# Airborne Satellite Antenna Steering and Mounting Systems

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**Abstract:** This paper describes the steering and mount systems of Airborne Satellite Antenna (ASA) as a most important and sensitive part of both Aeronautical Mobile Satellite Communication (AMSA) and Aeronautical Mobile Satellite Broadcasting (AMSB) systems. In general, most of ASA solutions are small and easy to install onboard aircraft such as Low Gain Antenna (LGA). However, in particular, some of ASA systems are quite complex, relatively large and heavy, especially airborne High Gain Antenna (HGA) for Aircraft Earth Stations (AES), such as Inmarsat-H, High Speed Data (HSD), Swift64, SwiftBroadband and Digital Video Broadcasting-Return Channel via Satellite (DVB-RCS) antennas, so they need sophisticated steering and mounting systems. Over the past decade are developed the steering ASA broadband system, which main components are reduced considerably in both physical size and weight. These reductions are presented in this research that brings greater Effective Isotropic Radiated Power (EIRP) from satellite transponders coupled with GaAs-FET technology at the front end the satellite receiver. In this paper are also introduced existing types of mechanical, electrical, combined and other mount systems of ASA steering system. The ASA has to be always pointed towards the satellite in spite of aircraft motions. At this point, the mount airborne satellite system as one of the main requirements in designing the mobile satellite antenna systems from the technical and rational viewpoints is discussed.

**Key Words:** ASA, AMSA, AMSB, LGA, HGA, DVB-RCS, BCU, ACU, Antenna Steering and Mounting

## 1. Introduction

The AES terminals are installed onboard aircraft radio communication and antenna sets capable of communicating via satellite with Ground Earth Stations (GES) in the Inmarsat or other satellite operators via their satellite networks for access to Terrestrial Telecommunication Networks (TTN). The Inmarsat at first, then Globalstar, Iridium and other new satellite operators later, were developed several standards of AES with special antennas for installation onboard of civil and military airplanes and helicopters**.** The Inmarsat AES via antenna terminal receives and process RF signals from the satellite, then format and transmit RF signals to the satellite at L, Ku or Ka-band.

The AES interfaces onboard communication and antenna systems, such as duplex Tel, Fax, data and video equipment for aircraft, which standards meets the requirements of the ICAO and industry standards such as ARINC Characteristics 741 as well as Inmarsat standards. In fact, ARINC 741 standard describes one physical implementation of the Inmarsat system, which Characteristics 741 for AES comprises Above Cockpit Units (ACU) or antenna dish and Below Cockpit Units (BCU) illustrated in **Figure 1.** The BCU are electronic elements of transceiver unit usually installed inside of the pilot cabin (cockpit), while ACU are mounted on either top or sides of the aircraft fuselage frame. The main elements of BCU and ACU units are as follows:

