X band downlink for CubeSat

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X band downlink for CubeSat
Current situation and perspectives

Existing telemetry systems

- Downlink systems in UHF or S band derived from HAM protocol and equipments
- Allow to download few hundred of Mb to 1.5 Gb per pass

→ Limitation of feasible mission with CubeSats

Interest of high data rate downlink on CubeSat

- Possibility to realize missions which need large dumping capacity
  - Earth Observation
  - Space Spectrum Survey
- Reduce the dumping time for formation flying or constellations

Expected characteristics of high data rate downlink

- Bring significant improvement with existing downlink solutions
- Present good performances with small stations
- Offer interoperability with usual ground segment
- Low cost

X band downlink for CubeSat
System analysis – Sizing parameters

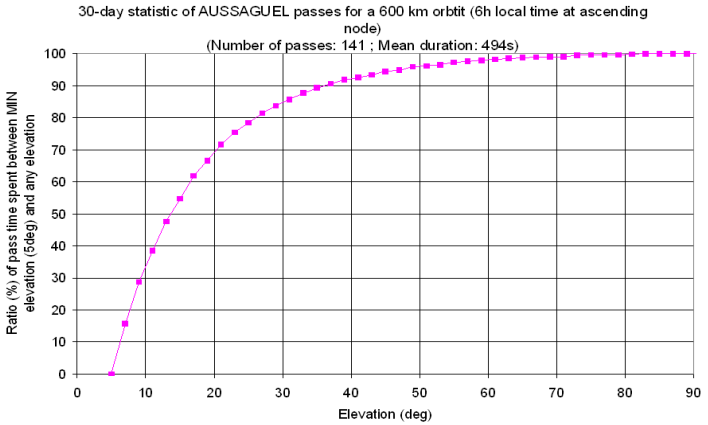
Elements considered for the link budgets

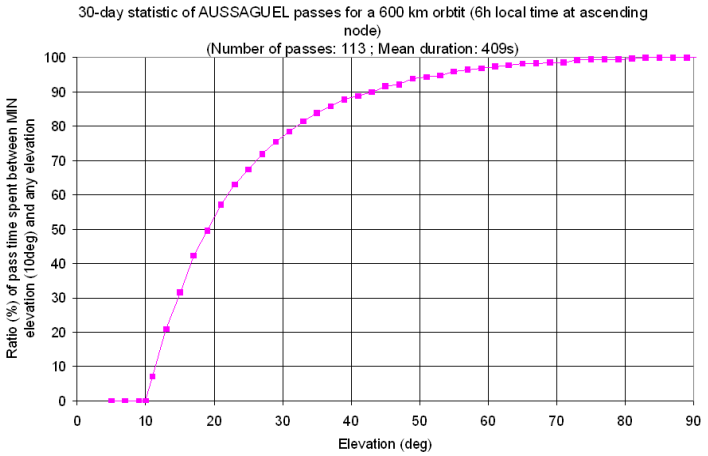
- Satellite EIRP
  - ✦Satellite antenna gain: 0 dBi at +/- 60°
  - ✦Transmitter RF output power: 33 dBm
  - → EIRP: 2 dBW

- Modulation and coding
  - ✦Power efficient standard
  - ✦Compatible with usual ground stations
  - ✦OQPSK with CC 7 ½ + RS 255/223
  - →Eb/No: 2.7 dB for BER< 10^{E}-9

- Ground station
  - ✦G/T: 25 dB/K at 10° elevation with 3.4m antenna
  - ✦G/T: 30 dB/K at 5° elevation with 5 m antenna

- Pass simulations with Aussaguel Station





X band downlink for CubeSat
System analysis - Downloading capacity with CBR

Downlink capacity with Constant Bit Rate mode (CBR)

- Data bit rate constant during pass
- Link budget established at the lowest elevation (5° or 10 °)

Satellite EIRP (dBW)	2	2	2	2
Station size (m)	3,4	3,4	5	5
G/T (dB/K)	25	25	30	30
Station elevation (°)	10	20	5	20
Eb/No for BER<10^-9 (dB)	2,8	2,8	2,8	2,8
Total losses (dB)	5	5	5	5
Margin (dB)	3	6.9	3	8.4
Bitrate (Mbps)	6,9	6,9	14,5	14,5
Data volume/pass (Gb)	2,8	2,8	7,2	7,2

