TASAT Simulations of NASA Image Satellite to Predict the Spin Rate

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1. Summary

TASAT[1-3] (Time-domain Analysis Simulation for Advanced Tracking) is a highly comprehensive program which uses extensive realistic inputs (close to 1000 lines of input) and generates a comprehensive set of outputs. Simulations can be done for passive tracking (solar radiation) as well as for active tracking (laser radiation). TASAT has been successfully used in several tracking and related directed energy applications. When NASA's Image satellite stopped transmitting signals to ground stations in December 2005, after functioning well for more than 5 years on Earth orbit, there was a desire to use AMOS 3.6m Advanced Electro Optical System (AEOS) to collect the passive image data and check the system status, in particular its spin rate. AMOS observations of the satellite were collected by a group led by Paul Kervin (Air Force Research Laboratory) and were published in detail in the previous AMOS conference[4]. Prior to that, there was a desire to use TASAT to check whether it is possible to predict the spin rate under passive and active imaging. The Image satellite is expected to maintain a spin rate of 0.5 rpm with spin axis perpendicular to the orbital plane, which helps in the stability of attitude. The spin also helps to maintain the orientation of the 250-m long thin antennas perpendicular to spin-axis. After loss of telemetry, experiments were performed using AMOS 3.6m AEOS to check the state of spin. Substantially more information on the satellite as well as details of the AMOS experiments on Image Satellite were presented in this conference by Hall et al. [4]. The goals for this paper are different in that it is important to check apriori if a simulation can tell whether data collected off passive imaging (solar imaging) contains information about the spin-rate and if so, how to extract it. In addition, TASAT helps in the experimental design for the same, such as needed

active illumination power (if one is using active imaging), types of sensors, atmospheric effects, realistic images etc..

2. Introduction:

The goals here are different from what has been previously presented for this satellite in that it is important to check a priori if a simulation can tell whether data collected off passive (solar) or active imaging contains information about an object's spin-rate and if so, how to extract it and the related constraints for both types of imaging. In particular, it will be shown that the Fourier transform of the signals from active and passive returns contain the fundamental frequency of the spin. Some time noisy signals are also present in the frequency spectrum of the signal and these can be deleted with some understanding of the geometry and the materials off the satellite.

3. TASAT Inputs and Outputs

TASAT uses extensive realistic input data, with over 1000 lines of input such as Satellite trajectory, the related materials, and other information such as object size etc., transmitter data such as laser power, divergence, beam diameter etc., telescope data such as primary, secondary and tertiary mirror information, focal lengths, location etc. extensive camera data that includes focal plane CCD array dimensions and properties, exposure time etc, atmospheric data characterized by tilt correlation information and Fried parameter, adaptive optics data (tracker, higher-order compensation loops etc.) and Solar information. TASAT gives extensive output data (about 160 output variables). Some of these include camera focal plane array (FPA) SNRs, tracker information, beam jitter, line of sight (LOS) information, passive (solar) and active images at FPA, gimbal angles, range, elevation and other satellite data, radiometry, passive and active optical cross sections (OCS). Simulations can be done on a PC within reasonable computation time. TASAT outputs have been extensively compared with field data collected at AMOS and SOR, comparing values such as calculated OCS, Power incident on the FPA, FPA image counts and noise statistics, and other measurable data.

4. Simplified Satellite Model

In this paper, we used an initial model (approximate in material data and geometry) for NASA Image satellite and two TASAT analyses for it. The first analysis primarily focuses on passive images and the second explores the possibility of active tracking using a full aperture laser source. Figure 1. shows the NASA MidEx class Image satellite (SSN 26113) model and the material data is not shown here. It has an eccentric orbit 1640 km X 45230 km X 89.5$^{0.}$ It has an octagonal shape with a diameter of 2.23 m and height of 1.52 meter. The spin period about z-axis is set to 125 sec. It has four long antennas, each 250 m long. Fig. 2, shows a comparison in different directions of the original satellite and simplified model. In terms of the model, even the simple model description is fairly long and hence not reproduced here. In the actual simulation, it may be difficult to observe the thin 250 m long antennas unless the solar phase angle is appropriate.

