Experimental Study of Spectrum Estimation and Reconstruction based on Compressive Sampling for Cognitive Radios

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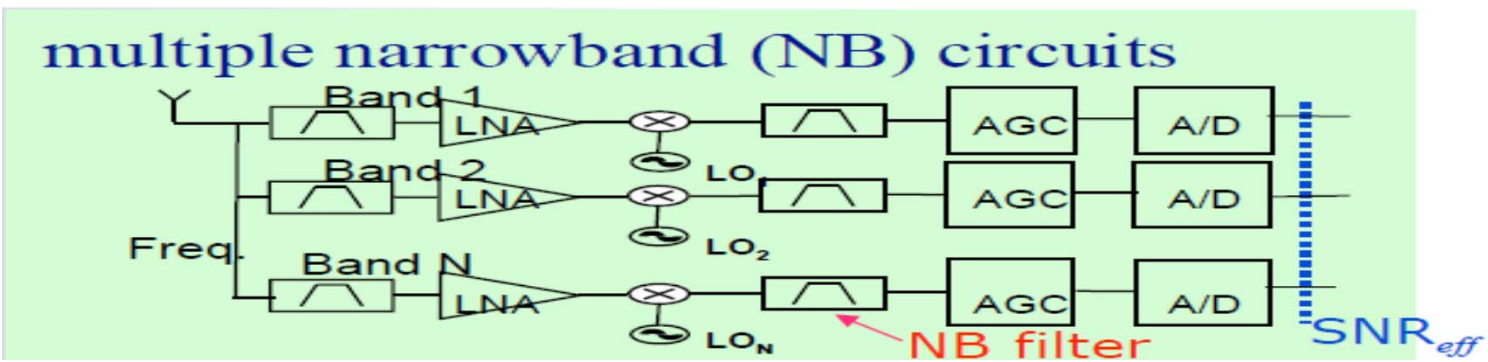
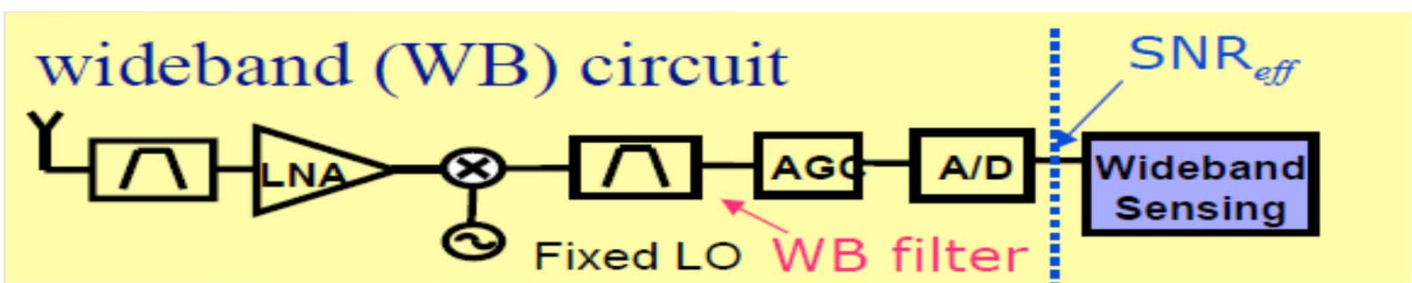
Contents

Wideband Signal Acquisition

- ❑Choices of RF Circuits: Multiple NB or single WB





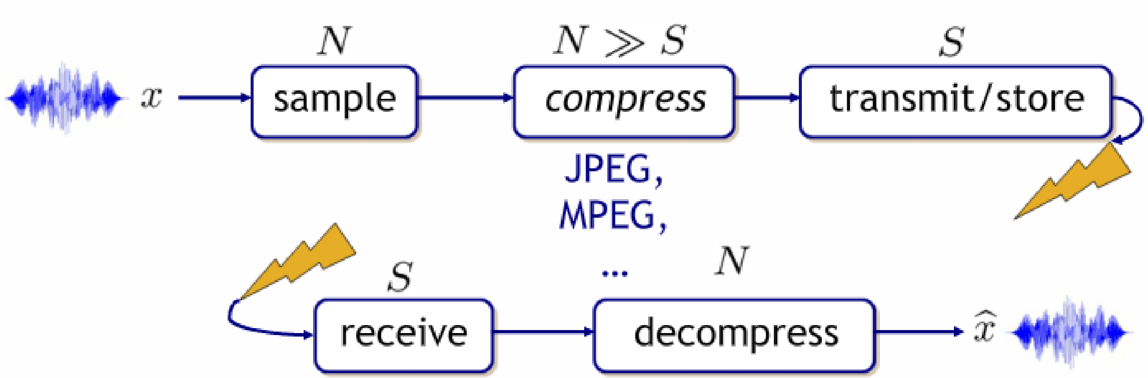
Compressed Sampling [Tian'07-08, Haupt'07]

