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Author: Mr. Ronnie Nader
Ecuadorian Civilian Space Agency (EXA), Ecuador, rnader@exa.ec

Mr. Hector Carrion
Ecuadorian Civilian Space Agency (EXA), Ecuador, hcarrion@exa.ec

Mr. Manuel Uriguen
Ecuadorian Civilian Space Agency (EXA), Ecuador, ingenieria@exa.ec

THE ECUADORIAN EXPERIENCE IN SPACE: THE NEE SATELLITE CONSTELLATION

Abstract

On April 25, 2013 after almost 4 years of development and testing the NEE-01 PEGASUS, the first Ecuadorian satellite took off to orbit on board an LM2D Chinese vector, launching from JiuQuan cosmodrome, it operated correctly until May 23 when a close approach with the SCC 15890 object probably impaired the attitude control and antennae systems of the satellite. On November 21 of the same year the NEE-02 KRYSAOR, the second Ecuadorian satellite was launched into orbit by a Russian Dnepr booster taking off from Yasny cosmodrome; it carried a novel device called PERSEUS which allowed the Ecuadorian Civilian Space Agency to recover the signal of the NEE-01 PEGASUS via intersatellite communication.

This is the result of 7 years of indigenous effort on the frame of the Ecuadorian Civilian Space Program, using only national personnel, devising our own solutions, from the very basics like PCB fabrication and coating formulation to building entire systems like EPS modules and titanium structures, designing our own solutions and building them with our own processes, going through the making of our own tools, like the GOLEM magneto dynamical shaker or the SESCA Space Environment simulation chamber and testing and developing our ground stations HERMES-1 and HERMES-2. In this paper we will review the results and the advances made in this path to reach space with our own ingenuity in the effort to share with the community what we have learned and humbly aspiring to inspire other nations to follow this path of discovery of their own capabilities, which in time will lead them to share with others their advances in the hopes of contributing to the advancement of mankind all.

Introduction: EXA is the Ecuadorian Civilian Space Agency, a civilian NGO created in 2007, in charge of the administration and execution of the Ecuadorian Civilian Space Program – ECSP[(2)].

As a part of the ECSP, a ground station had to be built from scratch, as a first step toward developing national satellite building capability.

This was project HERMES[(3)(4)(5)(11)16)], started in 2009, which rendered a ground station not only able to efficiently work satellites from HF to K band, but also became the first internet to orbit gateway[(10)], enabling the nation to acquire many capabilities such as space traffic monitoring and even the capability to relay live scientific satellite signals to any point in the world[(12)].

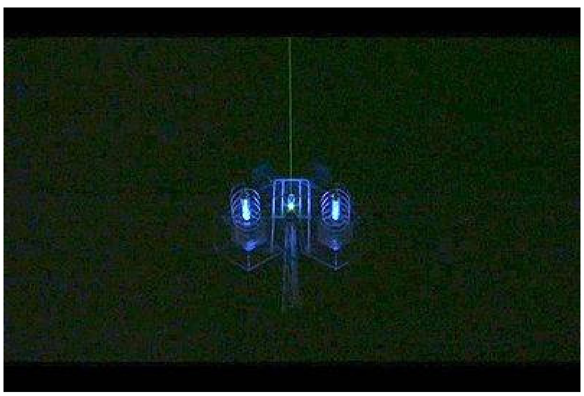


Fig-1 The MINOTAUR array during night operation

The HERMES-A Ground station has rendered better than expected results and it is also a powerful laboratory that allow us to experiment and learn for ourselves about satellite technology from firsthand experience. Also serves other international institutions abroad like the JAXA, The Michigan State University, the Graz Technical University, the Swiss EPFL and it is sometimes used for national security purposes when monitoring possible spacecraft collisions on its range of 6000kms, like the event of February 5 2010 between a Iridium 33 debris and the EPFL SwissCube[(7)].

Once the HERMES-A/MINOTAUR G/S gateway was complete, on April 2010 the EXA Directorate approved a project proposed by Cmdr. Ronnie Nader, Space Operations Director, the building of the first Ecuadorian satellite, the project was named Project PEGASUS and we moved on to the next phase of the ECSP.

By October 2013, HERMES-A was upgraded to a second parabolic antenna 6m in diameter in order to separate the command and reception functions with high point accuracy, high speed rotors and also upgraded the low noise boosters to 150 watts and the low noise amplifiers to +320dBm, new stand alone computerized rotor controllers and an optical telescope capability. Again this task was performed by EXA personnel exclusively.

Fig-2 The HERMES-2 ground station antennae array in Samborondon- Ecuador.

NEE-01 is the Ecuadorian registry number meaning 'Ecuadorian Space Ship – 01' in Spanish, so the spacecraft was christened **NEE-01 PEGASUS**[(1)] and the second one was christened **NEE-02 KRYSAOR.**

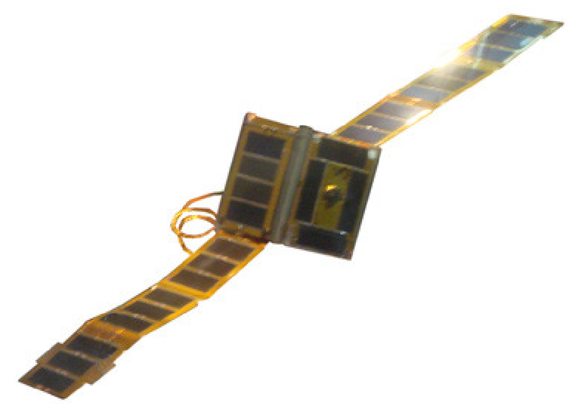


Fig-3 The NEE-01 PEGASUS in orbital flight configuration with its 2 DSA Multipanel solar wings deployed

Project was to be financed entirely by the EXA and the local industry, total budget was of US$30.000 for the research and building phase, as usual in EXA projects, all personnel was working in 'pro-bono' mode, the funding was solely dedicated to hardware, tools, books and facilities.

Team was led by Cmdr. Ronnie Nader and composed by Sidney Drouet, Manuel Uriguen, Hector Carrion and Ricardo Allu.

Fig-4 The NEE-02 KRYSAOR in orbital flight configuration with its 2 DSA Multipanel solar wings deployed

Design: The NEE-01 PEGASUS was designed as a 1U cubesat form factor, however, as soon as the initial design was complete, a serious limitation was discovered in the power budget calculations: lack of space for enough solar cells, so we decided to add a pair of multi-panel solar arrays[22] or 'wings' to address this deficiency.

