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ARGOS: HYPER AMPLIFICATION MANIFOLD FOR ENHANCING GROUND STATION RECEPTION

Abstract

As a need for accomplishing primary mission objective on the NEE-01 PEGASUS pico satellite we were faced with the need for dramatically enhance the reception sensibility of our actual HERMES-A/MINOTAUR ground station.

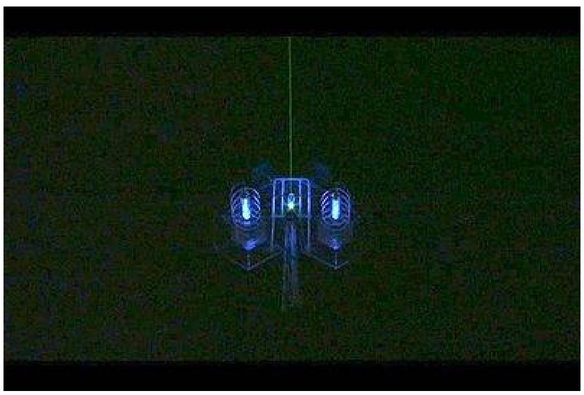
HERMES-A was already a powerful and very sensitive ground station, however, much more was needed in order to receive and decode a real time video transmission from orbit arriving to the antenna with signal levels as low as -160dbm. The solution was the ARGOS manifold which resembles more a radio telescope than a normal ground station. ARGOS is inspired in many techniques derived from a quantum physics approach and in some used in SETI systems as the problems we faced were more similar to those encountered in SETI signal reception and amplification than in normal space operations involving satellites in LEO orbit.

The mathematical model of the link budget developed for the CYCLOPS payload was the base for the calculation of the needed gains in each stage of the ARGOS manifold, components were selected and tested and finally the whole manifold was put to lab and field testing with outstanding results The result was a hyper amplification manifold capable of enhancing the sensitivity to up 320 dB and able to allow the decoding of video/audio signals as weak as -375dbm and as wide as 25Mhz with minimal signal blurring in an small package and using COTS components which resulted in a modest implementation budget.

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.

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, 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, 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.



The MINOTAUR array during night operation

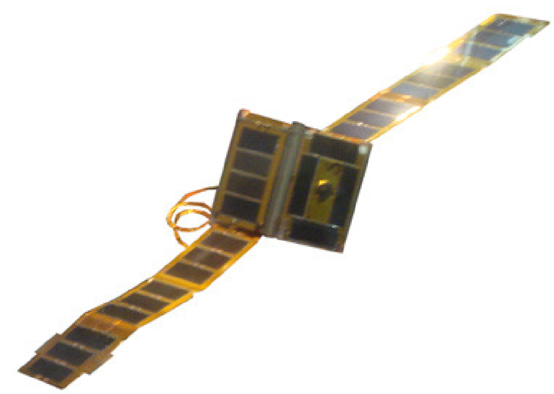
The HERMES-A Ground station has rendered best than expect results and it is also a powerful laboratory that allow us to experiment and learn for ourselves about satellite technology from firsthand experience. And also serves other international institutions abroad like the JAXA, The Michigan State University, 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.

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 with that we moved on to the next phase of the ECSP.

NEE-01 is the Ecuadorian registry number meaning 'Ecuadorian Space Ship – 01' in Spanish, so the spacecraft was christened **NEE-01 PEGASUS**

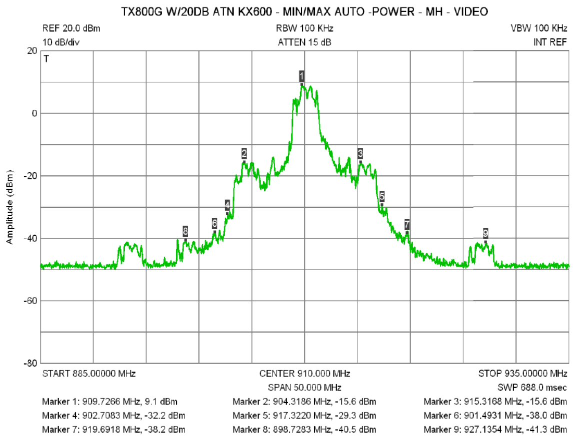
Project was to be financed entirely by the EXA and the local industry, specifically QUICORNAC, who provided half the funding needed, total budget was of US$30.000 for the research and building phase, as usual in EXA projects, all personnel was working in 'pro-bono' mode, the funding was solely dedicated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