5. TASAT Simulations (Passive Imaging)

Initial TASAT runs were set to the simulation period of 15.50 to 16.15 hours on Jan 28, 2006, Fourier analysis of photometric data collected from the VisIm I-band camera using the AMOS 3.6 m telescope on this date seemed to favor a spin rate of 125 secs. The raw data has shown about 25 peaks ver a total time duration of 1500 seconds. For the photometric data capture, the camera frame rate was set to 0.4 to 0.8 Hz. Thus for TASAT passive imaging simulations the frame period was set to 1.66 sec. Figure 3 shows the passive cross section over the time duration of 1500 seconds and the corresponding FPA SNR. The increase in FPA SNR and the passive cross section are expected as the satellite is getting closer to the culmination point where the range is lowest. The large peak fluctuations are due to z-spin. To verify this, we set the spin rate to zero for these simulations. Following these simulations we subsequently changed to the Fast TASAT mode ,which ignores atmospheric turbulence effects, and set the spin-rate of the model to 0.47 rpm (the last measured rate). The VisIm camera model was chosen for TASAT simulations and the focal plane array was set to 512X512 pixels with a 5.67e-07 IFOV, and the sample rate was then set to 1 sample/sec. To test the validity of TASAT extractions, the spin period of the Image satellite in the simulation was first set to 31.5 secs, then to 63.0 secs and then to 125 secs. The purpose was to examine the frequency spectrum of the outputs in each case, after performing an FFT of the passive cross section, and confirm that the correct spin period rate was extracted.. In Fig 4. the spin period was set to 31.5 secs and a peak at a frequency of 0.031 Hz was seen in the frequency spectrum of the simulated passive cross section data, yielding a spin period of 31.5 secs as expected. In Fig.5, the spin period was set 63 secs in the simulation and the TASAT output shows a peak at 0.0159 Hz, again yielding a spin period close to the expected 63 secs. Fig 5 also shows a strong peak close to 0.098 Hz, which corresponds to a spin period close 100 secs and it was thought this was determined to be approximately 6x the nominal rotation rate, and was coming from glints on first the front surface and then the back surface of the two booms. This would create 6 spikes as the body rotated.
Fig. 6 corresponds to a spin period of 125 secs and shows an initial peak at 0.008 Hz which also corresponds correctly to a 125 sec spin period. Once more, a strong peak occurs elsewhere in the spectrum which can be misinterpreted. In general, the noise level in the spectrum is probably due to interference among returns from various parts of the satellite and the number of data points (directly related to the camera sample rate) available to the FFT. The largest contributor to the nominal spin rate in the frequency spectrum was the little cone (antenna) on top of the object. The reason this peak was lower than the peak seen by the 10m triangular booms (antennas) was due to both surface area as well as reflectivity (see figure 4,5,&6). Removing the triangular booms did not necessarily enhance the measurement technique, but more likely just enhanced the level of the smaller peak with respect to the other peaks left remaining (making it the dominant peak by default, not just due to active illumination). What could be emphasized is the predicted increase in that peak compared to the previously seen passive level. The third largest peak seen in Fig 6. is most likely due to reflections off the 8 sides of the satellite. We could not easily reproduce the 4x spin rate seen in the raw data (due to the 250m wire antennas) due to computation time reatraints. It became computationally intensive to cast

enough rays to accurately sample the thin wire over and area 500m x 500m. This is probably a limiting factor for objects with such features but in not a typical limitation. The signifcantly large 6x peak created by the 10m booms, is likely a starting point for improving the physical model since the Raw data did not show this large of a contribution.

To improve the simulation, anti-aliasing techniques were used (also available in TASAT) and the spin rate was set 0.497 rpm (which is the last measured spin-rate of the Image satellite). The results are shown in Fig. 7. Again, the pass was simulated for a total period of 1500 secs as in the past. The frequency content of the passive cross section shows three peaks, the first one close to the real spin period and the other two coming out of the symmetrical presence of other components in the Image satellite which are also fairly reflective. Some knowledge of satellite geometry and material information can lead to resolution of the various peaks in the frequency spectrum of the signal.

6. TASAT Simulations (Active Imaging)

To strengthen the simulations, an active imaging simulation has been performed using a laser source at 1.029 microns and an aperture of 0.8 m and the same camera as receiver. By removing the 10 m white painted antennas, only one peak was noticed, which also correctly reproduced the spin rate input to the simulation (0.493 rpm) as shown in Fig. 8.