- ❑Conventional spectral estimation methods require to operate at or above Nyquist rate.
- ❑Requires high rate A/D or bank of low rate A/D for wideband signals.

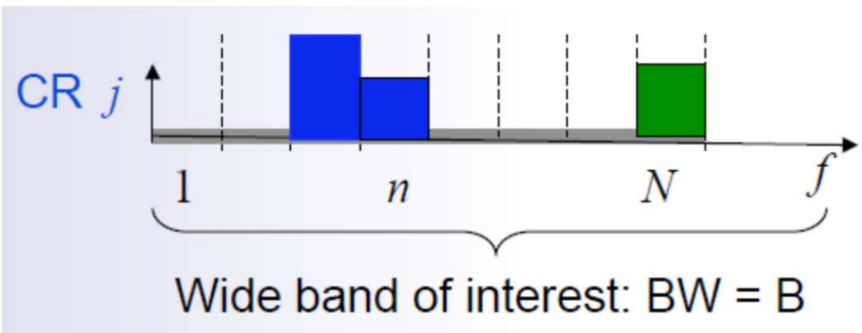
- ❑Compressed Sampling: sub-Nyquist rate sampling and reliable signal recovery via computationally feasible algos.
- ❑Applicable to sparse signals.

Compressed Sampling

❑CS is Essentially different from Sample-then-Compress (JPEG, MPEG etc)



