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School of Mechanical
Department of Aeronautical Engineering

UNIT- I – AVIONICS - SAEA1404

AVIONICS

UNIT - I DISPLAYS TECHNOLOGY

Avionics are the electronic systems used on aircraft, artificial satellites, and spacecraft. Avionic systems include communications, navigation, the display and management of multiple systems, and the hundreds of systems that are fitted to aircraft to perform individual functions.

1.AIRCRAFT AVIONICS

1.1 Communications

Communications connect the flight deck to the ground and the flight deck to the passengers. On-board communications are provided by public-address systems and aircraft intercoms.

The VHF aviation communication system works on the Airband of 118.000 MHz to 136.975 MHz. Each channel is spaced from the adjacent ones by 8.33 kHz in Europe, 25 kHz elsewhere. VHF is also used for line of sight communication such as aircraft-to-aircraft and aircraft-to-ATC. Amplitude modulation (AM) is used, and the conversation is performed in simplex mode. Aircraft communication can also take place using HF (especially for trans-oceanic flights) or satellite communication.

1.2 Navigation

Navigation is the determination of position and direction on or above the surface of the Earth. Avionics can use satellite-based systems (such as GPS and WAAS), ground-based systems (such as VOR or LORAN), or any combination thereof. Navigation systems calculate the position automatically and display it to the flight crew on moving map displays. Older avionics required a pilot or navigator to plot the intersection of signals on a paper map to determine an aircraft's location; modern systems calculate the position automatically and display it to the flight crew on moving map displays.

1.3Monitoring

The Airbus A380 glass cockpit featuring pull-out keyboards and two wide computer screens on the sides for pilots.

The first hints of glass cockpits emerged in the 1970s when flight-worthy cathode ray tubes (CRT) screens began to replace electromechanical displays, gauges and instruments. A "glass" cockpit refers to the use of computer monitors instead of gauges and other analog displays. Aircraft were getting progressively more displays, dials and information dashboards that eventually competed for space and pilot attention. In the 1970s, the average aircraft had more than 100 cockpit instruments and controls.

1.4 Aircraft flight-control systems

Aircraft have means of automatically controlling flight. Autopilot was first invented by Lawrence Sperry during World War I to fly bomber planes steady enough to hit precision targets from 25,000 feet. When it was first adopted by the U.S. military, a Honeywell engineer sat in the back seat with bolt cutters to disconnect the autopilot in case of emergency. Nowadays most commercial planes are equipped with aircraft flight control systems in order to reduce pilot error and workload at landing or takeoff.

The first simple commercial auto-pilots were used to control heading and altitude and had limited authority on things like thrust and flight control surfaces.

In helicopters, auto-stabilization was used in a similar way. The first systems were electromechanical. The advent of fly by wire and electro-actuated flight surfaces (rather than the traditional hydraulic) has increased safety. As with displays and instruments, critical devices that were electro-mechanical had a finite life. With safety critical systems, the software is very strictly tested.

1.5Collision-avoidance systems

To supplement air traffic control, most large transport aircraft and many smaller ones use a traffic alert and collision avoidance system (TCAS), which can detect the location of nearby aircraft, and provide instructions for avoiding a midair collision. Smaller aircraft may use simpler traffic alerting systems such as TPAS, which are passive (they do not actively interrogate the transponders of other aircraft) and do not provide advisories for conflict resolution.

To help avoid controlled flight into terrain (CFIT), aircraft use systems such as ground-proximity warning systems (GPWS), which use radar altimeters as a key element. One of the major weaknesses of GPWS is the lack of "look-ahead" information, because it only provides altitude above terrain "look-down". In order to overcome this weakness, modern aircraft use a terrain awareness warning system (TAWS).

1.7 Black BoxeS

Commercial aircraft cockpit data recorders, commonly known as a "black box", store flight information and audio from the cockpit. They are often recovered from a plane after a crash to determine control settings and other parameters during the incident.

1.8 Weather systemS

Weather systems such as weather radar (typically Arinc 708 on commercial aircraft) and lightning detectors are important for aircraft flying at night or in instrument meteorological conditions, where it is not possible for pilots to see the weather ahead.

Heavy precipitation (as sensed by radar) or severe turbulence (as sensed by lightning activity) are both indications of strong convective activity and severe turbulence, and weather systems allow pilots to deviate around these areas. Lightning detectors like the Stormscope or Strikefinder have become inexpensive enough that they are practical for light aircraft. In addition to radar and lightning detection, observations and extended radar pictures (such as NEXRAD) are now available through satellite data connections, allowing pilots to see weather conditions far beyond the range of their own in-flight systems. Modern displays allow weather information to be integrated with moving maps, terrain, and traffic onto a single screen, greatly simplifying navigation.

Modern weather systems also include wind shear and turbulence detection and terrain and traffic warning systems. In-plane weather avionics are especially popular in Africa,India, and other countries where air-travel is a growing market, but ground support is not as well developed.

1.9 Aircraft management systems

There has been a progression towards centralized control of the multiple complex systems fitted to aircraft, including engine monitoring and management. Health and usage monitoring systems (HUMS) are integrated with aircraft management computers to give maintainers early warnings of parts that will need replacement. The integrated modular avionics concept proposes an integrated architecture with application software portable across an assembly of common hardware modules. It has been used in fourth generation jet fighters and the latest generation of airliners.

2. The electromechanical instrumented flight deck

An electronic flight instrument system (EFIS) is a flight deck instrument display system in which the display technology used is electronic rather than electromechanical. EFIS normally consists of

- A primary flight display (PFD),
- Multi-function display (MFD) and
- Engine indicating and
- Crew alerting system (EICAS) display.
- Cathode ray tube (CRT) displays were used at first,
- Liquid crystal displays (LCD) are now more common.

The complex electromechanical attitude director indicator (ADI) and horizontal situation indicator (HSI) were the first candidates for replacement by EFIS. EFIS installations vary greatly. A light aircraft might be equipped with one display unit, on which flight and navigation data are displayed. A wide-body aircraft is likely to have six or more display units. An EFIS installation will follow the sequence:

- Displays
- Controls
- Data processors

EFIS might have all these facilities in the one unit.

2.1. Head up Displays

2.1.1. Introduction

Without doubt the most important advance to date in the visual presentation of data to the pilot has been the introduction and progressive development of the Head Up Display or HUD.

(The first production HUDs, in fact, went into service in 1962 in the Buccaneer strike aircraft in the UK.)

The HUD has enabled a major improvement in man–machine interaction (MMI) to be achieved as the pilot is able to view and assimilate the essential flight data generated by the sensors and systems in the aircraft whilst head up and maintaining full visual concentration on the outside world scene.

Fig 2.1. Head-up presentation of primary flight information (by courtesy of BAE Systems

The pilot is thus free to concentrate on the outside world during manoeuvres and does not need to look down at the cockpit instruments or head down displays. It should be noted that there is a transition time of one second or more to re-focus the eyes from viewing distant objects to viewing near objects a metre or less away, such as the cockpit instruments and displays and adapt to the cockpit light environ- ment. In combat situations, it is essential for survival that the pilot is head up and scanning for possible threats from any direction. The very high accuracy which can be achieved by a HUD and computerized weapon aiming system together with the

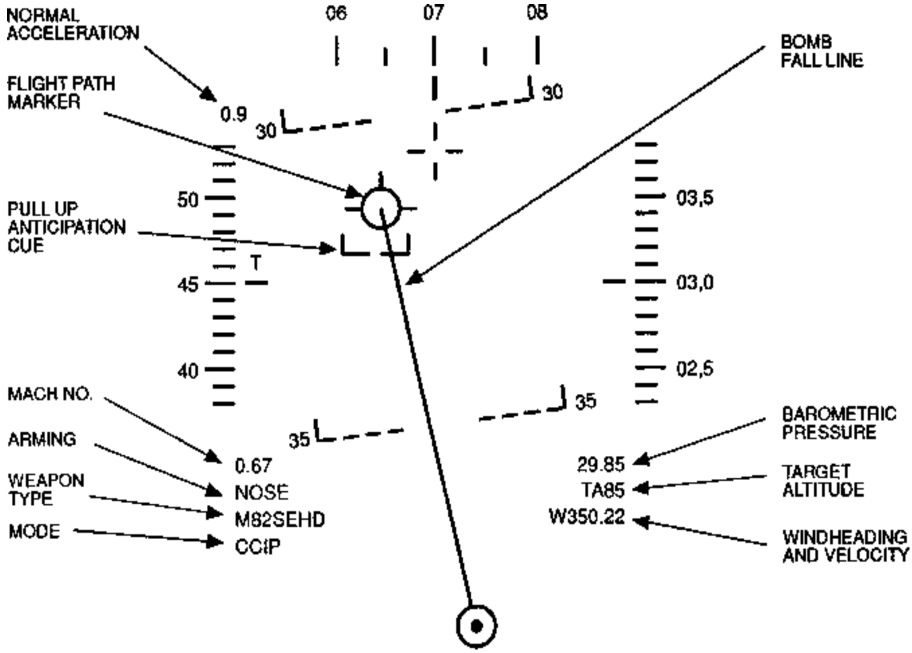


Fig2.2. Typical weapon aiming display (by courtesy of BAE Systems)

HUDs are now being installed in civil aircraft for reasons such as:

1. Inherent advantages of head-up presentation of primary flight information including depiction of the aircraft's flight path vector, resulting in improved situational awareness and increased safety in circumstances such as wind shear or terrain/traffic avoidance manoeuvres.
2. To display automatic landing guidance to enable the pilot to land the aircraft safely in conditions of very low visibility due to fog, as a back up and monitor for the automatic landing system. The display of taxi-way guidance is also being considered.
3. Enhanced vision using a raster mode HUD to project a FLIR video picture of the outside world from a FLIR sensor installed in the aircraft, or, a synthetic picture of the outside world generated from a forward looking millimetric radar sensor

Fig2.3 Civil HUD installation – BAE Systems VGS HUD installed in a Boeing 737-800 series airliner (by courtesy of BAE Systems).

in the aircraft. These enhanced vision systems are being actively developed and will enable the pilot to land the aircraft in conditions of very low or zero visibility at airfields not equipped with adequate all weather guidance systems such as ILS (or MLS).

Illustrates a civil HUD installation.

2.1.2. Basic Principles

The basic configuration of a HUD is shown schematically in Figure. The pilot views the outside world through the HUD combiner glass (and windscreen). The combiner glass is effectively a 'see through' mirror with a high optical transmission efficiency so that there is little loss of visibility looking through the combiner and windscreen. It is called a combiner as it optically combines the collimated display symbology with the outside world scene viewed through it.

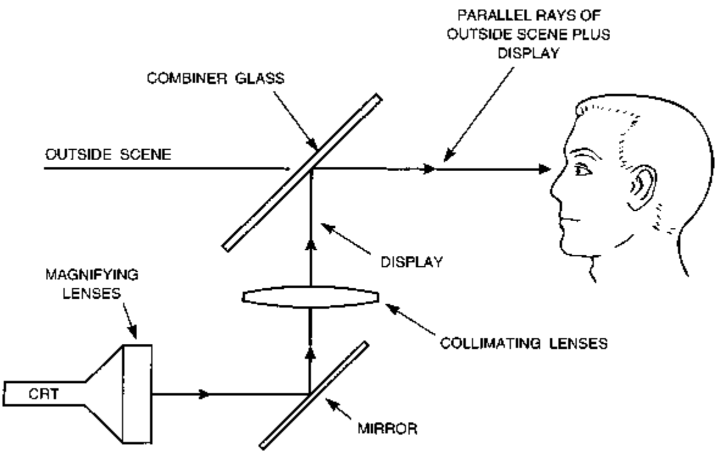


Fig2.4. HUD schematic.

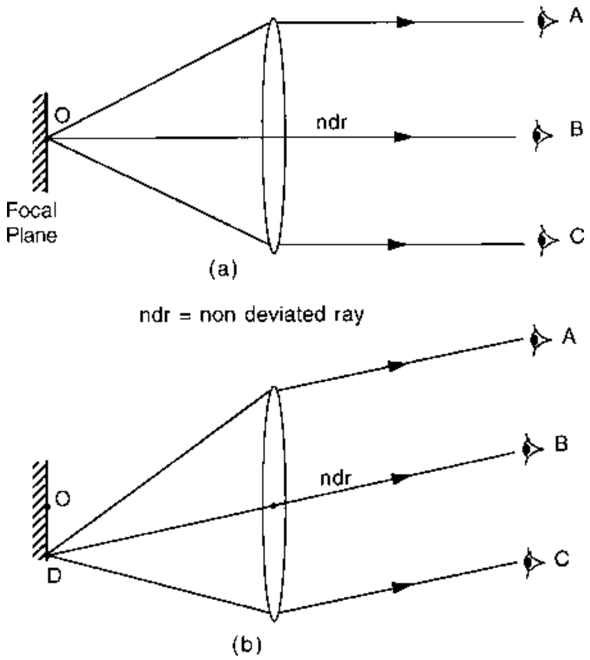


Fig2.5. Simple optical collimator.

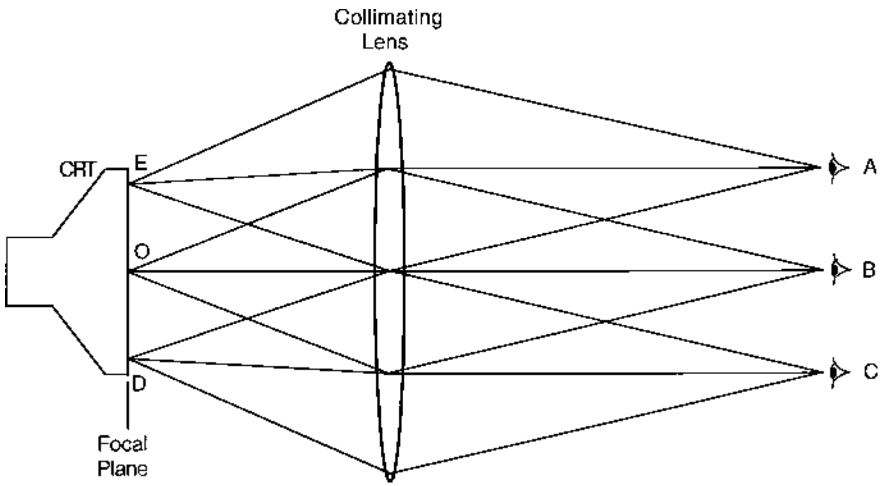


Fig2.6. Simple optical collimator ray trace.

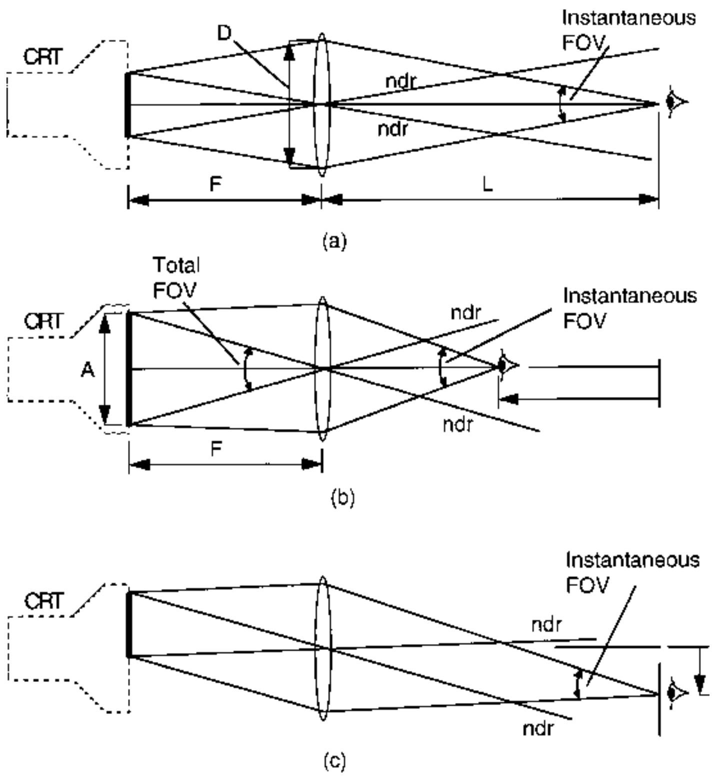


Fig2.7. Instantaneous and total FOV.

The analogy can be made of viewing a football match through a knot hole in the fence and this FOV characteristic of a HUD is often referred to as the 'knot hole effect'.

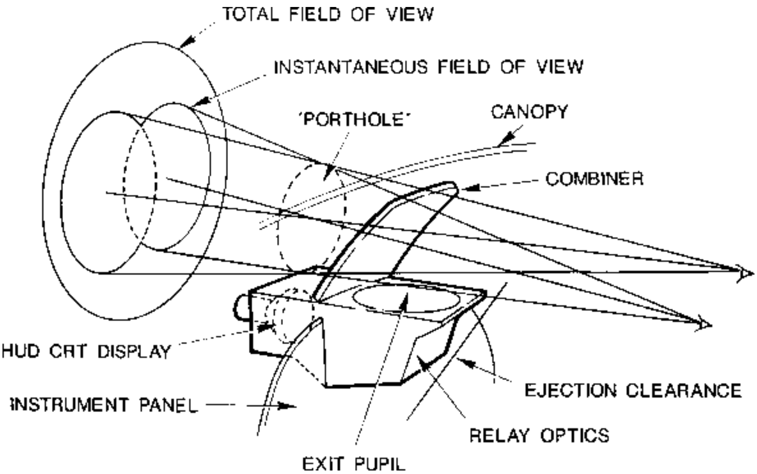


Fig2.8. HUD installation constraints and field of view.

In order to achieve an adequate contrast ratio so that the display can be seen against the sky at high altitude or against sunlit cloud it is necessary to achieve a

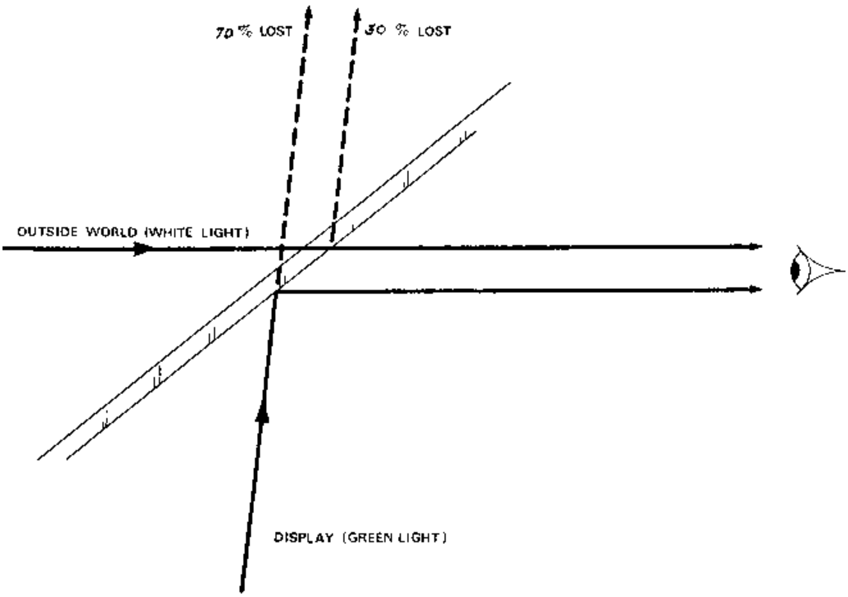


Fig2.9. Conventional refractive HUD combiner operation.

display brightness of 30,000 Cd/m^2 (10,000 ft L) from the CRT. In fact, it is the brightness requirement in particular which assures the use of the CRT as the display source for some considerable time to come, even with the much higher optical efficiencies which can be achieved by exploiting holographic optical elements.

Fig2.10 Instantaneous FOV of conventional HUD.

Fig2.11. Instantaneous FOV of holographic HUD.

2.4.1. Holographic HUDs

The requirement for a large FOV is driven by the use of the HUD to display a collimated TV picture of the FLIR sensor output to enable the pilot to ‘see’ through the HUD FOV in conditions of poor visibility, particularly night operations.

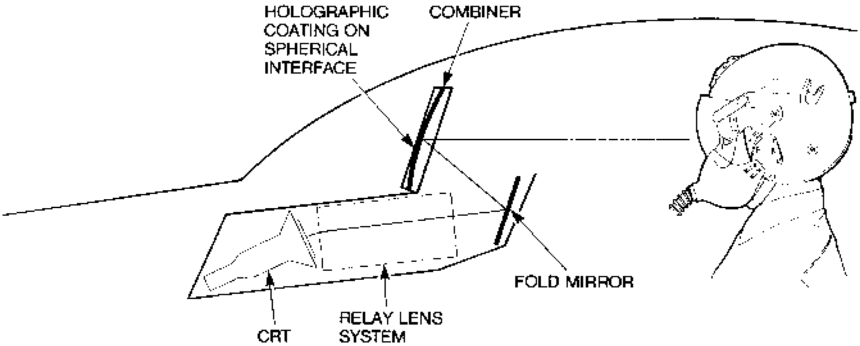


Fig2.12. Off-axis holographic combiner HUD configuration.

Fig 2.13. Collimation by a spherical reflecting surface.

car round Hyde Park Corner with a shattered opaque windscreen with your vision restricted to a hole punched through the window.)

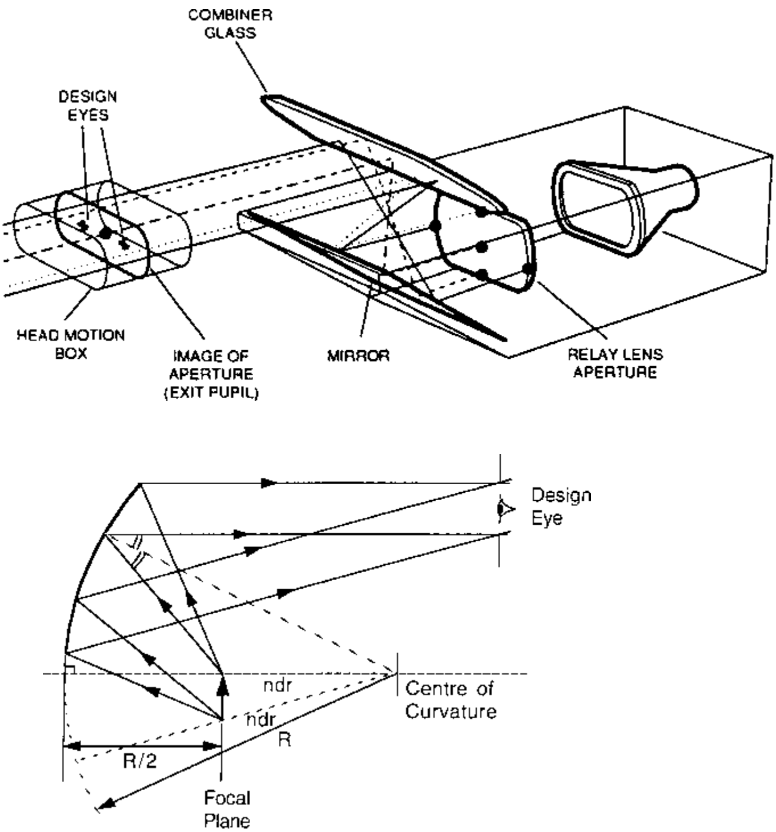


Fig 2.14. The head motion box concept.

Because the collimating element is located in the combiner, the porthole is considerably nearer to the pilot than a comparable refractive HUD design. The collimating element can also be made much larger than the collimating lens of a refractive HUD, within the same cockpit constraints. The IFOV can thus be increased by a factor of two or more and the instantaneous and total FOVs are generally the same, as the pilot is effectively inside the viewing porthole.

This is where a unique property of holographically generated coatings is used, namely the ability to introduce optical power within the coating so that it can correct the remaining aberration errors. The powered holographic coating produces an effect equivalent to local variations in the curvature of the spherical reflecting surface of the combiner to correct the aberration errors by diffracting.

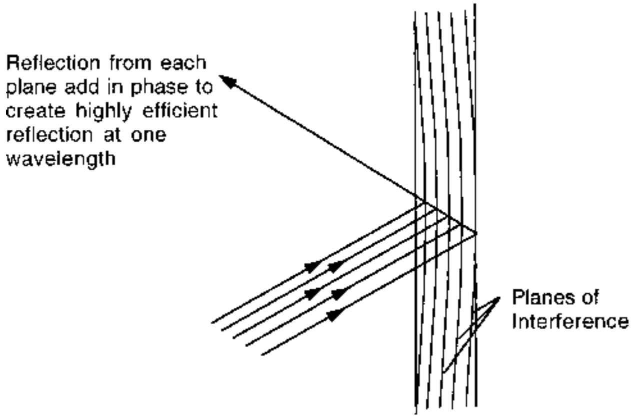


Fig 2.15. Holographic coating.

Fig 2.16 Angularly selective reflection of monochromatic rays.

At any point on the surface, the coating will only reflect a given wavelength over a small range of incidence angles. Outside this range of angles, the reflectivity drops off very rapidly and light of that wavelength will be transmitted through the coating.

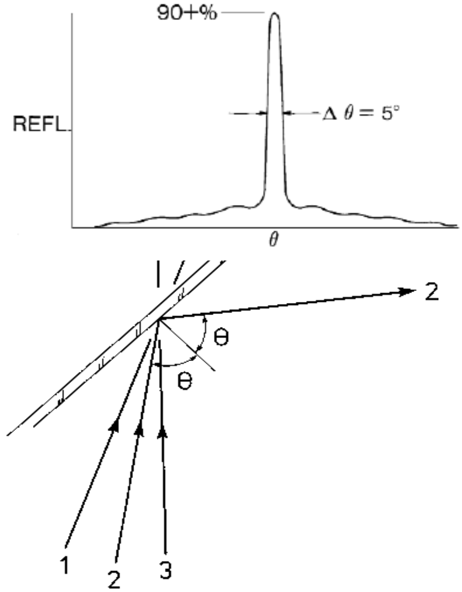
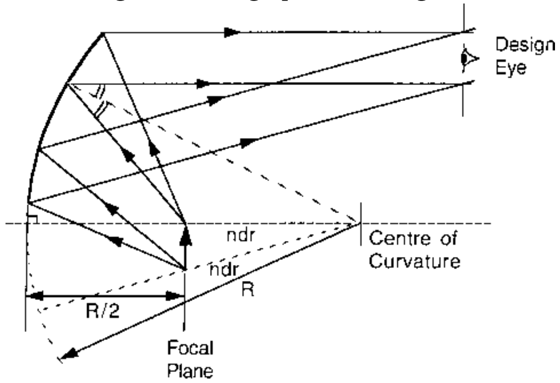


Fig 2.17. Holographic coat- ing



performance.

Uniformly across the reflector surface.

The process for producing the powered holographic combiner is very briefly outlined below.

The process has three key stages:

- Design and fabricate the Computer Generated Hologram(CGH).
- Produce master hologram.
- Replicate copies for the holographic combiner elements.

The CGH and construction optics create the complex wavefront required to produce the master hologram. The CGH permits control of the power of the diffraction grating over the combiner thus allowing correction of some level of optical distortion resulting in a simplified relay lens system.

Fig 2.18. Wide FOV holographic HUD installed in Eurofighter Typhoon (by courtesy of BAE Systems).

