Proposal for a nanosatellite microwave communication system, to achieve energy savings, high capacity data transmission, and position control feedback

Dr. Ante Salcedo[1] & Dr. Esaú Vicente-Vivas[2],

[1]Dpto. de Sistemas Digitales, ITAM, Río Hondo No. 1, 01000, México DF., asalcedog@itam.mx
[2]Instituto de Ingeniería, UNAM, Cd. Universitaria Coyoacan, 04510, México DF., evv@servidor.unam.mx

Abstract. This paper proposes the design of a microwave communication system for an under 10 Kgs Nanosatellite (NS) that is being designed and built at Instituto de Ingeniería - UNAM, Mexico. The proposed communication system was not contemplated in the original Nanosatellite proposal, nor in previous Mexican satellite projects, but it appears to be advantageous because of its narrow radiation pattern, and the high frequency at which it operates. As explained in the paper, we believe that the characteristics of such communications system will benefit the satellite with significant energy savings, high capacity for data transmission, and feedback information for position control. We present preliminary thoughts of the proposed communications system, describing the technology that is to be used for its implementation, and the benefits that such system brings to the nanosatellite. We also outline the next steps to be followed, so this paper should be considered as the starting point towards the design and implementation of the proposed nanosatellite microwave communication system.

Keywords: Nanosatellite, energy savings, position control, communications.

1 Introduction

Based on previous space project experiences such as the NASA´s Space Shuttle Get Away Special project developed by a Mexican team at Utah State University and the Satex Microsatellite project, the Instituto de Ingeniería (IdeI) UNAM took the initiative to develop an under 10 Kg nanosatellite with domestic technology, [1] and [2]. For these purposes IdeI has made informal academic alliances with several academic institutions from Mexico interested in developing satellite technology. With the Escuela de Aeronáutica IPN the structural design and the interface with the launching system are being worked. With the Centro de Investigación en Matemáticas (CIMAT) the satellite stabilization algorithms, the satellite dynamics model, the Earth magnetic field modelling, and a reference model that allows the satellite to be controlled from a terrestrial geographic point are being elaborated. With the Instituto de Geografía UNAM and CIMAT a research laboratory is expected to be integrated to validate three axes satellite stabilization means and algorithms with instrumented frictionless equipment. With ITAM we agreed to develop directive communications systems to optimize following issues: employed energy, communications bandwidth and redundant means for satellite pointing control around the communication axis.

It is important to highlight that NS project aims the validation of subsystems and technologies that are fundamental for Mexico to develop bigger satellites in the medium term for Remote Sensing as well as for Telecommunications services. For those satellites the stabilization resources are essential either to acquire images of good resolution of geographic sites of interest, or, to efficiently intercommunicate geographic sites from our country and its continental region.

It should also be emphasized from one side that the Mexican satellite projects have been developed for Low Earth Orbit (LEO), and from the other that they have employed low data rate communications links for the purposes of satellite control and telemetry acquisition. Besides, LEO operation implicates a communications bottle neck because the satellites are continuously moving around the Earth. Furthermore they move to speeds faster than 28,000 Km/hour, whereas in the best of the cases the line of sight between satellite and Earth station is limited to 14 minutes. Particularly, the problem becomes augmented when satellites are required to download important amounts of data (images, special telemetry, etc). Under this scope the present paper proposes the development of Nanosatellite microwave communication system, for energy savings, high capacity data transmission, and position control feedback.

2 Efforts to design and build a Mexican Nanosatellite

There have been two important efforts towards the development, launching, and operation of Mexican experimental microsatellites: the UNAMSAT (~14 Kg) project [3], and the SATEX (~50Kg) project [4], [5], [6] and [7]. Both projects have been able to rise funding, generate Mexican expertise, produce a working prototype, and in the case of UNAMSAT it had a successful satellite launch. However, in both cases the projects came to an end, without continuing into further research and/or consecutive project developments.