Limits on Sampling Rates

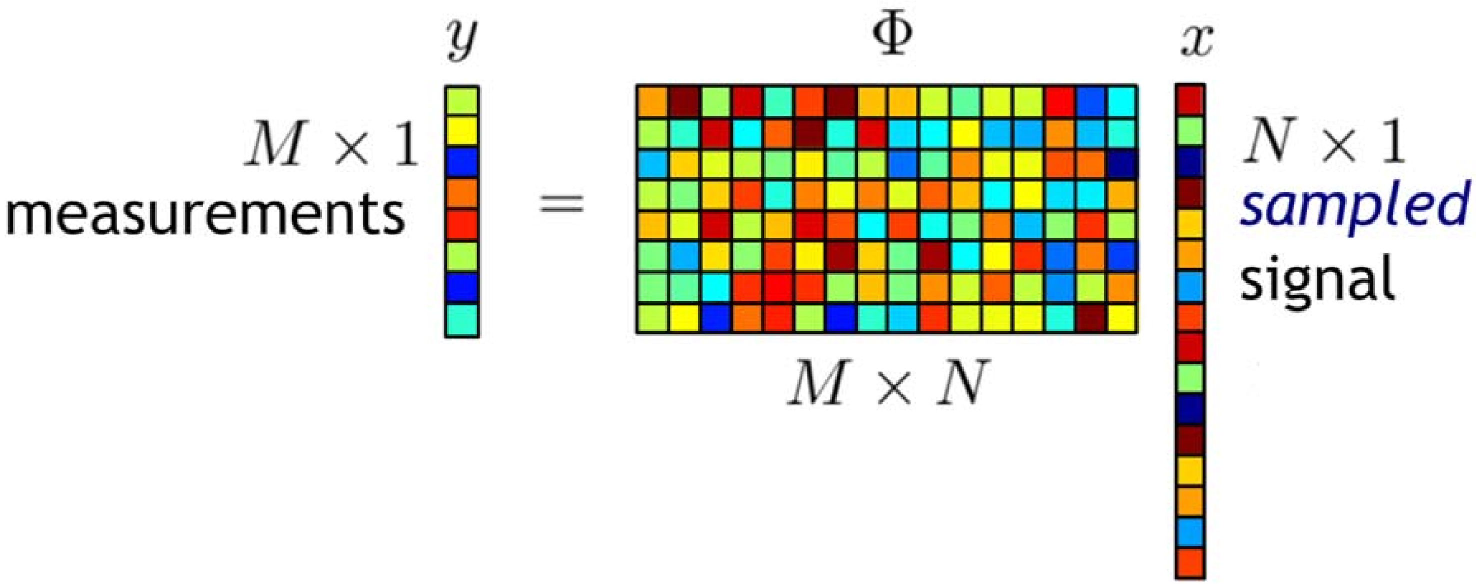


Spectrum occupancy ratio

$$r_{nz} = N_{nz}/N \ll 1$$

- Lower bounds on sampling rates f_s
  - Lowest f_s for reconstruction without aliasing
    - Nyquist Rate = $2B$
  - Lowest f_s for reconstruction of CR signals
    - Motivating factor for CR is low spectrum utilization
    - Landau rate = $2B_{eff} = 2r_{nz}B$ < Nyquist Rate

