AntelSat Amateur Radio services

Facultad de Ingeniería

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1 Introduction

AntelSat is a 2U CubeSat class nanosatellite, designed and developed by engineering teams from Uruguay's state university (fing.edu.uy) and the state telecom (Antel).

This document describes the features and services for amateur radio operators provided by AntelSat's radio links.

The information in this document is provided by the AntelSat team, and may be distributed freely.

More information on the AntelSat project can be found at `http://iie.fing.edu.uy`, and Twitter feed *@CX1SAT*.

Launch occurred 2014-06-19 19:11 UTC from Yasny, inside UNISAT-6, on a DNEPR rocket. Deployment from UNISAT-6 was on 2014-06-20 21:07 UTC. The spacecraft is probably `2014-033AR` at this time.

1.1 Revision history

Sections in this document are marked `PENDING`, `DRAFT` or `FINAL` to indicate status.

Revision	Main changes
[2013-05-27 Mon]	First draft
[2013-09-27 Fri]	Added encoding for telecommands and digipeater details
[2014-01-13 Mon]	Cosmetic review
[2014-06-07 Sat]	Update for flight software
[2014-06-20 Fri]	Corrected CW beacon details
[2014-06-22 Sun]	Added AX25 telemetry encoding
[2014-06-23 Mon]	Fixed minor typos.

Pending:

- Add callibration factors for all measurements

2 AntelSat telecommunications architecture

This document specifies the functionality of AntelSat VHF/UHF communication links.

The following is a list of AntelSat's modules:

ID	Module name
`EMS`	Energy management system
`MCS`	Main control system
`RX1`	Telecommand receiver
`RX2`	Telecommand and ham radio receiver
`BCN`	CW transmitter
`TXD`	Data transmitter
`TXS`	S-band transmitters (TXS1 and TXS2)
`PY`	Scientific payload
`BAT`	Battery pack
`ADCS`	Attitude determination and control module

The spacecraft contains 2 FM receivers in VHF (RX1 and RX2), 2 transmitters in UHF (BCN and TXD), and a 1+1 redundant transmitter in S-band. VHF and UFH antennas are $\lambda/4$ monopoles (4 in total), while the 2 redundant S-band transmitters each have a patch antenna. This makes for a total of 4 transmitters, 2 receivers and 6 antennas.

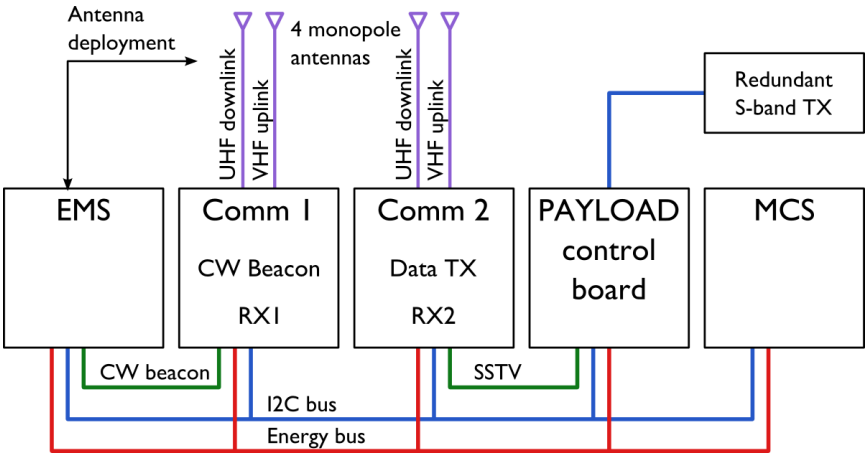

Figure 1: Simplified block diagram showing communications components.

BCN is a low power (200 mW) CW transmitter, with Morse code encoding. Its main purpose is to transmit a beacon loop with minimum status information. It also aids in diagnosing the radio uplinks. It is powered and managed directly by the EMS, so that it should survive even a fault in the MCS or in the I2C bus which links all modules.

TXD is a 1W multi mode transmitter, capable of operating in AFSK FM, 2 FSK, or SSTV modes.

