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Shipborne Satellite Antenna Mount and Tracking Systems

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ABSTRACT: In this papers are introduced the very sensitive components of the ship's antenna tracking system as the weakest chain of the Maritime Mobile Satellite Service (MMSS). Also are presented the complete components of Ship Earth Station (SES), such as antenna system and transceiver with peripheral and control subsystems independent of ship motion. The communications Mobile Satellite Antennas (MSA) for Maritime Satellite Communications (MSC) are relatively large and heavy, especially shipborne directional Inmarsat B and Fleet-77 antenna systems. Over the past two decades the directional antenna system, which comprises the mechanical assembly, the control electronic and gyroscope, the microwave electronic package and the antennas assembly (dish, arrays and steering elements), is reduced considerably in both physical size and weight. These reductions, brought about be greater EIRP from satellite transponders coupled with GaAs-FET technology at the front end the receiver leading to higher G/N RF amplifiers, has made the redesigning, adopting and installing of shipborne antennas even on tracks and airplanes a reality.

1 INTRODUCTION

Inmarsat started operations 1981 with only Inmarsat-A maritime service and for that reason devised an initial synonym: INternational MARitime SATellite (INMARSAT). The SES is electronic equipment consisting in antenna and transceiver with peripheral devices usually installed on board ships or sea-platforms and rigs.

Later, Inmarsat developed other SES standards with mandatory and obligatory equipment, such as B, M, mini-M, C, mini-C, D, D+, Fleet F77, F55 and F33, including latest FleetBroadband. In Figure 1. are presented Above Deck Equipment (ADE) and Below Deck Equipment (BDE) general block diagrams of electronic units for SES terminals. The main elements of BDE are the following units [01]:

1 Cabin Interface Unit (CIU) – With build in PC or system processor Cabin Interface Unit controls and monitors the whole system operations of the transceiver and direction of the antenna dish, and also performs different task of baseband signal conditions between all obligation and optional BDE peripheral equipment (Tel, Fax, Tlx, Video on one hand and Data) and Baseband Processor on the another hand.
2 Baseband Processor – This processor simply performs baseband processing of all transmitting and receiving audio, video and PC or data signals. In such a way, Baseband Processor comprises Intermediate Frequency (IF) amplifier, modems and timing circuits for multiplexing up and down signals. The synthesizer produces the highly stable frequencies required for modulation and demodulation and for signal switching.
3 Interface Terminal – Connects navigation Gyro Compass and Motion Sensor Units with CIU device for satellite tracking and electronic control of ADE.
4 Modulator and Demodulator – Both represents the nucleus of any transceiver. First modulates the baseband signal onto the IF carrier of transmitting signal and second demodulates the baseband signal from the IF carrier of the receiving signal.

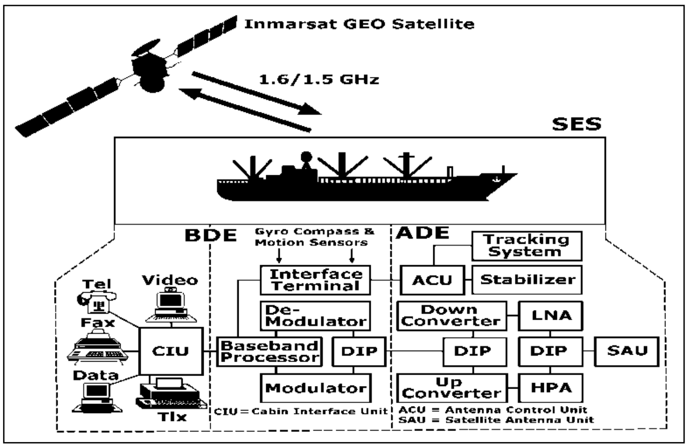

Figure 1. Maritime ADE and BDE Configuration
Courtesy of Book: "Global Mobile Satellite Communications" by St. D. Ilcev [01]

5 BDE Diplexer (DIP) – Enables direction of transmitting signals from Modulator to the ADE and receiving signals from ADE to the Demodulator.

