Deviations in CBERS-4 Satellite Direction Components From The Electromagnetic Disturbance of Communication Antennas

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Abstract. The CBERS-4 is a low Earth orbit satellite, with a set of antennas S-band/UHF for communication almost omni-directional. For the electromagnetic radiation from transmission antennas, was developed a model of electromagnetic disturbance considering the antennas theory and the laws of the conservation energy-momentum. Was propagated the orbit of the CBERS-4 satellite considering your state vector from the March 14, 2016, at 11h 14m 15.23s using the equation of motion in the form of cartesian components. From the state vector of the CBERS-4 satellite was possible to propagate the orbit for different periods, without disturbance (considering just the problem of two bodies) and with a disturbance of electromagnetic origin. The model of reaction of electromagnetic acceleration on the satellite depends on only the type of antenna. Quadrifilar and parabolic propeller antennas were considered in this paper. Using the equation of motion of the satellite based on the method of Runge-Kutta of fourth and fifth degree, the effect disturber this modeling was applied on the CBERS-4 considering the mass of satellite, characteristics of antenna, power irradiated and gain maximum of antenna. The final analysis discusses the values of components in the direction (radial, cross and normal) and the coordinates X-Y-Z considering the case disturbed to both antennas.

1. Introduction
The disturbed orbital motion of artificial satellites is historically discussed, and still presents problems not solve about the nature of the disturbances, and some disturbances still not characterised or considered in their propagated orbit models. Among the disturbances known and cited in the literature, Cook (1962), Seeber (1993), Montenbruck and Gill (2005), Eshagh and Najafi (2007), Cojocaru (2007), cite the influence of the gravitational attraction of the Moon and the Sun, pressure of solar radiation direct and indirect (albedo), relativistic effects, disturbances with origin in the Earth’s magnetic field, due to the wind solar, Poynting-Robertson effects and atmospheric drag. About the disturbance due to the electromagnetic effects from the antennas shipped in a GPS satellite, Ziebart, Sibthorpe and Cross (2007) and Solano et. al. (2012), discuss about a constant of acceleration radial around 2.7 x 10⁻¹⁰ m/s², as one of the elements responsible for the disturbance on their respective orbitals elements.

Many researchers consider the electromagnetic disturbance associated with pressure of solar radiation, and apart from Maral and Bousquet (1998) – that ratify in a few lines, that the electromagnetic radiation of antennas creates a pressure that cannot be disregarded if the power of transmission is high – others authors that suggests the existence of the effects of linear momentum from the disturbance of
origin electromagnetic, have not been found during the research of this work. According to Maral and Bousquet (1998), the force produced by the radiation of an antenna in a satellite with 1 kW of EIRP is 0.3 x 10^-3 N, affirming that the disturbance is significant if the diagram of radiation of an antenna quadrifilar propeller, presents the gain and concentrated directivity. Zhou, Liu and He (2008) and also Bukhsh and Jonsson (2010), published articles to deal with analyze the standards of interference of the system of antennas in a satellite, having the purpose of explain the phenomena of electromagnetic interference on a set of antennas, not considering their effects about the presence of a linear momentum.

The CBERS-4 satellite is a satellite of low orbit with modules of camera for geometric and radiometric analysis. It has a total mass of 2080 kg, power generated of 2300 W and antennas type quadrifilar and parabolic propeller, operating in the frequency spectrum of the VHF and UHF and in the range of S-band. These antennas allow a communication almost omni-directional, with the maximum of the radiation power spectrum oriented in the Z direction.

The objective of this research is to answer if the CBERS-4 low orbit satellite, with antennas transmitting electromagnetics signals (quadrifilar and parabolic propeller), admits a momentum when it sends an electromagnetic beam towards a receiving antenna in terrestrial ground. And in this case, observe the possible changes in the orbital elements, and from this to discuss the disturbances in the components: velocity, altitude, semi-major axis, orbit eccentricity, mean anomaly, longitude of ascending node, orbit slope, argument of perigee, X-Y-Z coordinates, and the radial, normal and tangential components of this satellite.