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



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

One of the primary missions for our first satellite was to transmit real time, live video from orbit and OSD telemetry for such purpose the CYCLOPS module was designed to handle the radio transmission, the real time video and the OSD telemetry, the camera has 720 lines of resolution and IR sensitivity of 0.0001 Lux, the video has no discernible delay, the TX power was set to 1W maximum on the 900Mhz UHF band, with a bandwidth use of about 25Mhz, of which the audio portion was assigned a 6Khz bandwidth slot to be used by the NEREID module which will be sending the digital data for the educational mission of the satellite, for more information see the original paper on reference (1) or visit the official NEE-01 PEGASUS website at http://pegaso.exa.ec.

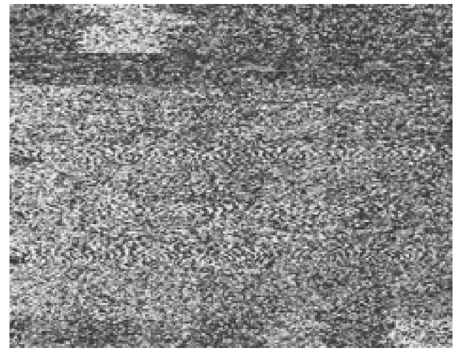


The NEE-01 PEGASUS signal graph for video/audio transmission, signal as an input attenuation of 20dB in order to avoid damage to the oscilloscope.

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

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

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



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, 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 will need to boost the power to at least 25W, impossible for a 1U cubesat form factor. Following over 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 equally almost impossible numbers.

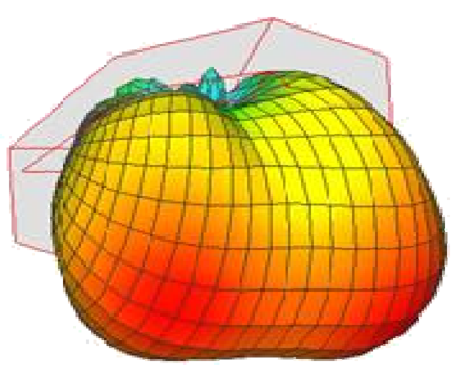
<u>Quantum approach:</u> An established rule in radio theory and experience is to treat radio signals as waves traveling in the space-time tensor matrix, we found that this approach was the least useful in understanding how could we be able to receive a incredibly low signal and amplify it to an impossibly high level, using the wave approach, fortunately for the team, one of its members had experience and training in quantum physics and some SETI experience and approached the problem from a novel and distinct perspective.

In quantum physics actually there is no ‘particle’ concept, but they are defined as cloud of possibilities called a quantum wave function, which disentangles once the particle has been observed, in our case, detected.

In the particular case of the antenna, is no more than a resonation manifold which purpose is to absorb photons and emit electrons, which in turn is defined by the ***hv*** relationship where ***h*** is the Planck constant and ***v*** is the frequency on the incoming photon. The tuning of an antenna is not more than the modulation of a space-time manifold to resemble or resonate the geometry of a stream of photons fluctuating wave-like in the space-time tensor matrix.

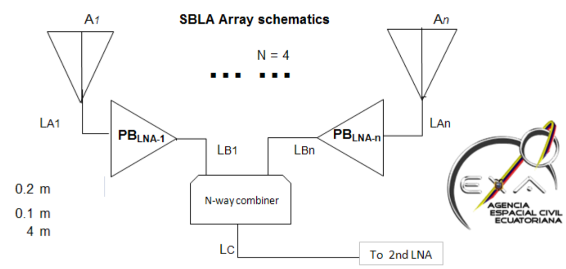
The proposed approach was not to treat the incoming signal as a wave traveling in space, but as an stream of photons forming a field which geometry resembles a wave-like fluctuation arriving at the antenna manifold, based on the fact that radio 'waves' are only a portion of the EM radiation spectrum and have the same nature as light, and thus it can be treated as a particle stream, so in essence we were faced with the problems encountered on radio astronomy and SETI fields.

