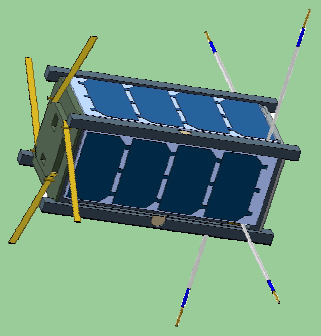
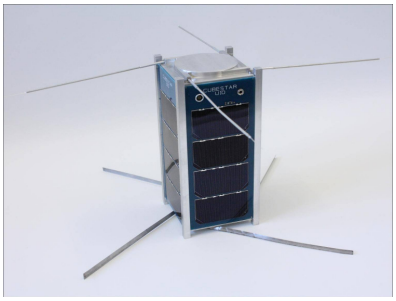
Design of a Prototype Communication System for the CubeSTAR Nano-satellite



Master presentation
by Johan Tresvig
24th Aug. 2010

The CubeSTAR Project

- Student satellite project at the University of Oslo
- Scientific motivation:
  - Demonstrate a new ”Space weather” satellite
- Academic motivation:
  - Recruit students to space science and engineering
- Built by graduate and under-graduate students



Engineering model of the CubeSTAR satellite

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The CubeSTAR Project

- Satellite systems built by students
  - Electronic Power System (EPS)
  - Attitude Determination and Control System (ADCS)
  - Communication system (COMM)
  - On-Board Data and Handling (OBDH)
  - Ground Station (GS)
- Project time frame, 2008-2012/13
- 2nd satellite in the ANSAT program
- CubeSTAR is built after the Cubesat satellite standard

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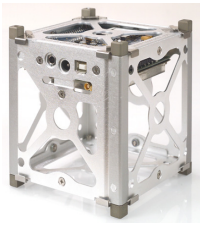
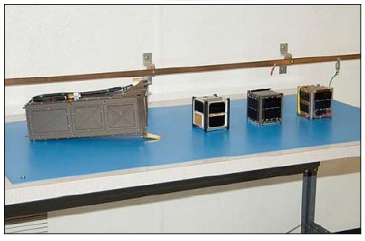
The Cubesat-standard

- Pico-/Nano-satellite size
- Developed by Calpoly and Standford University
- Designed for ”piggy-backing” on commercial satellite launches
- ”1U”
  - Dimensions: 10x10x10cm
  - Weight < 1.33kg
- The CubeSTAR satellite
  - ”2U”
  - 10x10x20cm





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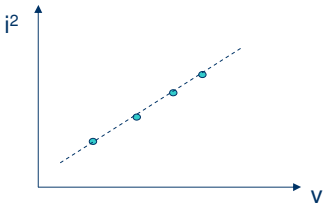
Scientific Experiment

- Space weather
  - Solar storms and "North-light"
  - Impacts the satellite operation
  - Communication and navigation is affected
- Langmuir probes is used to measure electron density
  - Sweep bias probe
  - Fixed bias probe
- Multiple-Needle Langmuir Probes (m-NLP)
  - New concept developed at UiO
  - 4 fixed bias langmuir probes
  - Measure electron density
  - High spatial resolution

Langmuir probe



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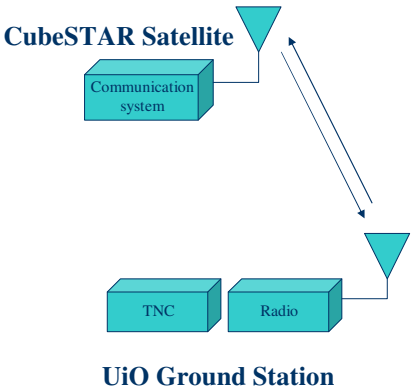
CubeSTAR Communication Group

COMM group is responsible for:

- Ground station
  - De-/encoding equipment
  - Radio
  - Antennas
- Space segment
  - Transceiver system
  - Antenna
- Communication protocol
  - A version of the AX25 packet protocol



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Thesis Goals

- Define the requirments of the CubeSTAR communication system (space segment)
  - Functional
  - Communication
  - Regulations
  - Space environment
- Design and implement the system
- Develop firmware drivers to interface the system with the CubeSTAR communication protocol
- Discuss and identify an antenna solution for the CubeSTAR satellite