→Important margins at high elevations, but not used

- Comparison with S band (@ 3Mbps)
  - x2.3 with 3.4 m station
  - x4.8 with 5 m station

X band downlink for CubeSat
System analysis - Downloading capacity with VBR

Downlink capacity with Variable Bit Rate mode (VBR)

- Principle of VBR
  - Bit rate commutations between pass
  - Commutations can be operated in time splitting or versus predicted Eb/No
- Transition sequences
  - IDLE sequences during transition time to avoid data losses
  - Time estimation losses: 5% with 3 bit rates (5 s/commutation)
- Downlink capacity with 2 and 3 bit rate commutations in time splitting

Station size (m)	3,4	5	3,4	5
Bitrate 1(Mbps)	6,9	14,5	6,9	14,5
Bitrate 2(Mbps)	15	31	10,9	21
Bitrate 3(Mbps)			25	45
Station elevation commutation 1(°)	10	5	10	5
Station elevation commutation 2(°)	18	14	15	10
Station elevation commutation 3(°)			24	18
Eb/No for BER<10^-9 (dB)	2,8	2,8	2,8	2,8
Means bitrate (Mbps)	11	22,75	14,3	26,8
Data volume/pass (Gb)	4,5	11,2	5,8	13,3

- Data volume comparison between CBR and VBR modes
  - x2.1 with 3.4 m station
  - x1.8 with 5 m station
- Data volume comparison with S band
  - x4.8 with 3.4 m station
  - x8.8 with 5 m station

X band downlink for CubeSat
Transmitter - General description

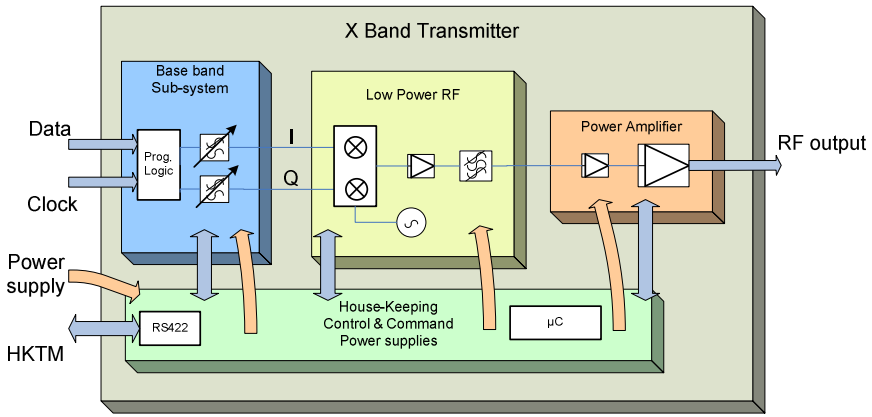
Transmitter specifications

Frequency	8025 to 8400 MHz by 1 MHz step
RF output power	30 to 33 dBm, programmable in flight
TOS	> 15 dB Return loss
Modulation	OQPSK
Filtering	BT 0.5 – 6th order Butterworth
Data rate	2.8 to 50 Mbps, programmable in flight
Coding	Convolutionnal 7 ½
Data/CLK	LVDS, synchronous
Supply voltage	8 to 20 V with no galvanic isolation
DC consumption	< 10W
Volume	< 0.4 l
Mass	< 0,4 kg
Footprint	< 10 *10 cm2
Life time	2 ans
Total radiated dose	5 krad
Operating temperature	-40℃ / +50℃