SETI tries to discriminate an non-natural signal pattern, this is, a sequence of pulses than can be assigned a mathematical order, coming from light years away, with power levels and flux densities that range into the nano an pico portion of the magnitude order, so in principle we had the same problem: To discriminate an non-natural, non noise-like, signal pattern of very low power, but much higher than those that SETI tries to find. So basically, if a radio telescope could amplify and detect photons coming from the end of the universe, we should be able to download a 1W video signal of 25 MHz bandwidth at 3000kms.

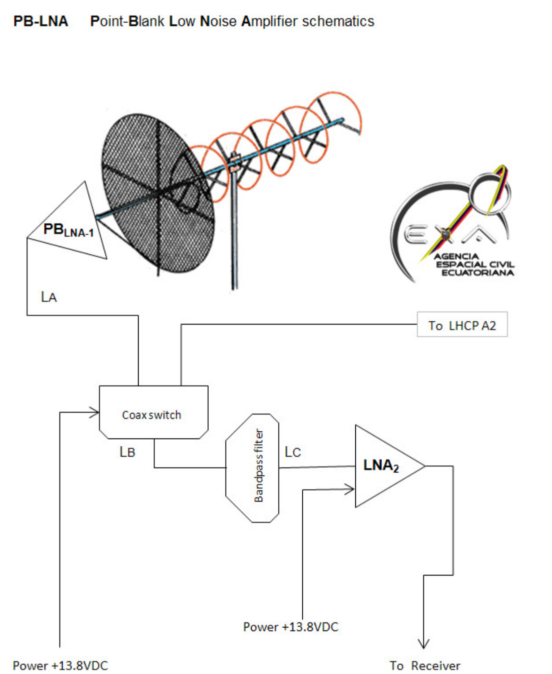


The combined far field geometry of the MINOTAUR-A array

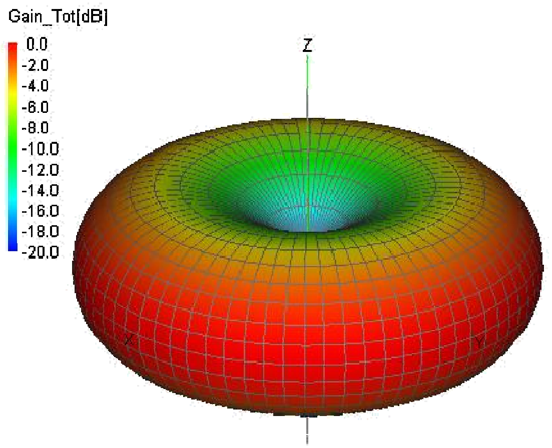
We basically defined two architectures to tackle the problem: The SBLA (Short Baseline Antenna array) and the PBLNA (Point Blank Low Noise Amplifier array) which objective was to extend the sensitivity of the far field, we selected this approach borrowing the 'far field' concept from the transmission point of view and 'inverted' it as we found empirically to be more fitting to explain some anomalies in experimental data



The main concept in the SBLA array is that of an antenna farm or a big virtual antenna, but with short baseline, coupled with the PBLNA technique, gives out a powerful amplification gain with minimal signal blurring.

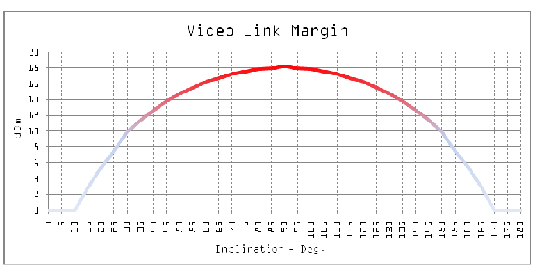


The idea behind the PBLNA is to have a series of LNAs as near as possible of the reception point in the antenna to minimize losses, this approach is very common in SETI installations as well as many commercial satellite reception systems, the main difference though, is that a cascade amplification will be applied to this manifold, using a series of multi cavity filters to minimize the expect signal blurring due the cascade amplification scheme.