The S-band transmission is a high bandwidth downlink intended solely for lossless image download, and is part of the payload. Transmission on S-band will only be started via telecommand.

RX1 and RX2 are FM receivers and decode AFSK 1200 bps AX.25 data packets.

RX1 will work on an unpublished frequency and is dedicated to encrypted telecommand only. Encrypted telecommand refers to the protected command uplink available to the AntelSat team and partner ground stations. RX1 is always active during normal satellite operation as required by ITU for commanding space radio stations.

RX2 will be available for amateur radio services. These services will be available as soon as in-orbit operations are commissioned and stable. RX2 and TXD work in half duplex mode as they share the codec CPU, so RX2 will be disabled during TXD data transmission (not during SSTV though).

In general, all telemetry values will be transmitted encoded.

The spacecraft's callsign is `CX1SAT`.

3 Frequencies

The frequencies assigned by IARU coordination board are the following:

Radio	Frequency
BCN (downlink)	437.280 MHz
TXD (downlink)	437.575 MHz
TXS (downlink)	2403.000 MHz
RX2 (uplink)	145.860 MHz

Note that these frequencies must be corrected for Doppler effect and eventually for temperature drift. Crystal temperatures are reported periodically on the CW beacon.

4 Satellite energy modes

The spacecraft has 2 energy modes, which are selected automatically by EMS:

Energy recovery mode Battery voltage has dropped below a minimum operation threshold. In this mode, all modules other than EMS are powered off.

Safe operation mode When battery voltage reaches above a safe operation threshold, the spacecraft is put into safe operation mode. The satellite will enter this mode with all services disabled and most modules shut down. Modules will be powered up, and services enabled, via telecommand.

Also, in accordance to ITU-R requirement for space radio stations, the spacecraft can be commanded into *radio silence mode*, with all emissions disabled.

5 BCN - CW transmitter

5.1 Recovery mode CW status beacon

When the spacecraft is in *energy recovery mode*, a short CW beacon message will be transmitted at a low rate (with a 3 minute gap, or 5 minute gap if MCS is defective).

The short beacon focuses on energy status and module failures.

Position	Value
1-6	Callsign (`CX1SAT`)
7	Average battery voltage
8	MPPT X power
9	MPPT Y power
10	MPPT Z power
11	I2C bus retry status
12	MCS retry status
13	COMM1 retry status
14	COMM2 retry status
15	ADCS retry status
16	PY retry status
17	TXS1 retry status
18	TXS2 retry status

General encoding of digits. Decimal digits are encoded using short Morse code letters in order to save energy.

Code	Digit
`E`	0
`I`	1
`T`	2
`S`	3
`A`	4
`N`	5
`H`	6
`U`	7
`R`	8
`D`	9

Battery voltage range encoding:

Code	Voltage range
E	< 3.20 V
I	3.20 V - 3.31 V
T	3.31 V - 3.42 V
S	3.42 V - 3.53 V
A	3.53 V - 3.64 V
N	3.64 V - 3.76 V
H	3.76 V - 3.87 V
U	3.87 V - 3.98 V
R	3.98 V - 4.09 V
D	> 4.09 V

MPPT power range encoding:

Code	Power
E	< 0.45 W
I	0.45 W - 0.90 W
T	0.90 W - 1.35 W
S	1.35 W - 1.80 W
A	1.80 W - 2.25 W
N	2.25 W - 2.70 W
H	2.70 W - 3.15 W
U	3.15 W - 3.60 W
R	3.60 W - 4.05 W
D	> 4.05 W

Subsystem retry status. This fields are generated by EMS and denote the number of errors trying to power up and communicate with the different modules.

Code	Retry status
E	No faults
I	1 fault detected
T	2 contiguous faults
S	3 contiguous faults
A	4 contiguous faults
N	Permanent fault; retry every 72 h

5.2 Safe mode CW status beacon

During normal operation, a CW status beacon loop will be transmitted with a 1 minute gap (or 90s gap if MCS defective).

The status beacon is as follows:

Following is the list of values encoded in the CW telemetry beacon during normal satellite operation.