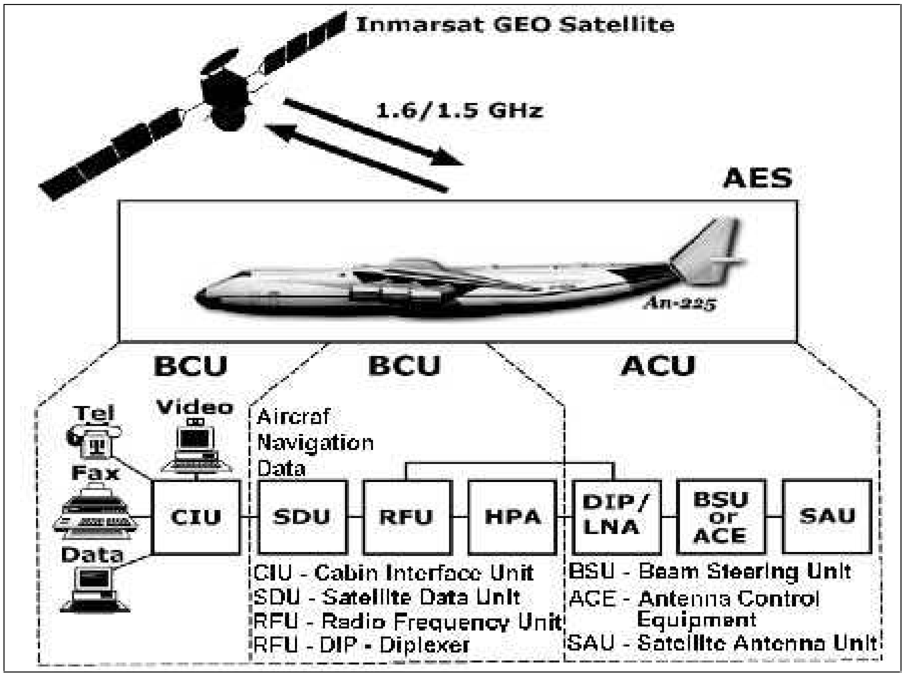

**Figure 1.** Aeronautical ACU/BCU Configuration – Courtesy of Manual: by Inmarsat **[1]**

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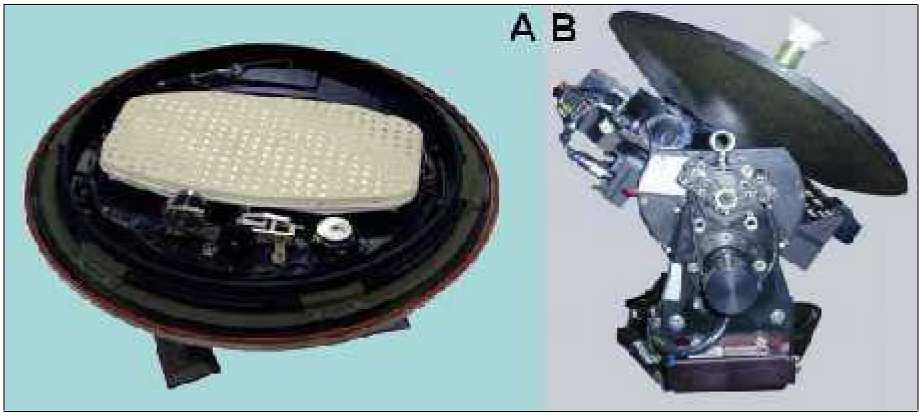

**Figure 2.** Steering Aircraft Antenna Systems – Courtesy of Brochure: by Ellipse/Orbit **[2, 3]**

**1. Satellite Data Unit (SDU)** - The SDU is the heart of the AES. It interfaces with other on board avionics including the aircraft navigation system (GPS, GNSS or GLONASS and new CNS), and performs most of the, protocol, data-handling, modulation/coding and demodulation/decoding functions of the AES.

**2. RF Unit (RFU) -** The RFU converts IF inputs from the SDU into L-band RF signals, which are sent to HPA for transmission. It also receives the L-band RF signal from the satellite via the LNA, converts them to IF and passes them to the SDU.

**3. High Power Amplifier (HPA) -** It amplifies the transmitted RF signal from the RFU to the appropriate power level required to maintain only the air-to-ground Mobile Satellite Communication (MSC) link.

**4. Diplexer/Low Noise Amplifier (DIP/LNA) -** Diplexer is providing separation of Rx (receiver) and Tx (transmitter) signals, while LNA amplifies the RF signals received by the antenna to compensate for system signal losses and proceed them to the RFU.

**5. Beam Steering Unit (BSU) -** The BSU is also otherwise known as Antenna Control Unit (ACU) when used with a mechanically steered antenna, controls the pointing of the airborne antenna. Namely, it receives instructions from the SDU on where to point the antenna beam. The instructions are converted into steering commands, either electronic or electro-mechanical, to point the antenna beam towards the desired satellite.

**6. Satellite Antenna Unit (SAU) -** The antenna as a part of ACU is the important component, which is mounted to the exterior of the aircraft fuselage enabling the system to transmit and receive RF signals to/from the satellite. In effect, there are the following three kinds of antennas specified by gain performance for use in the Inmarsat Aeronautical Mobile Satellite Communication (AMSC) systems: Low Gain Antenna (LGA), Intermediate Gain Antenna (IGA) and High Gain Antenna (HGA) **[1, 4, 5, 6]**.

## 2. Aircraft Antenna Steering System

Directional aircraft antenna system needs to be always positioned in the focus of satellite by a special antenna steering, i.e. tracking mechanism situated on special pedestal in protection radome, together with antenna dish or plate.

**1. Mechanically Steering Aircraft Antennas –** Since ships, land mobiles (road and trains) and aircraft move fast and change their direction frequently, electrical tracking is preferable, but in order to fully cover $360^o$ in azimuth a facility for mechanical tracking is used. Thus, an example of Ellipse TV of FDS company mechanical steered aircraft phased array antenna is shown in **Figure 2 (A).** During flight, the antenna has the ability to change its heading up to 40° per second without loosing sight of satellite. In such a manner, the radome houses a mechanically steered and low profile phased array antenna. The antenna rotates 360° and tilts 16° either side of horizontal plane. Unlike other systems this antenna has the ability to acquire satellite without need for the GPS or aircraft navigation position information.

