An SDR-Based Architecture Ground Station for Small Satellite Tracking

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Outline

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- Motivation and objective
- Conventional ground station
- Ground station with software defined radio
- Implementation
- NLS4 Tracking Results
- Conclusion

Background

- 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.

Spectral Problem

- Satellite frequency list in 435~438MHz:

Sat	Frequency	Sat	Frequency	Sat	Frequency
AO-51	435.1500 MHz	AO-16	437.0260MHz	CO-55	437.4000 MHz
CAPE1	435.2450 MHz	AO-16	437.0510MHz	Libertad-1	437.4050 MHz
AO-51	435.3000 MHz	GeneSat-1	437.0750 MHz	HO-59	437.4250 MHz
RS-22	435.3520 MHz	LO-19	437.1250 MHz	XI-V	437.4650 MHz
FO-29	435.7950 MHz	SSETI-1	437.2500 MHz	CO-57	437.4900 MHz
AO-27	436.7950 MHz	HO-59	437.2750 MHz	UWE-1	437.5050 MHz
SO-50	436.7950 MHz	NCUBE-2	437.3050 MHz	CO-52	437.5050 MHz
CO-55	436.8375 MHz	CP4	437.3250 MHz	SO-33	437.9100 MHz
CP3	436.8450 MHz	XI-V	437.3450 MHz	AAUSat-II	437.4250 MHz
CO-57	436.8475 MHz	CO-56	437.3850 MHz	COMPASS-1	437.2750 MHz
Cute-1.7+APDII	437.3850 MHz	SEEDS	437.4850 MHz		

Spatial Problem

- 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

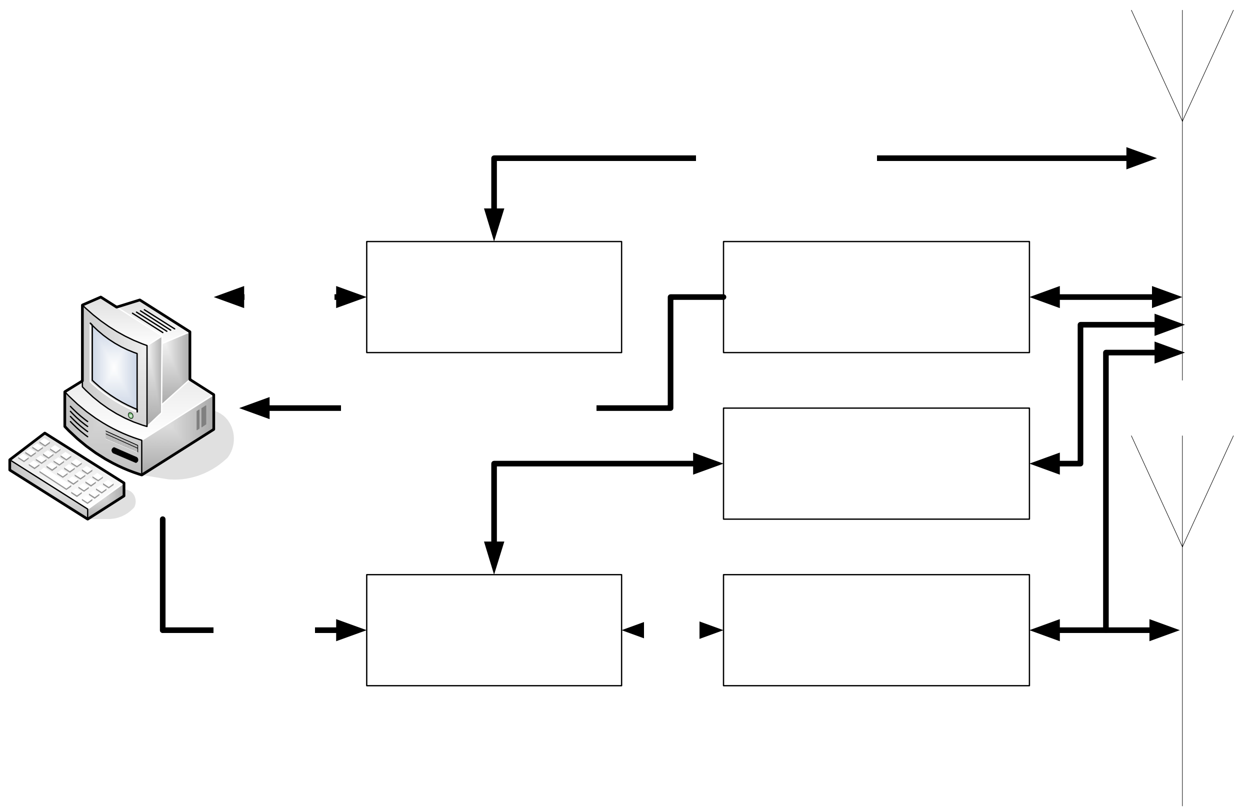
- In the early orbit phase, all small satellites are close for several days, even one month. All satellite developers are eager to assess the status of satellites as early as possible.
- The problems (for a ground station to track multiple satellites) are
  - How to receive all the satellite signals simultaneously?

    → Wide band and multi-channel
  - How to improve BER?

