Compressive Sensing Research for EW Applications

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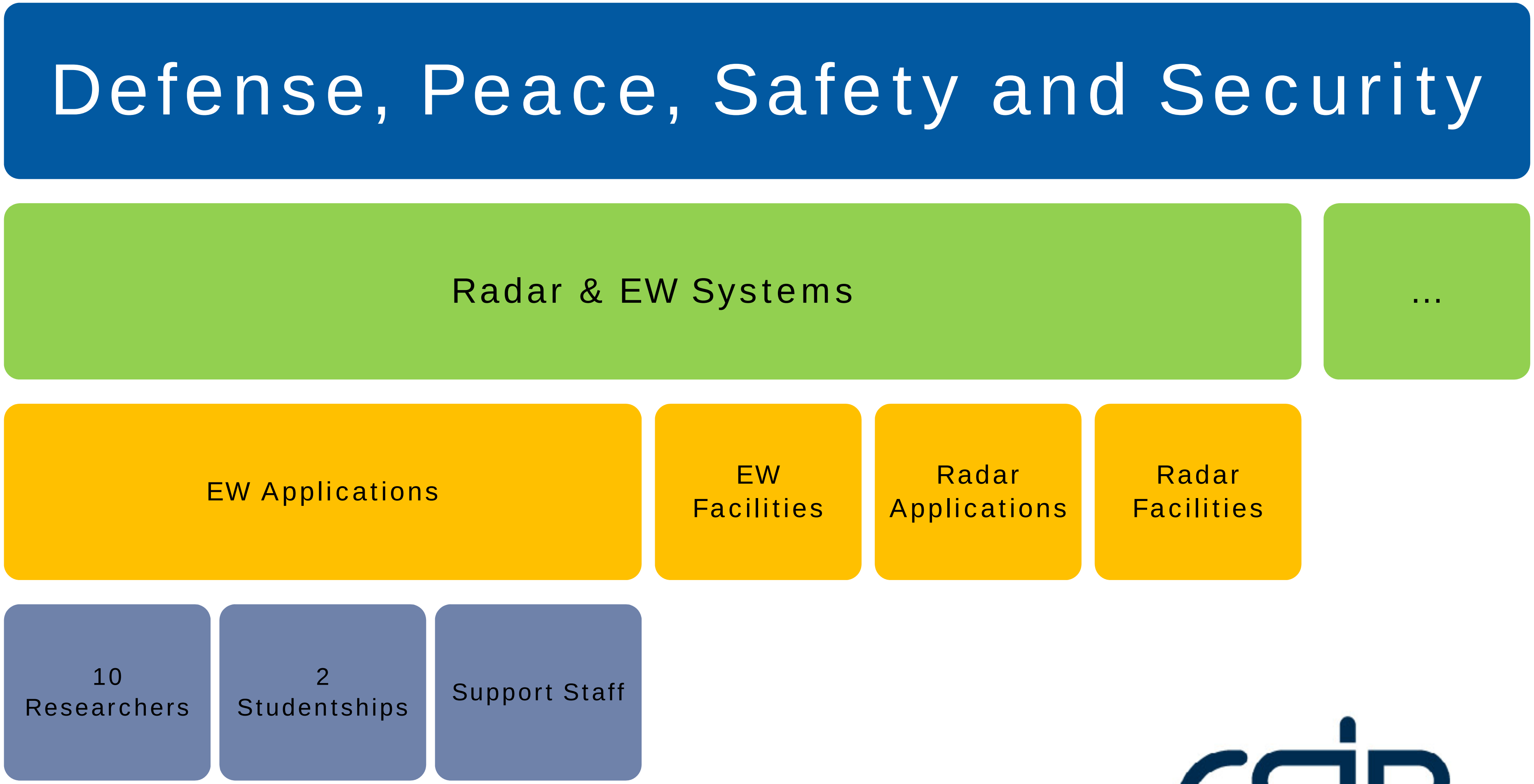
Presentation Outline

- Organisational structure
- EW research and development at the CSIR
- Problem statement
- Introduction to compressive sensing
- Results and findings
- Concluding remarks
- References