2.5. HUD Electronics

The basic functional elements of a modern HUD electronic system are shown in above figure. These functional elements may be packaged so that the complete HUD system is contained in a single unit, as in the Typhoon HUDabove.

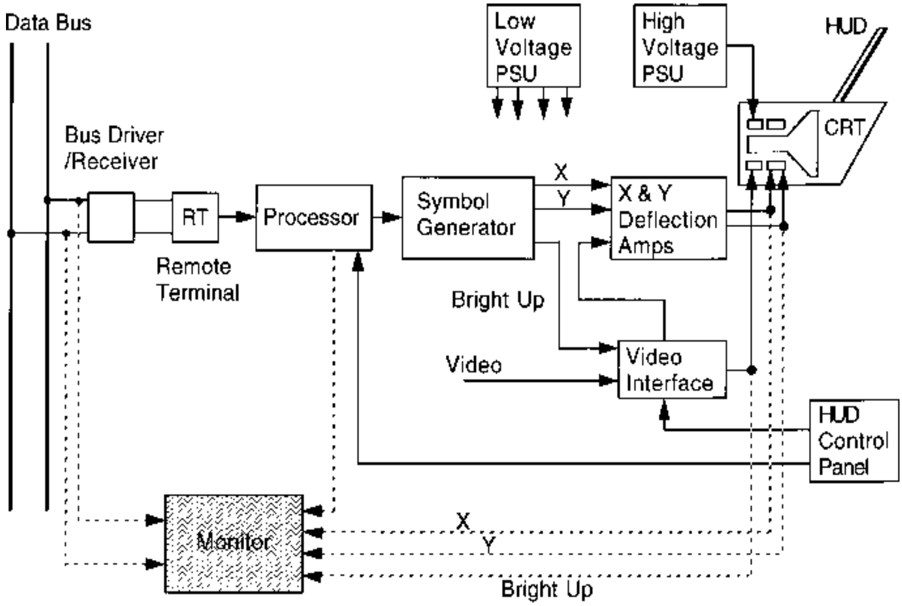


Fig 2.19. HUD electronics.

The display processor processes this input data to derive the appropriate dis- play formats, carrying out tasks such as axis conversion, parameter conversion and format management.

In addition the processor also controls the following functions:

- Self test,
- Brightness control (especially important at low brightnesslevels),
- Mode sequencing,
- Calibration,
- Power supply control.

2.6. Helmet Mounted Displays

2.6.1. Introduction

The advantages of head-up visual presentation of flight and mission data by means of a collimated display have been explained in the preceding section. The HUD, however, only presents the information in the pilot's forward field of view, which even with a wide FOV holographic HUD is limited to about 30° in azimuth and 20° to 25° in elevation. Significant increases in this FOV are not practicable because of the cockpit geometry constraints.

2.6.2. Helmet Design Factors

It is important that the main functions of the conventional aircrew helmet are appreciated as it is essential that the integration of a helmet mounted display system with the helmet does not degrade these functions in any way. The basic functions are:

1. To protect the pilot's head and eyes from injury when ejecting at high airspeeds. For example, the visor must stay securely locked in the down position when subjected to the blast pressure experienced at indicated airspeeds of 650 knots. The helmet must also function as a crash helmet and protect the pilot's head as much as possible in a crash landing.

2. To interface with the oxygen mask attached to the helmet. Combat aircraft use a special pressurised breathing system for high *g* manoeuvring.

3. To provide the pilot with an aural and speech interface with the communications radio equipment. The helmet incorporates a pair of headphones which are coupled to the outputs of the appropriate communications channel selected by the pilot. The helmet and earpieces are also specifically designed to attenuate the cockpit background acoustic noise as much as possible. A speech interface is provided by a throat microphone incorporated in the oxygen mask.

4. In addition to the clear protective visor, the helmet must also incorporate a dark visor to attenuate the glare from bright sunlight.
5. The helmet must also be compatible with NBC (nuclear–biological–chemical) protective clothing and enable an NBC mask to be worn.

Fig 2.20. Helmet mounted sight and off-boresight missile launch (by courtesy of BAE Systems)

2.6.3. Helmet Mounted Sights

- A helmet mounted sight (HMS) in conjunction with a head tracker system provides a very effective means for the pilot to designate a target.
- The pilot moves his head to look and sight on the target using the collimated aiming cross on the helmet sight.
- The angular co-ordinates of the target sight line relative to the airframe are then inferred from the measurements made by the head tracker system of the attitude of the pilot's head.
- In air to air combat, the angular co-ordinates of the target line of sight (LOS) can be supplied to the missiles carried by the aircraft.
- The missile seeker heads can then be slewed to the target LOS to enable the seeker heads to acquire and lock on to the target. (A typical seeker head needs to be pointed to within about 2° of the target to achieve automatic lock on.)
- Missile lock on is displayed to the pilot on the HMS and an audio signal is also given. The pilot can then launch the missiles.

2.6.4. Helmet Mounted Displays

- As mentioned in the introduction, the HMD can function as a 'HUD on the hel- met' and provide the display for an integrated night/poor visibility viewing system with flight and weapon aiming symbology overlaying the projected image from the sensor.
- Although monocular HMDs have been built which are capable of displaying all the information normally displayed on a HUD, there can be problems with what is known as 'monocularrivalry'.
- This is because the brain is trying to process different images from each eye and rivalry can occur between the eye with a display and that without.
- The problems become more acute at night when the eye without the display sees very little, and the effects have been experienced when night-flying with a monocular system in a helicopter.

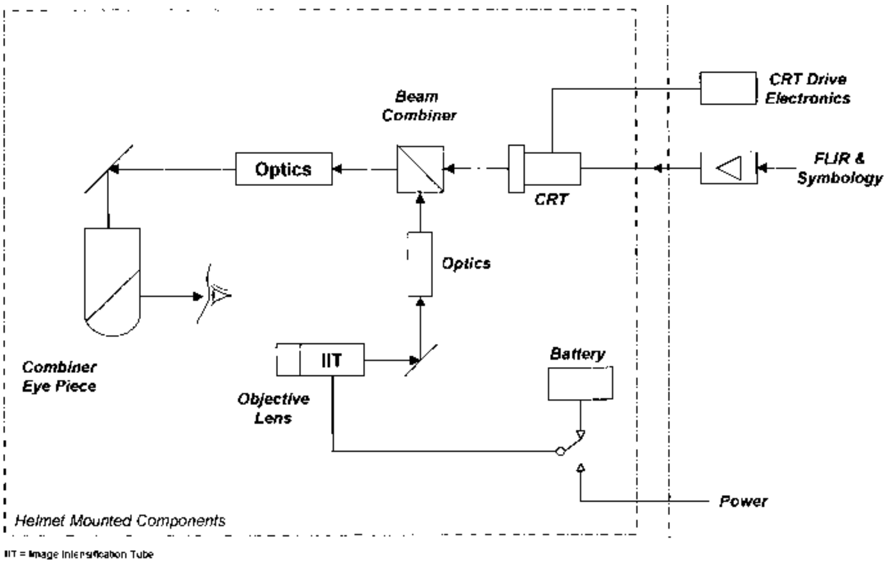


Fig 2.21. Optical mixing of IIT and CRT imagery.

It should be noted that special cockpit lighting is necessary as conventional cock- pit lighting will saturate the image intensifiers. Special green lighting and comple- mentary filtering are required.

Most night flying currently undertaken by combat aircraft is carried out using NVGs which are mounted on a bracket on the front of a standard aircrew helmet. The weight of the NVGs and forward mounting creates an appreciable out of balance moment on the pilot's head and precludes the pilot from undertaking manoeuvres involving significant *g*. The NVGs must also be removed before ejecting because of the *g* experienced during ejection. (A quick release mechanism is incorporated in the NVG attachment.)

Fig 2.22. Helicopter HMD with integrated NVGs (by courtesy of BAE Systems). This HMD forms part of the mission systems avionics for the Tiger 2 attack helicopter for the German army.

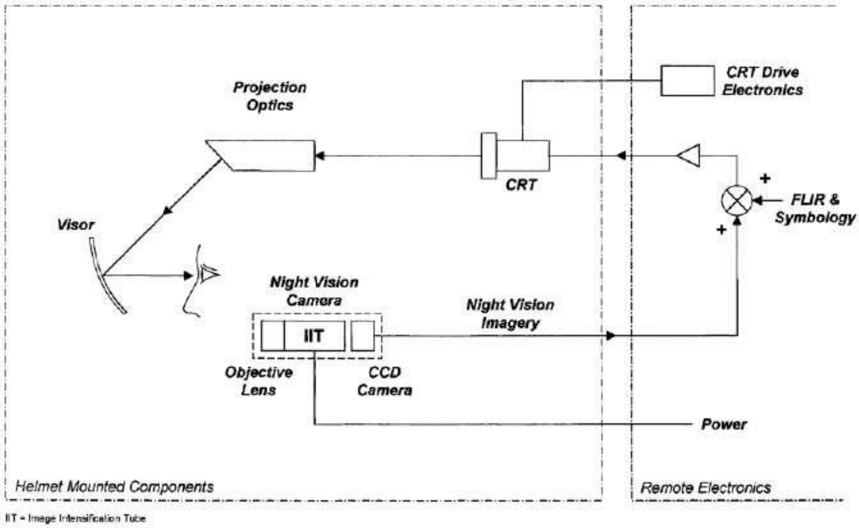


Fig 2.23. Electronic combination of IIT and CRT.

The performance of current night vision cameras is, however, inherently lower in terms of resolution than that provided by the best NVGs.

Fig 2.24. Eurofighter Typhoon binocular visor projected HMD (by courtesy of BAE Systems).

Right side illustration shows optical ray trace. Displays images are collimated by reflection from the spherical visor. Note use of 'brow' mirror to relay display images and electrical parts can be replaced quickly and sent off for repair without the pilot losing his personalised helmet.

It should be noted, however, that a helmet with an integrated HMD system will be a relatively expensive piece of kit and will need to be treated with more care and respect by the pilots than the current aircrew helmet.

2.6.5. Head Tracking Systems

The need to measure the orientation of the pilot's head to determine the angular co-ordinates of the pilot's line of sight with respect to the airframe axes has already been explained. It should be noted that the problem of measuring the angular orientation of an object which can both translate and rotate can be a fundamental requirement in other applications such as robotics. In fact the solutions for head tracking systems can have general applications.

Space does not permit a detailed review of the various head tracking systems which have been developed. Most of the physical effects have been tried and exploited such as optical, magnetic and acoustic methods.

Optical tracking systems work in a number of ways, for example,

(a) Pattern recognition using a CCD camera.
(b) Detection of LEDs mounted on the helmet.
(c) Sophisticated measurement of laser generated fringingpatterns.

Magnetic tracking systems measure the field strength at the helmet from a magnetic field radiator located at a suitable position in the cockpit. There are two types of magnetic head tracker system:

(a) An AC system using an alternating magnetic field with a frequency of around 10 kHz.
(b) A DC system using a DC magnetic field which is switched at low frequency.

Both systems are sensitive to metal in the vicinity of the helmet sensor. This causes errors in the helmet attitude measurement which are dependent on the cockpit installation. These errors need to be measured and mapped for the particular cockpit and the corrections stored in the tracker computer. The computer then corrects the tracker outputs for the in situ errors. The AC system is more sensitive to these errors than the DC system which is claimed to be 10 times less sensitive to metal than AC systems.

2.7. Head Down Displays

2.7.1. Introduction

Electronic technology has exhibited an exponential growth in performance over four decades and is still advancing. By the early 1980s, it became viable to effect a revolution in civil flight-decks and military cockpits by replacing the majority of the traditional dial type instruments with multi-function colour CRTdisplays.

'Wall to wall' colour displays have transformed the civil flight-deck – from large 'jumbo' jets to small commuter aircraft.

Fig 2.25. Primary flight display (by courtesy of Airbus).

2.7.2. Civil Cockpit Head Down Displays

The displays are duplicated for the Captain and Second Pilot and being multi-function it is possible to reconfigure the displayed information in the event of the failure of a particular display surface.

The electronic Primary Flight Display (PFD) replaces six electro-mechanical instruments: altimeter, vertical speed indicator, artificial horizon/attitude director indicator, heading/compass indicator and Mach meter. PFD formats follow the classic 'T' layout of the conventional primary flight instruments, as mentioned in Chapter 7. All the primary flight information is shown on the PFD thereby reducing the pilot scan, the use of colour enabling the information to be easily separated and emphasised where appropriate.

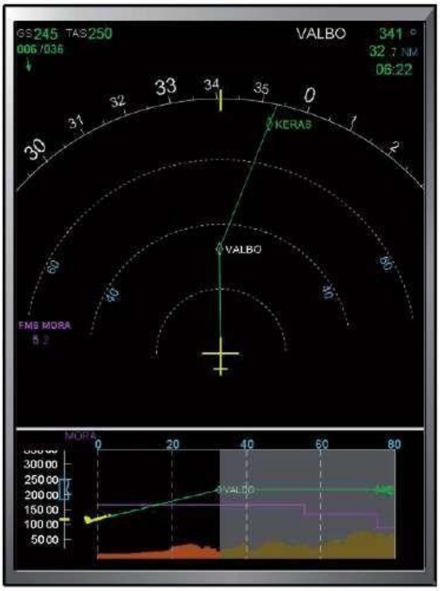


Fig 2.26. Navigation (or horizontal situation) displays (by courtesy of Airbus).

Fig 2.27. Engine/Warning display (by courtesy of Airbus).

world visual cues are not present (e.g. flying in cloud or at night) as the pilot can become disorientated. The normal display of attitude on the HUD is not suitable for this purpose, being too fine a scale which consequently moves too rapidly.

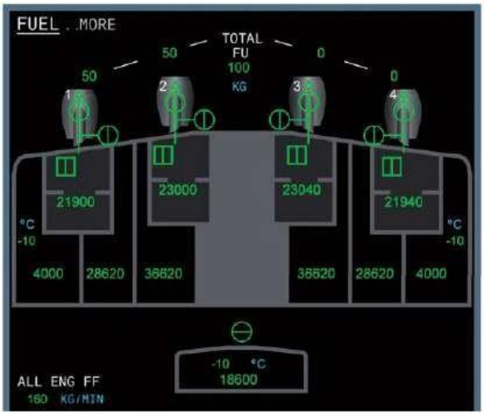


Fig 2.28. Systems Display (by courtesy of Airbus).

ILS or VOR formats, a map mode showing the aircraft's position relative to specific waypoints and a North up mode showing the flight plan. Weather radar displays may be superimposed over the map. The vertical flight profile can also be displayed.

2.7.3. Military Head down Displays

Video head down displays now include FLIR, LLTV and maps. All the HUD functions may be repeated overlaid on the video pictures. Fuel and engine data, navigation waypoints and a host of 'housekeeping' functions (e.g. hydraulics, pressurisation) may be displayed. A stores management display is also required showing the weapons carried and their status.

It is usual to have a bezel around the display with keys. Sometimes key functions are dedicated or they may be 'soft keys' where the function is written beside the key on the display. So called tactile surfaces are being introduced using such techniques as infrared beams across the surface of the display or even surface acoustic waves where the pressure applied can also be measured to give *X*, *Y* and *Z* co-ordinates.

Fig 2.29. Lockheed Martin 'Lightning 2' Joint Strike Fighter cockpit (by courtesy of Lockheed Martin)

The other two displays are smaller 5×5inch monochrome displays comprising a Systems Status Display (SSD) displaying systems status data and a Systems Control Display (SCD) displaying systems control data. Both displays have tactile data entry overlay.

The advanced cockpits for the new generation of fighter/strike aircraft have just two large colour displays as the primary head down displays.

2.8. Display Symbology Generation

Symbology such as lines, circles, curves, dials, scales, alpha-numeric characters, tabular information, map display features is drawn as a set of straight line segment approximation, or vectors (like a 'join the dots' children's pictures)

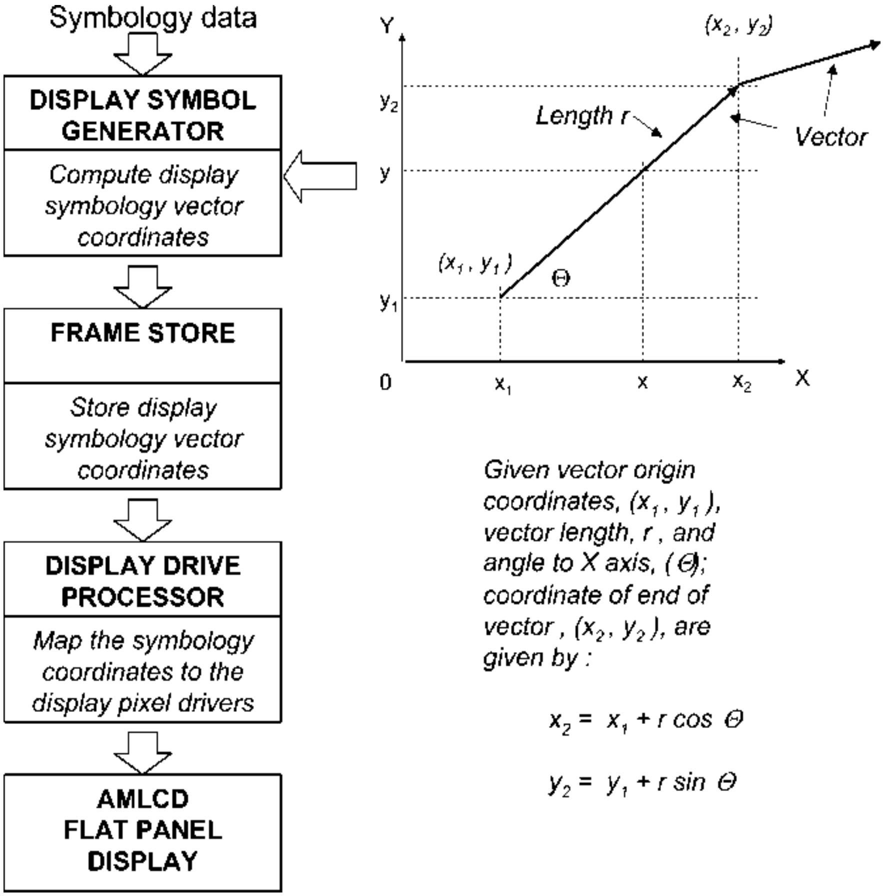


Fig 2.30. Symbology generation and display.

The system electronics use 'commercial off the shelf' graphics processing chips, frame stores and display drive processors (developed for video games, PCs, etc.).

2.9. Intelligent Displays Management

The exploitation of intelligent knowledge based systems (IKBS) technology, frequently referred to as 'expert systems', to assist the pilot in carrying out the mission is the subject of a number of very active research programmes, particularly in the United States. One of the US programmes is the 'pilot's associate program' which aims to aid the pilot of a single seat fighter/attack aircraft in a similar way to the way in which the second crew member of a two crew aircraft assists the pilot. The prime aim is to reduce the pilot work load in high work load situations.

Space constraints do not permit more than a very brief introduction to this topic, which is of major importance to the next generation of military aircraft as these will use a single pilot to carry out the tasks which up to now have required a pilot and a navigator/weapons systems officer.

The exploitation of IKBS technology on the civil flight deck will follow as the technology becomes established in military applications.

A subset of all the proposed expert systems on an aircraft is an intelligent displays management system to manage the information which is visually presented to the pilot in high work load situations.

It is the unexpected or uncontrollable that leads to an excessive work load, examples being:

- The 'bounce' interception by a counter attacking aircraft with very little warning.
- Evasion of ground threat – SAM (surface–air missile).
- Bird strike when flying at low altitude.
- Engine failure.
- Weather aborts or weather diversion emergency.

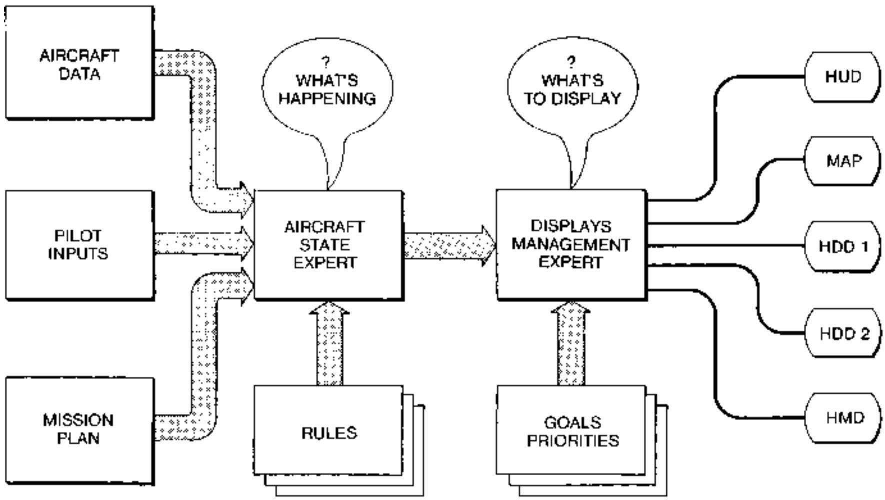


Fig 2.31 **Intelligent displays management (by courtesy of BAE Systems)**

Which deduces 'what is happening' from the aircraft data, pilot inputs, threat warning systems and the mission plan by the application of an appropriate set of rules. The aircraft state expert in turn controls the 'displays management expert' which determines the information displayed on the various display surfaces: HUD, map, head down displays or HMD according to an appropriate set of goals and priorities.

2.9.1. Displays Technology

This section deals with two recent developments in HUD and HMD displays technology which will have a major influence on future HUD and HMD performance, size, weight, reliability, and both initial cost and cost of ownership.

2.9.2. Replacing the HUD CRT

The vast majority of HUDs currently in service worldwide use a CRT as the display source, and CRT based HUDs will remain in service for many years to come.

The continuing development, however, of projected display systems has now enabled a competitive, higher reliability replacement of the HUD display source to be produced. New HUD systems exploiting these developments are now entering service and the CRT based HUD will be eventually superseded.

It is also possible to update existing CRT based HUDs with in effect a 'new lamps for old' replacement of the CRT together with updated electronics.

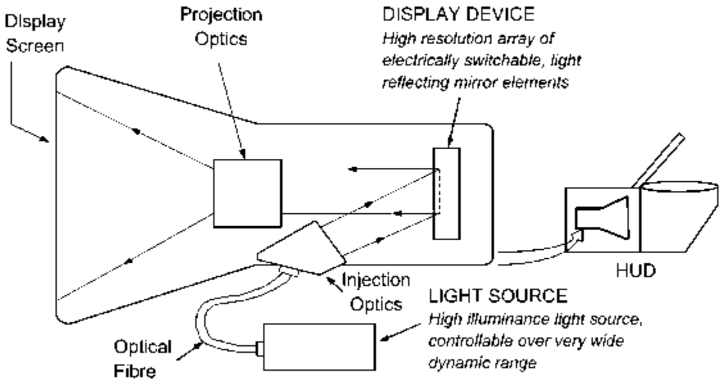


Fig 2.32. **Block diagram of a HUD projected display unit.**

The luminance of the light source is controllable over a very wide dynamic range to meet all ambient light conditions from very bright sunlight to night operation.

The only viable light source, until recently, was the laser and production HUDs using a laser light source are now entering service. These offer a five to tenfold increase in HUD reliability with MTBFs in excess of 20,000 hours with maturity.

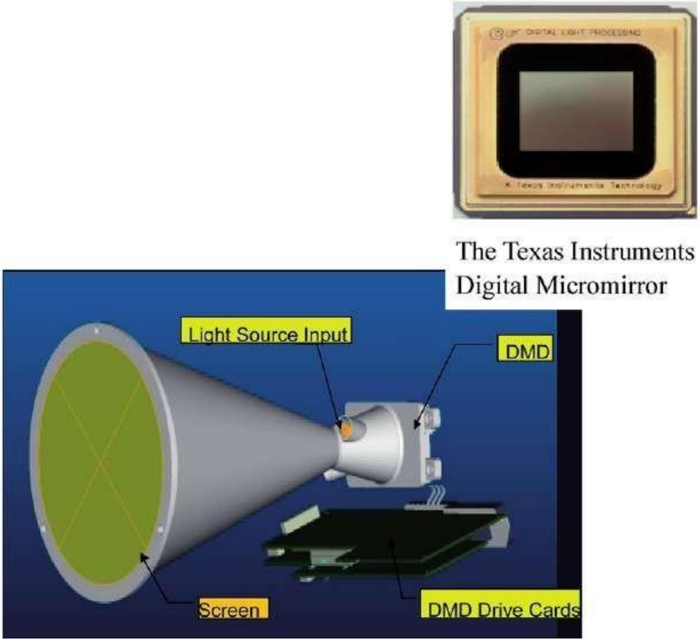


Fig 2.33 ‘Digital Light Engine’ projector display unit (by courtesy of BAE Systems).

Demonstrated very high reliability in a wide variety of civil and military display applications. They are also widely used in very large screen projection systems to display high definition video.

The Texas Instruments DMD™ is basically an array of over a million hinged micro-mirrors which can be individually deflected mechanically through (12°). Light modulation in a dark field projection system is achieved by tilting the micro-Mirror to reflect light from the illuminating source on to, or away from the dis- play screen. The micro-mirrors are matrix addressed and deflected by the electro- static forces created by applying a voltage to the appropriate mirror electrodes; each micro-mirror produces a display pixel.

2.9.3. HMD/HUD Optical System Technology

The preceding sections have covered the basic principles, functions and design of HUDs and HMDs which are currently in service, and which will remain in service for many years to come.

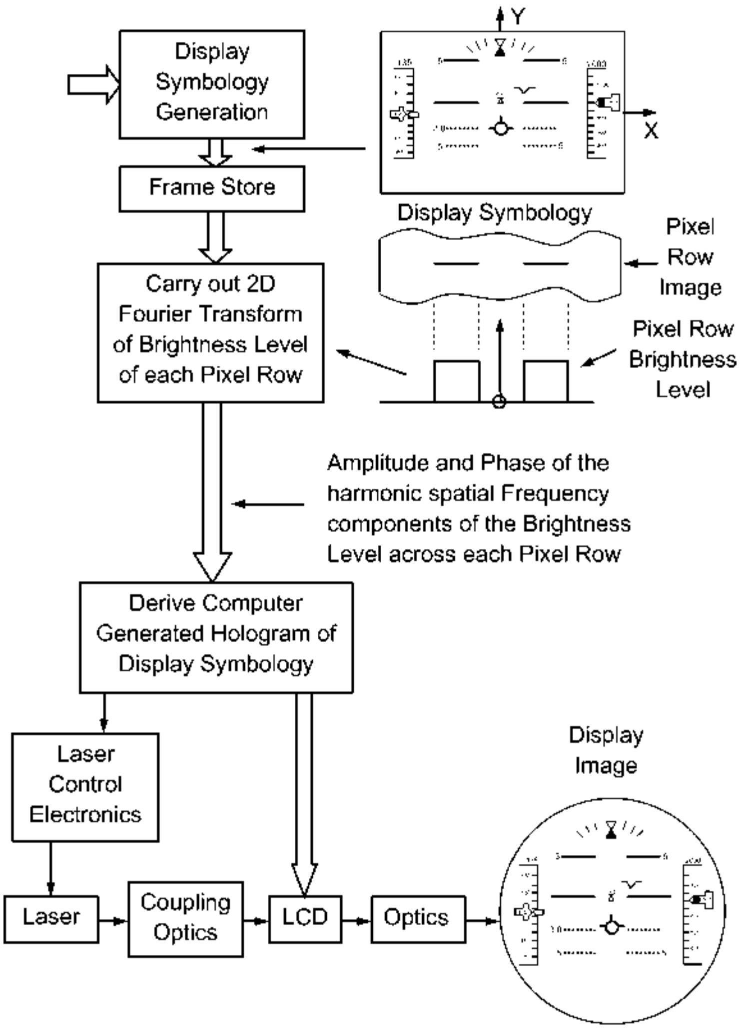


Fig 2.34. Block diagram of active CGH method of generating a fault tolerant display.