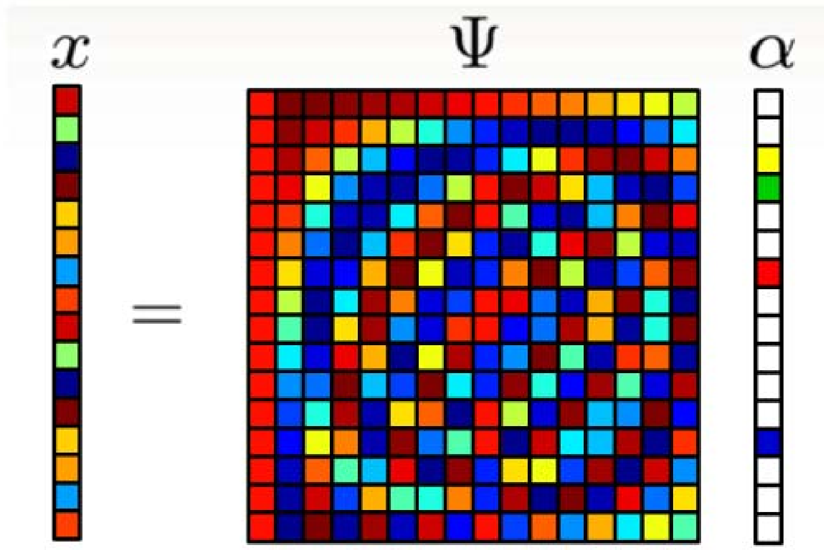
CS Basics



y
Φ
x
$M \times 1$
measurements
$=$
$N \times 1$
sampled
signal
$M \times N$

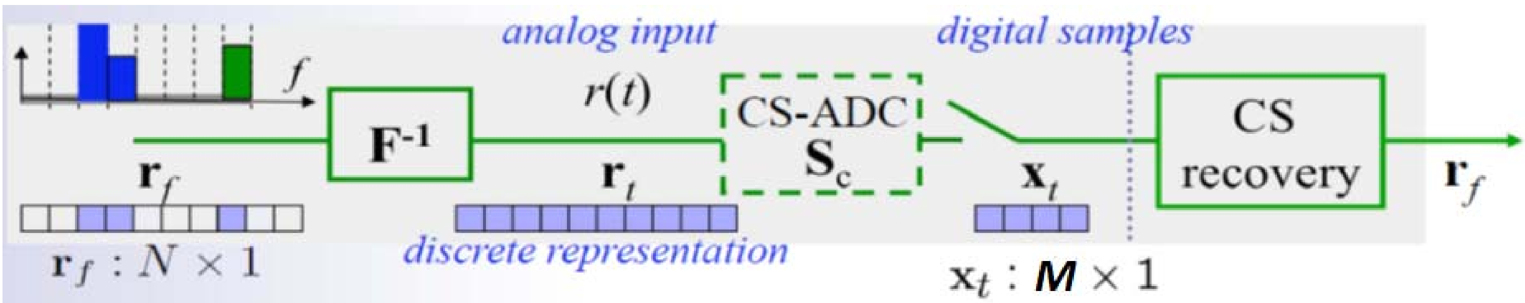
CS Basics

$$x = \sum_{j=1}^{N} \alpha_j \psi_j$$
$$= \Psi\alpha$$



- ❑Compressive sampling [Chen etal'98], [Candes etal'04-06]
  - ❑Given ***y*** and **ϕ**, unknown ***x*** can be found with high probability.