The ADE is mounted below the waterproof container or radome on the Stabilized Platform. The following units compose the ADE assembly:

1 ADE Diplexers (DIP) – The first diplexer passes all transmitting signals to the Up Converter and from Down Converter to the Demodulator. The second diplexer guides transmitting signals from HPA to the SAU and from SAU to the LNA.
2 Up and Down Converters – This unit accepts the modulated IF carrier from modulator and translates it to the uplink transmitted RF via HPA, by mixing with Local Oscillator (LO) frequency, while the Down Converter receives the modulated RF carrier from the LNA and translates its downlink receiving RF to the IF.
3 High Power Amplifier (HPA) – This unit provides amplification of transmitting signals by the Traveling Wave Tube Amplifier (TWTA) and Klystron Amplifier. The second HPA enables higher gain and better efficiency than TWTA but in smaller bandwidth of 2%. The amplified uplink signal goes via DIP to the SAU.
4 Low Nose Amplifier (LNA) – The LNA device provides initial amplifier stage of downlink signal coming from SAU via DIP without introducing much additional temperature noise. In this sense, the two most commonly used LNA products are new GaAs (Gallium Arsenide) FET (Field Effect Transistor) and old Parametric amplifiers. Thus, the recent developed GaAs FET LNA enables very low noise temperatures and takes advantages of its stability, reliability and low cost.
5 Antenna Control Unit (ACU) – Antenna Control Unit is providing control of the ship antenna Stabilized Platform (Stabilizer) and Tracking System. Thus, it maintains the antenna direction towards the focus of satellite against any motion of the ship.

2 ANTENNA MOUNT SYSTEMS

The MSA system is generally mounted on a platform, which has two horizontally, stabilized axes (X and Y), achieved by using a gyrostabilizer or sensors such as accelerometer or gyrocompass units. The stabilized platform provides a horizontal plane independent of mobile motion such as roll or pitch. For example, all mobiles have some kind of motions, but ship motion has seven components during navigation such as: roll, pitch, yaw, surge, sway, heavy, and turn, shown in Figure 2. Turn means a change in ship heading, which is intentional motion, not caused by wave direction, and the other six components are caused by wave motion. Surge, sway, and heave are caused by acceleration.

2.1 *Two-Axis Mount System (E/A and Y/X)*

An antenna mount is mechanically moving system that can maintain the antenna beam in a fixed direction. In MMSS, the mount must have a function to point in any direction on the celestial hemisphere, because ships have to sail across the heavy seas. It is well known that the mount of the two-axis antenna configuration is the simplest mount providing such functions [02]

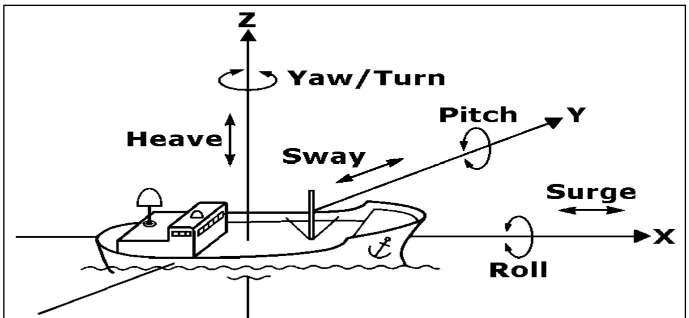

Figure 2. Components of Ship Motion
Courtesy of Book: "Mobile Antenna Systems Handbook" by K. Fujimoto and J.R. James [02]

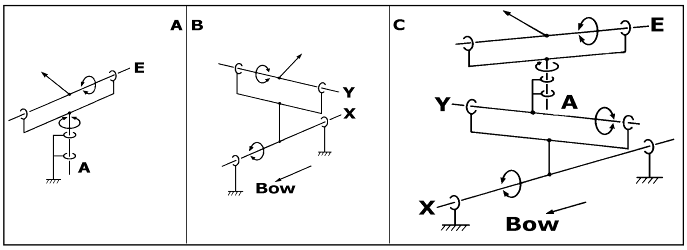

Figure 3. Two and Four-axis Mount Systems
Courtesy of Book: "Mobile Antenna Systems Handbook" by K. Fujimoto and J.R. James [02]

There are 2 typical mounts of the-axis configuration: one is E/A (elevation/azimuth) mount and the other is the Y/X mount. Simplified stick diagrams of both mounts are given Figure 3. (A) and (B) respectively. Thus, in the E/A mount, a full steerable function can be obtained by choosing the rotation range of the azimuth axis (A-axis) from 0-90°. In the Y/X mount a full steerable function is achieved by permitting the rotation angle from –90° to +90° to both the X and Y-axis. In fact, this is the basic configuration for the ships utility, so a special function required for its antenna mount system is to compensate the ship motions due to sailing and ocean waves, and to keep the antenna beam in nearly a fixed direction in space. In the case of the pointing and tracking under ship motions, the required rotation angle range of each axis is from 0° to more than 360° for the A-axis, and from –25° to +120° for the E-axis with respect to the deck level, assuming that the operational elevation angle is de facto restricted above 5° [01]. Otherwise, both mount types have several disadvantages.

