# Preliminary Design of the Power Subsystem for a University Nanosatellite

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**Abstract.** Nowadays, NanoSats are a cheap and easy way to develop space technology. They represent the best cost-benefit relation in terms of project cost, mass, power budget, communications performance, and launching cost. Therefore, this kind of projects can be developed in countries with emergent economies for technology demonstration purposes, remote sensing, technology improvement, human resource development, etc. Considering this scenario, Mexico is developing a 3.5 Kg University Nanosat (UN) which attempts to be the first of a series of NanoSats designed and developed by academic staff, postgraduate students and undergraduate students. This work presents the UN power subsystem design proposal, which employs some automotive commercial-of-the-shelf (COTS) parts successfully proven in previous international space missions.

**Keywords:** Nanosatellite, power generation, power storage, power regulation and power distribution.

## 1 Introduction

To date, the small satellites field has worldwide intense activities, with a huge participation of universities from industrialized countries, [1] and [2]. Few of them started microsatellite research in the 80s with the support of their local space agencies and space industries that were eager both to generate qualified human resources in the area and to qualify new space products.

In this way, the initial participation of very few developing countries was started with government initiatives that anticipated a future form of industrial revolution. These countries had the vision to invest, follow, and encourage its space activities expecting that some day would obtain a feedback action to grow and reinforce their industry. Among them we found examples like: China, India, and Brazil, [3]; countries that nowadays have become regional space powers. Between them, China is a special case that now is competing with worldwide space leaders. In recent years, nations such as Mexico, Korea, Taiwan, Chile, Portugal, Pakistan, Argentina, South Africa, Thailand, Singapore, Malaysia, Algeria, Nigeria, and Turkey have developed Microsatellite projects in partnership with experienced and worldwide recognized institutions like AMSAT, [4], and Surrey Satellite Technology Limited, [5]. The motivation of these countries is to stretch the technological gap in this important field which comprises a gate to develop other information technologies areas.

Until now, Mexico has accomplished two microsatellital missions. The first one, Unamsat A (17 Kg), was launched on March 28*, 1995, and his twin, Unamsat B, was dispatched on September 1996. There is a third effort, Satex (55 Kg), whose lack of financial support and organizational problems have avoided until now the completion of the mission. Nevertheless, a sound success is still required to obtain a substantial support in order to establish an enhanced and continuous satellite program.

Under this scenario, the UN project will assimilate the experiences and the know-how generated in the Satex project to design and manufacture a 3.5 Kg compact satellite bus capable to be adapted to different missions. In addition, the project will employ state of the art automotive electronics protected for use in space. The idea is to build a cheaper and better Nanosat to open the access of satellite technology to other local universities and institutions. At the same time the UN will offer enough on-board capabilities to admit different types of payloads. Additional project goals are to generate an attractive Nanosatellite platform in terms of development time (1 year in average), manufacture cost (60 thousand dollars excluding the payload cost) as well as in launching costs accordingly with the vehicle mass.

## 2 The University Nanosatellite

The prism shaped Nanosat has four solar panels attached to its body. In addition, four double sided solar wings were added to increase its power generation, figure 1. Six solar wings will be 18x9 cm while the other six will be 18x12.9 cm. The UN subsystems will reside in printed circuits which will be mounted in aluminium frames as well, figure 2. Therefore, the Nanosatellite platform will be composed of: power subsystem, telemetry sensors, structural subsystem, communications subsystem, flight computer, as well as room and resources (energy, communications and automation capabilities) to accommodate different payloads. Thus, the UN platform will contain all the necessary support subsystems for the satellite and its payloads.

The subsystems inherited from the Satex mission are: a flight computer, a structural subsystem reconverted to be used as Nanosatellite structure, sensors (magnetic field, temperature, current and voltage), as well as software for both satellite operations and Earth Station, [6]. In this way, the electronics modules and the frames will be assembled in tandem to form the satellite body, figure 1b. Once assembled its dimensions will be 18x9x12.9 cm.