Recent developments in holographic waveguide technology, however, will have a profound impact on future HMD and HUD design. Exploitation of this technology offers a major improvement in terms of mass, cost, volume, simplicity and optical performance.

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UNIT- II - AVIONICS - SAEA1404

UNIT - II
AVIONICS TECHNOLOGY

1.1 Introduction to avionics, need system and Evolution of electronics:

Avionics' is a word derived from the combination of aviation and electronics. It was first used in the USA in the early 1950s and has since gained wide scale usage and acceptance although it must be said that it may still be necessary to explain what it means to the lay person on occasions.

The term 'avionic system' or 'avionic sub-system' is used in this book to mean any system in the aircraft which is dependent on electronics for its operation, al- though the system may contain electro-mechanical elements.

For example, a Fly- by-Wire (FBW) flight control system depends on electronic digital computers for its effective operation, but there are also other equally essential elements in the sys- tem.

These include solid state rate gyroscopes and accelerometers to measure the angular and linear motion of the aircraft and air data sensors to measure the height, airspeed and incidence.

There are also the pilot's control stick and rudder sensor assemblies and electro-hydraulic servo actuators to control the angular positions of the control surfaces.

The avionics industry is a major multi-billion dollar industry world-wide and the avionics equipment on a modern military or civil aircraft can account for around 30% of the total cost of the aircraft.

This figure for the avionics content is more like 40% in the case of a maritime patrol/anti-submarine aircraft (or helicopter) and can be over 75% of the total cost in the case of an airborne early warning aircraft (AWACS).

Modern general aviation aircraft also have significant avionics content. For example, colour head down displays, GPS satellite navigation systems, radio com- munications equipment.

1.2 Evolution of electronics

Avionics can account for 10% of their total cost.

It should be noted that unmanned aircraft (UMAs) are totally dependant on the avionic systems.

These comprise displays, communications, data entry and control and flight control. The *Display Systems* provide the visual interface between the pilot and the air- craft systems and comprise

- Head Up Displays (HUDS),
- Helmet Mounted Displays (HMDS)
- Head down Displays (HDDS).

Most combat aircraft are now equipped with a HUD. A small but growing number of civil aircraft have HUDs installed

The HMD is also an essential system in modern combat aircraft and helicopters.

The prime advantages of the HUD and HMD are that they project the display information into the pilot's field of view so that the pilot can be head up and can concentrate on the outside world.

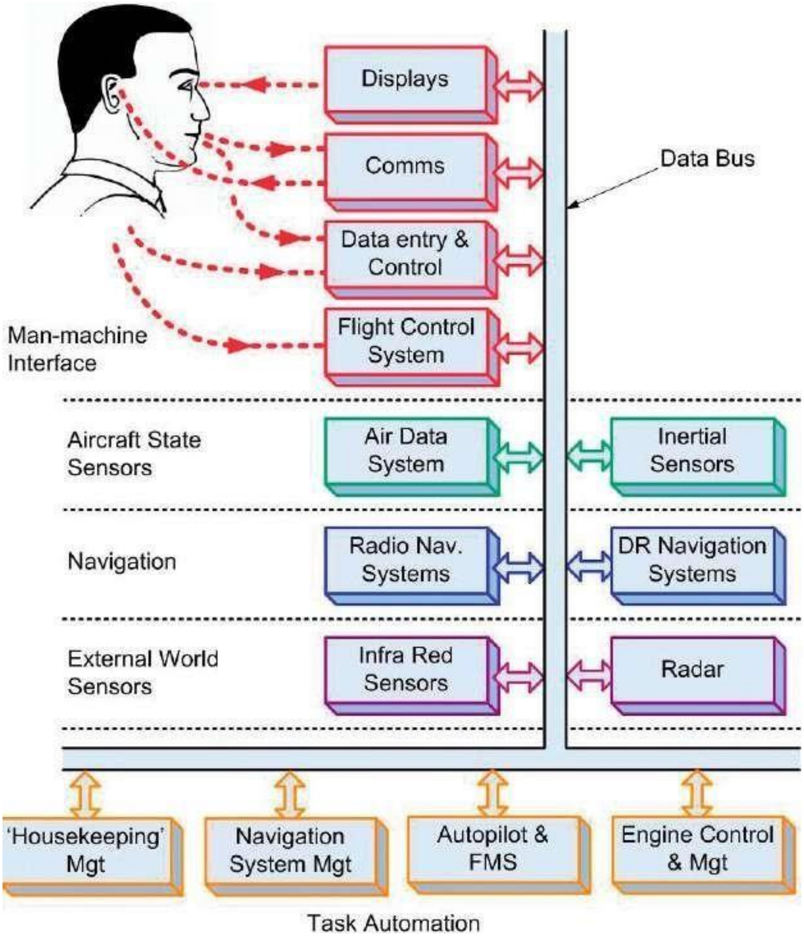

Fig 1.1. Core avionic systems

1.3 System integration:

The ***Data Entry and Control Systems*** are essential for the crew to interact with the avionic systems.

Such systems range from keyboards and touch panels to the use of direct voice input (DVI) control, exploiting speech recognition technology, and voice warning systems exploiting speech synthesisers.

The ***Flight Control Systems*** exploit electronic system technology in two areas, namely auto-stabilisation (or stability augmentation) systems and FBW flight con- trol systems. Most swept wing jet aircraft exhibit a lightly damped short period os- cillatory motion about the yaw and roll axes at certain height and speed conditions, known as 'Dutch roll', and require at least a yaw auto-stabiliser system to damp and suppress this motion; a roll auto-stabiliser system may also be required. The short period motion about the pitch axis can also be insufficiently damped and a pitch auto-stabiliser system is necessary.

Most combat aircraft and many civil aircraft in fact require three axis auto- stabilisation systems to achieve acceptable control and handling characteristics across the flight envelope.

FBW flight control enables a lighter, higher performance aircraft to be produced compared with an equivalent conventional design by allowing the aircraft to be de- signed with a reduced or even negative natural aerodynamic stability.
It does this by providing continuous automatic stabilisation of the aircraft by computer control of the control surfaces from appropriate motion sensors. The system can be designed to give the pilot a manoeuvre command control which provides excellent control and handling characteristics across the flight envelope.
'Care free manoeuvring' char- acteristics can also be achieved by automatically limiting the pilot's commands ac- cording to the aircraft's state. A very high integrity, failure survival system is of course essential for FBW flight control.

1.4. THE NATURE OF MICROELECTRONIC DEVICES

Microelectronics is a subfield of electronics. As the name suggests, microelectronics relates to the study and manufacture (or microfabrication) of very small electronic designs and components. Usually, but not always, this means micrometre-scale or smaller. These devices are typically made from semiconductor materials. Many components of normal electronic design are available in a microelectronic equivalent. These are also include transistors, capacitors, inductors, resistors, diodes and (naturally) insulators and conductors can all be found in microelectronic devices. Unique wiring techniques such as wire bonding are also often used in microelectronics because of the unusually small size of the components, leads and pads. This technique requires specialized equipment and is expensive.
Digital integrated circuits (ICs) consist of billions of transistors, resistors, diodes, and capacitors.
Analog circuits commonly contain resistors and capacitors as well. Inductors are used in some high frequency analog circuits, but tend to occupy larger chip area due to their lower reactance at low frequencies. Gyrators can replace them in many applications. As techniques have improved, the scale of microelectronic components has continued to decrease At smaller scales, the relative impact of intrinsic circuit properties such as interconnections may become more significant. These are called parasitic effects, and the goal of the microelectronics design engineer is to find ways to compensate for or to minimize these effects, while delivering smaller, faster, and cheaper devices.

1.4. Integrated Modular Avionics Architectures

The background to integrated modular avionics architectures has been explained in Section 9.1. The importance of finding a better way of implementing avionic systems can be appreciated when it is realised that avionics currently account for some 30% of the total cost of a new aircraft. Reducing these costs must thus play a major role in containing overall system costs and halting the cost spiral inherent in federated architectures as increasing performance and capability are sought. The IMA architectures provide higher levels of performance and system capability, in- creased equipment availability and reduced levels of maintenance, so lowering costs right across the system life cycle. Space constraints limit the treatment of this topic

to that of an overview explaining the basic philosophy, aims and objectives of the architectures and the implications of their implementation using standardised electronic modules.
The term avionics architecture is a deceptively simple description for a very complex and multi-faceted subject. Essentially, an avionic architecture is the total set of design choices which make up the avionic system and result in it performing as a recognisable whole. In effect, the architecture is the total avionics system design.

The system complexity means that there are very many parts of an avionics architecture and the architecture is best viewed as a hierarchy of levels comprising:

1. Functional allocation level. The arrangement of the major system components and the allocation of system functions to those components.
2. Communications level. The arrangement of internal and external data pathways and data rates, transmission formats, protocols and latencies.
3. Data processing level. Central or distributed processing, processor types, software languages, documentation and CASE (computer aided software engineering) design tools.
4. Sensor level. Sensor types, location of sensor processing, extent to which combining of sensor outputs is performed.
5. Physical level. Racking, box or module outline dimensions, cooling provisions, power supplies.

This is not an exhaustive list and there are many other important aspects of the avionics, e.g. control and displays, maintenance philosophy, etc., which are certainly a part of the avionics architecture.
The influence of the architecture also continues down to lower levels of implementation and technology detail. It is the higher levels, however, which are most often referred to as the ‘architecture’ and it is at these levels that integrated modular avionic concepts are most able to influence overallsystem costs.
The software concept is also modular, comprising a number of application programs running under the control of an executive operating system. The basic system requirements are:

- Suitable stable specifications for the interconnection between modules, both hardware and software.
- Hardware that is independent of the application in which it will be used.
- Executive and application software that is independent of the hardware on which it will run.
- Standard interface between the executive and the hardware for input/output.

This is often referred to as a three-layer stack and is shown schematically
The modular avionics concept relies on the use of a limited range of standard modules which are packaged in a standardised modular format and installed in a small number of common racks.
The concept of modular equipment is not new, however, and avionics manufacturers have frequently used modular packaging to seek a competitive cost advantage

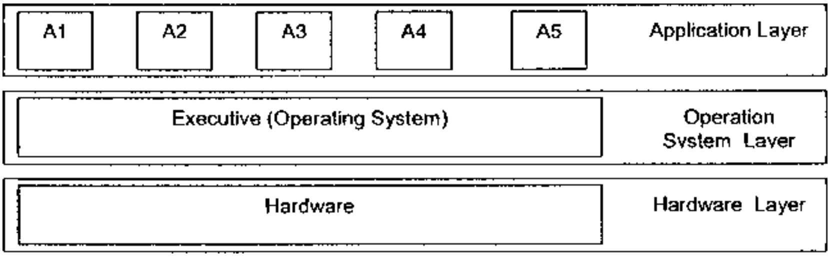

Fig 1.2. The ‘three layer stack’ modular software concept.

within their own equipment. What is different with the integrated modular avionic approach is:

(i) The use across a range of aircraft platforms (including helicopters) of standard ‘F^3I’ form, that is ‘form, fit, function and interface’, interchangeable modules procured from an ‘avionics supermarket’.
(ii) The integration of data and signal processing across traditionally separate aircraft sub-systems enabling wide scale use of reconfiguration to improve availability.
(iii) The use of sufficient built in test to enable faulty modules to be correctly diagnosed and replaced at first line without additional test equipment.

The use of a small number of standard modules potentially reduces the initial development and procurement cost of equipment through competition and eventually through economics of scale in the production of the modules. It also reduces the maintenance costs by reducing spares holding.

Similarly, the integration of functions across traditional equipment boundaries promises to reduce the proliferation of different module designs across the aircraft and it allows reconfiguration strategies to be adopted economically – it is cheaper to carry a spare set of modules that can be configured to act as different systems than it is to carry complete spare systems. The requirement for a second line avionics intermediate shop is eliminated since the high levels of fault detection and isolation (typically >98%) using built in test circuitry allow maintenance to consist of the replacement of a faulty module on the aircraft with the faulty module being returned to the original manufacturer for repair.

However, with these advantages come many implications for the way equipment is currently contracted for and built. The integrated system design increases enormously both the system complexity and the potential for interactions between subsystems. At the same time it blurs the traditional lines of responsibility that exist in the industry and it therefore requires a very careful and systematic design approach if integrated systems are to be put together successfully. To implement such highly integrated systems, very close collaboration between systems engineers from different avionic, airframe and software suppliers is required.

The above is a summary of the aims and objectives of modular avionics architectures and the broad issues that are being addressed.

The problems of component obsolescence in a standard module can be seen by looking at the very rapid advances in technology that are being made. Provision must therefore be made in a standard module design, particularly in the software, to allow for component obsolescence and updating with later technology components. The alternative is living with older technology and procuring sufficient devices in the initial purchase to provide replacement spares for the service life of the equipment.

To date, modular avionics is generally limited to the digital processing and communication areas of the mission systems, and the power supplies necessary to run them. Here, the complex functionality is implemented in software, and can be developed largely independent of the actual platform.

Both the Lockheed F-22 'Raptor' fighter in service with the USAF, and the Lockheed Martin F-35 'Lightning 2' Joint Strike Fighter, currently under development, exploit modular avionics in their mission avionics systems.

An overall avionic systems architecture for a military aircraft and designed for implementation using standard avionic modules is shown. The essential intercommunication system provided by the high speed multiplex data buses can be seen. The grouping together of the systems which carry out flight critical functions, such as flight control, propulsion control, electrical power supply con- trol, sensors and actuators, into the 'aircraft management system' is a noteworthy feature.

1.4.1. Civil Integrated Modular Avionic Systems

As in military systems, the use of new hardware, software and communication technologies has enabled the design of new system architectures based on resource sharing between different systems.

Current microprocessors are able to provide computing capabilities that exceed the needs of single avionics functions. Specific hardware resources, coupled with the use of Operating Systems with a standardised Application Programming Interface provide the means to host independent applications on the same computing resource in a segregated environment.

The AFDX Communication Network provides high data throughput coupled with low latencies to multiple end users across the bus network. The basic concepts are illustrated

The basic Line Replaceable Unit, LRU, becomes an avionics application which is hosted on one, or more, Integrated Avionic Modules (IAMs), providing shared computing resources (processing and memory and I/O).

External components like displays, sensors, actuators and effectors can be connected to standard or specific interfaces in the module or to *Remote Data Concentrators* (RDCs), normally located close to the sensors and actuators. The RDCs are connected to the IMA modules through data buses (ARINC 429 or CAN).

Note. CAN is a data bus system developed by the automobile industry, and is now being used in certain application areas in avionic systems.

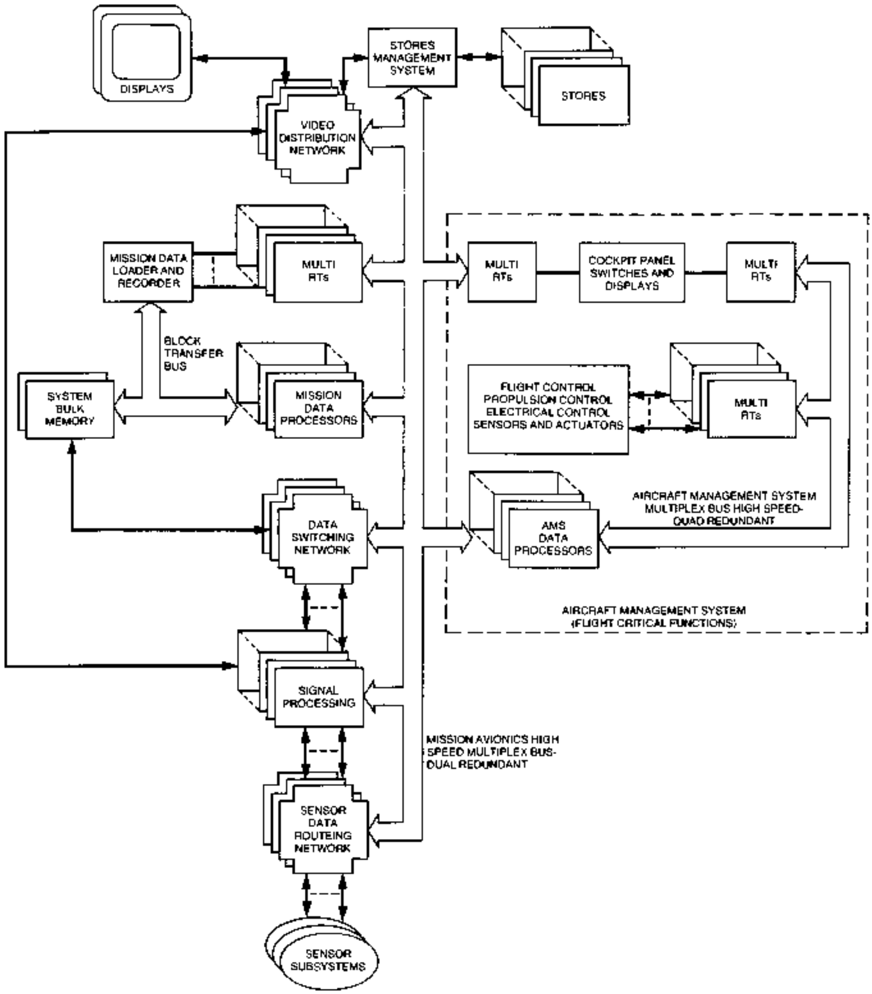

Fig. 1.3. Integrated avionic systems architecture.

The application software for a function will execute on one or more *Core Processing and Input Output Modules* (CPIOMs) in a partitioned environment providing segregation from other functions.

Several modules may be used for a single function to provide high integrity operation through cross-checking and/or increased availability.

The CPIOM provides a standard Application Programming Interface, API, to the applications and segregated computing resources (processing time, memory and I/O) to each application partition.

Input Output Modules (IOMs) provide interfaces between AFDX and other sig- nal types (ARINC 429, CAN, discrete and analogue), but do not host applications.

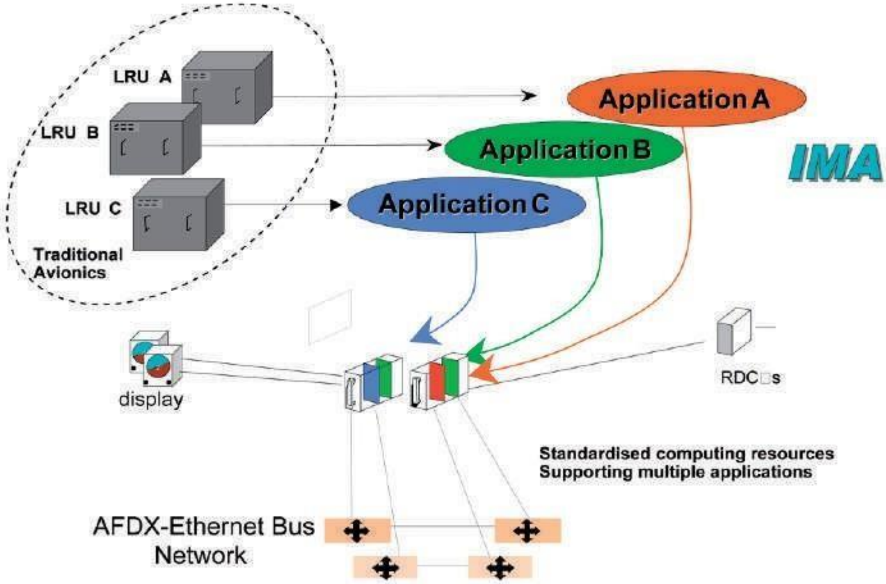

Fig 1.4. Principles of Integrated Modular Avionics (by courtesy of Airbus).

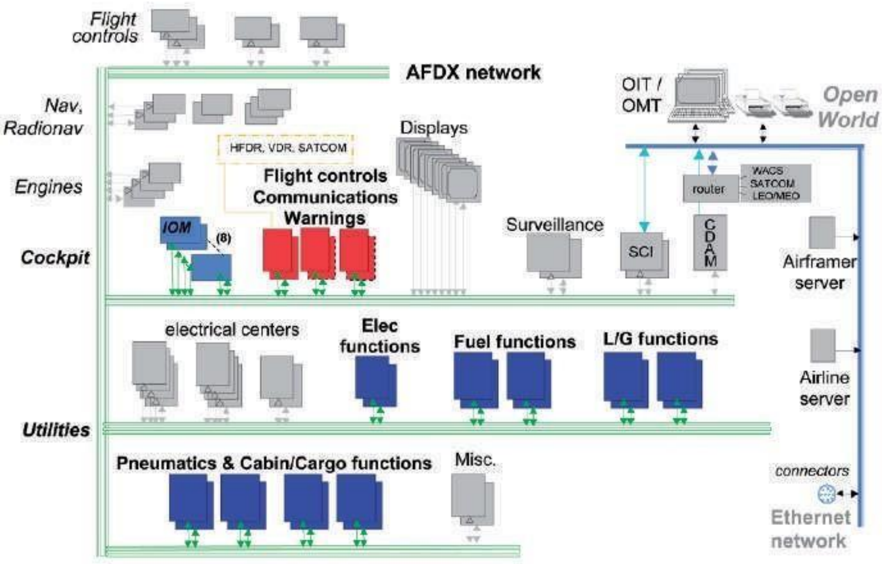

Fig. 1.5. Integrated modular avionic systems on the A380 (by courtesy of Airbus).

Both IOMs and Core Processing and CPIOMs are configurable through loadable configuration tables and also provide standard services such as data loading and Resource BITE (Built In Test Equipment).
Figure1.5 shows the integrated modular avionic systems on the Airbus A380.

1.5. Commercial Off-the-Shelf (COTS)

The term Commercial Off-the-Shelf (COTS) refers to the use of commercially available electronic hardware and/or software for the implementation of avionics systems. This hardware and software is designed for the general electronics marketplace, especially in the industrial control and personal and industrial computing sectors.
Until the mid-1990s, the majority of avionic systems were specifically designed for the application, although these used commercial components where suitable parts were available.
The technical development of semi-conductor devices was largely driven by the needs of the military avionics sector until the mid-1980s, but since then the commercial and industrial sectors have taken over, with the devel- opment and continual advancement of items such as personal computers, computer games and cell-phones. The use of complex electronic systems in the automotive sector is a growth area that mirrors some of the environmental constraints required by avionic systems, although to date, such systems have not employed COTS tech- nology.
COTS systems and equipment are mainly being used in commercial and milit- ary transport aircraft where the operating environment is relatively benign. This is initially found in areas where there is minimal risk from the failure of the systems, e.g. cabin entertainment systems, communications and long-term navigation, and includes both hardware and software. The use of COTS display surfaces such as matrix addressable LCDs has already been discussed briefly in Chapter 2.
The application of COTS equipment to military fighter and strike aircraft is lim- ited due to all aspects of the operating environment; mechanical (vibration, shock), climatic (temperature and pressure) and electromagnetic (including lightning and radiation effects). Special ‘ruggedised’ hardware is available at a significant cost premium; whether this should be referred to as COTS is questionable, since its application to other types of system would be very limited.
The use of COTS hardware and software equipment for applications that are safety-critical, e.g. flight and propulsion control sub-systems, raises issues associ- ated with the certification of such systems. Certification imposes demonstration of fitness for purpose, and assessments that all reasonable actions have been taken to ensure that the risk of failure is at an acceptably low level. Experience has shown that there are significant and possibly unacceptable risks with the use of COTS, both hardware and software, because of:

- Lack of design quality, documentation, guarantees andwarranty.
- Lack of stable standards and specifications.

- Short lifetime dictated by commercial pressures.
- Lack of guaranteed forward and backward compatibility.

Problems of software integrity would appear to preclude the use of most COTS software in safety critical applications. The use of COTS components is, however, likely to increase in military applications because of their intrinsic cost/performance benefits. Provision in the system software to accommodate new COTS components to replace obsolescent COTS components is clearly essential, as mentioned earlier. The degree of environmental isolation which can be provided by a suitably designed electronic rack/cabinet in terms of vibration isolation and cooling provision (forced air or liquid cooling or possibly both) could extend the use of COTS components in military applications.

The increasing use of COTS components in unmanned aircraft is also very likely.

1.6. Aircraft State Sensor Systems

These comprise the air data systems and the inertial sensor systems.

The Air Data Systems provide accurate information on the air data quantities, that is the altitude, calibrated airspeed, vertical speed, true airspeed, Mach number and airstream incidence angle.

The Inertial Sensor Systems provide the information on aircraft attitude and the direction in which it is heading which is essential information for the pilot in executing a manoeuvre or flying in conditions of poor visibility, flying in clouds or at night.

Accurate attitude and heading information are also required by a number of avionic sub-systems which are essential for the aircraft's mission – for example, the autopilot and the navigation system and weapon aiming in the case of a military aircraft.

1.6.1. Navigation Systems

Accurate navigation information, that is the aircraft's position, ground speed and track angle (direction of motion of the aircraft relative to true North) is clearly essential for the aircraft's mission, whether civil or military.

Navigation systems can be divided into dead reckoning (DR) systems and position fixing systems; both types are required in the aircraft.

The *Dead Reckoning Navigation Systems* derive the vehicle's present position by estimating the distance travelled from a known position from a knowledge of the speed and direction of motion of the vehicle.

They have the major advantages of being completely self contained and independent of external systems.

The main types of DR navigation systems used in aircraft are:

(a) Inertial navigation systems. The most accurateand widely used systems.
(b) Doppler/heading reference systems. These are widely used inhelicopters.
(c) Air data/heading reference systems These systems are mainly used as a reversionary navigation system being of lower accuracy than (a) or (b).

A characteristic of all DR navigation systems is that the position error builds up with time and it is, therefore, necessary to correct the DR position error and update the system from position fixes derived from a suitable position fixing system.
The *Position Fixing Systems* used are now mainly radio navigation systems based on satellite or ground based transmitters.
A suitable receiver in the aircraft with a supporting computer is then used to derive the aircraft's position from the signals received from the transmitters.

1.6.2. Task Automation Systems

These comprise the systems which reduce the crew workload and enable minimum crew operation by automating and managing as many tasks as appropriate so that the crew role is a supervisory management one. The tasks and roles of these are very briefly summarised below.
Navigation Management comprises the operation of all the radio navigation aid systems and the combination of the data from all the navigation sources, such as GPS and the INS systems, to provide the best possible estimate of the aircraft position, ground speed and track.
The *Autopilots and Flight Management Systems* have been grouped together. Because of the very close degree of integration between these systems on modern civil aircraft. It should be noted, however, that the Autopilot is a 'stand alone' system and not all aircraft are equipped with an FMS.
The autopilot relieves the pilot of the need to fly the aircraft continually with the consequent tedium and fatigue and so enables the pilot to concentrate on other tasks associated with the mission. Apart from basic modes, such as height hold and heading hold, a suitably designed high integrity autopilot system can also provide a very precise control of the aircraft flight path for such applications as automatic landing in poor or even zero visibility conditions

- Flight planning.
- Navigation management.
- Engine control to maintain the planned speed or Mach number.
- Control of the aircraft flight path to follow the optimised planned route. Control of the vertical flight profile.
- Ensuring the aircraft is at the planned 3D position at the planned time slot; often referred to as 4D navigation. This is very important for air traffic control.
- Flight envelope monitoring.
- Minimising fuel consumption.
- Fuel management. This embraces fuel flow and fuel quantity measurementand control of fuel transfer from the appropriate fuel tanks to minimise changes in the aircraft trim.
- Electrical power supply system management. Hydraulic power supply systemmanagement. Cabin/cockpit pressurisation systems.
- Environmental control system. Warning systems.
- Maintenance and monitoring systems.

