SOME ISSUES RELATED TO RADIOMETER EXPERIMENT ON THE ITASAT SATELLITE.

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Abstract. *The Integration and Tests Laboratory of National Institute for Space Research (LIT-INPE) has worked to qualify a radiometer, made by itself, in the space environment. Until the present moment, the radiometer experiment did not have an opportunity to be included on a space mission in order to concretize its qualification. For the ITASAT satellite, the experiment needs to be re-dimensioned. Nevertheless the ITASAT mission has what the LIT-INPE needs, an opened and a cheaper door. This work describes the experiment and the possible readout of this sensor, including its variation. A brief overview of the experiment is presented, once the intend is not to project it, but only approach the subject. This work also shows that the embark of the radiometer is feasible, however it requires some considerations like the time of response when referring to a transient profile imposed by the satellite spin. In the orbital profile this preocupation becomes very small.*

***Keywords**: ITASAT, radiometer experiment, radiometer design.*

1. INTRODUCTION

The ITASAT (a university satellite program) is an important opportunity to qualify the radiometer projected and manufactured in Brazil, precisely by Integration and Test Laboratory into National Institute for Space Research (LIT/INPE).

This experiment presents a simple construction and is a great tool for space radiation measurement (as solar and terrestrial loads). Also, such project represents a relevant acquirement in knowledge. Even the manufacturing is simple, the qualification is expensive and hard.

This is not the only project of a radiometer built by INPE (Santos et al, 2002), but it is the most complete radiometer manufactured made into INPE's dependences. It means that INPE is the main responsible by the project, construction, calibration and tests for this radiometer.

The objective of this paper is to describe summarily a thermal radiometer project: inputs, outputs and how some of them interfere in the project. In some of these inputs and outputs, some analysis will be presented in order to verify if they will be useful to be applied in the ITASAT satellite.

2. THEORY

2.1. Radiometer

Radiometers can be classified as radiation detectors in different levels of radiation, thermal or photoelectric ones. The photoelectric level can be made by solar cells. The thermal radiation is approached in this paper.

The thermal detectors, as explained before, are simple in construction and basically are made by a metallic membrane with a superficial treatment in order to capture the radiation through the optical properties. This treatment is made by paint. A thermistor is placed on the opposite side (the side not exposed to radiation). Usually, two thermistors are used to decrease the influence of the structure temperature: one on the membrane, other on the structure.

The metal needs to have a high thermal conductivity, and could be copper or aluminum. Figure 1 presents the painted surface of a copper membrane and the thermistors glued in the opposite side.

One of the ITASAT requirements, in terms of thermistors readings, is that at least one reading per minute should be done. The attitude control of the satellite will be accomplished by spin-stabilization. Thus, the radiometer could be used to measure temperature difference during a rotation, and such analysis is presented in this paper.

The device's sensitivity is the capacity of the membrane to absorb and to transmit the heat flux to the measurer (thermistor). In the satellite movement phase the membrane shall dissipate the heat to space. The thermal differences in the membrane are as following: how do they are seen? Is the time of exposure enough for measure these?

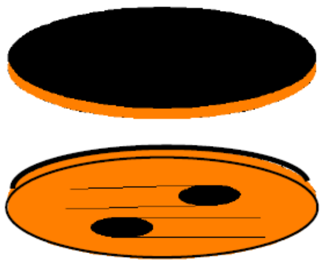

Figure 1. Illustrated sensor.

The membrane shall have a mass that makes easy the heat transfer to the environment, but it needs to be isolated from the structure in order to avoid undesired heat transfer. If it occurs the measurement is damaged.

2.2. Space positioning

An orbit can be described by some parameters such as: inclination (i), beta angle (β) and kind of orbit. The inclination is the angle measured between orbital plane and the plane that contains the Equator line. The Beta angle is the minor angular measure between the satellite orbit plane and the solar vector, and for any orbit the maximum variation is into 0° and 90°, that might be positive or negative (Wertz and Larson, 2005). The types of orbit are: Molnyia, Geosynchronous Equatorial Orbit (GEO) and Low Earth Orbit (LEO). A particular subtype of orbit is the Sun Synchronous Orbit (SSO).

The GEO orbit is characterized by a satellite enough distant, in which the translation velocity around the Earth is compensated by terrestrial rotation, meaning the satellite can ever pointed in the same direction. This orbit is near to 36,000 km.

The LEO is for low altitude and it is less than 2000 km. Its period is about 90 minutes (Gilmore, 2002).

