# A Software-Defined Radio Approach for the Implementation of Ground Station Receivers

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# Background

- Recently, small satellites and constellation are developed for earth observation or communication network.
- As many small satellites will be released in one 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 | | |
| CO-57 | 436.8475 MHz | CO-56 | 437.3850 MHz | | |

# Spatial Problem

- Example:

  CAPE-1, CP3, CP4 and AeroCube-2 are launched on April 17th, 2007.


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

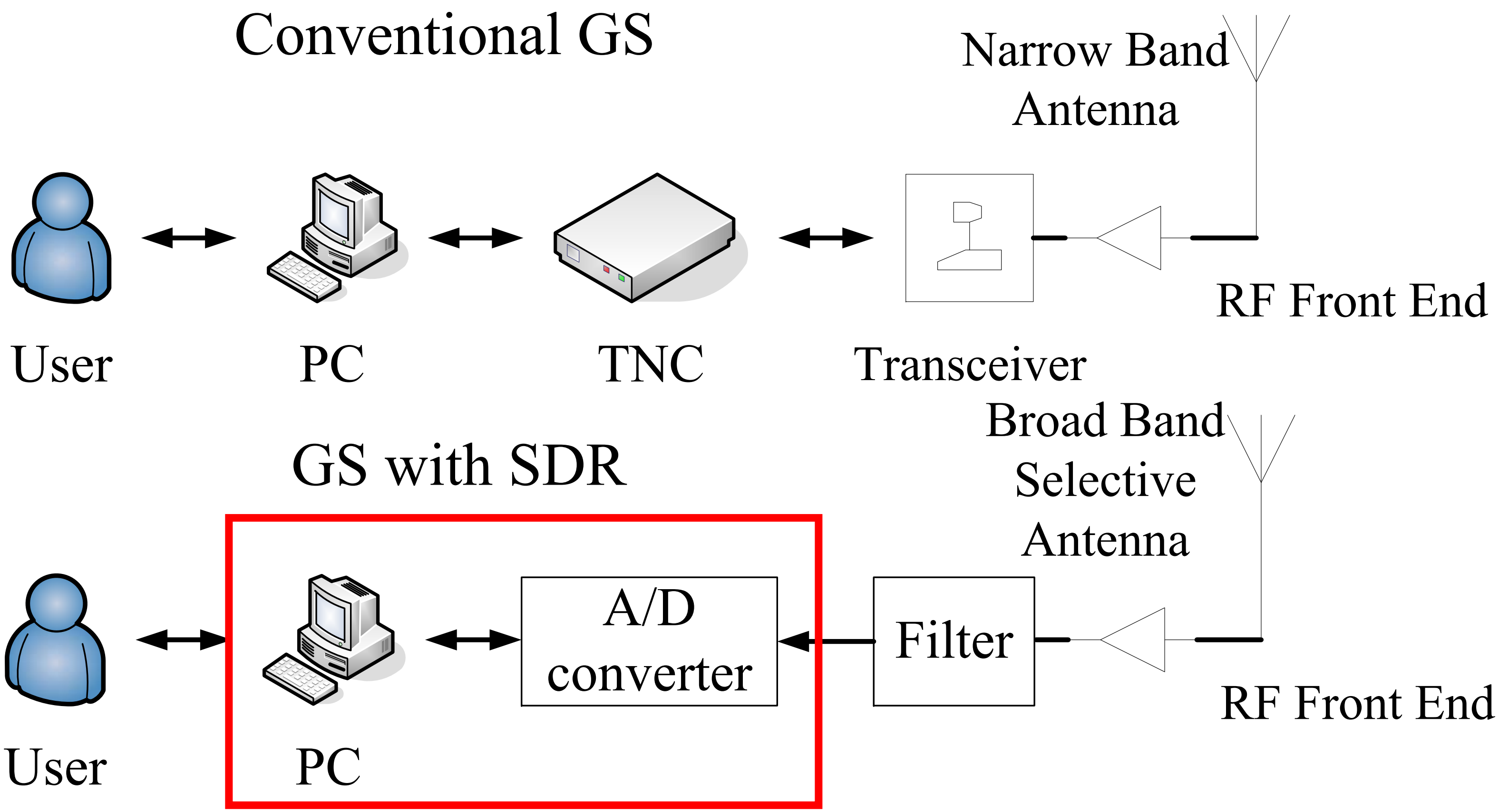
[1]


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 are
  - How to receive all the satellite signals simultaneously ?
    
    →Wide band and multi-channel
  - How to improve BER?
    