**2. Mechanical and Electrical Steering Aircraft Antennas -** Aircraft is moving very fast with frequently changes of their directions, altitude, attitude and speed what needs combination of special mechanical and electrical tracking antenna systems AL-1620-1 of Orbit company, shown in **Figure 2 (B).** This antenna integrates light duty high dynamic elevation over azimuth steering Digital Tracking Pedestal (DTP) and is equipped brushless servomotors, which includes a planetary gearbox for each axis. Each motor is driven by a Digital Servo Amplifier (DSA) and advanced processor responsible for motor current, motor velocity and axis position control loops. On the other hand, this unit also includes comprehensive Built-in-Test (BIT) abilities for the entire antenna pedestal. The sidelobe requirements are derived from a satellite system concept with $30^o$ angular separations between adjacent satellites **[2, 3]**.

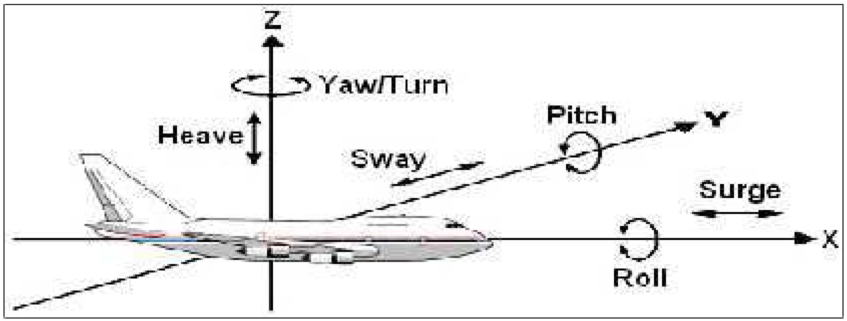

**Figure 3.** Components of Aircraft Motion – Courtesy of Manual: by Ilcev **[7]**

## 3. Antenna Mount and Tracking Systems

Over the past two decades, the directional mobile antenna system, which comprises the mechanical assembly, the control electronics and gyroscope, the microwave electronic package and the antenna assembly (dish, array or any similar), has reduced considerably in both physical size and weight.

### 4.3.1. Antenna Mount Systems

The ASA system is generally mounted on top a platform, which has two horizontally stabilized axes (X and Y), achieved by using a gyrostabilizer or sensors, such as accelerometers or navigation gyrocompasses. The stabilized platform provides a horizontal plane independently of mobile motion, such as roll or pitch. For example, all mobiles have some kind of motions components during traveling, such as: roll, pitch, yaw, surge, sway, heave and turn, illustrated in **Figure 3.** Turn means a change in the aircraft's heading, which is intentional not caused by wave motion and the other six components are caused by wave motion. Surge, sway and heave are caused by acceleration.

**1. Two-Axis Mount System (E/A and Y/X) –** An antenna mount is a mechanical moving system that can maintain the antenna beam in a fixed direction. Thus, there is two typical mounts of the two-axis mount system configuration: one is the elevation/azimuth (E/A) mount and the other is the Y/X mount. Simplified stick diagrams of both mounts are illustrated in **Figure 4 (A)** and **(B)**, respectively. In the E/A mount, a fully steerable function can be obtained by choosing the rotation range of the azimuth axis (A-axis) from 0 to $90^{o}$. In the Y/X mount a fully steerable function is achieved by permitting the rotation angle to be from $-90^{o}$ to $+90^{o}$ to both the X and Y-axis. Both mount types have several disadvantages.

**2. Three-Axis Mount System (E/A/X, E'/E/A and X'/Y/X) –** The three-axis antenna mount system is considered to be a modified two-axis mount, which has one additional axis. Thus, the three-axis mount of an E/A/X type as illustrated in **Figure 5 (A),** is the E/A antenna mount with one additional X-axis. However, the three-axis mount of an E'/E/A type, illustrated in **Figure 5 (B)** is the E/A mount with an additional cross-elevation axis, E. The three-axis mount of an X'/Y/X type is the two-axis Y/X mount system with the X'-axis on it to obviate the gimbal lock at the horizon, presented in **Figure 5 (C)**

**3. Four-Axis Mount (E/A/Y/X) –** The stabilized platform is made by the X/Y-axis to take out roll and pitch and a two-axis mount of the E/A type is settled on the stabilized platform. This is the four-axis mount configuration, shown in **Figure 4 (C).** The tracking accuracy of this mount is the best solution because the stabilization function is separated from the steering function and at any rate, four major components such as roll, pitch, azimuth and elevation angle are controlled by its own axis, individually **[4, 5, 7, 8]**.