The Molnyia describes an elliptical contour around the Earth (that stays far away from the ellipse centre). The maximum and minimum distances are into the GEO and LEO respectively.

The aforementioned orbits are under Earth's function: the changes in Earth's position regarding to its translation around the Sun changes the orbit angular position in relation with the Sun. However in a particular case, the SSO orbit, the plane of the satellite terrestrial orbit maintains the angular measurement in relation with the Sun.

The Figure 2 describes a hypothetical terrestrial orbit, like LEO, and its measures of the beta angle during the complete translation around the Sun.

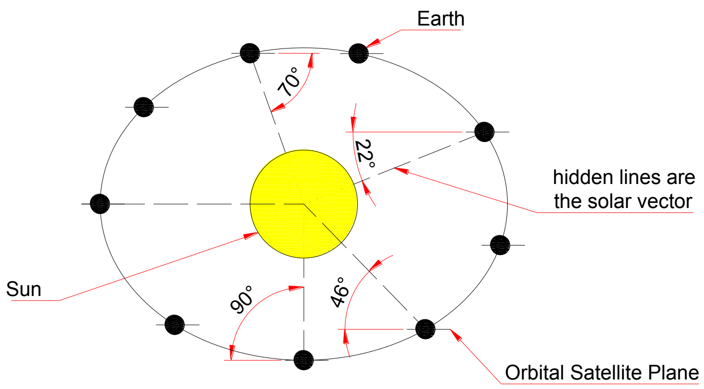

Figure 2. Representation of terrestrial satellite orbit and its beta angle measures around the Sun.

The variation of the beta angle is a composition between orbit inclination and Earth's translation movement. During its life the Earth's oblateness influences the beta angle too.

Inside the space positioning is either the Attitude Control that is a set of controls in the satellite movement like rotation and position of the panels in relation with the Sun.

Other parameter in the space positioning of the satellite is the nutation, which is a consequence characteristic of mass distribution. “The average nutation angle depends on the disturbing torque and also on the initial angular momentum imparted to the satellite” (Sidi, 1997). It is a movement of rotation out of the axis that passes by geometric centre. In general, the movement makes a cone with the geometric axis. An example is shown in Fig. 3.

The variation in angle by the nutation may result in a variable shadow on the sensor during the sipn.

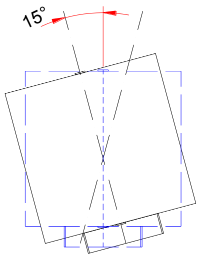

Figure 3. Illustration of nutation.

2.3. Thermal loads

During the terrestrial orbit the radiometer (and satellite) will be exposed to the loads like solar direct, albedo and terrestrial heat flux. The albedo corresponds to a parcel of solar radiation reflected by Earth and is variable according to the terrestrial surface. The major frequency of values is into a range of 0.03 and 0.52.

The albedo and the terrestrial radiation can be considered diffuses because the Earth’s surface is irregular and there is refraction in the atmosphere.

The solar constant changes during the orbit too. It occurs in function the distance between Earth and Sun (the terrestrial translation describes an ellipse) and solar activity cycle. This cycle has peaks in each 11 years nearly. The radiation can be considered between 1317 and 1419 W/m².

During the eclipse, only Earths radiation affects the sensor. For the calculations, the Earth’s temperature can be considered as a constant at -18°C. (Hengeveld et al, 2009)

3. DEVELOPMENT

3.1. Inputs and outputs from ITASAT satellite to radiometer

Some inputs and outputs to radiometer project are shown in Fig. 4.