The normal component is perpendicular to the orbital plane and positive in the direction of the angular momentum vector. The radial orthogonal component is along the vector radius of the satellite and positive outside the central body, and the transverse component is in the direction of the orbital plane and positive in the direction of the movement of the satellite.

2. Electromagnetic disturbance model

The communication between satellite antennas and a receiving station on terrestrial soil suggests an analysis, considering the conservation of linear momentum, about the effects of electromagnetic waves at the moment of transmission, on the set of antenna plus satellite. In the presence of a continuous transmission of the satellite antenna, for the communication link to occur, the presence of a linear momentum on the satellite can result in a disturbance in its orbit.

The considerations of satellite mass, orbit trajectory and antenna parameters used in spatial communications can suggest a strong correlation with a mathematical model that describes the real perturbative effects in the orbit of satellites, which perform communication from antennas with gain and power characteristics (of the order of tens of Watts) of known transmission.

Using the Electromagnetic Reaction Acceleration Model (Prop-Orbit Antenna) developed by Heilmann et. al. (2012, 2013), that considers the electromagnetic momentum on a satellite, and calculates the acceleration of electromagnetic reaction on a satellite, and the principal parameters of antenna theory: antenna type and power of radiation, in a graphical platform generated in MatLab environment that allows to choose the satellite, considering its respective state vector and the period of propagation of the orbit in days (with steps of 1-30 minutes).

2.1 Parameters of the CBERS-4 satellite

The satellite orbit describes its position in the orbital plane at a given time t and it is calculated using the six orbital parameters, called orbital elements or Keplerian. These parameters describe the movement of a satellite around the Earth. The parameters are: semi-axis major (a) [m], eccentricity (e), slope of the orbital plane (i) [°], straight ascension of the ascending node (Ω) [°], argument of the perigee (ω)[°] e mean anomaly (M). Where (a) and (e) describes the shape and size of the orbit described by the satellite; (Ω), (i) and (ω) are the Euler angles that define the location of the orbital plane in space.

With the orbital elements of the CBERS-4 satellite is possible to obtain its corresponding parameters of the state vector, composed of Cartesian coordinates of position and velocity, in relation to the inertial reference system (Montenbruck and Gill, 2005) (table 1).
Table 1. Parameters of the CBERS-4 satellite.

| Mass (kg) | EIRP\(^b\) (W) | Power\(^c\) (W) | Inertial System (24 hours after) |
|----------|-----------------|-----------------|---------------------------------|
|          |                 |                 | Position (m) | Velocity (m/s) |
| 2080     | 3400            | 2300            | -23111049.826047 | 289.165842 |
|          |                 |                 | 13056254.768326 | 494.145835 |
|          |                 |                 | 28064.586272   | 3831.432914 |

The table 1 shows the CBERS-4 parameters. The first line, item a, shows the Two Line Element \(^a\). The mass of the satellite is set at 2080 kg with an Equivalent Isotropically Radiated Power – EIRP \(^b\) of the satellite antenna of 3400 W. The antenna power \(^c\) is 2300 W, and the components of the speed and position of the satellite CBERS-4, 24 hours after for the three coordinates is shown in the right column of the table.

The CBERS-4 satellite input parameters refer to March 14, 2016, at 11\(^b\) 14\(^m\) 15.23\(^s\), with the orbital elements, obtained using an executable program called TrackStar Version 2.65, which converts the ephemeris data in the format TLS (Two Line Element) (which contains the orbital elements), for CBERS-4 satellite state vector data (Table 1).

For the model used in this work, parameters such as antenna gain, satellite mass and total power radiated from the satellite antenna are important for the correct modeling of disturbances in the satellite orbit. The value of the angle of opening of the antenna is considered in the value of the maximum gain of the antenna of the satellite and, therefore, will be intrinsically considered in the calculations (figure 1).

Figure 1. Parameter input screen of CBERS-4 satellite.