    →Interference cancellation

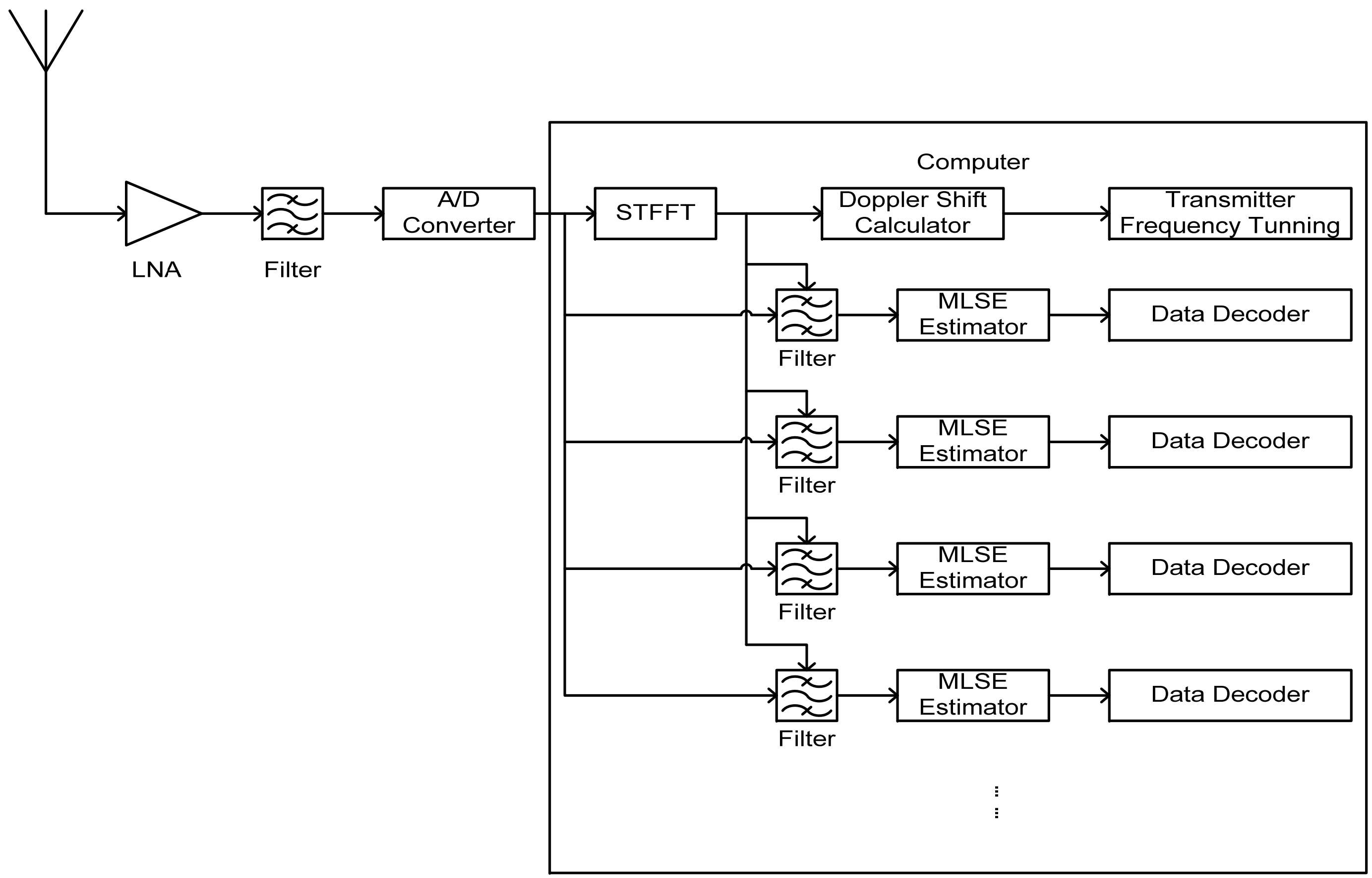
# Comparison




A Software Defined Radio (SDR) system is a radio communication system where components that have typically been implemented in hardware (i.e. mixers, filters, amplifiers, modulators/demodulators, detectors. etc.) are implemented using software. While the concept of SDR is not new, the rapidly evolving capabilities of digital electronics are making many processes that were once only theoretically possible practical.

# GS with SDR Architecture

Architecture: antennas, RF front end, A/D converter, PC.



# Down Conversion

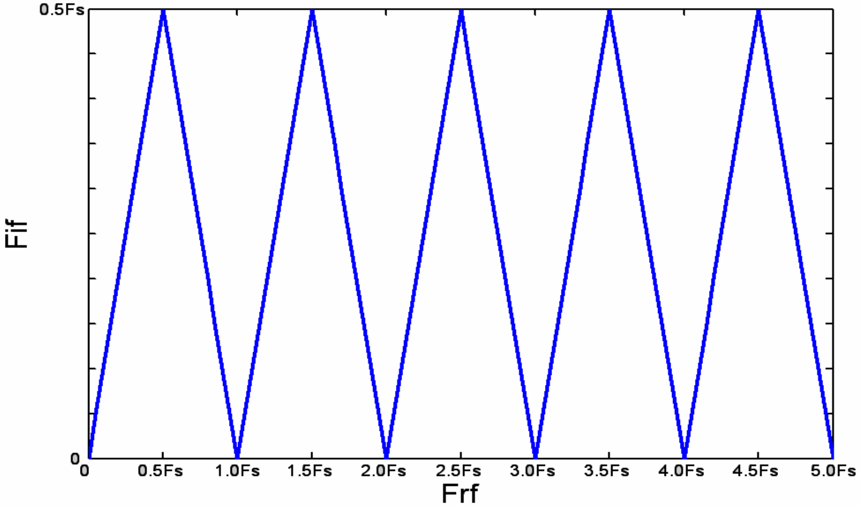
- Use band pass sampling to down-convert the signal.
- Need filter to prevent from aliasing

