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Performance Assessment of GSO Satellite before and after Enhancing Pointing Effect

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Abstract—This paper presents the effect of the orbit inclination on the pointing error of the satellite antenna and consequently on its footprint on earth for a typical Ku- band payload system.

The performance assessment is examined using both analytical simulations and practical measurements, taking into account all the additional sources of the pointing errors, such as East-West station keeping, orbit eccentricity, and actual attitude control performance.

An implementation and computation of the sinusoidal biases in satellite roll and pitch used to compensate the pointing error of the satellite antenna coverage is studied and evaluated before and after the pointing corrections performed.

A method for evaluation of the performance of the implemented biases has been introduced through measuring satellite received level from a mono-pulse tracking 11.1m transmitting antenna before and after the implementation of the pointing corrections.

Keywords—Satellite, inclined orbit, pointing errors, coverage optimization.

I. INTRODUCTION

FOR a satellite near the end of its operational life time and to increase its expected lifetime for additional period, the satellite is put in an inclined orbit by stopping the inclination control (north/south maneuver correction) and only performs east/west maneuver corrections to adjust the satellite in the longitudinal window. Using this approach more than 90% of the propellant consumption during the maneuvers is saved and the satellite lifetime could be extended up to more than 2 years in-orbit till a replacement is manufactured and launched in its place.

The geosynchronous orbit (GSO) inclination induces an effect on the pointing performance of the satellite. The effect includes the variation in the satellite attitude and consequently degradation in the uplink and the downlink performances due to the misalignment of the satellite antennas, which causes a shift in the satellite footprint on earth.

In this paper, we will discuss a way to re-adjust periodically the satellite antenna pointing towards its operational coverage area and consequently, retaining the point-to-point optimization between the transmitted earth station antenna and the satellite received antenna during the day. The performance enhancement will be practically discussed in both the satellite attitude and the uplink performance points of view.

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II. SATELLITE ANTENNA POINTING ERROR

Satellite antenna pointing errors may be classified in two main categories:

1. Static pointing error, occurring due to antenna alignment errors, sub-assembly misalignment errors, beam-forming network inaccuracies (path lengths, offsets, etc.).
2. Dynamic pointing error, occurring due to satellite orbital drift (slow/daily), dynamic response to in-orbit maneuvers of the satellite (fast), thermal distortion (slow/daily), beam-forming network variable mismatches (drifts, ageing, etc).

Usually, in satellite antenna design it is necessary to account for satellite orbit and attitude (roll, pitch and yaw) control during normal operation. Uncorrected pointing errors affect the satellite effective EIRP and G/T performance.

The effect can be assessed as a loss in effective gain at the Centre of Coverage (CoC) and at the Edge of Coverage (EoC):

$$\text{Gain Loss at the CoC, } \Delta G = -12 \times (\Delta\vartheta/\text{HPBW})^2 \qquad (1)$$

$$\text{Gain Loss at the EoC, } \Delta G = -17.4 \times (\Delta\vartheta/\text{HPBW}) \qquad (2)$$

where;

$\Delta\vartheta$ = Pointing Error, HPBW = Half-Power Beam Width

When un-controlled, the inclination of the equatorial orbit evolves under the effect of different forces and in particular, under the effect of the luni-solar gravity.

The luni-solar gravity causes an average motion of the orbit pole. The magnitude of these perturbations varies according to the respective periods of the Moon and Sun. The resulting motion of the orbit pole is a combination of a secular drift and periodic oscillations. The secular drift of the orbit pole depends mainly on the Moon orbit pole motion (18.6-year period), Fig. 1.

Geosynchronous orbit inclination constitutes a primary cause of daily continuous satellite yaw variation as depicted in Fig. 2 [1]. As a matter of fact the non-zero inclination causes the sub-satellite point to move along a figure-of-eight (Fig. 3) [2].

