ACCURATE ANTENNA REPOINTING FOR PATTERN MAPPING

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ABSTRACT

The attitude control system of the European Space Agency's Orbital Test Satellite (OTS) was originally designed for nominal earth pointing with only limited bias capability (of up to 2.5° in pitch and roll) which is more than adequate to remove earth sensor/wheel misalignments that could be incurred during or following launch. Subsequently, a need was expressed to support off-nominal coverage missions and antenna mapping tests. A method was thus defined that would provide greater repointing capability (up to 4.6°) while retaining the accuracy available with the precision infrared sensor.

The method is outlined, and the repointing limitations indicated that are inherent to the OTS sensor design (13° in roll and 7° in pitch). Operations and conditions are stated that enable these extremes to actually be reached. The error budget is presented for the case of antenna mapping, demonstrating that attitude restitution can be made so that beam centre position can be determined to an accuracy of 0.1° half cone angle. The significant advantages of the described method are that only one ground station is required, and that results can be available within 24 hours following completion of the test.

Results obtained with OTS are referred to, that support the claims. Finally desirable design modifications are discussed that could allow further increases in repointing capability of future satellites.

INTRODUCTION

Communication Satellite design hinges on fine pointing and high antenna performance to achieve adequate performance at the edge of the cover zones, in particular when spotbeams are carried as part of the payload.

Verification that performance specifications are actually met can be obtained in two distinct ways. The first method is to keep the spacecraft fine pointing, and map the antenna patterns by measuring flux at calibrated earth stations, preferably favourably distributed over the beam shape. The main advantage is that the spacecraft is in a steady state, but this is outweighed by the requirements on the earth stations i.e. all need to be calibrated and highly stable, while flux readings need to be corrected for local weather conditions. These disadvantages render this method labourious and prone to errors.

The second method is to use only one earth station and scan the beam through repointing the spacecraft. This method hinges on the ability to restitute the attitude of the spacecraft with a high accuracy. It is therefore important to limit the disturbance torques during the scanning. Although the used earth station needs to be calibrated and stable as in the first method, only constant weather is required during the mapping. Both methods have been applied succesfully on OTS (1, 2), notwithstanding the limited repointing capability the design was conceived for. The OTS repointing experiment (2) however was dedicated to mapping the spotbeam antenna patterns, in view of the limitations of the hardware implemented.

NOMINAL REPOINTING CAPABILITY OF OTS

Accurate attitude restitution on OTS requires the use of precision infrared earth sensors. Two types are flown for the purpose of technology redundancy. The scanning sensor (IRES A) makes use of a four bolometer configuration, schematically represented in Fig. 1. It locates the horizon through detection of earth/space and space/earth crossing events. Thresholds are set by peak detectors such that background radiation variations are compensated for. This detection system allows the sensor to achieve an accuracy of 0,03 degrees (3σ random) in both pitch and roll axes.

The thermal balance sensor (IRES B) makes use of a thermopile arrangement as shown in Fig. 2. This sensor determines the local thermal balance through measuring elements b. Background radiation is measured by elements a and c, which in fine pointing should compensate the readings obtained with elements b.

The detector size of this sensor was selected to be compatible with a bias range of 2.5 degrees. The resulting penetration into the earth image compromises the background compensation. With calibration an accuracy of 0.06 degrees (3σ random) can be achieved in fine pointing.

Both sensor detector configurations have been designed to support ± 2.5 degrees of repointing in both axes. An electrical bias capability has been provided which meets this range in nominal operations. In fine pointing the range of repointing accepted is only ± 0.2 degrees, as this was meant to compensate for misalignments that could be incurred during and following launch. A small range was deemed sufficient since pre-launch misalignments were established to be less than 0.07 degrees. With the scanning sensor it is possible to repoint 1° in roll and 2° in pitch, whilst retaining high accuracy. With the thermal balance sensor, outside the fine pointing range accuracy is not well defined as, dependent on the season, an error of max. 0.8 degrees can be introduced in the absence of background compensation .