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

$F_{IF}$: Intermediate frequency

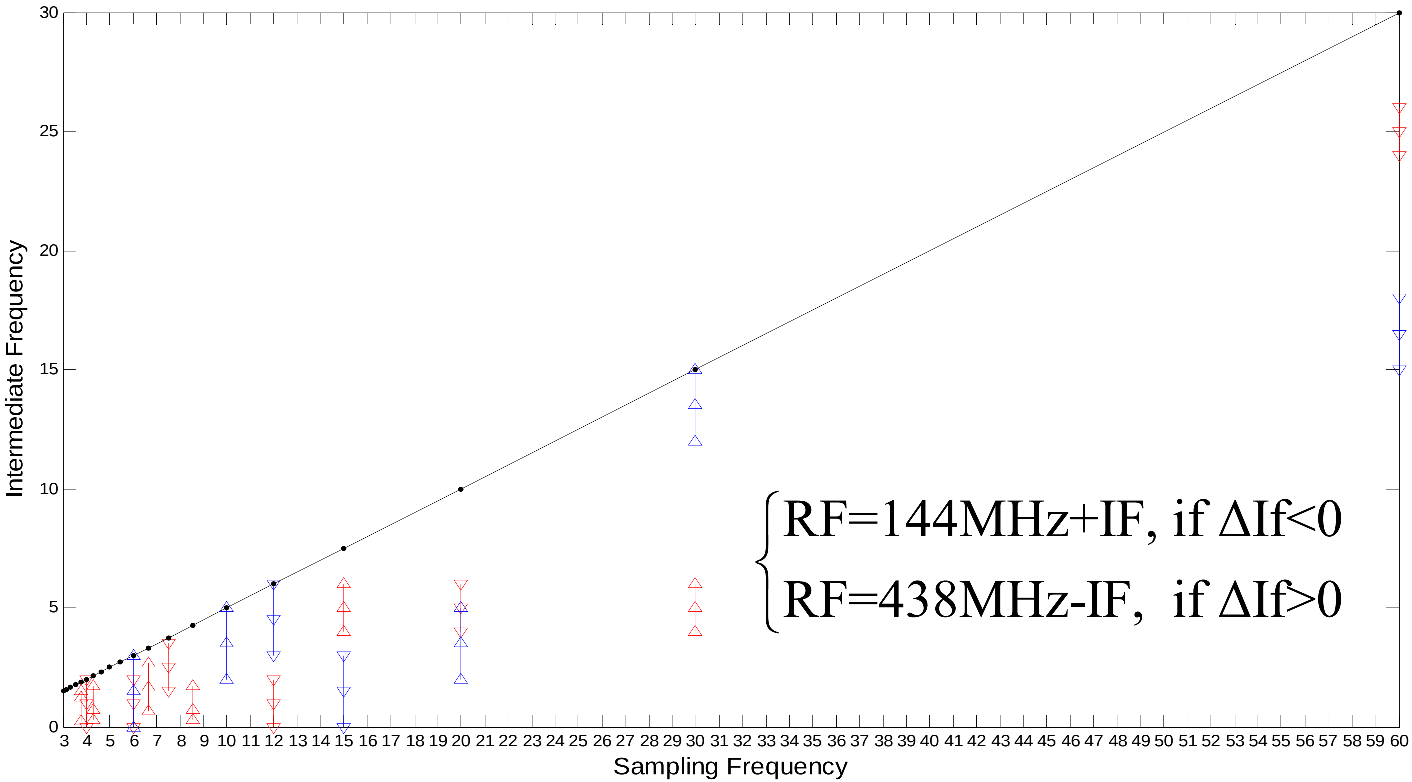
$F_{RF}$: Radio frequency

$F_S$: 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.

$$\text{Frequency resolution} = \frac{F_S}{N} = \frac{6\text{MHz}}{N} \leq 0.5\text{kHz}$$

$$\Rightarrow k \geq 14,\ N = 16384$$

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

# 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 is suitable.
  - SAIC: Single Antenna Interference Cancellation
- Furthermore, MIMO can be implemented at ground stations with multi-antenna.
  - MIMO: Multi-Input Multi-Output

# 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.

# CCI Cancellation

- Consider FM/FSK signal first and assume two signals in the same frequency.

$$r[k]=A_1[k]e^{j\theta_1[k]}+A_2[k]e^{j\theta_2[k]}+N[k]$$

A: amplitude, θ: phase

k: epoch, N: noise

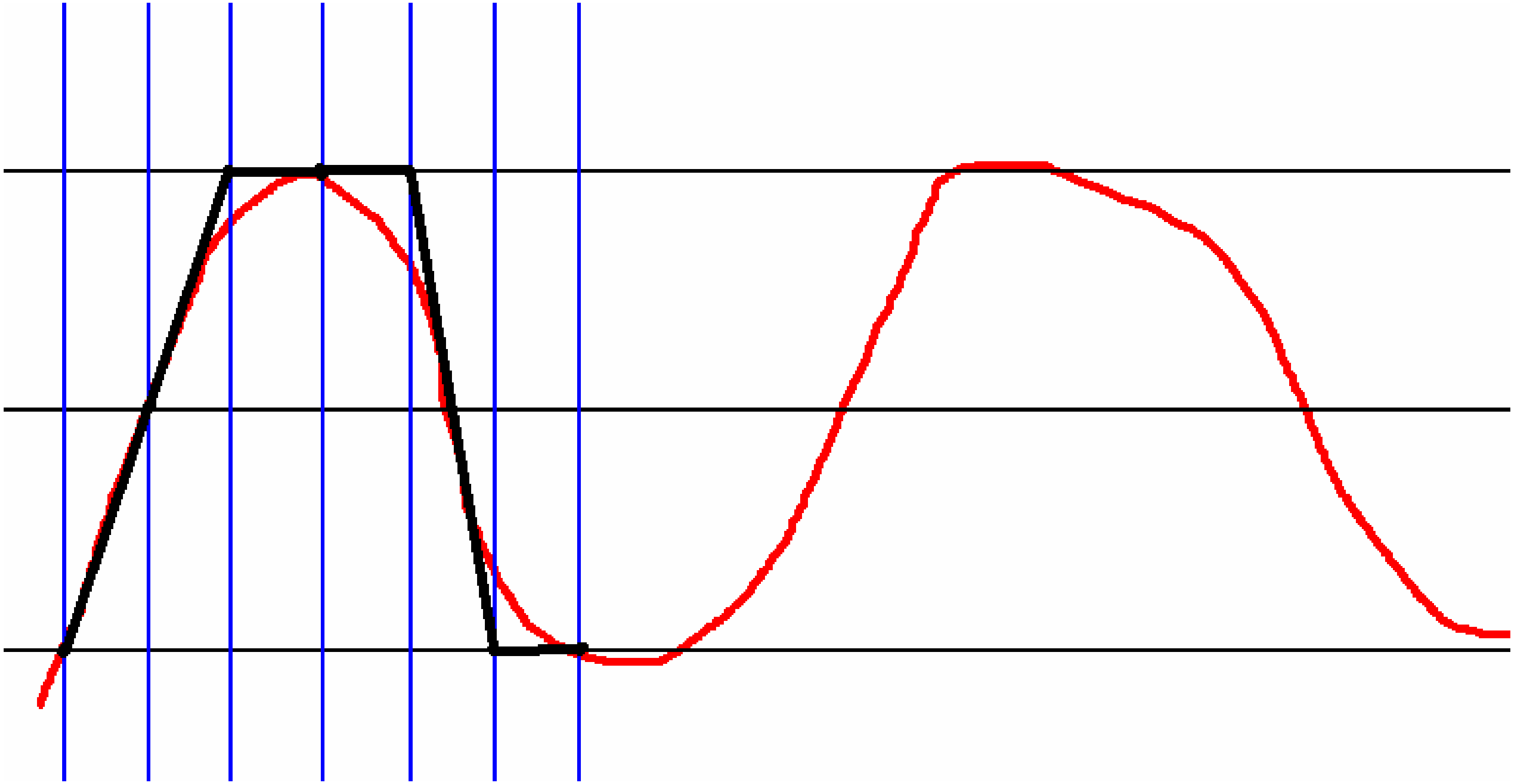
- The estimation will minimize
- $\int_{T_a}^{T_b} \left\| \hat{r}(t) - r(t) \right\|^2 dt$ ………(1)

- The problem is posed with an uncountable set of trajectory hypothesis. Therefore, [1] quantizes phase and make it with countable trace.