Sub-Nyquist rate Sampling



- ❑Received signal: $r(t): t \in [0, NT_s]$
  - ❑Discrete representation: $\mathbf{r}_t \leftrightarrow \mathbf{r}_f = \mathbf{F}\mathbf{r}_t$
- ❑Linear sampling: $\mathbf{x}_t = \mathbf{S}_c\mathbf{r}_t = \mathbf{S}_c\mathbf{F}^{-1}\mathbf{r}_f$
  - ❑Compression: $\mathbf{S}_c: M \times N$
- ❑Various designs of random samplers [Kirolos etal'06, Hoyos etal'08]

Sub-Nyquist rate Sampling

- Reconstruction is achieved by solving the following convex optimization problem:

$$\arg\min_{\mathbf{r}_f} \|\mathbf{r}_f\|_1, \qquad s.t. \quad \mathrm{x}_t = \mathbf{S}_c \mathbf{F}^{-1} \mathbf{r}_f$$

- Techniques to Solve the above problem:
  - Linear Programming: Basis Pursuit [Chen etal'98]
  - Iterative greedy algorithms: Matching Pursuit [Duarte etal'05] and Orthogonal Matching Pursuit [Tropp and Gilbert'07]

Formally the l_n-norm of x is defined as:

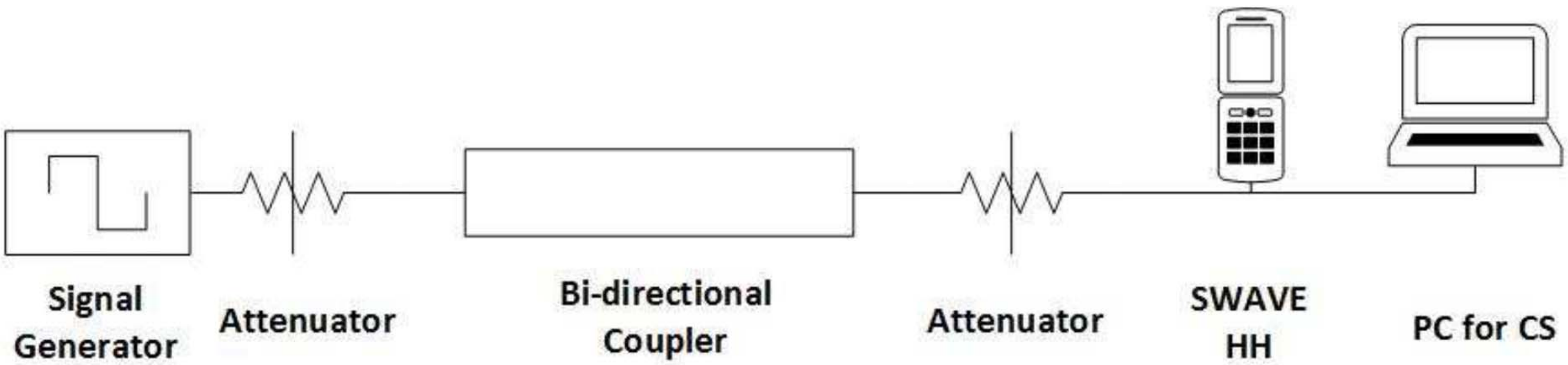
$$\|x\|_n = \sqrt[n]{\sum_i |x_i|^n}$$

Test bed Architecture

- Physical architecture of the assembled test bed

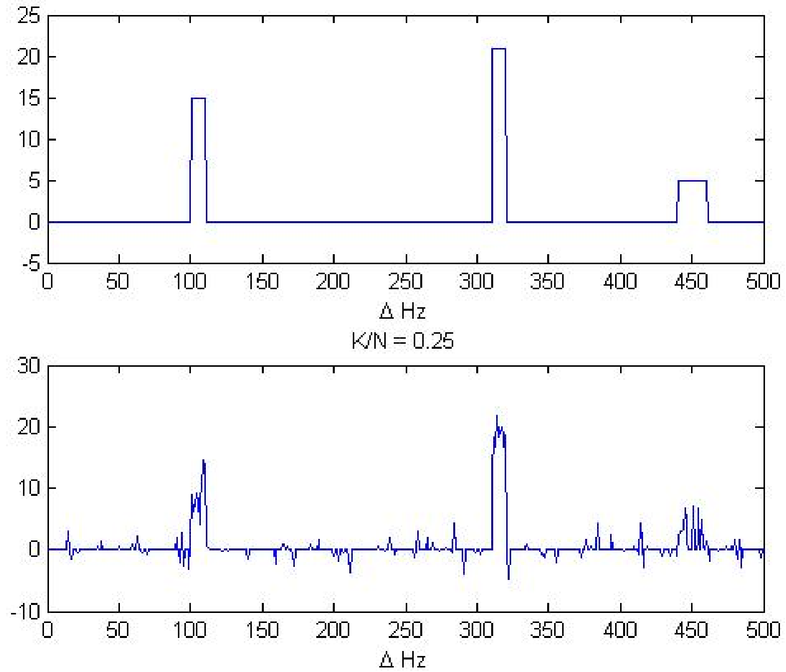
Test bed Architecture

- Simplified block diagram of the assembled test bed



CS on simulated data

- ❑Simulation paras:
  - ❑500 ΔHz wideband signal
  - ❑Non-zero elements = 40 ΔHz
  - ❑Occupancy = 40/500
  - ❑Basis Pursuit (BP) for compressed sensing.