7. Conclusions

TASAT simulations show that it is fully possible to predict the spin-rate of the IMAGE satellite form its cross-section returns. In all the simulated data sets, the first peak in the calculated frequency spectrum corresponded to the spin rate. Additional peaks in the data are caused in part by the high reflectivity of some parts of the satellites that appear to rotate at different spin rates due to their optical symmetry and their material reflectivities. But these effects can be identified easily given the details of the model. Simulation results indicate that the active tracking of the satellite provides larger optical cross sections, improving the accuracy of predictions. For this analysis, we have used an initial model of the satellite. With a more detailed model, better predictions of spin rate can be achieved. Additional work on physical modeling of the satellite and TASAT simulations could improve imagery.

8. Acknowledgements

The authors acknowledge the permission from Mr. Mike W. Prior (NASA, Hubble Space Telescope Operations Manager) and Richard J. Burley (IMAGE Operations Manager) to publish information on Image Satellite.

8. References

1. TASAT User Manual

2. Jim F. Riker et al., “TASAT-tracking for Ant-satellite System Simulation-Volume I, Executive Summary and Selected Results” , October 1990, RDA Logicon Associates.
3. Jim F. Riker et al., “TASAT-tracking for Ant-satellite System Simulation-Volume II, Theory & Architecture” , October 1990, RDA Logicon Associates
4. Doyle Hall, et al., “AMOS Observations of NASA’s IMAGE Satellite”, Proc. AMOS Conference, 2006, Maui, HI

9. **Figures**

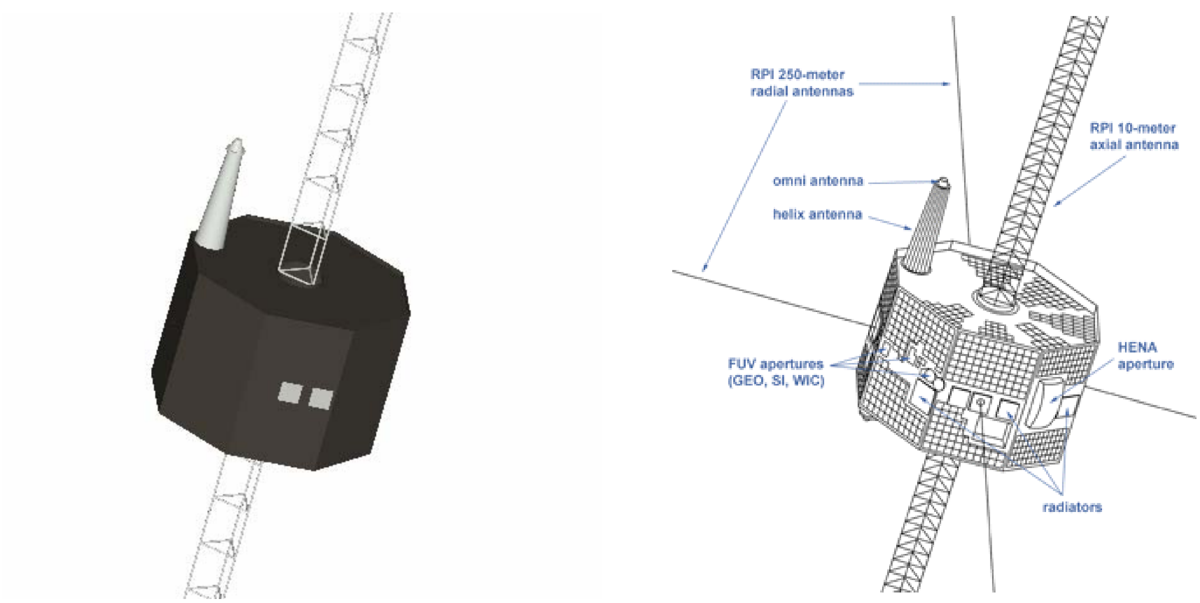
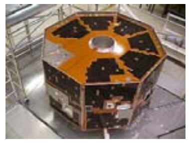
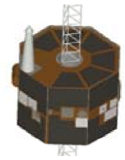


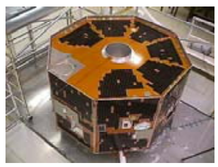
Fig 1. NASA IMAGE Satellite Approximate Model



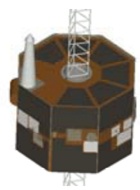
+X, +Y, +Z View



SMT Model (rev 1)