[1]: Charles R. Cahn. "Phase tracking and demodulation with delay," IEEE Trans. Inform. Theory, IT-20(1), pp:50-58, January 1974.

# CCI Cancellation

- Ex.



# CCI Cancellation

- In the absence of A2, we can quantize

$$\hat{\theta}^{(n)}(t)=a_k\theta_{max}^{(n)},\ a_k=\pm 1$$

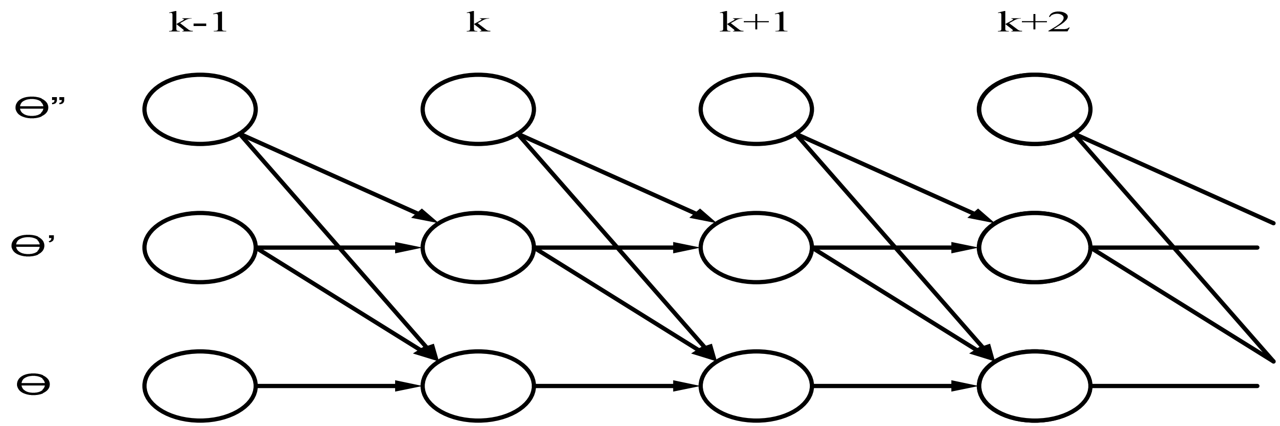
- The phase can be obtained by integral.
- In the thesis, we select n=2, and each state uses a truncated Taylor series to estimate the instantaneous frequency and the phase

$$\hat{\theta}_i'[k]=\hat{\theta}_i'[k-1]+\hat{\theta}_i''[k-1]T_s$$

$$\hat{\theta}_i[k]=\hat{\theta}_i[k-1]+\hat{\theta}_i'[k-1]T_s+\hat{\theta}_i''[k-1]T_s^2/2$$

# CCI Cancellation

- $\theta_{max}^{(2)}$ must be carefully chosen, [1] suggest it to be twice the actual peak value imposed by the modulation. In our case, we choose $88M\pi \, \mathrm{rad}/\mathrm{s}^2$
- Let the trellis depth is D, $\theta_{max}^{(2)}$ will be decided after r[k+D] is input to the MLSE estimator.

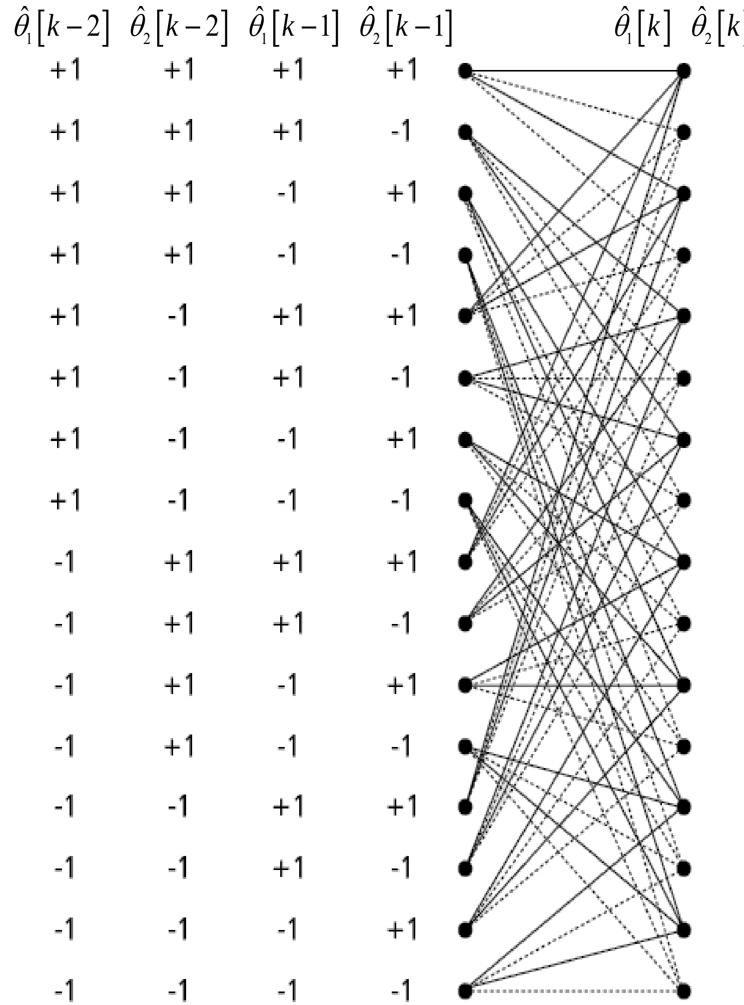


# CCI Cancellation

- For two signals, this approach needs Joint-MLSE.