    → Interference cancellation

Conventional Ground Station

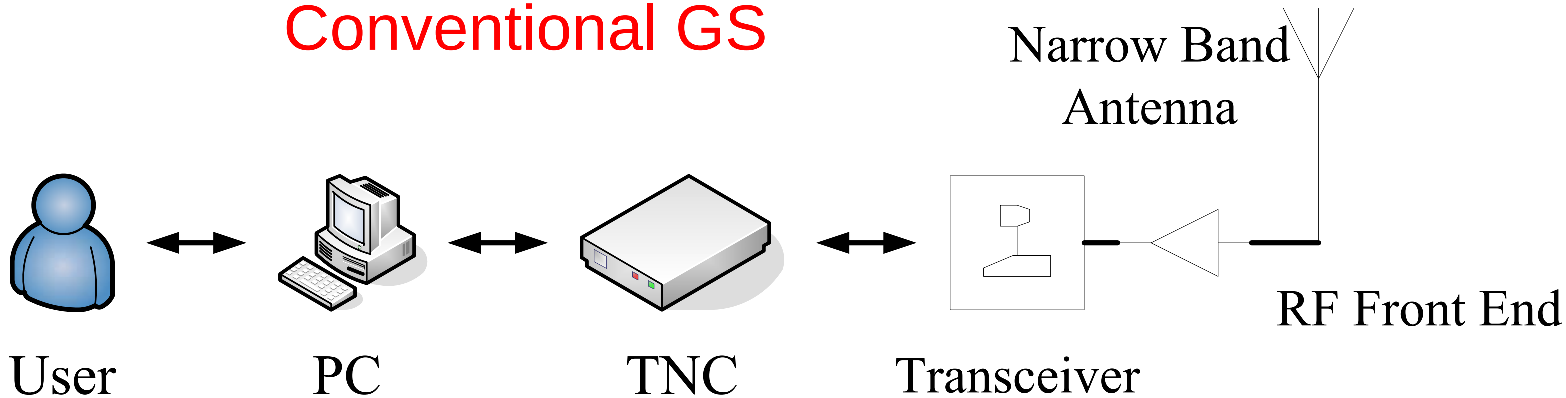
- Architecture
  - – Antennas, Amateur radio, TNC modem, PC.