Transmitter development concept

- COTS used
- PROBA-V X band TX heritage
- Myriade S band RX/TX quality approach

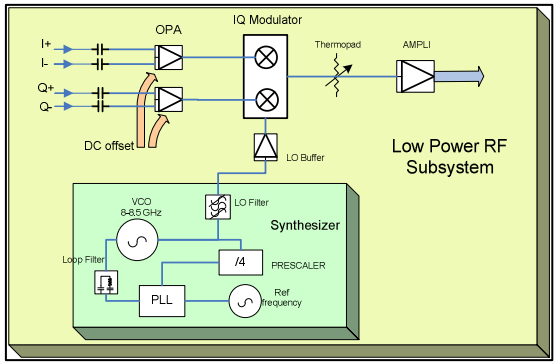
Transmitter general architecture



X band downlink for CubeSat
Transmitter - Base band and low power sections

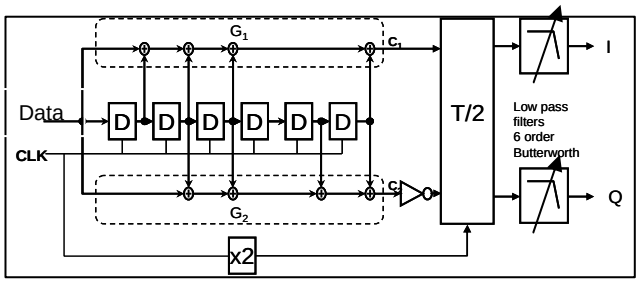
RF low power section

- Homodyne architecture to limit component number
- TCXO selected for size and consumption



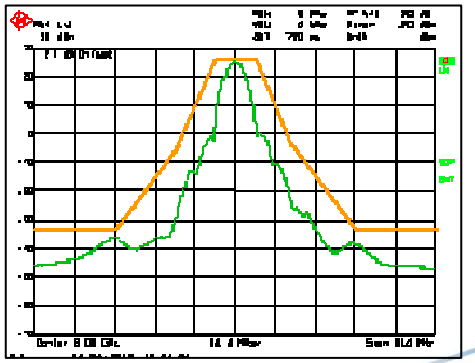
Interface with mass memory

- Digital architecture to facilitate the interface between TX and mass memory
- Framing or R/S operations not performed by TX



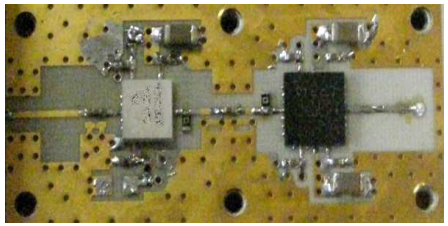
Occupation bandwidth

- Maximum bit rate limited to 50 Mbps to avoid channel filter after PA



X band downlink for CubeSat
Transmitter - Power amplifier

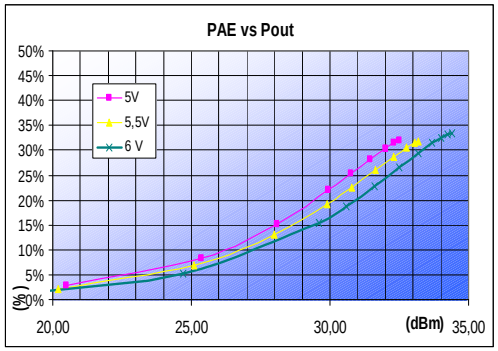
- Key feature because it represents 75% of total transmitter consumption

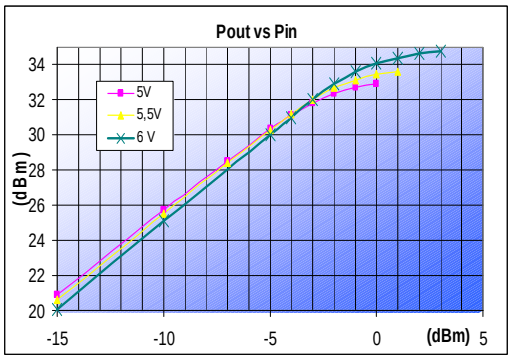


Amplifier size: 45 * 20 mm2

- Selected solution: trade off between efficiency/size

- Complete amplifier (driver + PA) presents more than 30 dB gain with 33 dBm RF output power and 33% PAE



