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Communications system for Colombia-1 picosatellite

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Abstract

The objective of this paper is to present information about research of the designs and developments for the communications systems in Colombia-1 picosatellite, under the project CubeSat-UD.

In this case, a time line based on preliminary studies of the communications channel was made, followed by the critical designs of each subsystem, and then the integration of all subsystems. Finally, the analysis of results, where the strengths and weaknesses of each study and designs are showed.

With this work, it was possible to have knowledge of the experience acquired so far, which led to the conclusion that the module had some limitations, failures that allows a new starting point for a design, not only for the CubeSat-UD project, but also for future developers and researchers of picosatellites, since, in this type of studies, the time factor is important because it tends to be extensive to reach a final design.

Keywords: CubeSat, TNC, Colombia-1, Transceiver, AX.25 protocol, OBC, Modulation.

INTRODUCTION

The space history changed on October 4, 1957 when the URSS first artificial satellite was launched, it was called Sputnik-1[1] throughout the years, the field of action of the satellites became varied and versatile, covering topics such as Earth Science[2], astronomy and astrophysics[3], and medicine [4] among others. To be able to organize and normalize the way in which the small satellites were built and orbit the standard CubeSat was created, established in 1999[5]. This is when the small satellites start to be called CubeSat only when the standard requirements are satisfied. The document that stablish the mechanical requirements, electric and operational among others for the standard CubeSat is known as CDS (CubeSat Design Specification)[6]. There is today a diversity of interests to develop this kind of projects, both commercial and military, and mostly academic[7].

The structure of a satellite is structured by diverse modules and subsystems: power, data, structure, mechanisms, attitude control, launching, mission and communication module which research and design is detailed along this article for the satellite Colombia 1.

One of the modules that is generally used in the communication module is bases on three subsystems, telemetry, and transmission/reception and implementation system of the protocol AX 25. All these work together to connect the data system and the earth station through a communication protocol. A diagram of blocks from the previous explanation is shown in Figure 1.

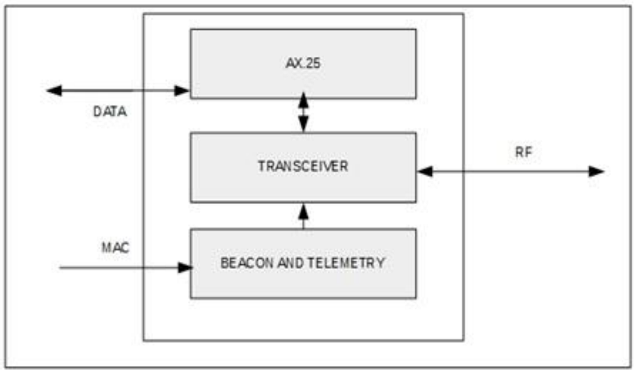

Figure 1: Block System of the Communication Module Colombia 1.[8]

DISCUSSION

Characterization of the communication channel and interference tests for colombia-1 :

As a first step, two analysis were made to characterize the channel, the first one was made with the link-up 440 MHz frequencies and for the 144 MHz link-down which corresponds to assigned frequencies for radio amateurs in Colombia[9], and in the second the frequencies tested were 930 MHz for the link-up and 915 MHz for the link-down. In addition, achievement assessment of the environment and module types access techniques was carried. The way to evaluate the channel was through the probabilistic module like the distributions by Rician, Ray leigh and Gaussian to calculate the power lost by the environment, the gap signal and reflections, where some variables must be taken into account such as the elevation angle, the azimuth angle and the obliquus distance.

Results from the first characterization

The modulation techniques tested in the first experiment were QPSK (Quadrature Phase-Shift Keying), QPSK with enhanced cosine FIR (Finite Impulse Response), MSK (Minimum-shift keying), with Gaussian filtered and OFDM (Orthogonal Frequency-Division Multiple Access). A correction system was made to all this FEC (Forward Error Correction) of ¾ which means that for each three information bits it results one redundancy bit. For the QPSK signal case with filter FIR enhanced cosine it was found that the power spectrum expands in a proportion of 4/3[10].

In the tables 1 y 2 the QPSK BER (Bit Error Rate) is detailed with enhanced cosine and OFDM. In the table 1 can be seen that the research was tested for two kind of channels, one with AWGN (additive White Gaussian noise) and the other with AWGN, fading of Rician and channel losses. In the table 2 the modulations QPSK and OFDM are shown with the implementation of a FEC. With these results it was concluded that the best schemes are QPSK and OFDM.

Table 1: Review of the Results of the simulation modulation System[10]

TYPE OF MODULATION	**Type of channel**			
	AWGN	**RICIAN +AWGN+LOSS**		
	BER= 10^{-6}	BER= 10^{-6}	BER= 10^{-5}	BER= 10^{-4}
QPSK	11dB	NA	18 dB	12 dB
QPSK with filter	12.5 dB	14.6 dB	12.5 dB	11 dB
OFDM	NA	16.5 dB	14 dB	12 dB

NA: Shows that the modulation system does not achieve the indicated BER for a relation Eb/No less than or equal to 18dB

Table 2: Synthesis results of the simulation systems of modulation with FEC[10]

TYPE OF MODULATION	**RICIAN +AWGN+LOSS**			
	WITHOUT FEC		**WITH FEC**	
	BER= 10^{-6}	BER= 10^{-5}	BER= 10^{-6}	BER= 10^{-5}
QPSK with filter	14.6 dB	12.5 dB	9 dB	8.5 dB
OFDM	16.5 dB	14 dB	9.5 Db	9 dB

Another aspect that was considered for the modulations, is to consider the efficient handling to the electromagnetic spectrum. With the OFDM technique and QPSK with filter FIR that reduce the bandwidths to 60% from the original. Moreover, with the implementation of FEC in the modulation schemes it reduced the bandwidths from the 80%[10], in addition to this, it had the advantage to get a better BER. From the medium access techniques, it was tested CDMA (Code Division Multiple Access), FDMA (Frequency Division Multiple Access), TDMA (Time Division Multiple Access) and OFDM from which conclusion was that the best techniques are FDMA and TDMA[10].