With a beam size of 2 degrees half cone angle for spotbeams, it is obvious from the above that nominal, repointing of OTS is not adequate to perform pattern mapping. This is particularly true when the measuring station is not located close to the beam centre, which adds to the maximum repointing angles required.

LIMITATIONS OF THE OTS REPOINTING RANGE

Since closed loop repointing is too restrictive, alternative schemes have been investigated and executed on OTS. It is obvious that closed loop pitch control must be retained in all cases. Extension in this axis can still be achieved, however, when the scanning sensor is used.

For highest accuracy, pitch readings are nominally obtained by summation of the output signals from the northern (or southern) pair of bolometers.

At half the gain, and consequently 40% increase in noise, such readings can be obtained from either bolometer. For the OTS scanning sensor (IRES A) the pitch repointing limit was demonstrated to be 4.6 degrees away from the centre position of the bolometer in use.

The maximum beam repointing occurs when this bolometer is brought to scan over the equator, and amounts to no less than 7° with an accuracy of 0.04°.

Scanning in East/West direction to this extent can thus be obtained by applying the electrical bias signal to the scanning sensor, with attitude reconstitution accounting for the roll and yaw angle at the time of repointing. Accurate knowledge of roll and yaw angles is mandatory, and can be provided by taking advantage of the phenomenon of orbital coupling.

It is well-known that for earth pointing satellites, roll and yaw angles exchange over a quarter orbit due to the slow pitch rotation. With no further thruster activity, roll and yaw angles are very accurately defined and only need to be corrected for the drift in the momentum vector position due to solar radiation pressure. The motion in roll then serves to perform the desired north/south scanning. The motion in yaw contributes to the pointing of the beam in East/West direction as determined by the known elevation angle of the centre of the beam with respect to the subsatellite point. For the OTS spotbeam pointing to Geneva (48°N) this correction introduces an error of 0.02° in the reconstituted value of the East/West scan.

The amplitude in roll that can be safely achieved is determined by the necessity to retain pitch control. If only one detector is used for pitch control, the alternating use of the detectors according to table I enables OTS repointing over a range of maximum 13° in North/South and 7° in East/West. Fig. 3 compares the capability of open loop and closed loop repointing for the OTS spotbeam.

On OTS, the IRES A configuration control can be selected automatically within the sensor. This feature interferes with the above scheme. Use of a specific single bolometer around local midnight is possibly overridden by the detector configuration selection. This phenomenon limits the roll amplitude for depointing to 2.5 degrees, to ensure that in such event pitch control is not even temporarily lost. The proven repointing range on OTS is thus 2.5 degrees in roll and 4.6 degrees in pitch. On the current models, this phenomenon has been eliminated, allowing utilization of the full repointing range on the MARECS/ECS spacecraft.Table II summarizes the error budget for repointing. This table shows that the major contribution to the error stems from the inaccuracy in flux readings of the calibrated earth station. It also demonstrates the major advantage of the scheme, namely that only one earth station is involved in the mapping. Repeatability must therefore be good, and this was confirmed by the spotbeam tests performed on OTS to be 0.04 degrees (2).

The useful limits for pattern mapping are derived from the above repointing range. Mapping requires a raster that can be completed during the period the antennae are in thermal equilibrium, in order to measure well defined beam centre positions.

On OTS, for highest confidence, mapping has been performed near solstices, when maximum diurnal effects occur shortly after sunset and sunrise. Antennae thermal equilibrium is then maintained for more than 3 hours before and after local midnight and local midday, which allows a useful raster of 6.5 degrees half cone angle. This size of raster is considered sufficiently large to enable adequate characterisation of global beams as for instance currently employed on MARECS Spacecraft (Fig. 4).

Fig. 5 summarizes the utilization of repointing available with the OTS system design. In this figure, the angle is determined by the period of thermal equilibrium of the antennae. The angle is controlled by the allowable yaw angle for tracking. When properly selected, prolonged repointing can be maintained in the range defined above. An experimental transmission between MADEIRA and LISBON at the occasion of the “Day of Portugal” offered the opportunity to practise such repointing for a period of more than 6 hours.