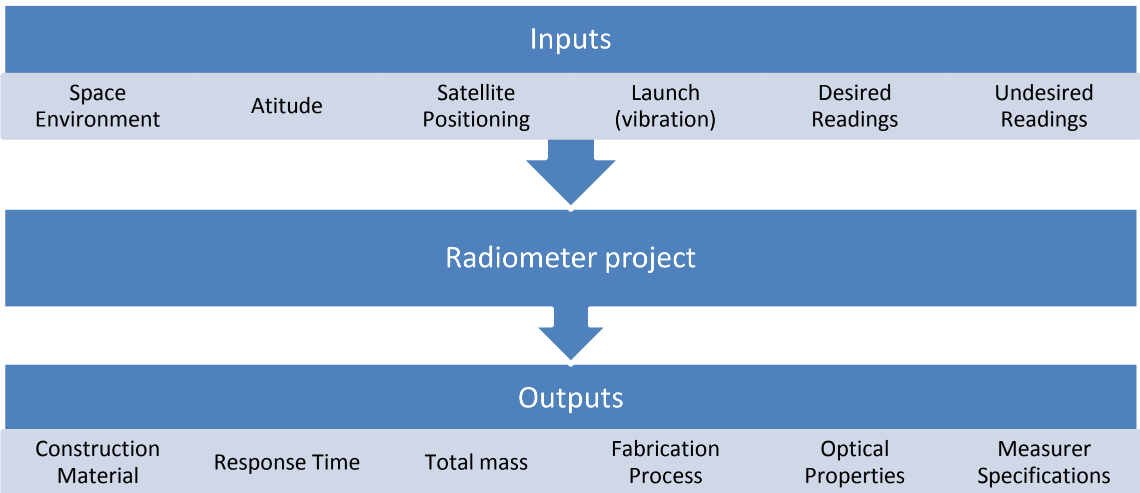

Figure 4. Inputs and outputs from radiometer project.

3.2. Space environment and attitude

The environment, in which the satellite will be exposed like said before, has the thermal loads direct from the Sun, albedo and terrestrial. It also has an exposition to atomic oxygen because the orbit is in LEO. The satellite will be in the altitude of 650 km approximately with an inclination of 25° and the attitude control will be done by spin-stabilization around 40 rotation per minute (RPM). A complete translation around the Earth is expected around 100 minutes.

In an ideal case, the solar panels will be pointed at 90 degrees with solar vector. But there is a nutation, which is not predefined, and in this paper it will be inferred in 0°, 5°, 10, 15°, 25° and 35°.

A significant change regarding to direct solar radiation is observed in the nutation angles. This difference is described by Eq. 1.

$$d^2 Q_{d1-d2} = \frac{i_1 dA_1 \cos\theta_1 dA_2 \cos\theta_2}{S^2} \qquad (1)$$

Where:

- the first term of the equation is the total energy per time unit that leaves dA_1 and comes dA_2 [W](Siegel & Howell, 1992).
- the second term represents the energy (i_1 in W/m²) that leaves the first surface (A_1 in m²) in any position ($\cos\theta_1$) and comes to the second surface (A_2 in m²) in any position ($\cos\theta_2$) (since both surfaces see themselves) divided by squared distance (S^2) between them.

To apply the equation some considerations were done: the first surface (Sun) is static and always at 90°. The energy that leaves the first surface and arrives the second surface will be 1400 W/m², and the distance between Earth and Sun is constant. The second surface is the one which will be moved.

The position of the sensors in the satellite is one on centre of the top panel and other on the bottom panel. In the ideal position (solar panel at 90° with solar vector) the top and bottom panels are pointed to space.

In Fig. 5, the albedo was considered in three levels (0.6, 0.3 and 0.1) for each angle of nutation, in order to simulate the possible points in the orbit. Still in the graphics, the X axis represents one spin and not a time. In regarding time, each complete rotation (each spin) is given in 1.5 seconds. When the angles are negatives (sensor pointed to the Earth) the load direct from the Sun are considered null.

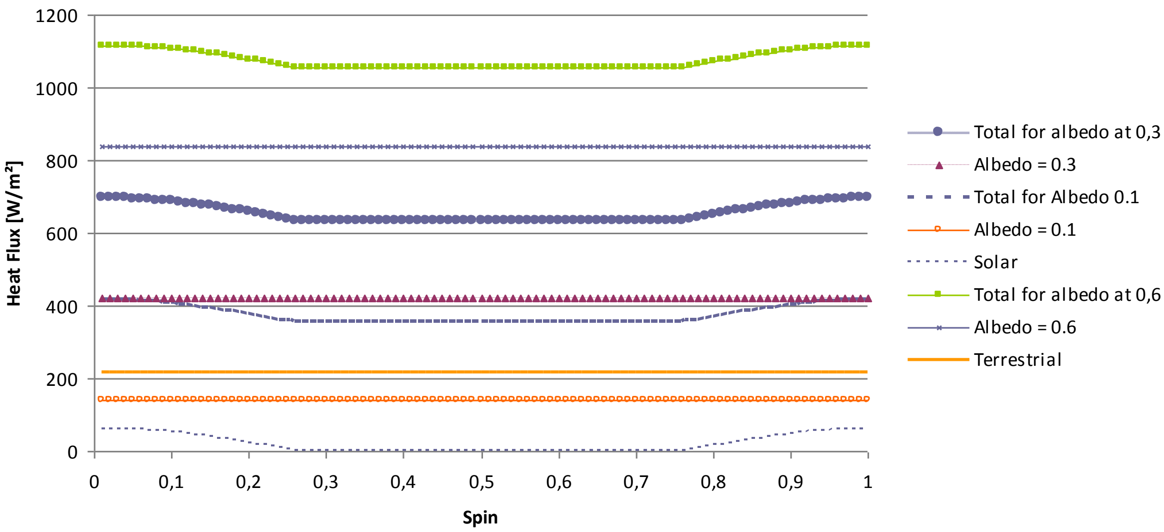

Figure 5. Thermal Loads in W/m² arrived on the sensor for the nutation = 5° for different albedo.