In recent years, information technologies have evolved so much, that the capacities offered by microsatellites in the 90s can now be achieved with much smaller satellites (~5Kg), known as nanosatellites. This kind of satellites are encouraging for Mexican scientists, because they tend to be cost accessible (~60,000 $USD) and much easier to ensemble and deploy. Thus, in 2004, a new effort to develop a Mexican satellite (this time a 3.5 Kg nanosatellite) was born at IdeI, UNAM, [1] and [2].

The design and construction of the IdeI-UNAM Nanosatellite, expects to gather the expertise gained during the SATEX project, and to incorporate technology that is commercially available for the construction of nanosatellites. In a first step, the project team is looking forward to develop a proof of concept that includes as much as possible good quality parts and protections to ease the transition to a nanosatellite prototype and then gather credibility and support for the project.

2.1 The Mexican Nanosatellite

The nanosatellite envisioned by the IdeI-UNAM project team, is expected to be located at 750 Km from Earth, and to travel at such speed that it will circle the Earth 18 times a day. Different from geosynchronous satellites, the nanosatellite will pass above a ground station several times a day. When the satellite overpasses the ground station, it will only be in visible range during approximately 10 to 14 minutes.

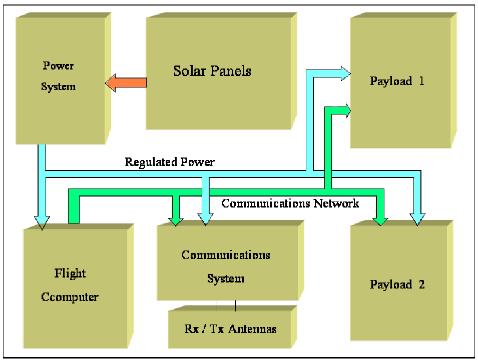

Fig. 1. Block diagram of NS subsystems

Fig. 2. Aluminium structural subsystem

Considering previous experience from the SATEX project, the proposed nanosatellite contemplates several subsystems, as illustrated in Figure 1. The payload systems are not necessary for satellite operation; and instead, they allow for experimental and test systems. While the payload systems have not been formally defined yet, there is a possibility that one of the payload modules may carry a position control system. Another payload module will be an infrared digital camera, so the satellite can broadcast aerial views.

Several subsystems of the satellite are in an advanced state of development, as they have been inherited from the SATEX project. Among these systems are the structural subsystem, flight computer, sensors, and software for the satellite operations and base station.

The structural subsystem holds together all other satellite subsystems, offering housing and protection to the circuits and systems in the satellite. The structure is composed by several independent aluminium frames (modules) that hold and interconnect the different subsystems in the satellite, as they bunch together in a piggy-back fashion (see Figure 2).

The communications system chosen for the NS vehicle is inspired by the communication system used in the QuakeSat mission [8], and uses the TEKK KS-900/960 data radio and the Bay Pac 9600 modem. This communication system operates at 436.675 MHz (UHF frequency) for data transmission and reception; which (in the case of QuakeSat mission) allowed downloading 3 MBits per day. The radio has the following characteristics: 2 Watts RF output, varactor controlled Direct FM modulation, -30 to +60 ^{o}C operation, 0.199 Kg weight and 7.5-12 V operation.

While not completely defined yet, the Rx/Tx antennas chosen for the NS vehicle are short dipoles (1/4λ) made by spring steel tape measure material. The satellite will hold several of such antennas, to allow easy deployment and insure a broad radiation pattern for simple finding of ground station.

At the ground station, on the other hand, the proposed system will have a directive Yagi-Uda antenna with a position control system that will move the antenna to optimize the received power. In this fashion, the ground station antenna will rotate following the satellite (while it is in range of visibility).