MODIFICATIONS FOR FURTHER EXTENDING REPOINTING CAPABILITY

As explained before, the OTS system using the scanning IRES is well capable of performing the majority of repointing tasks identified today. However, it may be necessary to consider modifications to the system that would enable further extension of the repointing range, for both types of sensors available.

For the thermal balance sensor, the option exists to refine the compensation method and hence improve on accuracy while retaining the repointing range. In this option, the analog type measurement shown in Fig. 2 is replaced by a “digital” thermopile configuration where each element is reduced in area and can act as measurement or compensation element, as required. This concept has actually been brought to prequalification standard by the manufacturer of this type of sensor (SODERN). It has a demonstrated capability (in the laboratory) to extend the repointing range up to 4.5 degrees, retaining the accuracy of the OTS static sensor.

A second option is, to use the sensor in combination with a high precision two-axes mechanism. Since the mechanism would now take care of the repointing requirements, the sensor basic accuracy can be significantly improved by reverting to the modified SYMPHONIE design now under production for the French TELECOM 1 program. The achievable accuracy of this sensor is 0.04 degrees in each axis. Whilst suitable mechanisms are still under development both in France and in the U.K., their accuracy can be assessed (from similar designs used to repoint antennae) to be one order of magnitude better.

Such a mechanism could certainly also be considered for extension of the repointing range of the scanning IRES. With the inherently large repointing capability in roll, a more attractive option exists, however, in increasing the oscillation amplitude of the scanning mirror. With the application of magnetic suspension, for instance as developed in the U.K., the earth image can be scanned through completely. While this modification improves the pitch repointing range dramatically, it would also provide more flexibility in particular when the sensor needs to be used for additional tasks outside the geostationary orbit.

CONCLUSION

The patterns of both spotbeam and global beam antennae can be satisfactorily mapped with the present design of attitude control systems on momentum bias spacecraft, when orbital coupling is actively employed. Using currently available scanning sensors, a raster scan over 6.5 degrees half cone angle is feasible at an accuracy of 0.1 degree (3 sigma).

Repointing of the beams to a maximum of 13 degrees in North/South direction, and of 4 to 7 degrees in East/West direction, can be performed to support missions outside the nominal cover zones for prolonged periods of time, basically using the same phonemenon.

Although there is no immediate need to provide for an extended range several options are being pursued, some under ESA contract, that would significantly improve the flexibility of spacecraft attitude control.

ACKNOWLEDGMENTS

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PITCH / ROLL	EAST	ZERO	WEST
North	4	2 + 4	2
Zero	3 + 4	3 out of 4	1 + 2
South	3	1 + 3	1

Table I **Detector use for maximum repointing**

Source	Error (degr.)	Remarks
Roll estimate	0.02	Incl. correction for solar radiation effects
Pitch reading	0.04	Incl. electical bias
Yaw correction	0.02	
Attitude error	0.05	RSS
Flux readings	0.09	Calibrated station, ± 0.1 dB
Beam centre position	0.1	RSS

Table II **Error budget on beam Centre position during repointing (for spotbeam)**