Results from the second characterization

With the goal of having another option for the modulation some of the traditional modulation techniques were tested such as QAM (Quadrature Amplitude Modulation), PSK (Phase Shift Keying), FSK (Frequency Shift Keying) and GFSK (Gaussian Frequency Shift Keying), in this case a range of 900-915 MHz is used to link-up and 916-930 MHz to link-down. In addition, a beacon 445 MHz frequency. With these conditions a new modeling channel was made, starting with the estimation of the frequency drift that resulted as a 19123.65 Hz Doppler drift. The maximum drift is around 20 kHz as a result of 930 MHz because it depends proportionally on the carrier frequency. The estimation of the Doppler effect is based on the average speed of the satellite and the carrier frequency[11].

As a result of this analysis the modulation scheme GSFK was selected as the best option because of the results of the signal to noise ratio and it was concluded that the best result was for the Modulation 8-GFSK, which is based on 8 FSK implementing a Gaussian filter that let determine by a statistical analysis the spectrum region contains between 90% and 99% of the signal energy[11].

In the implementation of 8-GSFK it was considered that the modulation index used was 0.5 rad, which stablish the deviation in frequency in 25.6 MHz, value that is accomplished through the maximum spectral efficiency handling or the relation between the bandwidths and the data rate.

The modeling through three curves, one of the curves represents the semi-analytical model which determine the requirements of bit energy related with the noise spectral density from the model stated and includes digital filters that mitigate the effect of the Gaussian white noise present in the communication channel. Under this scheme, it is required Eb/No 12dB in order to get a BER 1e-8. The second curve represents the theoretical model with the channel characterizing the effects of the Gaussian white noise where an energy of 7dB is needed to accomplish the required BER. Finally, the third curve represents the simulation of what can be seen that with a signal to noise ratio of 15.1 dB it gets a BER of 1e-6 and with Eb/No=24 dB it presents an error for each 1e8 samples[11].

The Gaussian filter in the receiver has the objective of deleting the thermic and interference noise from the higher harmonics that are present in the modulated signal, in other words is an adequate system for all kind of noise in the satellite link. With the implementation of 8-GFSK it reaches a spectral efficiency from the bandwidths that is around 6 bits/s/Hz. To have medium access, it is concluded that FHSS (Frequency Hopping Spread Spectrum) is a good option because it allows the carrier to go from a place to another to be conditioned which represents an advantage for it is possible to avoid putting the signal in a spectrum part where there is significant interferences[11].

After making the characterization of the channel for this project some of the interference types were taken that can be presented in a satellite link, like the interference from adjacent satellite systems, terrestrial, by crossed polarisation, adjacent channel, intermodulation and symbol. For the case of the satellite Colombia-1 a study for the VHF and UHF (Ultra High Frequency) bands was made, which channel width for the bandwidth of radio amateur is 25 kHz[11].

The system implemented to measure the interference must have the freedom of movement in azimuth and elevation. Thus, the measuring antenna was designed, the management of azimuth system, the position system in elevation, the software and the interface to manage all the system through a computer.

The antenna designed was a LPDA antenna or logarithmic arrangement of dipoles that will work in the previously mentioned bandwidths assigned for radio amateurs that are from 145.8 MHz to 146 MHz for the VHF band and 435 MHz to 438 MHz for UHF. For the antenna design it was defined a 320 MHz bandwidth, a gain of 7dB and an output impedance of 50 Ω, which resulted as an antenna composed by 9 elements[11]. The largest element of the antenna depends on the lowest frequency, in other words, it depends on the maximum wavelength possible within the range of the bandwidth[12]. In the Figure 2 can be seen the antenna designed.

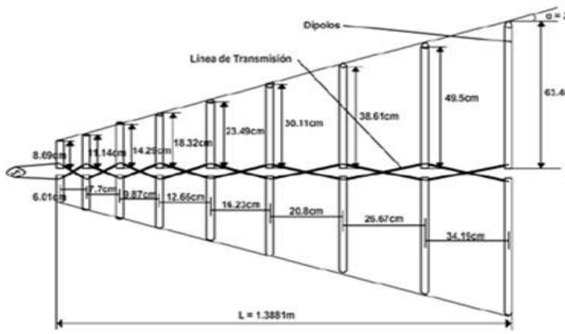

Figure 2: Design of the log-periodic antenna[11]

Results of channel availability for segments of the spectrum of interest

In the Table 3 is possible to see the Maxhold availability of the tested channels in the engineering faculties, science and education and technology of the Francisco José de Caldas District University in the VHF band it could be concluded that there are no available channels. However, in the UHF band it exists a channel availability for the link, which make this band more suitable to achieve the implementation of the earth station.

Table 3: Channel Availability in the three tested faculties10

Place	**BAND VHF(144 MHz -148 MHz) UHF(430 MHz-440 MHz)**	**Segments (MHz)**	**Channeling**	**Maxhold Availability**
Place 1: Engineering Faculty	Radio Amateurs VHF	145.7875-146.0125	Band for radio amateurs via satellite VHF, BW= 25 kHz, 9 channels.	None
	Radio Amateurs UHF	435.2125-436.4625	Band for radio amateurs via satellite VHF, BW= 25 kHz, channels 10 a 59.	11 a 16, 18 a 24, 29, 31 a 40, 42, 44 a 47, 51 a 59.
Place 2: Macarena Faculty	Radio Amateurs VHF	145.7875-146.0125	Band for radio amateurs via satellite VHF, BW= 25 kHz, 9 channels.	None
	Radio Amateurs UHF	436.1375-436.5375	Band for radio amateurs via satellite VHF, BW= 25 kHz, channels 47 to 62.	48 to 50, 57 to 62
Place 3: Technology Faculty	Radio Amateurs VHF	145.7875-146.0125	Band for radio amateurs via satellite VHF, BW= 25 kHz, 9 channels.	None
	Radio Amateurs UHF	436.1375-436.5375	Band for radio amateurs via satellite VHF, BW= 25 kHz, channels 47 to 62.	47 to 50, 52 to 62