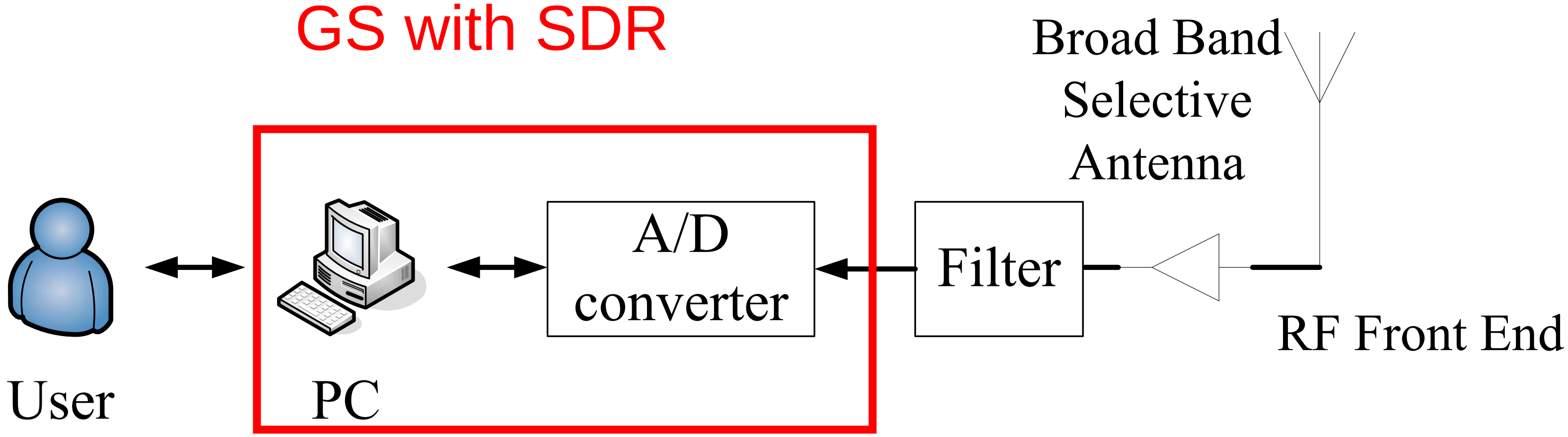
Ante

Comparison

Conventional GS

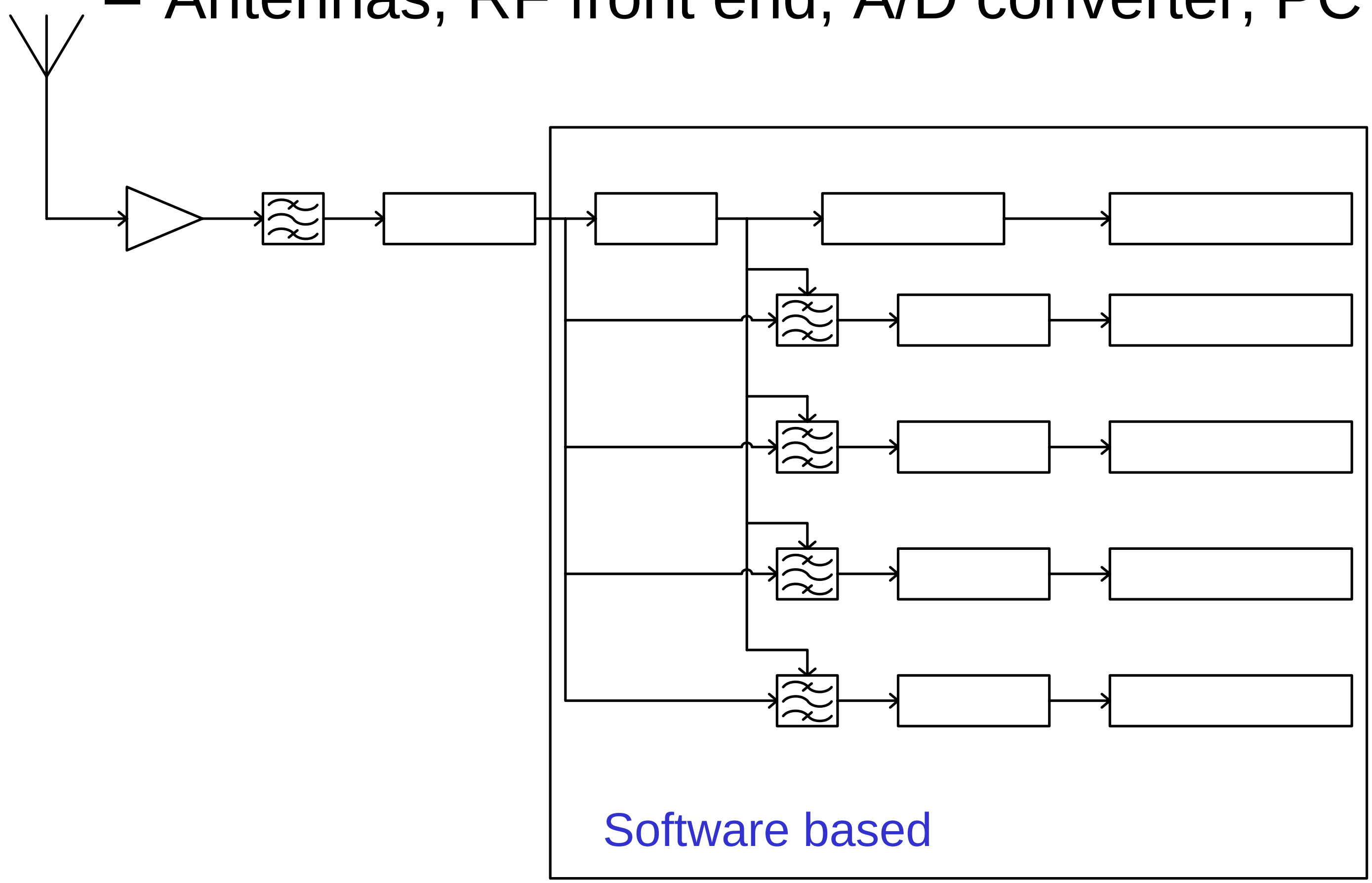


GS with SDR



GS with SDR Architecture

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



A/D
Converter

STFFT

LNA

Filt

Down Conversion

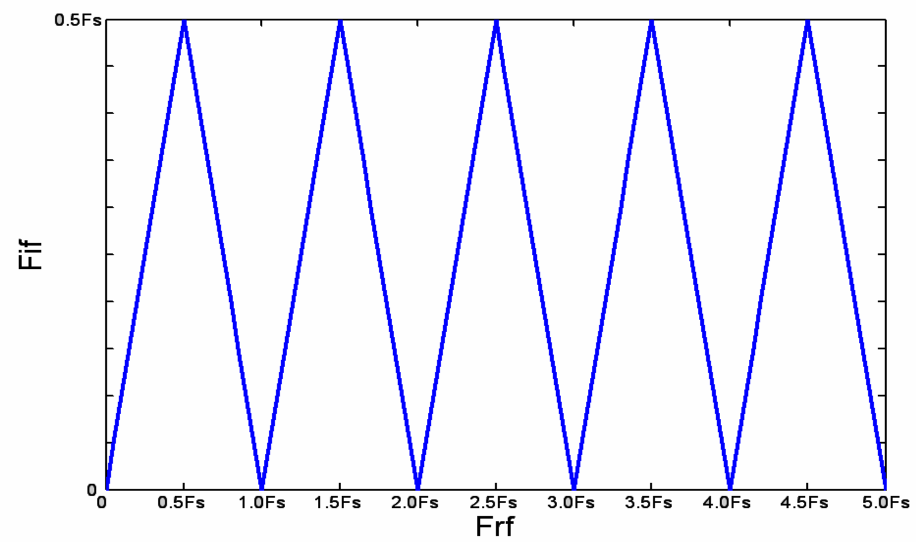
- Use band pass sampling to down-convert the signal.
- Need filter to prevent from aliasing