1. When the satellite is at orbit nodes (T0+6 and T0+18 hrs in Fig. 2, the sub-satellite point is above the Equator and the satellite has a yaw error equal to the inclination;
2. When the satellite is 90° away from the orbit nodes, (T0 and T0+12 hrs), the sub-satellite point is at the top (or bottom) of the eight and the yaw error is zero.
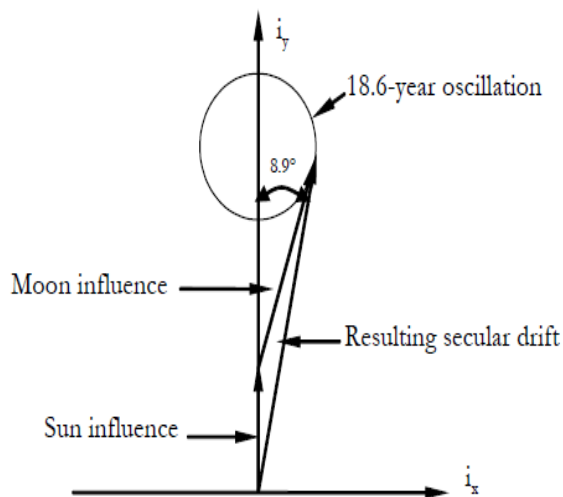
World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:9, No:12, 2015

Fig. 1 Secular drift of the inclination vector

From the ground station perspective, the satellite is seen as moving in the sky along a similar figure-of-eight around its nominal station [3]. The satellite reaches northerly and southerly latitudes (declinations) equal in value to the inclination of the orbital plane with respect to the equatorial plane. The inclination changes on a yearly basis by 0.75° - 0.95°, owing to the luni-solar perturbation and depending upon the orientation of the Moon orbital plane.

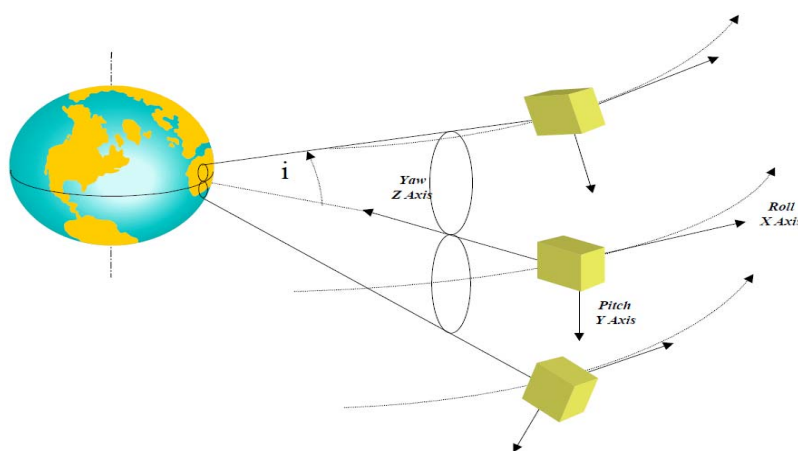Fig. 2 Satellite inclination-induced Yaw Variation along the orbit

Fig. 3 Satellite pointing in inclined orbit configuration

III. STATION KEEPING MANEUVER

A satellite in geostationary orbit is continuously perturbed by the forces due to the triaxiality of the Earth, luni-solar gravitational forces and solar radiation pressure [4]. The semi-major axis of the geostationary satellite tends to increase because of the perturbation from the Earth's tesseral harmonics. The orbital period is increased from the geosynchronous period, so the satellite is drifting west toward a stable point. The perturbations caused by the Sun and Moon are predominantly out-of-plane effects, causing a change in the inclination, and in the right ascension of the ascending node [5]. The eccentricity of a satellite is affected by the Solar radiation pressure.

The East/West Station-Keeping (EWSK) maneuver burn direction is tangent to the orbit, and it adjusts the drift rate and the eccentricity of the orbit. While the North/South Station-Keeping (NSSK) maneuver burn is normal to the orbit, and it adjusts the inclination of the orbit and right ascension of the ascending node, controlling the daily latitudinal excursions of the satellite.

The station-keeping maneuver strategy should be designed to minimize the expenditure of spacecraft propellant and the operation of the ground station. The East/West station-

World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:9, No:12, 2015

keeping box for the GEO satellite was analyzed and allocated with +/- 0.075° band. The same 14-day EWSK cycle is used in this study and the station keeping box allocation is summarized in Table I.

Generally, the EWSK and NSSK maneuvers should be coordinated to minimize the operational load in satellite control center by avoiding simultaneous maneuvers. A 14-day EWSK and 14-day NSSK maneuver cycles were applied to the collocation strategy. There is no NSSK maneuver for the inclined GSO satellite since the natural drift of the inclination is allowed, and it passes the equator two times in a day.