Preliminary design of the communication module :

Design and implementation of the beacon module of the pico-satellite colombia-1

The communication module of the pico-satellite Colombia 1, consists of three sub-modules: the Transceiver, the Beacon and the one for the implementation of the AX 25 protocol. The sub-module Beacon has as its main functions to give the telemetry of several variables of interest of the satellite condition, to generate the beacon signal for the earth stations to detect it and together with the other subsystems of the communication module make the link possible[13]. The determine functions according to the preliminary design for the communication module can be seen in the Table 4:

Table 4: Functions of the communication module[13]

No	Function	Submodule
1	To inform the OBC and the submodule Beacon of the data deception from the earth station (ES).	Rx AX.25
2	To inform the OBC and the submodule Beacon of the contact loss with the ES	Rx AX.25
3	To start a transmission in AX.25 when it is in contact with the ES	Tx AX.25
4	To inform the OBC when it is ready to transmit information to the ES	Tx AX.25
5	To take telemetry signals from the sensors of the pico-satellite	Beacon
6	To codify in Morse code the information of telemetry of the sensors of the pico-satellite	Beacon
7	To manage the switching between data transmission in AX.25 and Beacon transmission	Beacon
8	To transmit in CW the Beacon signal.	Beacon

Keeping in mind the functions of the table 4, the first critical design of the communication module, just like it is shown in the Figure 3. For the submodule Beacon the current sensors are considered, the voltage and the proportional heat to the telemetry of the satellite along with the use of the microcontroller PIC6F877A[14], in addition an antenna switch is proposed that alternate the Beacon signal and the mission signal that is in the AX.25 protocol, this with the objective of being able to use the same transmitter. The input and output functions of the system are reviewed in the tables 5 y 6.

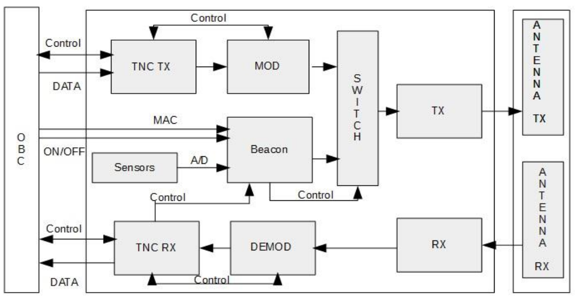

Figure 3. Critical Design of the communication module[13]

Table 5: Inputs of the communications module[13]

	TYPE OF SIGNAL	ORIGIN	DESTINATION	FUNCTION
1	Control	OBC	Tx AX.25	Indicates when there is a transmission
2	Control	OBC	Rx AX.25	Informs that it is ready to receive data.
3	Data	OBC	Tx AX.25	Mission Data
4	Data	Earth Station	Rx AX.25	Received data from the earth station in RF
5	Media Access Control	OBC	Beacon	Solution to Medium Access, indicates the origin station to target data.
6	Module Activation	OBC	Beacon	Activates the Beacon module after the satellite extricates from the P-POD
7	Energy Powering 3.3V	Power Module	Beacon y AX.25	Provides energy to the communication system.

Table 6: Output of the communication system[13]

	TYPE OF SIGNAL	DESTINATION	ORIGIN	FUNCTION
1	Control	Rx AX.25	OBC	Indicates when the communication starts.
2	Control	Tx AX.25	OBC	Indicates the availability to receive data.
3	Data	Rx AX.25	OBC	Data and commands received from the earth station.
4	Data/Beacon (CW)	Tx AX.25/Beacon	Earth Station	Data sent to the earth station in RF data AX.25 or Tx Beacon.

Submodule beacon of the pico-satellite colombia-1

Additionally to the functions for the Beacon mentioned before, it was proposed that this sub-module were formed by two blocks that can be seen in the Table 7. Figure 4 where there is a block scheme of the system which is divided in two segments. The space pico-satellite and the earth station, in the first bloc, the acquisition of data refers to the signals detected by the sensor, which are processed by an ADC (Analog-Digital-Converter), this data goes to the next block that makes the coding by the microcontroller through an application and a control system On/Off called OOK (On/Off Keying) in CW (Continuous Wave) which is transmitted in UHF band through a Beacon frame to the next block, that corresponds to the earth station.

Lastly, a CW decoder in code ASCII through the software CWGET to finally see it in the desktop application[13].

Table 7: Beacon Blocks[13]

BLOCK	SEGMENT
Adquisition of sensor data	Space (Pico-satellite).
Coding Beacon frame and CW Transmission.	Spacial.
Coding Beacon frame and CW Transmission.	Earth (Earth Station).
Decoding of the Beacon frame and WEB View.	Terrestrial.

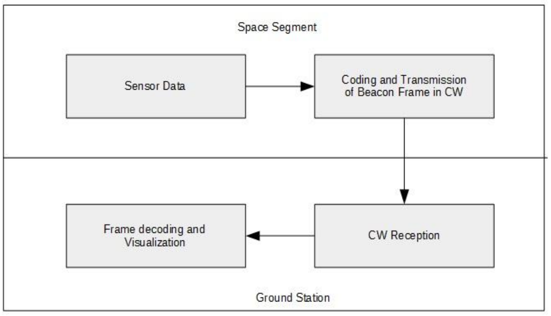

Figure 4: Block System of the Submodule Beacon.[13]

The subsystem is composed by various parts, such as the sensors used in order to have a steady voltage measurement, current and temperature, the microcontroller PIC16F977A[14] is responsible of setting the Beacon frame, the treatment, processing the signals, coding the frames in CW and also, of controlling the switch which function is to let the signal in that is going to be transmitted under the AX.25 protocol or from the Beacon signal. The block system inputs and outputs of the submodule Beacon related with other modules can be seen in the Figure 5.