The input parameters are: satellite type, state vector, propagation period (in days and minutes), satellite mass in orbit, antenna type (helix quadrifilar or parabolic) and antenna power. After the
inclusion of these parameters, the orbit was propagated by clicking on "Propagar Orbita". The result of the simulation is shown in the form of graphs as in Figures X.

As a result of the output of the program, we have a perspective of the orbit trajectory of the chosen satellite, and the possibility of constructing graphs that represent the behavior of its orbital elements.

3. Analysis of results
The orbit of the CBERS-4 satellite was propagated to a time interval of 5 days with step of 300 seconds, first with acceleration of the two bodies (reference orbit) and after this considering the Electromagnetic Reaction Acceleration Model (disturbed orbit). The results were then compared, between these orbits, by analyzing the positional deviations in the components radial ($\Delta R$), normal ($\Delta N$) and transversal ($\Delta T$), according to the model.

Also was realized an analytic study of this disturbance on the orbital elements, especially on the semi-axis major, aiming to interpret its periodic behavior.

The calculation of propagation requires that are considered, for an electromagnetic disturbance, the initial state vector, satellite mass (kg), power radiated by the antenna (W) an the maximum antenna radiation gain (dB)

Considering the communication of the CBERS-4 from a parabolic antenna with 2300 W of power, it was observed that the velocity, semi-axis major, eccentricity, mean anomaly, longitude of ascending node, orbit slope, and argument of the perigee, did not suffer significant variations, being in the order of magnitude of $10^{-4} - 10^6$. However, admitting a parabolic antenna, the altitude of the CBERS-4 suffered a variation of approximately 920 m, the X-Y-Z coordinates presented variations of 730 cm, 400 cm and 620 cm, respectively. The components had values of 0,9 cm (Radial), 0,0 cm (Normal) and 1000 cm (Transversal) (figure 2). For a quadrifilar propeller antenna, with a EIRP of ~3400 W, the propagation of the CBERS-4, for the same 5 days (with step of 300 seconds), resulted in an altitude disturbance equal to the case of a parabolic antenna, that is, with a variation of 920 m. The X-Y-Z coordinates presented a disturbance of 220 cm, 110 cm and 180 cm, respectively, values with variations in magnitude lower than the disturbance case of the X-Y-Z coordinates with a parabolic antenna.

The components of direction presented disturbances of the order of: 0,9 cm (Radial), 0,0 (Normal) e 210 cm (Transversal), indicating that the case of the satellite use quadrifilar propeller antennas results in perturbations in the X-Y-Z and steering coordinates, lower than in the case of using parabolic type antennas (figure 3).

Figure 2. Disturbance in radial, normal and transversal components (left). Variation of the X-Y-Z coordinates of the CBERS-4 satellite, for 5 days (step of 300 seconds) (right), for a parabolic antenna.
Figure 3. Disturbance in Radial, Normal and Transversal Components (left). Variation of the X-Y-Z coordinates of the CBERS-4 satellite, for (step of 300 seconds) (right), for a quadrifilar antenna.

The observed variations in the X-Y-Z coordinates and in the components of direction are the most disturbed parameters, according Montenbruck and Gill (2005), Eshagh and Najafi (2007) and Solano et al. (2012). It is necessary to establish corrections on these parameters, especially when dealing with a set of antennas, being these of the type parabolic and quadrifilar propeller. Due to the arrangement of antennas of this type infer a greater perturbation to the satellite, changing significantly the variables of the state vector and the components of direction.

4. Conclusion
With the orbital elements of the CBERS-4 satellite it was possible to obtain its corresponding parameters of the state vector, composed of Cartesian coordinates of position and velocity, in relation to the inertial reference system. The Electromagnetic Reaction Acceleration Model propagated its orbit from the March 14, 2016, at 11h4m15.23s, for 5 days and with step of 300 seconds, together with the mass value of this satellite, power radiated by the parabolic antenna (in Watt) and EIRP of the quadrifilar propeller antenna (in Watt). The effects of perturbation on the Radial, Normal and Transverse components of the CBERS-4 satellite were simulated, both of its variations in the X-Y-Z coordinates, for two types of antennas: quadrifilar and parabolic propeller. It was observed that for both CBERS-4 satellite antennas, velocity, semi-major axis, orbit eccentricity, mean anomaly, longitude of ascending node, orbit slope, argument of perigee, did not suffer significant variations.