As presented in Fig. 5, approximately in 0.25 of rotation there's a great decreasing in direct solar. In terms of time it is near to 0.39 seconds. Table 1 presents the amount of direct solar load that decreases in this period on each angle of nutation.

3.3. Mass and construction material versus desired measurement and time of response

Considering a disc made with copper that has 35 mm of diameter and 0.5 mm of thickness and one of the surfaces is covered with a black paint with absorptivity near to 0.98. The mass of the disc is 4 grams. With the equation presented by Bauer, 1965 (and Dereniak, 1984) and wrote as follows:

$$t = \frac{K}{V} \tag{2}$$

The K can be considered as the flux q in a second and comes from equation 3, from thermal capacitance. V is the quantity of heat lost per second per degree and can be substituted by the flux from Table 1. The fifth line is the result of the last consideration.

$$q = m * \Delta T * Cp \tag{3}$$

Where:
ΔT is the temperature difference [K];
Cp is the thermal capacitance [kJ/kg/K];
m is the mass of the body [kg].
For copper Cp is 0.42 kJ/kg/K and the initial mass considered is 0.004 kg.

Table 1. Thermal loads in W/m² decreased by each nutation.

Nutation (degrees)	5	10	15	25	35
Load (W/m²)	6.1E1	1.2E2	1.8E2	3.0E2	3.6E2
Load / time (W/m²/s)	1.6E2	3.1E2	4.7E2	7.8E2	9.3E2
Flux (W)	1.5E-4	3.0E-4	4.5E-4	7.5E-4	8.9E-4
Time constant	1.1E1	5.6E0	3.7E0	2.2E0	1.9E0

The constants in Tab. 1 show that the radiometer has a higher mass regarding to necessary response. However the thickness cannot be extremely low because it implies a hard manufacture. To perform an accurate measurement the time constant value must tends to one.

A study was accomplished varying mass and considering the disc with the same diameter, in order to analyze the ideal mass of the disc, it means, the mass that has a time constant value around one second (0,001ks).

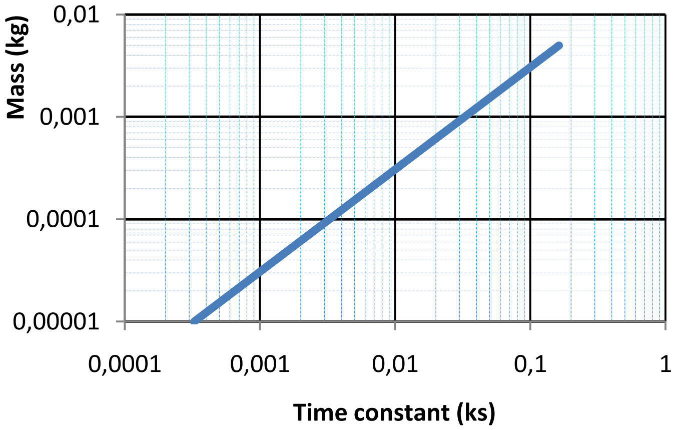

Figure 6. Time constant versus mass.

An ideal mass for the satellite's sensor with a nutation of 15° was achieved, and its value is around 0.03 grams, resulting on thickness of 0.13µm. These values result in serious constraints in manufacturing the object. In order to increase the thickness some calculations were performed however the results obtained were not satisfactory. The only available solution is to increase the value of the nutation angle to 35°, and these results are shown in Fig. 7.

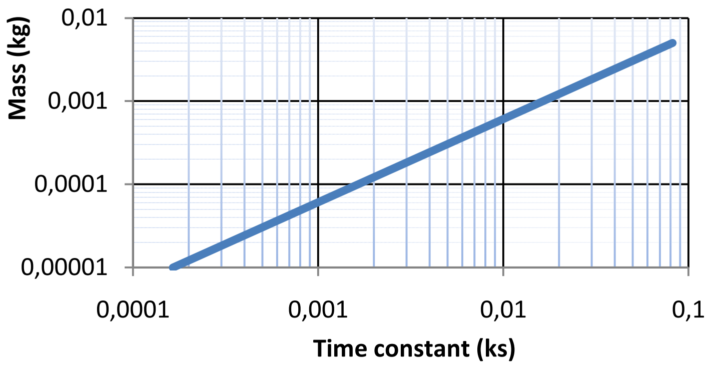

Figure 7. The time constant versus the mass - with nutation of 35°.