TABLE I
EWSK BAND ALLOCATION FOR 14-DAY CYCLE

Effects	Allocated Values
Guard band for OD and maneuver errors	0.02°
Guard band for luni-solar perturbations	0.014°
Allocation for drift	0.012°
Allocation for eccentricity	0.134°
Mean eccentricity limit	0.0004°

IV. EFFECT OF NON-ZERO INCLINATION ON FOOTPRINT

Fig. 4 shows the geometry of the nominal and the inclined geostationary orbits, with evidence of the inclined orbit ascending node and vertex. A typical multi-beam antenna footprint is sketched both for the nominal and for the inclined orbit. It highlights the effect of the orbit inclination on the antenna footprint. Fig. 4 shows the different nature of the antenna pointing error:

1. The pointing error at the orbit nodes is due to the satellite error in yaw;
2. The pointing error at the orbit vertex is due to the satellite declination error.
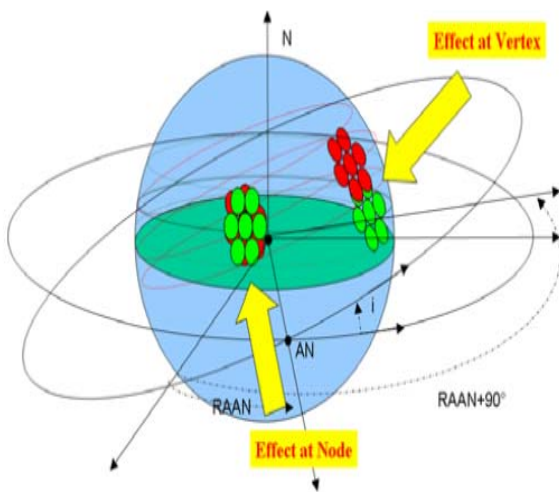

Fig. 4 Effects of Orbit Inclination on Antenna Footprint

To counteract for antenna pointing error induced by a nonzero inclination, corrections can be made to the satellite antenna pointing. Such corrections can be applied by:

1. Steering the whole spacecraft body;
2. Steering the antenna reflector (or sub-reflector);
3. Steering the beam pattern.

The corrections are done using any of the methods above, at the orbit nodes and at the vertex. At the orbit nodes the correction can easily be made by rotating the spacecraft body around the yaw axis by an amount equal to the orbit inclination i: as the yaw error decreases along the orbit away from nodes, so does the yaw correction, until it reaches zero at the orbit vertex. The correction to be applied at the orbit vertex is equivalent to a rotation of the spacecraft body around the roll axis somehow proportional to the orbit inclination i.

In this paper, the correction was done and analyzed using the 1st method "Steering the whole spacecraft body", through an on-board software "sidereal roll and pitch compensation" to implement the control algorithm [6]. It has been used to compute the roll and pitch compensations for a satellite located at pre-defined orbital position, the compensations have been computed to optimize the coverage of ten stations as seen in Table II.

TABLE II
STATION COORDINATES

Station	Longitude	Latitude
Cairo	31.24°	30.04°
Alexandria	29.92°	31.2°
Abu Dhabi	54.37°	24.47°
Doha	51.53°	25.29°
Amman	35.95°	31.96°
Kuwait	47.99°	29.38°
Muscat	58.55°	23.61°
Casablanca	7.60°	33.60°
Tunis	9.00°	34.00°
Bagdad	44.50°	33.3°

V. PAYLOAD MOTION COMPENSATION

To minimize the impact of the orbit inclination on the antenna coverage, the satellite attitude is controlled such as the inclination is compensated along the orbit.