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Functional Requirements

- Data link
  - **Uplink**, transmit commands from the ground station to the satellite
  - **Downlink**, transmit telemetry and housekeeping data from the satellite to the ground station
- Tracking signal
  - **Beacon**, transmit a tracking signal containg housekeeping data
  - Help the ground station team to locate the satellite
  - Transmit satellite status in the event that the data link can not be established

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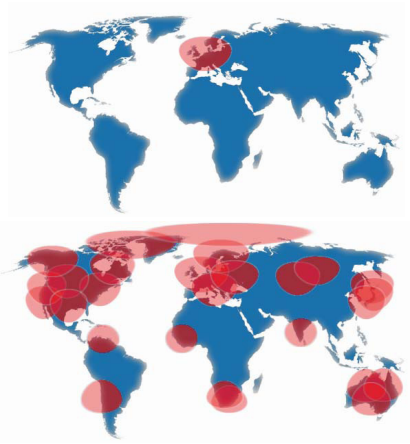
The Global Educational Network for Satellite Operations (GENSO)

- A software standard designed to connect ground stations and satellites of educational space missions
- Allows for teams to operate amateur satellite ground stations through the internet
- Designed for the amateur and academic community
- The CubeSTAR ground station is designed after the GENSO reference ground station



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Communication Scheme

- GENSO has recommended frequency bands:
  - Amateur satellite bands, greatly simplifies the application process for frequency band
  - VHF, UHF, S-band
- and radio configurations:
  - 9600bps / Gaussian Frequency Shift Keying (FSK) modulation scheme
  - 1200bps / Audio Frequency Shift Keying (AFSK) modulation scheme
  - Neither was applicable due to bandwidth and technical constraints

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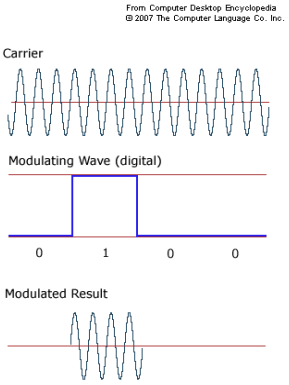
Radio configuration

- Frequency band
  - 434.8-438MHz
  - Amateur satellite band
- Data link
  - 4800 bps
  - Frequency Shift Keying
  - Gaussian filtering
- Beacon
  - Morse code, a common communication protocol, no decoding equipment is required
  - On-Off Keying (OOK) / Continious Wave (CW)
  - requires less output power
  - 10-15 Words per Minute (WPM)



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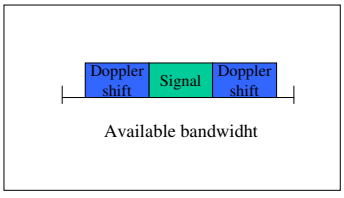
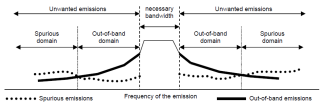
Inter-/National Regulations

- Internation Telecommunication Union (ITU)
  - Makes recommendations to regional and national regulatory bodies
- Norwegian Post and Telecommunication Agency (NPT)
  - amateur satellite frequencies
  - available bandwidth
- International Amateur Radio union (IARU)
  - responsible for coordination of amateur satellite frequencies





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Space Environment

- Radiation
  - Total Ionization Dose, performance degradation caused by accumulated radiation dose
  - Singel Event Upset, software corruption caused by a a high energy particle
  - Single Event Latchup, electric shortcut caused by a high energy particle
- Vacuum
  - Outgassing
  - Deformation
- Temperature
  - Operating temperature
  - $\div 40\,^{o}C \rightarrow \div 30\,^{o}C \leq T \leq 40\,^{o}C \rightarrow 85\,^{o}C$

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Link Budget

- Used to evaluate a wireless communication link given parameters like:
  - Transmitted power
  - Frequency
  - Bandwidth
  - Path loss
  - Modulation
- A budget for gain and attenuation of a radio signal
- Signal-to-Noise Ratio (SNR)
- Bit Error Rate (BER)
- Link margin, an error margin to account for unexpected attenuation in the link

$$S/N\,[dB] = \underbrace{(P_{tx} + G_t - L_{Path} - L_{atm} + G_r)}_{Signal} - \underbrace{(k_{Boltzmann} + T_{Noise} + Bandwidth)}_{Noise}$$