As presented in Fig. 7 the ideal mass, the value in Y axis that crosses the value one in X axis is around 0.06 grams, it means, the double in mass is the double in thickness but the manufacturing still is in a difficult way.

Changing the material to aluminum the thickness did not increase enough to making possible the fabrication. It results on 0.2µm thickness to 15° nutation, and 0.4µm thickness to 35° nutation.

For the next calculations, the cooper disc diameter remains the same (35mm) and thickness was raised up to 0.5mm. One of the surfaces is covered with black paint (emissivity 0.87 and absorptivity 0.96). The opposite surface is in usual copper, with properties inferred (emissivity 0.03 and absoptivity near 0.3).

The energy balance was accomplished with the following considerations:

- If the emitted energy is less than the absorbed, the emitted is considered null;
- The emitted energy by the sensor depends on its temperature at the instant immediately before the considered for emitting;
- The same way for the absorbed energy;
- A total of 10 spins to observe the stabilization;
- Reading of the total load received: solar direct plus albedo plus terrestrial;
- The initial temperature is 20°C.

A delay in the response was observed due to thermal mass, and the initial cycles may be unconsidered.

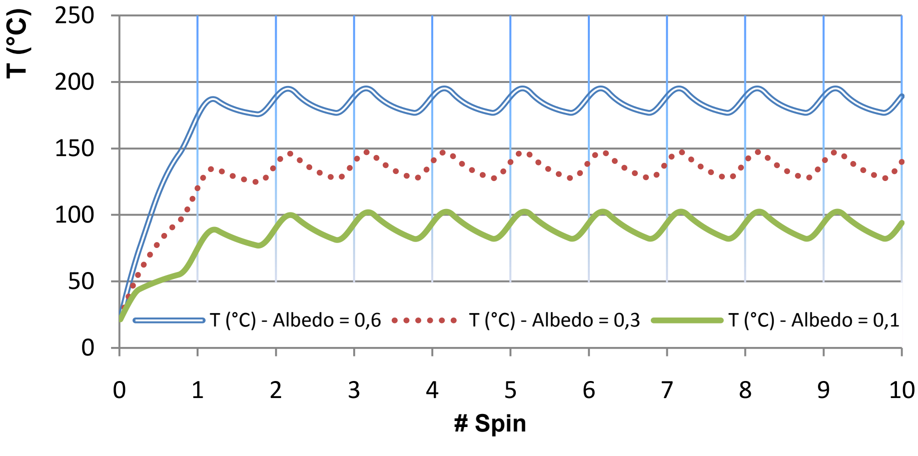

Figure 8. Thermal response during 10 spin – Copper – Nutation = 15°.

According to Fig. 8 the delay mentioned before is in the beginning of each cycle. There is a slightly increase in temperature and then, it starts decreasing almost linearly until the minimum, in almost the beginning the next cycle. It was also observed that the decreasing rate of temperature is slower than increasing rate.

The same considerations were adopted for the analysis with aluminum. Due to a higher specific heat, the response amplitude is lower, showing less sensitivity. Also, the number of cycles necessary to achieve equilibrium is higher.

3.4. Positioning in the satellite and desirable readings

The main proposed radiometers positioning: one device on the top panel and other under bottom panel with opposed painted surfaces.

It is possible to take benefit from the positioning of the radiometers to accomplish the measurements in separate ways, with measurements of terrestrial radiation in one device, and with albedo and solar radiation measured on the other sensor.

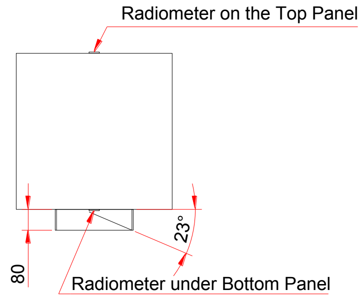

Figure 9. Proposed Positioning of the radiometers.

Part of the launch adapter will remain in the satellite during the orbit, and it will be useful to cover the device from the solar radiation incidence. Figure 9 shows the proposed positioning.

