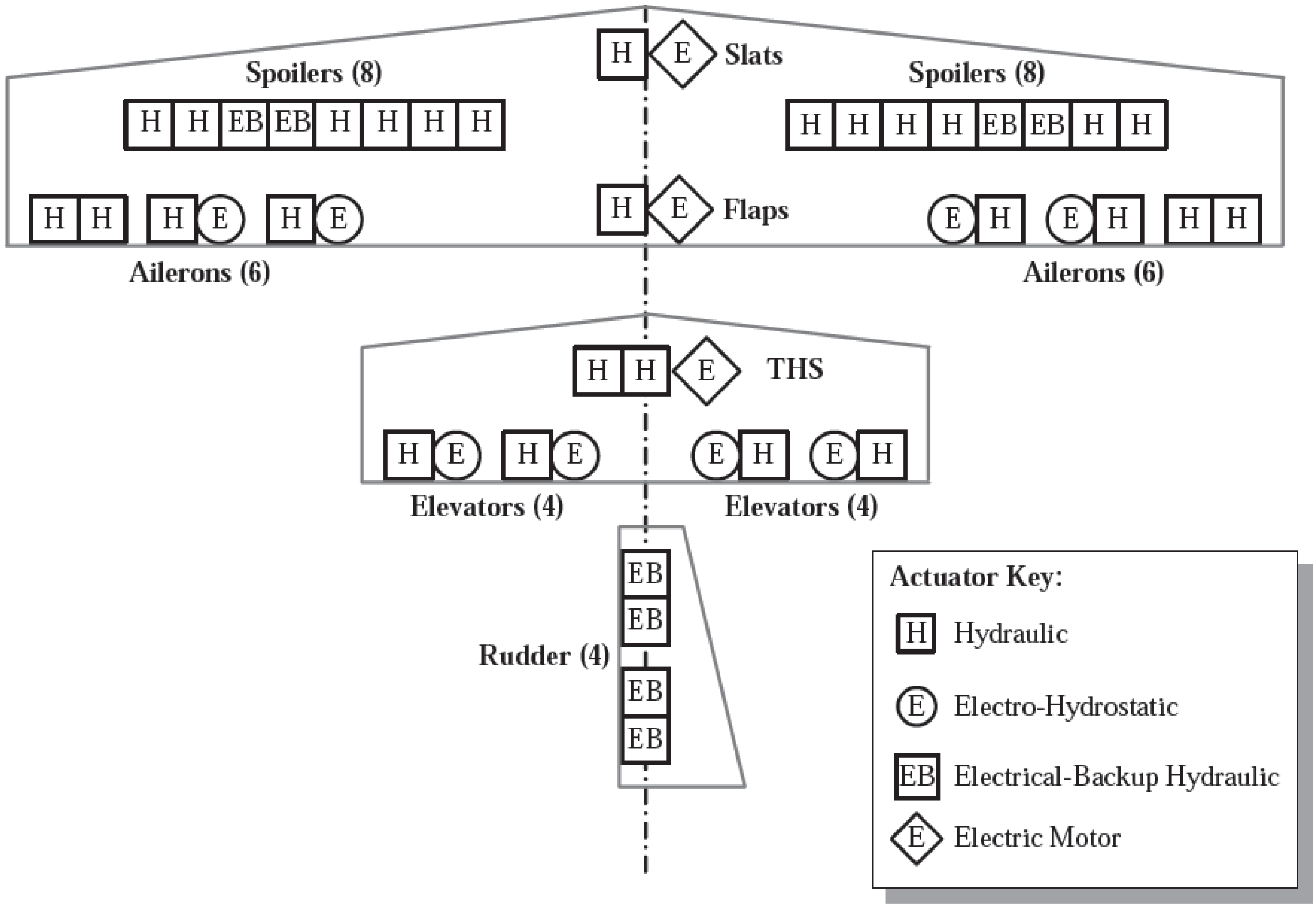


Figure 1.30 A 380 flight control actuation

Primary control surfaces:

Rudder 4 parts driven with electrical backup with AC 1 essential side 1, 2 essential side 2 and RAT as shown in above figures.

Elevator: 4 parts alternate with hydraulic and electro-hydrostatic and symmetric design from center. Energy with yellow and green hydraulic systems shown in above figures.

Aileron: 6 part left and 6 part right with symmetric design, Hydraulic-Hydraulic and electro-hydrostatic-Hydraulic and supported with AC E2, AC E1, Y and G with symmetry design as shown in above figures.

Secondary Control surfaces: Spoiler (8 parts left and right) and THS (H,H, E), Slats (H and E)and flaps (H & E) also design with redundant and symmetric design with various combination of energy driven actuator as shown in the above figures.

Table 1.3 A380 Flight control system actuator matrix

LEFT WING					RIGHT WING			
AILERONS		**SPOILERS**			**SPOILERS**		**AILERONS**	
Inbd	G AC E2	1	Y		Y	1	G AC E2	Inbd
Mid	Y AC E1	2	G		G	2	Y AC E1	Mid
Outbd	Y G	3	Y		Y	3	Y G	Outbd
		4	G		G	4		
		5	Y + AC 2E		Y + AC 2E	5		
		6	G + AC 1E		G + AC 1E	6		
		7	Y		Y	7		
		8	G		G	8		
R ELEVATORS				THS			**L ELEVATORS**	
Inbd	AC E1 G			G Y AC E2			AC E1 Y	Inbd
Outbd	AC E2 G						AC E2 Y	Outbd
				RUDDER				
				Upper 1 Y + AC E1 2 G + AC E2 Lower 1 G + AC E1 2 Y + AC E3				
KEY:								
	G	Green Hydraulic System					AC E1	AC 1 Essential Side 1
	Y	Yellow Hydraulic System					AC E2	AC 2 Essential Side 2
							AC E3	AC Essential (RAT)

3C	Design the generalized symbology generation of head-up-display with neat diagram for one of the design available in the market.	**03**	**CO1**	**L6**

Ans Following process require to design a symbology generation HUD:

1. Design parameters- HUD CRT diameter (measured across display face) , Required total FOV, derivation of IFOV, Collimating lens diameter, Collimating lens centre from combiner glass (measured along axis of lens), Pilot's design eye position from combiner glass (measured along pilot's LOS through centre of combiner).
2. Derivation of IFOV
3. Derivation of eye rotation or head movement
4. Deriving coordinate points for horizon line in case of pitch and roll angle
5. Wave form generation, amplification, and projection to the screen.