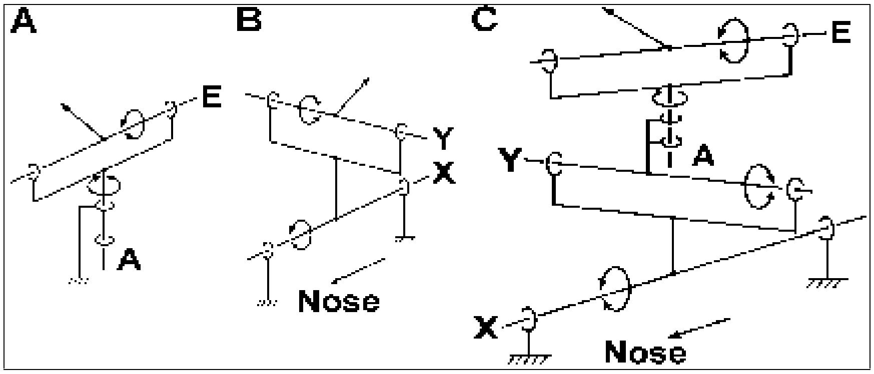

**Figure 4.** Two and Four-axis Mount Systems – Courtesy of Book: by Fujimoto **[4]**

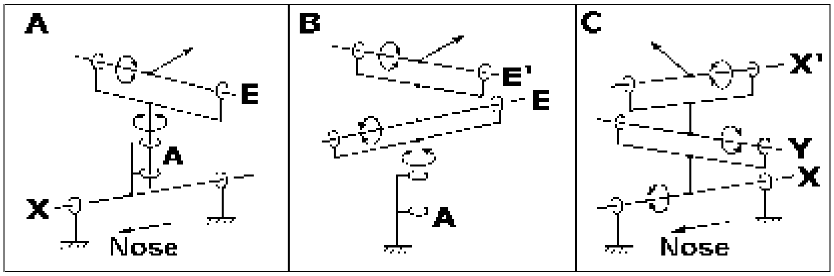

**Figure 5.** Three-axis Mount System – Courtesy of Book: by Fujimoto **[4]**

### 4.3.2. Antenna Tracking and Pointing Systems

The tracking and pointing system is another important function required of the antenna mount system. There are 3 tracking methods:

**1. Manual Tracking** – This is the simplest method, wherein an operator controls the antenna beam to maximize the received signal level.

**2. Step Tracking –** Among various auto track antenna systems, the step track has recently been recognized as a very suitable tracking facility for mobiles because of its simplicity for moderate tracking accuracy. The schematic block diagram of the step tracking system is shown in **Figure 6 (A).** Sample-hold circuits are used to hold the signal levels, which are compared before and after the antenna have been moved by an angular step. If the level increases, the antenna is moved in the same direction and vice versa, if the level decreases, the direction will be reversed.

**3. Program Tracking –** The proposed concept of the program tracking system is based on the open loop control slaved to the automatic navigation equipment, such as a navigation gyrocompass, GPS, the Omega and Loran-C systems. Namely, in program tracking, the antenna is steered to the point of the calculated direction based on the positional data of the navigation equipment. Since the satellite direction changes because of roll, pitch and turn, a function to remove these rapid motions is required in the program track, whose block diagram is shown in **Figure 6 (B) [4, 7].**

### 4.4. Antenna Location, Satellite Determination and Antenna Azimuth Limit

For installation satellite antenna on an aircraft has the following general guidelines: always install antenna on top of aircraft fuselage as far away from obstructions (tail section) as possible; install HPA/LNA Pack as close to the antenna as possible and AES transceiver in or near the cockpit (nose); and cross section of antenna has to me maximum 20°, shown in **Figure 7 (A).**

An Aircraft HGA antenna must be capable of locating and continuously tracking the GEO satellite available or selected for communication, namely if the aircraft has in view only one satellite or if the aircraft is in an overlapping position, respectively. An aircraft MSA may be moved through any angle in azimuth and elevation as the aircraft moves along its course. Thus, it is essential that electronic control of the antenna is provided using the following methods:

**1. Manual Commands –** When the operator has selected manual control, elevation is commanded by up and down control keys, whereas azimuth positioning is controlled clockwise and counter-clockwise keys.

**2. Automatic Control –** Once GEO satellite lock has been achieved, the system will automatically monitor signal strength and apply A/E corrections as required in order to maintain this lock as the aircraft changes course.

**3. Automatic Search –** An automatic antenna search routine commences 1.5 minutes after switching on the equipment, or it may be initiated by the operator. Therefore, the elevation motor is caused to search between 5° and 85° limits, whereas the azimuth motor is stepped through 10° segments. If the assigned common signaling channel signal is identified during this search the step antenna tracking system takes over to switch the antenna above/below and to each side of the signal location searching for maximum satellite signal strength **[4, 5, 7, 8]**.

