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ARION antenna control and stabilization system

Summary

The design philosophy of an antenna control system for a ship terminal intended to work into the MARISAT civil marine satellite communications system is described.

The required pointing accuracy is discussed in relation to antenna beam width and the disturbances caused by ships' motion. Various possible antenna mount axis configurations are considered, a preferred arrangement selected and some of its advantages outlined. The function of the stabilization, acquisition and autotrack systems is described and a block diagram is shown. The perplexity in the selection of an angular motion sensor is shown along with the requirements of a level sensor. The division of the system between the above and below-deck locations is shown. The practical accuracy in the acquisition and tracking modes is shown when subjected to a method of mechanical angular motion combined with an electrically simulated linear acceleration.

Introduction

The performance specification of the MARISAT civil maritime communications system demands a control system for the antenna mount to meet the requirements for acquisition, tracking and stabilization against ships' motion.

The required pointing accuracy is discussed in relation to the physical disturbances caused by ships' motion. Various mount configurations are described from which a preferred arrangement is selected. The stabilization, acquisition and tracking systems are described, with comments on gyros and level sensors. A method of performance assessment is included.

Required system accuracy

The antenna beam width is 10° and to ensure that the autotracking system acquires the satellite, initial pointing of the antenna must be within ±6°. The accuracy required of the antenna direction during autotracking depends on the margin of transmitted power and on the signal-to-noise ratio of the received satellite signal in the ship equipment. Half the total margin for the tracking system was allowed giving a pointing accuracy requirement of ± 2° in each axis.

Disturbance inputs

It is difficult to specify ships' motion. The specification in Table 1 was chosen as reasonable worst cases for relevant ships. It can be seen that stabilization is necessary and that it is doubtful that the ships' compass alone can be used for stabilizing the azimuth axis.

Table 1
Disturbance input specification

Roll	±25°	0.08Hz
Pitch	±7.5°	0.1Hz
Yaw	±4°	0.01Hz
Surge	±0.1g	
Sway	±0.1g	
Heave	±0.25g	
Roll induced sway	±0.5g	0.08Hz
Pitch induced surge	±0.2g	0.1Hz
Headway	30 Knots (15.4 m/sec.)	
Satellite movement	1°/hr.	
Ship turning rate	6°/sec	

Ship's Compass Errors
Roll and pitch error 2.8° single sided 0.2Hz
Compass – antenna alignment ±0.2°
Error due to ship manoeuvring ±2° (occurs 20 mins. after manoeuvre).

Operational constraints

Before a design of mount can be evolved the operational constraints must also be considered. It was decided that a slipring assembly would not be used and this produces a limited rotation azimuth axis with an automatic reset facility for a turning ship. Also, a function of the MARISAT system is that if a transmitted carrier is lost for longer than 55 secs., the assigned channel is lost and with some mount configurations to achieve reset within this time is difficult due to the long time constants used.

For an efficient tracking system it is necessary to update the acquisition data automatically to current satellite position to prevent the antenna reverting to the initial acquisition position during transient or longer fades, due to, say, higher parts of the ship structure masking the antenna during turns. Other important constraints are environmental conditions, low weight and viable cost.

With reference to the physical inputs and required performance specification, we must consider the selection of a geometric configuration.

Geometric configurations

The main types of possible mount arrangement will now be briefly considered:

PASSIVE STABILIZATION

This is the simplest system. The antenna would be mounted in gimbals with its centre of gravity just below the axes by enough to overcome friction. The total inertia would be adjusted to give a period of oscillation long compared with that of the ship. The antenna is steered in elevation by moving the centre of gravity around the elevation axis and in azimuth by slaving to the gyro compass. Such a system is fully described in Reference 1, and has a stabilization accuracy of about $\pm 6°$. This error is not reduced by the slow autotrack system and is therefore too large.

'FLYWHEEL' STABILIZATION

There are many combinations of this arrangement. The easiest to consider is where two heavy gyroscopic wheels are used to provide the stabilizing torques directly, with no amplification, to produce a level platform similar to but more accurate than the passive system. Disadvantages of this arrangement are – the ships' compass errors are not corrected, the mount and radome are significantly larger and heavier than for active systems and there is difficulty in re-acquiring in the required 55 seconds after azimuth cable unwrap. There are also doubts about the accuracy of the system when the ship is turning.

4-AXIS SERVO MOUNT

This consists of a servoed roll and pitch levelling and stabilizing platform, using instrument gyros or sensors, with a twin axis steerable mount similar to that in the flywheel design. Four axes involve four servo systems, but the separation of the stabilization from the steering function makes each straightforward. The short term errors from the ship's compass are directly coupled into the azimuth axis, but can be eliminated by use of a third gyroscope but this is an undesirable complication.