Few diagrams shown as reference

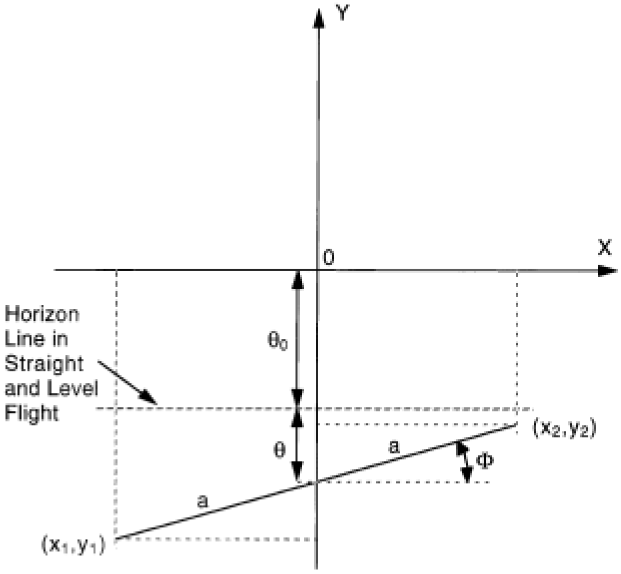


Fig. 2.20 Horizon line.

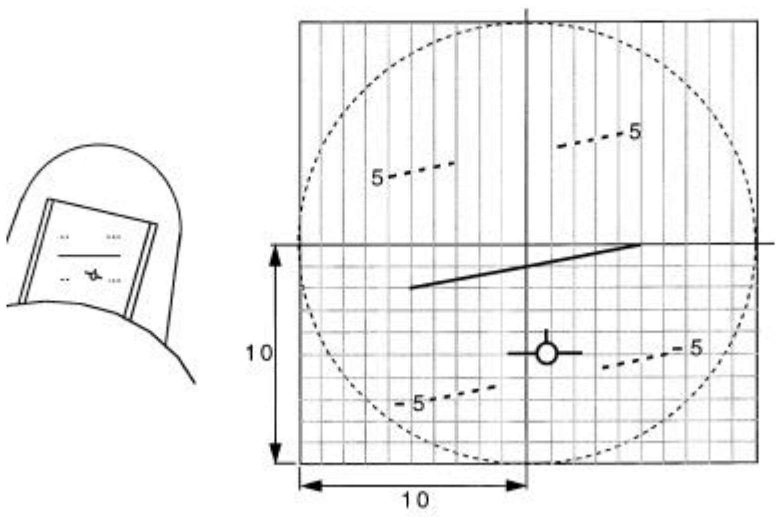


Fig. 2.21 HUD display of horizon line and velocity vector.

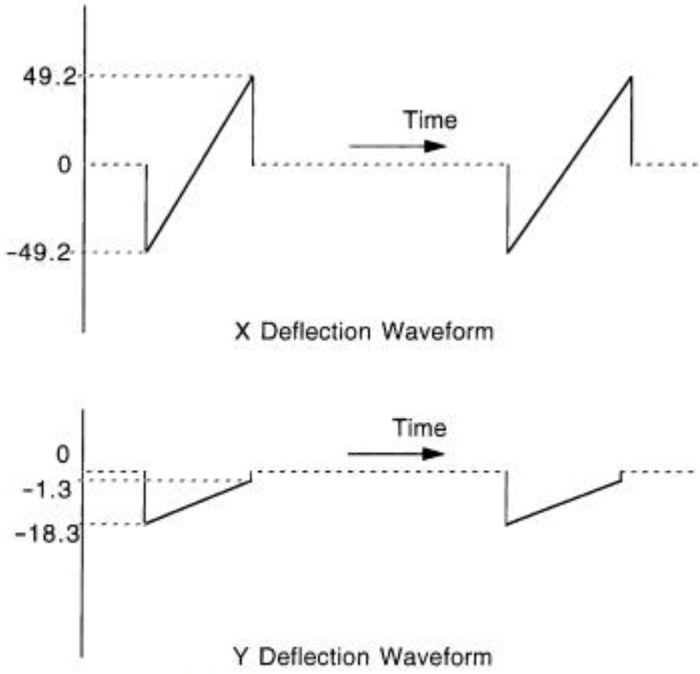
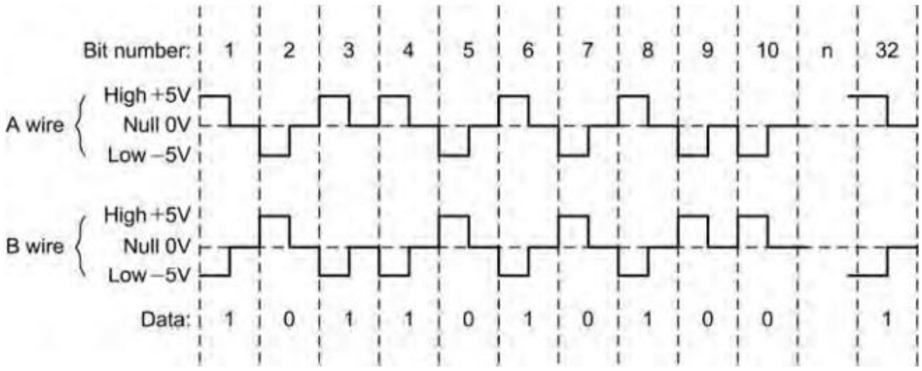


Fig. 2.22 *X* and *Y* deflection waveforms.