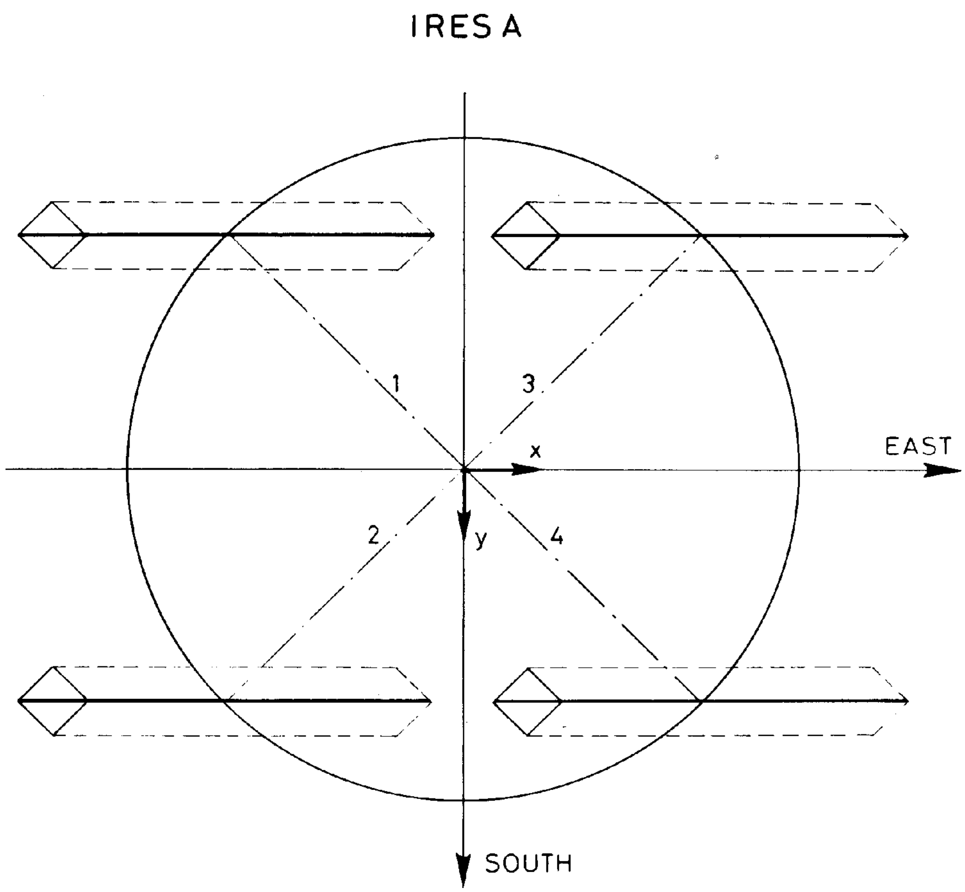

FIG. l SCANNING SENSOR DESIGN

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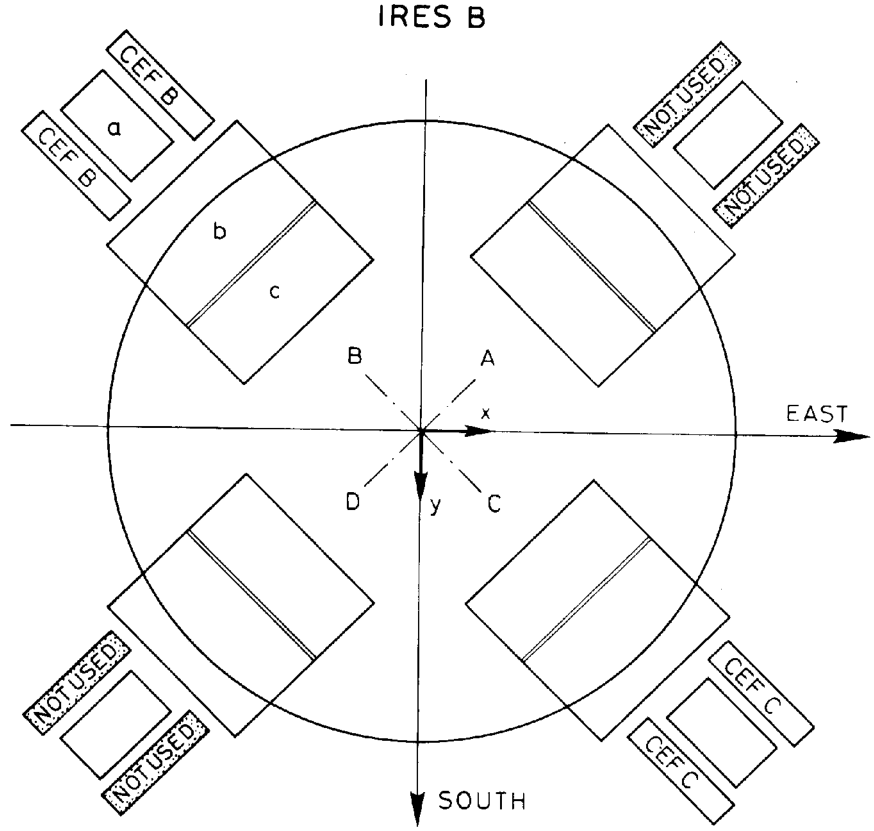