The adapter can be considered as a tube, and its function is to provide a space between the satellite and launcher. The main function of the adapter is to protect the satellite from the pyrotechnic loads or from the mechanical separator during the separation phase. As there is a tube, enough space is available to fix the device.

During the terrestrial orbit, the sensor under bottom panel will be exposed at same time to albedo and terrestrial load, and at some time it will be pointing to space.

Figures 10 and 11 show the position during an orbit around Earth, and some points of solar orbit.

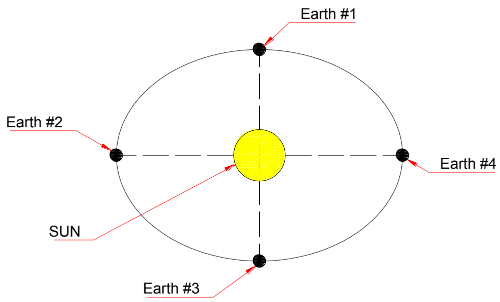

Figure 10. Space view of the Earth's orbit around the Sun.

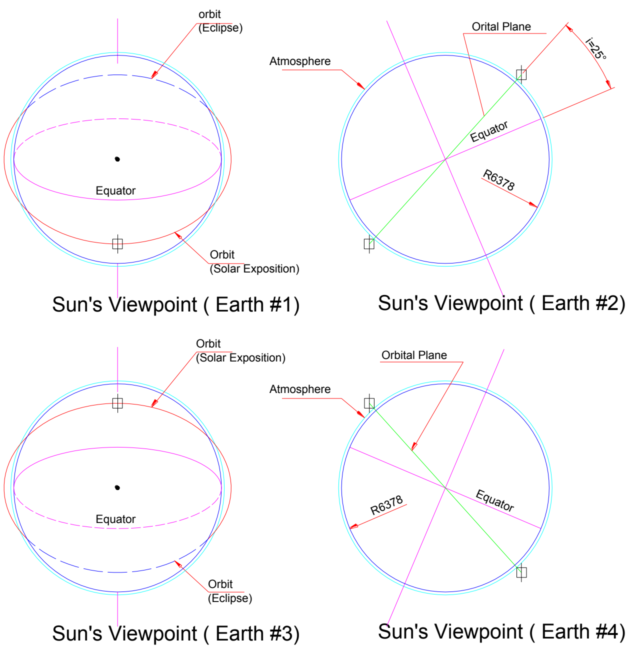

Figure 11. Sun's viewpoints of Earth and the satellite orbits.

By considering each point presented in Fig. 11 (the rectangles), it is easier to understand the proposed measurement, described as follows:

- When the satellite passes by point designed in Earth #1, albedo is a maximum on the sensor placed on the top, and the bottom sensor sees only space radiation;
- In the inferior point, in Earth #2, albedo is almost null and terrestrial combined with solar direct will be measured on the top sensor;
- When the satellite passes by superior point, in Earth #2, the top sensor will measure some portion of terrestrial radiation and solar radiation is present too, however, albedo is almost null;
- In the point shown in Earth #3, the bottom sensor will measure albedo, which is a maximum for this orbit, and terrestrial radiation. Solar radiation will not be measured, due to shadow from the adapter. The top sensor will receive incidence of solar radiation and a small part of albedo in association with terrestrial and space;
- In Earth #4, the same as pointed out in Earth #2 occurs with the precise corrections.