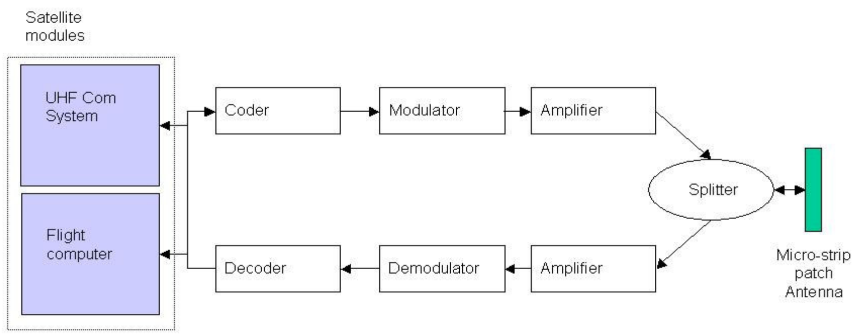

Fig. 3 Block diagram of NS subsystems

3 Proposal for a microwave communication module

As mentioned already, this paper proposes an alternative microwave communication system (MCS), based on high gain antennas operating at much higher frequencies (1-3 GHz). The proposed MCS is intended to become one of the payload modules that will allow communication with the ground station, providing a higher volume of data exchange, feedback for a satellite position control, and energy savings (if the main communications system is switched off after the MCS starts its operation).

To achieve an operating frequency between 1 and 3 GHz, the MCS will use micro-strip circuitry to feed a highly directive patch antenna that faces the ground station. If the patch antenna at the satellite can be accurately aligned with the ground station, the proposed MCS will constitute an excellent way to have efficient communications; however, small errors in alignment can reduce significantly the quality of communications.

Given that the satellite communicates with the ground station through the UHF system described in Section 1, the proposed microwave system won't be used until the satellite has been positioned to have one side facing Earth. Once the satellite is facing Earth, the MCS can be turned on, to achieve a quality of communications that surpasses the quality provided by the original UHF system (faster communications and more efficient use of available energy). In a first nanosatellite mission, the MCS can be loaded for experimental purposes only (as a payload); however, in consequent missions the UHF system could be used for initial communication with ground station, to achieve initial alignment before the microwave system is turned on and becomes the principal communication system (the UHF system can be turned off, or used for backup communications only).

Figure 3 shows the block diagram of the proposal. As shown, the system allows for transmission and reception through the same patch antenna. For the desired range of frequencies, the modules shown in the figure can be implemented with micro-strip technology, which tends to be compact (portable) and inexpensive. While the specific radios and components have not been chosen yet, they are commercially available and the complete system can be fitted within one of the aluminium modules considered in the satellite's structural subsystem.

4 Benefits for nanosatellite systems

As explained in the previous section, the major benefits that can be achieved with the MCS are: 1) the possibility to transmit higher amount of information, 2) the capacity to generate information to feedback the satellite position control, and 3) the possibility of saving energy, which in turn extends the satellites life or reduces the satellites weight. In this section, we further explain how to achieve such benefits.

4.1 High capacity communications channel

Like most nanosatellite projects, the nanosatellite being designed at IdeI-UNAM will carry a communication system that operates at 436.675 MHz (in the UHF band), and uses multiple linear dipole antennas to transmit/receive information. As explained before, this system is very convenient because dipoles have a broad radiation pattern that facilitates the establishment of a link between the satellite and the ground station

Fig. 4. Micro-strip patch antenna for 1-3 GHz [9]

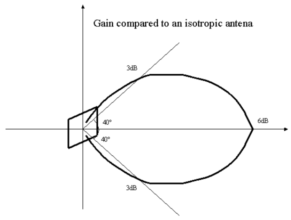

Fig. 5. Radiation pattern schematic for a patch antenna [9]

(i.e. the antennas don't have to be aligned). However, the frequency of operation is very low to establish a high speed digital communication link, and the broad radiation pattern is inconvenient because it wastes energy and is highly susceptible to noise.

With a carrier frequency of 436.675 MHz, the QuakeSat initiative at Stanford University, downloaded information at 9600 baud speed, which allowed downloading 3 MBits per day (~5 JPEG photographs, or one short video a day). This poor data transfer capacity will limit significantly the use of a digital camera (possible payload) to capture and download aerial views. Increasing the carrier frequency and the directivity of the communication antenna, allows to handle a larger communications bandwidth; which in turn allows a higher data transfer rate. With the 6dB gain characteristic of the patch antenna, we believe that the communications data rate could be at least doubled or tripled (6-9 Mbits/day). At the same time, as well as allowing a higher data transfer, the use of frequencies between 1 and 3 GHZ, allows the use of standardized wireless components, and a wireless digital communication protocol (such as WiMax).