Position	Value
1-6	Callsign (`CX1SAT`)
7	Battery average voltage
8	I2C bus status
9	MCS status
10	COMM1 status
11	COMM2 status
12	ADCS status
13	PY status
14	TXS1 status
15	TXS2 status
16	MCS Last Received Msg
17	MCS Digipeater enabled
18	MCS SSTV enabled
19	COMM1 max RSSI
20	COMM1 Rx Xtal 1 temperature
21	COMM1 Rx Xtal 2 temperature
22	COMM2 max RSSI
23	COMM2 Rx Xtal 1 temperature
24	COMM2 Rx Xtal 2 temperature
25	ADCS status
26	BT (CW break, optional)
27 ...	User message (optional)

The first fields are similar to the recovery status beacon.

Modules can be enabled or disabled via telecommand, or may be disabled automatically in case of multiple failures. Module status is encoded as follows.

Code	Module status
E	Module enabled
I	Module disabled
T	Failure

MCS status:

Last received message Sequence number (modulo 8) of the last telecommand received.

Digipeater enabled D if digipeater enabled, I if disabled, E if no data from MCS.

SSTV enabled S if SSTV request enabled, I if disabled, E if no data from MCS.

COMM 1 & 2 status:

Max RSSI Encoded value of the maximum RSSI (*Received Signal Strength Indication*) of RX1 and RX2 during the interval since the transmission of the last status beacon. This information is for adjusting or troubleshooting the uplink communication. Higher values indicate a stronger signal was detected by the FM decoder.

Xtal 1 / 2 temperature Encoded temperature of the 2 crystals of each RX1 and RX2. This information is for eventually correcting for frequency drift with temperature.

ADCS status:

Code	ADCS status
E	ADCS startup
I	Waiting for UTC upload
T	Waiting for TLE upload
S	Waiting form coprocessor
A	Sensor measuring
N	Mesasuring error
H	Actuators active
U	Control timeout
R	Coprocessor error

User message. This is a custom message that can be set via encrypted telecommand.

Example beacon

```
CX1SAT REEEEIIIIIIISNNANNE
```

This is decoded as follows:

Field	Code	Value
Battery average voltage	R	3.98 V - 4.09 V
I2C bus status	E	Enabled
MCS status	E	Enabled
COMM1 status	E	Enabled
COMM2 status	E	Enabled
ADCS status	I	Disabled
PY status	I	Disabled
TXS1 status	I	Disabled
TXS2 status	I	Disabled
MCS Last Received Msg	I	1
MCS Digipeater enabled	I	Disabled
MCS SSTV enabled	I	Disabled
COMM1 max RSSI	S	Level 3
COMM1 Rx Xtal 1 temperature	N	Level 5
COMM1 Rx Xtal 2 temperature	N	Level 5
COMM2 max RSSI	A	Level 4
COMM2 Rx Xtal 1 temperature	N	Level 5
COMM2 Rx Xtal 2 temperature	N	Level 5
ADCS status	E	Startup

5.3 Message reception confirmation

When a correct AX.25 packet is received by the spacecraft, an acknowledge message will be sent by BCN. This message is a Morse code 'R' (for *roger*), and will only be produced at a limited rate (i.e. if a sequence several messages is received, only the first will produce a confirmation).

A *correct packet* is any AX.25 packet received with good CRC verification, no matter the contents.

This mechanism works even if MCS is down, and allows for:

- Testing and adjustment the uplink equipment.
- Diagnosis of the satellite in case of major failures.
- Operation the satellite even in case of TXD failure or poor data downlink reception.
- Uplink propagation testing with minimum ground station equipment.

6 TXD - Data transmitter

TXD can operate in 3 modes:

- AFSK FM at 1200 bps, for AX.25 packet transmission.
- FSK at 1200 bps, for AX.25 packet transmission.
- SSTV for low resolution image transmission (Martin1 encoding).

Operation on FSK or AFSK FM will be selected by encrypted telecommand. While FSK provides for a better link margin, exact receiver tuning is critical. The default mode is AFSK FM, which provides a lower link margin, but exact frequency tracking is not required.

The data transmitted by TXD includes:

- Telecommand response / acknowledge.
- Extended telemetry beacon loop: during normal spacecraft operation, TXD will periodically transmit a packet containing full telemetry data.
- Housekeeping data and event logs upon request via encrypted telecommand.
- AX.25 digipeater downlink.