$$S/N - S/N_{req} = \text{Link margin} \geq 10 - 12dB$$

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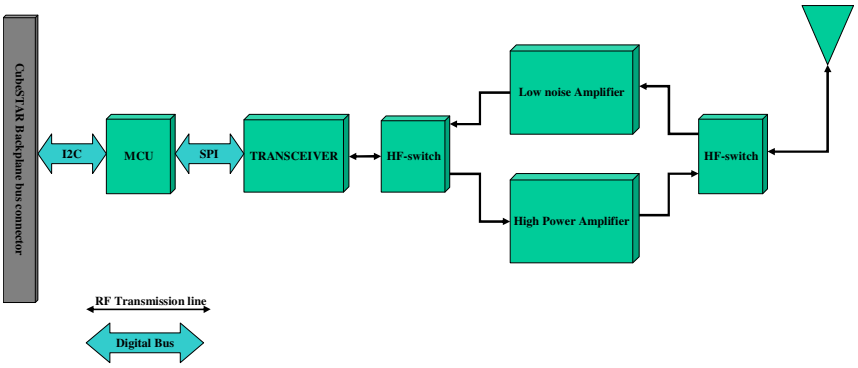
System Design



The CubeSTAR communication system

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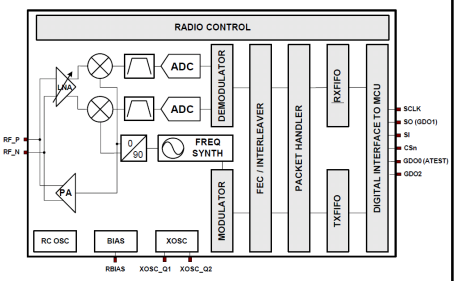
Transceiver Chip

- TI CC1101 Sub-1GHz transceiver chip
- Frequency band: 387-464MHz
- Modulation schemes
  - Frequency Shift Keying (FSK)
  - On-Off Keying (OOK)
  - Minimum Shift Keying (MSK)
- Operational mode
  - Serial mode
  - Packet handling mode



TI CC1101 transceiver chip

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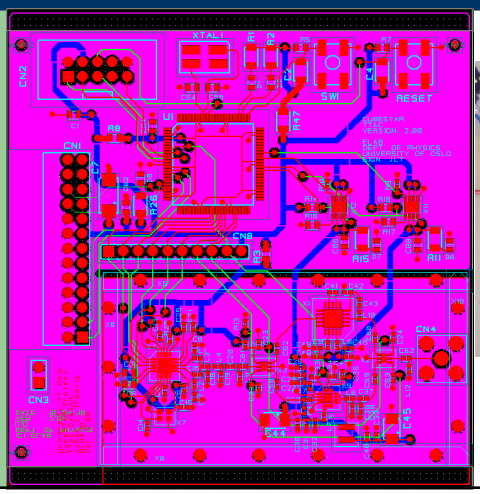
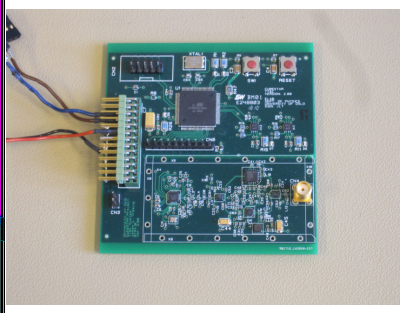
PCB





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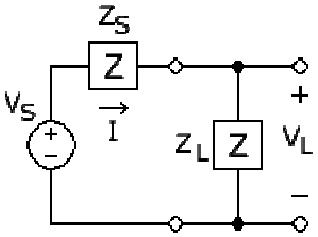
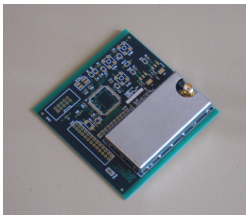
RF Design Methods

- Optimal power transfer
- Characteristic impedance,
  - (50 +/- j0) ohm
- 2-port network
- Shielding to protect RF circuit from external EMI and reduce EMI emmisions