+X, +Y, +Z View



SMT Model (rev 1)

Fig 2. Comparison of Real and Approximate Model of IMAGE Satellite at various stages

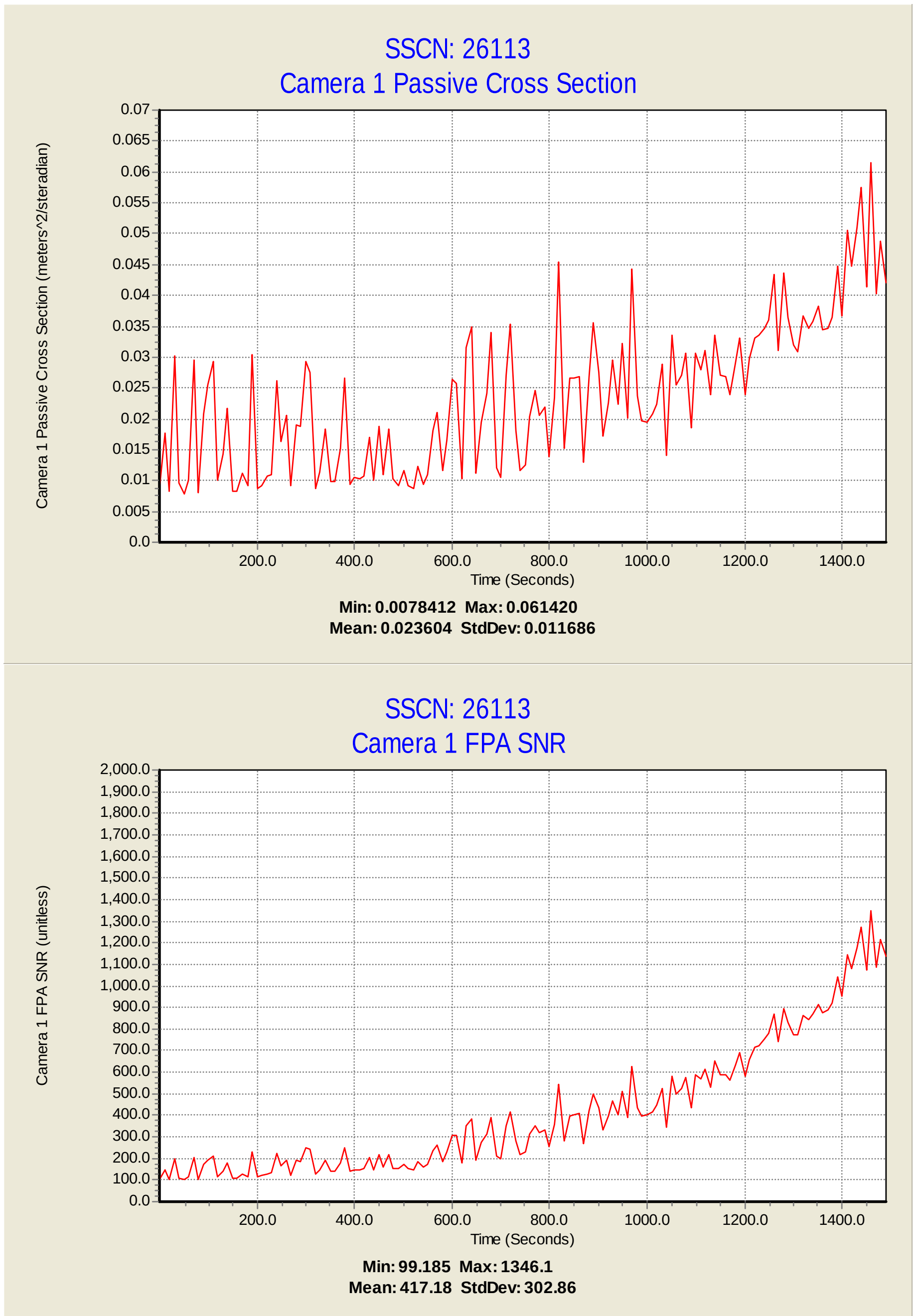


Fig. 3 (a). Passive Cross Section at Frame Period of 1.66 seconds for the IMAGE Satellite (b). The corresponding Camera 1 FPA SNR