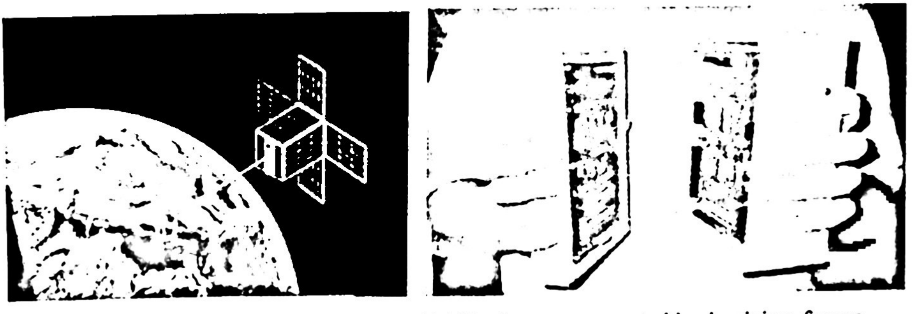

**Fig. 1 a)** The University Nanosatellite **b)** NS subsystems mounted in aluminium frames

### 2.1 The UN Power Subsystem

The Nanosat power subsystem will contain four different modules: power generation, power storage, power regulation, and power distribution. These subsystems will allow the Nanosatellite to generate the electrical energy required to operate its electrical equipments. Following sections describe the proposed preliminary design of UN power system. This is design will evolve in the short term into a proof of concept model and a later phase will be advocated to the construction of a flight model. This approach has been practiced before in the development of military small satellite power systems, [13] and [14]. Thinking about a the continuity of space activities in México, it will be very important continue the work not only in the small satellite field, but also in high efficient state of the art power systems, [15], because they will allow the placement of more sophisticated payloads in terms of communications, remote sensing, and so on. This particular research is being very successful in the microsatellite field, [16].

## 3 Power Generation Module

The UN power subsystem will generate its power from 12 solar panels connected in parallel fashion, figure 2. Four of them are attached to the satellite body and four of them will be double sided deployable wings. The last configuration will allow the satellite to generate enough electrical power without high requirements of stabilization. This solar panel distribution has flown successfully by the University of Stanford in the QuakeSat Mission, [7]. Each solar panel will contain inexpensive GaAs solar cells with cover glass specially developed for the space industry. The cells are 20x25 mm, 0.204 mm thick from Boreal Laboratories Ltd, obtained as leftovers from companies that build solar panels for commercial satellites. Its electrical output is 100 $mA/cm^2$ at 0.5V. Then, the chosen 5 $cm^2$ solar cell presents an output current of 500 mA and an output voltage of 0.5 V. The cell output voltage is actually very sensitive to the temperature at which the cell is operating at. In general, the solar cells and series strings are reported to lose about 0.24% in voltage for each 1 °C increase in operating temperature. This aspect is expected to be studied in more detail in order to complete the UN power system design. Besides, validation tests in laboratory will support the final design. Each panel has a label indication to know its location in the satellite. PC label indicates a body panel and PD designates a deploying panel. For deploying panels, the letter T indicates a rear panel, while the letter F specifies a front panel. In addition letters N, E, S, and O refer to north, east, south, and west panels, respectively. In this way designators PDTN, PDTE, PDTS and PDTO are related with rear deploying panels north, east, south and west, respectively. Whereas PDFN, PDFE, PDFS and PDFO specify front deploying panels north, east, south and west, respectively.

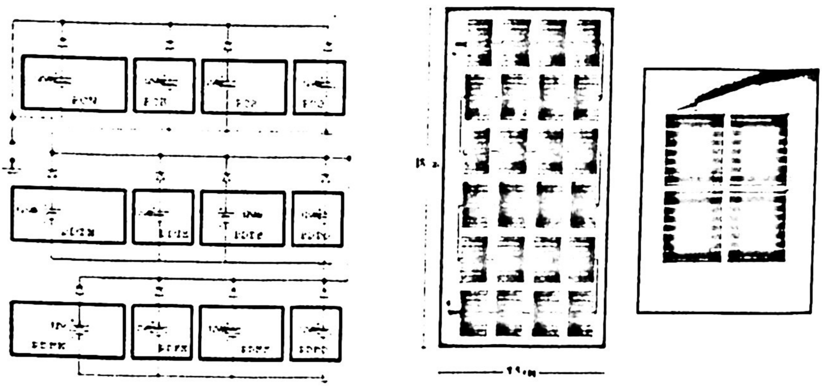

**Fig. 2** a) Solar panels distribution for the University Nanosatellite.

b) University Satellite solar array schematic composed by 24 cells arranged in series and photograph of solar cells to be employed.