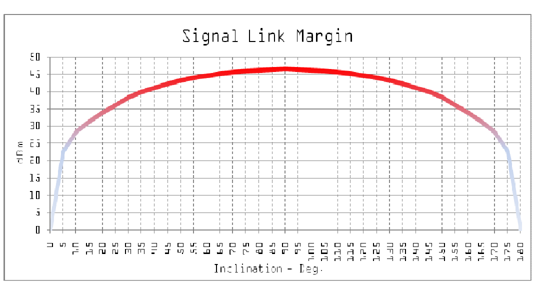


The NEE-01 PEGASUS dipole radiation pattern, which actually is tilted 90 degrees

The main idea is that a virtual far field (of reception) will have to make contact with the actual an real far field of the transmitting dipole on the satellite in a way that a minimum surface contact will render at least P4-quality signal levels at the exit of the signal decoder, thus reconfiguring the slope of the signal reception curve from this geometry:



To this geometry:



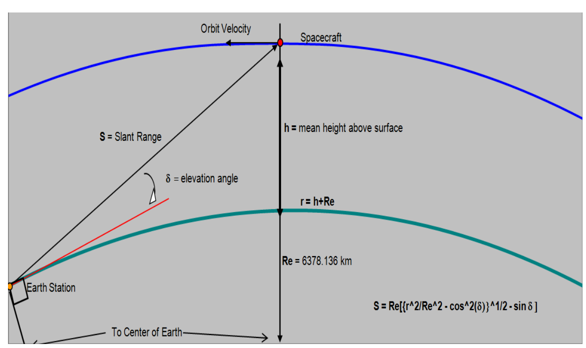
<u>Design:</u> ARGOS or **A**dvanced **R**adio signal **G**athering from **O**rbiting **S**pacecraft was designed as a cascading amplification manifold, divided in phases, first phase will be F0, the nearest to the antenna coupling and F4 the farthest from it or the nearest to the decoder, each amplification module was couple to a multi cavity filter forming a narrow band pass/low pass filter to reduce the signal blurring.

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

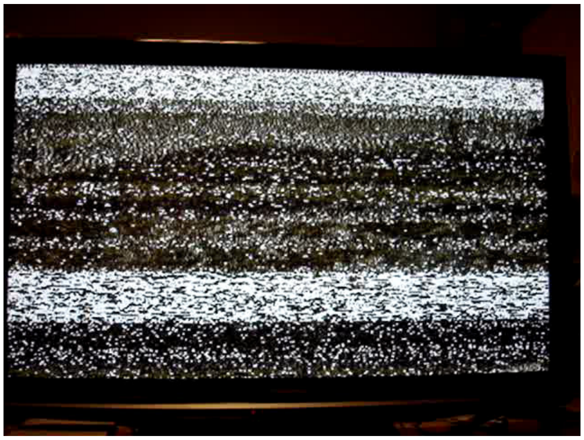
The interesting point to this is that all the components are COTS or commercially available, at very low costs, in public internet sites like eBay or specialized sites like LCom, which constitutes an advance for many amateur ground stations around the world or academic cubesat programs which can now 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.

<u>Testing:</u> in order to put our models to the test we started field experiments trying to simulate linearly the expected path loss we were going to have accordingly to the planned target orbit to our expected maximum slant range of 2.534 km



The best results were achieved by capturing the full 25 MHz bandwidth signal at 20.5 km. away (slant range) from a camera transmitting at 0.002W peak power with P5-quality signal level, which accordingly to our link budget calculation matrix render an effective FSPL of 117.1 dB attenuation and even when we could not find a weaker transmitter or one that could be fit with a proper attenuator without rising the VSWR too much that will risk burning the circuit, the levels were enough and the field tests were successful.



The resulting signal from 20.5kms away, without using any amplification, even with that kind of FSPL, the MINOTAUR –A array was able to discern some level of signal, the transmitting source was at 0.002W TX power.

The resulting signal from 20.5kms away, using phase F0 of the ARGOS manifold, the transmitting source was at 0.002W TX power, some interference can be observed due other sources in the vicinity.

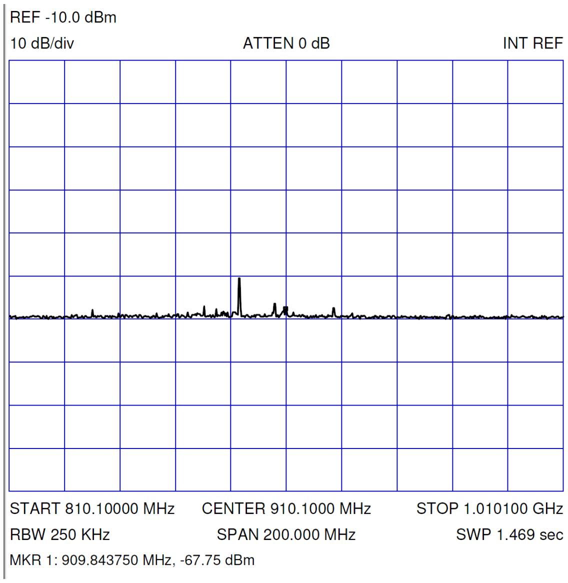
But we were still below the -160dB expect FSPL that we will have in the NEE-01 PEGASUS mission, so we turned to lab tests.