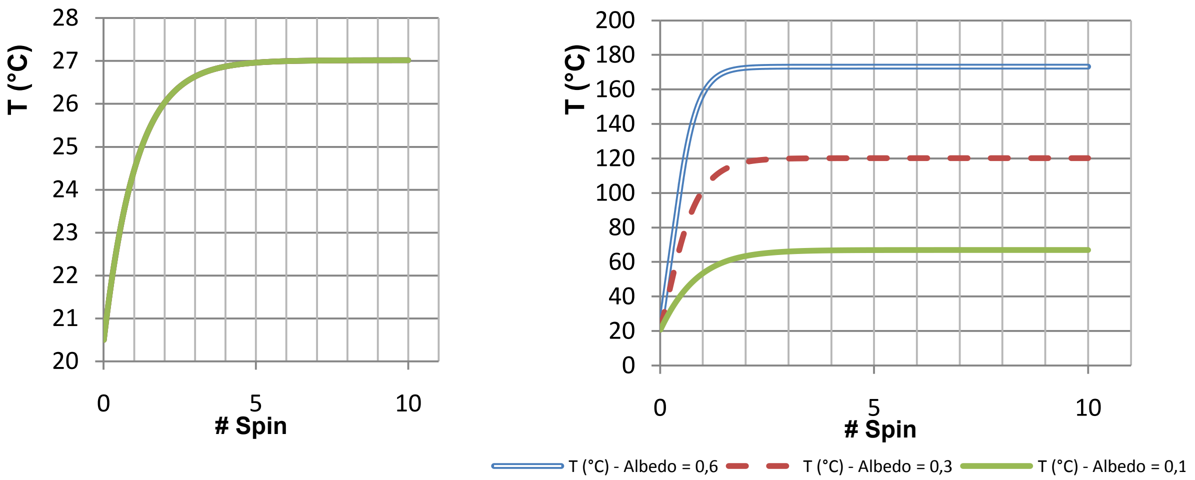

Figure 12. Thermal response during 10 spins – Copper – Nutation of 15°.

In the situation where the sensors will measure only terrestrial radiation, the temperature will stabilize about 27°C, and in the case where it will measure terrestrial radiation in association with albedo, as presented in Fig. 12.

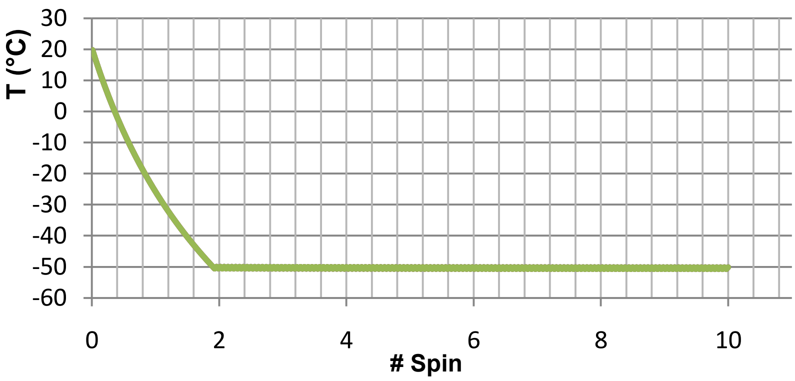

Figure 13. Thermal response during 10 spin with space radiation only – Copper – nutation = 15°.

In the case where the sensor will be pointed to only space, without receive any load, the temperature will be stabilized in -50°C as shown in Fig. 13.

3.5. Measurer specification and undesirable readings

In regarding to thermistors, they must have the minimal mass as possible to avoid interference. This interference is not focused in this paper.

The thermistor has a limit of operation, and according to the graphics presented in the figures, the superior limit for albedo with value of 0.6 is over 150°C. The superior limit for some thermistors is about 150°C, however, the inferior limit is unknown.

The dissipation of the thermistor is an important data that must be considered: for instance, if the dissipation of the thermistor is constant at 1mW/°C, when its temperature reaches 100 or 150°C the measurement can be affected until 10%.

To capture the peak and valley of temperature along one spin, the first thermistor (from the sensor on the top panel) needs to be read when the angle between the sensor and the sun is the maximum and the second thermistor (from the same sensor) needs to be read 0.81 seconds after the first.

Undesirable results will occur if the first sensor reading will not happen at suggested instant. Further undesirable result is obtained if the thermistors mass were extremely high in comparison with the disc mass.

3.6. Optical properties and undesirable readings

When the properties of the exposed surfaces have changed, a drastic change in the temperatures happened. In this analysis, a white paint (emissivity about 0.3 and absoptivity about 0.1) was considered. The results are shown in Fig. 14.