Figure 2b shows how a panel will look like with solar cells mounted on its surface. In addition, figure 2 presents a picture of the solar cell to be employed. Each panel contains 24, 20x25 mm, solar cells arranged in one single string. Therefore, the non regulated cell, to the positive terminal of the next cell in the string, with both cells being in the same solar cell row, d) Turn-around: connects the negative terminals of one solar cell, to the positive terminal of the next cell in the string, with one cell being in the next row of solar cell. The interconnections have stress-relief areas to accommodate the expansion and contraction of the cells due to temperature changes. They will be first soldered to the solar cells. A number of this subassembly will be then assembled to make a string, conforming to the cell layout of their respective panels. The assembling processes will employ a number of jigs that will be custom machined for laying out our specific type of solar cell.

The panel structures might be made of space rated Aluminium-6061. Some microsatellite panel structures are made of 0.25 inch thick solid Aluminium, others of 0.5 inch thick Aluminium honeycomb, while others are made of 2 parts: the solar panel containing the cells which is made out of 0.063 inch Aluminium sheet, and a structural support panel which is made out of 0.5 inch Aluminium honeycomb. The more convenient choice for the UN is being studied by now.

The outer UN Aluminium surfaces that will hold the solar cells will be overlaid with dielectric material, for electrical insulating purpose. Domestic facilities to accomplish this process are also investigated.

Once the solar panels become ready, the cells will be bonded to the FM73 (epoxy) covered solar panel surface using a controlled volatility RTV (silicon compound) that we expect to obtain from international suppliers. The RTV would adhere to the area between the two negative terminal solder spots on the back of the cell. Once determined the layout of the cells on a panel, the areas will be located on two 10-mils Mylar sheet. These areas will then cut out, forming masks. One of the mask is used to held the prearranged cells, while the other one is used for masking the areas on the FM73 covered solar panel that were not to be glued.

The Mylar used for this masking process should have been 20-mils thick. This will ensure that enough RTV will be present for optimum bonding between the cell and the F-77 (adhesive) covered solar panel surface. In case we do not have access to 20-mils Mylar, we might use 10-mils Mylar, which has also been used in microsatellites that underwent successfully shake tests.

## 4 Power Storage

The UN generated power is stored in four Li+ batteries, connected in an array of two parallel strings, each one containing two batteries in series. The batteries are Tadiran AA-sized lithium (model TLM-155HP), with a capacity of 5A of continuous current at 4.0V, a discharge capacity of 550 mAh, and an operating temperature range of -40°C to 85°C; figure 2b. Their typical applications include military and aerospace systems, due to its high power, long life and, extended storage, [8].

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The battery voltage will vary depending on the charge condition of the battery. It will range from 3.36 Volts at 80% discharged condition to 4.2 Volts, per battery, at fully charged condition. The 80% discharged condition is considered to be the minimum power level. Going beyond this point will put the nanosat at risk of not being able to recharge itself. The solar panels will be producing an average of 12 Watts of power. Since the capacity of the battery is 550 mAH, there will be no danger of over-charging the batteries. Therefore, charge limiters are not used, which also helps in simplifying the circuits. However, this scheme is still under analysis to verify its operation. In addition, laboratory tests are being planed for design validation purposes.