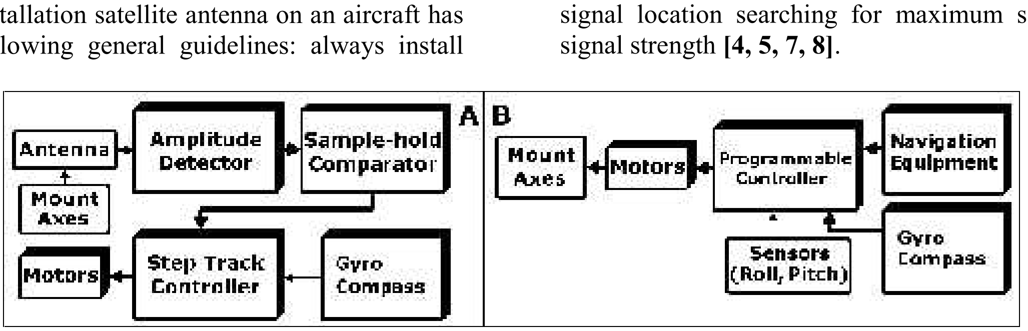

**Figure 6.** Functional Diagrams of Step and Program Tracking – Courtesy of Book: by Fujimoto **[4]**

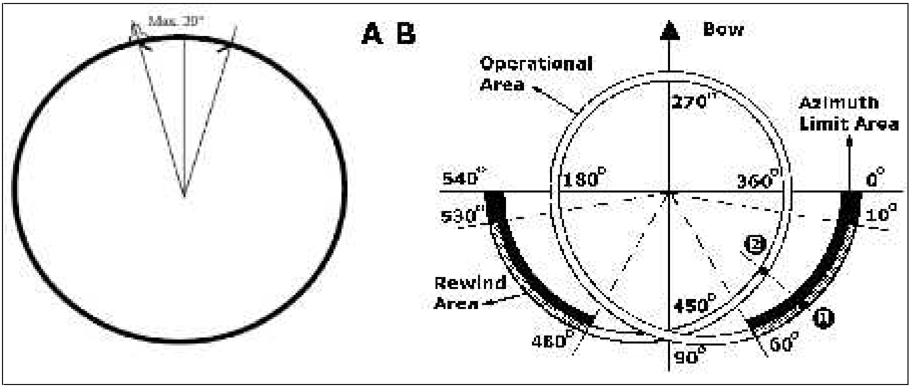

**Figure 7.** Cross Section of Aircraft and Azimuth Limit – Courtesy of Handbook: by Ilcev **[7]**

**4. Gyroscopic Control** – The Control Lock is maintained irrespective of changes to the course by sensing signal changes in the gyro repeater. Satellite signal strength is monitored and if necessary, the A/E stepper motors are commanded to search for maximum signal strength.

**5. Antenna Rewind** – The antenna installed on a fuselage or on the tail and is coupled by various control and signal cables to a stationary stable platform. Thus, if the antenna was permitted to rotate continuously in the same direction, the feeder cables would eventually become so tightly wrapped around the central support that they would either prevent the antenna from moving or they would fracture. To prevent this happening, a sequence known as antenna rewind is necessary, as is shown in **Figure 7 (B).**

In fact, an antenna has three areas with rewind time of approximately 30 seconds plus stabilizing time, giving a total of about 1.5 minutes:

**1)** Operational Area is the satellite antenna-rotating limit in the azimuth plane. The antenna can rotate a total of 540°, which is illustrated as a white area in **Figure 7 (B)**. Normally, the satellite antenna will operate in the operational area, which is between 60° and 480°.

**2)** Rewind Area is necessary for the following reasons: if the antenna moves into one of the rewind areas, namely, 10° to 60° or 480° to 530° (antenna azimuth lamp lights) and if no traffic is in progress, the antenna will automatically rewind 360° to get into the operational area and still be pointed at the satellite, which is illustrated as a dotted area in **Figure 7 (B)**.

**3)** Azimuth Limit Area is an important factor because when the satellite antenna is in this area the azimuth limit lamp lights. However, if the antenna moves into the outer part of the azimuth limit area, i.e., 0° to 10° or 530° to 540°, rewind will start automatically, despite traffic in progress **[4, 7, 9, 10]**.

### 4.5. Antenna Pointing and Tracking

The directional aircraft reflector antenna is highly directive and must be pointed accurately at the satellite to achieve optimum receiving and transmitting conditions. In normal operation the antenna is kept pointed at the satellite by the auto tracking system of, such as Swift system. Before the auto tracking can take over, the antenna must be brought within a certain angle in relation to the satellite. This can be obtained using the command "find" or by manually setting the antenna using the front push buttons on the terminal. For manual pointing it is necessary to provide the aircraft's plotted position, heading by gyro, azimuth angle map and elevation angle map of the satellite.