FIG. 2 THERMAL BALANCE SENSOR DESIGN

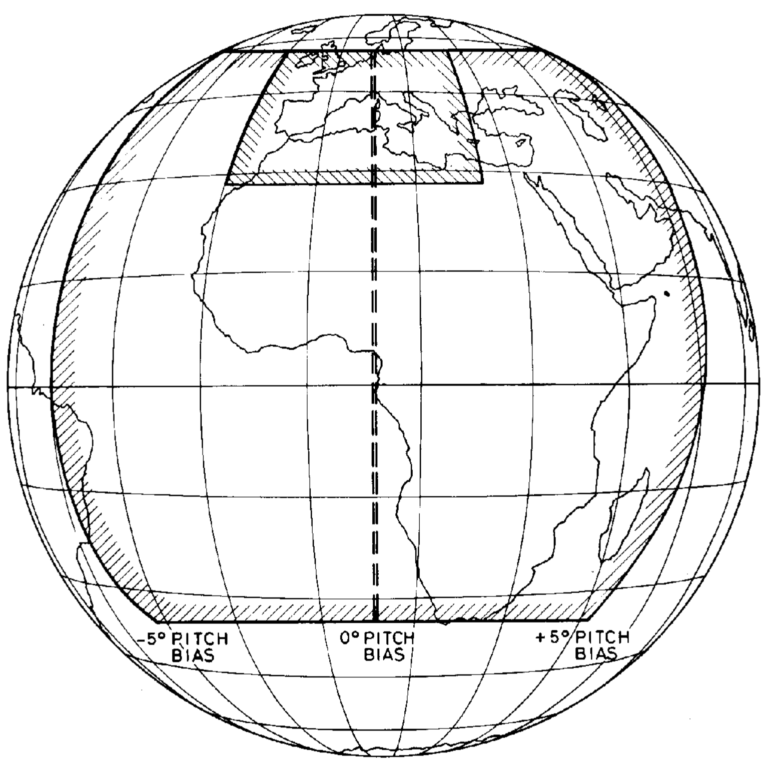

FIG. 3 OPEN LOOP AND CLOSED LOOP REPOINTING LIMITS