2.2 *Three-Axis Mount System (E/A/X, E'/E/A and X'/Y/X)*

The three-axis mounting system is considered to be modified two-axis mount, which has one additional axis. The three-axis mount of an E/A/X type is shown in Figure 4. (A), which is the E/A mount with one additional X-axis. The function of the X-axis is to eliminate the rapid motion of the two-axis mount due to roll. However, in this system, the possibility of the gimbal lock for pitch is still left near the zenith, when the E-axis is parallel to the X-axis. The three-axis mount of an E'/E/A type shown in Figure 4. (B) is the E/A mount with an additional cross-elevation axis E. In the mount system, the charge of the azimuth angle is tracked by rotating the A-axis, and the change of the azimuth angle is tracked by a combined action of the E and E' axes. Hence, the E and E' axes allow movements in two directions at a right angle. With an approximate axial control, this mount is free from the gimbal lock problem near both the zenith and the horizon. 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 remove the gimbal lock at the horizon, presented in Figure 4. (C). When the satellite is near the horizon, the X-axis takes out the rapid motion due to yaw and turn. In this sense, the X'-axis rotate within ± 120o, so the X'-axis can only eliminate the rapid motion within the angular range. In general, this axis mount is rather more complex than that of four-axis mount, because steering and stabilization interact with each other [02].

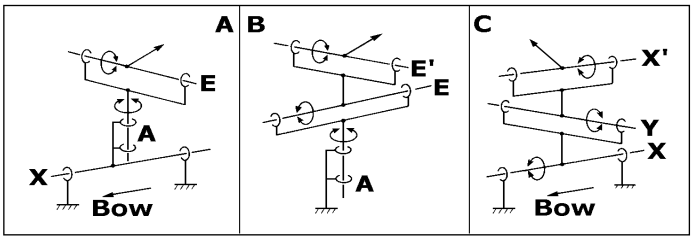

Figure 4. Three-axis Mount System
Courtesy of Book: "Mobile Antenna Systems Handbook" by K. Fujimoto and J.R. James [02]

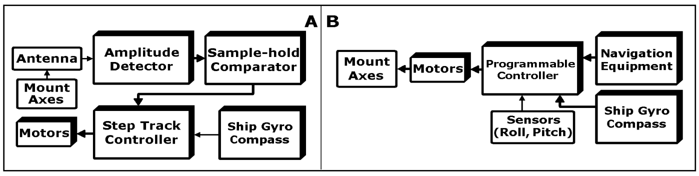

Figure 5. Functional Block Diagrams of Step and Program Tracking
Courtesy of Book: "Mobile Antenna Systems Handbook" by K. Fujimoto and J.R. James [02]

2.3 *Four-Axis Mount (E/A/Y/X)*

The stabilized platform made by X/Y-axis to take out roll and pitch, and two-axis mount of the E/A type is settled on the stabilized platform. This is four-axis mount solution, illustrated in Figure 3. (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, and azimuth and elevation angles are controlled by its own axis individually as well. Accordingly, the four-axis mount has been adopted in many SES antenna systems of the current Inmarsat-A and B standards [01].

3 ANTENNA TRACKING AND POINTING SYSTEMS

Tracking and pointing system is another important function required of the antenna mount system. It should be noted that the primary requirement for SES tracking MSA systems are that they have to be economical, simple and enough reliable. Tracking performance is a secondary requirement when an antenna beam width is broad [02].

1 Manual Tracking - This is the simplest method, wherein an operator controls the antenna beam to maximize the received signal level. At first, the operator acquires the signal and moves the antenna around one axis of the mount. If the signal level increases, the operator continues to move the antenna in the same direction. If the signal decreases, the operator reverses the direction and continues to move the antenna until the signal level is maximized. The same process is repeated around the second axis and the antenna is held af-

ter both axes when the received signal level decreases. This method is suitable for Land Mobile Satellite Communications (LMSC) and especially for portable and fly-away terminals.

2 Step Tracking - Among various existing auto track systems, the step track system has recently been recognized as a suitable antenna-tracking mode for SES terminals because of its simplicity for moderate tracking accuracy. In such a way, recent design and development of integrated circuits and microprocessors have brought a greatly remarkable cost reduction to the step track system, which principle is the same as that of the manual track. The only difference is that an electric controller plays the role of an operator in the manual track. The schematic block diagram of the step tracking system is shown in Figure 5. (A). Sample-hold circuits are used to hold the signal level, which are compared before and after the antenna has been moved by a present angular step. If the level is increasing, the antenna is moved in the same direction, and vice versa, if the level is decreasing, the direction will be reversed. This process will be carried out alternately between two axes levels, which accuracy depends on the sensitivity of comparators. As a result, the beam center is maintained in the vicinity of the satellite direction. Thus, wrong decisions on the comparison of levels generally arise from the S/N ratio and the level changes due to the multipath fading and the stabilization error.