- Trace number:

(Quantization level)^(Signals)^(Trellis depth)



# CCI Cancellation

- we change the amplitude estimation approach to Per-Survivor Processing (PSP).
- PSP offers improved performance because when a particular path through the trellis is chosen, the amplitude estimates used in that path are optimized for that path.
- From (1), what we need to optimize is

$$Q(X,Y)=aX^2+bY^2+cXY+dX+eY+f$$

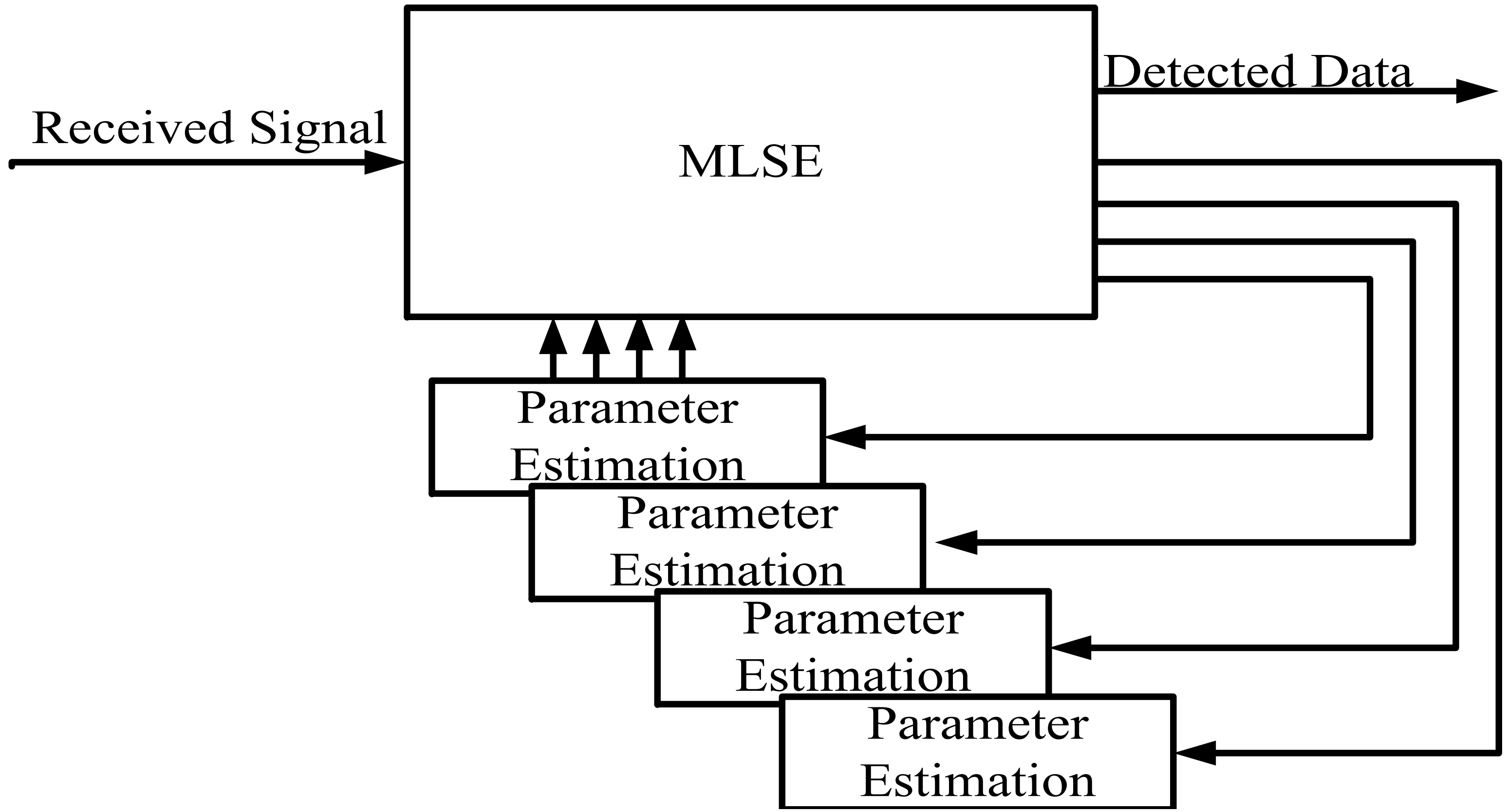
$$a=\sum_{i=1}^{k}1 \qquad b=\sum_{i=1}^{k}1 \qquad c=\sum_{i=1}^{k}2\cos(\theta_1-\theta_2)$$

$$d=\sum_{i=1}^{k}-2r\cos(\theta_r-\theta_1) \quad e=\sum_{i=1}^{k}-2r\cos(\theta_r-\theta_2) \quad f=\sum_{i=1}^{k}r^2$$