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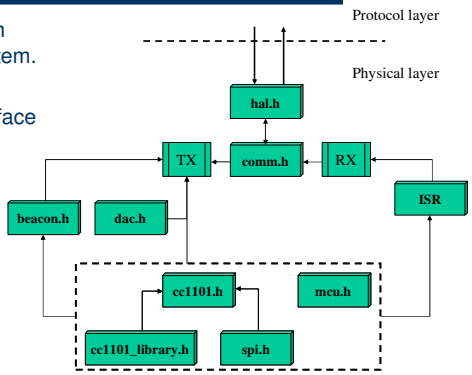
Hardware Abstraction Layer (HAL)

- HAL package is a library of system drivers for the communication system.
- Used by the protocol layer to interface with the hardware
- Interface
  - Send_packet(type, buffer, nr_bytes)
  - New_command
  - Command_buffer



The HAL architecture

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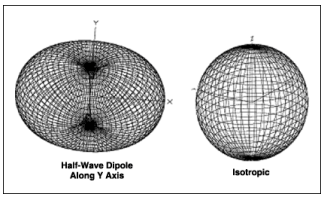
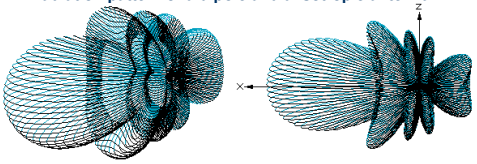
Antenna Considerations

- Omni-directional vs directional
- Polarization
- Simple mechanical design
- Small size
- 2 alternatives
  - Dipole antenna
  - Turnstile antenna



Radiation pattern of a dipole and a isotropic antenna



Linear, circular and elliptical polarized vawes

Radiation pattern of a Yagi antenna

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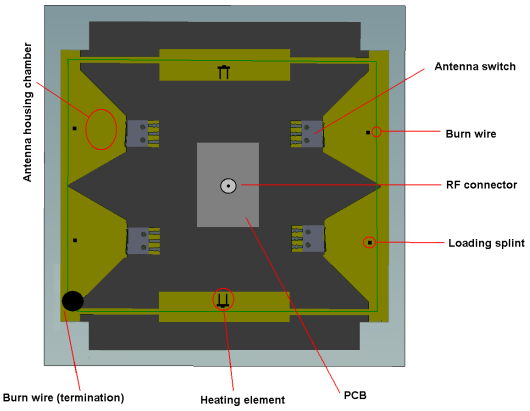
Antenna
- two alternatives

ISIS Turnstile Antenna
- Configurable
  - 2 dipol
  - Turnstile
- Tested
- Aquired

UiO produced antenna
- Configurable
  - 2 dipol
  - Turnstile
- Gain knowledge of antenna design
- Produce papers



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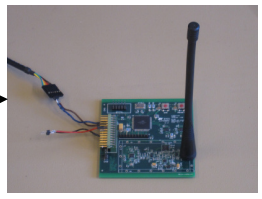
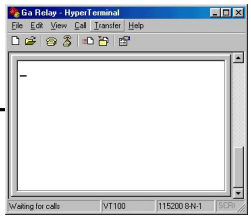
Test of Downlink and Beacon

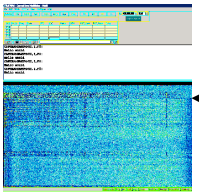


CubeSTAR transceiver

Ground station radio



Control and debug equipment



MixW Software TNC

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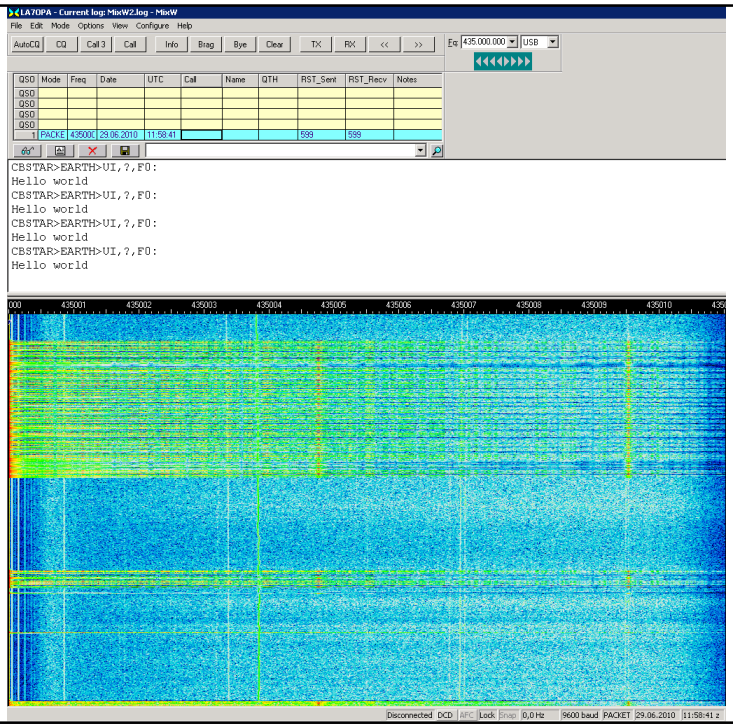