1.7. The Avionic Environment

Avionic systems equipment is very different in many ways from ground based equipment carrying out similar functions. The reasons for these differences are briefly explained in view of their fundamental importance.The importance of achieving minimum weight.

1. The adverse operating environment particularly in military aircraft in terms of operating temperature range, acceleration, shock, vibration, humidity range and electro-magnetic interference.
2. The importance of very high reliability, safety and integrity.

1.7.1. Minimum Weight

There is a gearing effect on unnecessary weight which is of the order of 10:1. For example a weight saving of 10 kg enables an increase in the payload capability of the order of 100 kg.
The process of the effect of additional weight is a vicious circle. An increase in the aircraft weight due to, say, an increase in the weight of the avionics equipment, requires the aircraft structure to be increased in strength, and therefore made heavier, in order to withstand the increased loads during manoeuvres.
Assum- ing the same maximum normal acceleration, or *g*, and the same safety margins on maximum stress levels are maintained

1.7.2. Environmental Requirements

The environment in which avionic equipment has to operate can be a very severe and adverse one in military aircraft; the civil aircraft environment is generally much more benign but is still an exacting one.
Considering just the military cockpit environment alone, such as that experienced by the HUD and HDD. The operating temperature range is usually specified from -40°C the pi-lot will not survive at these extremes but if the aircraft is left out in the Arctic cold or soaking in the Middle-East sun, for example, the equipment may well reach such temperatures. A typical specification can demand full performance at 20,000 ft within two minutes of take-off at any temperature within the range.

1.7.3. Reliability

The over-riding importance of avionic equipment reliability can be appreciated in view of the essential roles of this equipment in the operation of the aircraft
Every possible care is taken in the design of avionic equipment to achieve maximum reliability.
A typical RST cycle requires the equipment to operate satisfactorily through the cycle described below.

- Soaking in an environmental chamber at a temperature of $+70^{\circ}$C for a given period.
- Rapidly cooling the equipment to -55°C in 20 minutes and soaking at that Temperature for a given period.
- Subjecting the equipment to vibration, for example 0.5*g* amplitude at 50 Hz, for periods during the hot and cold soaking phases.

1.8. Data Bus Systems

Data bus systems are the essential enabling technologies of avionic systems integration in both federated and integrated modular avionics architectures.

They can be broadly divided into electrical data bus systems where the data are transmitted as electrical pulses by wires, and optical data bus systems where the data are transmitted as light pulses by optical fibres

1.8.1. Electrical Data Bus Systems

There are several electrical serial digital data bus systems in use in avionics systems. These systems can be broadly divided into two categories in terms of their data rate transmission capabilities, namely, data bus systems operating with a maximum throughput of 1 to 2 Mbits/s and high speed data bus systems with a throughput of 50 Mbits/s to 100 Mbits/s.

Space constraints have restricted the coverage of the lower speed systems to the MIL STD 1553B data bus system. This system is very widely used in military aircraft worldwide, although it originated in the US. It has become the established and dominant standard data bus system since its introduction in 1975.

It transmits and receives data at 1 Mbit/s and is also a relatively sophisticated data bus system. An understanding of its operation reads across to the other sys- tems in many areas, such as ARINC 429 which is a point to point system of lower capabilities (10 Kbits/s data rate) used in civil avionic systems and the more recent

1.8.2. ARINC 629 data bus system.

The ARINC 629 data bus system has many similarities with the MIL STD 1553 B system; the main difference is that it is an autonomous system, whereas the ‘1553’ system is a ‘command response’ system operated through a Bus Controller, It also operates at 2 Mbits/s as opposed to 1 Mbits/s for ‘1553’ The ARINC 629 data bus system is installed in the Boeing 777 airliner which entered airline service in 1995.

There are two standard high speed data buses which have been developed in the US for military applications. These are the ‘Linear Token Passing Bus’, LTPB, which operates at 50 Mbits/s and the ‘High Speed Ring Bus’, HSRB, which operates at 100 Mbits/s.

The high speed data bus system, however, which is becoming widely adopted, particularly in new civil aircraft (for example, the Airbus A380 airliner), is a system based on the ‘Ethernet’ data bus. The Ethernet data bus system is very widely used in commercial computing system applications. It has a data rate transmission capability of 100 Mbits/s and is mainly used for data file transfer.

1.8.3. ARINC 429

Mark33 Digital Information Transfer System (DITS)," is also known as the Aeronautical Radio INC. (ARINC) technical standard for the predominant avionics data bus used on most higher-end commercial and transport aircraft.It defines the physical and electrical interfaces of a two-wire data bus and a data protocol to support an aircraft's avionics local area network.

ARINC 429 is a data transfer standard for aircraft avionics. It uses a self-clocking, self-synchronizing data bus protocol (Tx and Rx are on separate ports). The physical connection wires are twisted pairs carrying balanced differential signaling. Data words are 32 bits in length and most messages consist of a single data word. Messages are transmitted at either 12.5 or 100 kbit/s

The transmitter constantly transmits either 32-bit data words or the NULL state (0 Volts). A single wire pair is limited to one transmitter and no more than 20 receivers. The protocol allows for self-clocking at the receiver end, thus eliminating the need to transmit clocking data. ARINC 429 is an alternative to MIL-STD-1553.

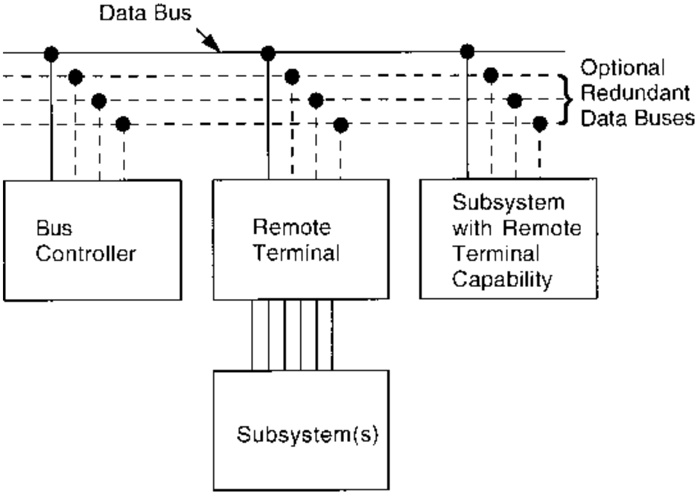

Fig1.6. Typical multiplex data bus system architecture.

The version which has been adapted for airborne applications is known as the ‘Avionics Full Duplex Switched Ethernet’, which has been shortened to ‘AFDX Ethernet’ network. It meets the civil aircraft avionic system requirements in all aspects and its commercially sourced components make it a very competitive system.
Its adoption in military aircraft avionic systems would appear to be a likely future development because of its cost advantages.

1.8.4. MIL STD 1553 Bus System

MIL STD 1553B is a US military standard which defines a TDM multiple-source–multiple-sink data bus system which is in very wide scale use in military aircraft in many countries. It is also used in naval surface ships, submarines, and land vehicles such as main battlefield tanks. The system is a half duplex system, that is operation of a data transfer can take place in either direction over a single line, but not in both directions on that line simultaneously.

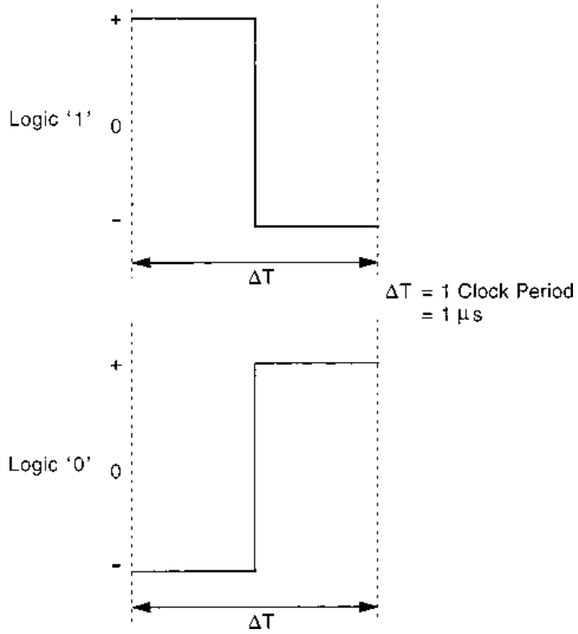

Fig1.7. Logic '1' and logic '0'.

the bus controller. Each sub-system is connected to the bus through a unit called a remote terminal (RT). Data can only be transmitted from one RT and received by another RT.

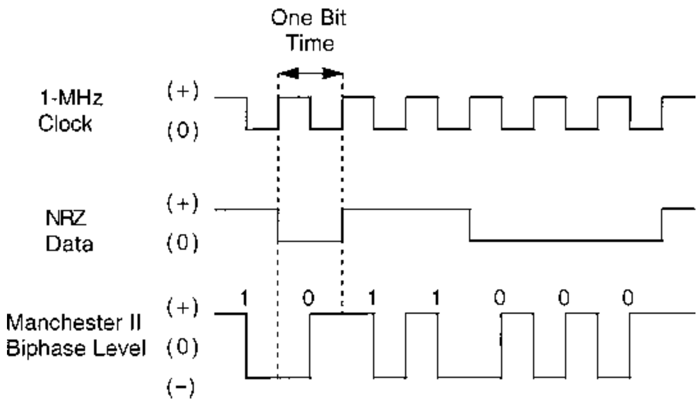

Fig1.8. Data encoding

A maximum of 31 terminals can be connected to the bus. The bus operation is asynchronous, each terminal having an independent clock source for transmission. Decoding is achieved in receiving terminals using clock information derived from the messages.

A command word comprises six separate fields. These are briefly explained be- low:

- The SYNC signal field is an invalid Manchester waveform so that it cannot be 'confused' with any data bits.
- The RT address field occupies 5 bits, each RT being assigned a unique 5 bit address. Decimal address 31(11111) is not assigned as a unique address and is

a broadcast address.

- The T/R bit is 0 if the RT is to receive, and 1 if the RT is to transmit.
- The sub-address/mode field, comprising 5 bits, is used for either an RT sub-address or mode control. The sub-address is used to route data to and from a location in the RT. A code of all zeros (00000) in the sub-address/mode field indicates that the contents of the word counts/mode field are to be decoded as a five bit mode command.

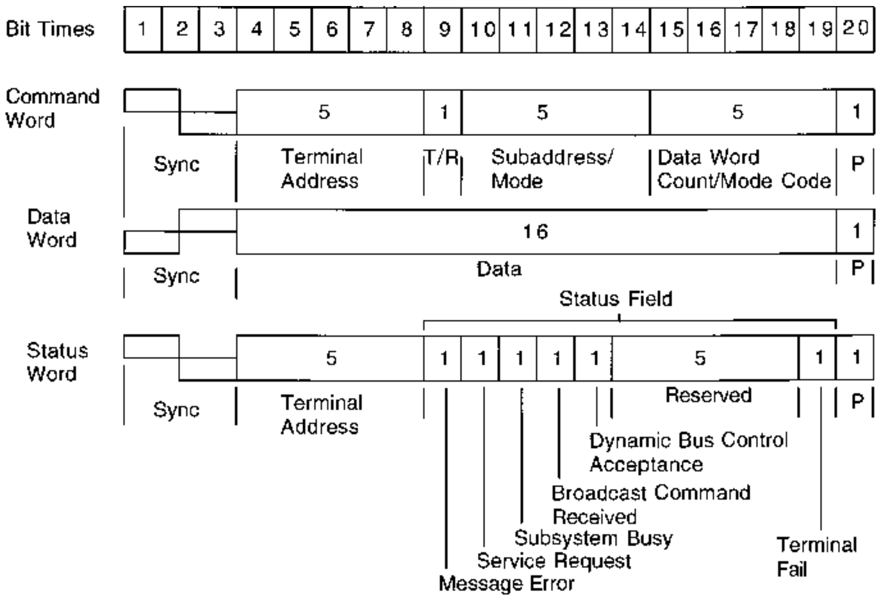

Fig1.9. Word formats.

- The data word count/mode code field, comprising 5 bits, is generally used for data transfers. The word count field indicates the number of data words to be transferred in any one message block, the maximum number being 32 (indicated by all zeros).
- The parity bit is 1 if there is an odd number of bits in fields 1–19.

A status word is the first word of a response by an RT to a BC command. It provides:

(a) A summary of the status/health of the RT.
(b) The word count of the data words to be transmitted in response to a command.

The fields are briefly described below:

- The SYNC signal field is the same as with a command word.
- The RT address field (5 bits) confirms the correct RT is responding.
- The status field comprises 11 bits. The message error bit is set if the previous command was not correctly understood. The instrumentation bit =0 to distinguish the word from a command word.
- The parity bit is set by the RT in the same sense as a command word.

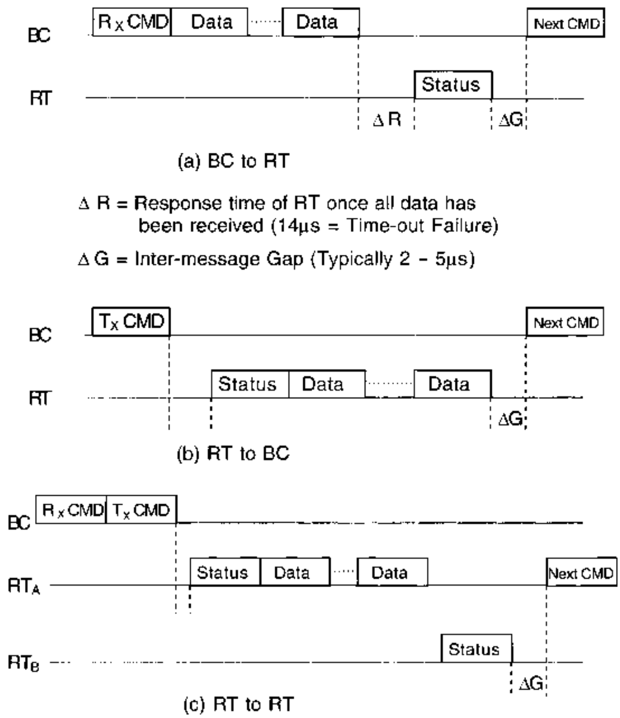

Fig1.10. Transfer formats.

There are ten possible transfer formats, but the three most commonly used formats are:

- BC to RT
- RT to BC
- RT to RT
- *Message data validation* – the terminal is designed to detect improperly coded signals, data drop-outs or excessively noisy signals.
- *Word validation* – the terminal checks that each word conforms to the following minimum criteria:
  - Word begins with a valid SYNC field.
  - Bits are in valid Manchester II code.
  - Information field has 16 bit plus parity.
  - Word parity is odd.

  When a word fails to conform to the above criteria the word is considered invalid.
- *Transmission continuity* – the terminal checks the message is contiguous as shown in the formats. Improperly timed data SYNCs are con- sidered a continuity error.
- *Excessive transmission* – the terminal includes a signal time-out which pre- cludes a signal transmission greater than 1 ms plus or minus 0.34 ms.

The data word is deemed valid when the data meet the above criteria and are received

1.8.5. Optical Data Bus Systems

Most readers are probably familiar to some extent with the use of optical fibres to transmit light signals. A brief explanation is set out below for those readers who need to refresh themselves on the subject and also to make clear the difference between multi-mode and single mode optical fibres and their respective applications. The transmission of light signals along any optical fibre depends on the optical property of total internal reflection.. Ray 1 is refracted in passing through the second medium, the relationship between the angle the incident ray makes with the normal, *i*, and the angle the refracted ray makes with the normal, *r*, being given by Snell's law.

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

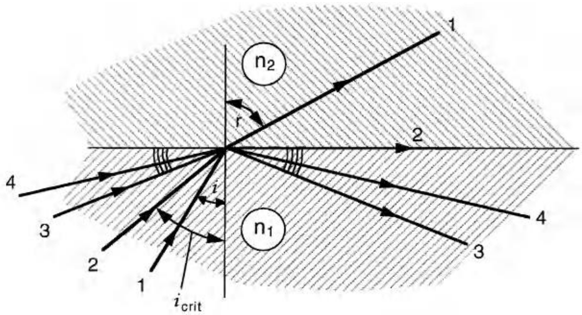

Fig1.11. Total internal reflection.

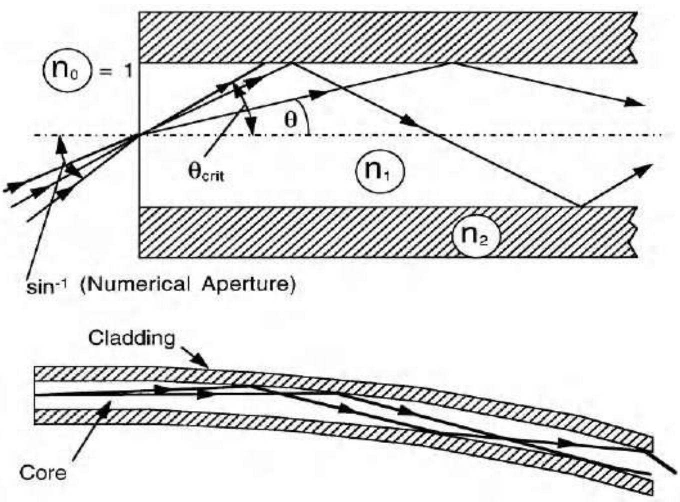

Fig1.12. Multi-mode optical fibre.

At the critical incidence angle, i_{crit}, ray 2 is refracted through an angle of 90° and does not pass through the second medium ($i_{crit} = \sin^{-1} n_2/n_1$). All rays with incid- ent angles greater than i_{crit} such as rays 3 and 4 are thus reflected back into the first medium. This condition is known as total internal reflection and is effectively a loss free process.

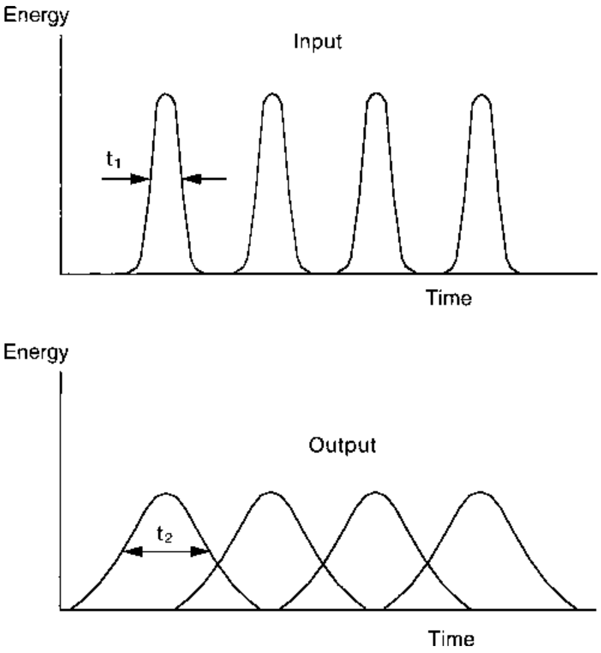

Fig1.12. Pulse broadening.

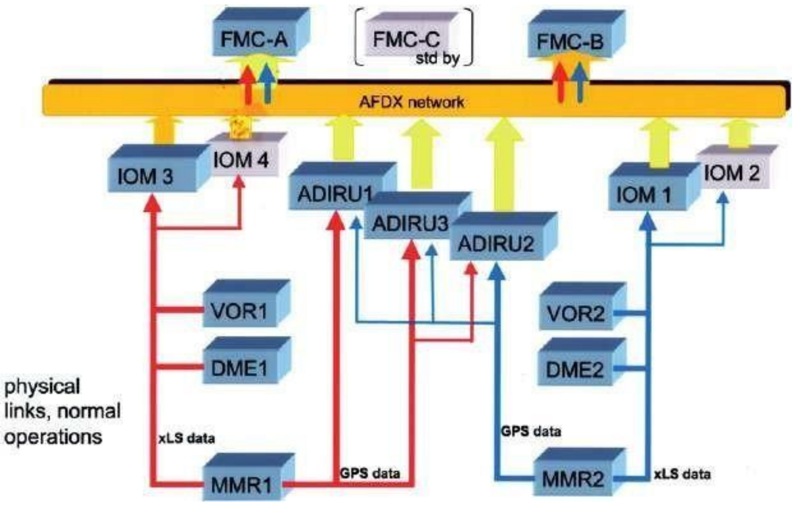

Fig1.13. Interconnection of Navigation System units by the AFDX network (by courtesy of Air- bus).

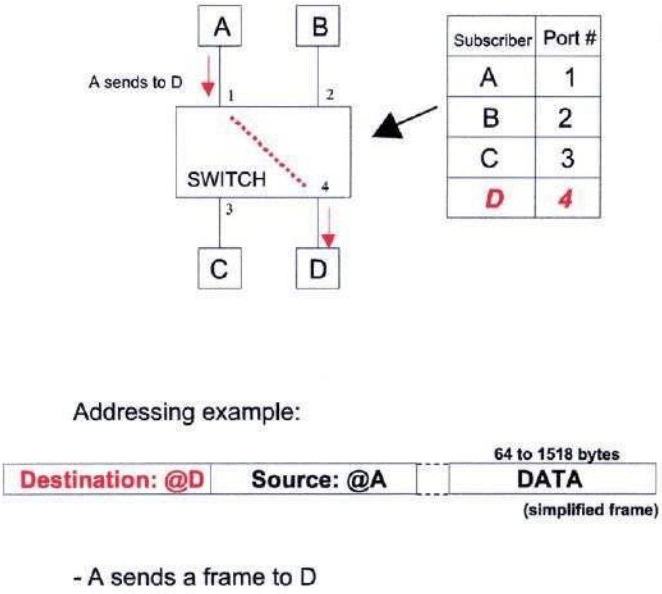

Fig1.14. Switched Ethernet principle.

And communication constraints with the objective of connecting subscribers which exchange large amounts of data with each other to the same switches.

1.9. AVIONICS PACKAGING

1.9.1 Putting Intelligence Closer to the Action

A distributed avionics system creates flexible capabilities in a smaller, lighter package. The Mini Modular Rack Principle (MiniMRP), standardized in ARINC 836A, is fast emerging as the leading choice for packaging of distributed systems. The MiniMRP provides standardized modules that can be easily deployed through an aircraft, allowing information to be collected and distributed around a fiber optic or copper backbone

1.9.2Modularity Simplifies Configuration:

By creating a series of standard modules, the MiniMRP system allows a mix-and-match approach to design and deployment. Modules can be used singly or combined as needed to create specific functionality throughout the aircraft. Module upgrades, replacements, or expansions are easily accomplished.

1.9.3. Lower Costs through Standardization

By providing compact, standardized modules, MiniMRP enhances the ability to distribute embedded computing functions throughout the aircraft. Standardization of both connectors inserts and modular enclosures sizes provide a commonality of components within an aircraft and across a wide range of different aircraft platforms.

1.9.4. Lower Costs – COTS Components

Designers of avionic systems can take advantage of commercial off-the-shelf (COTS) components, thereby streamlining the design cycle to enable a faster time to market. Additionally, they give designers access to well-established, high-volume products that can lower costs through economies of scale. Standardization creates a competitive ecosystem.

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UNIT- III – AVIONICS - SAEA1404

UNIT - III
SENSORS

Introduction

The cockpit display systems provide a visual presentation of the information and data from the aircraft sensors and systems to the pilot (and crew) to enable the pilot to fly the aircraft safely and carry out the mission. They are thus vital to the operation of any aircraft as they provide the pilot, whether civil or military, with:

- Primary flight information,
- Navigation information,
- Engine data,
- Airframe data,
- Warning information.

The military pilot has also a wide array of additional information to view, such as:

- Infrared imaging sensors,
- Radar,
- Tactical mission data,
- Weapon aiming,
- Threat warnings.

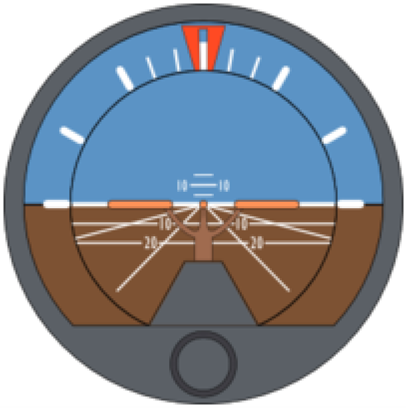
The pilot is able to rapidly absorb and process substantial amounts of visual information but it is clear that the information must be displayed in a way which can be readily assimilated, and unnecessary information must be eliminated to ease the pilot's task in high work load situations. A number of developments have taken place to improve the pilot–display interaction and this is a continuing activity as new technology and components become available. Examples of these developments are:

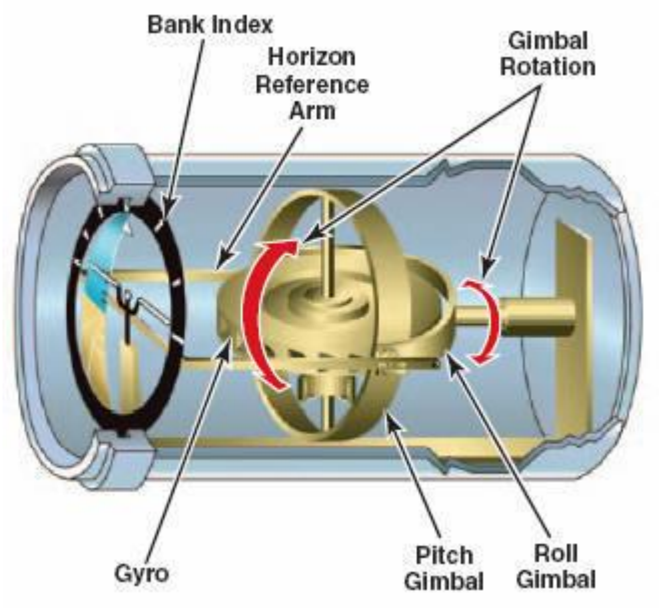
- Head up displays,
- Helmet mounted displays,
- Multi-function color displays,
- Digitally generated color moving map displays,
- Synthetic pictorial imagery,
- Displays management using intelligent knowledge-based system (IKBS) technology,
- Improved understanding of human factors and involvement of human factors specialists from the initial cockpit design stage.

Equally important and complementary to the cockpit display systems in the 'man machine interaction' are the means provided for the pilot to control the operation of the avionic systems and to enter data. Again, this is a field where continual development is taking place. Multi-function keyboards and multi-function touch panel displays are now widely used. Speech recognition technology has now reached sufficient maturity for 'direct voice input' control to be installed in the new generation of military aircraft. Audio warning systems are now well established in both military and civil aircraft.