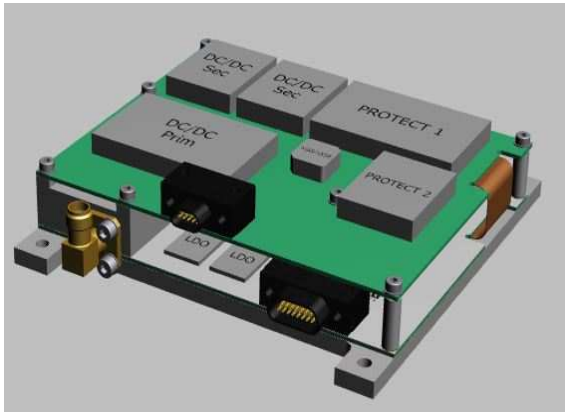


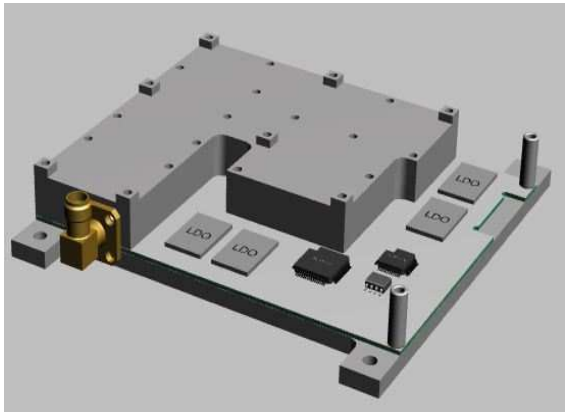
- Total transmitter consumption stays below 10W

	Base band	Low power RF	PA @2W	DC/DC	Total
Consumption	1,1W	1W	6,6W	1W	9.7 W

X band downlink for CubeSat
Transmitter - Mechanical structure

- Constituted by two stacked parts
- Top part contains power supplies functions and protections circuits
- Bottom part includes base band and RF sections, power amplifier and microcontroller
- Shielding limited only to RF sections
- Interconnection with flexible polyamide harness
- Separated connectors for power and data
- Dimensions and mass
  - Without connectors and fastener points: 100 x 80 mm²
  - Complete footprint: 100 x 100 mm²
  - Estimated mass: 300 g





X band downlink for CubeSat
Antenna - Specifications

Antenna requirements

- Small size
- Efficient
- Simple design
- Low cost

→ Isoflux antenna not possible with such requirements

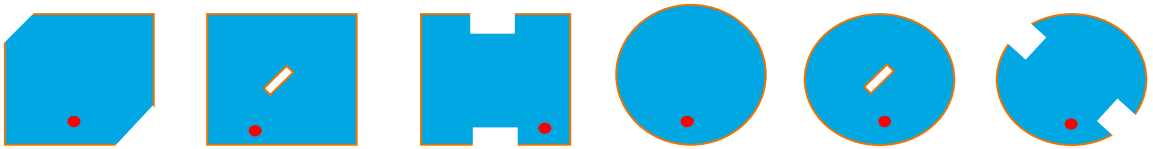
→ Patch antenna seems to be a good compromise

Antenna specification goals

- Frequency: 8.025 – 8.450GHz
- Circular polarization
- Gain > 0dBic with a ER< 3dB over a +/- 60°angle
- Return Loss < -20 dB over a 300MHz bandwidth
- Size as small as possible
- Technology as simple as possible

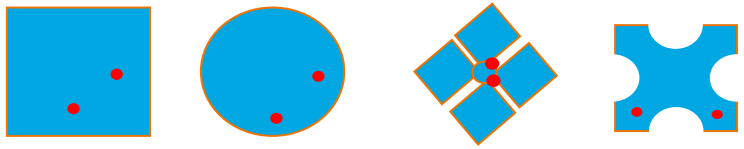
X band downlink for CubeSat
Antenna - Design selection

Patch geometries evaluated but not selected



Mono excitation patches

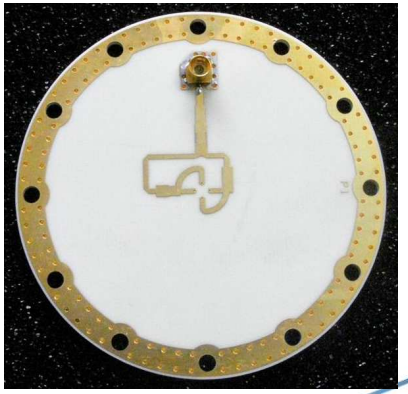
- Narrow pattern and bandwidth
- Poor ellipticity ratio and efficiency