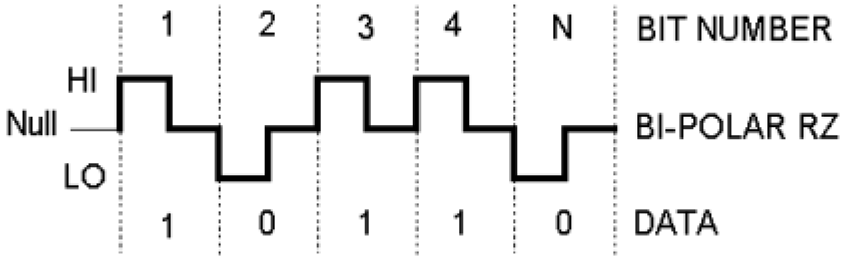
4A	In the aircraft data signal flow shows two twisted wires as shown in the figure. Identify the databus used in the aircraft and explain its electrical characteristics and communication protocols.	**03**	**CO5**	**L2**



Ans This is ARIN-429

A single transmitter is connected with up to 20 data receivers via a single twisted and shielded pair of wires. The shields of the wires are grounded at both ends and at any breaks along the length of the cable. The shields are kept as short as possible.

Modulation Return-To-Zero (RZ) modulation is used. The voltage levels are used for this modulation scheme.



Voltage Levels The differential output voltages across the transmitter output terminal with no load is described in the following table:

	HI(V)	NULL(V)	LO(V)
Line A to Line B	$+10 \pm 1.0$	0 ± 0.5	-10 ± 1.0
Line A to Ground	5 ± 0.5	0 ± 0.25	-5 ± 0.5
Line B to Ground	-5 ± 0.5	0 ± 0.25	$+5 \pm 0.5$

The differential voltage seen by the receiver will depend on wire length, loads, stubs, etc. With no noise present on the signal lines the nominal voltages at the receiver terminals (A and B) would be

HI	$+7.25$V to $+11$V
NULL	$+0.5$V to -0.5V
LO	-7.25V to -11V

In practical installations impacted by noise, etc. The following voltages ranges will be typical across the receiver input (A and B):

HI	$+6.5$V to $+13$V
NULL	$+2.5$V to -2.5V
LO	-6.5V to -13V

Impedance Levels

Transmitter Output Impedance

The transmitter output impedance is 70 to 80 (nominal 75) ohms and is divided equally between lines A and B for all logic states and transitions between those states.

Receiver Input Impedance

The typical receiver input characteristics are as follows:

- ✓ Differential Input Resistance RI 12,000 ohms minimum
- ✓ Differential Input Capacitance CI 50 Pf maximum
- ✓ Resistance to Ground RH and RG 12,000 ohms
- ✓ Capacitance to Ground CH and CG 50 pF

32	31 30	29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11	10 9	8 7 6 5 4 3 2 1
P	SSM	DATA → ← PAD ← DISCRETES	SDI	LABEL
		MSB LSB		

Generalized BCD Word Format

P	SSM	BCD CH #1	BCD CH #2	BCD CH #3	BCD CH #4	BCD CH #5	SDI	8 7 6 5 4 3 2 1
		4 2 1	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1		
0	0 0	0 1 0	0 1 0 1	0 1 1 1	1 0 0 0	0 1 1 0	0 0	1 0 0 0 0 0 0 1
Example		2	5	7	8	6	DME DISTANCE	

BCD Word Format Example (No Discretes)

32	31 30 29	28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11	10 9	8 7 6 5 4 3 2 1
P	SSM	DATA → ← PAD ← DISCRETES	SDI	LABEL
		MSB LSB		

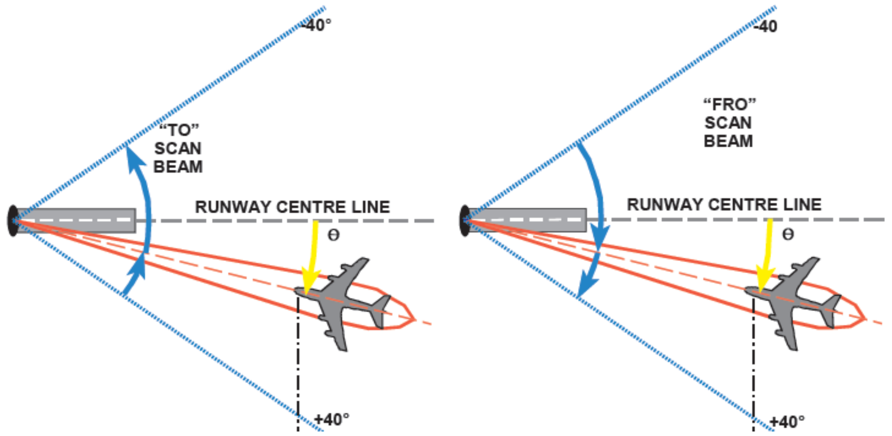
Generalized BCD Word Format

4B Sketch the diagram of the following cases with onboard indication: **03** **CO3** **L3**