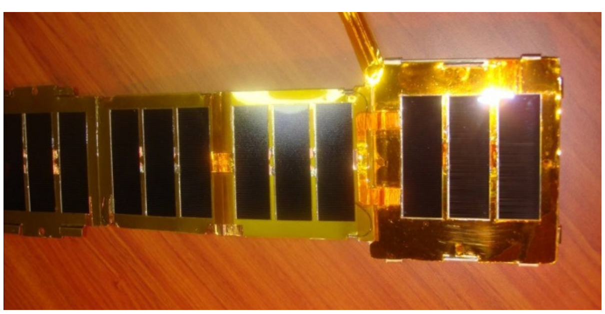


Fig-5 One of the DSA solar arrays with its 99.98% pure titanium scaffolds of 0.25mm and the SEAM/NEMEA shield

Characteristics:

-Mass: 1266g

-Dimensions: 10x10x75 cm (wings deployed)

-1W TX power on beacon mode, 3W on area coverage mode

-910MHz (PEGASUS) and 980MHz (KRYSAOR) transmission frequency with 25 MHz video bandwidth and 6 MHz audio

-MLI and titanium shielding.

-Command reception over FHSS 433 to 444 MHz over a 11 MHz bandwidth

-114dBm on-board reception sensitivity with diversity capability over 2 dipoles

-Capable of operation without batteries on solar power only.

-MCU-driven EPS with 8 input power channels each capable of supporting 6V@2A and 25ms switching capability.

Fig-6 Detail of the EPS-MCU daughterboard hand built by EXA personnel.

Equipment and Modules: The following is the list of modules that composes the payload of the spacecraft:

CYCLOPS[18]: This module handles radio transmission, real-time video and OSD telemetry. The camera has 720 lines of resolution and IR sensitivity of 0.0001 Lux and the video has no discernible delay.

<u>NEREIDA</u>[21]:This is the module responsible for transmitting the national anthem and the educational mission data; it has an onboard memory of 2GB

<u>PMSS:</u> This is the spacecraft navigation system, which uses the Earth's Magnetic Field (EMF) to stabilize its position in 2 axes, using 4 linear arrays of magnets and 2 sets of HyMu-80 inertial-magnetic dampers

<u>SEAM/NEMEA</u>[13]: Its purpose is to moderate the S/C temperature, to block the Alpha, Beta, X, Gamma and GCR (Galactic Cosmic Rays) within the limits of the possible, without producing Bremsstrahlung radiation

<u>DSA</u>[31]: It handles the unfolding and release of the multipanel solar arrays, is made of 99.98% pure Titanium and 1.5mm thickness, reaching 27cm once fully deployed, it is activated by the heat of the sun, using nanomorphodynamic techniques and memory metals.

<u>EPS:</u> It has 32 cells distributed in 2 arrays for a total of 28.8 amps or 107 watts, capable of operation without batteries on solar power only with MCU-driven core and 8 input power channels each capable of supporting 6V@2A and 25ms switching capability.

<u>ADS</u>[22]: The Antenna Deployment System is based on memory metals and is deployed using the heat of the sun in a gentle way to avoid any unwanted rotation.

<u>NTDS</u>[13]: The thermal distribution system uses internal heat to equalize the temperature inside the S/C, and is made of a thin layer of multiwall carbon nanotubes over a heat-reflecting shield to route the heat properly and use it during the eclipse phase of the orbit.

<u>Construction</u>: NEE-01 was built on the EXA facilities and as of the launch date had passed more than 1000 hours of tests. Its hull is made of 50% aluminum and 50% titanium. The design, test, assembly and integration was performed locally, down to the printed circuit level.

EXA imported the raw materials and worked them to final product; some components like battery cells, solar cells and basic electronics components like chips, condensers, etc, were also imported.

Fig-7 The process of conformal coating formulation and application

The design and assembly of the electronics was performed locally, from milling the PCBs out of blank FR4-06 sheets, down to formulating the conformal coating and the manually soldering sub-millimetric electronic components.

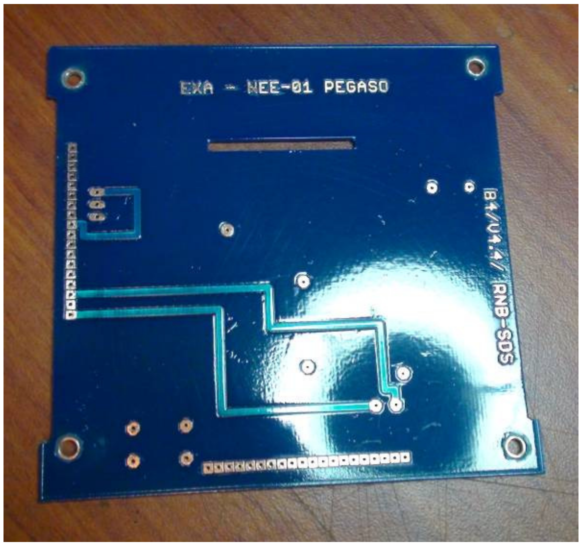


Fig-8 The process of conformal coating formulation and application and its results: The payload board substrate.

The main design included positioning the PC-104 module cards in a way in which the strongest shielding portion will be perpendicular to surface of the panels, so in this way the mass of the 2 battery arrays[20] could be used as shielding too. The battery arrays also shielded with copper, titanium (0.25mm) and carbon nanotubes as they also acted as thermal heat sinks.

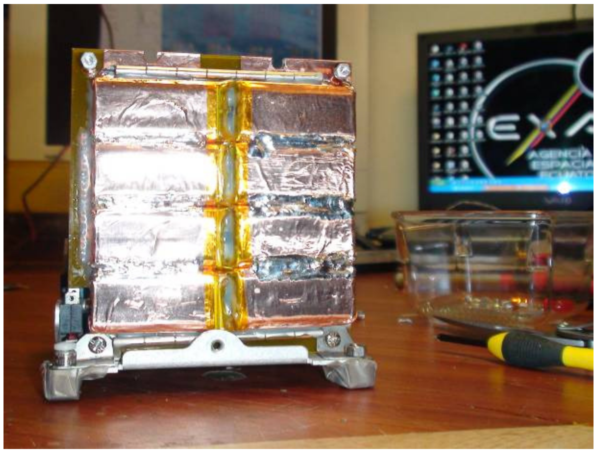


Fig-9 One of the early qualification models of the NEE-01, note the battery arrays positioned in the sides of the spacecraft to act as radiation and thermal shields in conjunction with the SEAM/NEMEA MLI

The battery arrays design and manufacture was made in house, each one had 16 cells, 8 to each side of the Kapton layered PCB, each li-poly cell had a nominal voltage of 3.7V and a nominal capacity of 900mAh, Due to the special dimensions and weight requirements, we designed these cells to measure 19mm x 5mm and 30mm, and outsourced its fabrication to a foreign manufacturer.