3-AXIS SERVO MOUNT (ELEVATION OVER CROSS ELEVATION OVER AZIMUTH)

Various combinations of this configuration are possible but one that has been used in a Marconi design relies on a small single axis levelling platform at the back of the antenna. This is used as a horizontal elevation reference and is also maintained level in the cross-elevation plane by a cross-elevation axis. The level transducers and gyros are all mounted on this small platform and do not rotate with the elevation axis. The short term compass errors are again coupled directly into the azimuth axis, and there is also an error in azimuth, caused by the geometry of the axes when the ship rolls. These again can be eliminated by use of a gyro in the azimuth axis.

3-AXIS SERVO MOUNT (CROSS-ELEVATION OVER ELEVATION OVER AZIMUTH)

This arrangement, illustrated in figure 1, has been chosen for the ARION system as the most cost effective design for this application. Its main advantages are that only two gyros are needed and these stabilize the two x-y axes of the antenna at all attitudes. When the satellite is near the zenith the cross-elevation axis takes out roll without requiring rapid azimuth axis motion. When the satellite is near the horizon the cross-elevation axis is parallel with the azimuth axis and takes out short term compass errors and the geometrical error of the azimuth axis. The acquisition control circuits become more complicated since all three axes interact and both azimuth and elevation angle measurements involve averaging over several roll cycles. The autotracking system is, however, simplified as the elevation and cross-elevation axes remain aligned across the signal direction. The axis arrangement produces a compact mechanical design and the smallest size radome and base for a given antenna diameter. This is very important as the radome and base contribute more than half of the total weight of the above-decks equipment. The antenna control system for this design is now discussed.

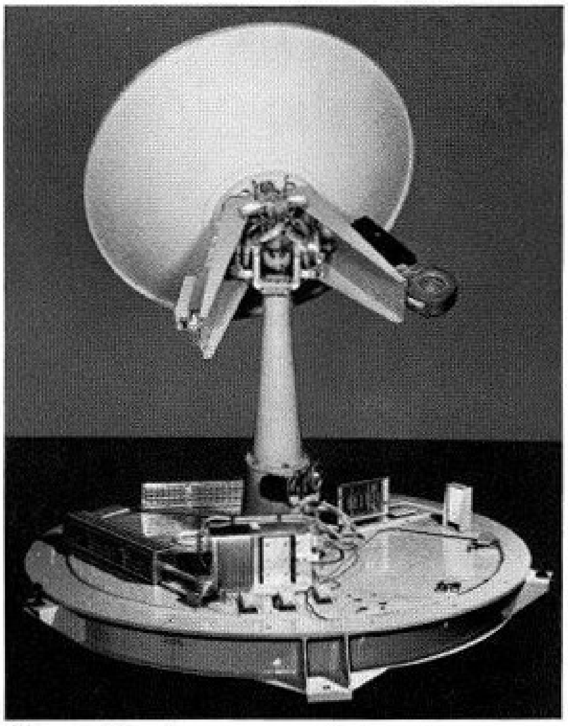

Figure 1. View of antenna mount showing axis arrangement chosen for ARION

Antenna control system

A simplified block diagram of the antenna control system is shown in figure 2.

The system can, for convenience, be divided into three separate functions – stabilization, acquisition and autotracking, which are now considered.

STABILIZATION SYSTEM

The stabilization system relies on two rate gyroscopes mounted as a twin axis package on the back of the antenna. The output of each of these gyros, via suitable