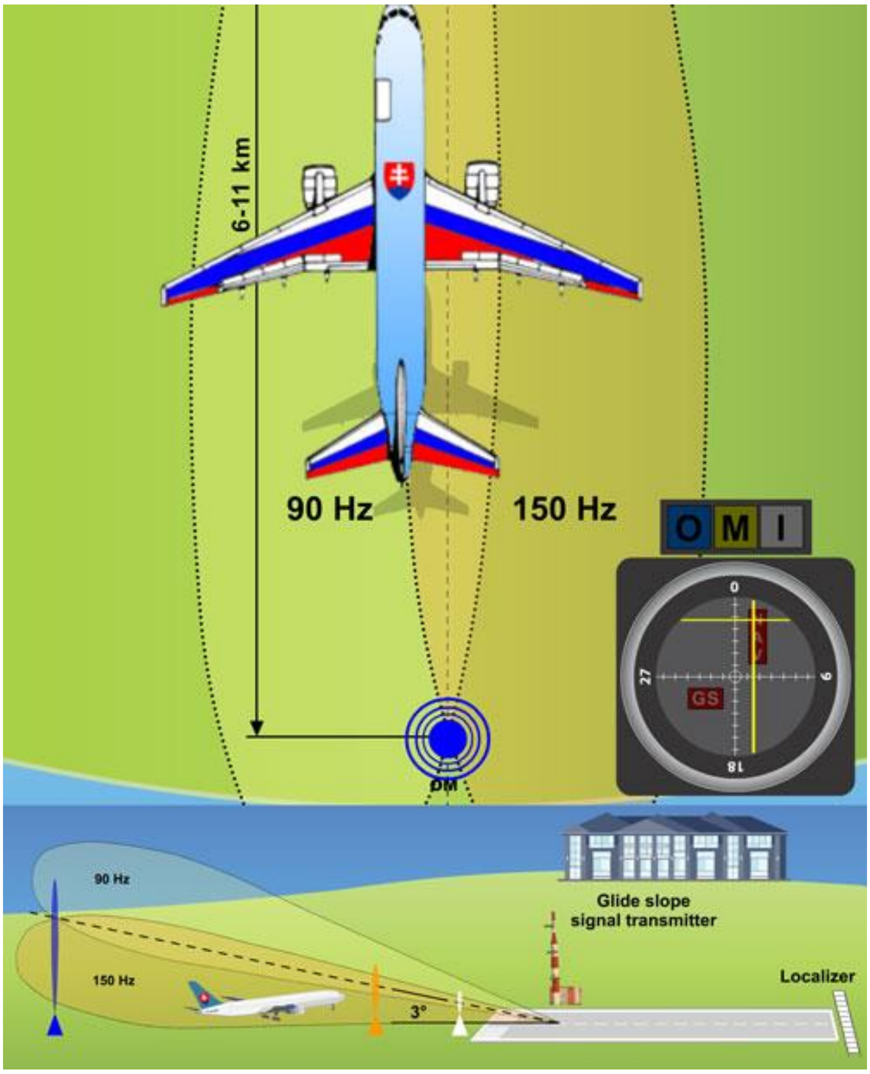
(i) A case when the aircraft is located left of the runway's axis and too low under the glide slope

(ii) TRSB Component

(iii) Write function of given figure:

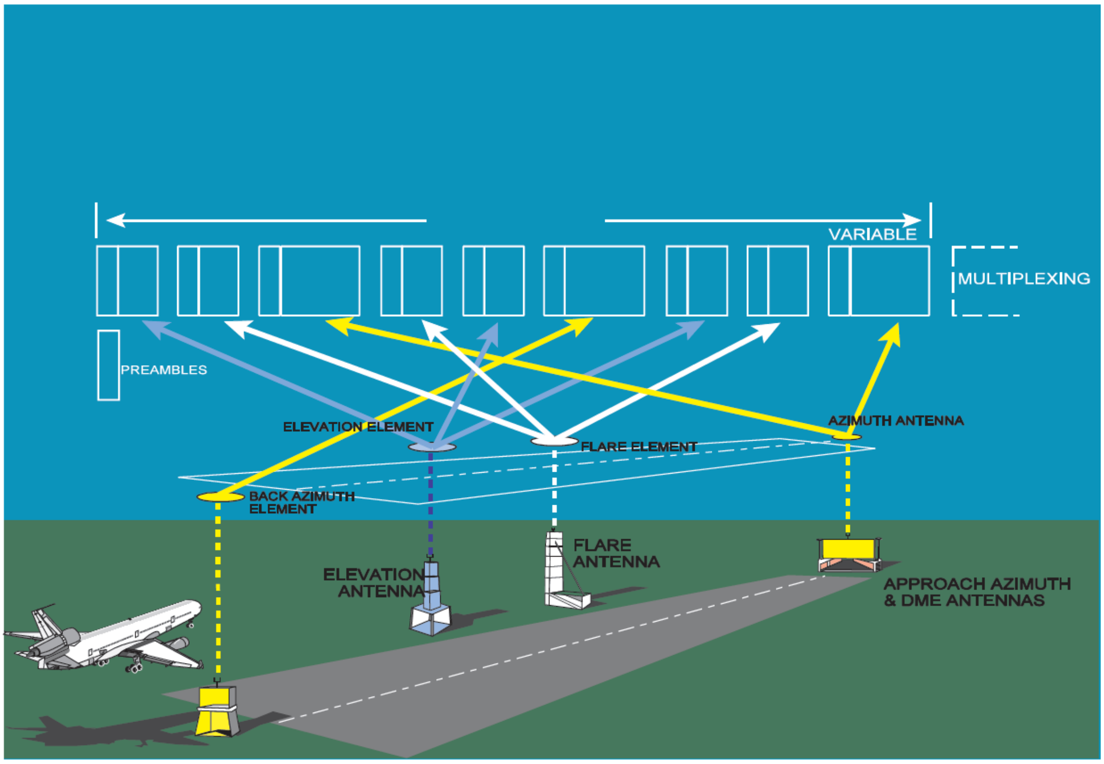


Ans (i) A case when the aircraft is located left of the runway's axis and too low under the glide slope



A case when the aircraft is located left of the runway's axis and too low under the glide slope