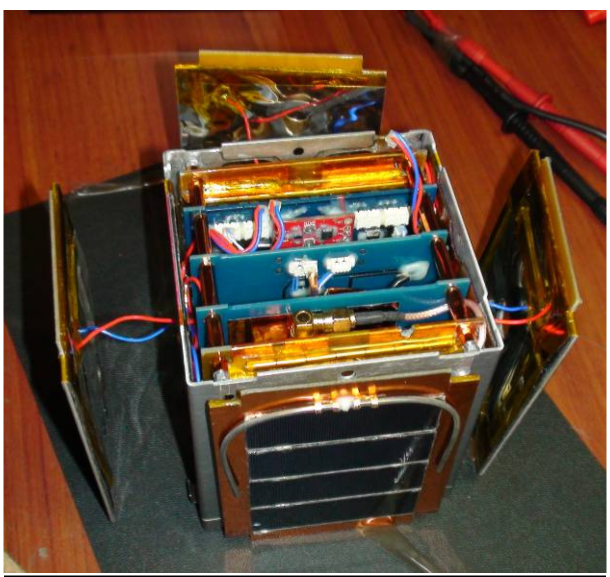


Fig-11 A top view of the NEE-01 PEGASUS payload integrated into its S/C hull with the SEAM/NEMEA shielding on the back of the solar panels.

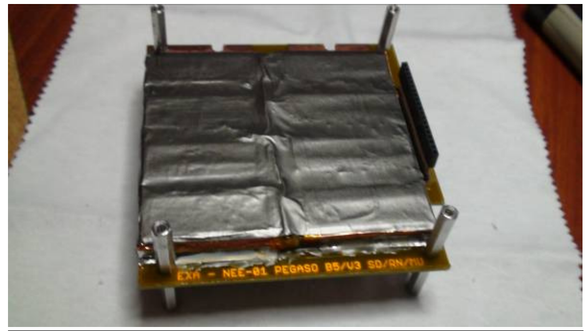


Fig-10 One of the 2 battery arrays for the NEE-01 flight model with the carbon nanotubes over graphite substrate installed, and over this layer is a thin gold-covered kapton layer which finalizes the shielding of the arrays

Launch: NEE-01 was launched into orbit on 2013 April 25 23h00 local time [27][28][29][30] by a Chinese Long March 2D launch vehicle, from the Jiuquan Satellite Launch Center. It entered its target orbit approximately 13 minutes later. The launch was coordinated by ISISpace[14] on behalf of GWIC, the owner of the launch vehicle. The orbital parameters were:

Reference system Geocentric
Regime Sun-synchronous
Semi-major axis 7,014.62 km
Eccentricity 0.0019229
Perigee 630 km
Apogee 657 km
Inclination 98.04 degrees
Period 97.45 minutes
Mean motion 14.78

NEE-02 was launched into orbit on 2013 November 21 02h10 local time[23][24][25][26] by a Russian Dneper launch vehicle, from the Yasny Cosmodrome. It entered its target orbit approximately 15 minutes later. The launch was coordinated by ISISpace[15] on behalf of IKSC Kosmotras, the owner of the launch vehicle. The orbital parameters were:

Reference system Geocentric
Regime Sun-synchronous
Semi-major axis 7,029.69 km
Eccentricity 0.0085226
Perigee 598 km
Apogee 718 km
Inclination 97.76 degrees
Period 97.76 minutes

NEE-01 has a very different audio beacon than NEE-02: PEGASUS transmits its name and callsign in CW, 600Hz, 50ppm, with a very particular pattern switching every 50 CW segments from 300, 600 and 1200Hz and transmitting its beacon every 10 CW segments and sending an SSTV image every 20 CW segments. While KRYSAOR transmits its data in high speed modes like QPSK and BPSK among other modes in just one data block each, and sending a SSTV signal every block and then its beacon in 600Hz CW, all this using the 6KHz audio channel of the video link.

Fig-12 The NEE-01 and NEE-02 payloads ready to be integrated into their S/C hulls.

How to get a video signal from space: When it came to calculating the link budget needed to receive a signal like this one, with a P5 quality level, preliminary calculations indicated a 150dB signal attenuation due to free space path loss only, and more attenuation would come from antenna pointing losses, polarization, atmospheric variables, etc. which accounted for a near 160dB signal loss.

Fig-13 A P5-quality video signal level, Signal/Noise ratio of >45 db, >1000 microvolt signal strength.

Fig-14 A P2-quality video signal level, Signal/Noise ratio of 8-20 db, 15-50 microvolt signal strength.

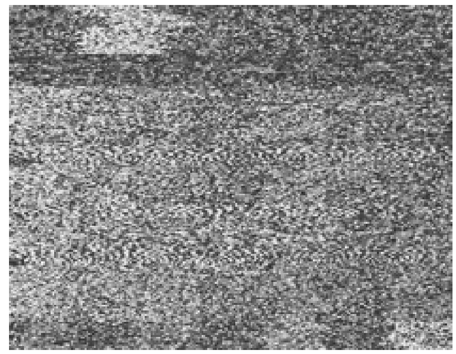


Fig-15 A P0-quality video signal level, Signal/Noise ratio of <3 db, <5 microvolt signal strength.

Taking into account that the maximum gain for the MINOTAUR-A sensor array was only 32dB maximum at that time, we were a long way from having the minimum of -55dB signal level established by our signal decoder sensitivity. So at this point a solution had to be found, either by boosting the power of the transmitted signal or enhancing the station sensibility in a dramatic way.

Since our basic concept in the PEGASUS project was to be as simple as possible in its design, preliminary calculations indicated that we would need to boost the power to at least 25W, impossible for a 1U cubesat form factor. Following the concept of making the best effort on ground and not in space, we were faced with the challenge of enhancing the station sensibility with very difficult to reach parameters.

ARGOS[15] or **A**dvanced **R**adio signal **G**athering from **O**rbiting **S**pacecraft was designed as a cascading amplification manifold, divided in phases, first phase will be F0, the nearest to the antenna coupling and F4 the farthest from it or the nearest to the decoder, each amplification module was couple to a multi cavity filter forming a narrow band pass/low pass filter to reduce the signal blurring. The ARGOS techniques are described in depth in its own paper presented in the 62^{nd} IAC and can be found in the references section of this paper.

Basically we are using a radio telescope to download the signal of a satellite.

The interesting point to this is that all the components are COTS or commercially available, at very low costs, in public internet sites like eBay or specialized sites like LCom, which constitutes an advance for many amateur ground stations around the world or academic cubesat programs which can now invest less in power budgets on their spacecrafts and not much more in the retrofitting their ground stations to reach powerful capabilities.

Investing less effort and resources in power budgets on the spacecraft accounts for more successful missions, maybe even more survival time in orbit, especially those with high beta angles in SSO orbits.