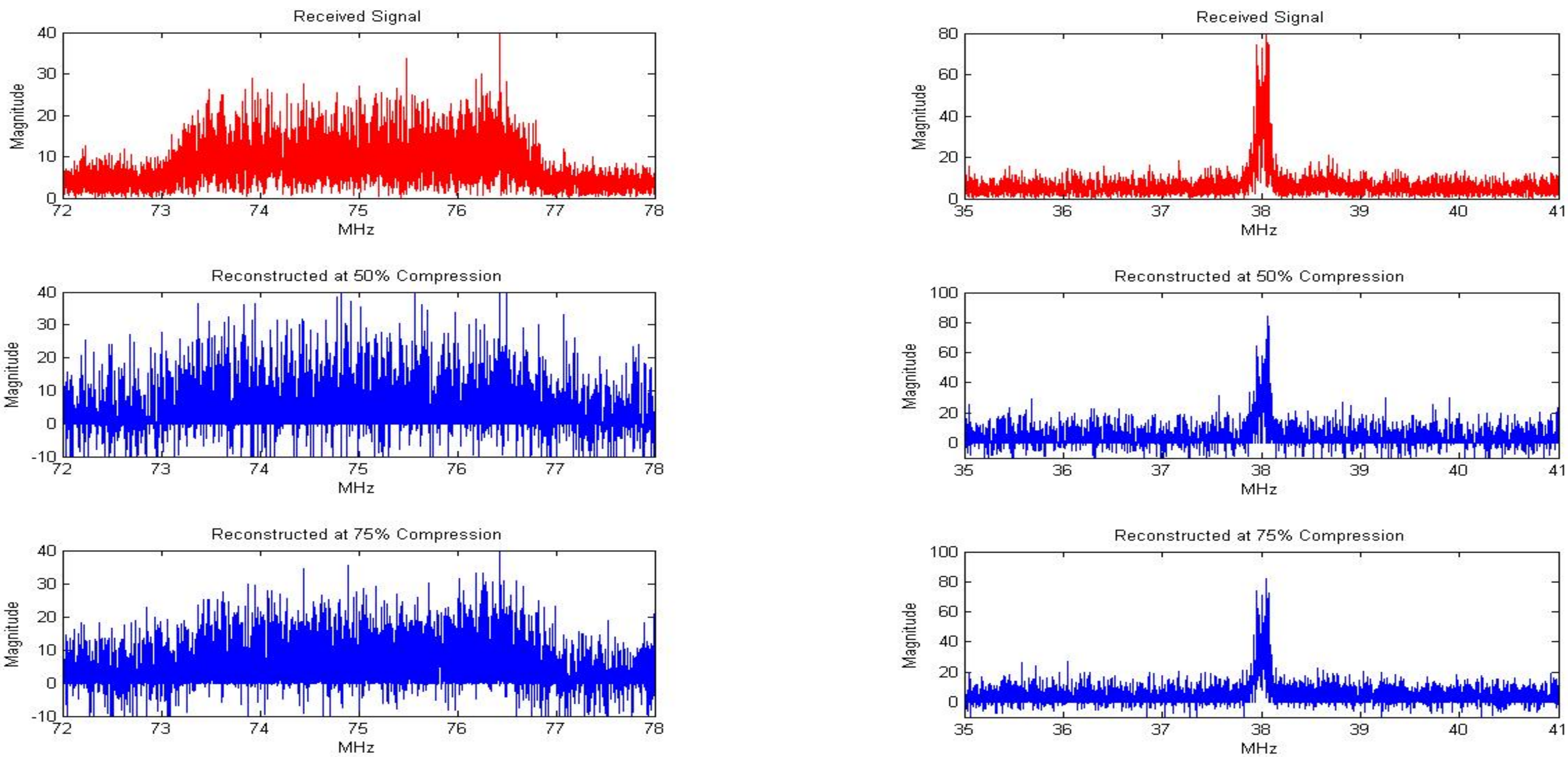


CS on test bed data

- Accumulated data:
  - 120 MHz wideband spectrum
  - Sampling rate of SWAVE HH = 250 Msamples/s
  - FPGA output = 8192 samples / 1.3 s (not sufficient for meaningful waveform realization)
  - 10 bursts of 8192 samples (8.192×10^4 samples)

- Analyzed waveforms:
  - 3 MHz wideband Gaussian waveform
  - 250 KHz narrowband GSM waveform

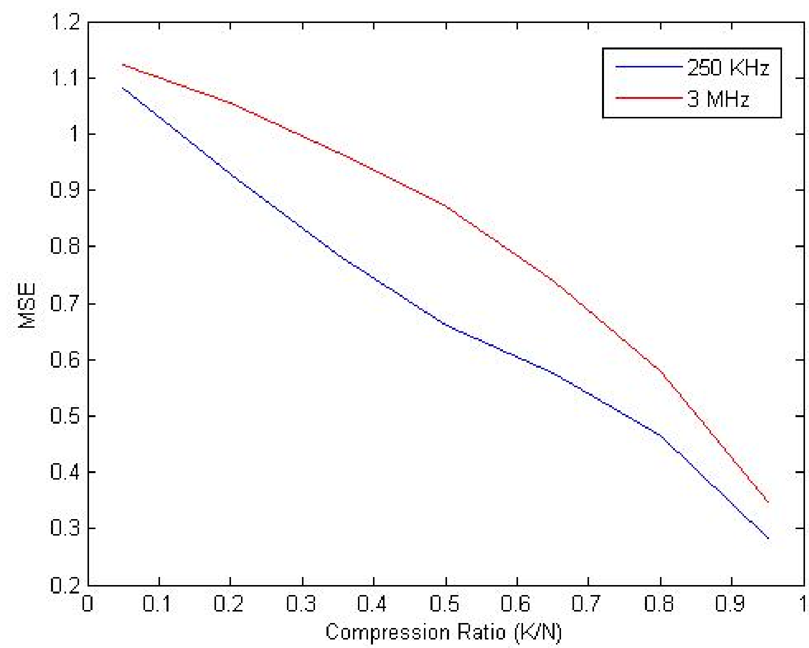
CS on test bed data



CS on test bed data

- ❑MSE Performance:

$$\mathrm{MSE} = E\left\{\frac{||\hat{s} - s||_2^2}{||s||_2^2}\right\}$$



Conclusions and Future Directions

- Successfully transmitted and received the real-world communication signals from the SDR test-bed.

- Successful implementation of CS algorithm on the test-bed data with acceptable performance.

- Developing an intelligent jammer detection algorithm for wideband radios using CS techniques.

Acknowlegdements

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Thank you

Q & A