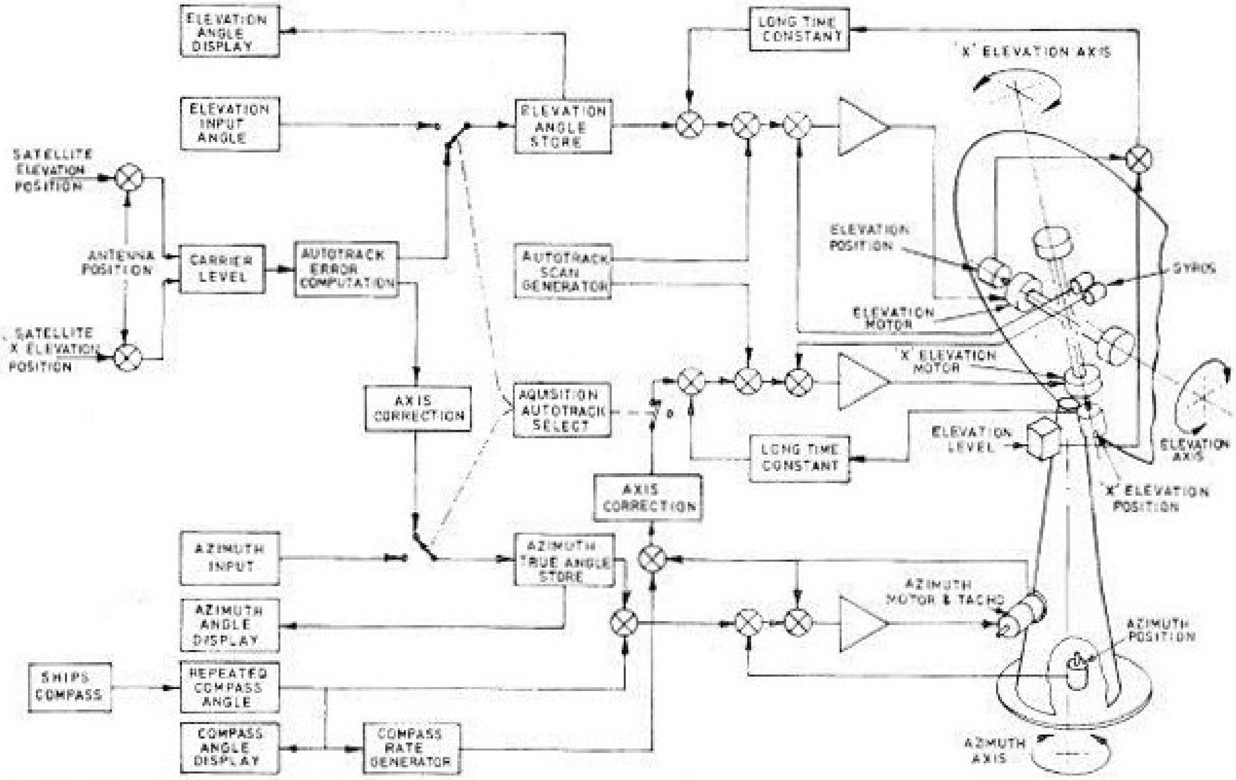

Figure 2. Control system block diagram

amplification and shaping, drives a direct drive torque motor on the elevation and cross-elevation axes. These two closed loops maintain the antenna pointing in a given direction, isolating it from the ship's motion. The antenna is balanced to reduce disturbance torques due to lateral accelerations. The azimuth axis is also stabilized from ship's heading changes using an output from the ship's gyro compass. This only acts as a long term correction as the cross-elevation axis stabilizes in the azimuth plane at low elevation angles. The cross-elevation axis is maintained operating about its mechanical centre by the output of a potentiometer on the axis. This is connected into the gyro rate loop via a 100 second time constant and integrator/lead network to prevent significant response of the axis to the ship's motion. The stabilization system remains active in both the acquisition and autotrack modes.

ACQUISITION SYSTEM

To produce an acquisition system the stabilized axes must be provided with a reference. The elevation axis horizontal reference is a local gravitational level transducer, the output of which is coupled into the stabilization loop via a 100 second time constant and a network similar to the cross-elevation reference. An elevation axis synchro measures absolute angles from this reference and is compared with the output of a digital command on the control console in the radio room. The azimuth axis also uses a synchro mounted on the azimuth axis and this is compared with a converted digital command from the control console. The difference angle, with ship's compass correction added, is used to drive the azimuth motor/gearbox and antenna to the required angle.

A digital method of updating and storing azimuth and elevation angles during autotracking has been chosen and this is implemented by clocking up counters, which store the azimuth and elevation demand angles, from a voltage-controlled oscillator. During normal acquisition the counter is clocked up by manual switches at one of two pre-determined rates; during autotrack the derived tracking error updates these counters. Thus the satellite position is always retained in the system during a long carrier signal fade.

AUTOTRACKING

The autotracking system is a two-axis carrier level sampling system, sometimes referred to as a step-track hillclimbing system. The design aim for the step-track system is to produce minimum tracking loss with the simplest system.

Considering one axis for simplicity, the system operates by sampling the receiver carrier level from two angles by physically moving the antenna angular position, and producing an error angle from the difference. This error is used to drive the antenna in the direction of the maximum signal. The sample time at each of the sample angles must be made long enough to average the system noise. Noise results from two main sources; the residual dynamic angular pointing error of $\pm 0.5°$ at 0.1Hz due to ship's motion, after stabilization, and an apparent low frequency modulation of received carrier due to an effect known as multipath fading. The multipath modulation under worst case conditions is estimated to be as much as 10dB; equivalent to a dynamic pointing error of $\pm 9^\circ$ in the region of 0.1 to 10Hz depending on sea state.

A step amplitude of 0.5° with an integration period of 30 seconds gives optimum results for simulated tests although it may be possible to reduce one or both of these values for practical conditions.

Two of the most important system components are now considered.

ANGULAR MOTION SENSORS

There are a number of possible sensor types that can be employed for the stabilization of this type of system. Four types are compared in Table 2 and show the difficulty in choice, especially in assessing the technical risk involved with the novel type of sensor.