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

F_{IF} : *Intermediate frequency*

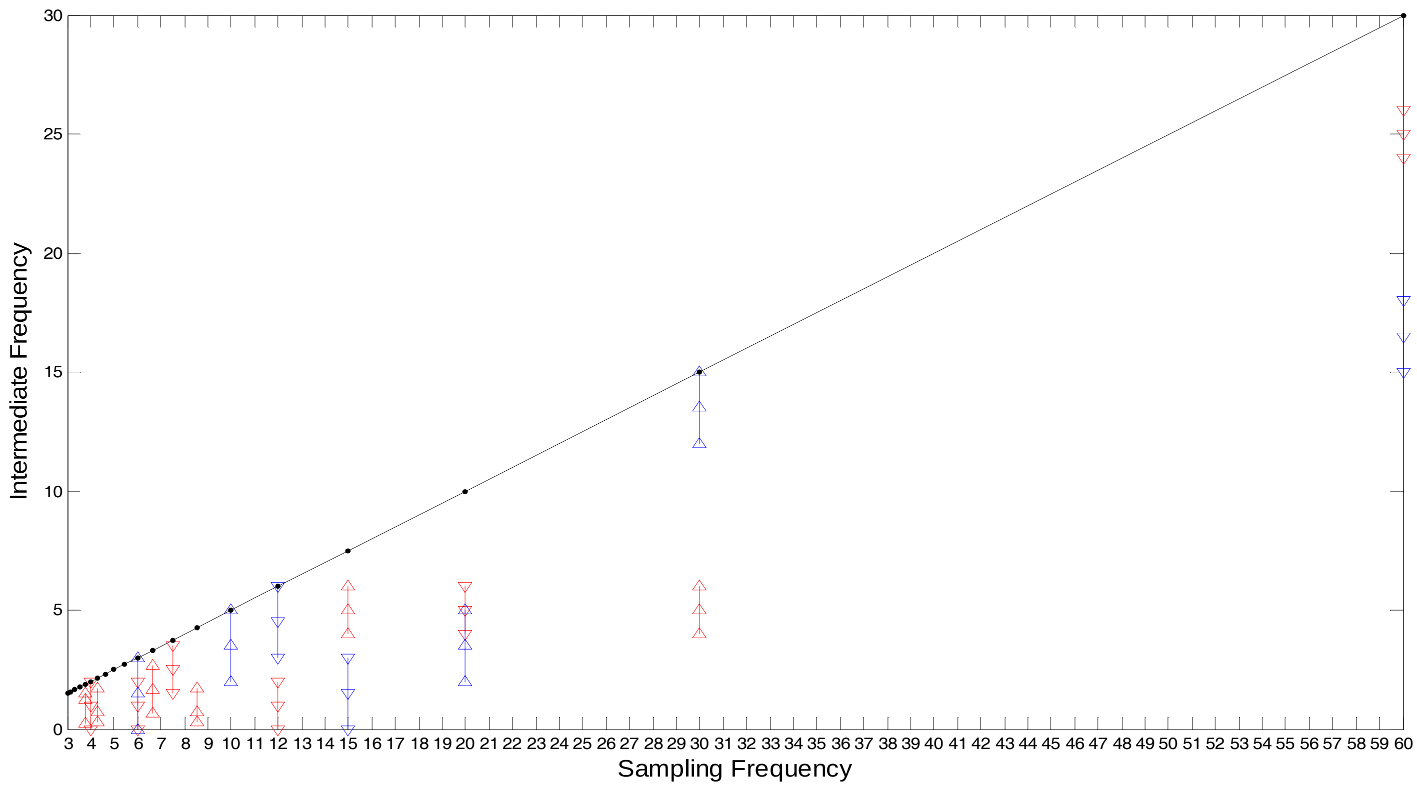
F_{RF} : *Radio frequency*

F_S : *Sampling frequency*



Fs Selection

- Consideration: linearity (folded area), frequency resolution and available Fs.



Frequency Estimation

- 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.

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

$$Time\ resolution = N \times T_s = \frac{16384}{6M} = 2.7307\ ms$$

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.

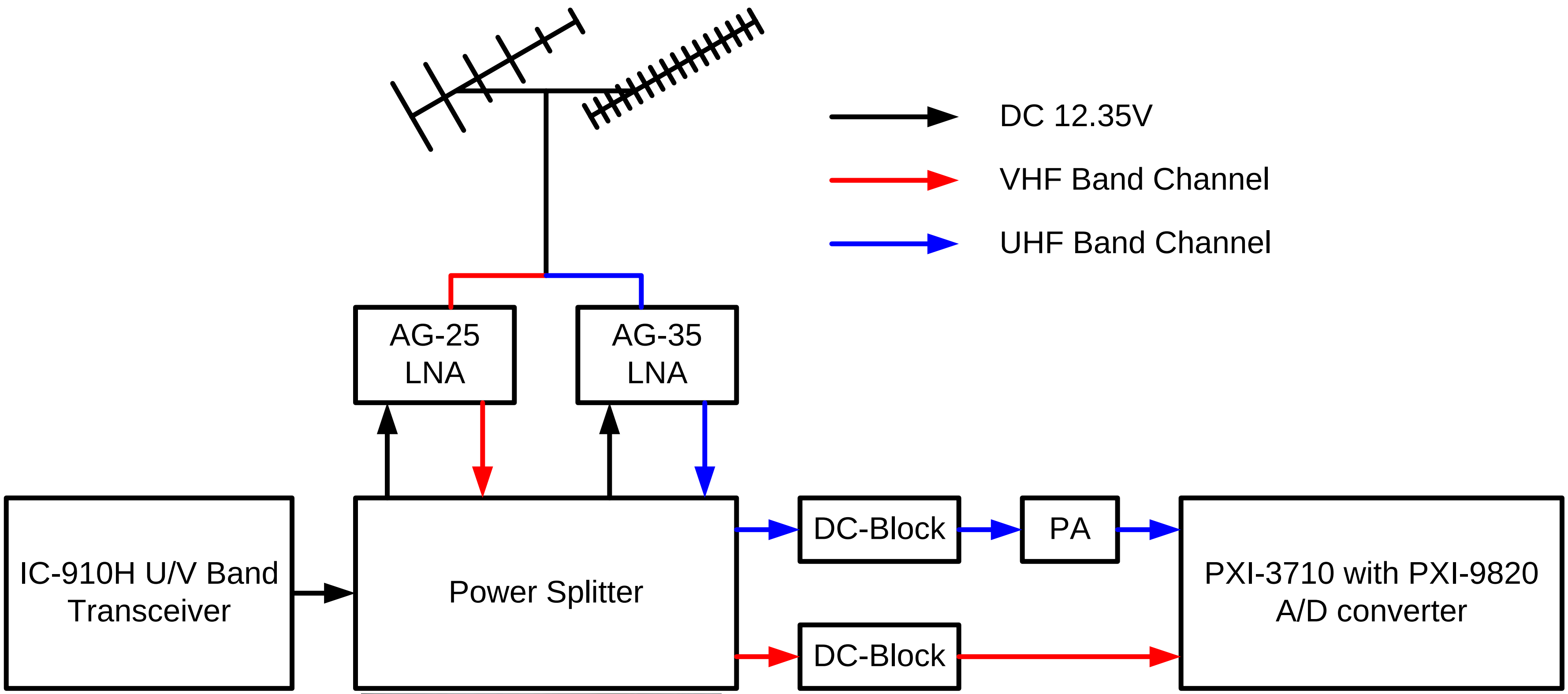
CCI Cancellation

- 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.