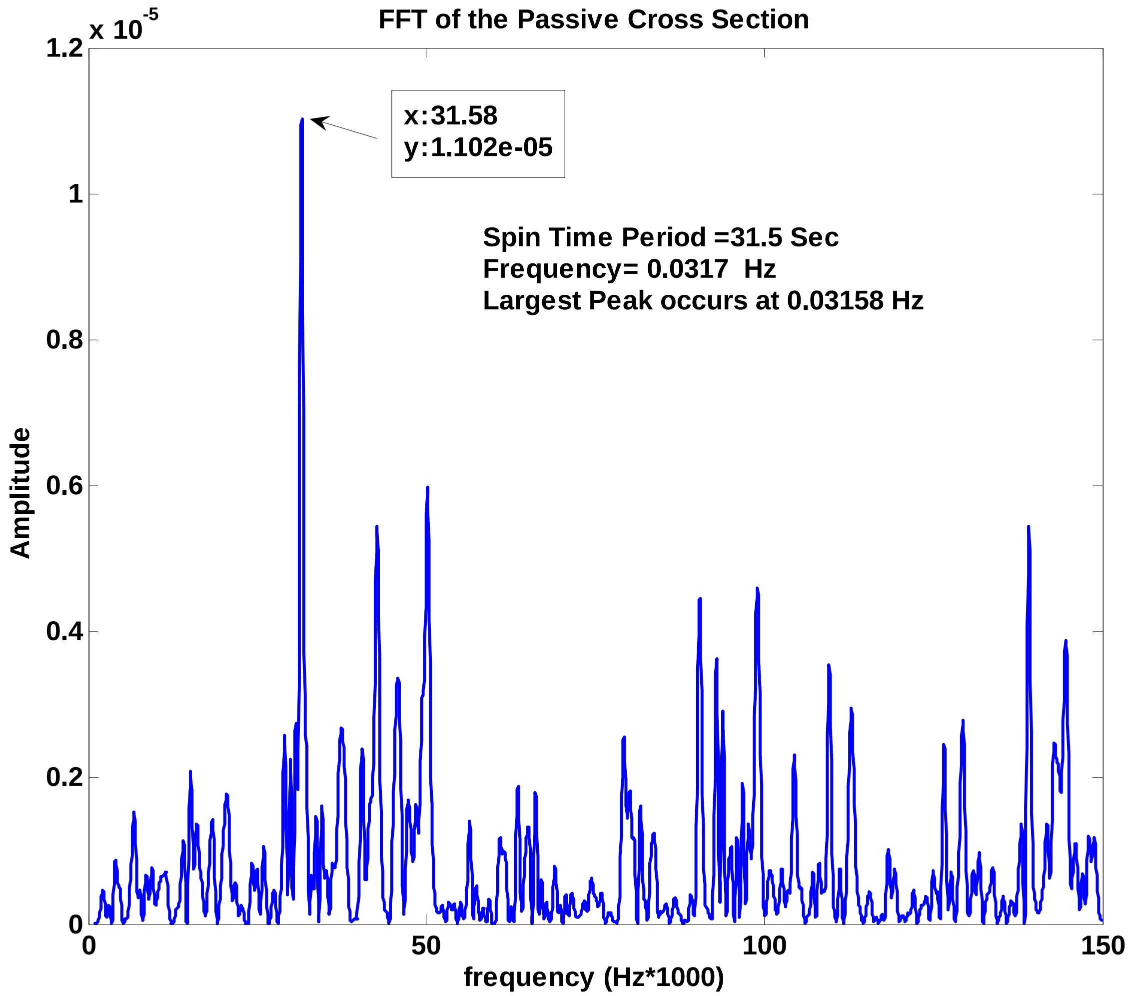


Fig. 4. FFT of the passive cross section of the IMAGE satellite with a spin period of 31.5 seconds.