Testing and Qualification: Both flight models were successfully tested according to the launch service provider (LSP) specifications and the qualification models were tested 50% over the LSP qualifications in the EXA facilities and the ISIS facilities in Delft, Netherlands.

EXA facilities included the Space Environment Simulation Chamber (SESCA)[19], capable of generating up to 200C degrees luminal heat and -120C cold at the same time, SESCA also has one manipulator module, and was designed to support pressures down to 2.0E -7 mBar. Also the GOLEM Magneto Dynamic Shaker facility capable of generating up to 20G in all 3 axes in frequencies up to 5000Hz.

SESCA took almost a year to be developed and enter operation, dealing with high vacuum involves sophisticated leak detection techniques and very specialized pumps and sensors, while also taking into account the complexity of the chamber: the more features the chamber had, the more possible leaking points it would have.

SESCA originally had five windows, which in turn we reduced to only 2. Also the windows became squared, rather than round, as it was very hard to seal them properly otherwise.

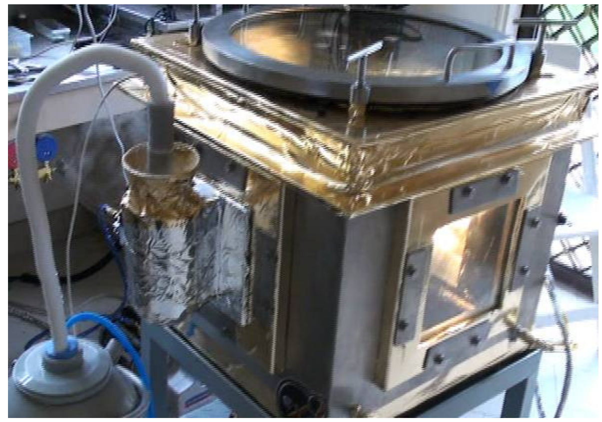


Fig-16 the latest working design of the SESCA chamber shown in operation with both the cryogenic (KRYOQVANT) and thermal (HELIOS) modules at the same time.

How to simulate thermal vacuum properly: The main idea behind the SESCA design was to simulate the orbital conditions as faithfully as possible, which is why we needed to generate high temperatures on one side, simulating illumination and very low temperatures on the opposite side, thereby simulating an eclipse.

Fig-17 Detail of the vacuum pump operating in mid-thermal vacuum, with the temperature inside the chamber over 200C.

For proper testing and operation of the qualification and flight models inside the chamber we had to route properly sealed wires and cables inside the chamber, SESCA has 4 interfaces that allows for sensor connections and remote operation of the model that allows us to simulate various modes of operation while simulating space conditions, this means that we not only can test materials and assembly resistance and behaviors but can also operate the satellite fully during the test tied to a wide variety of sensors inside the chamber.

For the cryogenic module we pumped liquid nitrogen during the operation circulating in a special design of a coil inside the chamber, the test subject never touches or comes in contact with this coil. The main idea is to force the subject to radiate heat by creating a 'temperature hole' in the space surrounding it but only in the opposite side of the thermal module, this one in turn is powered by 4 heating lamps arranged in an square fashion, we can put 2 conventional lamps on the up and bottom sides and 2 UV-C radiating lamps on the left and right sides to more closely resemble the sun's radiating spectra.

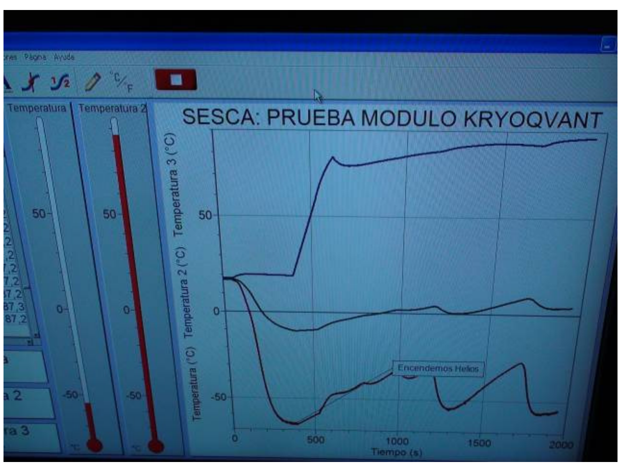


Fig-18 SESCA simulating the thermal vacuum of space. The center line is the thermal state of the test subject, and these results closely resembles the temperature gradients reported by both the NEE-01 and the NEE-02

As shown in figure-18, the temperature gradient shown during the simulation runs in SESCA closely resembles the temperature gradients reported by the telemetry of both NEE-01 and NEE-02 satellites and, in turn, validates the design and operational procedures of the SESCA facility.

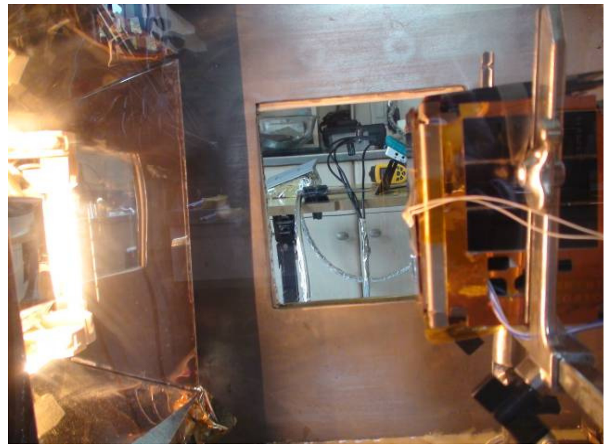


Fig-19 The NEE-01 PEGASUS flight model being tested in SESCA's thermal vacuum

<u>How to simulate a rocket launch</u>: Qualification tests requires a particular vibration test pattern and each launch vehicle has its own vibration pattern that is handed to all the payload owners who are going to use that launch vehicle. The challenge was to build a facility that allowed us to simulate these vibrations for all the required launch vehicles in order to meet the LV owner requirements, the "No test, no flight" condition applies. Each payload owner has to hand test documentation that supports the fact that their payload has been subject to the vibration and thermal test requirements that meets the LV owner specifications.

The EXA team embarked into building a magneto dynamical shaker: A facility capable of producing vibrations in all 3 axes and capable to handle up to 20G in all 3 axes in frequencies up to 5000Hz. After reviewing the available technology in this field we came to the unproven conclusion that we could generate the required accelerations using sound: so we basically took a special speaker and set up a test rig to prove our hypothesis.