SDR Implementation(1/4)

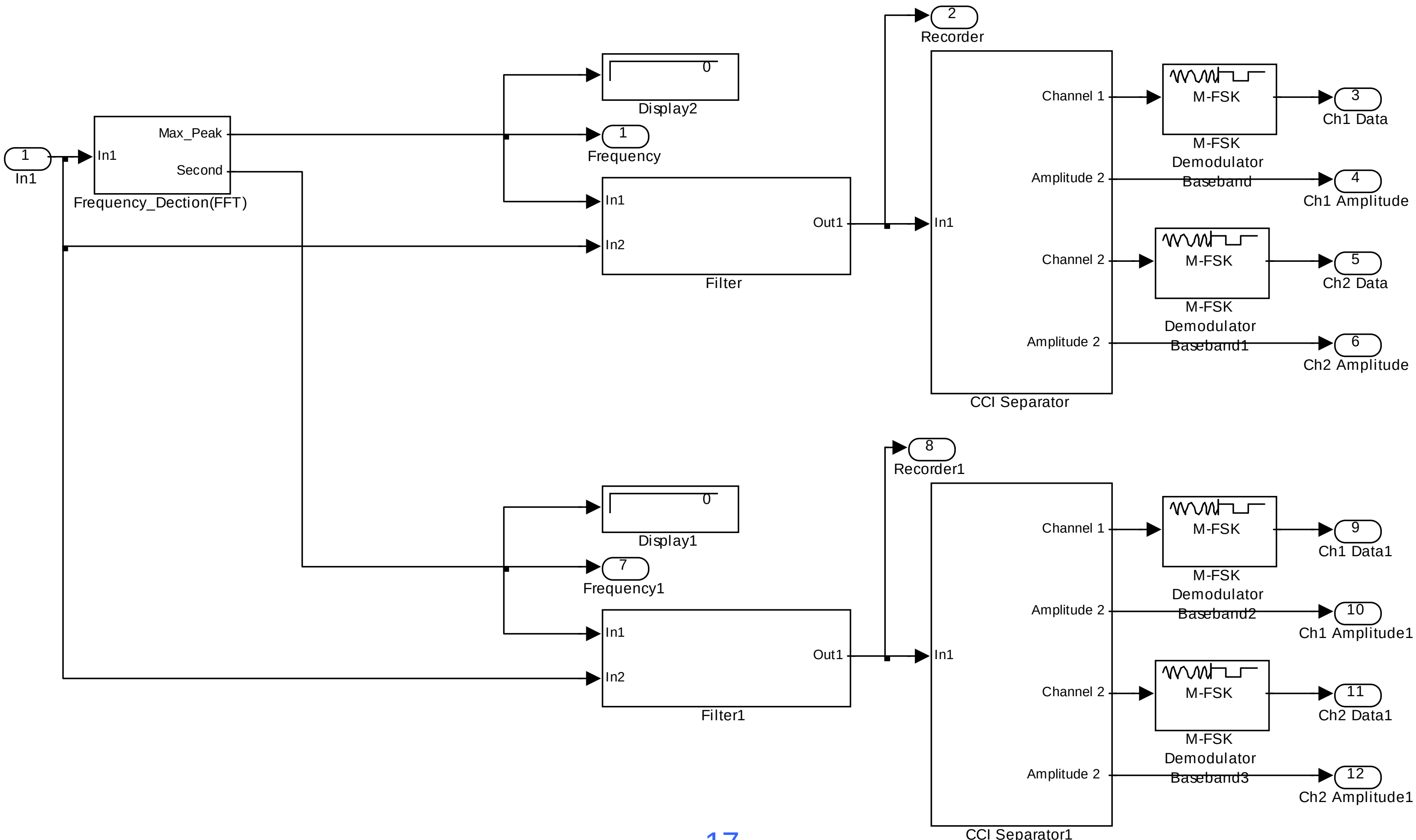
- The receiver consists of ADLink PXI-3710 system controller and ADLink PXI-9820 A/D converter.
- Features:
  - 14-bit A/D resolution
  - Up to 60MS/s
  - 3dB bandwidth : about 30MHz
- Receiver function blocks are built in MATLAB/Simulink

SDR Implementation(2/4)



SDR Implementation(3/4)

- Receiver block diagram



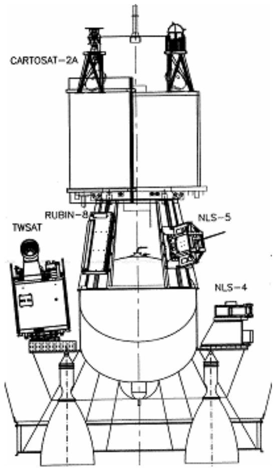
SDR Implementation(4/4)

- PXI-3710 has several interface 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 get the RF frequency.