The integration and management of all the display surfaces by audio/tactile inputs enables a very significant reduction in the pilot's workload to be achieved in the new generation of single seat fighter/strike aircraft. Other methods of data entry which are being evaluated include the use of eye trackers.

Attitude Indicator





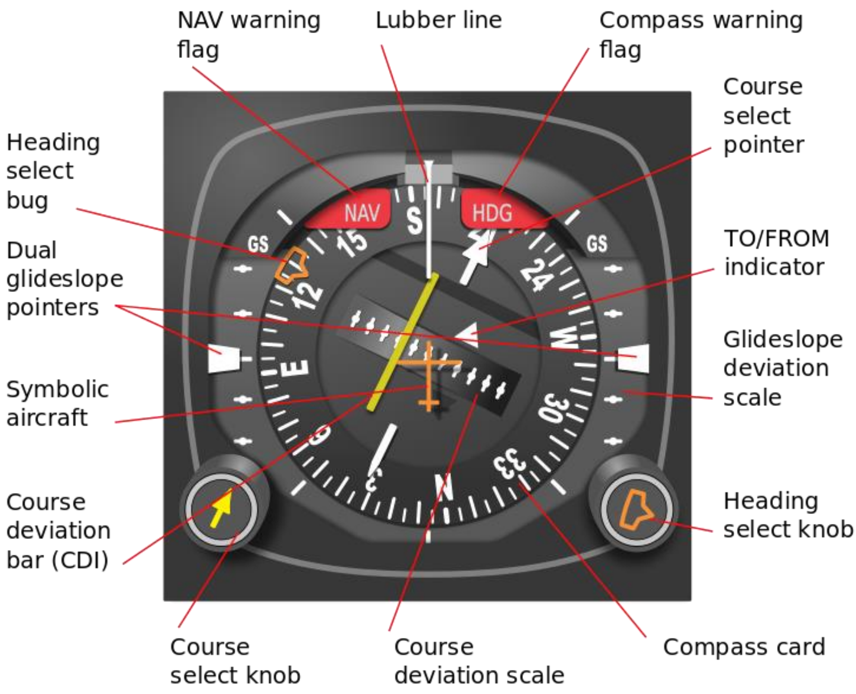
- Provides an artificial horizon (not AOA!) to the pilot to display information about both pitch and bank
- Gyroscope has two gimballs that the aircraft can rotate about for pitch and bank
- 10,20,30,60,90 degree markings for bank
- Pitch angle is indicated by a series of lines, each representing 5° or 10° of pitch
- Pilot can set where the miniature airplane meets the horizon before takeoff

Errors

- **Turn Error**
  - During a normal coordinated turn, centrifugal force causes the gyro to precess toward the inside of the turn.
  - This precession increases as the bank steepens; therefore, it is greatest during the actual turn
  - Error disappears as the aircraft rolls out at the end of a 180 degrees turn at a normal rollout rate.
- **Acceleration Error**
  - As the aircraft accelerates, gyro precession causes the horizon bar to move down, indicating a slight pitch up attitude.
- **Deceleration Error**
  - Deceleration causes the horizon bar to move up, indicating a false pitch down attitude

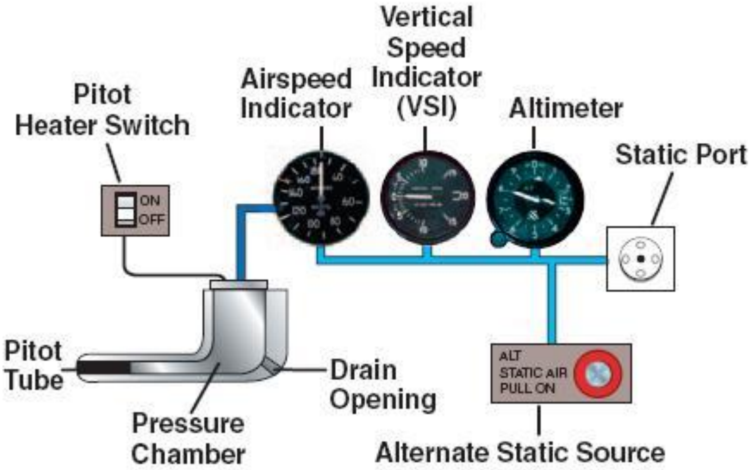
Horizontal situation indicator

The heading indicator (also known as the directional gyro, or DG) displays the aircraft's heading with respect to magnetic north when set with a compass. Bearing friction causes drift errors from precession, which must be periodically corrected by calibrating the instrument to the magnetic compass.[1]:3-19 to 3-20 In many advanced aircraft (including almost all jet aircraft), the heading indicator is replaced by a horizontal situation indicator (HSI) which provides the same heading information, but also assists with navigation.

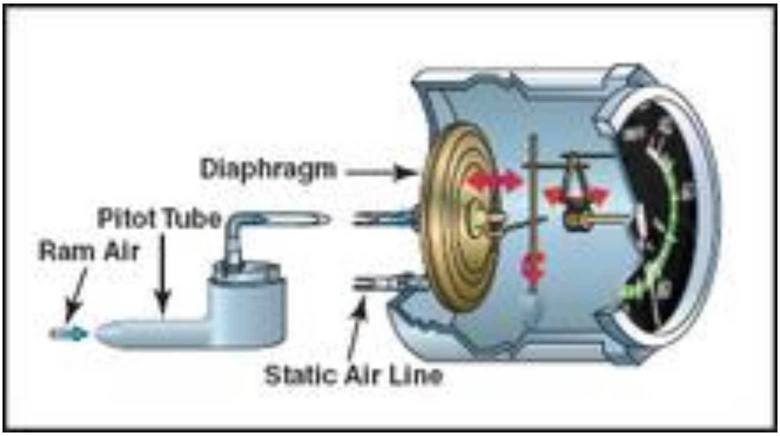


Pitot static instruments

The pitot-static system obtains pressures for interpretation by the pitot-static instruments. While the explanations below explain traditional, mechanical instruments, many modern aircraft use an air data computer (ADC) to calculate airspeed, rate of climb, altitude and Mach number. In some aircraft, two ADCs receive total and static pressure from independent pitot tubes and static ports, and the aircraft's flight data computer compares the information from both computers and checks one against the other. There are also "standby instruments", which are back-up pneumatic instruments employed in the case of problems with the primary instruments.



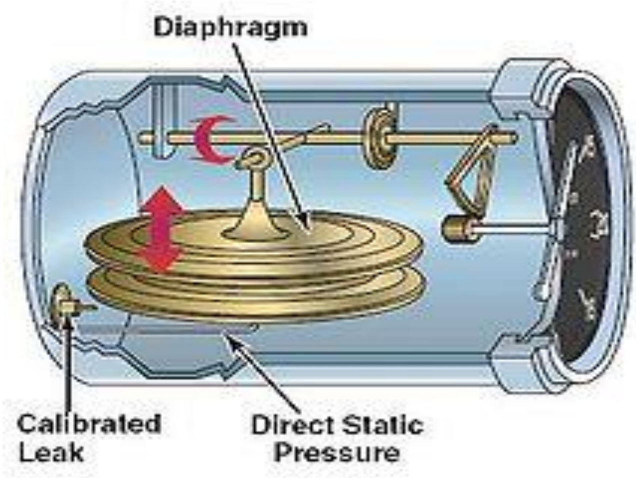
Airspeed indicator



The airspeed indicator is connected to both the pitot and static pressure sources. The difference between the pitot pressure and the static pressure is called dynamic pressure. The greater the dynamic pressure, the higher the airspeed reported. A traditional mechanical airspeed indicator contains a pressure diaphragm that is connected to the pitot tube. The case around the diaphragm is airtight and is vented to the static port. The higher the speed, the higher the ram pressure, the more pressure exerted on the diaphragm, and the larger the needle movement through the mechanical linkage.

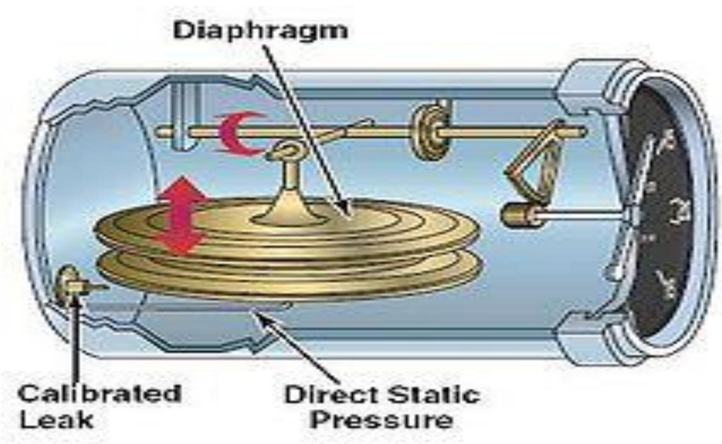
Altimeter

The pressure altimeter, also known as the barometric altimeter, is used to determine changes in air pressure that occur as the aircraft's altitude changes.[4] Pressure altimeters must be calibrated prior to flight to register the pressure as an altitude above sea level. The instrument case of the altimeter is airtight and has a vent to the static port. Inside the instrument, there is a sealed aneroid barometer. As pressure in the case decreases, the internal barometer expands, which is mechanically translated into a determination of altitude. The reverse is true when descending from higher to lower altitudes.



Main errors produced in altimeter!! 1) Blockage error 2)Lag error 3)Instruments error 4)Position error 5)Temperature error 6)Barometric error 7)Transonic Jump

Vertical speed indicator



The variometer, also known as the vertical speed indicator (VSI) or the vertical velocity indicator (VVI), is the pitot-static instrument used to determine whether or not an aircraft is flying in level flight.[5] The vertical speed specifically shows the rate of climb or the rate of descent, which is measured in feet per minute or meters per second.The vertical speed is measured through a mechanical linkage to a diaphragm located within the instrument. The area surrounding the diaphragm is vented to the static port through a calibrated leak (which also may be known as a "restricted diffuser"). When the aircraft begins to increase altitude, the diaphragm will begin to contract at a rate faster than that of the calibrated leak, causing the needle to show a positive vertical speed. The reverse of this situation is true when an aircraft is descending. The calibrated leak varies from model to model, but the average time for the diaphragm to equalize pressure is between 6 and 9 seconds.

AIR DATA

An air data computer (ADC) is an essential avionics component found in modern glass cockpits. This computer, rather than individual instruments, can determine the calibrated airspeed, Mach number, altitude, and altitude trend data from an aircraft's pitot-static system.

AIR DATA INERTIAL REFERENCE UNIT (ADIRU)

An air data inertial reference unit (ADIRU) is a key component of the integrated air data inertial reference system (ADIRS), which supplies air data (airspeed, angle of attack and altitude) and inertial reference (position and attitude) information to the pilots' electronic flight instrument system displays as well as other systems on the aircraft such as the engines, autopilot, aircraft flight control system and landing gear systems.[1] An ADIRU acts as a single, fault tolerant source of navigational data for both pilots of an aircraft.[2] It may be complemented by a secondary attitude air data reference unit (SAARU), as in the Boeing 777 design.

AIR DATA REFERENCE

The air data reference (ADR) component of an ADIRU provides airspeed, Mach number, angle of attack, temperature and barometric altitude data. Ram air pressure and static pressures used in calculating airspeed are measured by small ADMs located as close as possible to the respective pitot and static pressure sensors. ADMs transmit their pressures to the ADIRUs through ARINC 429 data buses.

INERTIAL REFERENCE

The IR component of an ADIRU gives attitude, flight path vector, ground speed and positional data.[1] The ring laser gyroscope is a core enabling technology in the system, and is used together with accelerometers, GPS and other sensors to provide raw data. The primary benefits of a ring laser over older mechanical gyroscopes are that there are no moving parts, it is rugged and lightweight, frictionless and does not resist a change in precession.

Air data sensors

Air data is a measurement of the air mass surrounding an airplane. The two physical characteristics measured are pressure and temperature. Air data is acquired through various sensors on the aircraft and is used to calculate altitude, speed, rate of climb or decent, and angle-of-attack or angle-of-sideslip.

The pressure measurements consist of static pressure (Ps) and total pressure (Pt).

- Static Pressure (Ps) is the absolute pressure of still air surrounding the aircraft. This is the barometric pressure at the altitude where the aircraft is traveling and is independent of any pressure disturbances caused by the motion of the aircraft.
- Total Pressure (Pt) is the sum of the local atmospheric pressure (Ps) and the impact pressure (Qc) caused by the aircraft's motion through the air.
- Impact Pressure (Qc) is the pressure a moving stream of air produces against a surface that brings part of the moving stream to rest. It is the difference between the total pressure (Pt) and the static pressure (Ps).

These pressure properties are related by the formula: **Qc = Pt - Ps**

Ps and Pt are acquired by one or more pitot static probes on the aircraft body. Qc is calculated from these values.

Ps is used to calculate the altitude of the aircraft.

Qc is used to calculate the speed of the aircraft.

Altitude is derived from a series of equations using the static pressure. Altitude calculations are based on a "standard atmosphere," which assumes a known relationship between pressure, temperature and atmospheric density.

Generally, the lower the static pressure, the higher the altitude. Temperature is measured in order to calculate true airspeed (the actual speed of the plane through air) from indicated airspeed and temperature. A temperature probe on the body of the aircraft acquires temperature values. Pressure and temperature data sensing is sometimes combined in the same sensor.

Indicated airspeed (IAS), true airspeed (TAS) and Mach number are versions of an aircraft’s speed and have a temperature component incorporated

Indicated Airspeed (IAS): The speed of an aircraft relative to the surrounding air. It is uncorrected for any installation or instrument errors. Indicated airspeed equals true airspeed at standard sea level conditions only, and it is a function of impact pressure (Qc).

True Airspeed (TAS): Indicated airspeed corrected for nonstandard temperatures that can be determined using Mach number and total temperature. It is the actual aircraft speed through the air mass.

Mach number: The ratio of true airspeed and the speed of sound in the surrounding air. The speed of sound is proportional to the square root of the average temperature. Mach number is calculated using the ratio of impact pressure (Qc) to static pressure (Ps).

.

Magnetic Sensing

Magnetic sensors detect moving ferrous metal. The simplest magnetic sensor consists of a wire coiled around a permanent magnet. A ferrous object approaching the sensor changes magnetic flux through the coil, generating a voltage at the coil terminals.
Magnetic pickups sense linear or rotary motion without an external power source. They have high resolution, generating many pulses/in. of target travel and can sense very small ferrous objects. For example, one sensor responds to 96-pitch gears, while Hall- effect sensors can only register 16-pitch gear teeth. In these applications, magnetic transducers can be accurate to hundredths of a mechanical degree. For sensing rotating shaft speed, on the other hand, output-pulse frequency is converted to rpm at an accuracy of 0.1%.

Magnetic sensors measure speeds up to 600,000 rpm. Maximum sensor frequency is in the megahertz region, with usable frequencies limited by internal sensor impedance and external load.
Speeds near zero, however, cannot be measured because output voltage depends on the rate of change of flux through the coils. As frequency approaches zero, sensor output drops to the millivolt range.
The absence of electronic elements in magnetic sensors allows operation beyond temperatures (-65 to 300°F) associated with solid-state devices. Magnetic sensors built with special materials operate at cyrogenic temperatures and withstand temperatures excursions greater than 400°F. Magnetic sensors are almost impervious to shock, operating at levels exceeding 30,000 g.
Since magnetic sensors can detect ferrous discontinuities through nonferrous metals, they can be hermetically sealed within nonferrous housings to withstand 100% humidity or complete immersion in water and oil. Sensors enclosed in stainless steel can operate in salt spray or sand and dust environments, and under differential pressures up to 20,000 psi.

Eddy Currents: Eddy-current sensors detect ferrous and nonferrous metals. A high-frequency magnetic field induces eddy currents in metal targets. The eddy currents generally change the sensor's oscillation amplitude, which is sensed by a coil to create an output signal. For measuring speed, these sensors register metallic discontinuities in a moving target at a rate of about 5 kHz, but some models respond up to about 20 kHz.
Maximum response speed is determined by the method used to sense oscillator amplitude. Devices that sense amplitude changes with conventional demodulator/integrator circuits are slower than those that convert oscillator amplitude into a string of pulses whose widths vary with frequency.
Eddy-current devices also produce pulses with high positional accuracy. Because eddy-current sensors do not depend on a time rate of change to register motion, their response does not diminish near zero speed like that of magnetic pickups.
Eddy-current devices are seldom contaminated by dirt or metal particles, but sensing distance is typically limited to the diameter of the sensor (usually 0.06 to 3 in.). These sensors must also be enclosed in nonmetallic packages because they cannot sense through metals.

Inertial Sensors

Inertial sensors are sensors based on inertia and relevant measuring principles. These range from Micro Electro Mechanical Systems (MEMS) inertial sensors, measuring only few mm, up to ring laser gyroscopes that are high-precision devices with a size of up to 50cm. Within this note, we will briefly summarize these cases of inertial sensors that are most important to the autonomous navigation of unmanned aircraft. Inertial sensors for aerial robotics typically come in the form of an Inertial Measurement Unit (IMU) which consists of accelerometers, gyroscopes and sometimes also magnetometers. Subsequently, we will briefly summarize the main principles of accelerometers and gyroscopes widely used in unmanned aviation.

Accelerometers

Accelerometers are devices that measure proper acceleration ("g-force"). Proper acceleration is not the same as coordinate acceleration (rate of change of velocity). For example, an accelerometer at rest on the surface of the Earth will measure an acceleration g= 9.81 m/s^2 straight upwards. By contrast, accelerometers in free fall orbiting and accelerating due to the gravity of Earth will measure zero.

Accelerometers are electromechanical devices that are able of measuring static and/or dynamic forces of acceleration. Static forces include gravity, while dynamic forces can include vibrations and movement. Accelerometers can measure acceleration on 1, 2 or 3 axes. Currently, 3-axes devices are becoming more common due to the great cost reduction. Figure 1 depicts the axes found on such a device. It is highlighted that the accelerometer will measure according to its own body of reference and based on the effect of the external forces on it.

$$\omega_n = \sqrt{\frac{k}{m}}, \quad \zeta = \frac{c}{2\sqrt{km}}$$

RADAR SENSORS

Radar is a detection system that uses radio waves to determine the range, angle, or velocity of objects. It can be used to detect aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain. A radar system consists of a transmitter producing electromagnetic waves in the radio or microwaves domain, a transmitting antenna, a receiving antenna (often the same antenna is used for transmitting and receiving) and a receiver and processor to determine properties of the object(s). Radio waves (pulsed or continuous) from the transmitter reflect off the object and return to the receiver, giving information about the object's location and speed.

Radar was developed secretly for military use by several nations in the period before and during World War II. A key development was the cavity magnetron in the United Kingdom, which allowed the creation of relatively small systems with sub-meter resolution. The term *RADAR* was coined in 1940 by the United States Navy as an acronym for RAdio Detection And Ranging

A radar system has a transmitter that emits radio waves called *radar signals* in predetermined directions. When these come into contact with an object they are usually reflected or scattered in many directions. But some of them absorb and penetrate into the target to some degree. Radar signals are reflected especially well by materials of considerable electrical conductivity—especially by most metals, by seawater and by wet ground. Some of these make the use of radar altimeters possible. The radar signals that are reflected back towards the transmitter are the desirable ones that make radar work. If the object is *moving* either toward or away from the transmitter, there is a slight equivalent change in the frequency of the radio waves, caused by the Doppler effect.

Radar receivers are usually, but not always, in the same location as the transmitter. Although the reflected radar signals captured by the receiving antenna are usually very weak, they can be strengthened by electronic amplifiers. More sophisticated methods of signal processing are also used in order to recover useful radar signals.

The weak absorption of radio waves by the medium through which it passes is what enables radar sets to detect objects at relatively long ranges—ranges at which other electromagnetic wavelengths, such as visible light, infrared light, and ultraviolet light, are too strongly attenuated. Such weather phenomena as fog, clouds, rain, falling snow, and sleet that block visible light are usually transparent to radio waves. Certain radio frequencies that are absorbed or scattered by water vapour, raindrops, or atmospheric gases (especially oxygen) are avoided in designing radars, except when their detection is intended.

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UNIT -IV

NAVIGATION AND LANDING AIDS

Introduction

Gyroscopes (hereafter abbreviated to gyros) and accelerometers are known as inertial sensors. This is because they exploit the property of inertia, namely the resistance to a change in momentum, to sense angular motion in the case of the gyro and changes in linear motion in the case of the accelerometer.
They are fundamental to the control and guidance of an aircraft. For example, in a FBW aircraft the rate gyros and accelerometers provide the aircraft motion feedback which enables a man- oeuvre command control to be achieved and an aerodynamically unstable aircraft to be stabilized by the flight control system (as explained in Chapter 4).

Gyros and accelerometers are also the essential elements of the spatial reference system or attitude/heading reference system (AHRS) and the inertial navigation system (INS). They largely determine the performance and accuracy of these systems and account for a major part of the system cost.

The AHRS and INS share common technology and operating principles. This chapter covers gyros and accelerometers and attitude derivation from strap-down gyros and accelerometers. It provides the basic background to inertial navigation and AHRS systems, which are covered in Chapter 6 'Navigation Systems'.

Gyros and Accelerometers

The accuracy requirements for gyros and accelerometers can differ by several orders of magnitude depending on the application.

Not surprisingly, the costs can also differ by an order of magnitude or more.

The quest for and attainment of the accuracies required for inertial navigation have involved many billions of dollars expenditure worldwide and the continual exploitation of state of the art technology. For example, the world's first laser was demonstrated in 1960 and the first experimental ring laser gyro (RLG) was demonstrated in 1963 with an accuracy of a few degrees per hour.

The first production RLG based inertial navigation systems (which requires 0.01°/hour accuracy) went into large scale civil airline service in 1981. Strap-down RLG based IN systems now
dominate the market; a technology revolution

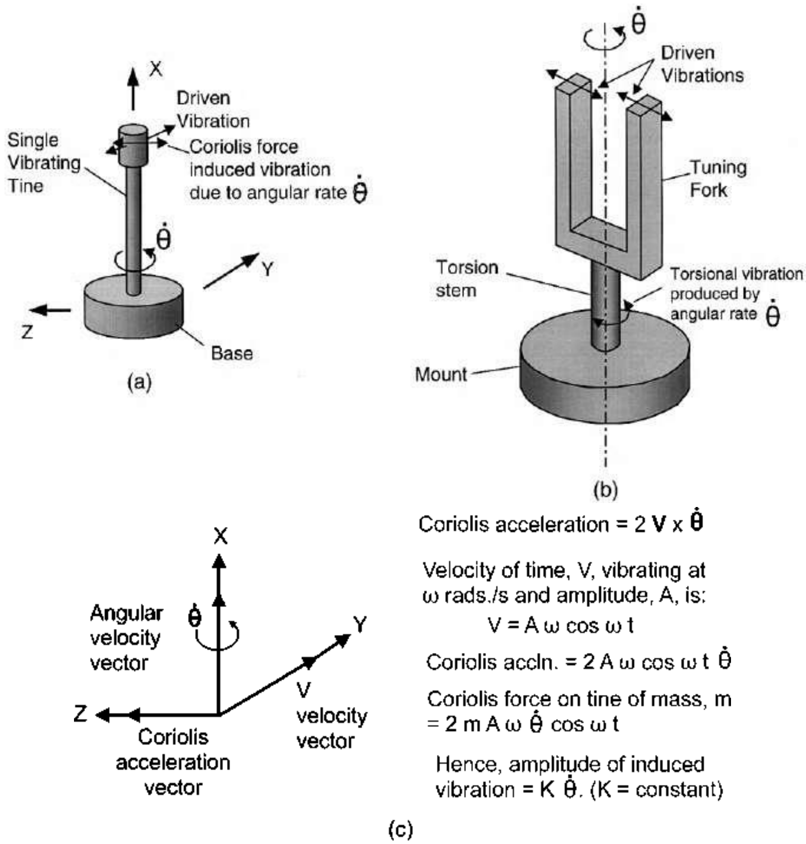


Fig 5.1. Tuning fork rate gyro.

ment suffers from the unacceptable characteristic that the smallest linear motions applied to its base cause unacceptably large errors. To overcome the effect of base motion, it is necessary to use balanced oscillations in which the oscillations of one mass are counter-balanced by equal and opposite motion of a second equal mass.

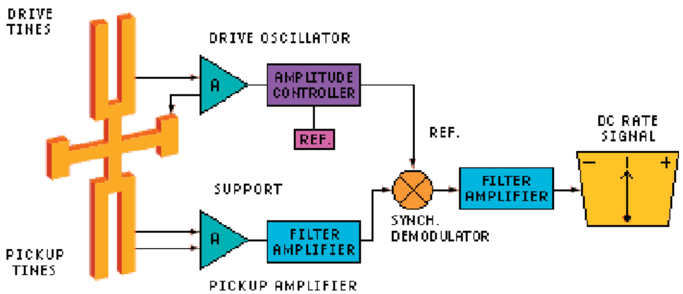


Fig 5.2 Quartz rate sensor (courtesy of Systron Donner Inertial Division).

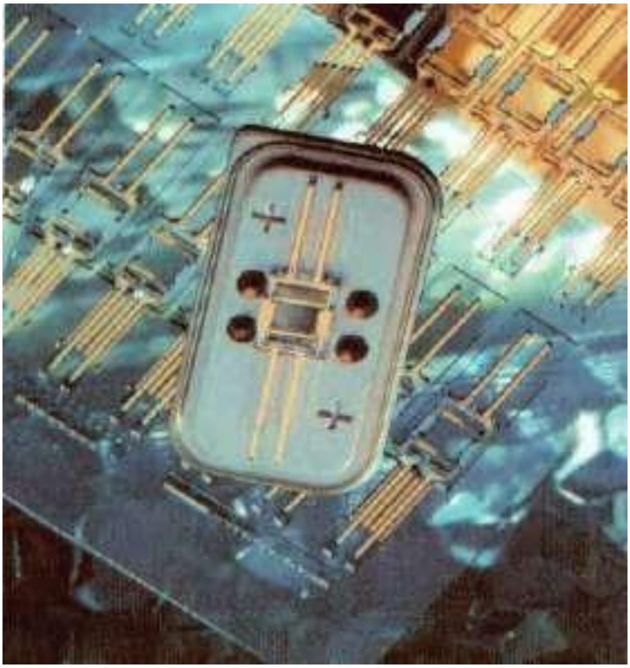


Fig 3.3. Quartz rate sensor fabrication wafer with device overlaid (courtesy of Systron Donner Inertial Division).

Optical Gyroscopes

Introduction

Optical gyroscopes such as the ring laser gyro and the fibre optic gyro measure angular rate of rotation by sensing the resulting difference in the transit times for laser light waves travelling around a closed path in opposite directions.

This time difference is proportional to the input rotation rate and the effect is known as the ‘Sagnac effect’ after the French physicist G

The Sagnac effect time difference, OT , between the clockwise (cw) and anti-clockwise (acw) paths is given by

$$OT = \frac{4A}{c^2}\theta$$

where A is the area enclosed by the closed path, c the velocity of light and $\dot{\theta}$ the angular rate of rotation about an axis normal to the plane of the closed path.