Inputs and outputs of the submodule beacon

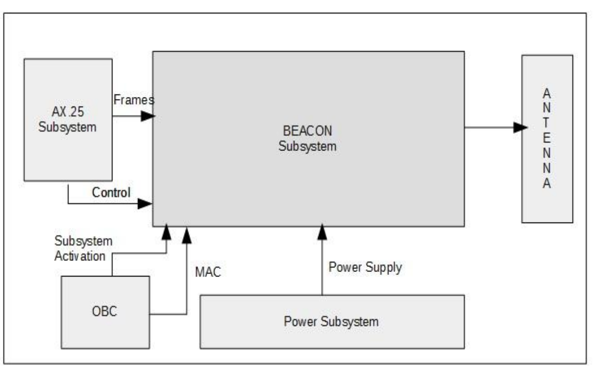

Figure 5: Inputs and Outputs of the submodule Beacon with another picosatellite modules[13]

As can be seen in the Table 8 y 9 the system designed consist of 4 inputs and one output, this output always corresponds to the signal that is going to be sent to the earth station being one part of information from the AX.25 protocol or the CW pitch to identify the satellite[13].

Table 8: Inputs submodule Beacon with another picosatellite modules[13].

	TYPE OF SIGNAL	ORIGIN	DESTINATION	FUNCTION
1	Data	Tx AX.25	Switch	Data sent to the switch to be transmitted to E.S.
2	Control	Rx AX.25	Microcontroller	To inform the Beacon of the contact to E.S.
3	Control	OBC	Microcontroller	Information Solution Access to Medium.
4	Powering Energy	Power Module	Beacon y AX.25	To provide energy to the communication system.

Table 9: Outputs submodule Beacon with another picosatellite modules[13]

	TYPE OF SIGNAL	ORIGIN	RECEIVER PART	FUNCTIÓN
1	Data/Beacon	Submodule Beacon	E.S	Data from AX.25 or Beacon signal sent to Earth.

Operation of the submodule beacon

The module stated consider two scenarios, the first when the satellite is not in contact with the earth station which covers 96% of the time, where a beacon signal has to be transmitted to identify itself each two minutes, to save energy and the second when is in contact with the satellite that has a time between 12 and 15 minutes twice a day generating calculations for the attitude control module. When there is a contact with the earth station the beacon must be aware of the AX.25 frame sent with the purpose of enabling the switch that makes it possible to send the frames from the satellite. If the satellite does not accept the connection, the beacon must activate the switch to be able to transmit in CW the sensor signals and the beacon signal to identify themselves[13].

Hardware

In the Figure 6 the block scheme reviews the elements used in the design made for the BEACON check, the antenna used in the satellite part that was used in the checks was the WLP434 which operating 434 MHz frequency and an impedance of 50 Ohm[15].

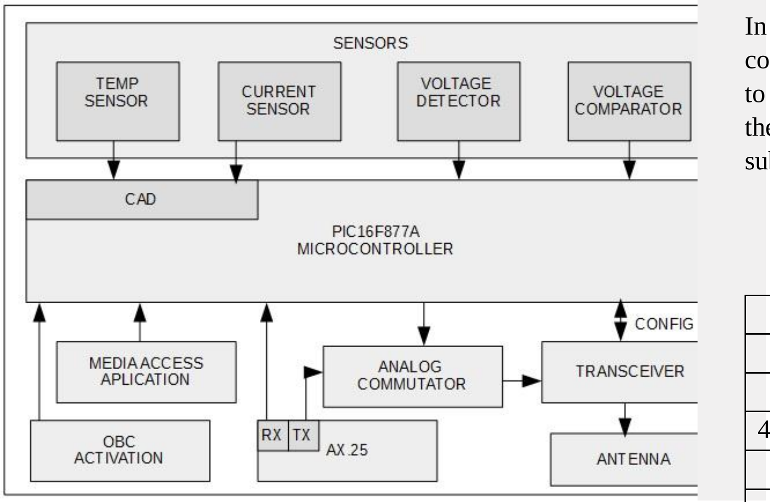

Figure 6: Hardware block System from the communication module[13].

Transmission of the beacon frame

The transmission of the beacon frame is made by Morse code (CW) because in this kind of projects it is necessary that the power consumption would be the minimum possible and the bandwidth reduced. For this, the transceiver CC1000[16] is chosen, it has the OOK (On-Off Keying) application that is used to transmit in CW. The microcontroller turns off and on the carrier signal that sends the CC1000 and allows to make the CW of the Beacon frame.

Beacon frame

The Table 10 shows the fields for the Beacon frame: where "Templ" corresponds to a temperature OBC, "temp2" communication Card temperature, "Temp3" Battery Bank temperature and "Temp4" Transceiver Temperature (CC1000) that corresponds to the temperature sensors that are coded with two characters that stablish a temperature between -40 °C to 125 °C given by the LM60[18] sensor chosen in the design, two fields for voltage, one for the current and the last three fields represent the station of the data source, the destination station and the status of the picosatellite.

Table 10: BEACON FRAME [13]

FIELDS	I.D	Temp 1	Temp 2	Temp 3	Temp 4	V 1	V 2	I 1	E O	E D	E
characters	COL	AA	BB	CC	DD	E	F	G	H	I	J

Power consumption of the beacon system

In the Table 11 can be found the description of the power consumption, it does not include the signal amplifier that has to be used in the final card of the communication module, nor the necessary elements for the implementation of the AX.25 subsystem which estimates a total value of 100.149 mW[13].