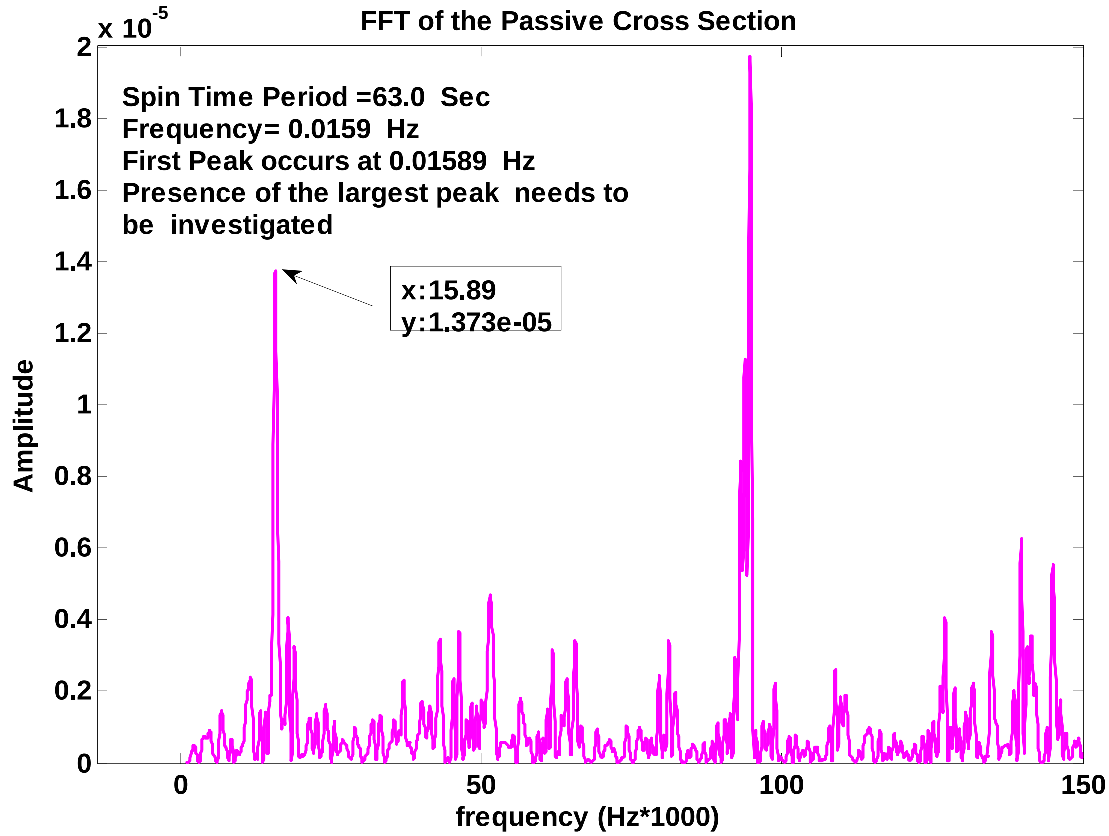


Fig. 5. FFT of the passive cross section of the IMAGE satellite with a spin period of 63.0 seconds.