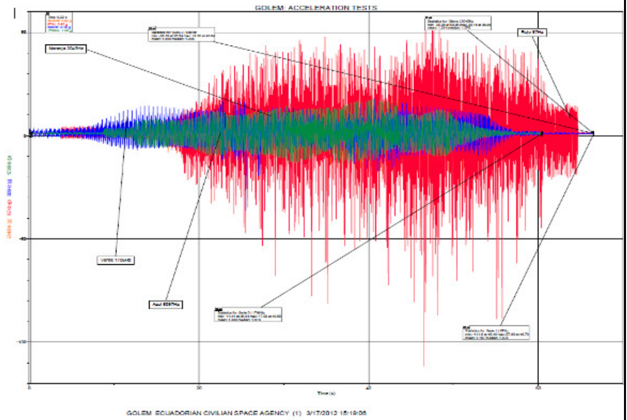


Fig-20 Proof-of-Concept GOLEM acceleration test, reaching from +20G to -100G in frequencies up 5100Hz.

After the first test yielded positive results reaching from +20G to -100G, and at frequencies up to 5100Hz, we put ourselves to the task of perfecting the device with better amplifiers, acceleration sensors and a computer with a high fidelity sound card capable of generating frequencies with less spurious frequencies. The idea was to concentrate more power on the target frequency and waste almost no power in undesired side frequencies and harmonics. This task branched over to the amplifier also and, with the proper filters, included the building of the speaker. After about 3 months of development and testing we could achieve the results depicted in Fig-21

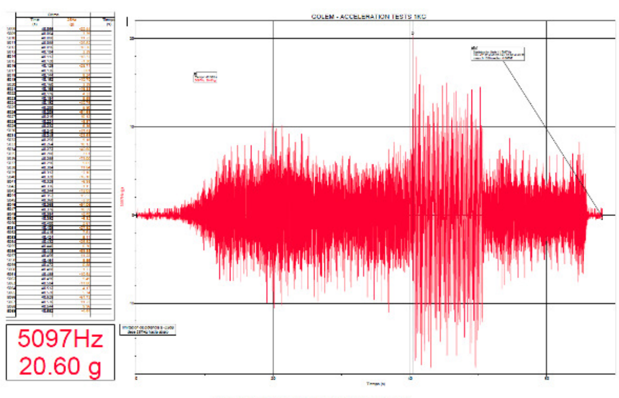


Fig-21 Final model GOLEM acceleration performance test, accelerating a mass of 1Kg to +20.6G at 5097Hz.

Fig-22 The NEE-01 flight model being subject to LSP vibration tests on the GOLEM magneto dynamical shaker facility.

Building our own EPS: Maybe one of the most critical systems for a spacecraft is the Electrical Power System manager or EPS. In our case, it was required that we design and build or own EPS manager, as we have done with everything else on both spacecrafts. It is worth noting that this subsystem also encompassed a lot of other subsystems, like the solar panels, the batteries, the attitude control subsystem and even the shielding and thermal distribution subsystems.

Our EPS is capable of operation without batteries on solar power only, it is MCU-driven EPS with 8 input power channels each capable of supporting 6V@2A and 25ms switching capability, each input channel corresponds to a solar panel, 4 of them in the +X, -X, +Y, -Y and 4 in the $+Z_{a\ \text{(dorsal side)}}$, $+Z_{b\text{(ventral side)}}$, $-Z_{a\text{(dorsal side)}}$ and $-Z_{b\text{(ventral side)}}$ for the DSA solar wings.

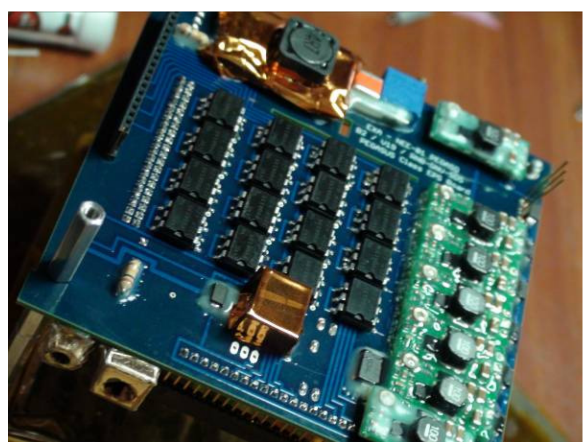


Fig-23 The NEE-01 flight model EPS during assembly and near completion.

Our EPS included 32 SSR chips giving the module the capability of managing each one of the 32 battery cells in the 2 battery banks, each one with 16 cells being connected in parallel for an output of 3.7V@28.8A. This output in turn was distributed to 4 power channels of 16V, 12V, 5V and 3.7V to power the main payload and the command reception systems, as well as the PERSEUS device and active DSA release in the specific case of the NEE-02.

Qualification: Why ~~to~~ do all this testing in house, if we still had to do them again in the Netherlands?~~.~~ Because in order to be accepted in the manifest of the launch vehicles, a third party had to vouch for us and make this very same tests again. Also because we were one of the new actors in space and this was our very first time~~,~~ so, to be sure, we had to present our satellites for the tests we already had passed in house. This is also why our tests were ~~up~~ 55% more demanding than the original testing required. We build them to last.

Fig-24 The EXA team in the ISIS clean room on Delft, Netherlands after qualification. Cmdr. Nader holds NEE-01 while Eng. Uriguen holds NEE-02.

First Operations: Although launched on April 25, first contact with NEE-01 was made on May 5th, 2013. The infamous TL lottery came into play and we jumping from one TLE set to another for about 10 days. In this case specifically, the LM2D ejected its secondary payloads on a vector perpendicular to the flight path. In the first days both NEE-01 and Cubebug-1 were very near each other, so EXA worked with the Argentinean team who was having the same problems trying to identify their satellite.

However in the first few hours, with the original TLE's still valid before the satellites began to drift from those TLE, in its first pass over Germany, a local radio amateur, Mike Rupprecth[(43)(44)]; with whom we had been working with for some time now and had instructed on how to build an ARGOS module for receiving the NEE-01 signal. He was able to detect the signal and relay it to us via the HERMES Internet Relay gateway. Consequently at about 4 AM in the morning we could hear the audio portion of the NEE-01 transmission[(42)], but could not see the video as Mike Rupprecth reported a problem that cause his computer to reboot every time he connected the video cable to the capture card.

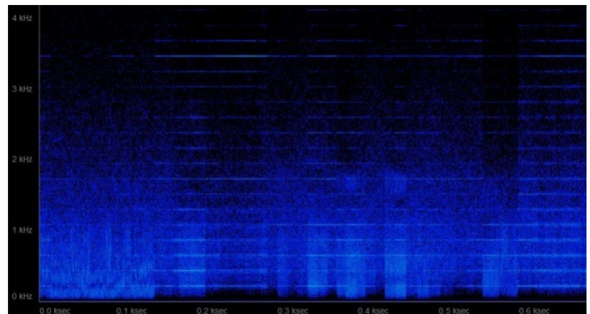


Fig-25 A screen capture by Mike Rupprecht on April 29th, 2013 of the NEE-01 pass over Germany, and using EXA's ARGOS module.