For the simulation with a parabolic antenna transmitting in the S-band/UHF frequency and its radiated power of 2300 W, the altitude, after the propagation of the orbit of the 5 days, obtained a variation of 920 m. The X-Y-Z coordinates had variations of 730 cm in X, 400 cm in Y and 620 cm in Z. For a quadrifilar propeller antenna, the variation in altitude was the same 920 m, while the coordinates X-Y-Z had variations of 220 cm in X, 110 cm in Y e 180 cm in Z.

The simulations also showed that for a parabolic antenna operating in this frequency range, it implies a variation of 0.9 cm in the Radial direction, 0.0 cm in the Normal direction and 1000 cm in the Transversal direction. Meanwhile, in the case of a quadrifilar propeller antenna, the component variations were 0.9 cm in the Radial direction, 0.0 in the Normal direction and 210 cm in the Transversal direction.

Although the CBERS-4 satellite has antennas of both types the results show that, from this simulation, the satellite communication operations with a terrestrial antenna of the quadrifilar propeller type offers on this satellite a lesser electromagnetic disturbance, when compared to a parabolic antenna, even the quadrifilar propeller antenna having an equivalent isotropically radiated power de 3400 W, compared to the radiation power of the parabolic antenna, of 2300 W. These simulations considered only the propagation of the CBERS-4 satellite orbit from the electromagnetic disturbance of one antenna.
at a time, when in reality the antennas operate in an arrangement, which should increase the perturbation values at the X-Y-Z coordinates, and the Radial, Normal and Transversal components.

References
[1] Bukhsh W A and Jonsson B L G 2010 Element Position Perturbation for a Narrow Spot Beam with Applications to Satellite Communication Antennas Progress in Electromagnetics Research PIER 104 pp 283–295
[2] Cook G E 1962 Luni-solar Perturbations of the Orbit of an Earth Satellite. Geophysical Journal of the Royal Astronomical Society vol 6 issue 3 pp 271–291
[3] Cojocaru S 2007 A Numerical Approach to GPS Satellite Perturbed Orbit Computation The Journal of Navigation 60 pp 483–495
[4] Eshagh M Najafi Alamdari M 2007 Perturbations in Orbital Elements of a Low Earth Orbiting Satellite Geodesy Department
[5] Heilmann A, Ferreira L D D and Dartora C A 2012 Perturbative Effects of Antenna Radiation Reaction on Artificial Satellite Aerospace Science and Technology 23 pp 352 – 357
[6] Heilmann A, Ferreira L D D and Dartora C A 2013 Antenna Radiation Effects on the Orbits of GPS and INTELSAT satellites Acta Astronautica 88 pp 1 – 7
[7] Maral G and Bousquet M 1998 Satellite Communications Systems: Systems, Techniques and Technology 3nd ed England John Wiley & Sons Ltd
[8] Montenbruck O and Gill E 2005 Satellite Orbits: Models, Methods and Applications Springer
[9] Seeber G 1993 Satellite Geodesy: Foundations, Methods and Applications Berlim W Gruyter
[10] Solano C J R, Hugentobler U and Steigernberg P 2012 Impact of Albedo Radiation on GPS Satellites Institute for Astronomical and Physical Geodesy Munich Germany
[11] Ziebart M, Sibthorpe A and Cross P 2007 Cracking the GPS – SLR Orbit Anomaly ION GNSS 20th International Technical Meeting of the Satellite Division Fort Worth Texas September pp 25-28
[12] Zhou B, Liu Q and He X 2008 Research on the Electromagnetic Interference of Antennas on the Satellite Piers online 4 no 3