All downlink is unencrypted.

6.1 Telemetry beacon loop

During normal operation, an AX.25 telemetry beacon loop will be transmitted.

By default, there is a 1 minute pause between telemetry transmissions. This rate can be changed via telecommand.

The telemetry beacon packets have the following AX.25 header information:

- Origin callsign `CX1SAT` with SSID 0
- Destination callsign `TELEM` with SSID 0
- Protocol ID `0xF0` (no layer 3 protocol)
- Type `UI` (unnumbered information)

Each telemetry transmission consists of 3 packets, each starting with `T1`, `T2` and `T3` respectively.

- T1 contains EMS telemetry data.
- T2 contains MCS, COMM1 and COMM2 telemetry data.
- T3 contains ADCS telemetry data.

Note that if a module is not active, the missing telemetry data in `T2` will be filled with spaces. `T3` is only present if ADCS module is powered up.

All telemetry data is encoded in hexadecimal digits in order to avoid handling binary data. Bytes are ordered in little endian (least significant byte first); for example, `350A` means `0x0A35`.

All structures are padded to a 2-byte word boundary due to MSP430 architecture. This is most relevant for `T2` that contains 3 structures, and may also introduce a dummy byte at the end of the message.

Data types are signed/unsigned integers (16 bits), signed/unsigned long integers (32 bits), IEEE 754 float (single precision, 32 bits), and a few unsigned char (8 bits).

All ADC values (voltages, currents, temperatures, RSSI) are transmitted as a raw ADC output count (12 ADC bits, encoded in 16 bit words).

ADC callibration factors for each field are given here (**PENDING**).
The following sections specify the fields in each of the 3 messages.

6.2 T1 telemetry: EMS

Type	Value
unsigned int	Running time in s
unsigned int	X cells current
unsigned int	Y cells current
unsigned int	Z cells current
unsigned int	EMS current
unsigned int	CW bcn current
unsigned int	I2C bus current
unsigned int	MCS current
unsigned int	COMM1 current
unsigned int	COMM2 current
unsigned int	ADCS current
unsigned int	Payload current
unsigned int	TXS1 current
unsigned int	TXS2 current
unsigned int	X cells voltage
unsigned int	Y cells voltage
unsigned int	Z cells voltage
unsigned int	Batt pair 1 voltage
unsigned int	Batt pair 2 voltage
unsigned int	EMS voltage
unsigned int	MCS voltage
unsigned int	COMM1 voltage
unsigned int	COMM2 voltage
unsigned int	ADCS voltage
unsigned int	Payload voltage
unsigned int	TXS1 voltage
unsigned int	TXS2 voltage
unsigned int	EMS temperature
unsigned int	MPPT X voltage
unsigned int	MPPT Y voltage
unsigned int	MPPT Z voltage
unsigned int	Antennas deployed

6.3 T2 telemetry: MCS, COMM1, COMM2

MCS telemetry

Type	Value
unsigned long	Timestamp
unsigned long	Last received UTC
long	Clock drift
unsigned int	Running time in s
5 x char	Last telecommand seq nrs from FING
5 x char	Last telecommand seq nrs from ANTEL
5 x char	Last telecommand seq nrs from OTHERS
char	Dummy padding for word alignment

The first two fields are the UNIX time value for the system clock, and the last uploaded UTC time.

Clock drift is the clock difference between the system clock and uploaded UTC time at the time of upload.

The last 15 bytes correspond to the last telecommand sequence numbers received for each of the 3 encryption keys.

COMM1 telemetry

Type	Value
unsigned int	RSSI
unsigned int	Xtal 1 temp
unsigned int	Xtal 2 temp
unsigned int	Received frame count

RSSI at the FM decoder is sampled at 9600 samples per second. The maximum value is retained between each CW beacon transmission. This value is reported here and in the CW beacon.

The frame count corresponds to the total number of valid AX.25 frames (layer 2). This counts the packets received with correct CRC, regardless of the contents or validity of layer 3 information.

This counter overflows back to 0 after 65535.