Mike Rupprecth was also able to decode the CW and SSTV[(42)] signals from the satellite in subsequent passes as it is detailed in his blog.

From May 16th up to May 21st all the satellite transmissions were successfully broadcasted via EarthCam, and it was reported that between 1 and 3 million people around the world were connecting to watch the passes. Thousands of Ecuadorians reported watching the broadcasts in their jobs, and at home, and many schools started to work with the SSTV and CW audio signals and decoded them successfully.

Fig-26 A snapshot of the first public video transmitted by the NEE-01 during May 16 2013, 10h41m pass over South America.

NORAD officially identified the satellite as NEE-01 PEGASUS on May 13, 2013.

EXA did also received some emails from Japanese and Australian radio operators claiming to have detected the carrier wave and even decoding the CW audio messages[45]

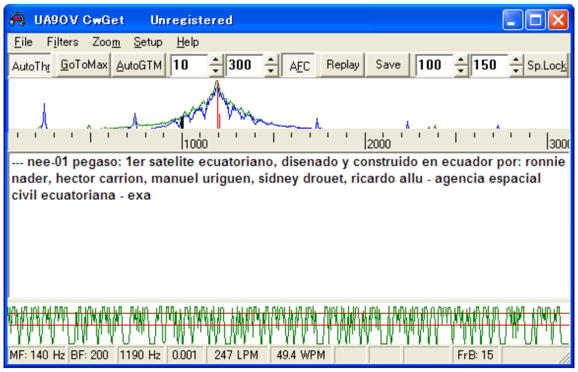
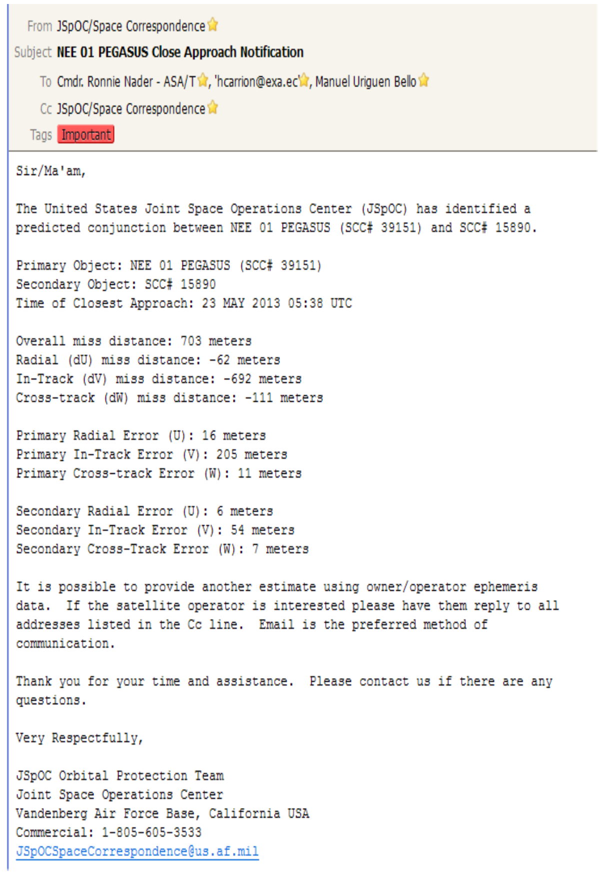


Fig-27 Screen capture showing the decoding of the CW signal of the NEE-01 from the Japanese amateur operator JE9PEL © Mineo Wakita JE9PEL.

The Incident[41]**:** On May 21 at 20h10 local time, we received a Close Approach Notification (CAN) from JSpOC/NORAD informing EXA as the satellite operator, that a probable conjunction would occur between NEE-01 and NORAD Catalog Number 15890 on May 23 at 0538 UTC, this was our first CAN, and after analyzing the data EXA came to the conclusion that the conjunction was risky, as the Radial Miss Distance was only 62 meters.

EXA notified high ranking government officers and, after consultations these officials, decided to make it public. A press conference was called on May 22nd, at 10h30 local time[46],to brief the public on the situation.

The last meaningful transmission of NEE-01 was on May 21 2013 starting at 23h12, and on May 22nd, 2013 there were no scheduled transmissions as the passes were too low. However, after a long analysis, EXA decided to put the satellite in survival (safe) mode, which meant that it would broadcast continuously along its orbit with nominal power; as opposed to operating in the Overlord Mode, in which it transmits only when activated by HERMES-A ground station and with high power. This command was sent to the satellite during low passes on May 22nd at approximately 21h00 and 23h00 local time.



From JSpOC/Space Correspondence
Subject **NEE 01 PEGASUS Close Approach Notification**
To Cmdr. Ronnie Nader - ASA/T, 'hcarrion@exa.ec', Manuel Uriguen Bello
Cc JSpOC/Space Correspondence
Tags Important

Sir/Ma'am,

The United States Joint Space Operations Center (JSpOC) has identified a predicted conjunction between NEE 01 PEGASUS (SCC# 39151) and SCC# 15890.

Primary Object: NEE 01 PEGASUS (SCC# 39151)
Secondary Object: SCC# 15890
Time of Closest Approach: 23 MAY 2013 05:38 UTC

Overall miss distance: 703 meters
Radial (dU) miss distance: -62 meters
In-Track (dV) miss distance: -692 meters
Cross-track (dW) miss distance: -111 meters

Primary Radial Error (U): 16 meters
Primary In-Track Error (V): 205 meters
Primary Cross-track Error (W): 11 meters

Secondary Radial Error (U): 6 meters
Secondary In-Track Error (V): 54 meters
Secondary Cross-Track Error (W): 7 meters

It is possible to provide another estimate using owner/operator ephemeris data. If the satellite operator is interested please have them reply to all addresses listed in the Cc line. Email is the preferred method of communication.

Thank you for your time and assistance. Please contact us if there are any questions.

Very Respectfully,

JSpOC Orbital Protection Team
Joint Space Operations Center
Vandenberg Air Force Base, California USA
Commercial: 1-805-605-3533
JSpOCSpaceCorrespondence@us.af.mil

Fig-28 The original notice from JsPOC on May 21, 2103 received by the EXA's Space Operations team.

By May 22nd, at 23h18 local time, we received an update from the CAN indicating that the radial miss had reduced even further and was 58 meters then.

By May 23rd, at 01h42 local time, we received an update of the CAN indicating that a full collision had not happened.