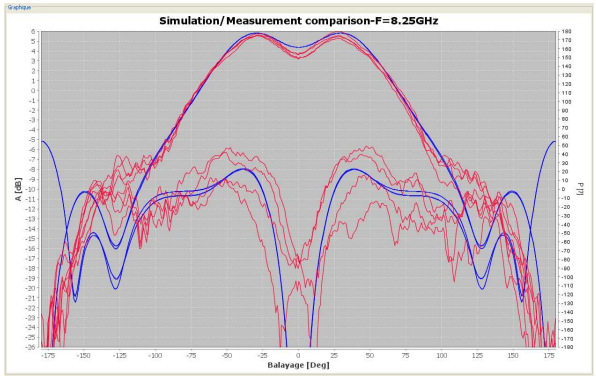
Dual excitation patches

Selected design

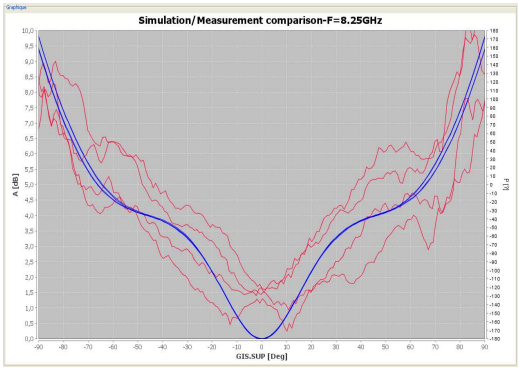
- Circular geometry with 4 excitation points
- Resistor free splitter to maximize efficiency
- Dimensions: 7 cm with internal reflector
- Board: 3 layers Rogers 4003 substrate



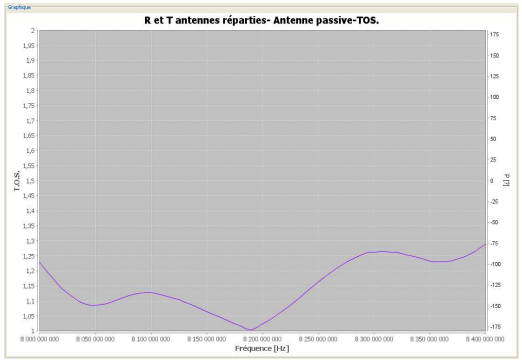
X band downlink for CubeSat
Antenna - Measurement results



Gain

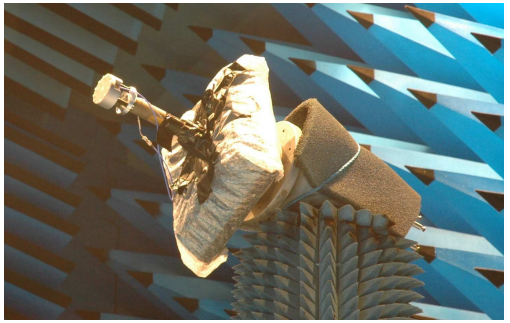


Ellipticity ratio



VSWR

- Despite simple design and technology, good performances achieved, very close to the goals
  - ✦Gain >0dBic over+/- 60°
  - ✦Ellipticity ratio <6dB over +/-60°
  - ✦VSWR < 1.3:1 over 400MHz
  - ✦Efficiency > 80%



- Qualification tests still to be carried out, with particular attention to thermal aspects, but should not be critical with this type of antenna

X band downlink for CubeSat
Conclusion

- System analysis confirms the interest of X band downlink for CubeSat missions with large data volume to dump
- Variable Bit Rate mode allows to download 6 to 14 Gb per pass with simple patch antenna and small stations
- Micro transmitter prototype is currently in pre development to demonstrate feasibility and validate performances
- Simple patch antenna can be used to support X band downlink
- Several CubeSat mission studies in progress could lead soon to the development this high data rate telemetry subsystem
- X band downlink would definitely open new landscapes to future CubeSat missions

Thank you for your attention