Table 11: Power Consumption Devices.[13]

DEVICE	CONSUMPTION IN mW
Transceptor CC1000	96.12 @ 10 dBm
PIC 16F977A	1.8
4 temperature sensors LM60	2.2
2 voltage scanner Xc61c	0.007
Current sensor ZXCT	0.020
Switch ADG918	0.00275

Transceiver for the CubeSat picosatellite colombia-1 in the vhf/uhf band

The base transceiver ADF7020-1[19] was chosen because it meets the specific requirements proposed for this device: it has a maximum weight of 100g, its power consumption is lower to 300 mW, it permits FSK and GFSK modulations, transmission speed of 9600 bps, it operates in 440 MHz frequencies in transmitted mode, 140 MHz in receiver mode, it can withstand sudden changes in temperature, and frequency control to reduce the Doppler effect. The output power is not the required, for this reason an external power amplifier ADL5531 was chosen[20] that has an input and output impedance of 50 ohm. For the correct running of the device, the mating of the impedances was created for both receiver and transceiver to ensure the maximum transference power[21].

Design and implementation of a transmission system and data reception with the ax.25 protocol

In the Figure 7 a block diagram can be seen where the location of the subsystem of implementing the AX.25 protocol is given in a general outline of the communication module.

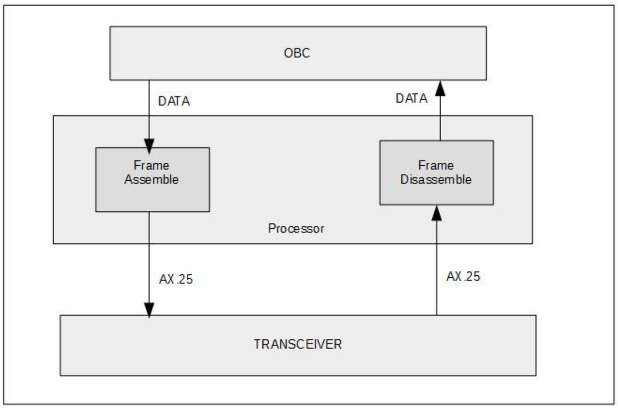

Figure 7: Block Diagram of the AX.25 Protocol[23]

To have communication between the subsystem of AX.25 protocol and the data module (OBC) a communication protocol was designed and implemented onboard the CubeSat COLOMBIA-I

Communication protocol between the communication module and the data module

The OBC protocol is based on 6 steps that permit an excellent communication by the standard SPI between the data module (OBC) and the AX.25, using little information processing for not interfering with the processing times during the executing of the AX.25 protocol; each step consists on an octet or 8 bits that are divided into 4 bits for the control indicator of the protocol, and 4 bits for the index number[22].

Protocol implementation

Since the microcontroller of the communication module is in charge of assembling, disassembling the frames and identifying each field to extract the information and pass it to a top layer it was necessary that the selection of the device took into account the protocol needs. Another important part of the AX.25 protocol is the way in which it communicates with the rest of the layers, especially with the OBC because this last one is the one in charge of storing and processing the information onboard the picosatellite. The outline to stablish communication with the OBC can be seen in the Figure 8 as well as each of the status in the Table 12 [23].

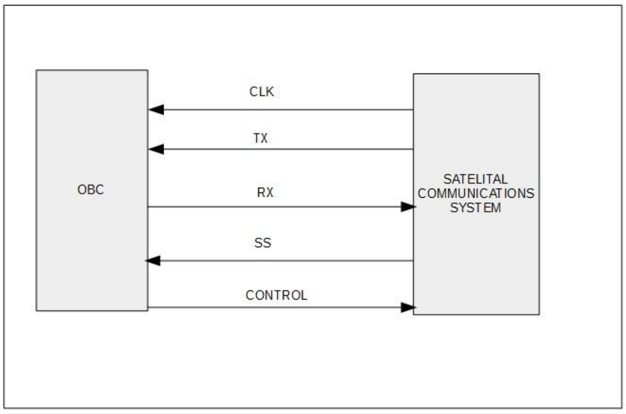

Figure 8: Lines between the communication module and OBC[23].

Table 12: Lines between the communication module and the OBC[23]

Status	Description
CLK	Clock for the communication, is made by the communication system.
TX	Data transmission from communications to OBC
RX	Data transmission from communications to OBC
SS	The line SS indicates to the OBC when it is possible to transfer or not.
CONTROL	This OBC line indicates the availability to send and receive data from communications.

For this protocol, it was defined two types of octets, control and information. The information octets were transmitted once the communication was stablished. The control octets have 7 different types. To distinguish the control octets, they are divided into two parts of 4 bits each one. The last 4 bits correspond to an indicator, while the first 4 correspond to a number that is interpreted according to the corresponding indicator[23].

Communication protocol testing between OBC and the communication module

In the first part the implementation was made in PIC16F877A[14] and TI-MSP430[24] microcontrollers, the code was done in C language using the platforms MATLAB[25] and Cross Studio, CrossWorks MSP430[24]. The lines used by the communication module and OBC consist on pulses TTL between O V and 3,3 V.

The second test made was the opening of a file in the memory of solid state for the writing of information, recording and file closing. In this test it was identified that the time that the TI-MSP430 takes to make this actions can vary, and that there was a data loss in the communication, this is because the files should have been written whereby it required a conversion to ASCII, for this it was implemented a fifth communication line called "Control". The average time that the microcontroller PIC16F877A with an external clock of 16 MHz had to wait before sending a command again, change of the line status or CLK was approximately between 5 Us and 15 Us, therefore the clock "CLK" implemented has a period of 30 Us. To confirm that the information is being stored a determined field of 255 octets was transmitted in the empty memory, after the transmission the new file was revised storing the memory with the name of Bogota, and contained 2040 data between ones and zeros; subsequently that file was retransmitted to the communication module, checking that there were no errors in the file by a CRC-16 implemented in the same PIC16F877A.

The third test was the implementation of the protocol commands between the communication module and OBC, following the six already described steps simulating the communication with two earth stations. Also, a transmission of nine frames of 255 octets each one was included, and the files that the OBC provided for that purpose were monitored. In this check there was no data loss nor mistreatment to any file in the memory of solid state.