By May 23rd, 10h42 local time, the very first pass after the conjunction, we were not able to detect any meaningful signal from NEE-01, nor in subsequent passes up until a week later; when we were able to detect the vertical sync TV signal appearing and disappearing at a high pass in the sky. This was not enough to form an image, but enough to be sure that the satellite was in tumbling; as NEE-01 carries 2 TX antennae and 4 RX antennae.

On May 23rd, 2013 we called a press conference at 15h30 local time[48] and announced what had happened and what we knew at that time, also announcing that we had started a rescue operation that we nicknamed PERSEO. We also announced that we would implement our OMEGA communication protocol, which meant that we would not talk to the press until the operation was finished during a 90 ~~days~~ period, and this was expected to conclude on August 28th, 2013[47]. If after that date we were not able to recover the use of the satellite, then we would activate the insurance policy.

At that time we were able to detect a vertical TV sync high in the sky where NEE-01's position would have been at that particular moment. However we also noted that signal came and went, on and off, which indicated for us a tumbling due the geometry and position of the RX antennae on the spacecraft. The power rate or received signal strength varied chaotically, and without a discernible pattern.

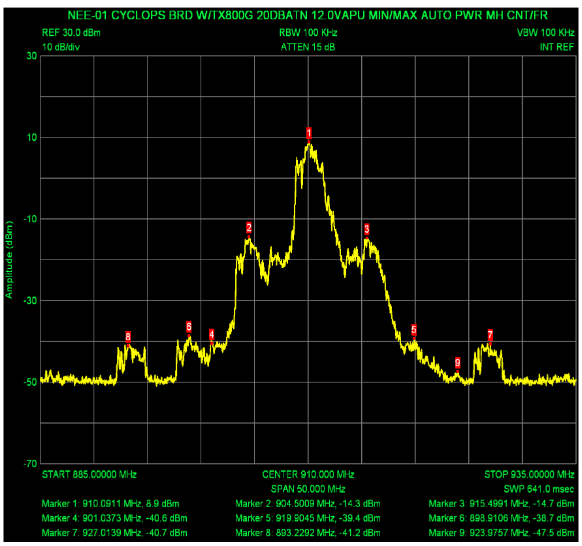


Fig-29 The original received signal for NEE-01 around May 2013, before the anomaly. Compare this signal with the signal depicted in Fig-30 for September 2013, nicknamed "The Ghost of Pegasus".

On June 13th, 2013 we were able to gain command of the activation and deactivation during the night passes. There were some ~~few~~ actions we could take, each time there was a high pass, in order to make NEE-01 stop rotating until the PMSS navigation system could take over. If we achieved that threshold, then it would only be a matter of days until the spacecraft could potentially stabilize and we would then be able to broadcast again.

<u>Proof of life:</u> From this point forward, we attempted to receive the signal from NEE-01 almost every day, but soon became clear to us that in this condition~~s~~ it would be futile to attempt contact on days where the passes where not over 30 degrees. On the best days we could detect a faint EM signature, which for us meant that we could see a very small 'walking' carrier signal just over the -89 dBm threshold traveling from +910.xxx to -909.xxx, and with a 20 to 25 Mhz bandwidth. This coincided with the orbit of the NEE-01's doppler change, which was expected ~~and~~ with the time and day of the pass, and we conducted many tests to rule out the possibility of background noise.

We nicknamed this faint EM signature as "The Ghost of PEGASUS" or TGP.

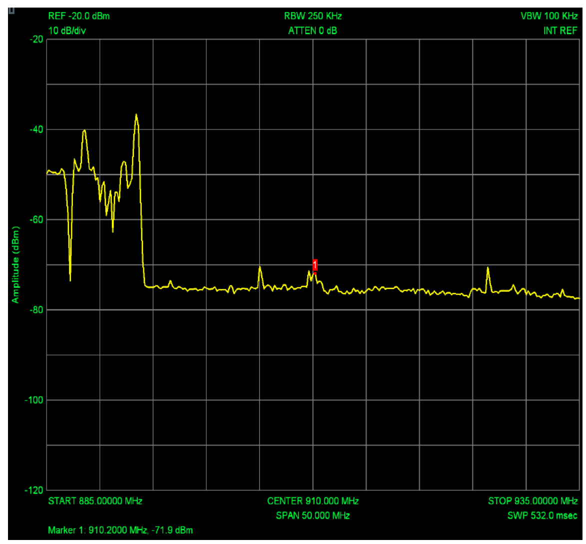


Fig-30 Screen capture of the EM signature for NEE-01 around September 2013, nicknamed "The Ghost of Pegasus". The ARGOS hyper-amplification manifold was operating at full capacity and providing +120dBm filtered, narrow band amplification.

By the end of August this signal channel was stable, however being the most powerful in the whole signal, it would not raise over -83 dBm and the whole signal would not raise over -85 dBm in the best case.

Reaching the end of August also meant that we were near the deadline of the insurance policy coverage and so, not being able to regain the signal of the NEE-01, we notified the proper authorities. They, in turn, notified the insurance company; who, with due diligence, executed the policy and we had to declare the NEE-01 lost.

The PERSEUS device: Declaring our first satellite lost was a blow to us and to the country, however we knew that the spacecraft had survived and it was working properly. If not, no signal would have been received and no response to our commands would have been recorded.

The task ahead was clear: To forget about NEE-01 and focus our efforts in the getting NEE-02 ready to launch. However, the whole team could just not let NEE-01 go, as we had invested too much and the country really cared about it. NEE-01 was our first satellite and it was something very personal to all of us. It would have been easier if we had never received any signs of life from it after the incident, but we knew it was up there, alive and working. Even after such event, it was a testimony of our engineering and ingenuity, and we could just not abandon him, he was like a son to all of us.

So we kept tracking NEE-01 as usual, and a few days later we came to the conclusion that the most probable cause for the phenomena we were observing was that the incident somehow have deformed the antenna in a way that it could no longer point in the proper direction. We arrived at this conclusion by analyzing and simulating what would have been the attitude of NEE-01 during the incident, and we found out that the side facing the supposed particles was exactly the side were the main TX antenna was mounted over.

The side panels were reinforced with the SEAM-NEMEA shielding, which included 2 sheets of 0.25mm CP-2 titanium alloy, 99.98% pure and behind that there was a 9 mm gap between the panel and the battery array which was also heavily shielded, so assuming that something hit the spacecraft, whatever thing it was, did it over the most shielded part of the spacecraft.

But this also meant that there was nothing we could do here on earth to receive the signal properly, especially if the panel was out of alignment and the antenna had lost its zero. We would just have to let it go.

Unless we could do something in orbit. While we might not have been able to do anything here on earth, surely could do something in space.