3 Program Tracking - The concept of the program system is based on the open-loop control slaving to the automatic navigation equipment, such as a ship gyrocompass, GPS, the Omega and Loran-C systems. In the program tracking, the antenna is steered to the point of the calculated direction based on the position data of the navigation equipment. Since the satellite changes because of roll, pitch, and turn direction, a function to remove the rapid motions is required in the program track, which block diagram is shown in Figure 5. (B). The error of navigation equipment is negligibly small for the program track system, while the error of it mainly depends on the accuracy of sensors for roll, pitch, and turn directions, what is the stabilization error. In fact, an adequate sensor for the program track system is a vertical gyro, because it is hardly affected by the lateral acceleration. When the stabilization requirement is lenient, the conventional level sensor, such as inclinometer, a pendulum, and a level, may be used with careful choice of the sensor's location.

Therefore, the controller calculates the direction of the satellite orbit to compensate differences for the ship's motions affected by all components. In any event, the simpler the axis configuration of the mounts, the more complex the program calculation procedure becomes.

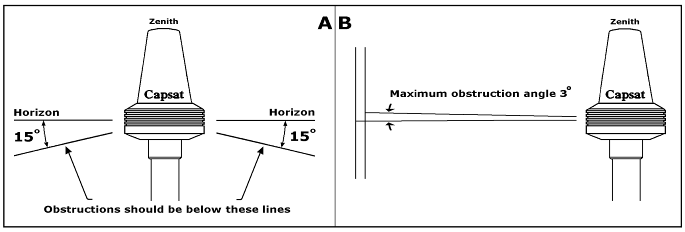

Figure 6. Safe Distance of Inmarsat-C Antenna from Obstructions
Courtesy of Manual: "Sailor Maritime Inmarsat-C" by Thrane & Thrane [03]

More exactly, since the program controller has to execute different calculations of many trigonometric functions, a microprocessor is a candidate for the controller. However, the program tracking system is also applicable to the four-axis mount. A combination with the step track system is more desirable because the error of the program track system can be compensated by the step track system and its error due to the rapid ship motions can be compensated for by the program tracking system [01].

4 OMNIDIRECTIONAL SHIPBORNE MSA MOUNTING

When installing MSA is necessary to find a location on board of ship that is as free from any obstructions as possible. On the other hand, also is important to maintain a certain distance to other communication antenna systems, especially radar installations. Finally, the best place for the MSA on board ship would be above radar scanning antennas or far a way from them. Otherwise, the minimum safe distance should be maintained to HF antenna 5 m, to VHF antenna 4 m, and to magnetic compass 3 m [04].

The omnidirectional antenna is designed to provide satellite coverage even when the vessel has pitch and roll movement up to 15^o. In this sense, to maintain this coverage the ship antenna should be free from any obstructions in the area down to 15^o below the horizon, as is shown in Figure 6. (A). Since this may not be possible in the fore and aft directions of the vessel, the clear area can be reduced to 5^o below the horizon in the fore and aft directions and 15^o below the horizon in the port and starboard directions. Otherwise, any compromise in this recommendation will degrade performance. If an obstruction such as a pole or a funnel is unavoidable, the distance to these objects should large enough, so that the obstruction only covers 3o. For instance, if the diameter of ship obstruction object is 0,1 m, the safe distance should be about 2 m, as is shown in Figure 6. (B).

The safety levels for the Thrane & Thrane Capsat-C Antenna Unit and similar Inmarsat-C aerials are based on the ANSI standard C95.1-1982. Namely, this standard recommends the maximum power density at 1,6 GHz exposed to human beings not to exceed 5 mW/cm^2. Therefore, at the maximum radiation output power from Inmarsat-C antenna of 16 dBW EIRP corresponds to a minimum safety distance of about 30 cm. So, the future standard from the European Telecommunication Standard Institute (ETSI) concerning 1,5/1,6 GHz Mobile Earth Station (MES) the new recommendation will be maximum 8 W/m^2 (0,8 mW/cm^2) with minimum safety distance on 62 cm at 16 dBW of EIRP **[01]**.