A. Roll Pointing Error Compensation

To counteract the roll pointing error induced by the orbit inclination, a roll bias can be commanded to ensure the satellite z-axis points the equator at the Earth surface rather than the Earth center (Fig. 5). This roll bias shall be sinusoidal at sidereal period to follow the inclination effect. It is maximum at high and low points of the inclined orbit.
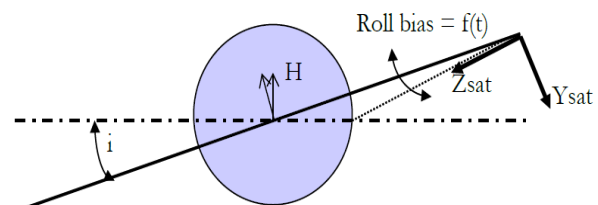

Fig. 5 Roll Compensation Principle

B. Yaw Pointing Error Compensation

The satellite is controlled in pitch, using the fixed momentum wheel (FMW) and in roll, with the solar sailing

World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:9, No:12, 2015

(SOSA). The yaw is not directly controlled: its pointing is ensured through the orbital coupling. A direct compensation setting a yaw bias cannot be envisaged.

The same principle of orbital coupling has to be used to minimize the yaw pointing error at ascending nodes. The yaw pointing error is compensated by an appropriate combination of:

- a roll bias for N/S coverage pattern correction (rotation around Xsat),
- a pitch bias for E/W coverage pattern correction (rotation around Ysat),

This combination is assessed to minimize the payload coverage motion at Earth surface. It thus depends on the payload coverage. Fig. 6 shows the effect of a pitch bias and a roll bias for the S/C at the north and equator.
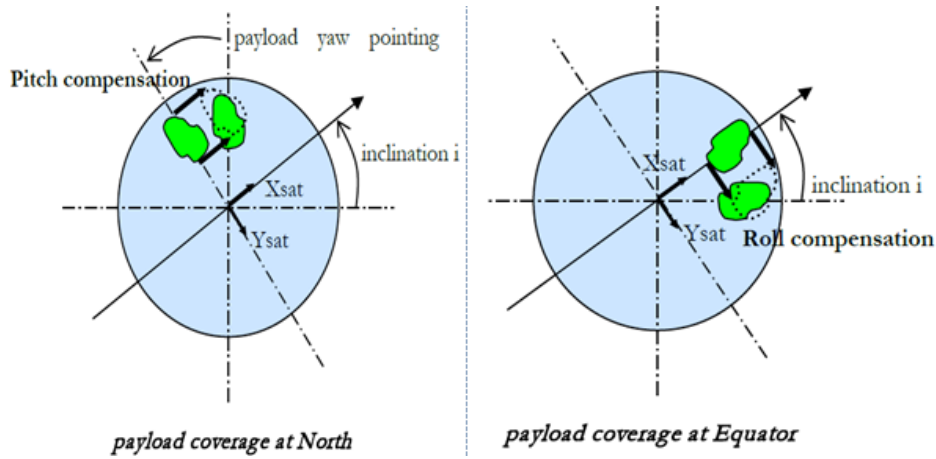
VI. ANALYTICAL SIMULATION

For an inclination angle equal to 1.5deg, Table III provides the corresponding sidereal oscillation parameters.

The satellite attitude would follow sine motion of amplitude inclination angle as shown in Fig. 7.

Next, we could see in Fig. 8 the pointing error with respect to the different stations with and without the correction.

In Fig. 9, it is shown the residual pointing error with respect to all the stations in Roll and Pitch.

TABLE III
SIDEREAL OSCILLATION PARAMETERS

Constant roll bias	0.000°
Roll amplitude	0.199°
Constant pitch bias	0.00°
Pitch amplitude	0.132°
Sidereal oscillator phase	-128.89°