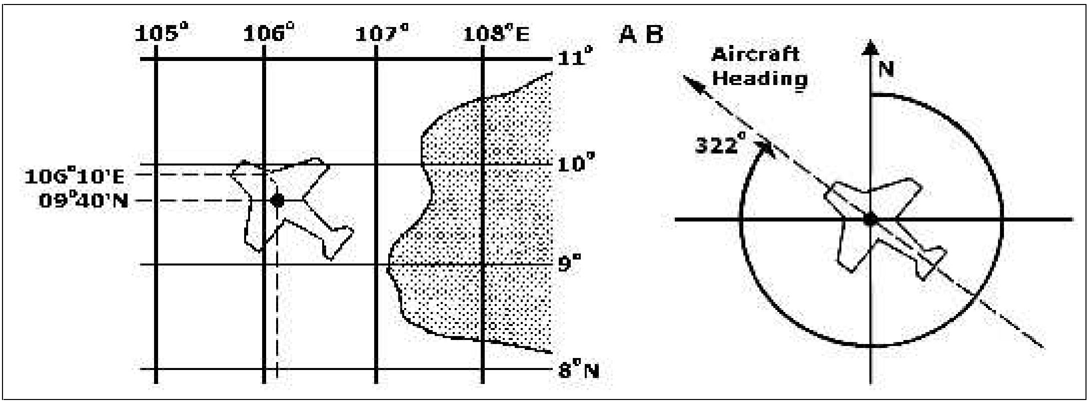

**Figure 8.** Antenna Pointing – Courtesy of Handbook: by Ilcev **[7]**

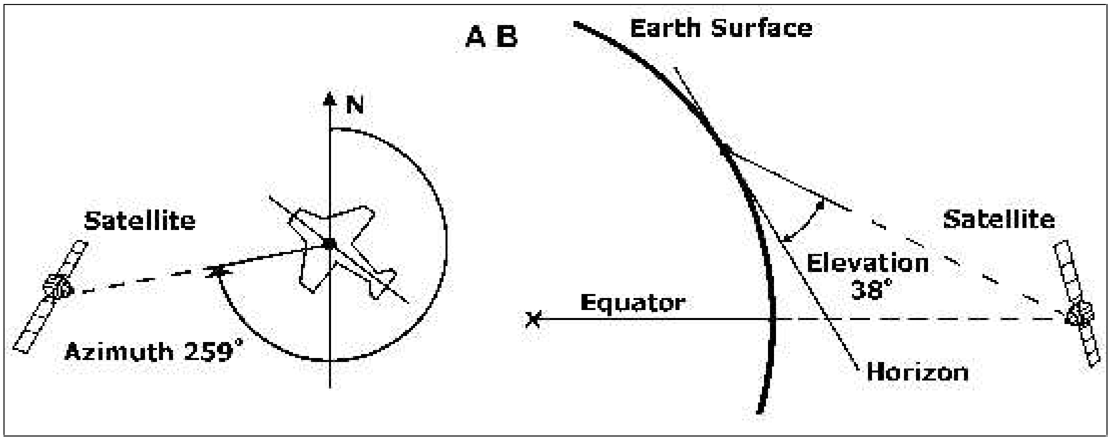

**Figure 9.** Azimuth and Elevation Angle – Courtesy of Handbook: by Ilcev **[7]**

**1. Aircraft's Plotted Position** – The plotted position is needed to decide which satellite can be used or Inmarsat network area can be tuned: Atlantic Ocean Region-West (AORW) or Atlantic Ocean Region-East (AORE), Indian Ocean Region (IOR), Pacific Ocean Region (POR), depending on the aircraft's actual position, as shown in **Figure 8 (A)**. Sometimes, the aircraft can be in an overlapping area covered by two or even three Inmarsat satellite constellations. In this case it will be important to choose convenient GES communication and coverage facilities and to point the antenna towards one of overlapping ocean regions.

**2. Aircraft's Heading by Gyrocompass** – The permanent keeping in order the aircraft heading determined by navigation gyrocompass is needed for the antenna auto-tracking system, illustrated in **Figure 8 (B).**

**3. Azimuth Angle** – The antenna azimuth is the angle between North line and horizontal satellite direction as seen from the aircraft, which is presented by example of 259°, in **Figure 9 (A).** Thus, the actual azimuth angle for the various satellite positions due to the certain aircraft's plotted position can be found on the special azimuth angle maps.

**4. Elevation Angle** – The elevation angle is the satellite height above the horizon as seen from the aircraft, as is shown by the example of 38°, in **Figure 9 (B) [04, 07, 08, 11]**.

### 4.6. Airborne Antenna Mounting and Steering

The antenna gain is the fundamental parameter controlling antenna operation, which very good gain coverage, exceeds 12 dBi in 90% and 9.5 dBi over 100% and 14 to 17 dBi within 50% of the Inmarsat hemisphere and extends from 5° upward over the horizon in all level of flight. With superior receive gain, less satellite power is required for nominal service and more satellite channels can therefore be supported.