Organisational Structure in the CSIR



Defense, Peace, Safety and Security

Radar & EW Systems

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EW Applications

EW Facilities

Radar Applications

Radar Facilities

10 Researchers

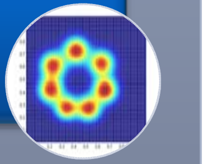
2 Studentships

Support Staff

EW Research and Development at the CSIR

- Electronic Support (ES)
  - Emitter parameter detection and estimation
  - Emitter location
  - Emitter classification
- Electronic Attack (EA)
- Electronic Protection (EP)
- EW/Radar and Communication facilities

Theoretical and Applied Research



- SEWES development
- EW receivers
- Communications modelling
- RCS modelling

Modelling & Simulation

- RCS measurement and analysis
- Operational support
- EW related training

Knowledge Base Application

Problem Statement in Context

- Modern EW receivers are required to operate in signal environments with ever-increasing density and diversity
  - The distinction between radar and communications is blurred
  - Commercial “invasion” of the military spectrum
- Receivers are required to
  - Cover wider instantaneous frequency bands
  - Maintain high probability of intercept (POI)
  - Detect, locate and classify with high accuracy etc.

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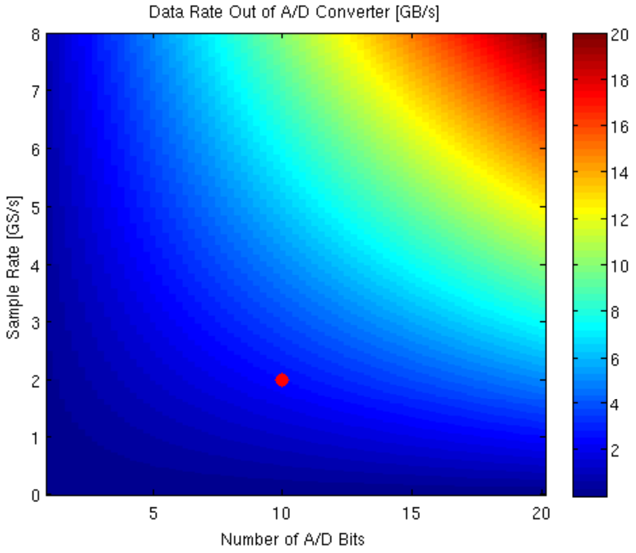
The Problem Gets Worse

- Wideband digital receivers inherently have high data rates
  - 2 GS/s A/D conversion using 10 bits, the data rate is 20 Gb/s
    - a 250 GByte disk fills up in 1.67 minutes – then what?
  - Multiple low rate A/D channels accumulate the same amount of data
    - Adding physical channels can be expensive
- Any processing causes bit growth
  - Thus, processing data rates are even higher
  - Reliable data transport becomes an issue



Consequences of a Non-solution

- Sampling with less bits reduces dynamic range
- Intercept probability is low
    - Receivers are forced to have look-through intervals
    - Sampling at slower rates imply narrow-band use
- Signal processing remains basic
    - LPI or specialised emitters cannot be detected
    - Poor ability to analyse diverse emitters
- Unwanted receiver latency
    - Undesirable in tactical applications where time is important
    - Detail signal analysis is done off-line

Would it be possible to represent, transport and process high data rate signals without losing the ability of the EW receiver to search for, detect, locate and classify emitters?

To answer this question we go against the common perceptions in data acquisition and processing

Introducing Compressive Sensing (CS)

- Conventional sampling of signals follow Shannon’s famous theorem
  - The sampling rate must be at least twice the maximum frequency present in the signal (the so-called Nyquist rate)
- CS theory states that signals can be recovered from far fewer samples or measurements over the conventional method
- For CS to be possible two principles apply
  - Sparsity
  - Incoherence

Sparse Representation of Signals

- Almost every signal has a representation in a *convenient* orthonormal basis
  - Fourier (frequency domain)
  - Cosine (real valued FFT)
  - Wavelet
  - Gabor (spatial frequency domain)

$$x(t) = \sum_{i=1}^{n} \psi_i(t) c_i$$

$$c_i = \langle x, \psi_i \rangle$$

- Sparsity relates to the degree of compression
- Signals are sparse when most of the coefficients are small and the few large coefficients contain most of the information
  - We can discard a large fraction of coefficients without significant loss