AX.25 protocol

The AX.25 protocol is an operational mode of the standard HDLC (High-level Data Link Control) of the CCITT (Consultative Committee for International Telegraphy and Telephony)[17], that mode has an important characteristic that works as well in half-duplex setting as in full-duplex setting and it is oriented to the connection through numbered frames[26].

For its implementation, the first think that is taken into account is that the AX.25 protocol onboard the picosatellite must begin in the reception mode because the picosatellite does not know the location of the earth stations. However, the earth stations in search of the picosatellite and can find it thanks to the beacon signal. The earth station receives the beacon signal and identify the target picosatellite, after this the communication starts with AX.25 from the earth station sending an unnumbered frame SABM (Set Asynchronous Balance Mode), and immediately the beacon signal is interrupted to start the communication from AX.25. The developed program fulfills with the description in the Figure 9, that corresponds to the AX.25 protocol, the communication with OBC, the use of the modulation AFSK – Bell 202, and its easy modification. Though, the main function of the program is the AX.25 protocol, which also must include the requirements of the project CubeSat UD.

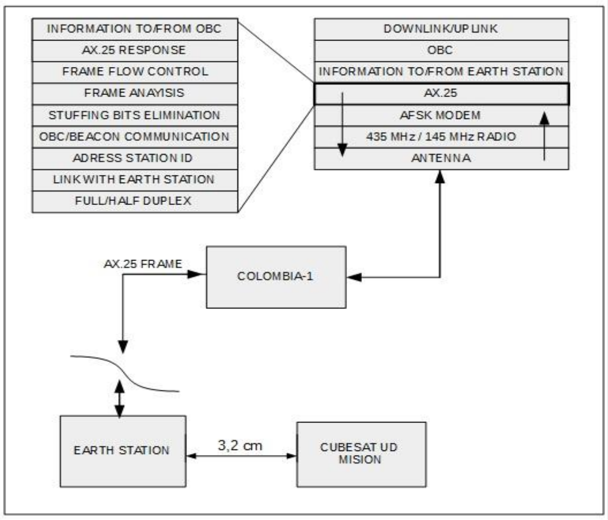

Figure 9: Blocks Diagram of AX.25[22].

For the programming of the AX.25 module, the first to consider is that the protocol is found in a ship or infinitive cycle if there is no change in the line, for example the reception of a bit 0 that can be the beginning of the flag, and then depending on the time of data transmission, for the case of the picosatellite Colombia-1 to a rate of 1200 bps, 8 bits are stored to be analyzed to detect the flag. If the flag is received all the octets are stored, deleting bits stuffing until another flag is found. The analysis of the frame consider the calculation of CRC-16, the analysis of the direction field, the field of the information control. If the frame get with no error and the field of control rate is correct, the error reported is zero (0), which allows the formulation of an answer or it waits for another frame.

Results analysis :

Design and implementation of the communication module for the picosatellite colombia-1 of the project CubeSat-UD

The critic design works under the AX.25 protocol, the beacon submodule and the Transceiver. In the Figure 10 is shown in the block diagram of the Beacon submodule, in the Figure 11 the transceiver and finally in the Figure 12 the AX.25

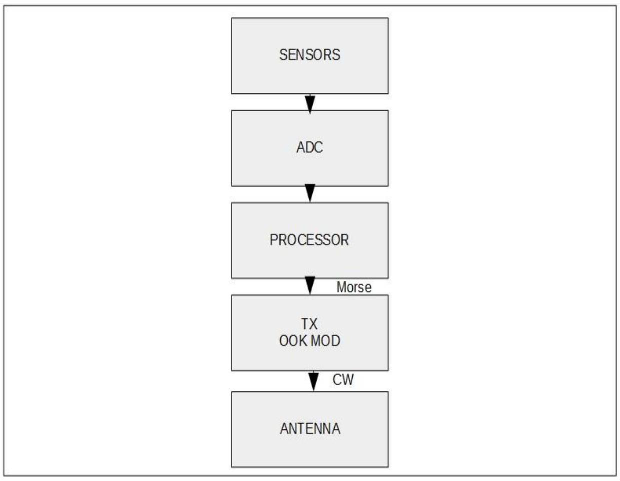

Figure 10: Block Diagram of the Beacon Submodule [23].

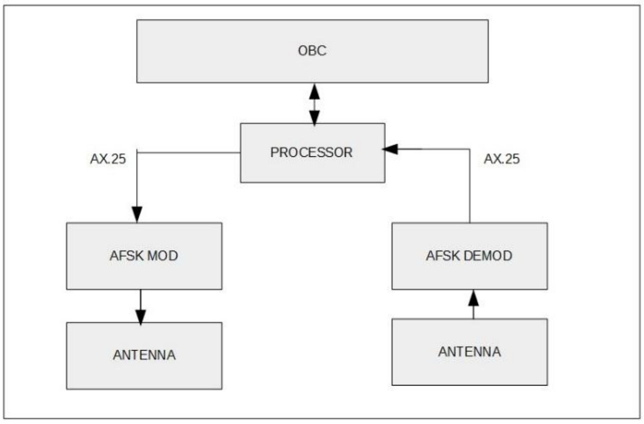

Figure 11: Block Diagram of the Transceiver Submodule [23].

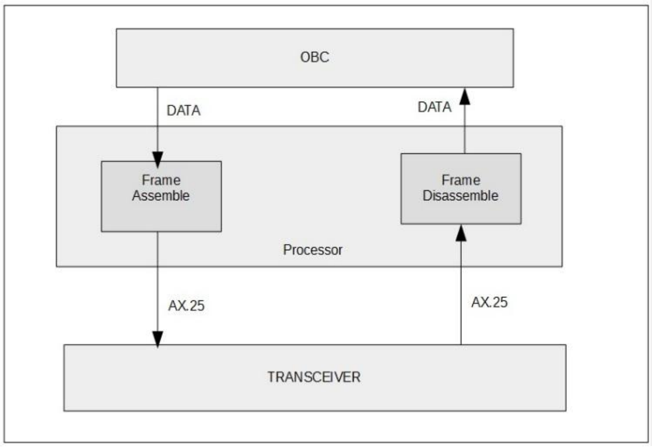

Figure 12: Block Diagram of the AX.25 Protocol[23]

Tests

Five tests were made. The first test was the one of the integrity of the module which objective was to verify the functioning of the entire card by the communication port RS232 and the measuring sensors which were optimized.