### 4.6.1. AES Antenna Mounting

The airborne antenna assembly can be mounted on top of the aircraft or on the sides of the fuselage. Ideally, the best position for placing the aircraft antenna is a location on the centerline of the aircraft coordinate system, as is illustrated in **Figure 10 (A)**.

The antenna assembly location should be moved forward or aft along the centreline from the ideal position to maintain proper separation from other aircraft antenna systems. Thus, all L-band aircraft antennas must be separated by at least 50.8 cm, with 1.5 m preferred.

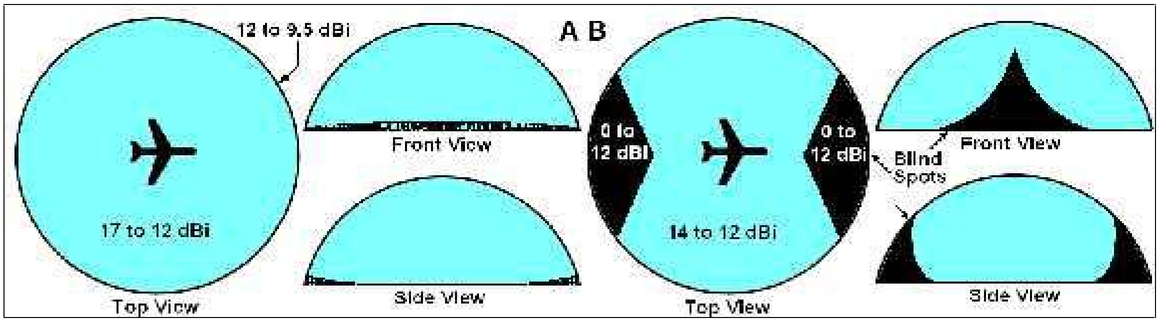

**Figure 10.** Top-Mounted and Typical Side-Mounted Airborne Antenna – Courtesy of Handbook: by Ilcev **[7]**

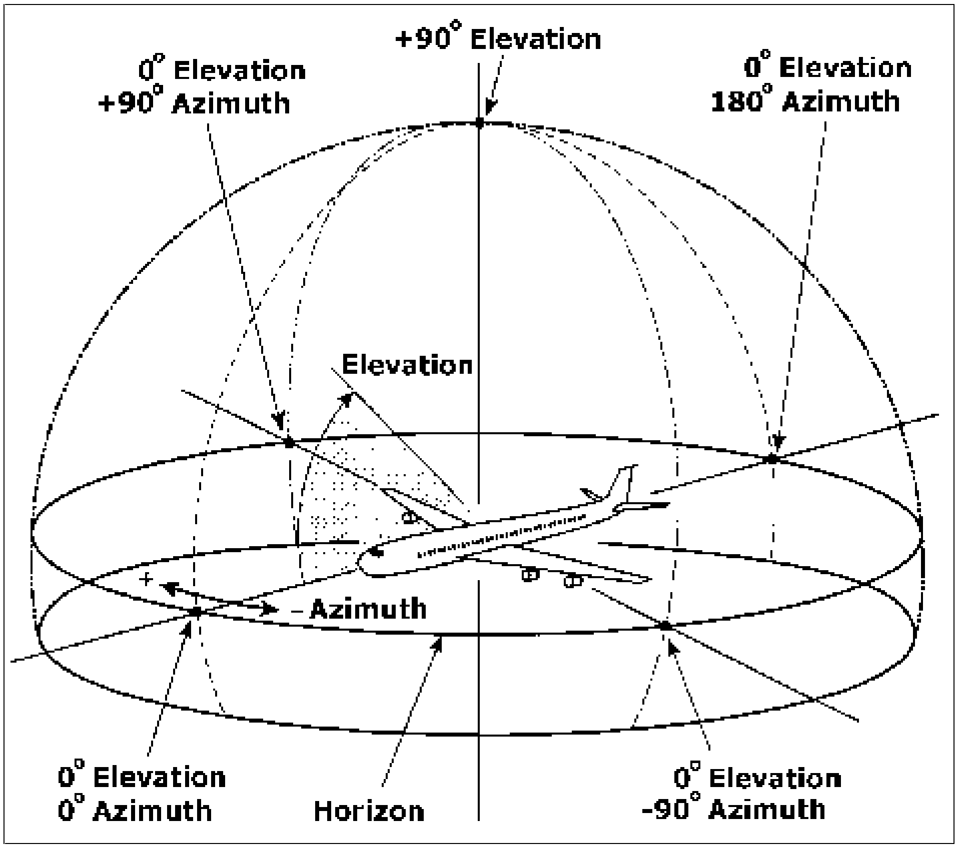

**Figure 11.** Antenna - HGA Coordinate System – Courtesy of Manual: by Canadian Marconi **[12]**

The satellite antenna should be located at a distance of at least 5 m from GPS antenna and the magnetic steering compass. Thus, it is not recommended to locate the antenna close to any interference sources such as the radar antenna, lie within the antenna's beam width of 10° when it points at the satellite. The antenna should also be separated as far as possible from the HF antenna and preferably by at least 5 m from the antennas of other communications or navigation equipment, such as satellite navigator or the VHF and other related radio antennas. The top mount provides satellite coverage independently of the direction of aircraft travel with 100% clear view, while front and side views have a very small shadowing on the lower levels of the hemisphere. This heading-independent antenna gain coverage is a very significant advantage and very important condition for all type of aircraft before planning their routes.

The typical side-mounted antennas have an inherent coverage deficiency due to their limited scan range. Nose and tail bearings and shallow elevation angles to the satellite can reduce HGA gain values below 12 dBi, sometimes all the way to zero. These triangular areas, called blind spots or "keyholes", occur in an aircraft's fore and aft directions, extending horizontally about 45° to each side at an elevation angle to the GEO satellite of 5° and rising to a point about 45° above the nose and tail, shown in **Figure 10 (B).** Recent experience by a number of airlines has confirmed that the blind spots cause problems in certain flight areas, such as Pacific.

The **Table 1** compares the top-mounted with a typical side-mounted antenna design.

**Table 1.** Comparison of Top-Mount and Side-Mount Airborne Antennas

| Gain Characteristics | Top-Mount | Side-Mount |
|---|---|---|
| Minimum Gain over 75% Inmarsat Hemisphere | 13 dB | 12 dB |
| Average Gain over 75% Hemisphere | 15 dB | <13 dB |
| Minimum Gain over 100% Hemisphere | >9,5 dB | 0 dB |

In **Figure 10 (B)** is illustrated that top view of a side-mounted airborne antenna is reduced on the nose and tail of aircraft with shadowing of about 12% in total, while both front and two side views of the aircraft have significant shadowing spots of about 15% each **[4, 7, 10, 11]**