(ii) TRSB Component



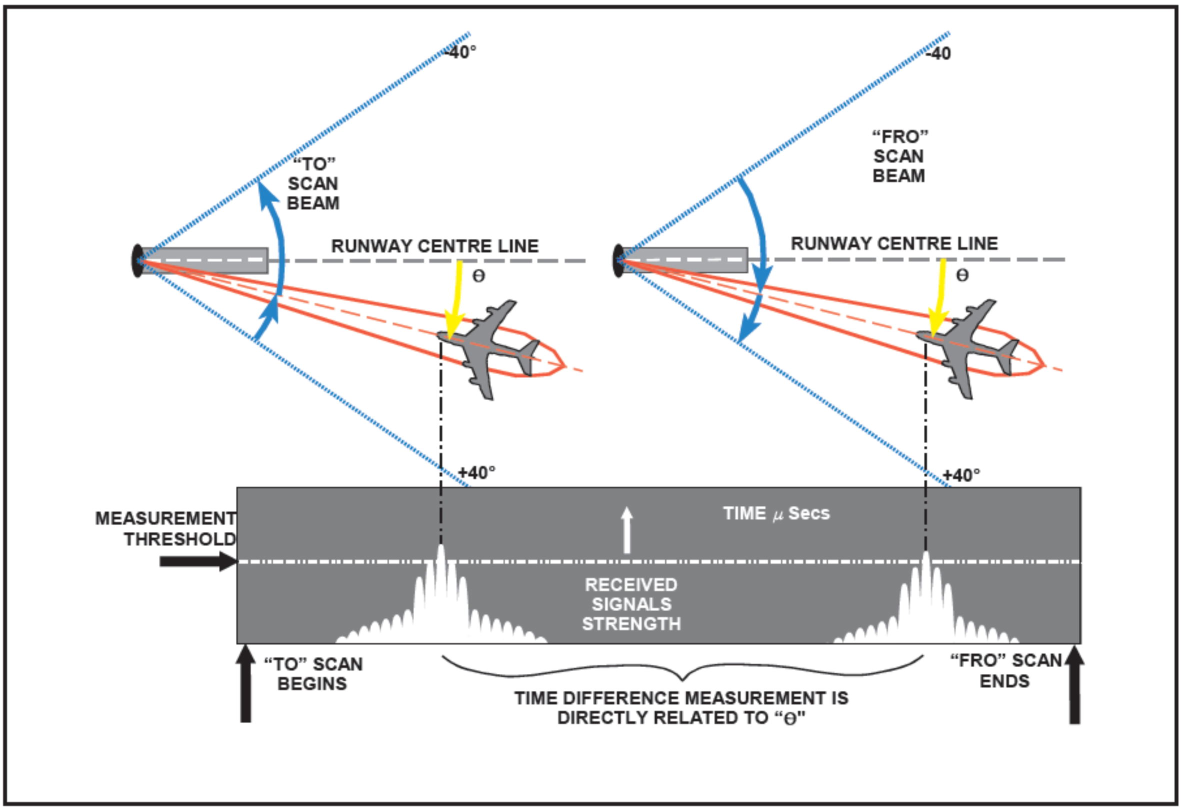


Figure 10.4

Time referenced scanning beam (TRSB) is utilised in azimuth and elevation as follows:

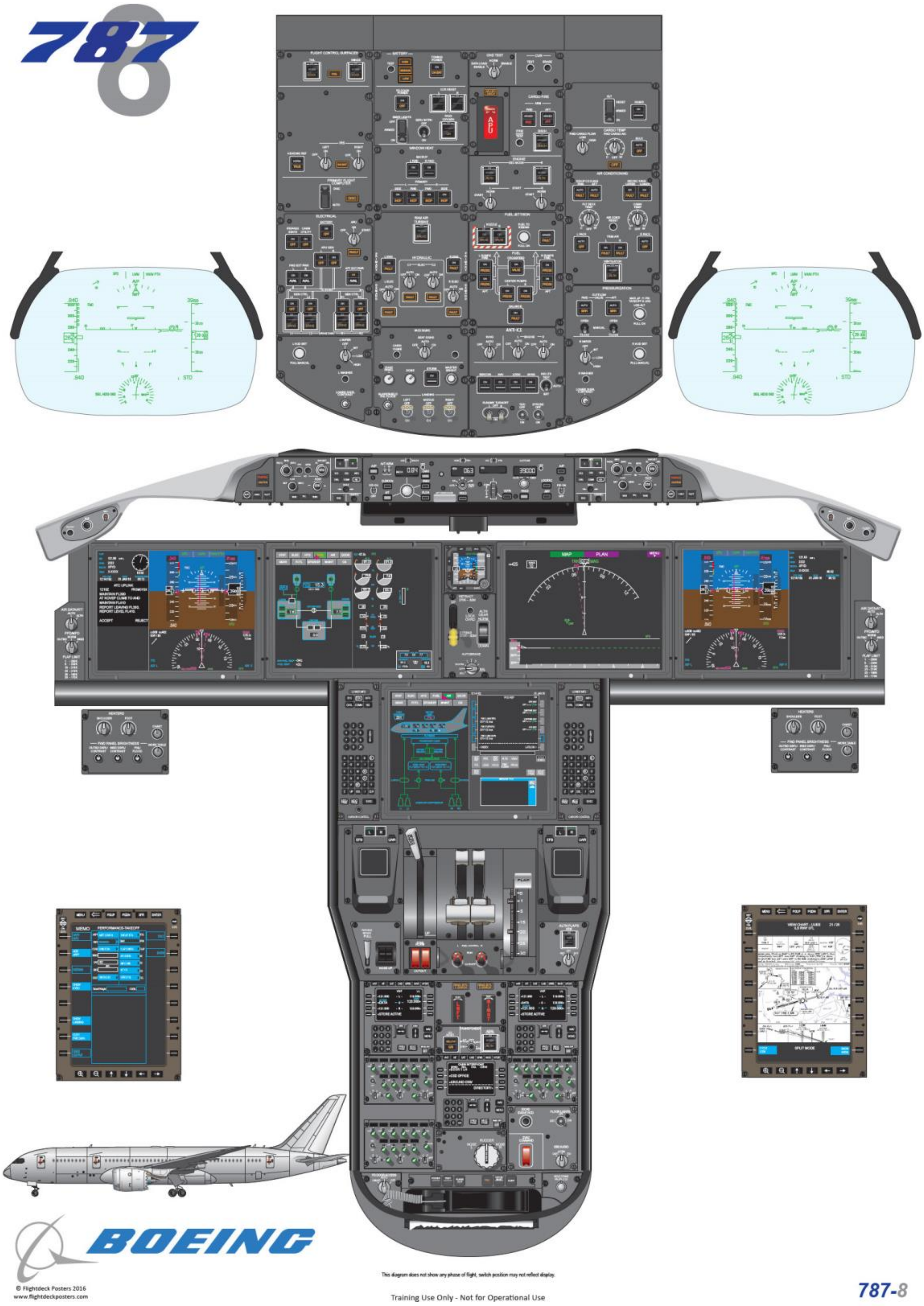
- The aircraft computes its azimuth position in relation to the runway centre-line by measuring the time interval in microseconds between the reception the 'to' and 'fro' scanning beams.