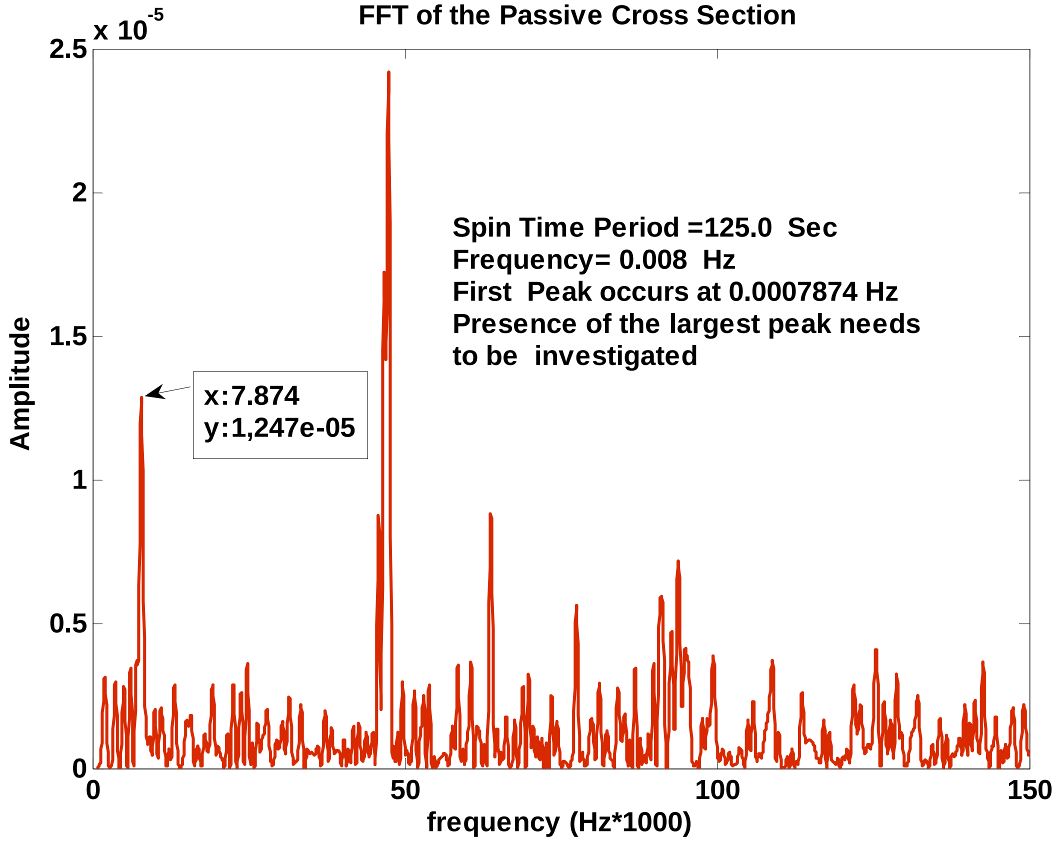
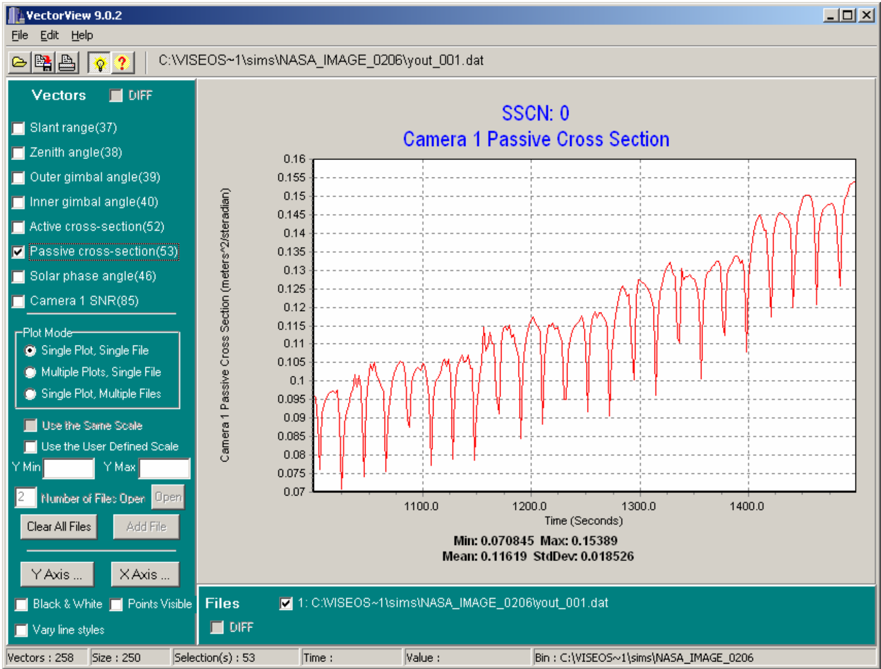


Fig. 6. FFT of the passive cross section of the IMAGE satellite with a spin period of 125.0 seconds.