$$F_{IF}\downarrow \;\Rightarrow\; F_{RF} = 144MHz + F_{IF}\;\;(VHF)$$

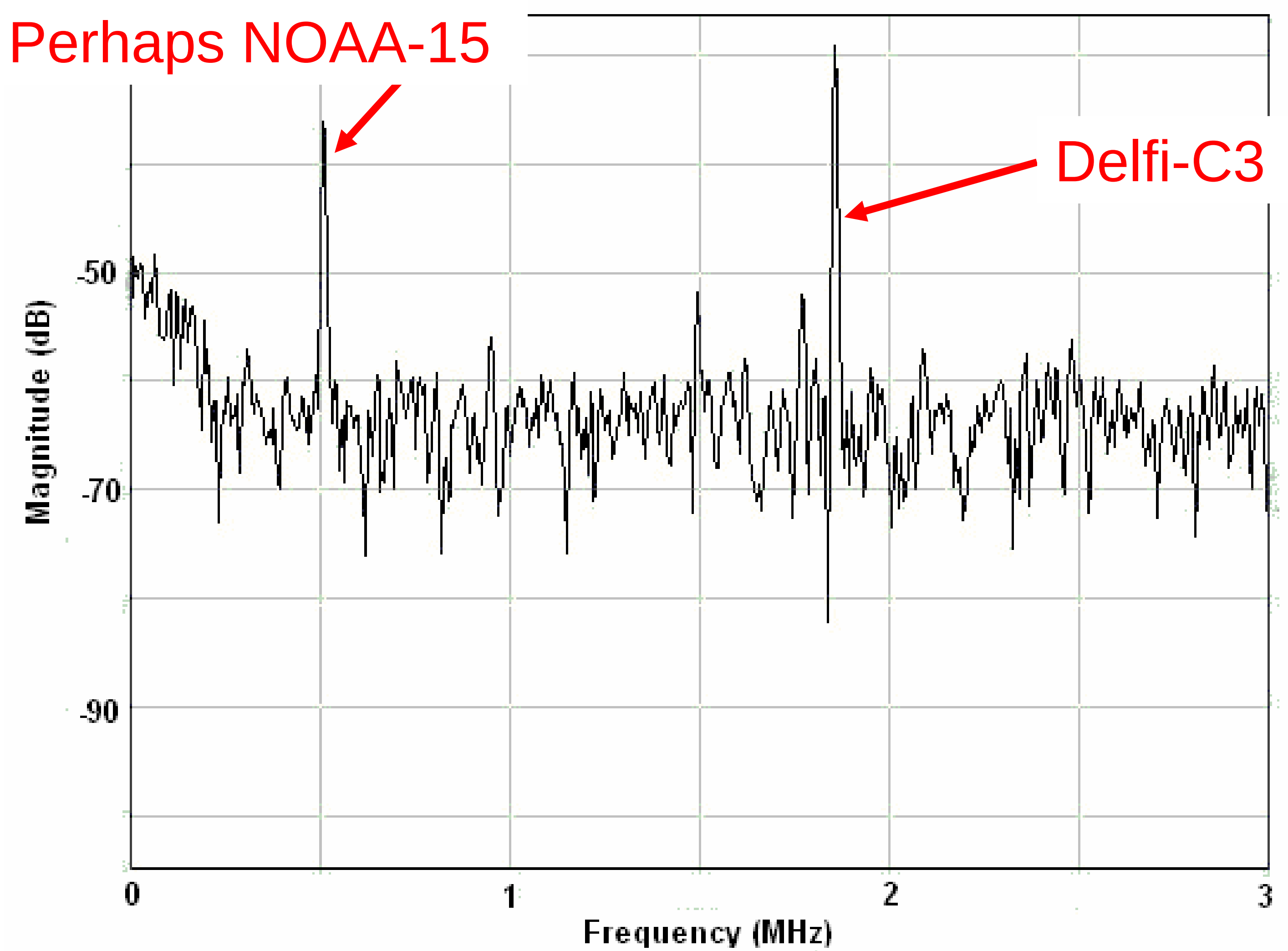
$$F_{IF}\uparrow \;\Rightarrow\; F_{RF} = 438MHz - F_{IF}\;\;(UHF)$$