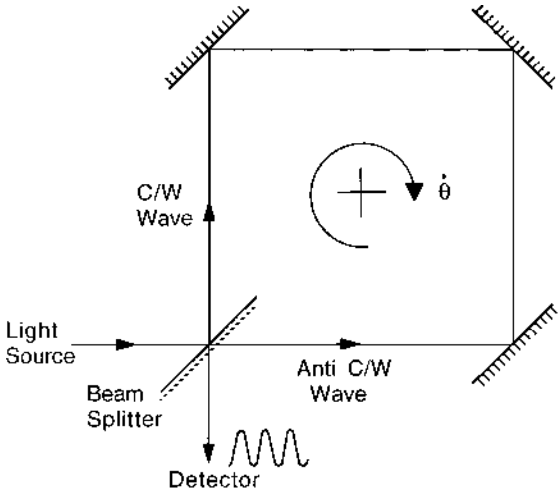


Fig 5.4. Sagnac interferometer. The clockwise and anti-clockwise waves interfere to produce a finge pattern which shifts when the interferometer is subjected to input rate, $\dot{\theta}$.

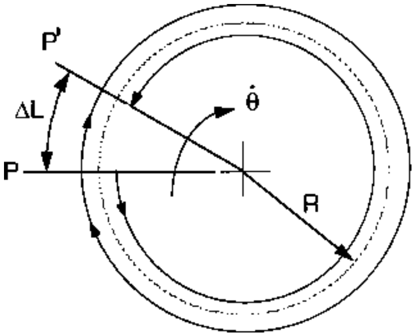


Fig 5.5. Sagnac effect.

$$OL = cOT$$
$$OL = \frac{4A}{c}\dot{\theta}$$

A rigorous derivation of the above formulae requires the use of the general theory of relativity. A simpler kinematic explanation, however, is given below for the case of a circular path in vacuo.

In time T, P has moved to P^1 and the path length for the cw photon is equal to $(2\pi R + R\dot{\theta}T)$ and the path length for the acw photon is equal to $(2\pi R - R\dot{\theta}T)$.
The difference in transit time,

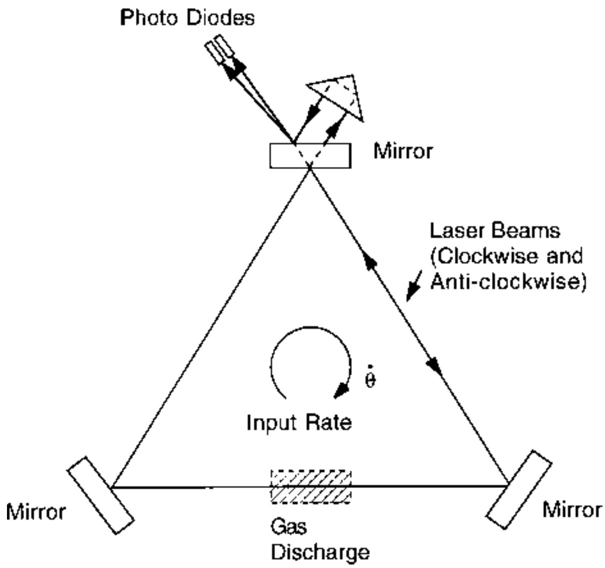


Fig 5.6. Laser gyro schematic.

The IFOG operates basically as a Sagnac interferometer and measures the phase shift in the fringe pattern produced by the input rotation rate. The accurate measurement of very small Sagnac phase shifts has required the development of special techniques which will be explained. The IFOG was initially developed to an AHRS level of accuracy and the first large production orders for IFOG based AHRS were placed in 1991. Development to inertial accuracy has since taken place in many organisations and IFOG based IN systems are nowavailable.

The resonator type of fibre optic gyro, or RFOG, operates in a similar manner to the RLG but with the resonant ring of optical fibre driven by an external laser diode. Two acousto-optical modulators are used to shift the laser frequency injected into the cw and acw paths respectively with the modulation frequencies being controlled by servo loops to maintain the resonance peak condition. The difference in the resonant frequencies of the two paths is then directly proportional to the input rotation rate as with the RLG. Development of the RFOG appears to be on the 'back-burner' at the present time, as the IFOG type is giving an excellent all round performance.

Attention has thus been concentrated on the RLG and the IFOG.

The Interferometric Fibre Optic Gyro

The implementation of the interferometric type of FOG is best explained in a series of stages starting with the simple basic system.

Light from the laser diode source is passed through a first beam splitter and a single optical mode is selected. The light passes through a second beam splitter and propagates in both directions around the fibre coil. In the absence of rotation, as already explained, the transit times are identical so that when the light arrives back at the second beam splitter, perfect constructive interference occurs with accompanying fringe pattern. The gyro output signal is obtained by directing the returning light via the first beam splitter to a photo-detector.

As explained, an input rotation rate about an axis normal to the plane of the coil results in a difference in the transit times between the clockwise and anti-clockwise beams as given by equation,
viz.

$$OT = \frac{4A}{c^2}\theta$$

If the fibre coil has N turns, $A = \pi R^2$ N where R is the mean radius of the coil, and N can be expressed in terms of the length of the coil, L and the mean radius R, i.e.

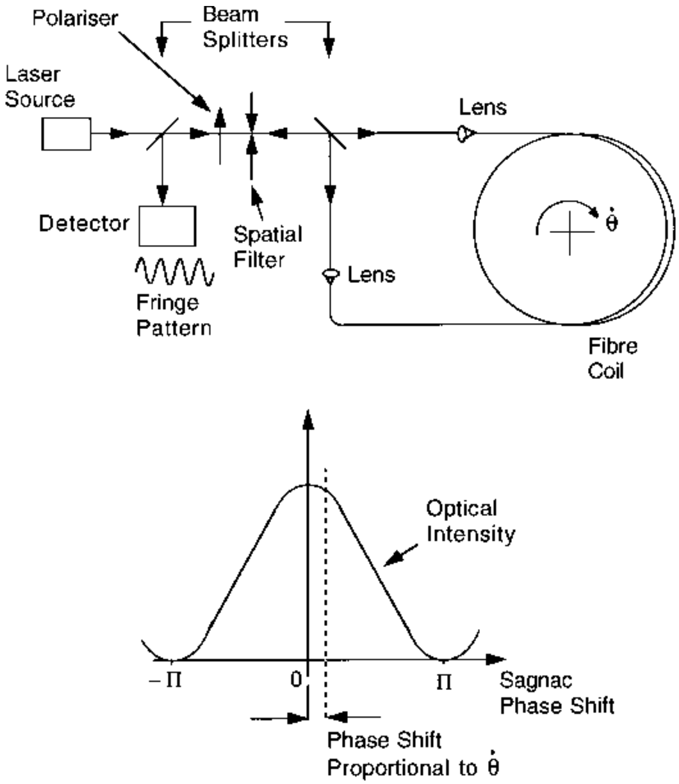


Fig 5.7. Basic fibre optic gyro.

$$N = \frac{L}{2\pi R}$$

hence

$$OT = \frac{LD}{c^2}\theta$$

This transit time difference results in the Sagnac phase shift, given by

$$8_s = \omega OT$$

This phase shift between the clockwise and anti-clockwise travelling light waves results in a reduction in the intensity of the light at the detector. This change in intensity is very small for useful rotation rates and has required the development of special techniques.

For example, a typical FOG with an optical path length $L = 200$ m, coil diameter, $D = 70$ mm and source laser wavelength $= 1.3$ microns, when subjected to an input rate of 10°/sec will have a Sagnac phase shift of

$$8_S = \frac{2\pi \times 200 \times 70 \times 10^{-2}}{1.3 \times 10^{-6} \times 3 \times 10^{-8}} \times 10 = 2.26^\circ$$

Resolution of Earth's rate (15°/hour) requires the measurement of a phase shift of 3.38 arc seconds. Resolution of 0.01°/hour seems barely credible at first sight but is achievable as will be shown.

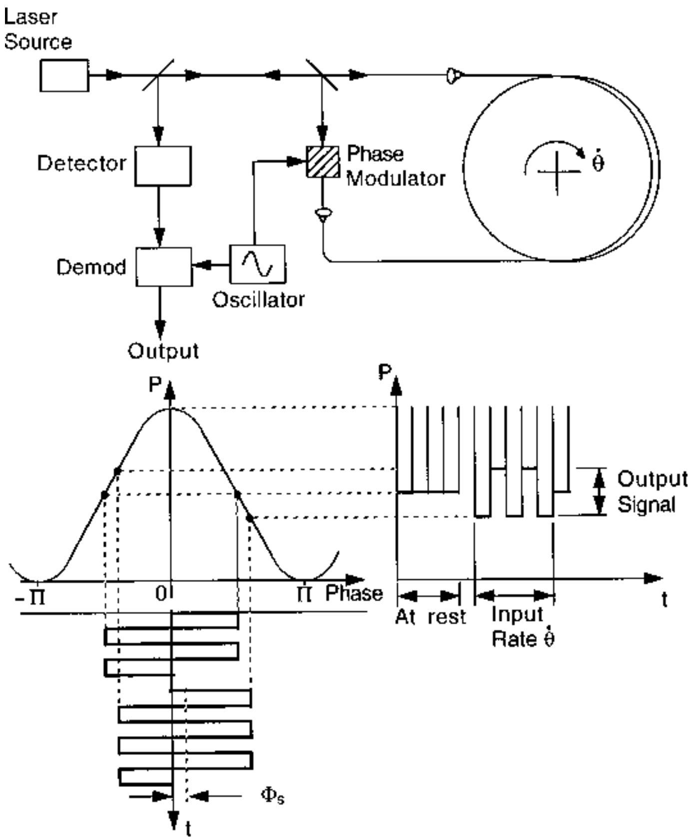


Fig 5.8. Phase modulation – open-loop IFOG.

The light intensity output signal from the photo-detector is converted to a digital value by an A to D converter followed by digital demodulation and integration. The loop is closed by driving the integrated optics phase modulator with a voltage ramp whose slope is proportional to the input rate. This ramp produces a non-reciprocal phase shift between the light waves so as to restore and maintain the sensor at the zero-rotation condition.

The advantages of the closed-loop system are:

(a) Output is independent of light source intensity variations as the system is always operated at null.
(b) Output is independent of the gains of individual components in the measurement system as long as a very high open-loop gainis maintained.
(c) Output linearity and stability depend only on the phase transducer.

The voltage ramp driving the phase modulator generates a frequency difference to null the phase difference produced by the input rate.

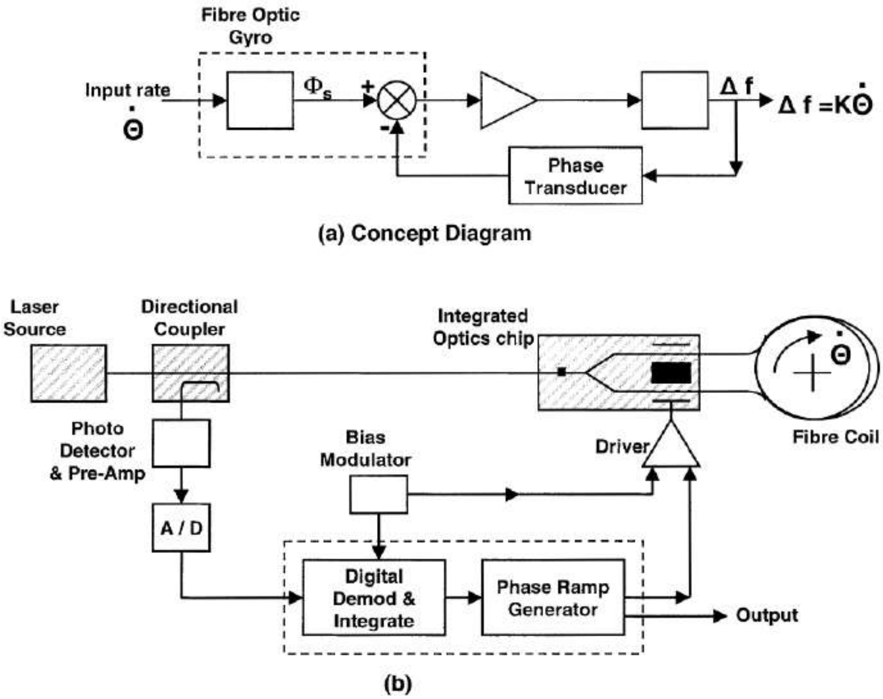


Fig 5.9 Closed-loop interferometric FOG.

Frequency difference and phase shift are directly related. The phase shift, *8*, that light experiences in propagating along a single mode optical fibre of length, *L*, and refractive index, *n*, is given by

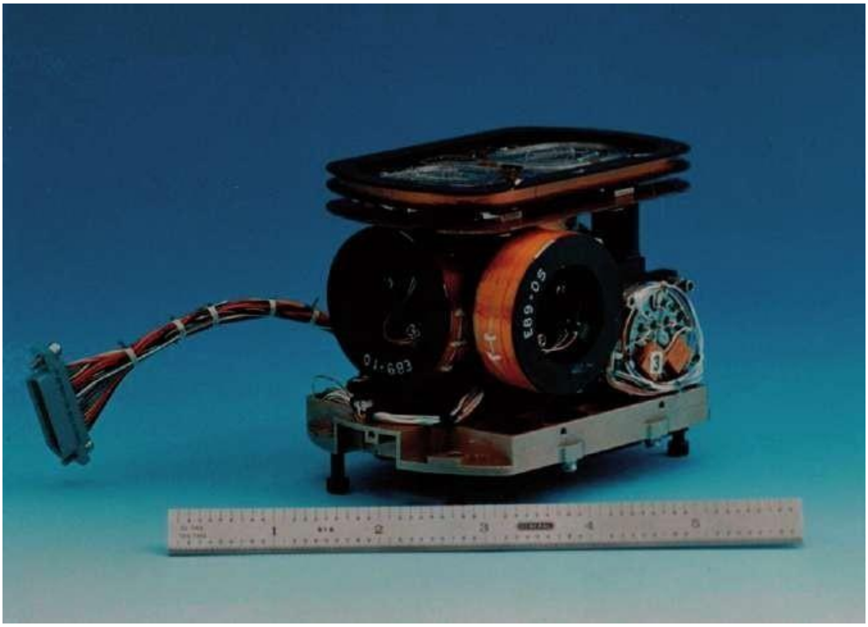


Fig 5.10. Fibre optic gyro inertial measuring unit (courtesy of Smiths Industries).

i.e.

$$Of = K_1\dot{\theta}$$

where $K_1 = D/n\lambda$.

The output characteristic is thus the same as the RLG and the IFOG behaves as an integrating rate gyro.

The scale factor stability is dependent on the stability of D, n and λ.

For the example FOG already used $D = 70$ mm, $\lambda = 1.3$ mm, $n = 1.5$. Substituting these values, one output pulse corresponds to an angular increment of 5.75 arc seconds.

Equation (5.11) can be shown to be the same as the RLG output equation by multiplying the numerator and denominator of (5.11) by $\pi D/4$, viz.

$$Of = \frac{D}{n\lambda}\frac{\pi D/4}{\pi D/4}\dot{\theta} = \frac{4A}{\lambda(n\pi D)}\dot{\theta}$$

The equivalent optical perimeter ($n\pi D$) corresponds to the RLG path length, L. The inherent simplicity of the FOG and the use of *Integrated Optic Chips* where the various electro-optical elements are integrated on to a substrate leads to low manufacturing costs and the IFOG is a highly competitive gyro in terms of cost, reliability, ruggedness and performance.

Integrated three axis versions are being produced with the three FOGs sharing the same laser diode source.

Accelerometers

Introduction – Specific Force Measurement

The acceleration of a vehicle can be determined by measuring the force required to constrain a suspended mass so that it has the same acceleration as the vehicle on which it is suspended, using Newton's law: force = mass × acceleration.

The measurement is complicated by the fundamental fact that it is impossible to distinguish between the force acting on the suspended mass due to the Earth's gravitational attraction and the force required to overcome the inertia and accelerate the mass so that it has the same acceleration as the vehicle. The vehicle acceleration, **a**, being produced by the vector sum of the external forces acting on the vehicle, namely, the propulsive thrust, **T**, lift, **L**, drag, **D**, and the gravitational force, $m\mathbf{g}$, acting on the aircraft mass, m.

(The bold print denote the quantities are vector quantities.)

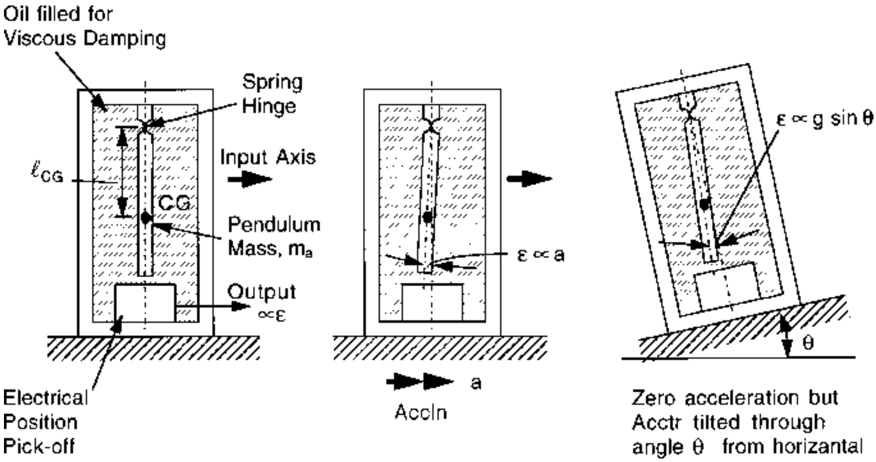


Fig 5.11. Simple spring restrained pendulous accelerometer.

$$\mathbf{T} + \mathbf{L} + \mathbf{D} + m\mathbf{g} = m\mathbf{a} \; (\;)$$

$$\mathbf{a} = \frac{\mathbf{T} + \mathbf{L} + \mathbf{D}}{m} + \mathbf{g}$$

The vector sum of the external forces excluding the gravitational force divided by the aircraft mass, that is $(\mathbf{T} + \mathbf{L} + \mathbf{D})/m$, is known as the 'specific force'. The force, $\mathbf{F_a}$, required to constrain the suspended mass, m_a, is thus given by

$$\mathbf{F_a} + m_a\mathbf{g} = m_a\mathbf{a}$$

$$\frac{\mathbf{F_a}}{m_a} + \mathbf{g} = \mathbf{a} = \frac{(\mathbf{T} + \mathbf{L} + \mathbf{D})}{m} + \mathbf{g}$$

Hence

$$\mathbf{F_a} = m_a$$

the accelerometer will thus measure the specific force component along its input axis and *not* the vehicle acceleration component.

Simple Spring Restrained Pendulous Accelerometer

A simple spring restrained pendulous accelerometer is shown schematically. This comprises an unbalanced pendulous mass which is restrained by the spring hinge so that it can only move in one direction, that is along the input axis. The spring hinge exerts a restoring torque which is proportional to the angular de- flection from the null position. When the case is accelerated the pendulum deflects from the null position until the spring torque is equal to the moment required to ac- celerate the centre of mass of the pendulum at the same acceleration as the vehicle.

The transfer function of the simple accelerometer described is a simple quadratic lag filter of the type

$$\frac{\text{Output}}{\text{Input Accln.}} = \frac{K_0}{D^2 + 2\zeta\,\omega_0 D + \omega_0{}^2}$$

K_0 is the accelerometer scale factor, and the undamped natural frequency ω_0

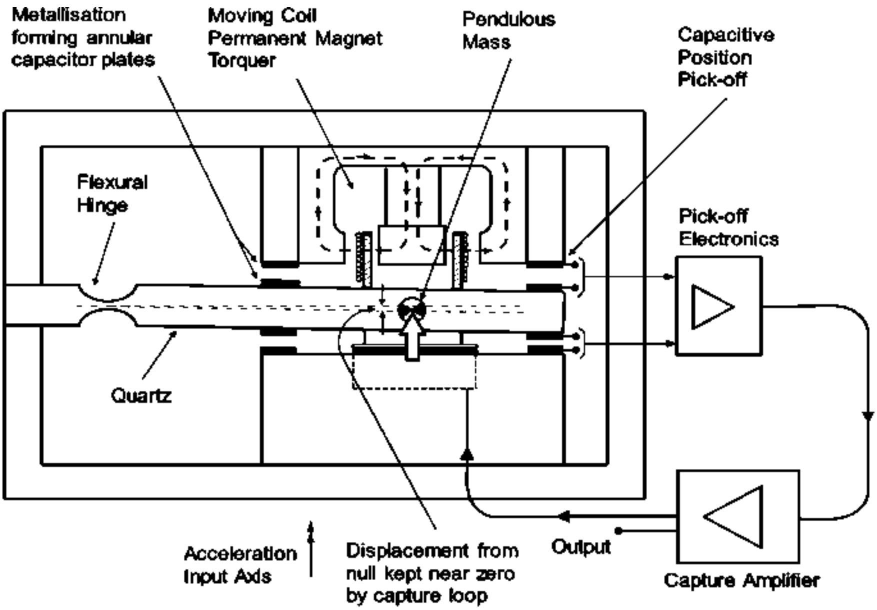


Fig 5.12. Torque balance pendulous accelerometer schematic.

(Strictly speaking, the specific force is measured.) Pulse torque operation of the capture amplifier is generally used giving a pulse rate output which is directly proportional to the input acceleration. Each pulse represents a velocity increment, for example 0.05 m/s (0.1 knots approx.), providing an inherent integration.

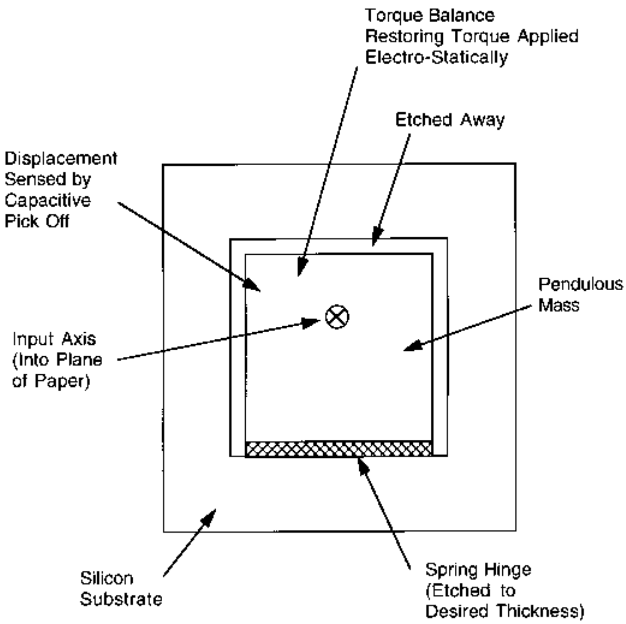


Fig 5.13. 'Solid state' dry accelerometer construction.

Accelerometers used in very severe environments with very high vibration and shock levels are generally oil filled to increase their robustness.

'Solid state' accelerometers fabricated from silicon using semi-conductor manufacturing technology are now being widely used for lower accuracy applications. The technology offers very small size and low manufacturing costs.

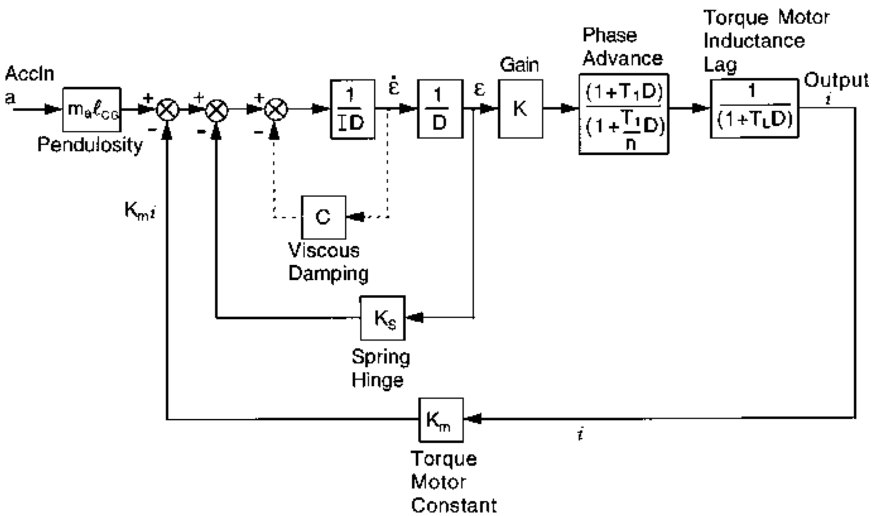


Fig 5.14. Torque balance accelerometer loop.

given by
$a = a_{max} \sin \omega t$

where a_{max} is the peak value of the vibration acceleration, a, and ω is the angular frequency.

The displacement of the pendulum from null is given by

$$\varepsilon = \frac{a_{max}}{K} \sin(\omega t + 8)$$

where K is dependent on the loop gain at frequency ω and 8 is the phase shift between ε and a.

Sensed cross-axis acceleration is $\varepsilon \cdot a_{max} \sin \omega t$

$$= \frac{a^2_{max}}{K} \sin \omega t \cdot \sin(\omega t + \varphi)$$

The product term [sin ωt . sin$(\omega t + \varphi)$] has an average value of cos $8/2$ so that a proportion of the input vibration is rectified. This error source contributes to the 'g^2 error sensitivity' of the accelerometer as it is proportional to the square of the vibration acceleration.

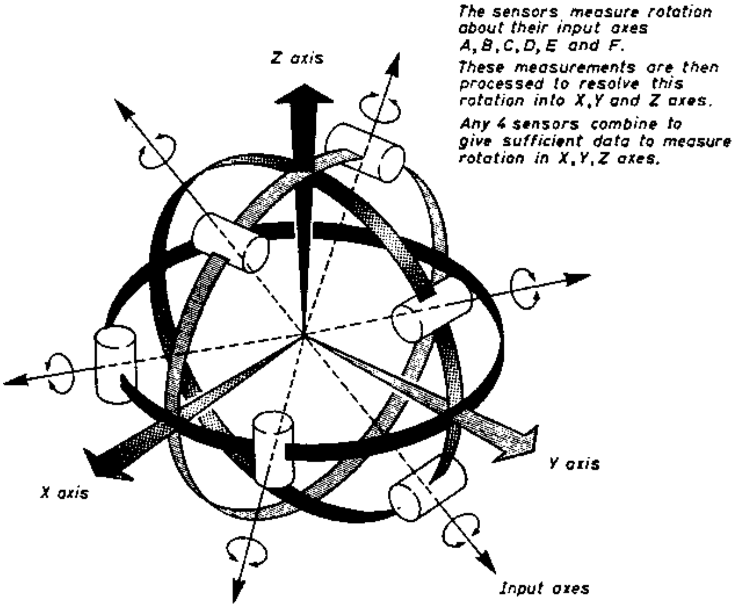


Fig 5.14. Skewed axes sensors – dodecahedron configuration.

Skewed Axes Sensor Configurations

One of the attractive features of a strap-down system is that economical failure absorption configurations are available. One such configuration is an arrangement of six single axis rate gyros and six accelerometers, with their input axes skewed with respect to the principal axes

The gyro outputs denoted by letters A to F are functions of the body rates.

$$A = p \sin \alpha + r \cos \alpha$$
$$B = -p \sin \alpha + r \cos \alpha$$
$$C = p \cos \alpha + q \sin \alpha$$

$$D = p \cos \alpha - q \sin \alpha$$
$$E = q \cos \alpha + r \sin \alpha$$
$$F = q \cos \alpha - r \sin \alpha$$

where $\alpha = 31.716747^\circ$, the angle between the gyro input axes and the body axes. There are thus six equations in three unknowns which can give two independent measures of each body rate. Sophisticated algorithms can be used to isolate a failed gyro and re-combine the data from the remaining sensors in an optimum way.