Incoherence

- It is common to sense signals in one basis and represent them in another basis
    - Frequency domain representation using time domain samples
- Coherence measures the largest correlation between any two elements of the sensing and representation basis

Time Domain	Frequency Domain
$\varphi_k[n] = \delta_k[n-k]$	$\psi_m[n] = e^{j2\pi mn/N}$
$\Phi = [\varphi_1, \varphi_2, \ldots, \varphi_k]$	$\Psi = [\psi_1^T, \psi_2^T, \ldots, \psi_m^T]$

$$\mu(\Phi, \Psi) = \sqrt{N} \max_{1 \le k, m \le N} \left| \langle \varphi_k, \psi_m \rangle \right|$$

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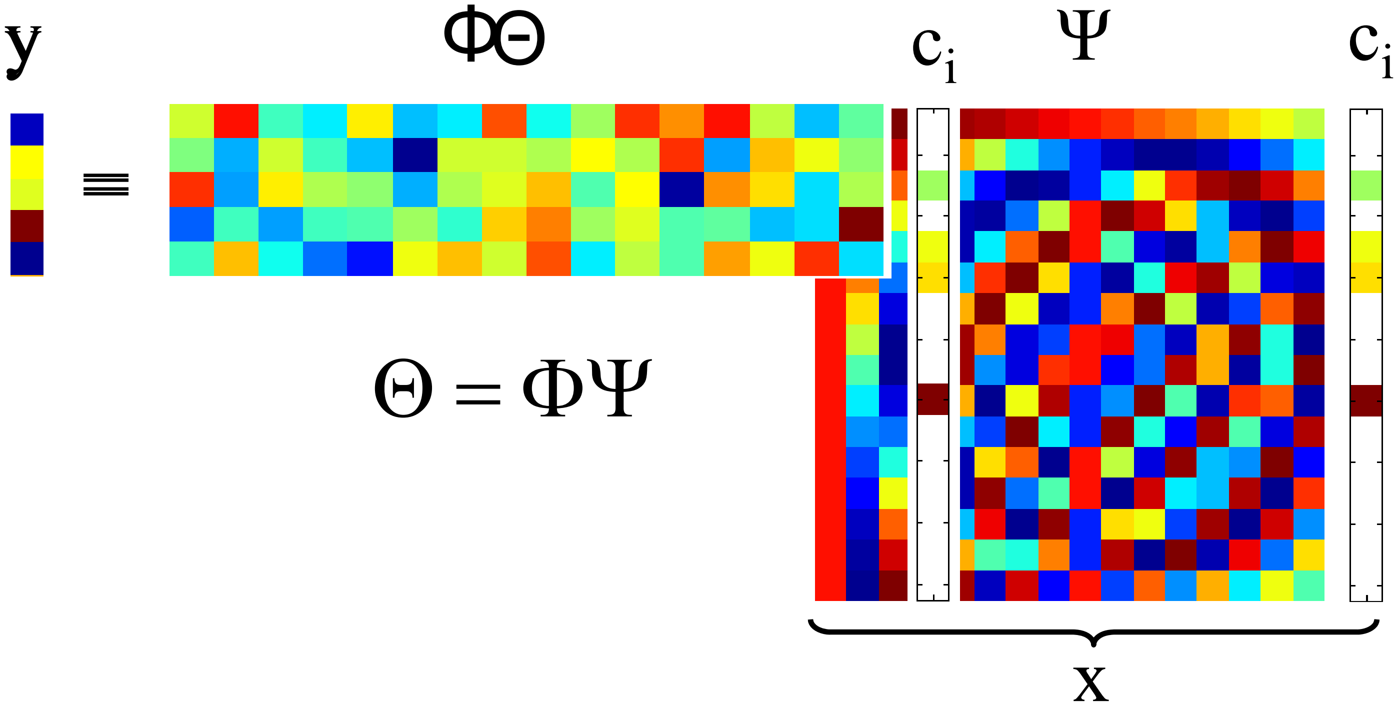
Useful Properties in CS