5 DIRECTIONAL MSA MOUNTING AND STEERING

The directional ship Above Deck Equipment (ADE) consists of an antenna unit mounted on a pedestal, an RF unit, power and control unit, all covered by a radome. Ideally, the antenna should have free optical sight in all directions above an elevation angle of 5o. The antenna must be placed as high as possible on the best position on board of ship to avoid blind spots with degradation and/or loss of communication link, caused by different deck obstacles [05].

5.1 *Placing and Position of SES Antenna Unit*

The directional antenna has a beamwidth of 10^o and ideally requires a free line of sight in all directions above an elevation angle of 5^o. Possible obstructions will cause blind spots, with the result of degradation or even loss of communication link with the satellite. So, complete freedom from degradation of the signal propagation is only accomplished by placing the ship antenna above the level of possible obstructions.

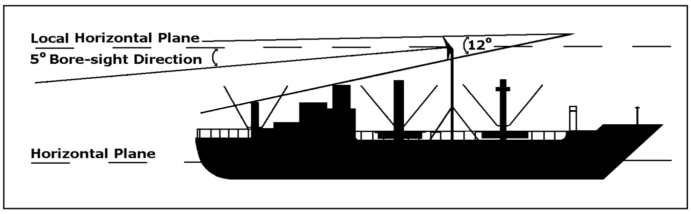

Figure 7. Theoretical Antenna Installation
Courtesy of Book: "Global Mobile Satellite Communications" by St. D. Ilcev [01]

This is normally not feasible and a compromise must be made to reduce the amount of blind spots. The degree of degradation of the communication depends on the size of the ship obstructions as seen from the antenna, hence the distances to them must also be considered. However, it should be remembered that the antenna RF beam of energy possesses a width of 12^o angle cone and consequently, objects within 10 m of the radome, which cause a shadowing sector greater than 6^o, are not likely to degrade the electronic equipment significantly. Preferably, all obstructions within 3 m of the shipborne antenna system should be avoided.

Obstructions less than 15 cm in diameter can be ignored beyond this distance. Knowing the route that the ship normally sails allows a preferable sector of free sight to be established, thus facilitating the location of the antenna unit.

In such a way, the antenna beam must be capable of being steered in the direction of any GEO satellite of the Inmarsat constellation, whose orbital inclination does not exceed 3^o and whose longitudinal excursions do not exceed ±0.5^o. Therefore, means must be provided to point the antenna beam automatically towards the satellite with sufficient accuracy to ensure that the G/T and EIRP requirements, namely receive and transmit signal levels, are satisfied continuously under operational conditions.

Careful and important consideration should be given to the placing of an Inmarsat-A or B standard ADE with antenna radome. Essentially, the focal point of the parabolic antenna must be pointing directly at the GEO satellite being tracked without any interruption of the microwave beam, which may be caused by any obstruction on the ship. Inmarsat specify that there should be no obstacle that is likely to downgrade the performance of the equipment in any angle of azimuth down to an elevation of –5^o, which is not easy to achieve. Thus, the SES design and installation guidelines of Inmarsat explains a theoretical satellite antenna installation instructions mode satisfying this advice but with the disadvantage that the antenna system is very high above the vessel's deck and would be impossible to install in such a way, see Figure 7. Differently to say, this type of installation is not practical because in reality a ship's satellite antenna would certainly be very adversely affected by extremely strong and gusty wind, will have higher inclination angles, vibration and it would be difficult to gain access for maintenance purposes [06].

If ship's structures do interrupt the antenna beam, blind sectors will be caused, leading to degraded communications over some arc of azimuth travel. Thus, if it is like that and as is often the case, it is impossible to find a mounting position free from all obstructions; the identified blind sectors should be recorded. It may be possible for the operator, when in an area served by two satellites, to select the one whose azimuth and elevation angles with respect to the ship's position are outside the blind sector. Obviously, this method is not enough practical because the satellite overlapping sectors inside of Inmarsat's four ocean regions cover relatively small areas. The best solution to avoid all blind sectors is to place the antenna unit on top of the radar mast or on a specially designed mast.

5.2 *Antenna Mast and Stabilizing Platform*

The mast has to be designed to carry the weight of the antenna unit, maximum 300 kg, depending on model design or manufacturer, presented in Figure 8. (A). It must also be able to withstand the forces imposed by severe winds up to 120 knots on the radome and strong vibrations due to very rough seas on the whole ADE construction. The top end of the mast should be fitted with a flange with holes matching the bolts extending from the bottom of the radome. In addition, the flange must not be so large as to interfere with the hatch in the bottom of the antenna unit. In this sense, the holes through the mast flange must be positioned symmetrically around the ship's longitudinal axis.