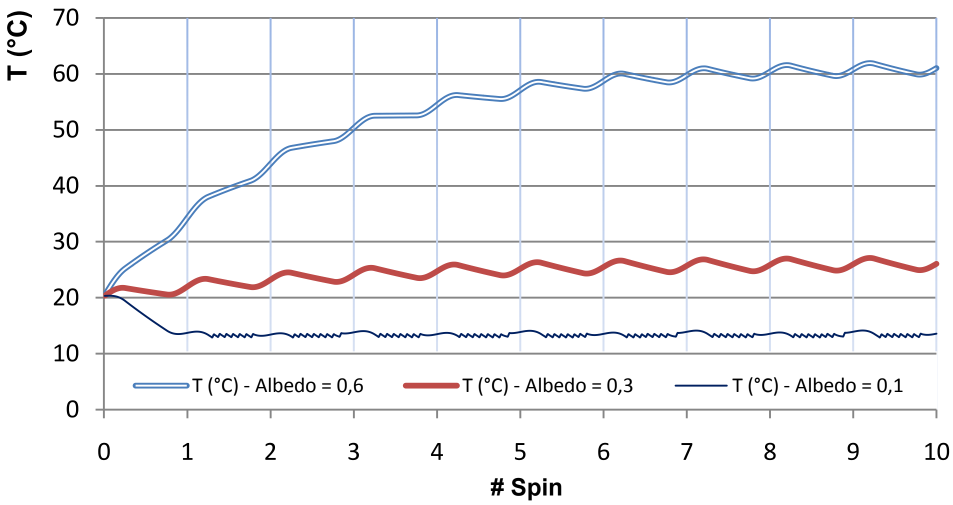

Figure 14. Thermal response during 10 spins – Copper with white paint – Nutation = 15°.

As presented in Fig. 14, the stabilization was different for each point where the satellite passes, according to albedo values variation. It should be noted that with albedo at 0.1 the temperature stabilizes quickly, and the temperature oscillation in the sensor is very small. Therefore, it can be considered constant. At this position, the point in which the acquisition was started, is not relevant.

The case in which the sensor will be pointing to the space, without solar or terrestrial loads, is presented in Fig. 15.

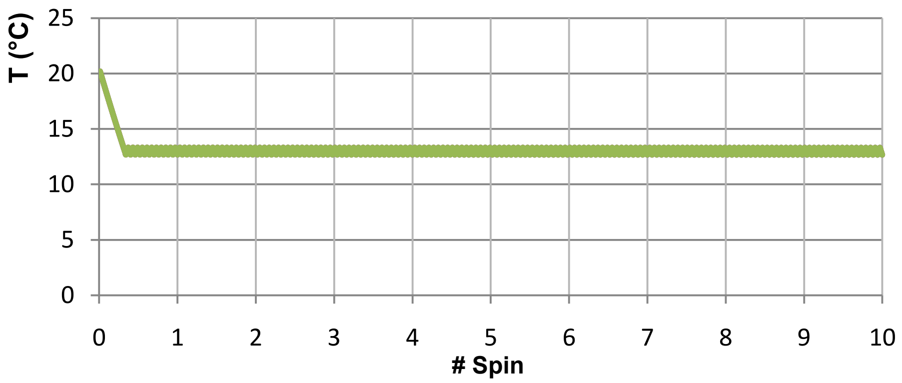

Figure 15. Thermal response during 10 spin with only space radiation and white paint – Copper – nutation = 15°.

As presented in Fig. 15, the stabilization has occurred at 13°C.

3.7. Vibration and fabrication process

During launching the satellite and its components will be subjected to severe vibration. As a result, the radiometer must be projected to support this mechanical charge. The device must be mounted on a rigid structure.

The sensor (disc with thermistors) must be thermally isolated from the supporting structure in order to avoid thermal interference. The mass of the thermistors is an additional difficulty to vibration analysis, because they must be fixed in the disc and the disc will be fixed in the structure by three or four points in the boundaries.

The fabrication of parts like disc, fixture device of the disc and the supporting structure will be made at INPE's dependences. The cleanness, paint, mounting, calibration and tests will be performed under clean area of the laboratories. The cleanness class shall be at least 100.000 (100.000 particles until 5µm of diameter by cubic feet of air).

3.8. Calibration and tests

After the fabrication of prototypes, it is necessary to calibrate and test the devices, including thermal and structural tests.

The thermal tests are accomplished into Thermal Vacuum Chamber at LIT, with skin heaters controlled by fonts. In these fonts the amount of heat is known and the temperature in the sensors is measured by its own thermistors.

The mechanical vibration test is one of the structural tests. The sensors can be fixed in a plate that shakes them in a sinusoidal scan, and in a random movement with the levels of acceleration known, to simulate the environment of launching. Between each test, some measures can be performed, in order to compare the results before each test.

4. CONCLUSION

With the presented results, it is possible to state that the radiometer is able to be part of the ITASAT satellite. Some main objectives purposes in this paper were accomplished satisfactorily. These subjects include some inputs, outputs of a radiometer project and a discussion about facts that may interfere in the ITASAT mission. Some points regarding to structural issues are going to be resolved in the future.

The readings with an additional mass (glue and thermistor), time response and read error of the measurer are only possible to verify with a thermal test into a vacuum chamber.

Because the time of reading of the sun sensor and its error plus time to process the action of measure by on board computer, the employ of the radiometer to measure the variation of radiation during one spin is possible but is not easy to get it. So the recommendation is to measure the variation in radiation during the orbit at the points purposed on this work in the section 3.4.

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