- Transformations are linear
  - Assuming sparsity and incohrence
- Random matrices are mostly incoherent with any basis
  - Φ matrices can literally be random values
- Thus *N* input samples are compressed into *M* values
  - $M << N$
  - K-sparse signal, $K \leq M$
  - $M = 3K$ works well in most cases

Graphical Example

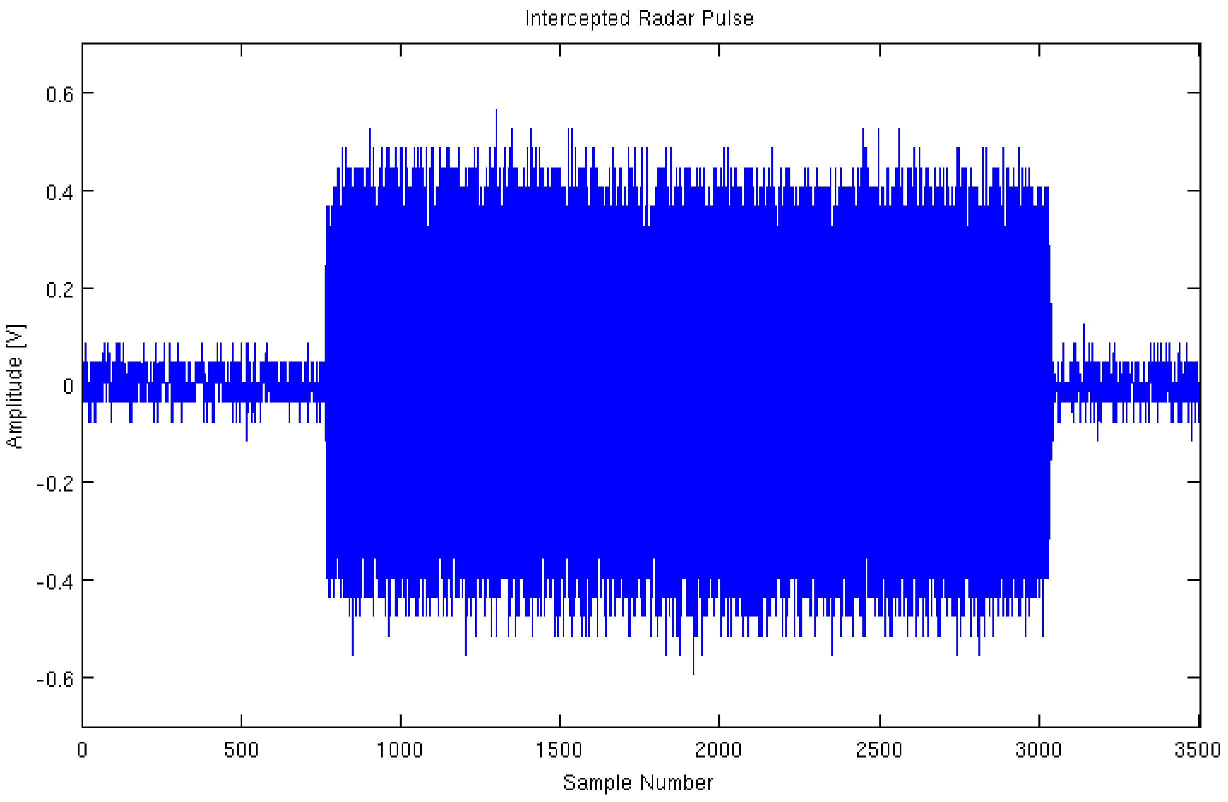


$$\Theta = \Phi\Psi$$