COMM2 telemetry

Type	Value
unsigned int	RSSI
unsigned int	Xtal 1 temp
unsigned int	Xtal 2 temp
unsigned int	Received frame count
unsigned int	Transmitted frame count

COMM2 telemetry is similar to that of COMM1, with the addition of a transmitted frame counter, which also overflows after 65535.

6.4 T3 telemetry: ADCS

Type	Value
unsigned int	+X photodiode
unsigned int	+Y photodiode
unsigned int	+Z photodiode
unsigned int	-X photodiode
unsigned int	-Y photodiode
unsigned int	-Z photodiode
int	X magnetometer
int	Y magnetometer
int	Z magnetometer
int	MSP430 temperature
int	Estimated roll angle
int	Estimated pitch angle
int	Estimated yaw angle
float	Est X angle rate
float	Est Y angle rate
float	Est Z angle rate
float	X position
float	Y position
float	Z position
float	X velocity
float	Y velocity
float	Z velocity
float	Sun model X
float	Sun model Y
float	Sun model Z
float	Magnetic model X
float	Magnetic model Y
float	Magnetic model Z
float	Est sun vector X
float	Est sun vector Y
float	Est sun vector Z
uint8_t	ADCS mode
uint8_t	Flags
uint8_t	Status

ADCS flags is the sum of:

Flag	Value
Magnetorquer off	8
Gyro off	4
Magnetometer off	2
Sun sensors off	1

ADCS status:

Value	Meaning
0	ADCS started
1	Waiting UTC clock
2	Waiting TLE
3	Waiting for coprocessor
4	Measuring
5	Measurement error
6	Actuating
7	Control timeout
8	Coprocessor error

7 AX.25 digipeater service

Energy and ground operations permitting, AntelSat will provide a standard AX.25 digipeater service.

Availability of this service is indicated on the telemetry loops (both on BCN and TXD).

Packet transmission rate for this service will be limited in order to save energy and to not downgrade RX1 sensitivity.

Digipeater functionality is according to AX.25 version 2.2. Packets will be retransmitted if any of the *relaying stations* in the AX.25 header are set to `CX1SAT`.

For example, sending a packet from `CX0CFI` to `CX2SC` using AntelSat as digipeater, the packet header must be:

```
CX0CFI -> CX2SC v CX1SAT
```

The repeated packet will indicate `CX1SAT` as an already traversed repeater.

A repeater chain with up to 2 repeaters can be handled by AntelSat.

8 SSTV transmission

Another service available for amateur radio operators is the possibility to request a SSTV image transmission.

A command on RX2 (format **TBD**) will request a snapshot of one of the 2 payload cameras (visible or IR), and start transmission of the SSTV image.

This service is very energy demanding, so it will be available whenever energy levels permit, and with a considerable energy recovery period after each transmission.

In order to request an SSTV image transmission, the ground station should send an AX.25 frame with the following parameters:

- Type: `UI` (unnumbered inofrmation frame)
- Protocol: `0xF0` (no layer 3 protocol)
- Destination: `CX1SAT`
- Data (packet payload):
  - `SV` to request visible spectrum image capture.
  - `SI` to request near IR image capture.
  - `ST` to request a test image.

Upon reception of the command by the spacecraft, if the service is enabled and there is no pending data to transmit, an SSTV image transmission will initiate using the default *Martin 1* encoding.

The SSTV mode may be temporarily switched (via encrypted telecommand) to the lower resolution *Martin 2* encoding.

9 Summary specifications

On-board radios:

Name	Functions	Freq (MHz)	Specs and modes
RX1	Telecommand receiver	undisclosed	AFSK FM 1200 bps AX.25
RX2	Amateur radio rcvr.	145.860	AFSK FM 1200 bps AX.25
BCN	Status beacon	437.280	23 dBm RF output
	Packet acknowledge		CW / Morse code
TXD	Data download	437.575	30 dBm RF output
	Telemetry beacon		AFSK FM, 1200 bps AX.25
	SSTV download		FSK, 1200 bps AX.25
			SSTV Martin 1 / 2
TXS	Payload downlink	2403.000	30 dBm RF output
			GFSK / MSK
			500 kbps maximum

Callsign: `CX1SAT`