At this point we need to realize that we were decoding a full video image, at 24 frames per second from a signal as low as 2 milliwats, but those 0.002W were not arriving at the antenna, such low power was the one measured *leaving* the transmitter antenna (or less, due the imperfect VSWR match), which in turn means that such power was distributed in a spherical surface of 41 km of diameter when making contact with the very small surface of our antenna, so if we try to measure the actual power arriving to the resonating manifold, the photon flux density will be infinitesimal.

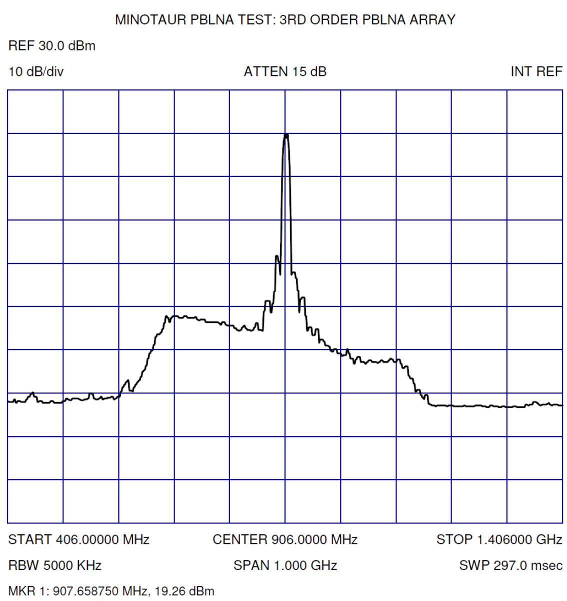
The lab tests were made by disconnecting the cable physically from the antenna and fitting the reception manifold, from the mouth of the first PBLNA module down to the oscilloscope were the video decoder should be. Then we connected the mouth of the transmitter to the mouth of the reception manifold using a string of attenuators in series, rendering the following results:

Attenuation dB	Resulting Signal dB (rounded)	ARGOS phase activated
120	+20	F0
160	+30	F0/F1
200	+10	F0/F1
240	+19	F0/F1/F2
280	+22	F0/F1/F2/F3
300	+2	F0/F1/F2/F3
340	-18	F0/F1/F2/F3

The measurement was made using an SDR SignalHound 1hz to 4Ghz oscilloscope setting the internal attenuation accordingly to strength of the resulting signal in order to avoid the damaging the device and to preserve the resolution bandwidth within the practical reading limits. The attenuators were 20 and 40dB MA Com devices, newly purchased and calibrated for the test, the connectors on the ARGOS manifold were Amphenol SMA gold plated, and the solder used was 96/4 silver solder, no cable was used in the devices.



The originating signal at 1W with 240dB physical attenuation, the internal oscilloscope attenuation was set to 0dB, the signal level was -67.75dB



The resulting amplified signal with 240dB physical attenuation, the internal oscilloscope attenuation was set to 15dB to avoid damaging the device. Signal level was 19.26dB

We dismissed the simulation of the antenna gain in order to make the tests more critical. From the results of this test we could experimentally determine that the resulting amplification was not linear but geometrical, we could not continue testing further down due the lack of more attenuators (we had 20dB and 40dB attenuator units), however, even with a simulated SPL of 340dB the resulting -18dB signal level was more than enough to comply with our lower limit of -55db imposed by our reception decoder.

Theoretical calculations indicate a possible 470dB amplification is possible with all 4 phases of ARGOS working simultaneously, however we do not know how many phases we could add until the signal degradation becomes too great for the signal to be discernible from the noise, or in other words, that the SNR becomes too great.

Acknowledgments: The EXA team that built the NEE-01 PEGASUS and developed the ARGOS system, want to thank our main sponsor, QUICORNAC for its faith and financial support that allowed us to complete this historical project successfully. We also acknowledge the inspiration brought to us by reading the many versions of the Sputnik history and most specially the gallant history of the Amateur Satellite Program.

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