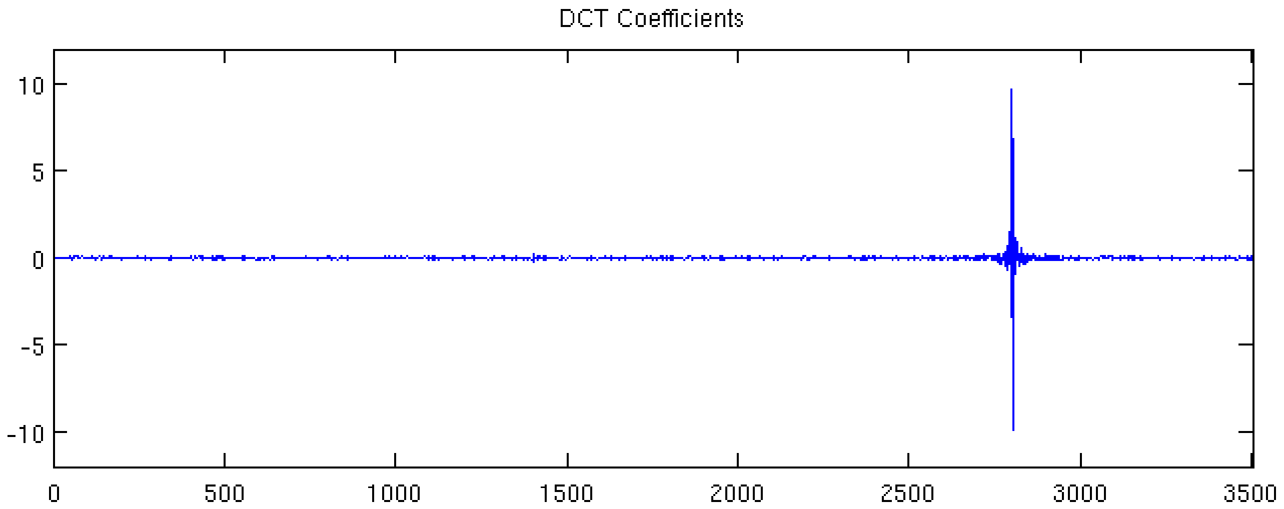
Results and Findings on EW Receiver Data

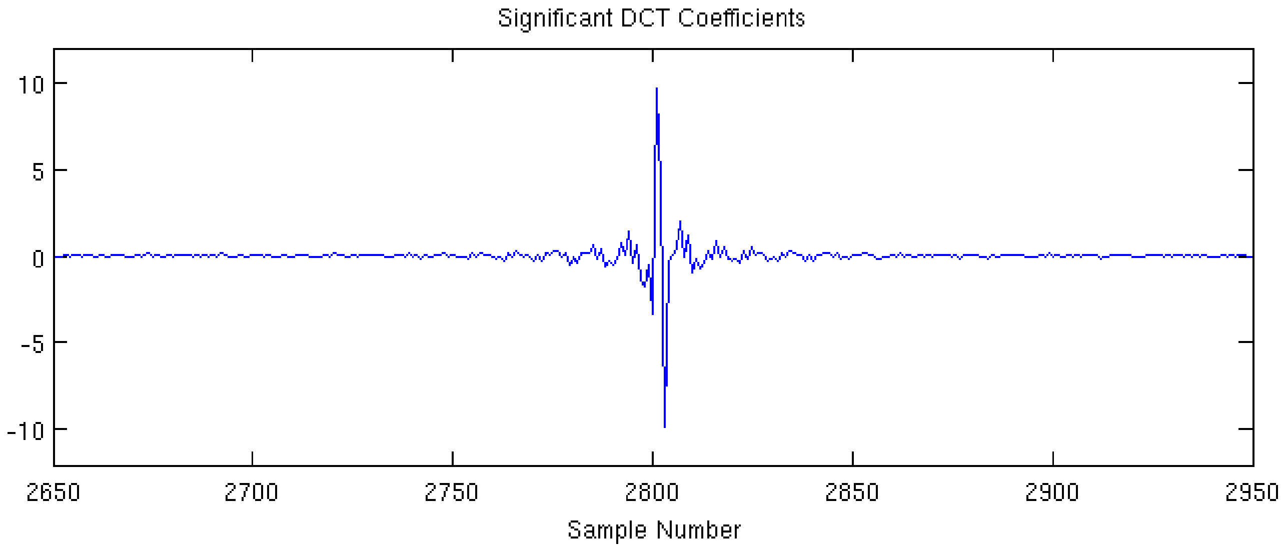
- Use typical intercepted radar data sampled at 250 MSps
  - Calculate signal sparsity on both DCT and DFT domains
  - Compress the signal using a matrix with random of values 0 and 1
  - Recover the signal from the compressed versions
  - Perform post signal recovery analysis