The second test was to verify the working frequency of the transmitter, the receiver and the crystal from which they depend, for that reason the receiver and the transmitter were measured with a square wave of 5 MHz and 2.5 MHz respectively and whereby the results gotten were good with a rate frequency that goes from 129 MHz to 145 MHz for reception link and from 389 MHz to 440 MHz for transmission link.

The third test was to measure the power generated by the module using the 440 MHz bandwidth a modulated signal OOK which was expected to obtain a successful measurement in the 435 MHz frequency but it did not work.

The fourth test was to measure the sensibility of the receiver with a 140 MHz bandwidth using a modulated signal in FSK with a deviation of ±5 kHz. That was why the generator was set with a 140 MHz frequency, modulation DC FM and deviation of 10 kHz. The power output of the generator was reduced to -65 dBm and the cable loss that is 3dB was added, which permitted the verification in the screen of the Hyper Terminal of the correct arrival of data through a repetitive sequence of the alphabet. Thus, the sensibility of the receiver is -68 dBm, which equate to 148.58 pW.

The fifth test it was verified that the frames generated by the Beacon submodule are coded in the right way and detected by the ES radios for a frequency of 435 MHz. Finally, the communication with the OBC was approved reason why nine frames of 255 bytes were sent between the OBC and the communication module using the developing system for MSP430, where the OBC was implemented, which got successful results.

Final design of the communication module:

Integration card of the communication module of the picosatellite colombia-1 project CubeSat-UD

The final specifications stablished were: The modulation and demodulation used must be AFSK, the reception frequency will be 144 MHz and the transmission one 440 MHz, the signals must be coded and transmitted using the AX.25 protocol ensuring the error checking to request the resend of the frames received with errors, the transmission speed will be 1200bps, the sense that will manage the whole system will be implemented in a microcontroller of low consumption from the manufacturer Texas Instruments, the card size will be 10x10 with a power consumption reduced without including the power required by the transmitted antenna, with the lowest weight possible[27].

On the other side, its structure has three submodules: transmission/reception submodule, Beacon submodule, contains the telemetry information of the picosatellite and starts the data transmission because once the Earth Station detects the presence of the Beacon Signal of the picosatellite

Colombia-1 which gives position to the link.

The final design stablish that the communication module must include a microcontroller of the family MSP430 from Texas Instruments and an interface BELL 202[29], composed by two integrated MX614. In the card it is not include the RF module, that is implemented using the radio plaque YAESU VX-3R, a switch was included to transmit the Beacon signal and the data in AX.25 using the same interface. In the Figure 13, the final block diagram of the communication module is presented and in the Figure 14 its prototype.

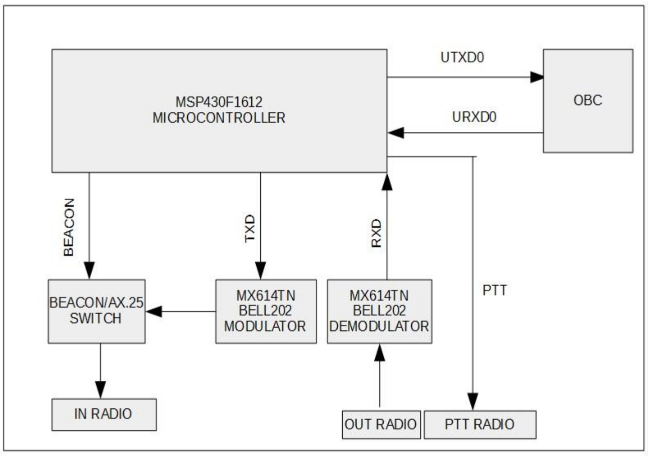

Figure 13: Block Diagram of the Communication Module[27].

Figure 14: Final Version with YAESU VX 3 transceiver attached[27].

Tests with CubeSat kit

As the first test process the development and implementation of the communication module was carried using the developing cards from CubeSat Kit. The software proved is a complete version that could successfully integrate the functions of the Beacon and AX.25. Within the Beacon frame, an indicator is sent or ID of the information measured by the sensors in the satellite: temperature, voltage, current, the origin station, the station of destination and the state of the satellite. The possible states of the satellite in the Beacon frame are coded as shown in the Table 13:

Table 13: States of the Satellite. Taken from Integration Card of the communication module of the picosatellite Colombia 1 Project CubeSat-UD[27].

State	Indicator	Description
Free	**F**	Free and can receive data from any station
Occupied	**O**	Occupied with data for the Earth Station specified in the destination field.
Any	**A**	Indicates that has data for any Earth Station
Not Available	**N**	Not available

The Media Access Control is implemented through the use of the status field. The Beacon frame transmits in CW using the modulation FSK through the modem MX614 Bell 202[29]to 430.43 MHz from the emulation of the satellite composed by two computers from the laboratory. Once the Beacon frame is transmitted it starts the detecting process carried by Earth Station using the Radio Kenwood DM-700[31], and using the external Terminal Node Controller (TNC)[30], it starts giving the position to the link to send the information that has be on the satellite using the AX.25.

The program is executed to detect the Beacon and it starts the Beacon transmission from the emulated satellite (PC1, using the developing card Kalman and the modem circuit). The detecting program shows options to store texts files that have to be stored the root folder of the ES interface.

After this, the ES interface is executed and all the settings mentioned before are typed and also it is necessary to type the information that is going to be transmitted. This information must be plain text (Characters ASCII) ad must be typed in “Load information field”.

After the Beacon detection the link giving position is carried by the Earth Station and immediately by the external TNC[30].