There are other configurations of skewed sensors which are also used. For example, three orthogonal sensors with their input axes aligned with the aircraft principal axes and a fourth sensor with its input axis skewed at 45° to the principal axes.

Two such independent sensor sub-assemblies can tolerate three gyro failures.

GPS – Global Positioning System

Introduction

GPS is basically a radio navigation system which derives the user's position from the radio signals transmitted from a number of orbiting satellites.

The fundamental difference between GPS and earlier radio navigation systems, such as LORAN-C (now no longer in use), is simply the geometry of propagation from ground based transmitters compared with space borne transmitters. An orbiting satellite transmitter can provide line of sight propagation over vast areas of the world. This avoids the inevitable trade-offs of less accuracy for greater range which are inherent with systems using ground based transmitters. The satellite signals also penetrate the ionosphere rather than being reflected by it so that the difficulties encountered with sky waves are avoided.

GPS provides a superior navigation capability to all previous radio navigation systems. For these reasons and also space constraints, coverage of radio navigation systems has been confined to GPS.

Satellite navigation can be said to have started with the successful launching by the Russians of the world's first orbiting satellite, SPUTNIK 1 in October 1957. The development of the first satellite navigation system TRANSIT 1, was triggered by observations made on the radio signals transmitted from SPUTNIK 1 and was initiated at the end of 1958. TRANSIT 1 resulted in a worldwide navigation system which has been in continuous operation since 1964.

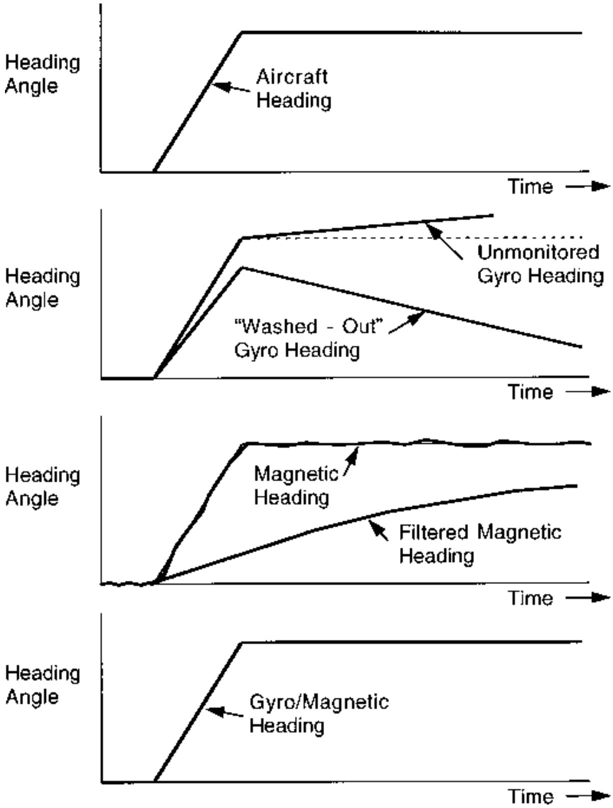


Fig 5.15. Complementary filtered gyro/magnetic heading response to constant rate of turn.

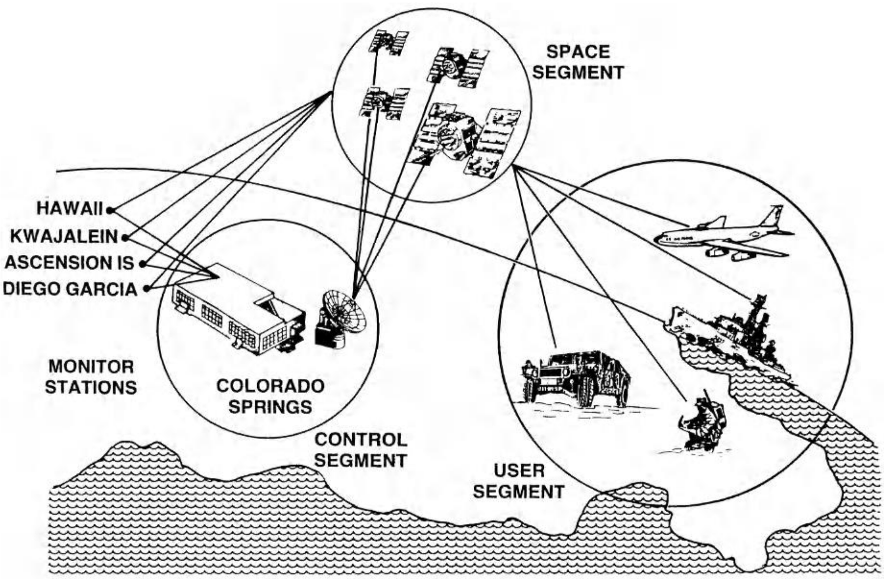


Fig 5.16. The GPS system.

A very similar satellite navigation system called GLONASS has been developed by the Russians. Although designed for military applications (like GPS), it is available but is not being used elsewhere at the present time(2010).

3.1. GPS System Description

The overall GPS system comprises three segments, namely the space segment, the control segment and the user segment and is shown schematically

Space Segment. This comprises 24 GPS satellites placed in six orbital planes at 55° to the equator in geo-synchronous orbits at 20,000 km above the Earth. The orbit tracks over the Earth, forming an ‘egg beater’ type pattern.

Twenty-one satellites are required for full worldwide coverage and three satellites act as orbiting spares.

3.1.1. Basic Principles of GPS

The basic principle of position determination using the GPS system is to measure the spherical ranges of the user from a minimum of four GPS satellites. The or- bital positions of these satellites relative to the Earth are known to extremely high accuracy and each satellite transmits its orbital position data.

Each satellite transmits a signal which is modulated with the C/A pseudo-random code in a manner which allows the time of transmissionto be recovered.

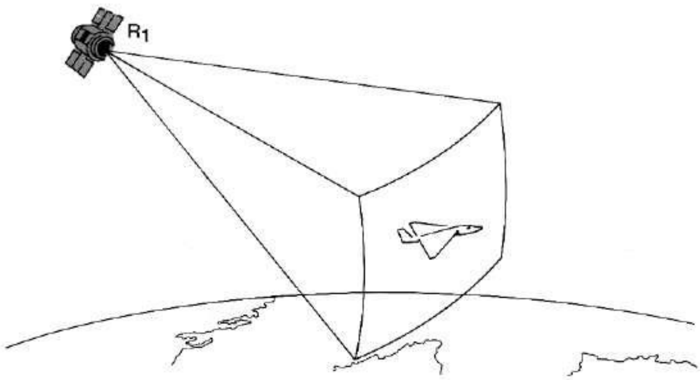


Fig 5.17. GPS spherical ranging.

The spherical range of the user from the individual transmitting satellite can be determined by measuring the time delay for the satellite transmission to reach the user.

Multiplying the time delay by the velocity of light then gives the spherical range, *R*, of the user from the transmitting satellite. The user’s position hence lies on the surface of a sphere of radius, *R*.

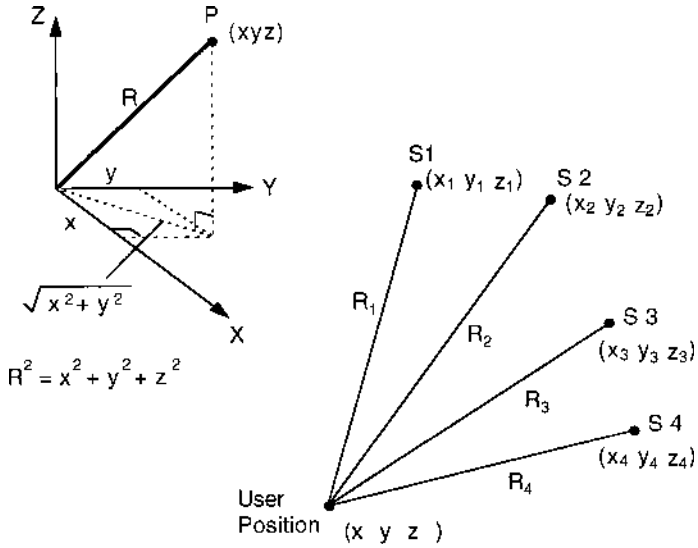


Fig 5.18. User–satellite geometry.

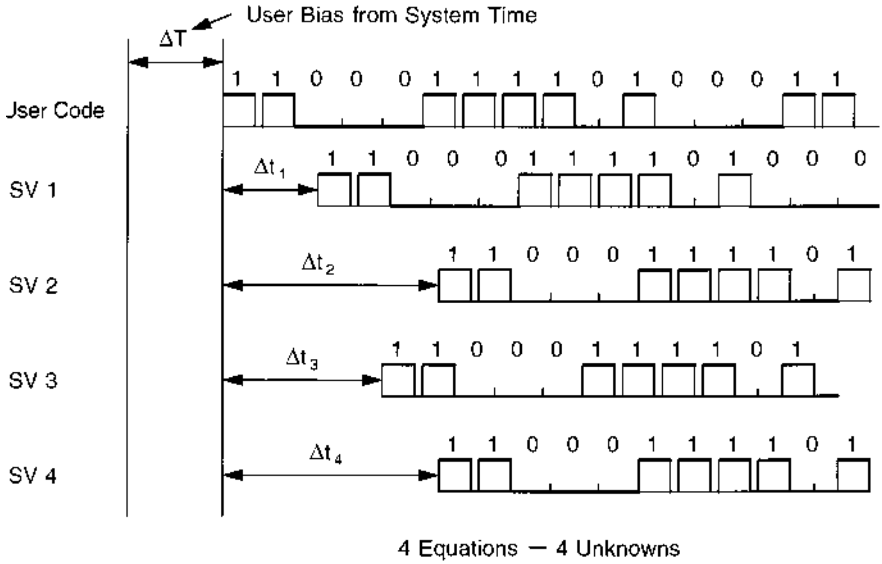


Fig 3.19. GPS satellite waveforms with perfect satellite clocks.

$$R_{1p} = cOt_1$$
$$R_{2p} = cOt_2$$
$$R_{3p} = cOt_3$$
$$R_{4p} = cOt_4$$

Let the range equivalent of the user's clock offset be T , i.e.

$$T = cOT$$

Hence, from basic 3D co-ordinate geometry

$$R_1 = [(X - X_1)^2 + (Y - Y_1)^2 + (Z - Z_1)^2]^{1/2} = R_{1p} - T$$

$$R_2 = [(X - X_2)^2 + (Y - Y_2)^2 + (Z - Z_2)^2]^{1/2} = R_{2p} - T$$

$$R_3 = [(X - X_3)^2 + (Y - Y_3)^2 + (Z - Z_3)^2]^{1/2} = R_{3p} - T$$

$$R_4 = [(X - X_4)^2 + (Y - Y_4)^2 + (Z - Z_4)^2]^{1/2} = R_{4p} - T$$

when R_1, R_2, R_3, R_4 are the actual ranges from the user's position to the four satellites S1, S2, S3, S4 and the coordinates of these satellites are $(X_1\ Y_1\ Z_1)$, $(X_2\ Y_2\ Z_2)$, $(X_3\ Y_3\ Z_3)$, $(X_4\ Y_4\ Z_4)$ respectively.

.

Each satellite time is related to GPS time by a mathematical expression and the user corrects the satellite time to the GPS time using the equation

$$t = t_{s/c} - Ot_{s/c}$$

where t is the GPS time in seconds, $t_{s/c}$ is the effective satellite time at signal transmission in seconds and $Ot_{s/c}$ is the time offset between the satellite and GPS master time.

The time offset is $Ot_{s/c}$ computed from the following equation

$$Ot_{s/c} = a_0 + a_1(t - t_{o/c}) + a_2(t - t_{o/c})2 + Ot_r$$

where a_0, a_1, and a_2 are polynomial coefficients representing the phase offset, frequency offset and ageing term of the satellite clock with respect to the GPS master time and Ot_r is the relativistic term (seconds). The parameter t is the GPS time and $t_{o/c}$ is the *epoch time* at which the polynomial coefficients are referenced and generally $t_{o/c}$ is chosen at the mid point of the fit interval. The polynomial coefficients a_0, a_1, a_2 are estimated by the control segment for each satellite clock and periodically uplinked to the satellite.

These coefficients are transmitted together with the satellite orbital position data, termed the *Ephemeris parameters*, to the navigation user equipment as navigation messages. The clock corrections for the four satellites are designated τ_1, τ_2, τ_3, and τ_4.

The spherical ranges R_1, R_2, R_3 and R_4 are thus given by

$$R_1 = c(Ot_1 + OT - \tau_1)\quad R_2 = c(Ot_2 + OT - \tau_2)\quad R_3 = c(Ot_3 + OT - \tau_3)$$

$$R_4 = c(Ot_4 + OT - \tau_4)$$

All satellite clocks are mathematically synchronised to the GPS master time by means of these clock correction terms. The error in synchronisation will grow, however, if the polynomial coefficients a_0, a_1 and a_2 are not updated periodically.

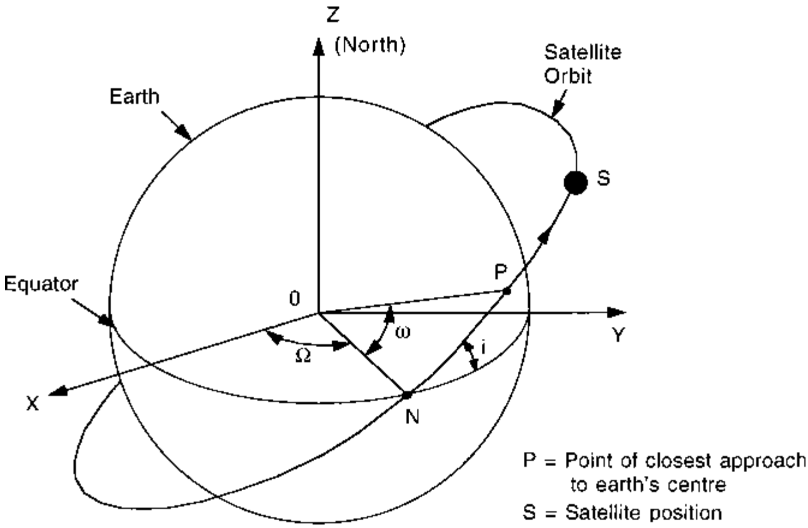


Fig 5.20. Satellite-Earth geometry. Ephemeris parameter definition.

The navigation equations are basically non-linear as can be seen in equations (6.56), (6.57), (6.58) and (6.59), but can be linearised about nominal values for their solution by applying Taylor's series approximations.

3.1.2. Integration of GPS and INS

GPS and INS are wholly complementary and their information can be combined to the mutual benefit of both systems. For example:

- Calibration and correction of INS errors – the GPS enables very accurate calibration and correction of the INS errors in flight by means of a Kalman filter.
- The INS can smooth out the step change in the GPS position output which can occur when switching to another satellite because of the change in inherent errors.
- Jamming resistance – like any radio system, GPS can be jammed, albeit over a local area, although it can be given a high degree of resistance to jamming. The INS, having had its errors previously corrected by the Kalman filter, is able to provide accurate navigation information when the aircraft is flying over areas subjected to severe jamming.
- Antenna obscuration – GPS is a line of sight system and it is possible for the GPS antenna to be obstructed by the terrain or aircraft structure during manoeuvres.
- Antenna location corrections – the GPS derived position is valid at the antenna and needs to be corrected for reference to the INS location. The INS provides attitude information which together with the lever arm constants enables this correction to be made.

3.2. Differential GPS

3.2.1. Introduction

As explained in the preceding section the horizontal position accuracy available to all GPS users (civil and military) is now 16 m. This was not the case, however, until 2000 when the restriction of 'Selective Availability' wasremoved.

Concerns about potential enemies using GPS to deliver missiles and other weapons against the US had led to a policy of accuracy denial, generally known as Selective Availability. The GPS ground stations deliberately introduced satellite timing errors to reduce the positioning accuracy available to civil users to a horizontal positioning accuracy of 100 m to a 95% probability level.

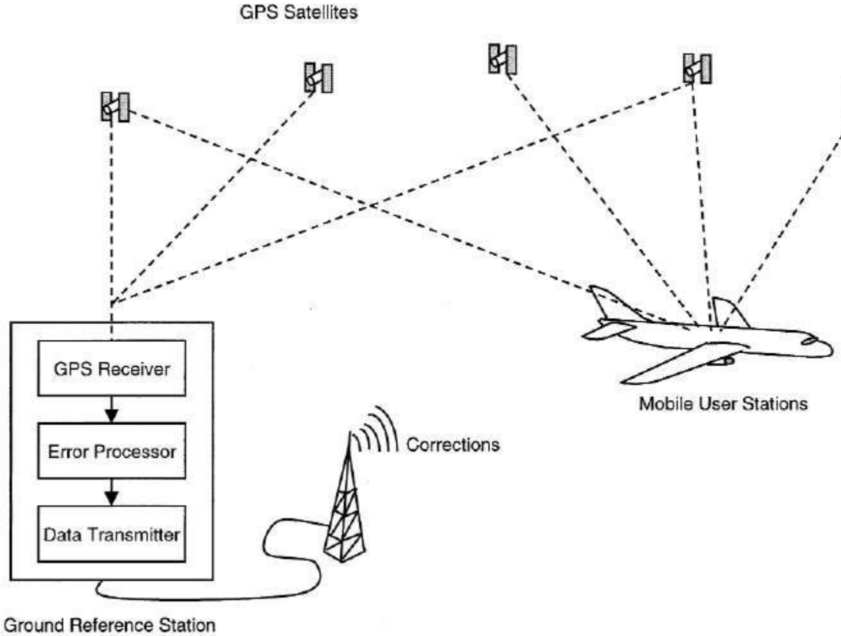


Fig 5.21. The differential GPS concept.

DGPS can be defined as:

The positioning of a mobile station in real-time by corrected (and possibly Doppler or phase smoothed) GPS pseudo ranges.

The corrections are determ- ined at a static 'reference station' and transmitted to the mobile station. A monitor station may be part of the system, as a quality check on the reference station transmissions.

The success of DGPS can be seen from its application to new markets such as locating land vehicles used by the emergency services. Successful trials for automatic landings and taxi-way guidance have also been conducted.

It is now widely used in land and hydrographic surveying applications.

3.2.2. Basic Principles

The basic principle underlying DGPS is the fact that the errors experienced by two receivers simultaneously tracking a satellite at two locations fairly close to each other will largely be common to both receivers.

The basic differential GPS concept is illustrated. The position of the stationary GPS Reference Station is known to very high accuracy so that the satellite ranges can be very accurately determined, knowing the satellite ephemeris data.

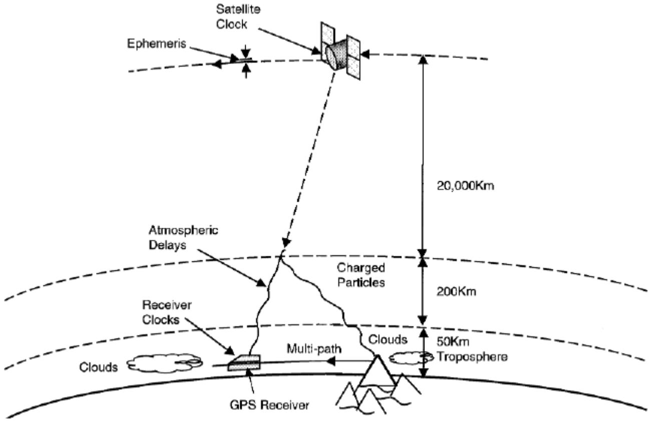


Fig 5.22. GPS error sources.

The errors in the pseudo-range measurements can then be derived and the required corrections computed and transmitted to the user's receiver over a radio link. The errors present in a GPS system are illustrated

GPS satellite clocks. GPS satellites are equipped with very accurate atomic clocks and corrections are made via the Ground Stations, as explained in the preceding section.

Summary of GPS error sources.

Typical error budget (in metres)

Per satellite accuracy	Standard GPS	Differential GPS
Satellite clocks	1.5	0
Orbit errors	2.5	0
Ionosphere	5.0	0.4
Troposphere	0.5	0.2
Selective availability*	30.0	0
Receiver noise	0.3	0.3
Multi-path (reflections)	0.6	0.6
Typical positioning accuracy		
Horizontal	50.0	1.3
Vertical	78.0	2.0
3D	93.0	2.8

*Note: Selective Availability error is shown to demonstrate the effectiveness of the DGPS technique, although the Selective Availability restriction has now been removed.

A predicted correction factor for the Earth's atmosphere path is made in the receiver but this is based on a statistical model and there are inevitable residual errors present.

Multi-path errors. The GPS satellite signal is received by the direct line of sight (LOS) path, but the signal may also be received as the result of reflections off local obstructions.

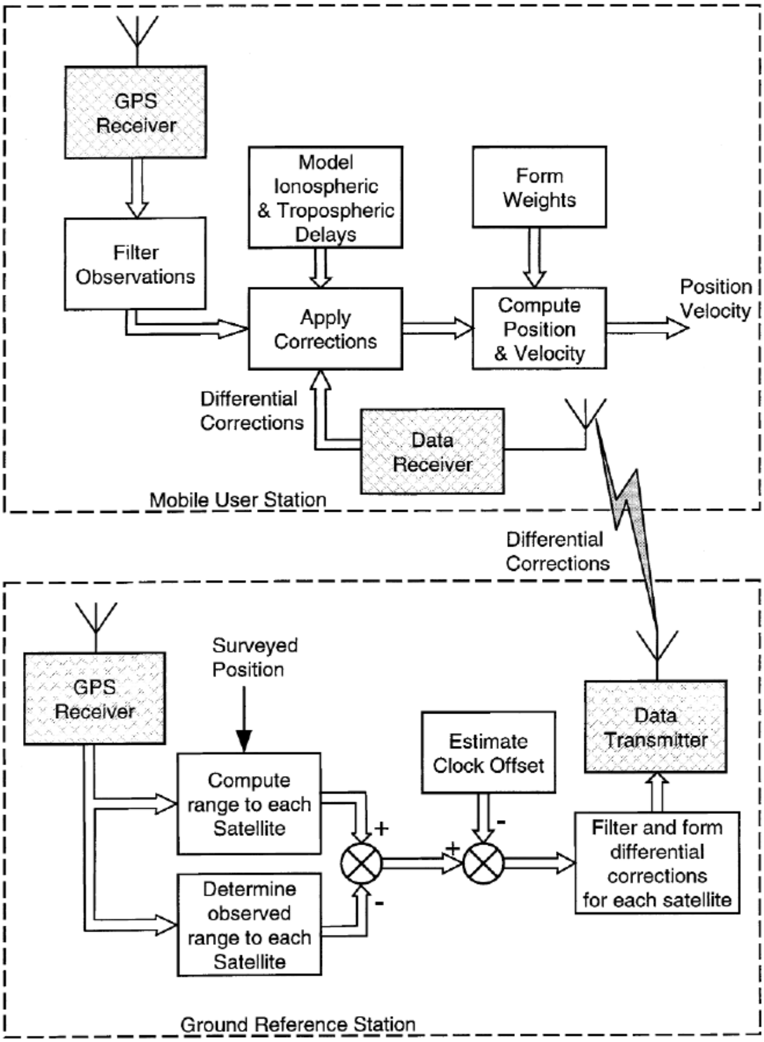


Fig 5.23. Simplified functional diagram of a generic differential GPS system.

The satellite pseudo-range measurement in the user's GPS receiver is carried out by the correlation of the received satellite signal with the receiver generated replica of the known satellite C/A code using a code tracking loop. The accuracy of the time measurement by the C/A code tracking loop is inevitably ultimately limited by noise sources such as multi-path reception.

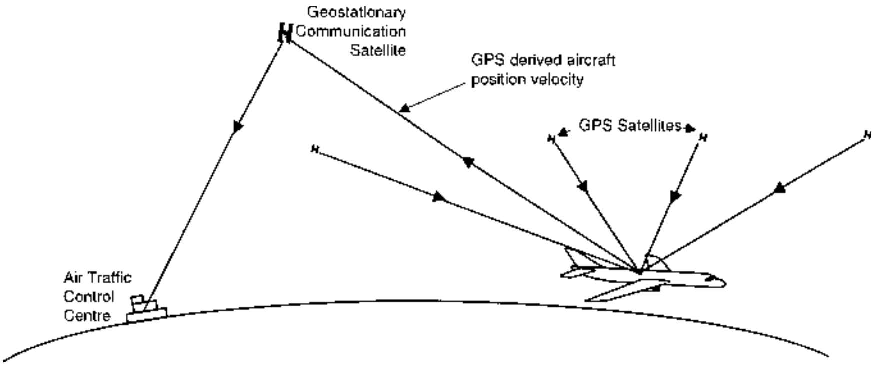


Fig 5.24. Remote air traffic control.

GPS receivers also employ carrier tracking loops to monitor the Doppler shifted carrier component of the satellite navigation signals. The Doppler shift is proportional to the radial velocity of the receiver relative to the satellite. The velocity of the user vehicle is computed from these Doppler shifts.

The Ground Reference GPS Station in the DGPS system uses these Doppler frequency shift measurements to improve the accuracy of the pseudo-range measurements. Integrating the Doppler shift over an interval provides a measurement of the change in satellite-to-receiver range.

Future Augmented Satellite Navigation Systems

The advent of satellite navigation systems and satellite communication links has provided new capabilities for aircraft precision navigation, particularly in civil operations.

Providing the integrity and accuracy requirements can be met, satellite navigation systems are able to support all phases of flight including all-weather precision approaches to airports not equipped with ILS (or MLS) installations.

Successful concept proving trials were, in fact, conducted by the UK Air Traffic Control authorities in conjunction with British Airways around 1996. The trials used the on-board GPS receivers and SAT COM radios in a British Airways Boeing 747 airliner to monitor the aircraft flight paths on normal commercial flights to the West Indies.