Intercepted Radar Pulse

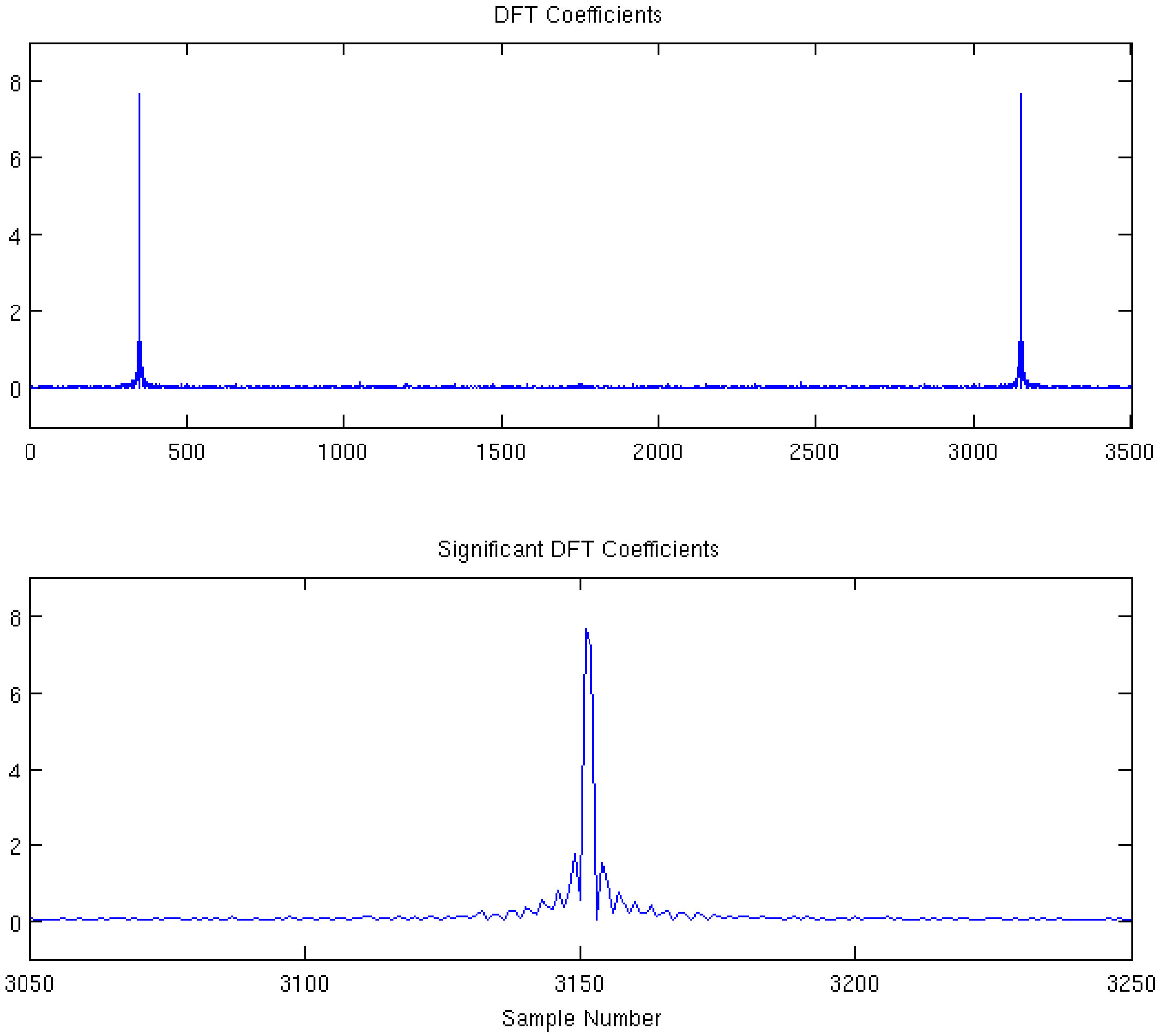


Discrete Cosine Basis

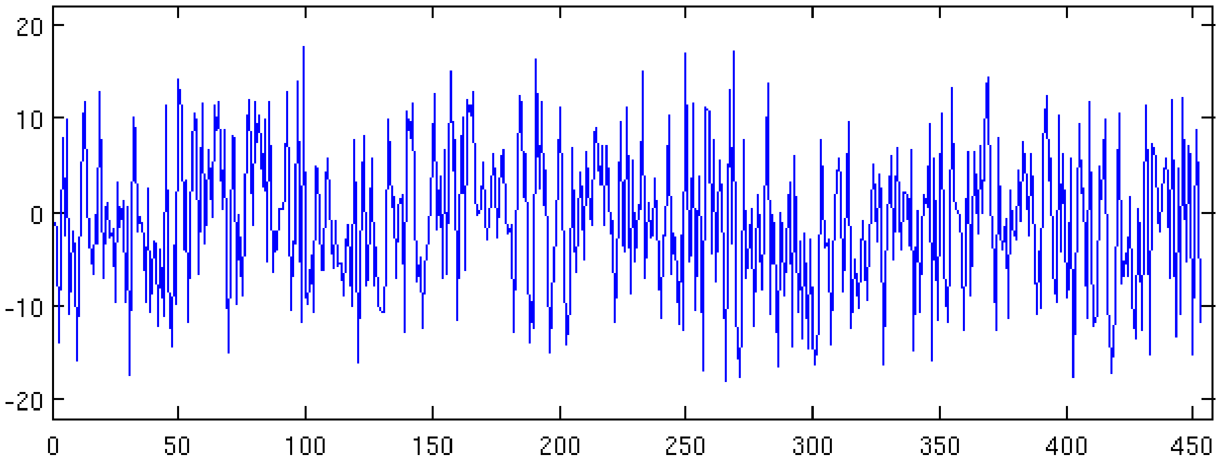