If the height of the mast makes it necessary to climb up to the antenna unit, a ladder must be provided on the mast column. A guardrail must be attached to the upper section for safety purposes. Finally, if the height of the mast exceeds approximately 4.5 m, an access platform should be attached to the mast about 1.5 m below the radome bottom.

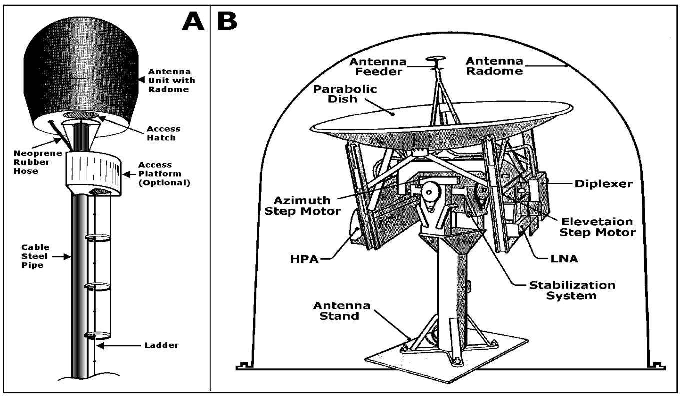

Figure 8. ADE Mast and Stabilized Platform
Courtesy of Manuals: "Saturn 3" by EB Communications and "Maritime Communications" by Inmarsat [04]

The radome completely encloses the periphery of the base plate assembly to protect the electronic and mechanical components from corrosion and weather. It is usually fabricated from high-gloss fibreglass and is electronically transparent to RF signals in the assigned frequency band. The radome is secured to the circular or square antenna stand (base plate) with several screws and can be removed easily without special tools.

The antenna-stabilized platform is housed inside the radome and consists in the electrical and mechanical elements, presented in Figure 8. (B). At this point, there are two antenna control stepper motors. First, there is the azimuth step motor, which controls the position of the antenna reflector in the horizontal A plane (azimuth) and second, is the elevation step motor that controls the vertical E plane (elevation). Each motor has four phase-inputs coming from the drive circuit in the BDE Control Board and a supply voltage from the master power supply located on the antenna stand. Accordingly, as a stepper motor turns the antenna, it also adjusts the setting of the relevant sensor potentiometer. The sensor voltage supply is the reference voltage for the A/D converter on the Control Board. In the other words, two stepper motors move the satellite antenna in both azimuth and elevation angles and moves the relevant sensor potentiometers, which provide feedback information on the position of the antenna. In fact, the antenna stabilization system, or gyroscope with two gyro motors, stabilizes the platform for the antenna against the roll and pitch of the ship. A two-turn solenoid clamps the antenna platform to the gyroscope assembly. Therefore, a diplexer passes the Rx signal from the antenna to the LNA and the Tx signal from the transceiver assembly to the antenna. The LNA amplifies the Rx signal and the HPA amplifies the Tx signal. The parabolic dish radiates EM energy to and from the antenna feeder in Rx or Tx direction, respectively. In such a mode, the antenna assembly is mounted below the radome for protection purposes [07].

5.3 *Antenna Location Aboard Ship*

The ship's antenna unit should be located at a distance of at least 4.5 m from the magnetic steering compass. At this point, it is not recommended to locate the antenna close to any interference sources or in such a position that sources such as the radar antenna, lie within the antenna's beam width of 10o when it points at the satellite. The ADE should also be separated as far as possible from the HF antenna and preferably by at least 5 m from the antenna systems of other communications or navigation equipment, such as the antenna of the satellite navigator or the VHF and NAVTEX antennas. In addition, it is not practical to place the antenna behind the funnel, as smoke deposits will eventually degrade antenna performance. Regardless of the location chosen for the antenna, it should be oriented to point forwards in parallel with the ship's longitudinal axis when in the middle of its azimuth range, which will correspond to zero degrees on the azimuth indicator [08].

The EM RF signals are known to be hazardous to health at high radiation levels. In such a way, it is inadvisable to permit human beings to stand very close to the radome of an SES when the system is communicating with a satellite at a low elevation angle. In this case, Inmarsat recommends that the radiation levels in the vicinity of the antenna should be measured. The crew members and passengers should not be admitted to areas closer than 10 m away from the antenna unit at desk level above 2 m, measured beneath the lowest point of the radome, as shown in Figure 9. (A).