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CUBESTAR

Remaining work

- Firmware development
  - The data link must be able to handle packets longer than 64 byte
  - Develop an I2C driver for the internal CubeSTAR bus
  - Integrate the HAL driver into the protocol layer
- Testing
  - RF testing using network and spectrum analyser
  - EMC testing and antenna integration using an anachoic chamber (is external bandpass filter needed?)

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Recommendations

- Consider the current modulation scheme against other modulation schemes with a higher spectral efficency (bps/Hz)
- Operational redundancy, to increase the chance of mission success
  - An extra transceiver system for redundancy
  - Mitigate antenna problems and electrical malfunction
- Adaptive radio
  - Range between satellite and ground station may vary between from 600km to 1900km
  - Current link budget assumes max distance 1900 km
  - The transmitter output power may be reduced as the distance between satellite and ground station closes and conserve power
  - Important to maintain a constant S/N

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Conclusion

- Identified the key requirments for a CubeSTAR communication system
- Analysed the link through a link budget and verified that the link closes
- Designed and implemented a prototype system
- Transmitted an AX25 data packet from the communication system to the ground station
- Transmitted a beacon from the communication system
- Remaining work:
  - Consider using a more spectral efficent modulation scheme to increase the data throughput
  - Verify through testing that the system upholds the current EMC regulations and if not modify the design
  - Integrate the HAL driver into the protocol layer

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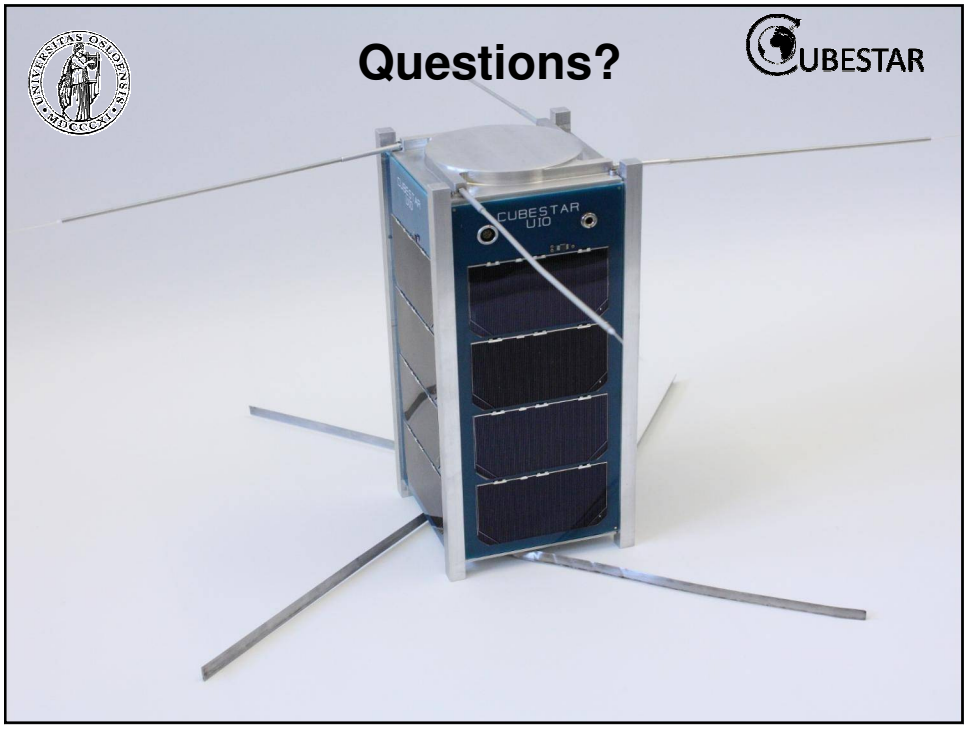
Questions?
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