Once the up-link finishes with the information completely transferred to the satellite it is necessary to assign the call sings to make the emulation of the destination of the Earth Station (ES). This way, the transmission process of the Beacon frame starts again which is detected for the now emulated ED. The link is stablished and instantly the information is sent to the ED previously upload to the satellite in a plain text through the AX.25 protocol and this way the correct functioning of the Down-link is evidenced. Additionally, the communication system was tested with OBC needed for the storing of the information in the SD memory.

Results of the tests

The beacon frame is achieved in the Earth Station, the link is stablished appropriately and it is possible to upload the expected information to the satellite. It was also possible to stablish the link with the destination of the earth station for the downloading of information that is previously loaded to the satellite. It is important to highlight that the tests were made forcing the satellite status in the Beacon frame to F "Free". The tests of information storing in the SD memory that is located in OBC were satisfactory.

Tests of the final card

With the purpose of validating the correct working of the card designed it was necessary to make a number of tests that are related in the Table 14.

Table 14. Tests maade with the ModCom card Vrs.3.Taken from Integration Card of the communication module of the picosatellite Colombia 1 Project CubeSat-UD[27].

Description	Results	Observation
Voltage measurement 3.3V in the microcontroller	3.31V	Voltage within the range (1.8V a 3.6V MSP430F1612)[28]
Voltage measurement 5V to the regulator input	5.02V	Voltage within the range (-0.3V a 6V TPS75801KTT)
Voltage measurement 3.7V to the regulator output	3.82V	Voltage within the range (3.7V a 4V VX-3R) y (3.3V a 5V MX614TN)
Programation of the microcontroller	Successful	Ìt was programed using MSPFETP430IF con un adapter FPC flat belt.
Measurement of the Beacon signal in the pin 12 of the micro.	3.1V	Extend 3.1V when the beacon is transmitted to. 3.1V continuing to AX25
Measurement of the PTT signal in the pin 13 of the micro.	3.1V	0V when there is no transmission
Measurment of the signal TXD in the pin 14 of the micro.	0V	Extend 3.1V when it transmits AX25
Measurement of the signal RXD in the pin 15 del micro.	2.3V	
Measurement of the input signal of the Transceiver	80mV@2202Hz	Signal with period T=454ms
Detection of the Beacon signal in the Earth Station	Successful	CWGET is used
Link establishment	Successful	BOGOTA with COL-01
Transference of an Earth Station file – ModCom	Successful	Plain text file.
Transfrence of a ModCom file – Earth Station	Successful	The file is returned to ES
Transference to OBC of the received information	Successful	
Storing checking in the SD memory of the received information	Successful	Plain text file stored.
Updating checking of the control files (Index and origins)	Successful	Plain text file stored.

This way, the final design of the card of the communication module is concluded where the requirements were accomplished such as the transmission of the Beacon signal fulfilling the standard stabilized to detect in the Earth Stations. The successfully integration of the Radio Yaesu VX 3R to the communication module designed, also the successfully establishment of double via communication with the central OBC module.

From these tests it was possible to reduce to one quarter of the time of the transmission reducing the same duration of time from point to space, this is traduced in a reduction of the 75% in the transmission time. This is because the duration time from point to space in the Beacon transmission depends on the capacity of detection of the Earth Station. Also, the communication between OBC and the communication module was established using only 3 transmission lines of 5 initial. This reduction means a 40% less of the lines used initially[28].

In cooperation with the OBC module was reduced from 8 to 1 the number of files destined in the SD memory card to store the information originating from each Earth Station, which means a reduction of 87.5% in the amount of stored files. On the other side, it was possible to integrate the switch of the

Beacon transmission and AX.25, this switch is controlled by the microcontroller and in the moment in which it is required to go from a transmission state to another without any problem[28].

In total three versions were done of the communication module, the final design was the third version for the Colombia-1, this was the result of the research made such as the study of modulation techniques where they were analyzed and gave as result that the best modulations that could be implemented were the OFDM, QPSK and GFSK. However, for this final design the AFSK modulation was chosen because the standard used for the communications between modules that is made by the BELL 202 standard, this states the transmission speed of bits 1200 bps, also this type of modulation and has noise immunity for it does not depend on the extent. The two studies made from the Channel, one of them worked with a 440 MHz frequency for transmission and 144 MHz for reception and the second with 930 MHz and 915 MHz from which the first were chosen.

CONCLUSIONS

Contrary to the designs made where a low range microcontroller is used for each subsystem (Beacon and communication with the OBC), in this design it was decided to have only one low range microcontroller called MSP430F1612 where all the submodules that compose the communication system were implemented, this is because it allows a space and power saving

The microcontroller MSP430F1612 is in charge also of receiving and coding the signals originating of the current, voltage and temperature sensors used which were the same used in a study that gave as result a communication module with the name Colombia-1 Version 2.0, which correspond to ZXCTT1009 as current sensor, XC61CN300 as voltage sensor and the TC1046 for temperature.

The first Transceiver used was the ADF7020-1, though this one did not fulfill the requirements in the output power programmed even when an external amplifier is adapted. That is why then it was decided to use the reference transceiver YAESU VX 3, this provides until 1,5 W of transmission power in VHF and 1 W in UFH, it also works with the expected frequencies of 144 MHz and 430 MHz and allows to work with the AFSK modulation. However, it has a limiting of not being able to vary the rate transmission of bits of 1200bps contrary to what other transceivers tested in previous studies.

The AX.25 communication protocol was successfully implemented, whereby it was possible to transmit the information about an assembly that simulates the communication between the Earth Station and the communication module Colombia-1. On the other hand, the software for analyzing frames was achieved and allows to do a strict control of the transmission of information.

Finally, with this design of the communication module and the research made until now, new ideas to work on this issue have emerged in the research group GITEM++ to be applied in the design of the Earth Station, the communication module and interfaces that permit the information exchange between different kind of satellites no matter the protocol that is being used.

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