The conventional spinning wheel gyros have an average life of around 6000 hours (0.7 years continuous operation) to full specification and probably a greater life with a fall-off in some parameters. A greater life can be achieved by operating at half gyro wheel speed. The designs are highly proven and multisourced. Regarding the fluidic types of sensor and the fluid accelerometers, the longer life of 10,000 hours is often an estimate based on MTBF calculations and on a few prototypes and the validity of this has to be assessed along with the higher technical risk of achieving the specification at predicted cost.

The gas bearing gyro has perhaps a lower technical risk than the fluidic and fluid accelerometers as it is built around a well-tried gyro design. Its higher procurement cost can be offset by a lower cost of ownership and its life is quoted as 10,000 starts and replacement would not be required for several years under normal circumstances. The best gyro available during development was a standard ball bearing gyro but it is probable that future production systems will be fitted with gas bearing gyros depending on successful evaluation and availability.

The other important transducer is the level sensor which is now discussed.

LINEAR ACCELEROMETER

To enable the system to be driven to a given elevation angle, a reference horizontal datum is required. The usual method of achieving this is to use an inclinometer or linear accelerometer. A servoed linear accelerometer has been chosen for this system and is mounted horizontally to measure very small tilts. In practice the accelerometer also has to measure large lateral accelerations and large roll/pitch angles. The roll/pitch angles are measured by using a synchro mounted on the elevation axis and are scaled and subtracted from the accelerometer. Only one accelerometer is used and this maintains alignment with the elevation axis by rotating in azimuth. The accelerometer also corrects the elevation angle for a listing ship.

SYSTEM PHYSICAL LAYOUT

The track antenna and its mount must be sited at a location on the ship's structure which is high enough to prevent masking of the satellite for a high percentage of operation. The mount is located within a radome to give protection from the environment. The controls for mode selection and acquisition data must be in the radio room and the separation of these can be up to 50m for the standard design. The system has to be split in such a way as to minimize the technical difficulties involved in long cables and at the same time to be easily serviced and cost effective. In this design using analogue techniques for the stabilization system and digital techniques for the acquisition and autotrack system offers the best technical solution and at the same time gives an excellent interface between equipment in the above-decks and below-decks location. The analogue above-decks electronics mounted on the radome base provides the processing and power amplification for the gyro loops, level reference and azimuth axis rate loop. Analogue position transducers are used on the mount, their outputs converted to digital levels as required. The below-decks electronics are mainly digital as this is most cost effective for angle storage and display updating. With the electronics split in this way almost all interfaces can be arranged to be digital with line drivers and receivers.

PERFORMANCE EVALUATION

The full dynamic simulation of the environmental conditions in Table 1 is very difficult and not cost effective; ideally to simulate ship's motion the antenna mount would need to be mounted on a 76m high pole and the base of the pole subjected to the ship's angular, lateral and vertical motion. Instead a part mechanical

Table 2
Comparison of angular motion sensors
(The more x the better)

	Production	Alternative source of supply	Ability to meet spec.	Predicted life	Proved life	Lowest technical risk	Lower cost of ownership
Conventional gyro	xxx	xxxxx	xxxxx	xxx	xxxxx	xxxxx	xxx
Gas bearing gyro	xx	x	xxxxx	xxxxx	xxx	xxxx	xxxx
Fluidic sensors	xxxx	xx	xxx	xxxx	xx	xxx	xxxxx
Fluidic accelerometers	xx	x	xxxx	xxxx	xxx	xxx	xxx

and part electrical simulation of environmental disturbance conditions can be carried out. This is achieved by calculating the effects of lateral and vertical acceleration from all sources and scaling and summing these with their respective phase relationship to the accelerometer output. The ship's angular motion is simulated by means of a simple rocking table and the ship's turning by a simple turntable. After the angular motion tests have been completed and errors calibrated, this input can also be simulated electrically enabling smaller environmental test chambers to be used during the usual hot and cold tests.

The test results obtained on the three-axis mount described produced a stabilization error of better than $\pm 0.5°$. The acquisition accuracy in each axis under the worst combination of conditions was $\pm 1.7°$ in azimuth and $\pm 1.5°$ in elevation giving a spacial error of $\pm 2.55°$, one sigma. The autotrack system removes all of the fixed acquisition error, transducer and alignment errors, and produces a tracking accuracy of $\pm 1.5°$ most of which is the 0.5° autotrack scan and the residual sea motion.

At the end of its restricted azimuth axis travel the antenna can re-set, rotating 360°, and re-acquire the satellite within 55 seconds at all temperatures.

Conclusion

The control system, of which some design features have been described, successfully meets the requirements of stabilization, acquisition and tracking for a terminal working into the MARISAT system and should also meet the requirements of the future MAROTS and INMARSAT system.

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Reference

1 R. J. KIRKBY, 1973: 'A simple stabilized Antenna Platform for Maritime Satellite Communications', *IEE*. Conference publication No.95.