NLS4



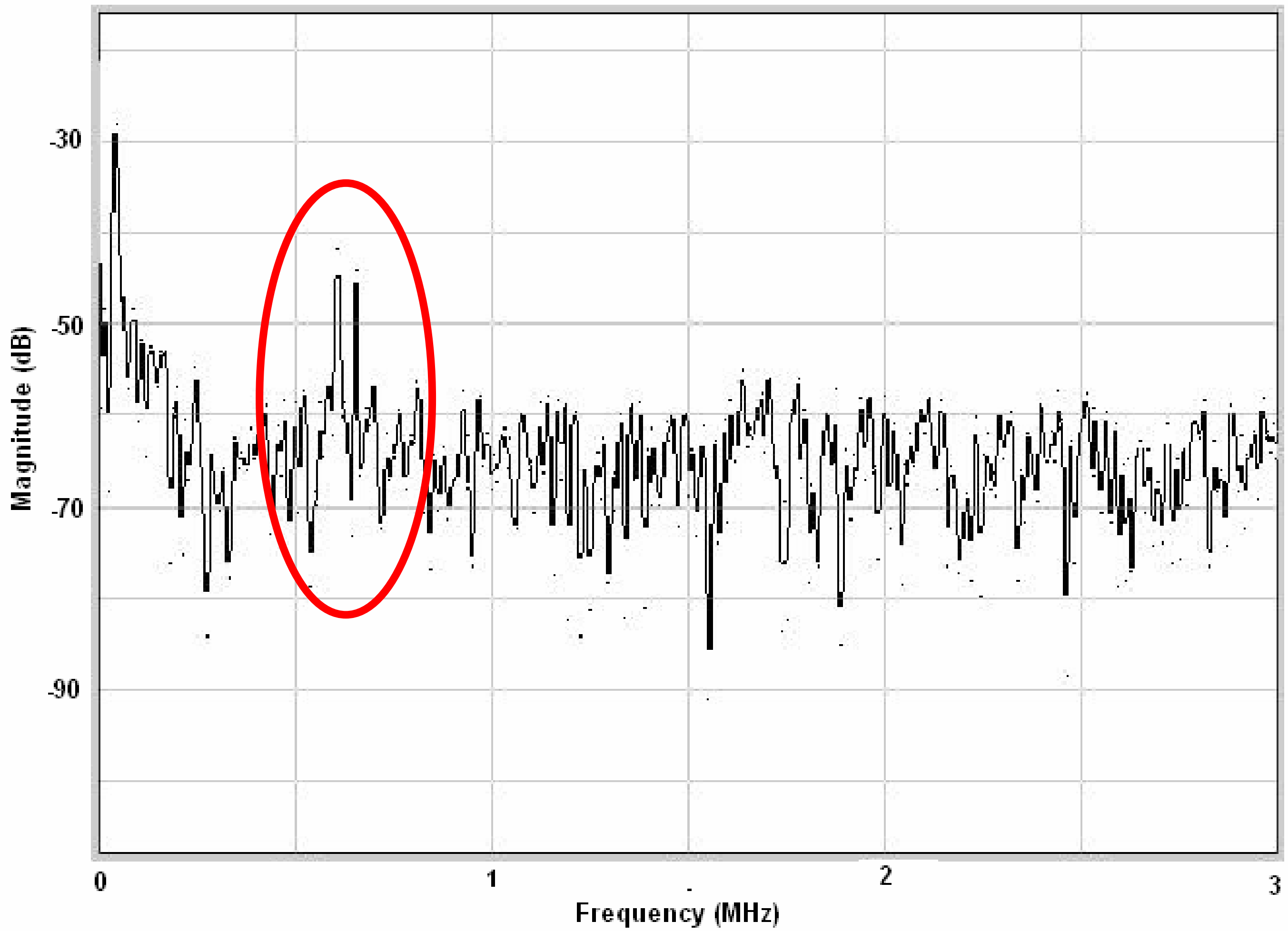
- **NLS4:** Nanosatellite Launch Service 4
- **Launch date:** April 28th, 2008
- **Launch vehicle:**
  - Antrix Polar Satellite Launch Vehicle (PLSV-C9)
- **Satellites onboard:**
  - AAUsat-2 (Denmark), CanX-2 (Canada), Cute-1.7+APD II (Japan), COMPASS-1 (Germany), Delfi-C3 (Netherlands), SEEDS (Japan)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

Result of VHF Band Receiving



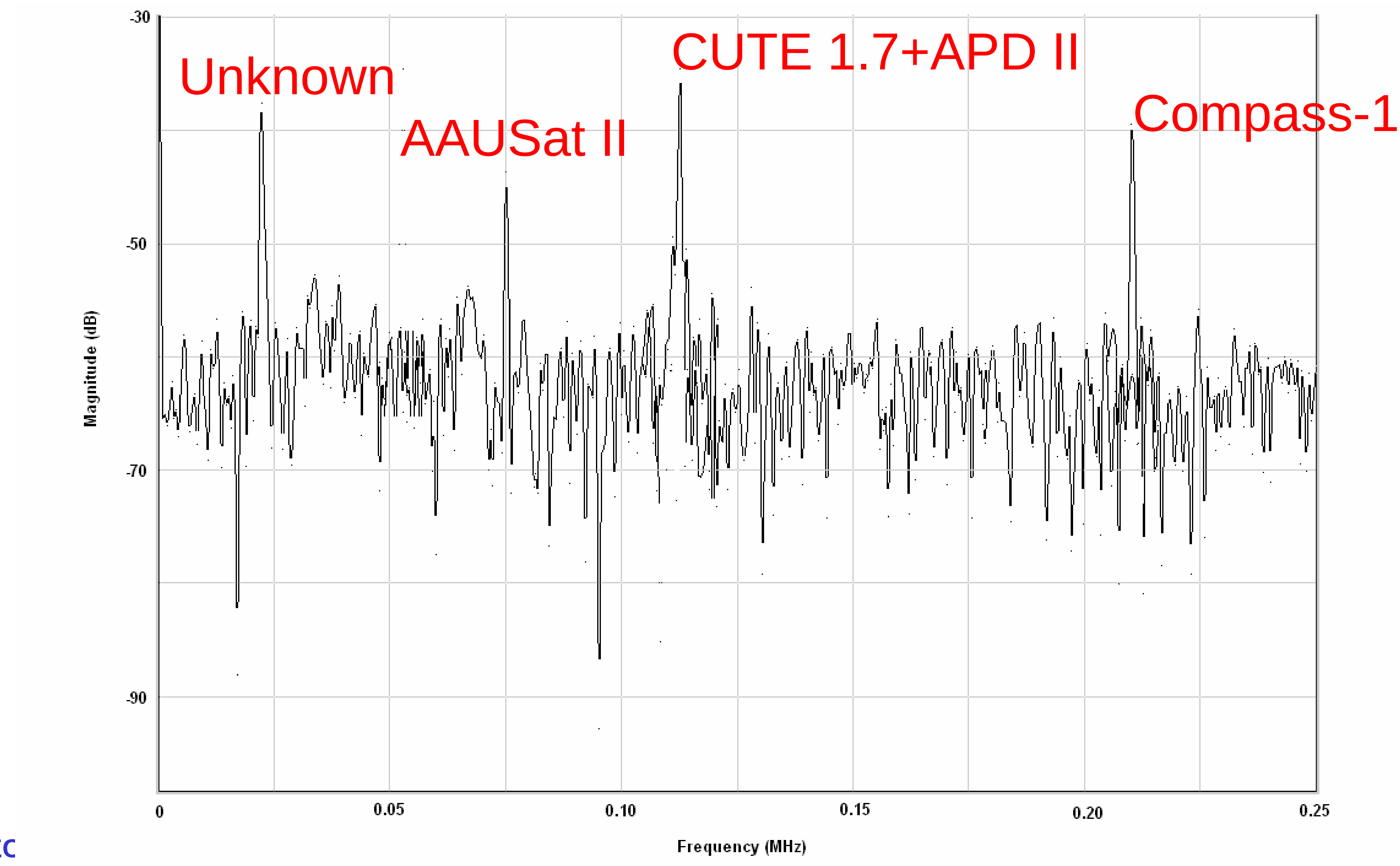
Result of UHF Band Receiving(1/2)