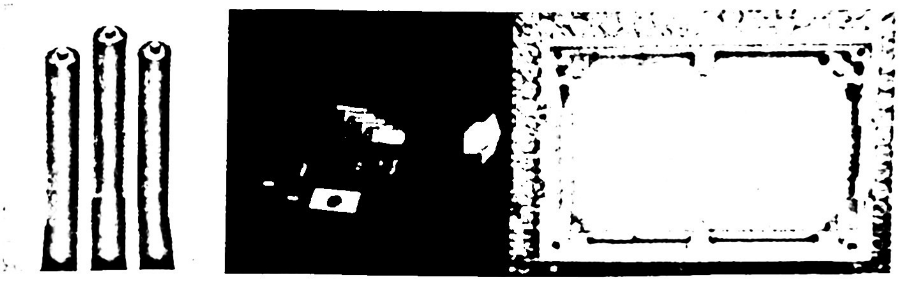

Fig. 3 NS subsystems will be mounted in aluminium frames batteries

It was decided to use one battery system, with no backup. An extra battery would increase weight considerably. Also, given the high reliability and performance of the type of battery selected, one battery pack should be more than sufficient to provide continuous power over the entire orbit and over the satellite's mission life.

## 4.1 Battery Pack

The batteries will be confined in a battery pack housed in an individual box, figure 5. They will be potted by RTV566 compound, made by General Electric, to provide adequate thermal mass for ensuring the proper operating temperatures. The box will have few temperature sensors to monitor the battery's temperature.

## 4.2 Battery Charging

The battery charging control process will be carried out by a MAX1873, which allows 2 batteries to be charged at the same time, [9] and [10]. This means that there are two Max1873 to control the charge of the four batteries. The COTS component was chosen for the UN because it was successfully validated in space orbit by the Quakesat mission

[7]. The Max 1873 datasheets contain a typical application circuit. In our case, this circuit was modified to fit the Nanosat power source characteristics (solar panels arrays); being 12 V and 0.5 A the best operative case. The most important modifications were the value of the inductor L1, the battery current sense resistor Rcsb, and the P-channel MOSFET switch selection, figure 6. For Rcsb selection [9] it is considered that Icgh takes its maximum value, which in our case is 0.5 A. The next equation was employed for Rcsb calculation:

$$Rcsb = 2.0\ V / Icgh = 4.0\ \Omega$$

The inductor value must be selected to obtain a reasonable ripple current. The greater the inductance, the lower the ripple current [9]. Typically, an inductor is chosen with a ripple current between 30% to 50% of DC average charging current. The next equation was used for inductor calculation:

$$L = \left[V_{BATT}\left(V_{DCIN} - V_{BATT}\right)\right] / \left(V_{DCIN(MAX)} \times f_{sw} \times I_{CGH} \times LIR\right)$$

Where:
LIR = ratio of ripple current, in our case 50 %
DCIN(MAX) = 12 V
BATT = 8.4 V
Fsw = switching frequency, nominally 300 kHz

In this case we obtained L = 38.04μH, however, a commercial inductance value of 35 μ H fulfils the requirements. At last, the MOSFET switch must be selected to meet the efficiency or power dissipation requirements of the charging circuit. The charger was selected to meet the power dissipation. In general for MOSFETS, the worst case power dissipation due to on-resistance ($P_R$) occurs at the maximum duty cycle, where the operating conditions are: minimum source voltage and maximum battery voltage [9]. This can be approximated by the following equation:

$$P_R = \left(V_{BATT(MAX)} / V_{DCIN(MIN)}\right) \times R_{DS(ON)} \times I_{CHG}^{\ 2}$$

For the chosen MOSFET, IRFR9014, $R_{DON}$ = 500 mΩ, then $P_R$ = 116.66 mW. This power dissipation is minimal for the IRFR9014 considering its maximum power capability of 25 W.