The significant increment in data transfer capacity, joint with the possibility to use modern, standardized, commercial communication technology (components and protocols), makes very attractive the idea of using the proposed MCS and encourages the authors to further investigate and work towards its implementation.

4.2 Energy savings

As explained before, the use of dipole antennas is important to establish a communication link whatever their alignment is, because dipole based communication systems radiate energy into many directions (one of which needs to find the ground station despite the alignment of the dipole). However, since only the energy radiated towards the base station is utilized, the waste of energy is also very high. Dipole based communication systems use too much energy to achieve a specific signal to noise ratio (C/N) at the receiver location.

If instead of dipole antennas, the system used directive antennas (such as horns, apertures and/or micro-strip patches), most of the transmitted energy would reach the base station, thus reducing the amount of energy that needs to be invested to achieve a given C/N. The problem with directive antennas is that they need to be accurately aligned, or the quality of communication becomes poor and the energy waste becomes large.

Typically, while a linear dipole has a gain of ~0dB, a patch antenna has a gain of 6dB; which means that to have a given signal to noise ratio (C/N) the dipole needs four times more power than the patch. This is why, even if shortly after deployment the satellite requires a dipole based communications system, in the long run it is desirable that the satellite communicates using directive antennas, because the enormous power/energy reduction factor (1/4) result in large energy savings, which have a direct impact on the expected satellites life.

Again, the quick calculation of energy savings encourages further investigation, and supports the idea that the MCS is a good option for an experimental purposes payload.

4.3 Feedback for position control system

Finally, the narrow radiation pattern that characterizes the patch antenna, and that makes difficult the initial satellite positioning, turns out to be a very desirable quality for control purposes. First of all, as explained before, the high directivity of the antenna reduces significantly the energy waste during transmission; but also the linear decay of the antenna gain due to small variations from the optimal alignment, produces a decay in the transmitted/received power, thus giving valuable information to feedback the satellite position control system.

In order to have a stable feedback for the position control system, the ground station is being designed in such fashion that it will produce a uniform (omni directional) radiation in the direction of the satellite; in order to have the satellite control system forcing the satellite to face ground station, rather than having (as current nanosatellite projects) a directional antenna on the ground station with a control system that makes it face to the satellite. In principle, the ground station will have a spherical dome with micro strip patches all over it (which will be presented in future works), just for control purposes.

Considering that typical radiation pattern for patch antennas exhibits an approximately linear response to small alignment variations (see Figure 5), and that the intensity of received power (Watts) can be easily measured and sampled, the received power constitutes an excellent variable to be monitored and used to feedback the position control system.

5 Discussion and conclusions

While this paper proposes to incorporate a microwave communication system to the IdeI-UNAM nanosatellite (which was not contemplated before) and highlights its benefits, the task to do is not easy. There are indeed many problems to be solved, and calculations to be done before a clear conceptual proof of concept design is completed.

Among the many tasks that need to be carried out, we need to come up with accurate calculations of communication links, we need to evaluate propagation effects (such as attenuation) at the operating range of frequencies, we need to come up with a better estimation of the noise levels and an accurate calculation of the power, signal to noise ratio, bandwidth and data transfer rates. We need to build a model to understand variations due to distance and alignment errors, and to understand how the misalignment information can be used to correct position. We also need to establish commercial components that can be used to implement the system and carry on short experiments and tests to demonstrate that the proposal can bring the promised benefits. On the other hand, even if not explained in this project, we need to work on a detailed specification of the ground station communications base, which is crucial to achieve stable control feedback, and a significant bandwidth increase.

The work ahead is long and hard; however, we know that the technology for implementation is available, and the quick calculations summarized along this paper make us believe that the proposed system will contribute the IdeI satellite with: good energy savings, high capacity communications channel, and valuable position control feedback. We have no doubt that the proposed system is viable, and that the work necessary is worth, as the prize at the end of the road is sweet and encouraging.

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