An SDR-Based Architecture Ground Station for Small Satellite Tracking

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Outline

- Background
- Motivation and objective
- Conventional ground station
- Ground station with software defined radio
- Implementation
- NLS4 Tracking Results
- Conclusion
Recently, small satellites and constellations are developed for earth observation or communication network.

As many small satellites will be released in a piggy-back launch, the closeness in spatial and spectral separation between different small satellites may render problems for ground stations in satellite tracking, especially in the early orbit phase.
### Satellite frequency list in 435~438MHz:

<table>
<thead>
<tr>
<th>Sat</th>
<th>Frequency</th>
<th>Sat</th>
<th>Frequency</th>
<th>Sat</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO-51</td>
<td>435.1500 MHz</td>
<td>AO-16</td>
<td>437.0260MHz</td>
<td>CO-55</td>
<td>437.4000 MHz</td>
</tr>
<tr>
<td>CAPE1</td>
<td>435.2450 MHz</td>
<td>AO-16</td>
<td>437.0510MHz</td>
<td>Libertad-1</td>
<td>437.4050 MHz</td>
</tr>
<tr>
<td>AO-51</td>
<td>435.3000 MHz</td>
<td>GeneSat-1</td>
<td>437.0750 MHz</td>
<td>HO-59</td>
<td>437.4250 MHz</td>
</tr>
<tr>
<td>RS-22</td>
<td>435.3520 MHz</td>
<td>LO-19</td>
<td>437.1250 MHz</td>
<td>XI-V</td>
<td>437.4650 MHz</td>
</tr>
<tr>
<td>FO-29</td>
<td>435.7950 MHz</td>
<td>SSETI-1</td>
<td>437.2500 MHz</td>
<td>CO-57</td>
<td>437.4900 MHz</td>
</tr>
<tr>
<td>AO-27</td>
<td>436.7950 MHz</td>
<td>HO-59</td>
<td>437.2750 MHz</td>
<td>UWE-1</td>
<td>437.5050 MHz</td>
</tr>
<tr>
<td>SO-50</td>
<td>436.7950 MHz</td>
<td>NCUBE-2</td>
<td>437.3050 MHz</td>
<td>CO-52</td>
<td>437.5050 MHz</td>
</tr>
<tr>
<td>CO-55</td>
<td>436.8375 MHz</td>
<td>CP4</td>
<td>437.3250 MHz</td>
<td>SO-33</td>
<td>437.9100 MHz</td>
</tr>
<tr>
<td>CP3</td>
<td>436.8450 MHz</td>
<td>XI-V</td>
<td>437.3450 MHz</td>
<td>AAUSat-II</td>
<td>437.4250 MHz</td>
</tr>
<tr>
<td>CO-57</td>
<td>436.8475 MHz</td>
<td>CO-56</td>
<td>437.3850 MHz</td>
<td>COMPASS-1</td>
<td>437.2750 MHz</td>
</tr>
<tr>
<td>Cute-1.7+APDII</td>
<td>437.3850 MHz</td>
<td>SEEDS</td>
<td>437.4850 MHz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example:
CAPE-1, CP3, CP4 and AeroCube-2 were launched on April 17th, 2007.

The picture of CP4 taken by AeroCube-2 on April 17th, 2007

Positions of CAPE 1, CP3, CP4 and AeroCube-2 on May 17th, 2007
Motivation and Objective

- In the early orbit phase, all small satellites are close for several days, even one month. All satellite developers are eager to assess the status of satellites as early as possible.
- The problems (for a ground station to track multiple satellites) are
  - How to receive all the satellite signals simultaneously?
    → Wide band and multi-channel
  - How to improve BER?
    → Interference cancellation
Conventional Ground Station

➢ Architecture
  – Antennas, Amateur radio, TNC modem, PC.
Comparison

Conventional GS

User → PC → TNC → Transceiver → RF Front End → Antenna

GS with SDR

User → PC → A/D converter → Filter → Antenna → RF Front End
GS with SDR Architecture

- Architecture
  - Antennas, RF front end, A/D converter, PC

Software based
Down Conversion

- Use band pass sampling to down-convert the signal.
- Need filter to prevent from aliasing

\[
F_{IF} = \begin{cases} 
\text{rem}(F_{RF}, F_S), & \text{if } \text{fix}\left(F_{RF}, \frac{F_S}{2}\right) \text{ is even.} \\
F_S - \text{rem}(F_{RF}, F_S), & \text{if } \text{fix}\left(F_{RF}, \frac{F_S}{2}\right) \text{ is odd.}
\end{cases}
\]

- \(F_{IF}\) : Intermediate frequency
- \(F_{RF}\) : Radio frequency
- \(F_S\) : Sampling frequency
Fs Selection

- Consideration: linearity (folded area), frequency resolution and available Fs.
Because of Doppler shift, the received frequency is not fixed.