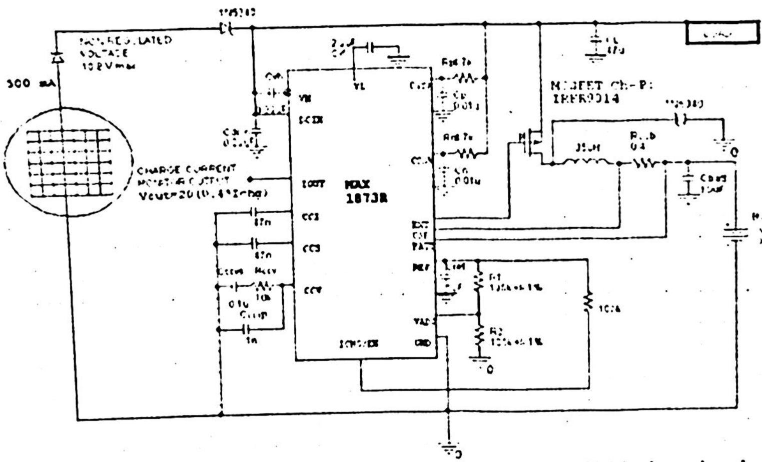

Fig. 6 Battery charge diagram. The Max1873 can charge two 4.2 V Li+ batteries; however, the maximum charge current is limited to 500 mA.

### 4.3 Unregulated Line

Unregulated DC power will be supplied to the Communication Subsystem. This involves direct connection from the charge regulator input terminals to the power input terminals at the Communication Subsystem. The unregulated voltage level will vary depending on the charge condition of the battery.

## 5 Power Regulation

The required regulated voltages for the UN model will be +5V and -5V. The former will be used by the flight computer, telemetry sensors, and probably for payload energizing. The last is planed to be used with power stabilization sensors (magnetometer and fine sun sensors), payloads as well as a polarization voltage for the Latch-up sensor placed in the flight computer. Regarding the communications system, it will be energized with the unregulated voltage obtained directly from the batteries.

In this way, the COT DFC6U5S5 device was chosen for power regulation in the UN. The 77 % efficiency DFC6U5S5 can provide a regulated voltage with up to 6 watts of output power, which means more than 1 Amp of output available current, [11]. This current is enough for the UN equipment requirements. In addition, the device accepts a wide

3.5 to 16 Volt input range allowing the operation from the UN batteries. Moreover, its output is electrically isolated, thereby allowing the output to be configured as a negative or a positive output voltage. Besides, its isolated and filtered output allows usage in low noise circuits. Therefore this device will allow to obtain the +5V and -5V power supplies required for the Nanosatellite model. Besides, few of them may be used in case the satellite loads demand more current than that provided by the device.

## 6 Power Distribution

Once the required regulated voltages are available in the UN platform, they have to be controlled directly from the flight computer according with satellite mission needs specified from Earth. In other words, the flight computer should be able to switch on or switch off any satellite equipment to carry out specific satellite tasks. To accomplish this power distribution scheme, the UN laboratory model will employ MOSFET IRFF130 from International Rectifier, which has a drive capacity of 8 Amp, 100V, 0.18 Ω, [12]. This device will drive any one of the UN loads without problem. However, several of them will be necessary to control every one of the controllable satellite modules (communications transmitter, sensors, actuators and payloads). On the other hand, other automotive COTS devices are being considered for the UN engineering model. We would like to include a surface mount device, with good driving capabilities and with less voltage restrictions to be commuted.

## 7 Concluding Remarks

The paper has presented the preliminary design of the power subsystem for the University Nanosat laboratory model which is expected to weight about 3.5 Kg. In order to shrink the manufacturing cost of the UN, the exposed design makes use of commercial-off-the shelf components that have been successfully qualified in previous small satellite missions. Moreover, the projected design employs good quality cheap solar cells, which will allow the generation module to be composed of 12 solar panels with two different sizes. However, each panel will hold the same amount of solar cells and therefore the same electrical characteristics. In this way the module will provide in average an estimated power of 12 Watt, at 12 V and 500 mA. This will be enough to energize the flight computer, telemetry sensors and communications equipment and a couple of payloads. Regarding the power storage module, it will contain 4 Li+ military spec batteries and his voltage charger will consist of COTS automotive electronics. The power regulation as well as the power distribution modules will also be implemented with COTS electronics.

It is expected in the short term to perform laboratory tests in order to validate the proposed design for the UN power system. In this way a modular and cheap Nanosatellite laboratory model might evolve into an engineering model. Even more, in the medium term the UN laboratory model might evolve into a flight model if financial support is obtained. In this sense a publicity campaign is expected to be deployed with the help of the Nanosatellite proof of concept that will contain the power system presented in this paper.

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