Fig. 6 Yaw Compensation Principle
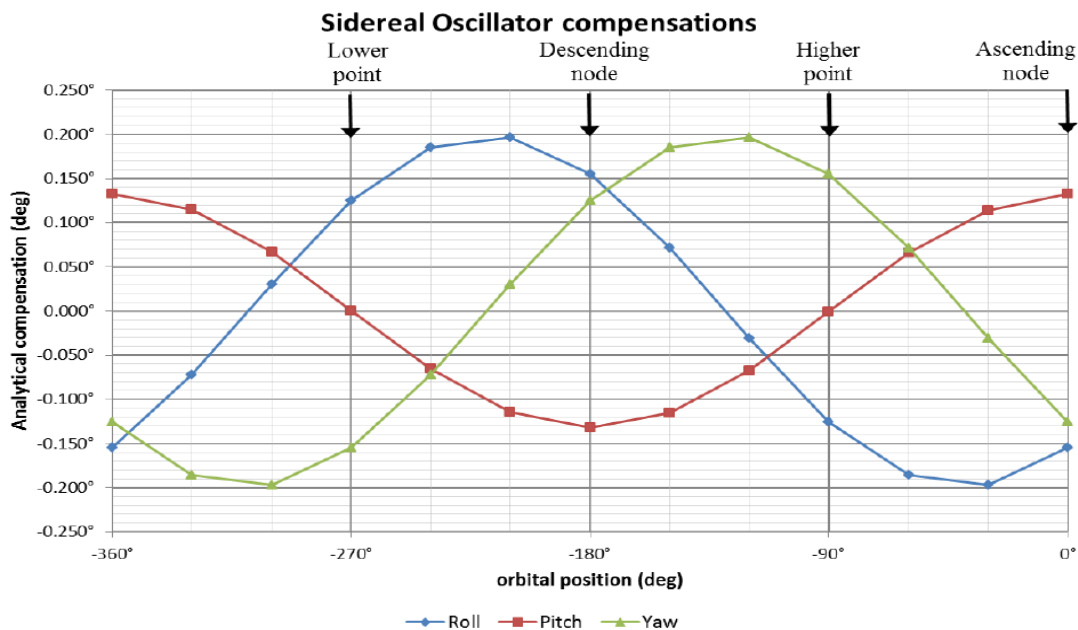
Fig. 7 Compensations processing outputs

World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
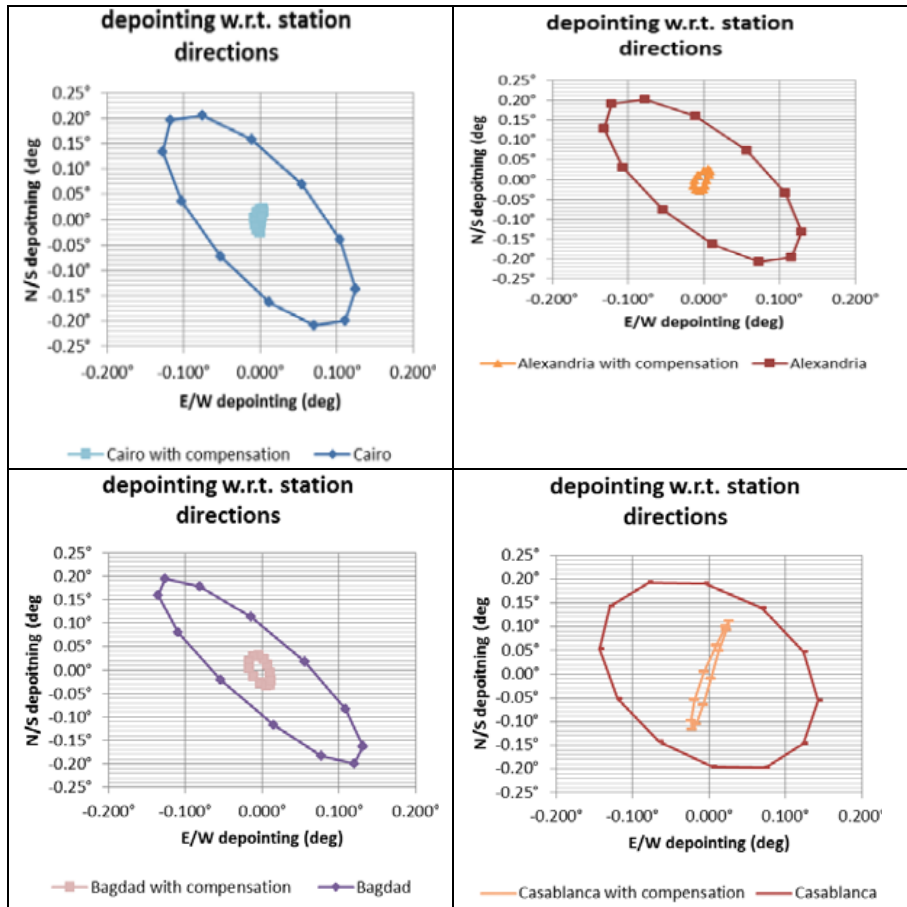Vol:9, No:12, 2015