- The beam starts the 'to' sweep at one extremity of its total scan and travels at a uniform speed to the other extremity. It then starts its 'fro' scan back to its start position.

- The pilot can choose to fly the runway on-course line (QDM) or an approach path which he selects as a pre-determined number of degrees ± the runway direction.

Aircraft detects the signal twice and it help to calculate the angle in proportional to time.

4C	Derive the requirements of cockpit design and integration of avionics systems in modern Boeing aircraft. Sketch the cockpit layout in 2D.	**04**	**CO1**	**L3**
Ans	Comment: Sketch only line diagram: This is for help to check systems selected in answer.			



Few Major Design Requirements:

1. Display-PFD, ND, MFD, HUD, SD, Engine display, Glare shield panel
2. Flight management systems, autopilot system
3. Controls: Engine control yoke system, rudder pedal
4. MAPs

5. Seat
6. Communication and navigation display panel
7. Switches, oxygen mask
8. Overhead panel switches with features: oxygen, energy-primary and secondary, pitot static system with heater control, engine, fuel pump,
9. Databuses
10. Pedestal

Discuss the design and integration V-Model

5A With neat diagram analyze the flight management system function in the case of failure of one of the FMC. **02** **CO3** **L4**

Ans

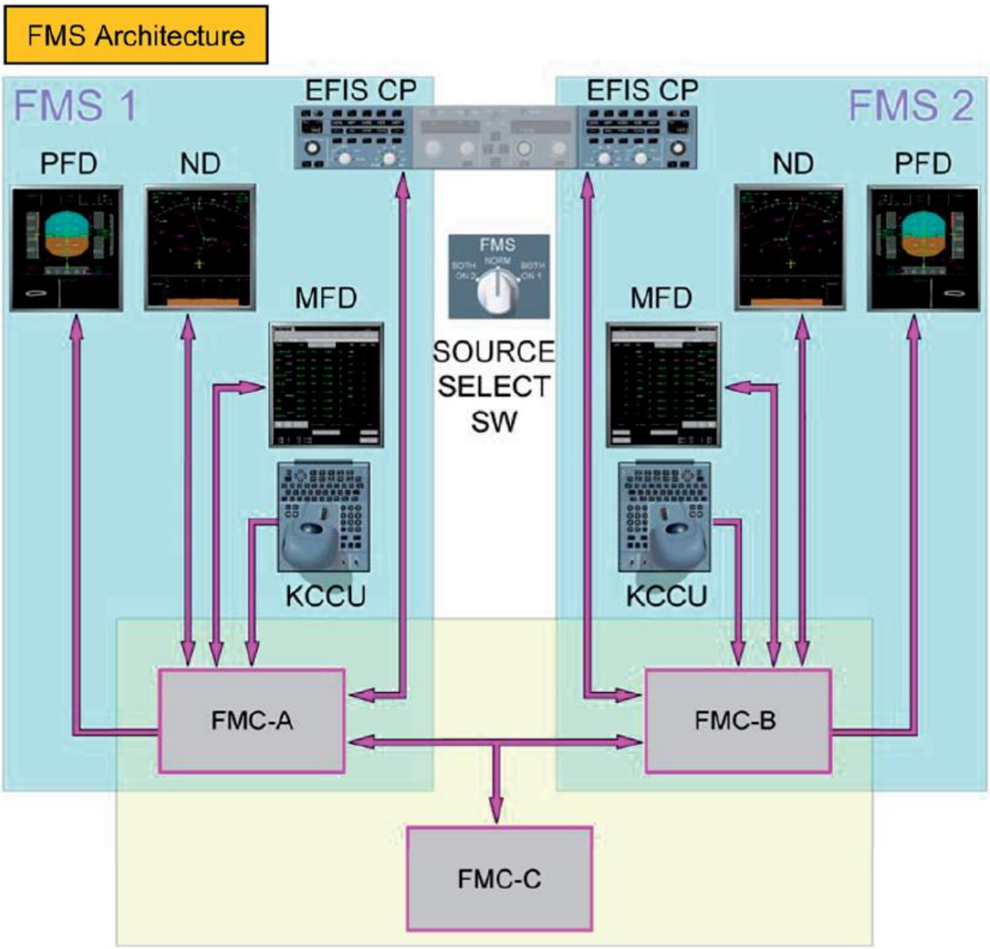


Fig. 8.16 FMS architecture (by courtesy of Airbus).

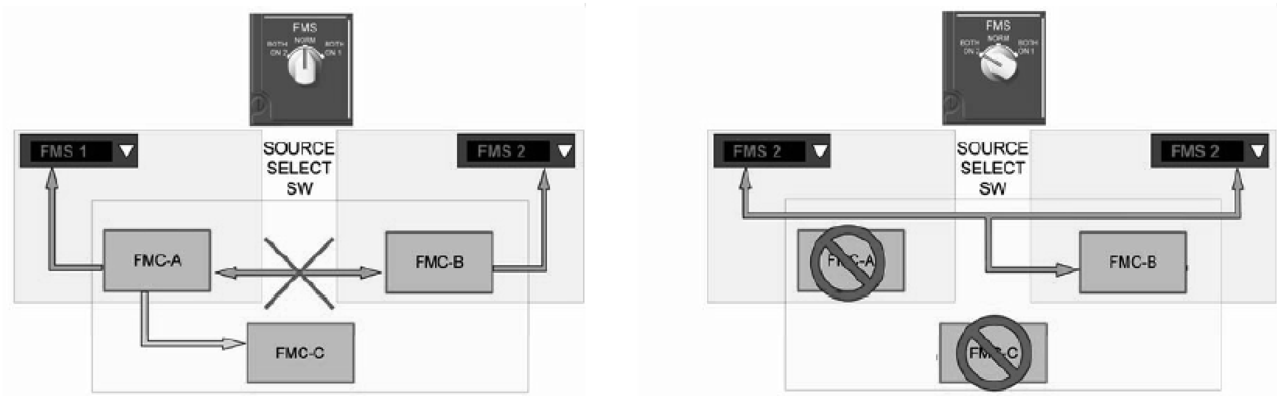


Fig. 8.18 Independent Mode and Single Mode configurations (by courtesy of Airbus).