- Sampling Frequency: 6MHz

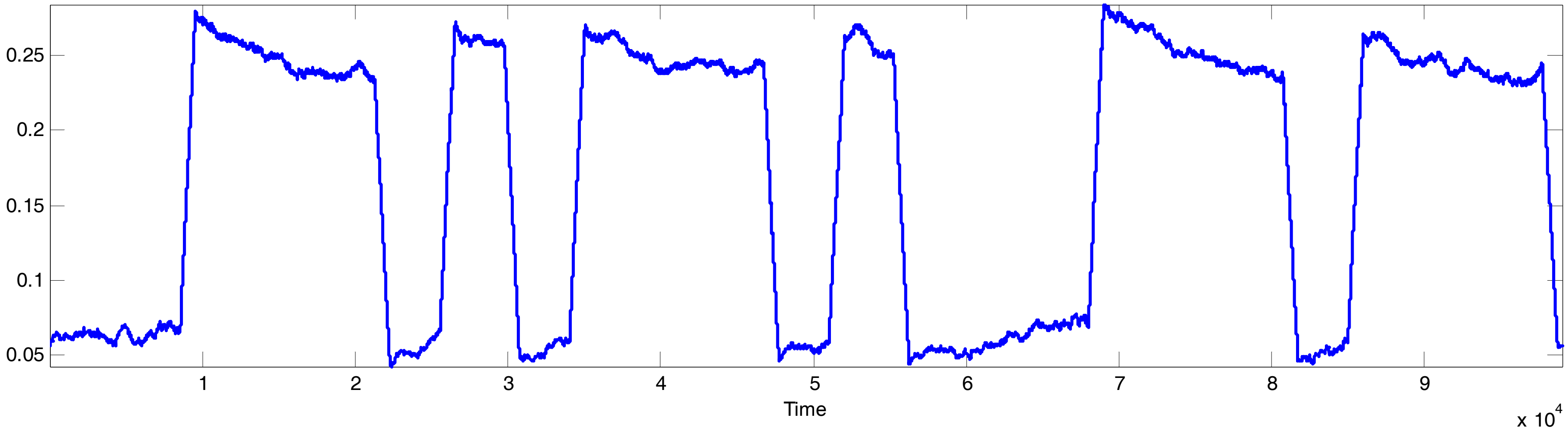


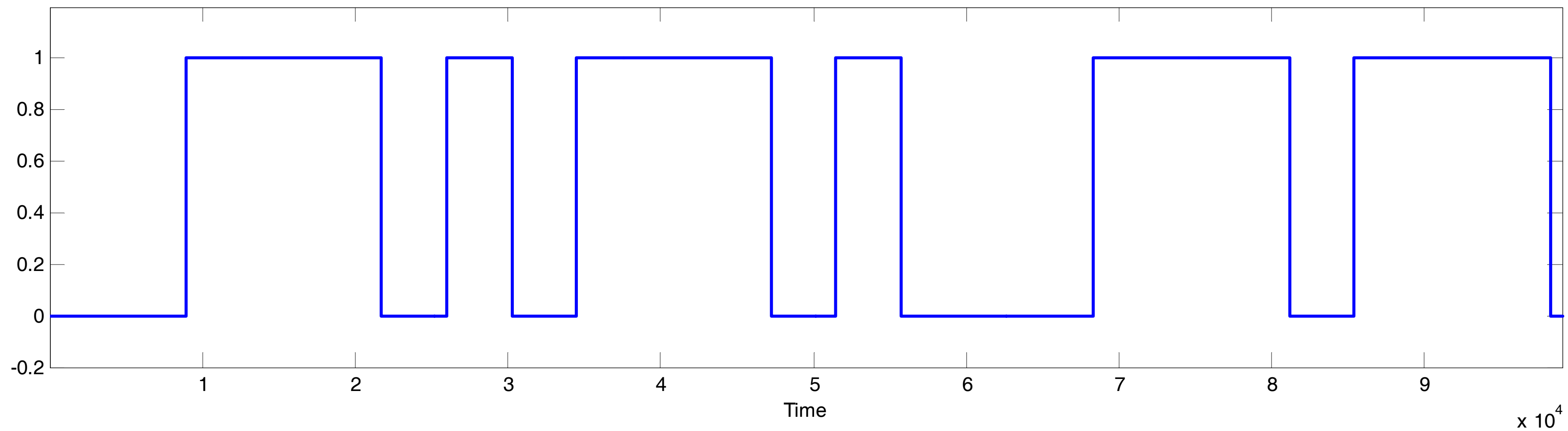
Result of UHF Band Receiving(2/2)

- Sampling Frequency: 0.5MHz



Compass-1 CW Signal Decoding





Decoding Result

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

- Compass-1:

?mpass29000000?000000001602c?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.

Reference

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Thanks for your attention!