At this time we happened to be preparing another spacecraft to be sent to an orbit which, out of pure luck, would intercept the orbital path of the upper projection of the NEE-01 every two weeks. This would take place at a minimum distance of 100km, at the poles and 300km over the Ecuador; the exact location where an intervention could take place. And we just happen to live there.

So we came up with the idea of installing a simple repeater inside the NEE-02 as a secondary payload, a small reception device tuned in the same frequency of the transmission frequency of the NEE-01 and directly connected to the input of the main transmitter of the NEE-02, we still had 9 command channels available in the main MCU port and we would only need 2 command channels to operate it.

Luckily for us we had all the materials at hand and all the expertise to build it. In fact, we already had been working on such a device for a different project some 2 years ago, and we already had a chipset that allowed us to have a -121dBm sensitivity over the target frequency with 2 diversity channels. We had to mount 2 more dipoles over the NEE-02 hull and make them deployable by using the same techniques we used to build the DSA arrays. These 2 dipoles were made from a NiTinol 0.25mm diameter core and shrouded by a 0.12mm Pt-Ir alloy sheet bind to a 18K Au fastener. So from mid August to mid September the PERSEUS device was ready, tested and installed on the NEE-02, which was ready to be shipped to the ISISpace installations in the Netherlands, and then integrated into the ISIPod alongside the Argentinean Cubebug-2.

However this was a long shot, all theory in principle. As sound theory and no unproven or fancy technology, obviously this project was not announced or notified to anyone except the very few people involved in it. If it worked, we could get the NEE-01 back but, if not, it would be business as usual. The status quo would remain.

We had nothing to lose and everything to gain.

Fig-31 Eng, Manuel Uriguen working on the NEE-02 already integrated in the ISIPod #3, and behind him the space head module of the Dnepr RS20B that would inject it into orbit.

NEE-02 Launch and Operations: On November 21st, 2013 the NEE-02 was launched as planned and reached its target orbit. Due to the PERSEUS operation, we announced to the press that we needed about 40 days to start operating the satellite. In actuality, however, we had the first beacon contact on the day after the launch, indicating that the satellite was responding to commands and that the DSA were deployed and operating properly.

NEE-02 was part of a record launch of 33 objects[(49)], and with the help of Dr. Thomas Kelso from Celestrak, we were able to locate it as DNEPR-OBJECT AB and start operating it again like 2 weeks after launch.

The NEE-class satellites are unlike any other cubesat projects. They need very accurate pointing due to the strict link budget that comes associated with the problem of getting a 25Mhz bandwidth TV signal at 3000 kms away and has a maximum EIRP of 3W. This is why we developed the ARGOS , which works in conjunction with very large ground antennae with pointing accuracies below 0.2 degrees and narrow beams of less than 3 degrees, and very precise rotators and controllers too. Consequently a TLE lottery supposes a very tedious and sometimes frustrating work in this case.

By that time we already had HERMES-2 tested and working with upgraded rotors, so the TLE lottery became an easier work.

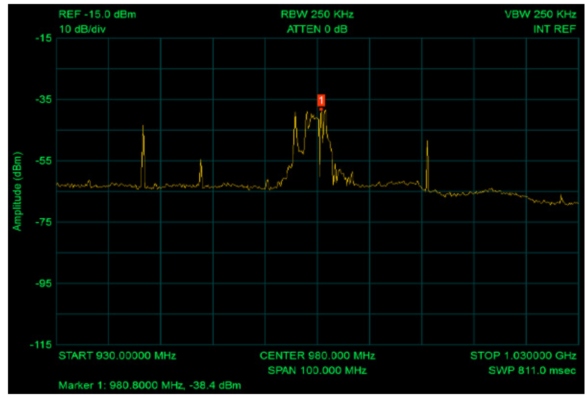


Fig-33 Signal spectrum of the NEE-01 signal re-transmitted by the NEE-02 in its center frequency carrier during one of the first PERSUS operations in mid December 2013. Note the audio signal horn at 976 to 974 MHz, which corresponds to the original 906MHz on the NEE-01 center frequency; while the rest of the signal indicates that video signals are also being received and retransmitted.

By mid December 2013, we were able to make the first successful in-orbit tests of the PERSEUS device, with a maximum range of 2000 km of separation between the spacecrafts and minimum range of 800km of separation, and could ~~heard~~ the audio portion of the whole signal coming from NEE-01.

Both spacecrafts fly near each other enough for us to activate the PERSEUS device only every 2 weeks approximately, so our windows of communication opportunity with NEE-01 are reduced to 3 or 4 days per month. We have also tried to receive NEE-01 transmission directly from earth, but with negative results as of the completion of this paper. However, all attempts to receive its transmission via PERSEUS have been successful

Although the repeater was designed to re-transmit the full video and audio signal, we were only able to receive the audio portion of the signal. Nonetheless, this was enough for us at that time to know that many of our assumptions were correct in the matter of the functionally of both the PERSEUS device and the NEE-01.

On January 25th, 2014, the first public transmission of NEE-02 was aired in a national TV broadcast, and during the middle of the transmission we were able to successfully operate the PERSEUS device and link it with the NEE-01 via NEE-02. The audio portion was clearly heard, although no video signal was received from the ground station. On an emotional note, the Ecuadorian people could clearly heard the NEE-01 voice beacon indentifying itself as the first Ecuadorian satellite and reproducing the national anthem from space, once again.

We had recovered PEGASUS. (32) (33) (34) (35) (36) (37) (38)

Fig-35 Krysaor re-transmits Pegasus signal, 10h05m, January 25, 2014.

Summary: This rather short paper has tried to detail only some of the technical work we embarked on in order to reach space in our own way and with our capabilities; in sum, with our hands. However, the story is much longer and complicated than what can be described in these short 15 pages, which is why we encourage the reader to invest some time in reading the references cited at the end of this document. Even with all these references, however, the story still falls short as it doesn't completely describes many technical minutiae and every small technique which, in the end, made a difference in every process and problem we tackled over.

This path has produced more than 50 papers from the EXA; some of which are cited here and some not, as they are not directly involved, but the knowledge and experience detailed on each of them added up in different moments of our history to reach the goal of touching the sky in our own way and with our own hands.

The sincere hope is that the information conveyed here will contribute to inspire others with the same goal to live up to the stature of their dreams, as we indented to do.

Acknowledgments: The EXA team wants to thank many people, both in house and around the world for their faith, patience and help. Among them includes our own government and the people of Ecuador, who, on an April's night finally came to see with their own eyes how a long-cherished dream came true. As one old man said in a local TV interview: "*God did let me live long enough to see this…*". We will probably need another 15 pages to name each of them, but if one of you is reading these words now, we deeply thank you for all your help, all your hope, and all your efforts.

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