In normal operation,

FMC-A provides data to FMS-1, FMC-B provides data to FMC-2 and FMC-C is the standby computer.

Out of the two active computers, one FMC is the 'master' and the other is the 'slave', depending on which autopilot is active and the selected position of the FMS Source Select Switch.

The two active FMCs independently calculate data, and exchange, compare and synchronise these data.

The standby computer does not perform any calculations, but is regularly updated by the master FMC.

In the case of a single FMC failure, for example FMC-A, FMC-C provides data to FMS-1.

5B	Design with a neat diagram of AC and DC total electrical power systems in A380 aircrafts. Discuss the system engineering involved in it's design it and briefly highlight the components used in it.	**05**	**CO4**	**L6**

Ans Electrical system engineering to designing electrical systems involved-derive the requirement of power generation, primary and secondary power source for backpu or power redundancy design in case of failure, power conversion in AC to AC either step up or step down or AC to DC -for high load or low load requirements, AC or DC requirement in the aircraft, power distribution in primary or secondary, protection of power generation, conversion and distribution. After requirement it can be broke down to modulewise design and develoment, integration of LRUs, LRM, testing and verification and validation of power performance. Its design also depends on light and heavy aircraft where power requirement will be different.

Its design focus on following:

- Power generation
- Primary power distribution and protection
- Power conversion and energy storage
- Secondary power distribution and protection

The basic functions of the electrical system's components are to:

- Generate Power
- Control Electrical Power
- Protect the Electrical System
- Distribute Electrical Power Throughout the Aircraft

Many components are involved in aircraft electrical power system as below:

- AC Generator
- Constant Speed Drive
- Integrated Drive Generator
- Transformer Rectifier Unit
- Generator Control Unit

Briefy dicuss above system functions.

Design of A 380 total AC and DC electrical power system design shown in the below:

Briefly highlight its working.

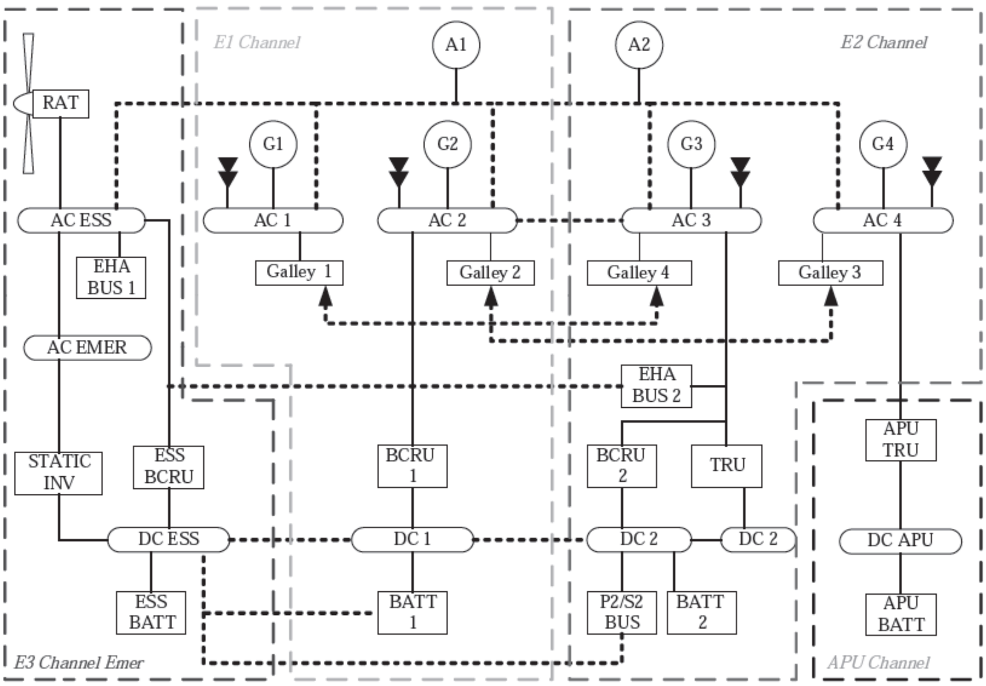
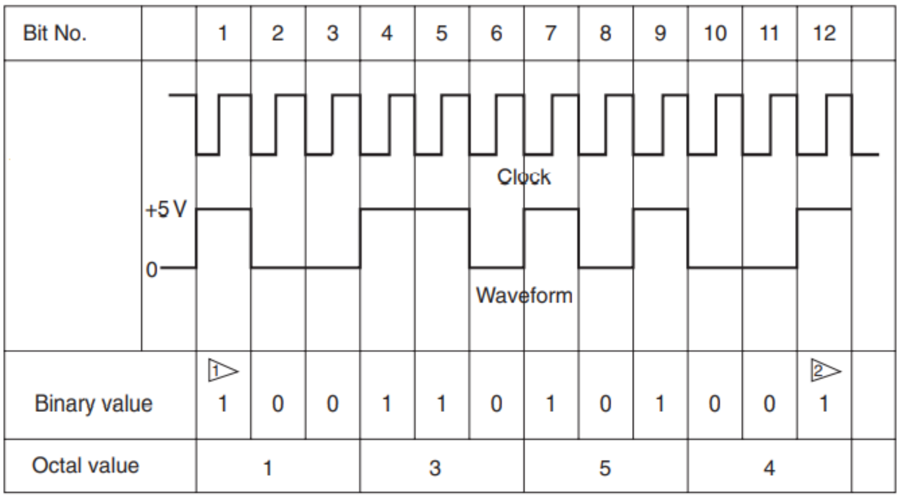
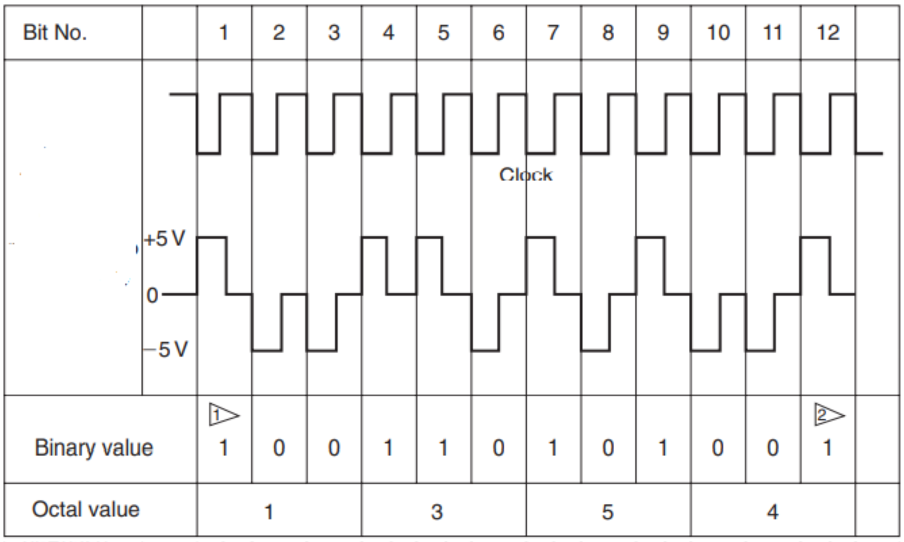