### 4.6.2. Beam Steering Performances

Steering of the airborne HGA is controlled by the Beam Steering Unit (BSU), which transmits steering commands to the HGA terminal over an asynchronous EIA-RS-422A serial data link. The HGA interprets the steering command and steers the antenna beam to the desired position. The BSU translates antenna beam position data and beam change commands received from the Satellite Data Unit (SDU in a standard digital format into signals needed to select phasing of the antenna elements that result in the antenna beam pointing at the desired satellite.

During subsystem operation, open-loop steering and control words are received from the SDU. The steering words contain azimuth and elevation information for the direction in which the beam will be steered, using the coordinate system, which is illustrated in **Figure 11. A**fter receiving an open-loop steering word, the BSU calculates the beam number (one of more than 1,000) and associated phase-shifter settings, which are then up linked to the HGA at a maximum rate of 20 Hz, via an RS-422A serial data links. However, should the rate of transmission of the open-loop steering words exceed 20 Hz, the BSU buffers the incoming words unit it has up linked and strobes in the phase-shifter terminal settings for current azimuth/elevation value. If multiple steering words have been received during the processing time, only the most recent value is retained. Control words will be processed as they are received. Another function of the BSU includes reporting of the selected antenna beam and gain to the SDU.

Moreover, operational software of BSU meets the requirements of Level 2 Flight Essential category. In addition to operating software, the BSU terminal contains diagnostic software to assist ground maintenance personnel in fault isolation. The diagnostic software is capable of identifying faults to a more detailed level than required by ARINC 741 **[4, 7, 12]**.

## 5. Conclusion

The aircraft antenna configuration needs to be compact and lightweight. These requirements are difficult to achieve, because the compact antenna has major disadvantages such as low gain and that has wide beam coverage, while directional aircraft antenna has quite heavy components. However, a new generation of powerful satellites with high EIRP and G/T performances should permit the design of compact and lightweight antennas.

New physical antenna shapes and less weight are very important requirements in connection with compactness and lightweight, what will permit easier installation and maintenance. Thus, with airborne antennas on large jumbo jets, installation requirements are not as limited compared to very small aircraft and helicopters, because even small jets have more space on fuselage for antenna installations. Small jets and especially helicopters require low profile and lightweight equipment. The antenna requirements are the same in jumbo intercontinental aircraft, although more stringent conditions are required to satisfy ICAO standards. Low air drag is one of the most important and crucial requirements for aboard aircraft antennas. However, a phased array antenna is considered to be the best candidate for aircraft and helicopters mount because of its very low profile, convenient mechanical strength and easy installation.

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