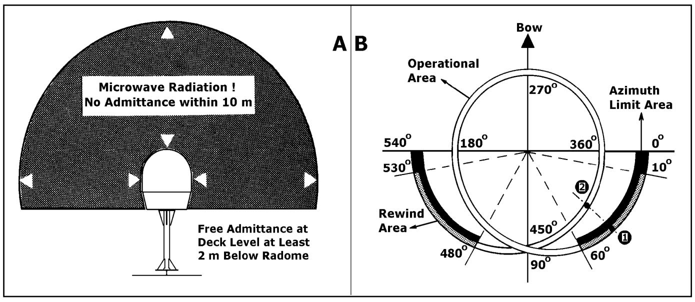

Figure 9. Antenna Radiation Precautions and Azimuth Limit
Courtesy of Manual: "Saturn 3" by EB Communications [04]

No restrictions, therefore, are required when the antenna radome is installed at least 2 m above the highest point accessible to crew and passengers. Authorized personnel should not remain close to the antenna system for periods exceeding 1 hour per day without switching off the RF transmitter. However, radiation plan diagrams may be produced and located near the antenna as a warning for crew members, passengers and ship's visitors, or distances from the antenna may be physically labeled at the relevant place.

5.4 *Satellite Determination and Antenna Azimuth Limit*

An Inmarsat-A, B and M MSA must be capable of locating and continuously tracking the GEO satellite available or selected for communication, namely if the ship has in view only one satellite or if the ship is in an overlapping position, respectively. Thus, Inmarsat-C has an omnidirectional antenna and does not need a tracking system. Locating and tracking may be done automatically, as in the case of an SES, or manually, as with a portable MES [01].

In fact, it is common practice to believe that the GEO satellites are fixed and that once the link has been established it will remain so as long as the mobile does not move. However, ships or other mobiles are always moving during operational management of voyages and satellites are under the influence of a number of variable astrophysical parameters, which cause it to move around its station by up to several degrees. At this point, an ADE tracking system must counteract this by repositioning the SES antenna at regular intervals and in case of need. The carrier signal is monitored continuously and, if a reduction in its amplitude is detected, a close-programmed search is initiated until the carrier strength is again at maximum. No loss of signal occurs during this process, which is automatically initiated. Obviously, the greatest tracking problem will arise when the SES is moving at speed with respect to the satellite. In a more general sense, an Inmarsat-A and B MSA may be moved through any angle in azimuth and elevation as the vessel moves along its course. In this case, it is essential that electronic control of the antenna is provided. In practice, ship antenna control system may be achieved by manual and/or even automatically by simple electronic feedback methods [02].

1 Manual Commands – When the radio or navigation operator onboard ships has selected manual control, elevation is commanded by up and down keys, whereas azimuth positioning is controlled clockwise and counter-clockwise keys. In such a case, a command would be used when the relative positions of both the vessel and the satellite are known. Azimuth and elevation angles of antenna can be derived and input to the equipment, by using the two A and E charts of Inmarsat satellite network coverage. Once the antenna starts to detect a satellite signal, the operator display indicates signal strength. Fine positioning can now be achieved by moving the ship antenna in A and E in 1/6th degree increments until maximum field strength is achieved.

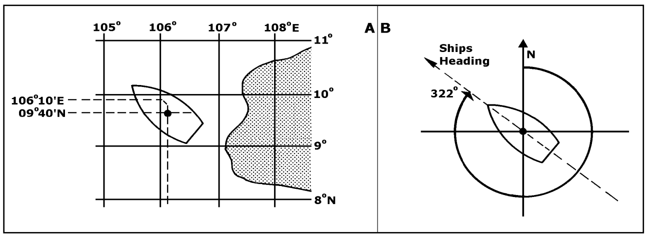

Figure 10. Antenna Pointing
Courtesy of Manual: "Saturn 3" by EB Communications [04]

2 Automatic Control – Once geostationary satellite lock has been achieved, the system will automatically monitor signal strength and apply A/E corrections as required in order maintaining this lock as the vessel 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^{o} and 85^{o} limits, whereas the azimuth motor is stepped through 10^{o} segments. In s such a manner, if the assigned common sig-

naling channel signal is identified during this search the step tracking system takes over to switch the antenna above/below and to each side of the detecting signal location searching for maximum signal strength.

4 Gyroscopic Control – Using this mode the lock is maintained irrespective of changes to the vessel's course by sensing signal changes in the ship's gyro repeater circuitry. In the proper manner, satellite signal strength is monitored and if necessary, the A/E stepper motors are commanded to start searching for the maximum signal strength.