Figure 5.40 A380 total electrical system showing segregation

5C	Figure given below represents Flight data recorder system codes. Identify the Non -return -to zero (NRZ) and Bipolar -return -to zero (Bipolar RZ) and explain them using the given figure.	**03**	**CO5**	**L2**





Ans Non return to zero: In this case signal will maintained either maximum voltage or minimum voltage for complete period. It will be either 1 with high voltage or 0 with low voltage.

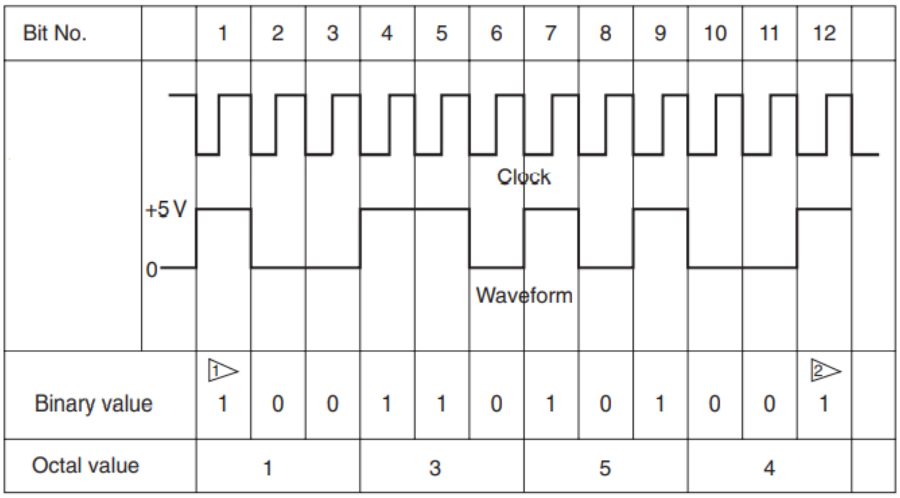
In Bipolar return to zero: Signal will start with High voltage half period and half period Null. This gives 1.

Signal start with low voltage stay half period at low and return to zero and stay half period null. This gives zero.

In the ARINC 429: Voltage variation normally will be as below at receiver terminal.

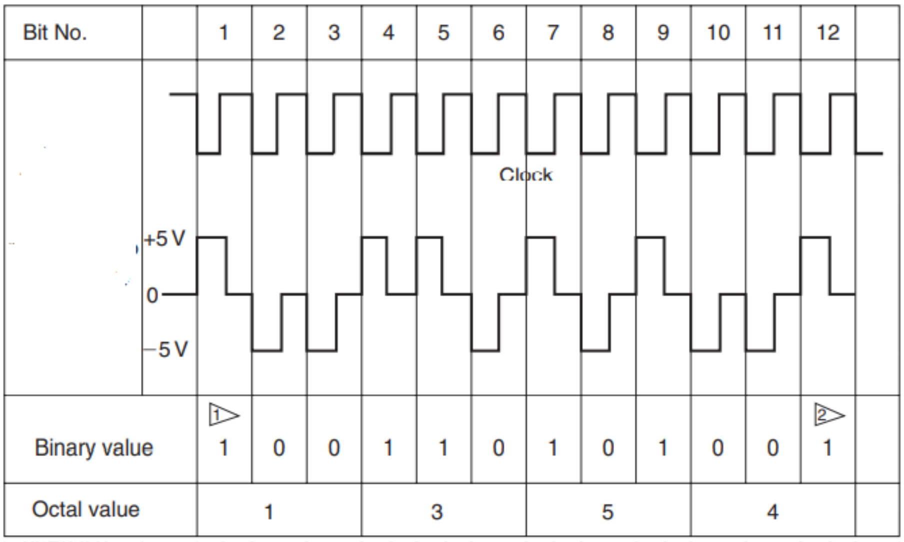
HI	+7.25V to +11V
NULL	+0.5V to −0.5V
LO	−7.25V to −11V

HI	+6.5V to +13V
NULL	+2.5V to −2.5V
LO	−6.5V to −13V



Non -return -to zero (NRZ)

Data transmitted with the value= 1354



Bipolar -return -to zero (Bipolar RZ)

Data transmitted with the value= 1354

Signal pattern in both cased will be different for same information due to different protocols.