$$X=A_1 \qquad Y=A_2$$

# CCI Cancellation

- Block diagram of MLSE with PSP

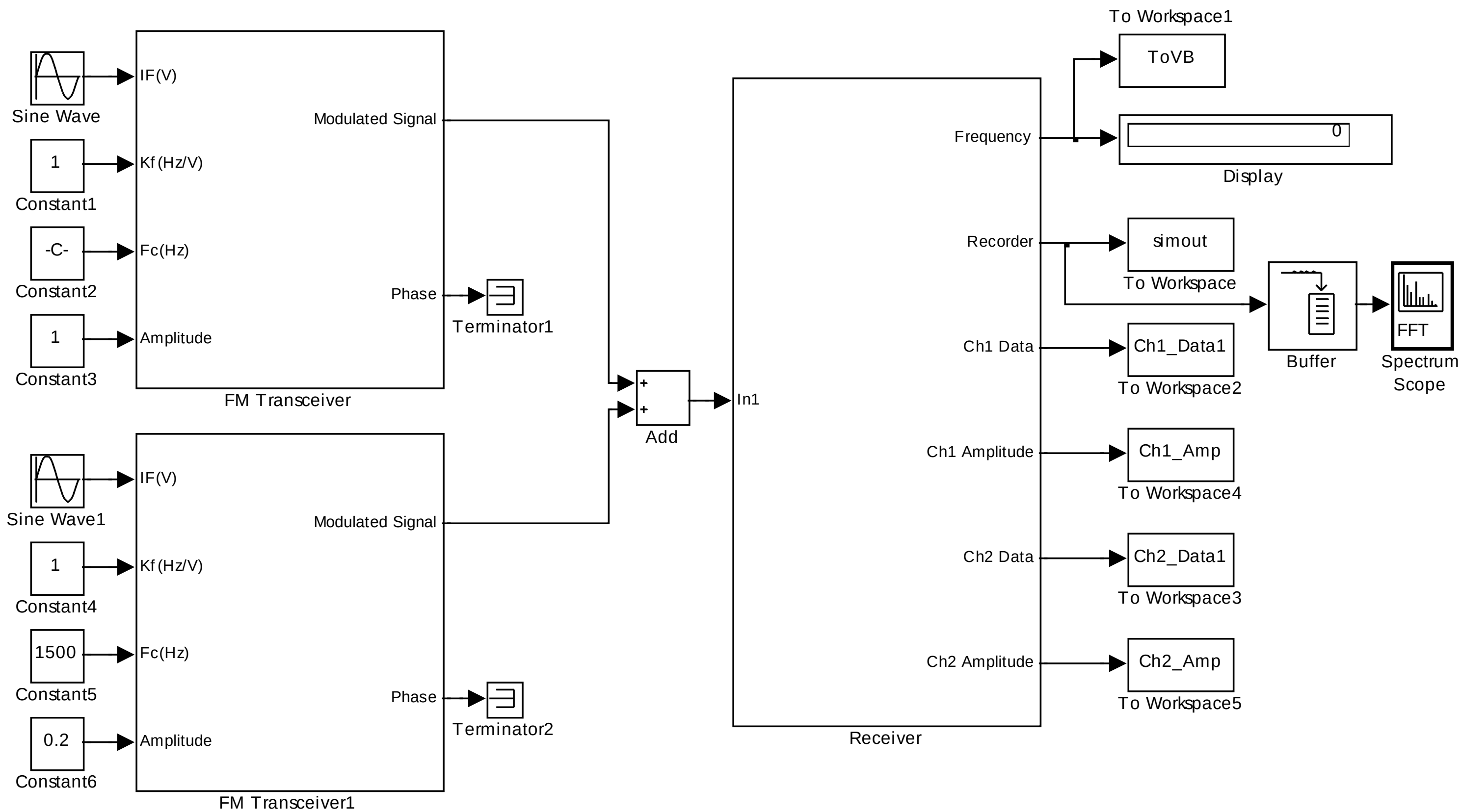


# SDR Implementation

- 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

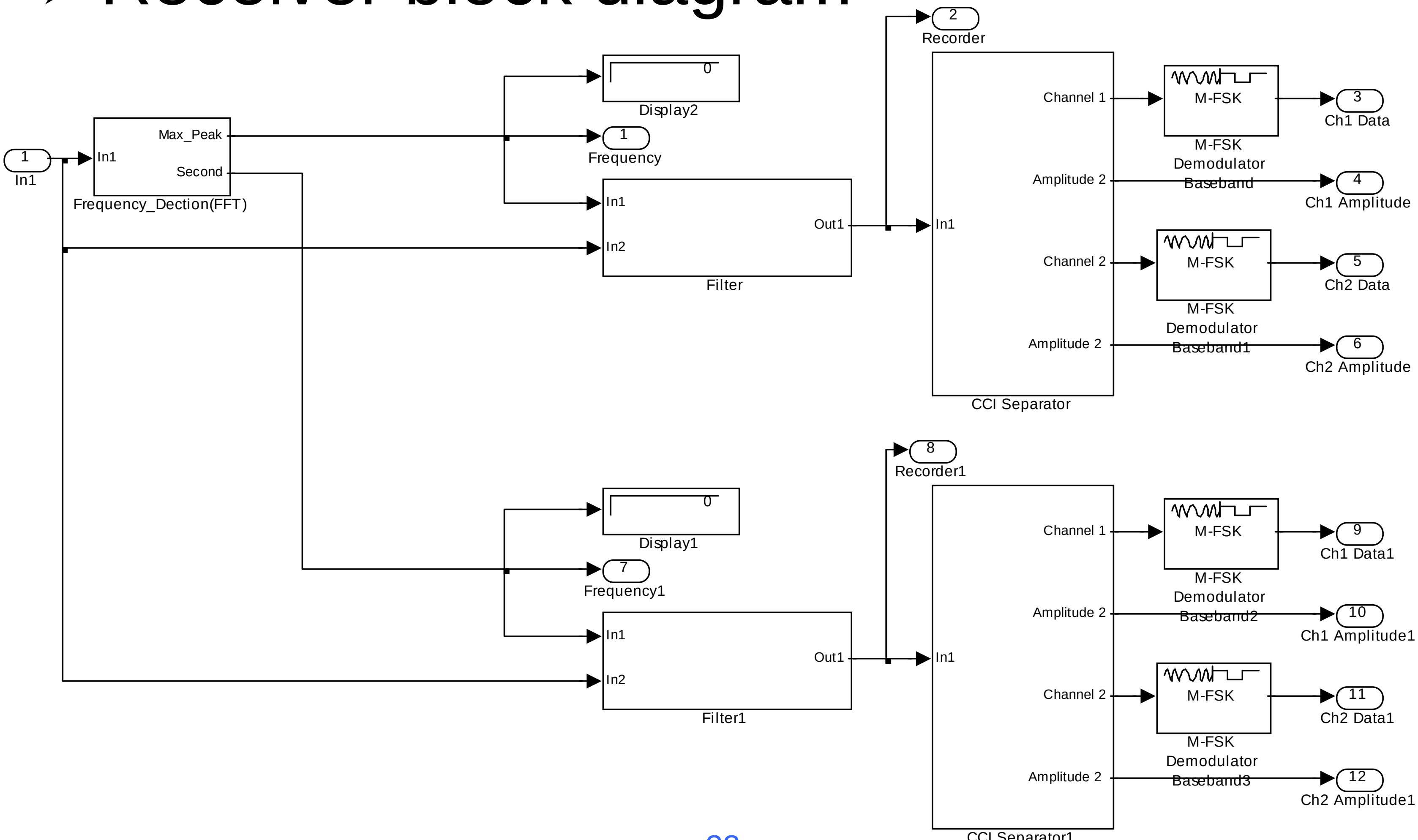
# SDR Implementation

- Simulation block diagram

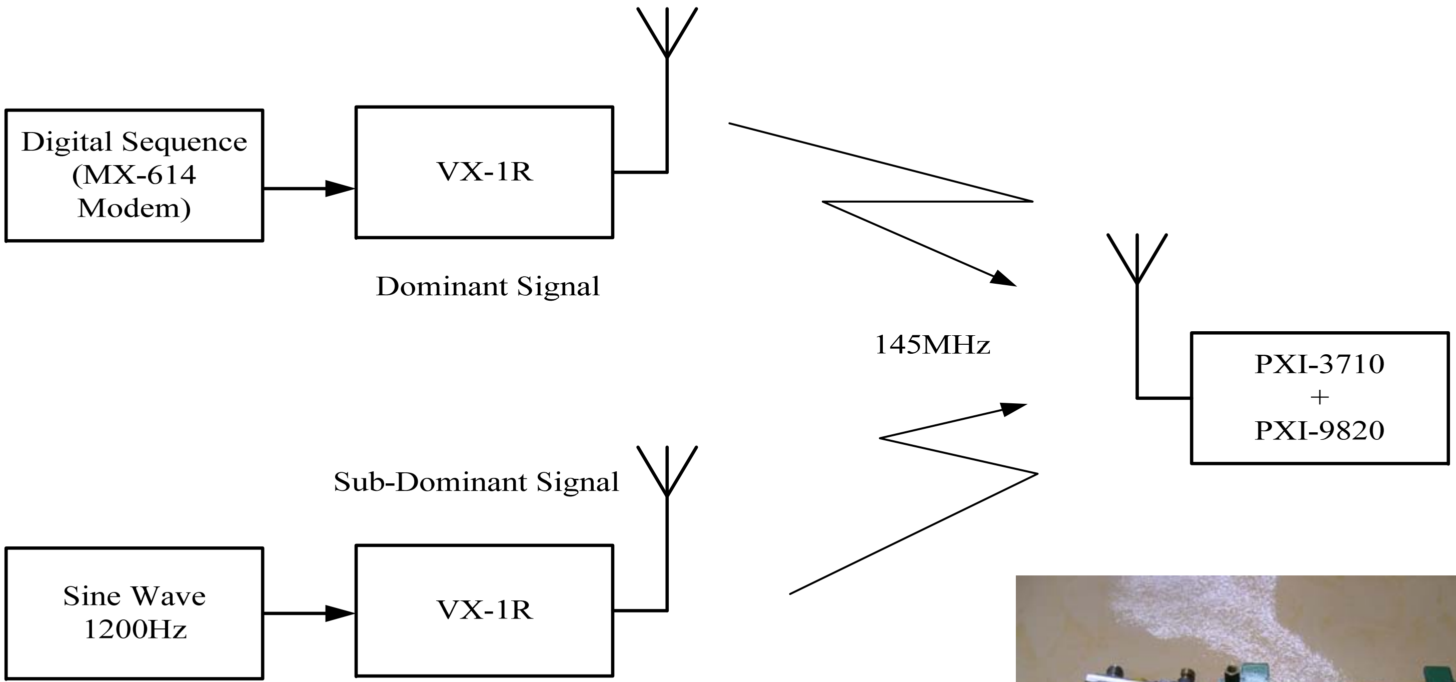


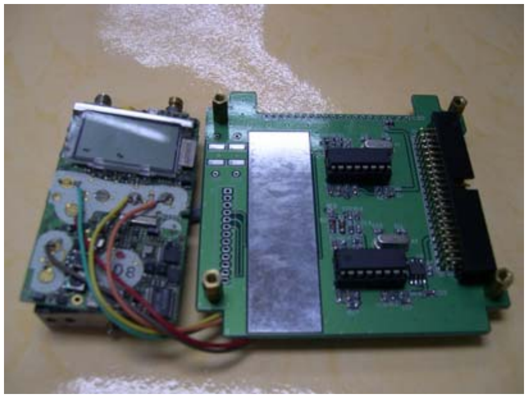
# SDR Implementation

- Receiver block diagram



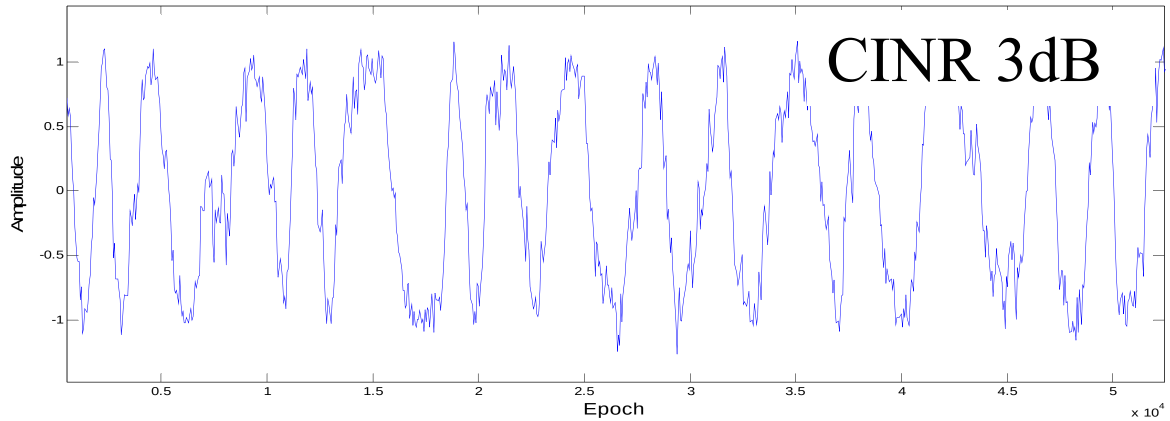
# Experiment Setting

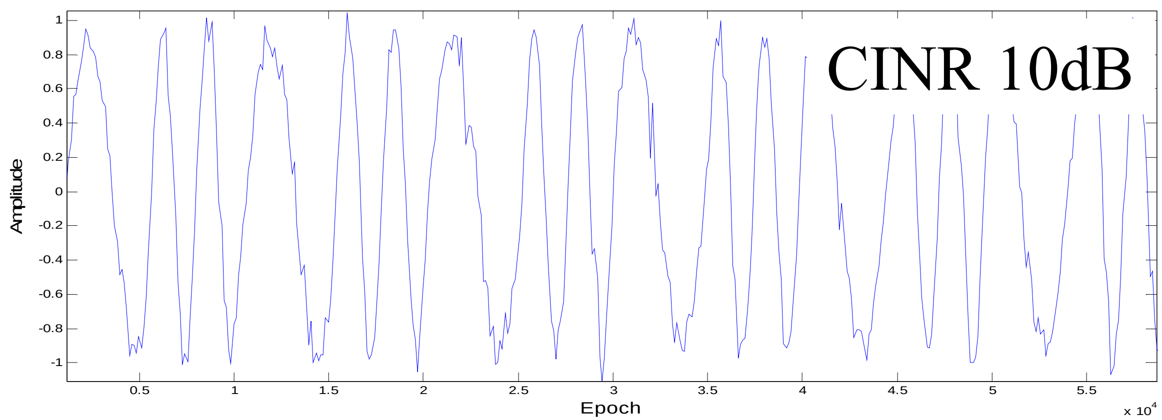


# Experiment Result

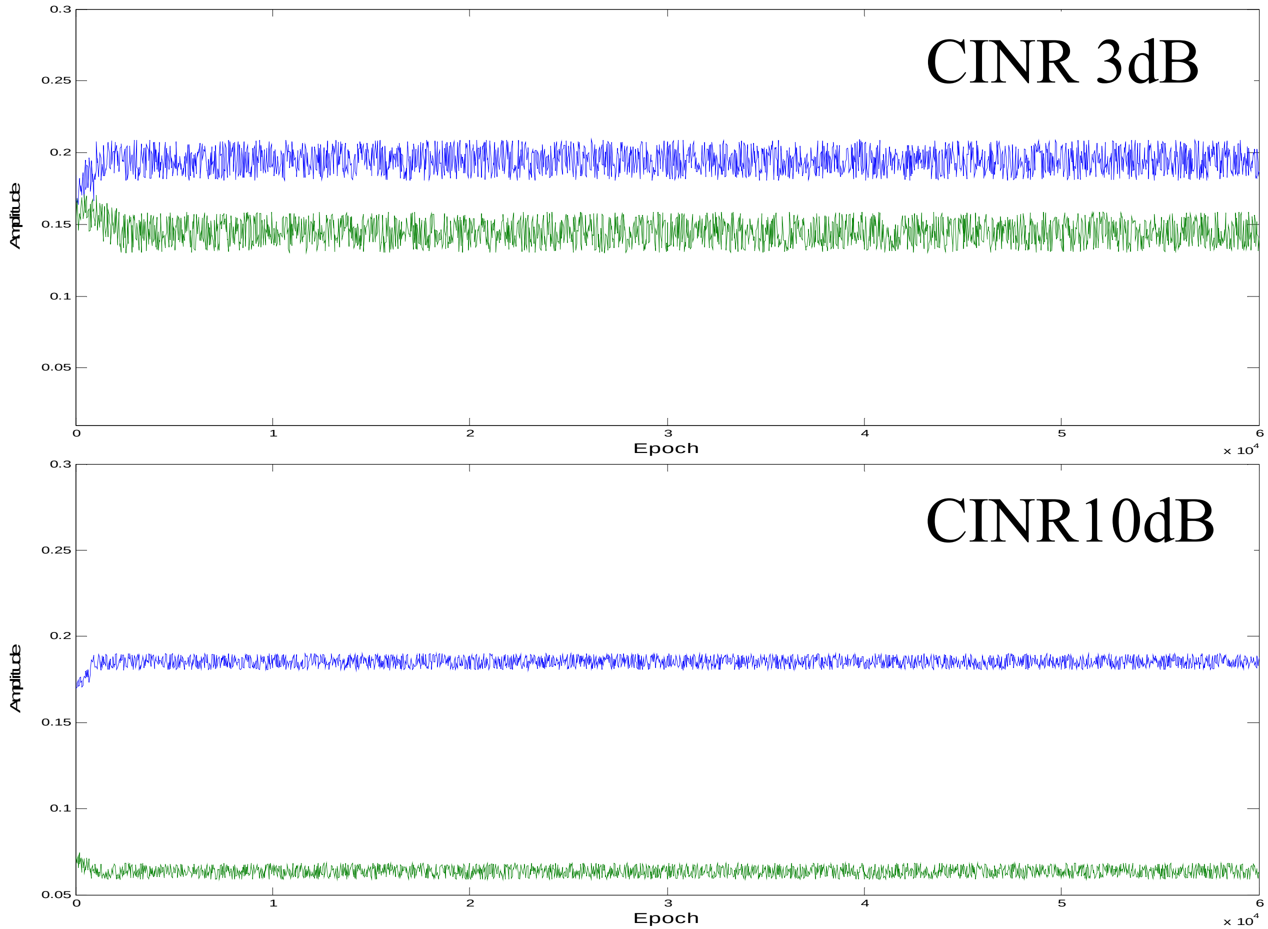
➢ Demodulated signal



# Experiment Result

- Amplitude estimation



# SDR Implementation

- 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.