5 Antenna Rewind – The antenna in the ADE is provided on a central mast 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 9. (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:

- Operational Area is the antenna-rotating limit in the azimuth plane. In fact, the antenna can rotate a total of 540^o, which is shown as a white area in Figure 9. (B). Normally, the vessel antenna will operate in the operational area, which is between 60^o and 480^o.
- Rewind Area is necessary for the following reasons: if the antenna moves into one of the rewind areas, i.e., 10^o to 60^o or 480^o to 530^o (antenna azimuth lamp lights) and if no traffic is in progress, the antenna will automatically rewind 360^o to get into the operational area and still be pointed at the satellite, which is illustrated as a dotted area in Figure 9. (B). For example, the antenna moves from position 1 to 2 and the rewind lamplights. If the SES is occupied with a call and the ship turns so that the antenna enters the rewind area, no rewind will take place unless the antenna comes into the azimuth limit area.
  If this happens, rewind will take place and the call will be lost. The azimuth-warning indicator on the operator display will light to indicate that antenna rewinding is in progress.
- Azimuth Limit Area is an important factor because when the antenna is in this area the azimuth limit lamp lights. If the antenna moves into the outer part of the azimuth limit area, i.e., 0^o to 10^o or 530^o to 540^o, rewind will start automatically, despite traffic in progress.

5.5 *Antenna Pointing and Tracking*

The directional 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, for example, Saturn 3 SES. 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 or via teleprinter command. For manual pointing it is necessary to provide the ship's plotted position, ship's heading by gyro, azimuth angle and elevation angle map of the satellite [01].

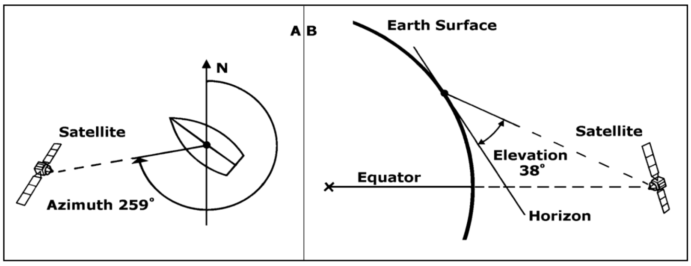

Figure 11. Azimuth and Elevation Angle
Courtesy of Manual: "Saturn 3" by EB Communications [04]

1 Ship's Plotted Position – The plotted position is needed to decide which satellite can be used, namely which Inmarsat network area can be tuned: Indian Ocean Region (IOR), Pacific Ocean Region (POR), Atlantic Ocean Region-West (AORW) or Atlantic Ocean Region-East (AORE), depending on the ship's actual position, as presented in Figure 10. (A). Sometimes, the ship can be in an overlapping area covered by two or even three Inmarsat satellites. In this case it will be important to choose convenient CES and to point the antenna towards one of overlapping ocean regions.

2 Ship's Heading by Gyrocompass – The method of the permanent heading of the ship course determined by gyrocompass is needed for the antenna auto-tracking and focusing system during navigation, illustrated in Figure 10. (B). In this case, this scenario is not needed for omnidirectional ship antennas, such as for Standard-C, mini-C and D+ equipment. This connection is very important for new Inmarsat Fleet and FleetBroadband standards.

3 Azimuth Angle – This is the angle between North line and horizontal satellite direction as seen from the ship, as is shown by example of 259o, in Figure 11. (A). The actual azimuth angle for the various satellites due to the ship's plotted position can be found on the azimuth angle map.

4 Elevation Angle – The elevation angle is the satellite height above the horizon as seen from the ship, as is shown by the example of 38o, in Figure 11. (B). In this case, the actual elevation angle for the various satellites due to the ship's plotted position can be found on the Elevation angle map.

6 CONCLUSION

It is obvious that shipborne MSA configuration needs to be compact and lightweight. These requirements will be difficult to achieve because ship's directional antenna has quite heavy components for stabilization and tracking, and because the compact antenna has two major electrical disadvantages such as low gain and wide beam coverage. Therefore, a new generation of powerful satellite transponders with high EIRP and G/T performances should permit the effective design of more powerful, compact and lightweight MSA for ship applications. On the other hand, new physical shapes of radome and less weight of components are very important requirements in connection with compactness and lightweight, what will permit easier installation and regular maintenance of ship antennas. With shipborne antennas on oceangoing large ships, installation requirements are not as limited compared to fishing vessels or very small boats and yachts, because even small ships have enough space to put mast on compass deck and to install an antenna system. However, in the case of small ships, especially yachts, very low profile and lightweight equipment is required, such as the Inmarsat Fleet F33, Mini-M or C omnidirectional antenna installations.

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