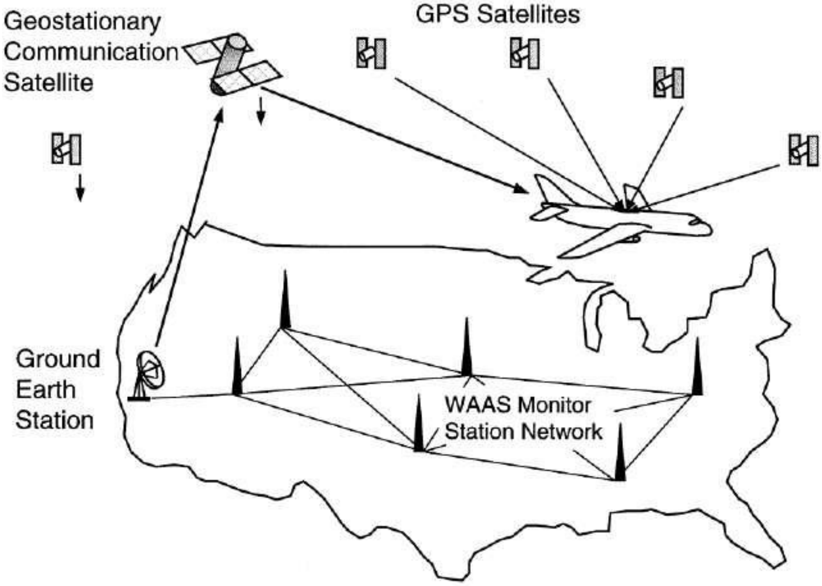


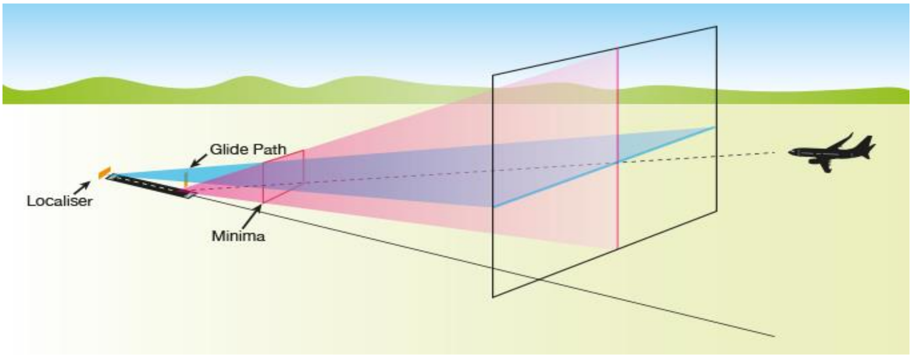
Fig 5.25. Wide area augmentation system, WAAS, concept.

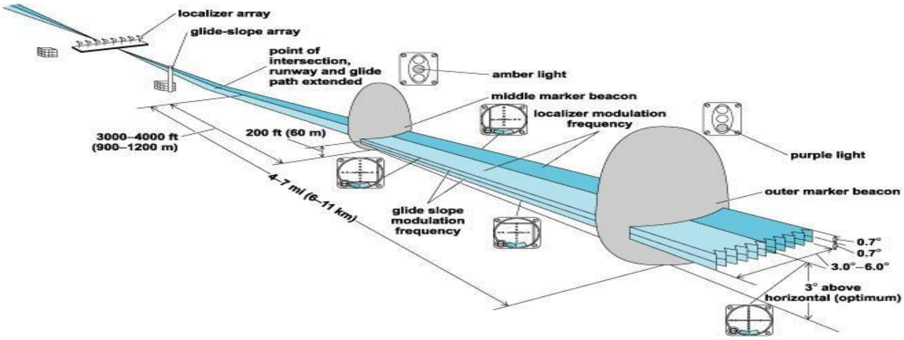
Extensive trials of a WAAS evaluation system have been conducted by the FAA over the last decade, with very promising results. It appears very likely that the full system will be

INSTRUMENT LANDING SYSTEM

- An ILS is a highly accurate radio signal navigation aid used by pilots landing at an airport when there is poor weather and/or low visibility. It consists of two antennas which transmit signals to receivers in the aircraft cockpit—a glide path tower located next to the runway at the northern end and a localiser antenna at the southern end. These antennas provide the pilot with vertical and horizontal guidance when landing in low visibility.

- An ILS may be used outside these conditions as a preferred approach particularly for international operators. It may also be used by some aircraft at night and there will be occasions where aircraft and airlines require the ILS approach for licensing and training requirements.





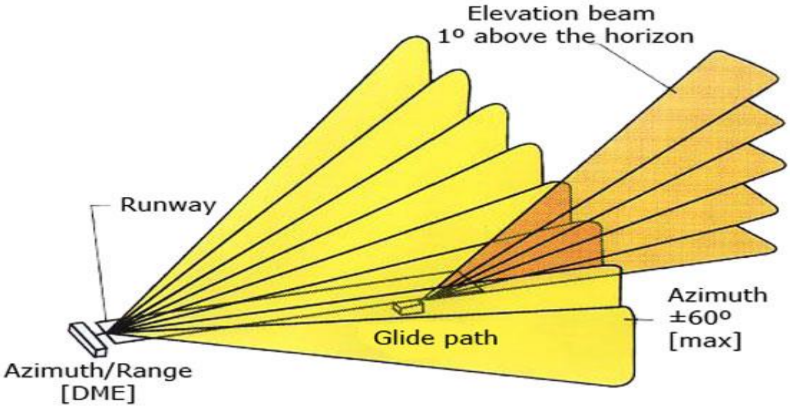
The ILS system is nowadays the primary system for instrumental approach for category I.-III-A conditions of operation minimums and it provides the horizontal as well as the vertical guidance necessary for an accurate landing approach in IFR (Instrument Flight Rules) conditions, thus in conditions of limited or reduced visibility.The accurate landing approach is a procedure of permitted descent with the use of navigational equipment coaxial with the trajectory and given information about the angle of descent.

The equipment that provides a pilot instant information about the distance to the point of reach is not a part of the ILS system and therefore is for the discontinuous indication used a set of two or three marker beacons directly integrated into the system. The system of marker beacons can however be complemented for a continuous measurement of distances with the DME system (Distance measuring equipment), while the ground part of this UKV distance meter is located co-operatively with the descent beacon that forms the glide slope. It can also be supplemented with a VOR system by which means the integrated navigational-landing complex ILS/VOR/DME is formed.

MICROWAVE LANDING SYSTEM

The MLS is a system of precission approach for landing by instruments and constitutes a kind of an alternative to the ILS system. It provides information about the azimuth, optimal angle of descent and the distance, as well as data about the reverse course in case of an unsuccessful approach. It has several advantages compared to the ILS, for example a greater number of possible executed approaches, a more compact ground equipment, and a potential to use more complicated approach trajectories.

However for certain reasons, in particular the advancement of the GPS satelite navigation, was the installation of new devices halted and finally in 1994 completely canceled by the FAA organization. On european airports we can rather seldom come across an MLS.



The MLS provides an accurate landing approach for an aircraft in the area of the final approach, where the path of the final approach isn't identical with the enlonged runway's axis. The system works with a microwave beam that is transmitted towards the sector of approach and scans the sector both in the horizontal as well as the verical plane. An aircraft in the approach sector receives the signal and with the help of this beam evaluates it's location in space. The aircraft's position is therefore determined both in the horizontal direction of approach and the vertical plane, in whatever point of reach of the scanning beam. Because the microwave technology is radiated into the space of approach in a given time and it's not spread out over different directions, no signal interruption results from various obstacles or terrain protrusions as it was with the ILS system. The MLS system can thus be situated also in developed areas, where an ILS system couldn't be set up. An onboard computer enables to solve the approach manoeuvre from a random direction, for variously oriented runways, even along a curved of bend landing trajectory. The MLS system is approved by the ICAO for every three categories of an accurate landing approach.

The MLS system is comprised of ground pieces of equipment that are divided into the protractor components, rangefinder components, and the onboard hardware. The information about the angles of the approach course, descent, flare and the course of an unsuccessful approach are aquired through an onboard antenna or the aircraft itself by measuring the time between two passages of an oscillating lobe of a high frequency signal . The distance is determined with the help of an ancillary device, the DME rangefinder. The MLS system further sends with the help of phase modulation and time-division multiplexing additional data, as identification, system status and so on. The ground equipment consists in the basic configuration of an Azimuth Transmitter (AZ) with an added DME rangefinder, perhaps even a more precise DME/P, in close distance of a course transmitter and near an elevation transmitter, see Fig. 1. A scaled up configuration is supplemented with a course transmitter for an unsuccessful approach and a flare transmitter.round Distance Measuring Equipment (DME).The rangefinder unit presents a DME which is positioned together with the course transmitter. In connection with requirements of accuracy of the MLS system arose a demand to refine the DME system, which was accomplished with the accurate DME/P rangefinder (along with the DME/W and DME/N). Hence the function of the DME is to provide a pilot information about the distance from a specific point which is essential for pinpoint calculation of the plane’s position in the three-dimensional space.Ground protractor components. The ground principle of both protractor parts of the MLS system for horizontal and vertical homing of an aircraft is to create levelled emiting diagrams, oscillating at a constant speed in directions „TO‘‘ and „FROM“, and to measure the elapsed time between two passages of an oscillating plane lobe through an onboard MLS antenna.

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UNIT IV

COMMUNICATIONS AND NAVIGATION AIDS

TRAFFIC COLLISION AVOIDANCE SYSTEM OR TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM

A traffic collision avoidance system or traffic alert and collision avoidance system (both abbreviated as TCAS, and pronounced tee-kas) is an aircraft collision avoidance system designed to reduce the incidence of mid-air collisions between aircraft. It monitors the airspace around an aircraft for other aircraft equipped with a corresponding active transponder, independent of air traffic control, and warns pilots of the presence of other transponder-equipped aircraft which may present a threat of mid-air collision(MAC). It is a type of airborne collision avoidance system mandated by the International Civil Aviation Organization to be fitted to all aircraft with a maximum take-off mass (MTOM) of over 5,700 kg (12,600 lb) or authorized to carry more than 19 passengers. CFR 14, Ch I, part 135 requires that TCAS I is installed for aircraft with 10-30 passengers and TCAS II for aircraft with more than 30 passengers.

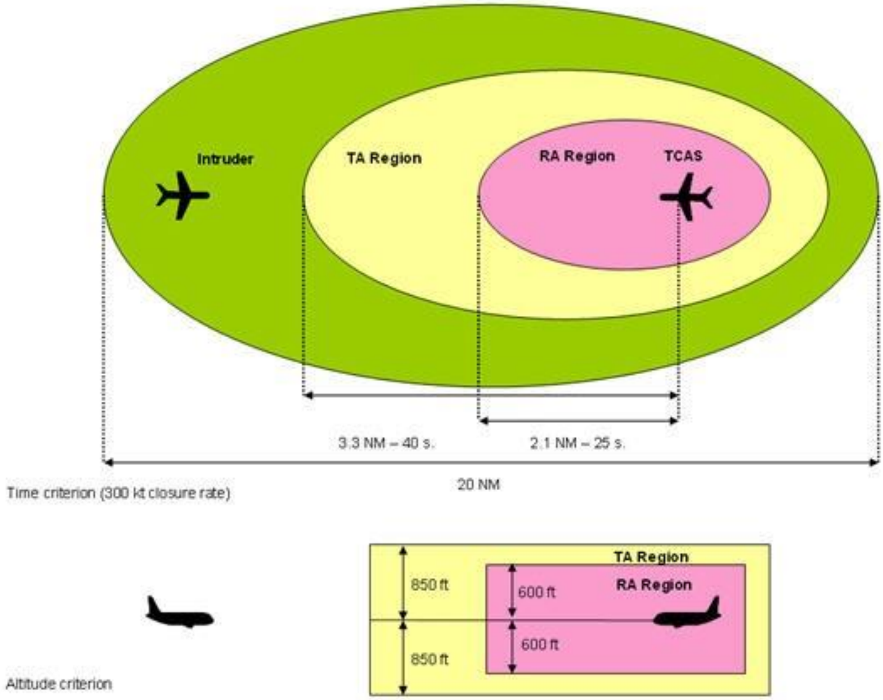
ACAS / TCAS is based on secondary surveillance radar (SSR) transponder signals, but operates independently of ground-based equipment to provide advice to the pilot on potential conflicting aircraft.

In modern glass cockpit aircraft, the TCAS display may be integrated in the Navigation Display (ND) or Electronic Horizontal Situation Indicator (EHSI); in older glass cockpit aircraft and those with mechanical instrumentation, such an integrated TCAS display may replace the mechanical Vertical Speed Indicator (which indicates the rate with which the aircraft is descending or climbing).

System description

TCAS involves communication between all aircraft equipped with an appropriate transponder (provided the transponder is enabled and set up properly). Each TCAS-equipped aircraft interrogates all other aircraft in a determined range about their position (via the 1.03 GHz radio frequency), and all other aircraft reply to other interrogations (via 1.09 GHz). This interrogation-and-response cycle may occur several times per second.

The TCAS system builds a three dimensional map of aircraft in the airspace, incorporating their range (garnered from the interrogation and response round trip time), altitude (as reported by the interrogated aircraft), and bearing (by the directional antenna from the response). Then, by extrapolating current range and altitude difference to anticipated future values, it determines if a potential collision threat exists.



Example of ACAS Protection Volume between 5000 and 10000 feet

TCAS and its variants are only able to interact with aircraft that have a correctly operating mode C or mode S transponder. A unique 24-bit identifier is assigned to each aircraft that has a mode S transponder.

The next step beyond identifying potential collisions is automatically negotiating a mutual avoidance manoeuver (currently, manoeuvers are restricted to changes in altitude and modification of climb/sink rates) between the two (or more) conflicting aircraft. These avoidance manoeuvers are communicated to the flight crew by a cockpit display and by synthesized voice instructions.

A protected volume of airspace surrounds each TCAS equipped aircraft. The size of the protected volume depends on the altitude, speed, and heading of the aircraft involved in the encounter. The illustration below gives an example of a typical TCAS protection volume.

System components

A TCAS installation consists of the following components:

TCAS computer unit

Performs airspace surveillance, intruder tracking, its own aircraft altitude tracking, threat detection, resolution advisory (RA) manoeuvre determination and selection, and generation of advisories. The TCAS Processor uses pressure altitude, radar altitude, and discrete aircraft status inputs from its own aircraft to control the collision avoidance logic parameters that determine the protection volume around the TCAS aircraft.

Antennas

The antennas used by TCAS II include a directional antenna that is mounted on the top of the aircraft and either an omnidirectional or a directional antenna mounted on the bottom of the aircraft. Most installations use the optional directional antenna on the bottom of the aircraft. In addition to the two TCAS antennas, two antennas are also required for the Mode S transponder. One antenna is mounted on the top of the aircraft while the other is mounted on the bottom. These antennas enable the Mode S transponder to receive interrogations at 1030 MHz and reply to the received interrogations at 1090 MHz.

Cockpit presentation

The TCAS interface with the pilots is provided by two displays: the traffic display and the RA display. These two displays can be implemented in a number of ways, including displays that incorporate both displays into a single, physical unit. Regardless of the implementation, the information displayed is identical. The standards for both the traffic display and the RA display are defined in DO-185A.

Operation modes

TCAS II can be currently operated in the following modes:

Stand-by

Power is applied to the TCAS Processor and the mode S transponder, but TCAS does not issue any interrogations and the transponder will reply to only discrete interrogations.

Transponder

The mode S transponder is fully operational and will reply to all appropriate ground and TCAS interrogations. TCAS remains in stand-by.

Traffic advisories only

The mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. However, TCAS will only issue traffic advisories (TA), and the resolution advisories (RA) will be inhibited.

Automatic (traffic/resolution advisories)

The mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. TCAS will issue traffic advisories (TA) and resolution advisories (RA), when appropriate.

TCAS works in a coordinated manner, so when an RA is issued to conflicting aircraft, a required action (i.e., Climb. Climb.) has to be immediately performed by one of the aircraft, while the other one receives a similar RA in the opposite direction (i.e., Descend. Descend.).

Alert

TCAS II issues the following types of aural annunciations:

- Traffic advisory (TA)
- Resolution advisory (RA)
- Clear of conflict

When a TA is issued, pilots are instructed to initiate a visual search for the traffic causing the TA. If the traffic is visually acquired, pilots are instructed to maintain visual separation from the traffic. Training programs also indicate that no horizontal maneuvers are to be made based solely on information shown on the traffic display. Slight adjustments in vertical speed while climbing or descending, or slight adjustments in airspeed while still complying with the ATC clearance are acceptable.

When an RA is issued, pilots are expected to respond immediately to the RA unless doing so would jeopardize the safe operation of the flight. This means that aircraft will at times have to manoeuver contrary to ATC instructions or disregard ATC instructions. In these cases, the controller is no longer responsible for separation of the aircraft involved in the RA until the conflict is terminated.

On the other hand, ATC can potentially interfere with a pilot's response to RAs. If a conflicting ATC instruction coincides with an RA, a pilot may assume that ATC is fully aware of the situation and is providing the better resolution. But in reality, ATC is not aware of the RA until the RA is reported by the pilot. Once the RA is reported by the pilot, ATC is required not to attempt to modify the flight path of the aircraft involved in the encounter. Hence, the pilot is expected to "follow the RA" but in practice this does not always happen.

Some countries have implemented "RA downlink" which provides air traffic controllers with information about RAs posted in the cockpit. Currently, there are no ICAO provisions concerning the use of RA downlink by air traffic controllers.

The following points receive emphasis during pilot training:

- Do not manoeuver in a direction opposite to that indicated by the RA because this may result in a collision.
- Inform the controller of the RA as soon as permitted by flight crew workload after responding to the RA. There is no requirement to make this notification prior to initiating the RA response.
- Be alert for the removal of RAs or the weakening of RAs so that deviations from a cleared altitude are minimized.
- If possible, comply with the controller's clearance, e.g. turn to intercept an airway or localizer, at the same time as responding to an RA.
- When the RA event is completed, promptly return to the previous ATC clearance or instruction or comply with a revised ATC clearance or instruction.

ELECTRONIC WARFARE

Electronic warfare (**EW**) is any action involving the use of the electromagnetic spectrum or directed energy to control the spectrum, attack of an enemy, or impede enemy assaults via the spectrum. The purpose of electronic warfare is to deny the opponent the advantage of, and ensure friendly unimpeded access to, the EM spectrum. EW can be applied from air, sea, land, and space by manned and unmanned systems, and can target humans, communications, radar, or other assets.

Electronic attack (EA)

Electronic attack (EA) (previously known as Electronic Counter Measures (ECM)) involves the use of EM energy, directed energy, or anti-radiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability. In the case of EM energy, this action is referred to as jamming and can be performed on communications systems (see Radio jamming) or radar systems (see Radar jamming and deception).

Electronic Protection (EP)

Electronic Protection (EP) (previously known as electronic protective measures (EPM) or electronic counter countermeasures (ECCM)) involves actions taken to protect personnel, facilities, and equipment from any effects of friendly or enemy use of the electromagnetic spectrum that degrade, neutralize, or destroy friendly combat capability. Jamming is not part of EP, it is an EA measure.

The use of flare rejection logic on an Infrared homing missile to counter an adversary's use of flares is EP. While defensive EA actions and EP both protect personnel, facilities, capabilities, and equipment, EP protects from the effects of EA (friendly and/or adversary). Other examples of EP include spread spectrum technologies, use of Joint Restricted Frequency List (JRFL), emissions control (EMCON), and low observability or "stealth".

An Electronic Warfare Self Protection (EWSP) is a suite of countermeasure systems fitted primarily to aircraft for the purpose of protecting the aircraft from weapons fire and can include among others: DIRCM (protects against IR missiles), Infrared countermeasures (protects against IR missiles), Chaff (protects against RADAR guided missiles), DRFM Decoys (Protects against Radar guided missiles), Flare(protects against IR missiles).

An Electronic Warfare Tactics Range (EWTR) is a practice range which provides for the training of aircrew in electronic warfare. There are two such ranges in Europe; one at RAF Spadeadam in the United Kingdom and the POLYGON range in Germany and France. EWTRs are equipped with ground-based equipment to simulate electronic warfare threats that aircrew might encounter on missions.

Antifragile EW is a step beyond standard EP, occurring when a communications link being jammed actually increases in capability as a result of a jamming attack, although this is only possible under certain circumstances such as reactive forms of jamming.

Electronic warfare support (ES)

Electronic Warfare Support (ES), is the subdivision of EW involving actions tasked by, or under direct control of, an operational commander to search for, intercept, identify, and locate or localize sources of intentional and unintentional radiated electromagnetic (EM) energy for the purpose of immediate threat recognition, targeting, planning, and conduct of future operations.[1] These measures begin with systems designed and operators trained to make Electronic Intercepts (ELINT) and then classification and analysis broadly known as Signals intelligence from such detection to return information and perhaps actionable intelligence (e.g. a ship's identification from unique characteristics of a specific radar) to the commander.

The overlapping discipline, signals intelligence (SIGINT) is the related process of analyzing and identifying the intercepted frequencies (e.g. as a mobile phone or radar). SIGINT is broken into three categories: ELINT, COMINT, and FISINT. the parameters of intercepted txn are-: communication equipment-: freq, bandwidth, modulation, polarisation etc. The distinction between intelligence and electronic warfare support (ES) is determined by who tasks or controls the collection assets, what they are tasked to provide, and for what purpose they are tasked. Electronic warfare support is achieved by assets tasked or controlled by an operational commander. The purpose of ES tasking is immediate threat recognition, targeting, planning and conduct of future operations, and other tactical actions such as threat avoidance and homing. However, the same assets and resources that are tasked with ES can simultaneously collect intelligence that meets other collection requirements.[1]

Where these activities are under the control of an operational commander and being applied for the purpose of situational awareness, threat recognition, or EM targeting, they also serve the purpose of Electronic Warfare surveillance (ES).

Multifunctional EW system

In February 2015 the Russian army received their first set of the multifunctional electronic warfare system, known as Borisoglebsk 2. After some months of testing, it has been used in Ukraine. Svenska Dagbladet claimed its initial usage caused concern within NATO.

A Russian blog describes Borisoglebsk 2 as "The 'Borisoglebsk-2' when compared to its predecessors has better technical characteristics: wider frequency bandwidth for conducting radar collection and jamming, faster scanning times of the frequency spectrum, and higher precision when identifying the location and source of radar emissions, and increased capacity for suppression."

AIR TRAFFIC CONTROL

Air traffic control (ATC) is a service provided by ground-based controllers who direct aircraft on the ground and through controlledairspace, and can provide advisory services to aircraft in non-controlled airspace. The primary purpose of ATC worldwide is to prevent collisions, organize and expedite the flow of air traffic, and provide information and other support for pilots. In some countries, ATC plays a security or defensive role, or is operated by the military.

To prevent collisions, ATC enforces traffic separation rules, which ensure each aircraft maintains a minimum amount of empty space around it at all times. Many aircraft also have collision avoidance systems, which provide additional safety by warning pilots when other aircraft get too close.

In many countries, ATC provides services to all private, military, and commercial aircraft operating within its airspace. Depending on the type of flight and the class of airspace, ATC may issue instructions that pilots are required to obey, or advisories (known as flight information in some countries) that pilots may, at their discretion, disregard. The pilot in command is the final authority for the safe operation of the aircraft and may, in an emergency, deviate from ATC instructions to the extent required to maintain safe operation of their aircraft.

Ground control

Ground Control (sometimes known as Ground Movement Control) is responsible for the airport "movement" areas, as well as areas not released to the airlines or other users. This generally includes all taxiways, inactive runways, holding areas, and some transitional aprons or intersections where aircraft arrive, having vacated the runway or departure gate. Exact areas and control responsibilities are clearly defined in local documents and agreements at each airport. Any aircraft, vehicle, or person walking or working in these areas is required to have clearance from Ground Control. This is normally done via VHF/UHF radio, but there may be special cases where other procedures are used. Aircraft or vehicles without radios must respond to ATC instructions via aviation light signals or else be led by vehicles with radios. People working on the airport surface normally have a communications link through which they can communicate with Ground Control, commonly either by handheld radio or even cell phone. Ground Control is vital to the smooth operation of the airport, because this position impacts the sequencing of departure aircraft, affecting the safety and efficiency of the airport's operation.

Some busier airports have Surface Movement Radar (SMR), such as, ASDE-3, AMASS or ASDE-X, designed to display aircraft and vehicles on the ground. These are used by Ground Control as an additional tool to control ground traffic, particularly at night or in poor visibility. There are a wide range of capabilities on these systems as they are being modernized. Older systems will display a map of the airport and the target. Newer systems include the capability to display higher quality mapping, radar target, data blocks, and safety alerts, and to interface with other systems such as digital flight strips.

Local control or air control

Local Control (known to pilots as "Tower" or "Tower Control") is responsible for the active runway surfaces. Local Control clears aircraft for takeoff or landing, ensuring that prescribed runway separation will exist at all times. If Local Control detects any unsafe condition, a landing aircraft may be told to "go-around" and be re-sequenced into the landing pattern by the approach or terminal area controller.

Within the tower, a highly disciplined communications process between Local Control and Ground Control is an absolute necessity. Ground Control must request and gain approval from Local Control to cross any active runway with any aircraft or vehicle. Likewise, Local Control must ensure that Ground Control is aware of any operations that will impact the taxiways, and work with the approach radar controllers to create "holes" or "gaps" in the arrival traffic to allow taxiing traffic to cross runways and to allow departing aircraft to take off. Crew Resource Management (CRM) procedures are often used to ensure this communication process is efficient and clear, although this is not as prevalent as CRM for pilots.

Flight data and clearance delivery

Clearance Delivery is the position that issues route clearances to aircraft, typically before they commence taxiing. These contain details of the route that the aircraft is expected to fly after departure. Clearance Delivery or, at busy airports, the Traffic Management Coordinator (TMC) will, if necessary, coordinate with the en route center and national command center or flow control to obtain releases for aircraft. Often, however, such releases are given automatically or are controlled by local agreements allowing "free-flow" departures. When weather or extremely high demand for a certain airport or airspace becomes a factor, there may be ground "stops" (or "slot delays") or re-routes may be necessary to ensure the system does not get overloaded. The primary responsibility of Clearance Delivery is to ensure that the aircraft have the proper route and slot time. This information is also coordinated with the en route center and Ground Control in order to ensure that the aircraft reaches the runway in time to meet the slot time provided by the command center. At some airports, Clearance Delivery also plans aircraft push-backs and engine starts, in which case it is known as the Ground Movement Planner (GMP): this position is particularly important at heavily congested airports to prevent taxiway and apron gridlock.

Flight Data (which is routinely combined with Clearance Delivery) is the position that is responsible for ensuring that both controllers and pilots have the most current information: pertinent weather changes, outages, airport ground delays/ground stops, runway closures, etc. Flight Data may inform the pilots using a recorded continuous loop on a specific frequency known as the Automatic Terminal Information Service (ATIS).

Approach and terminal control

Many airports have a radar control facility that is associated with the airport. In most countries, this is referred to as Terminal Control; in the U.S., it is referred to as a TRACON (Terminal Radar Approach Control). While every airport varies, terminal controllers usually handle traffic in a 30-to-50-nautical-mile (56 to 93 km) radius from the airport. Where there are many busy airports close together, one consolidated Terminal Control Center may service all the airports. The airspace boundaries and altitudes assigned to a Terminal Control Center, which vary widely from airport to airport, are based on factors such as traffic flows, neighboring airports and terrain. A large and complex example is the London Terminal Control Centre which controls traffic for five main London airports up to 20,000 feet (6,100 m) and out to 100 nautical miles (190 km).Terminal controllers are responsible for providing all ATC services within their airspace. Traffic flow is broadly divided into departures, arrivals, and overflights. As aircraft move in and out of the terminal airspace, they are handed off to the next appropriate control facility (a control tower, an en-route control facility, or a bordering terminal or approach control). Terminal control is responsible for ensuring that aircraft are at an appropriate altitude when they are handed off, and that aircraft arrive at a suitable rate for landing.

Not all airports have a radar approach or terminal control available. In this case, the en-route center or a neighboring terminal or approach control may co-ordinate directly with the tower on the airport and vector inbound aircraft to a position from where they can land visually. At some of these airports, the tower may provide a non-radar procedural approach service to arriving aircraft handed over from a radar unit before they are visual to land. Some units also have a dedicated approach unit which can provide the procedural approach service either all the time or for any periods of radar outage for any reason.