# 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
- The Doppler shift can be exactly known, not estimated by an orbit prediction software. It is very useful for both uplink and downlink and increases successful contact probability.

# Reference


[1] http://polysat.calpoly.edu/CP4.php

[2] Peter B. Kenington, RF and Baseband Techniques for Software Defined Radio, Boston, Artech House, 2005

[3] Jeffery H. Reed, Software Radio: A Modern Approach to Radio Engineering, Prentice Hall PTR, 2002.

[4] W. Etten, “Maximum Likelihood Receiver for Multiple Channel Transmission Systems,” IEEE Trans. Commun., Vol. 24, No. 2, pp. 276–83, Feb. 1976.

[5] Rodney G. Vaughan, “The Theory of Bandpass Sampling,” IEEE Trans. on Signal Processing, Vol. 39, No. 9, September 1991.

[6] Riccardo Raheli, Andreas Polydoros and Ching-Kae Tzou, “Per-Survivor Processing: A General Approach to MLSE in Uncertain Environments,” IEEE Trans. on Communications, Vol. 43, No. 2/3/4, Feb/March/April 1995

[7] Akos, D.M. Stockmaster, M. Tsui, J.B.Y. Caschera, J., “Direct Bandpass Sampling of Multiple Distinct RF Signals,” IEEE Trans. Commun., Vol. 47, Issue 7, pp. 983-988, Jul 1999.

[8] Jon Hamkins, Ed Satorius, Gent Paparisto and Andreas Polydoros, “A Comparative Study of Co-Channel Interference Suppression Techniques,” Proc. 5th IMSC, pp. 327-332, June 1997.

[9] Mostafa et al., “Single Antenna Interference Cancellation (SAIC) for GSM Networks,” Proc. IEEE VTC, Orlando, FL, pp. 1089–93.

[10] http://en.wikipedia.org/wiki/Software-defined_radio

# Q & A

Thanks for
your attention!
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