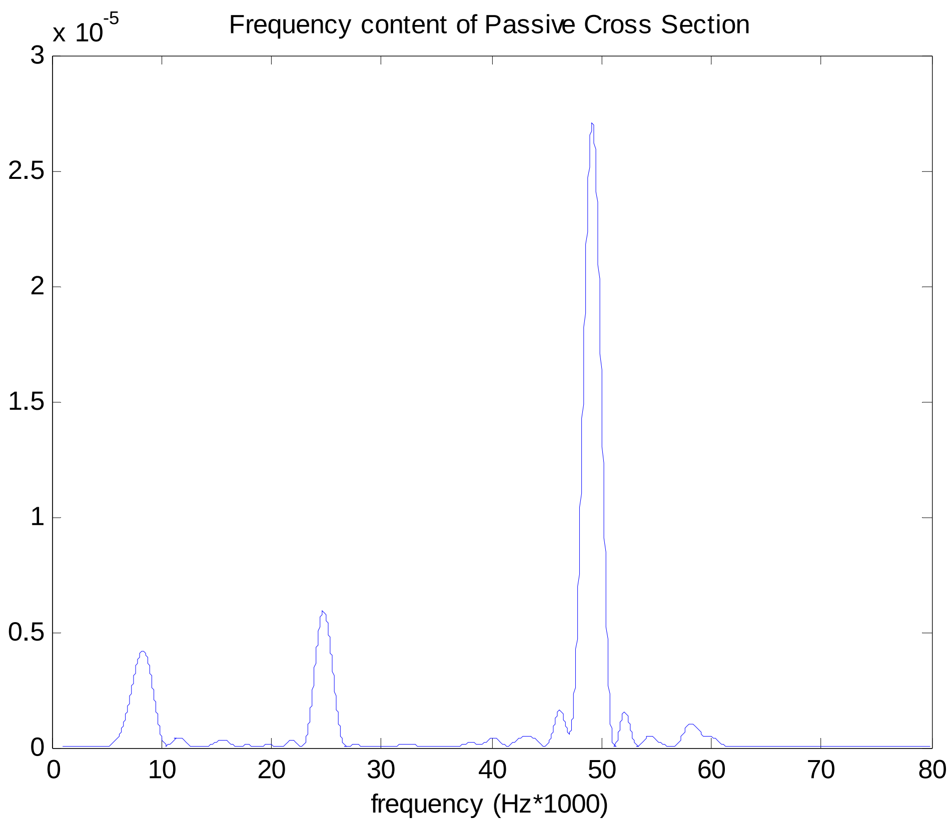


Fig 7. Top figure shows the passive cross section after using anti-aliasing from TASAT and the bottom figure shows the corresponding frequency spectrum

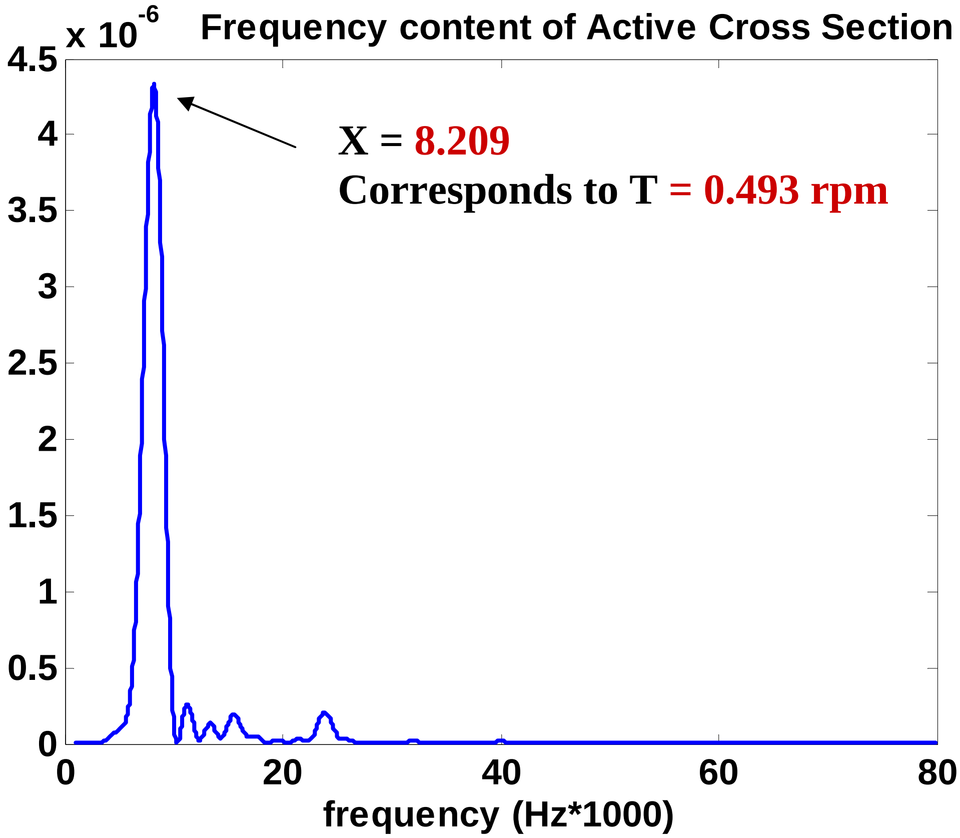


Fig 8. The frequency content of active cross section of IMAGE Satellite.