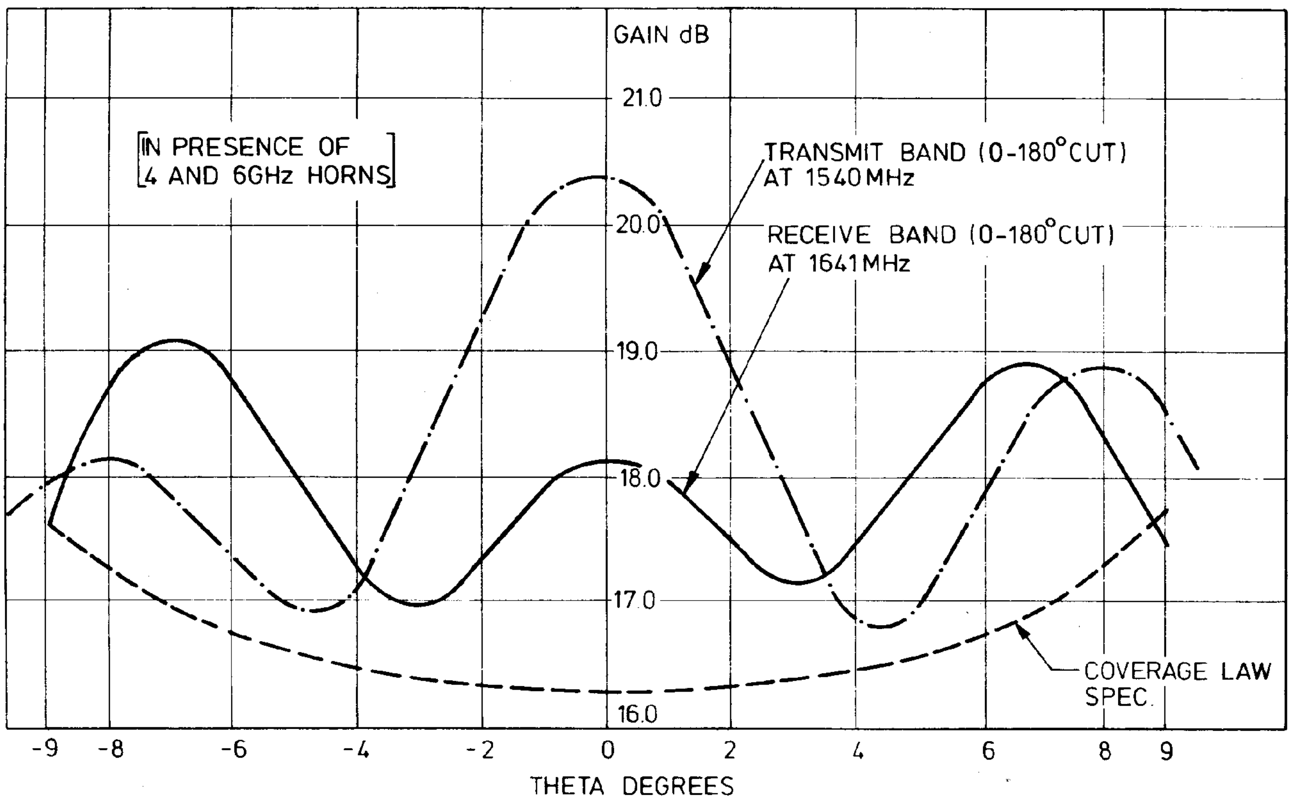

FIG. 4 GLOBAL BEAM COVERAGE ON MARECS

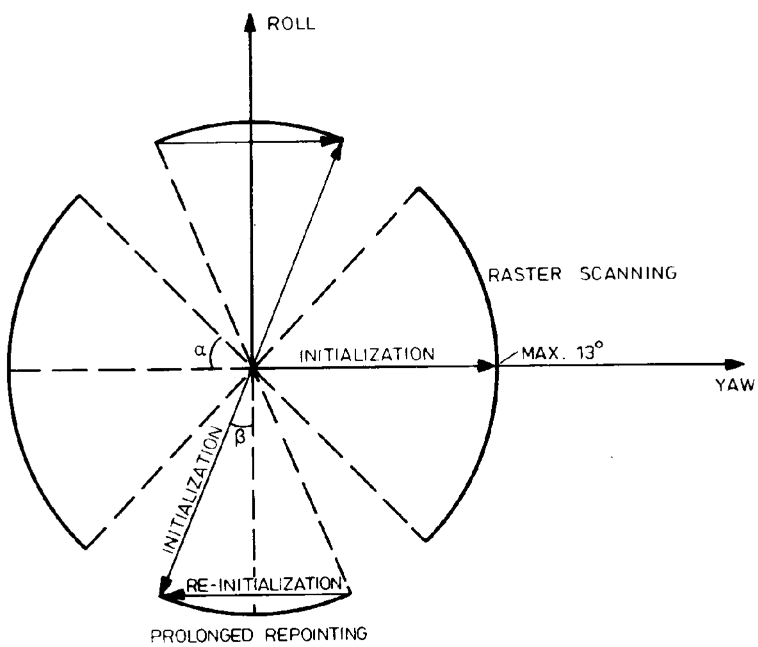

FIG. 5 SUMMARY OF REPOINTING UTILIZATION