Fig. 8 The pointing error
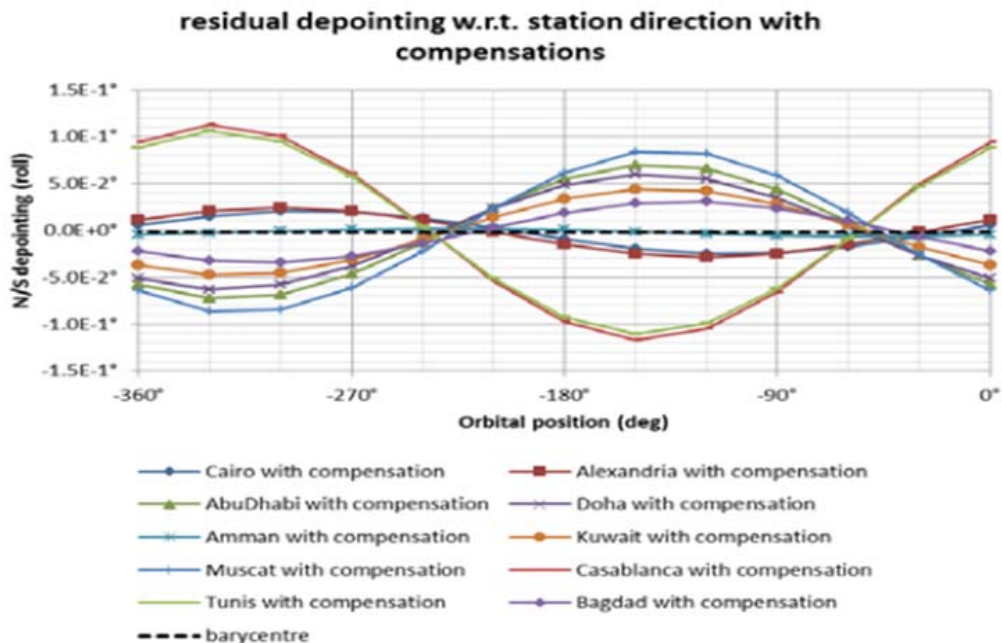

Fig. 9 pointing error with respect to all the stations

World Academy of Science, Engineering and Technology
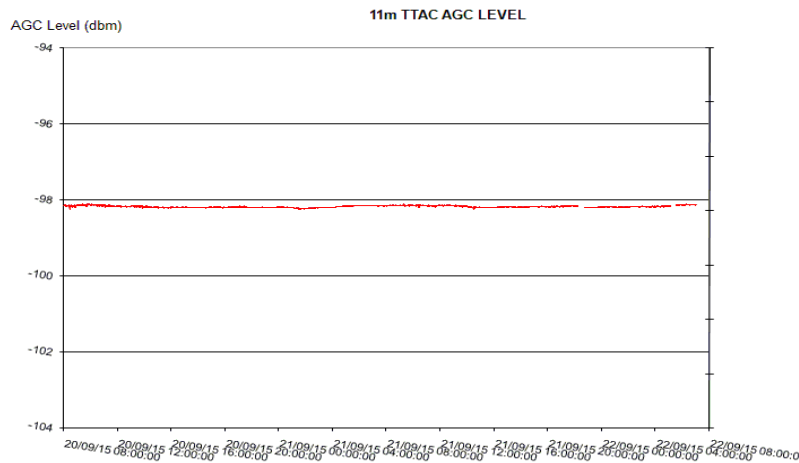International Journal of Electronics and Communication Engineering
Vol:9, No:12, 2015

(a)