By Short-Time FFT, frequency information varying with time can be estimated.

The frequency information will be transmitted to the dynamic filter and Doppler shift calculator.

\[
Frequency\ resolution = \frac{F_S}{N} = \frac{6\text{MHz}}{N} \leq 0.5\text{kHz} \quad (N = 2^{14} = 16384)
\]

\[
Time\ resolution = N \times T_s = \frac{16384}{6M} = 2.7307\ ms
\]
Co-Channel Interference

- For separating multiple signals in the same frequency band, co-channel interference (CCI) cancellation methods are developed.

- For general ground stations, SAIC (Single Antenna Interference Cancellation) is suitable.

- Furthermore, MIMO (Multi-Input Multi-Output) can be implemented at ground stations with multi-antenna.
Several SAIC methods are proposed:
- Cross-coupled phase-locked loop (CCPLL)
- Phase-tracking circuit (PTC)
- Joint Viterbi estimation based on the maximum likelihood estimation (JMLSE)

The CCPLL and PTC methods typically outperform the JMLSE when the modulation parameters are dissimilar. Good performance for the PTC requires both dissimilar parameters and a prior knowledge of the co-channel signal amplitudes.

JMLSE provides for a more robust estimation of the co-channel signals.
The receiver consists of ADLink PXI-3710 system controller and ADLink PXI-9820 A/D converter.

Features:
- 14-bit A/D resolution
- Up to 60MS/s
- 3dB bandwidth : about 30MHz

Receiver function blocks are built in MATLAB/Simulink
SDR Implementation (2/4)

IC-910H U/V Band Transceiver

AG-25 LNA
AG-35 LNA

Power Splitter

DC-Block
PA

PXI-3710 with PXI-9820 A/D converter

DC 12.35V
VHF Band Channel
UHF Band Channel
Receiver block diagram
- PXI-3710 has several interfaces to connect with ground station devices.
- The SDR and conventional transceivers can be combined in PXI-3710 with ‘MATLAB ActiveX’ component in Visual Basic.
- Transceiver calls the frequency information in MATLAB workspace and gets the RF frequency.

\[
F_{IF} \downarrow \Rightarrow F_{RF} = 144MHz + F_{IF} \quad (VHF)
\]

\[
F_{IF} \uparrow \Rightarrow F_{RF} = 438MHz - F_{IF} \quad (UHF)
\]
NLS4

- **NLS4**: Nanosatellite Launch Service 4
- **Launch date**: April 28th, 2008
- **Launch vehicle**: Antrix Polar Satellite Launch Vehicle (PLSV-C9)
- **Satellites onboard**: AAUsat-2 (Denmark), CanX-2 (Canada), Cute-1.7+APD II (Japan), COMPASS-1 (Germany), Delfi-C3 (Netherlands), SEEDS (Japan)
- **Inclination**: 98 degree
- **Altitude**: 630 km
Result of VHF Band Receiving

Perhaps NOAA-15

Delfi-C3
Result of UHF Band Receiving (1/2)

- Sampling Frequency: 6MHz
Result of UHF Band Receiving (2/2)

- Sampling Frequency: 0.5MHz

- Unknown
- CUTE 1.7+APD II
- AAUSat II
- Compass-1
Compass-1 CW Signal Decoding
Decoding Result

- After decoding the filtered IF signal in Morse code format, we got some results:

- **Compass-1:**
  
  ?mpass29000000?00000001602c?1508

- **Cute1.7+APDII:**
  
  cute 87 c6 a? a? 48 17 cute 8????8624 ????12 1
Conclusion

- We have proposed a method to improve ground station capability with software defined radio.
- The benefit provided by the SDR receiver are:
  1. Multi-channel
  2. Wide frequency range
  3. CCI cancellation
  4. More accurate Doppler shift information
- In May 2008, the proposed SDR receiver has already received simultaneously several signals from cubesats launched by NLS4.
Thanks for your attention!