(b)
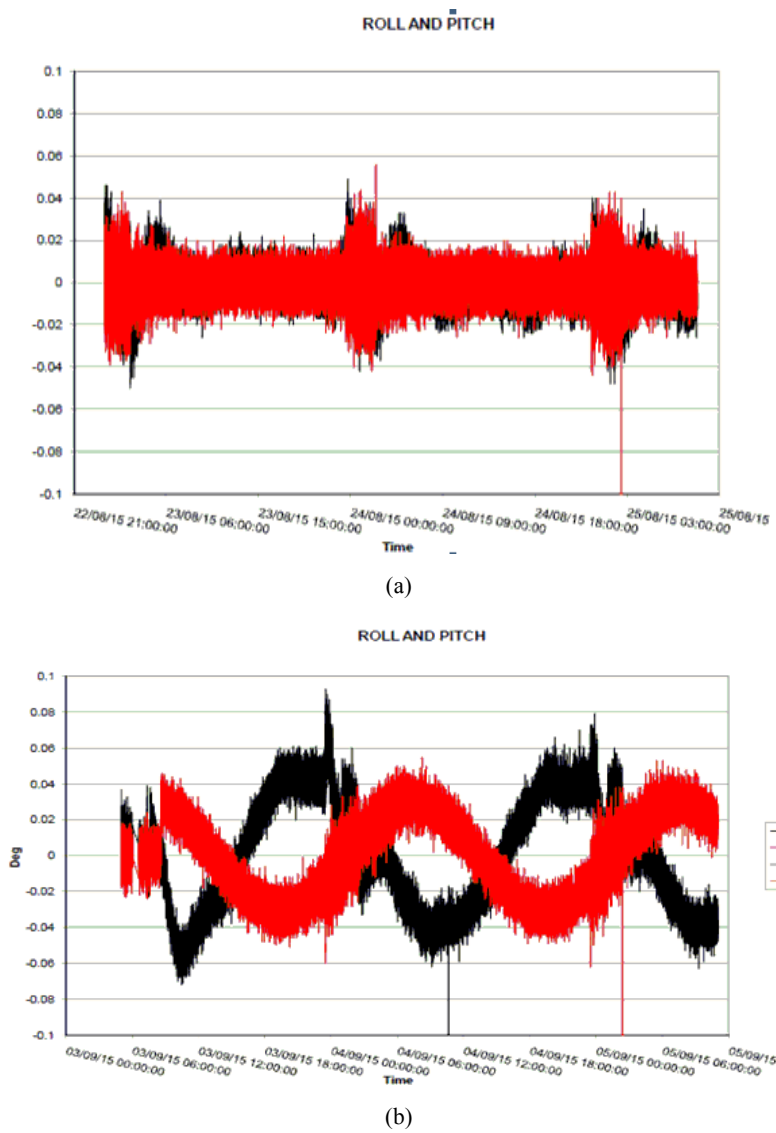
Fig. 10 (a) Satellite Attitude before patch loading (b) Satellite Attitude after patch loading

(a)

World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:9, No:12, 2015
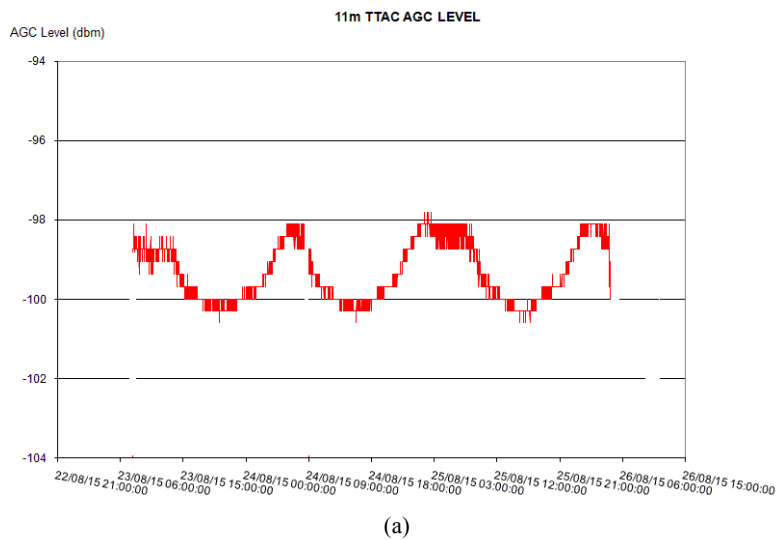
(b)

Fig. 11 (a) AGC level from 11m tracking E/S before patch (b) AGC level from 11m tracking E/S after patch

IV. CONCLUSION

The paper presented the consequence of operating a satellite in an inclined orbit, were the targeted coverage area is affected. Implementing an on-board software program to periodically re-adjust the satellite to correct the inclination effect is considered the most efficient and common way compare to the other methods that needs on-board hardware configurations.

A method for ground verification of implemented software was developed using the available 11.1m mono-pulse tracking transmitting antenna, which provided a good results for both the reception level and the daily signal variation. This indicated that the satellite had been well oriented towards the earth station after the software adjustment.

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