DCT Coefficients

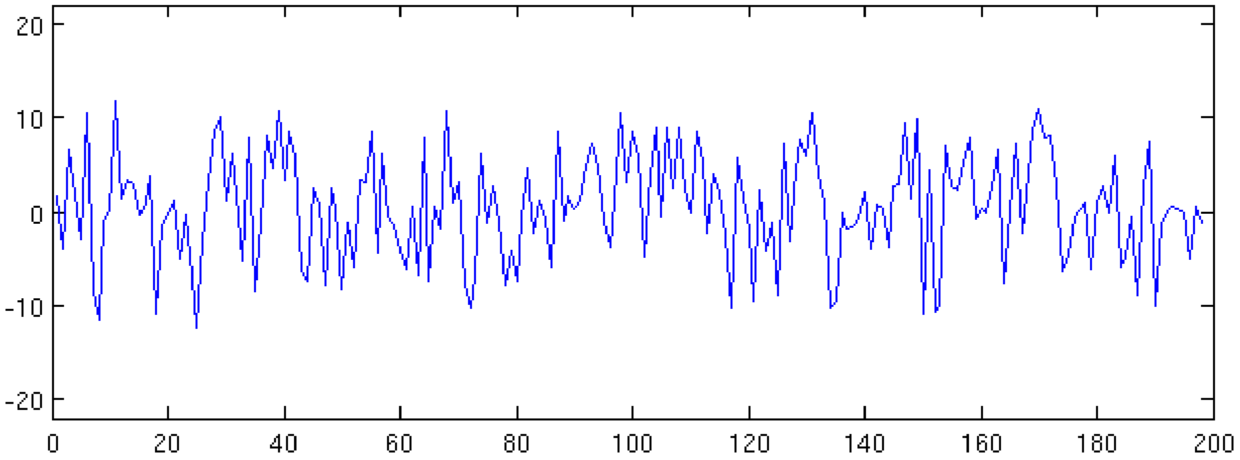

Significant DCT Coefficients

Discrete Fourier Basis

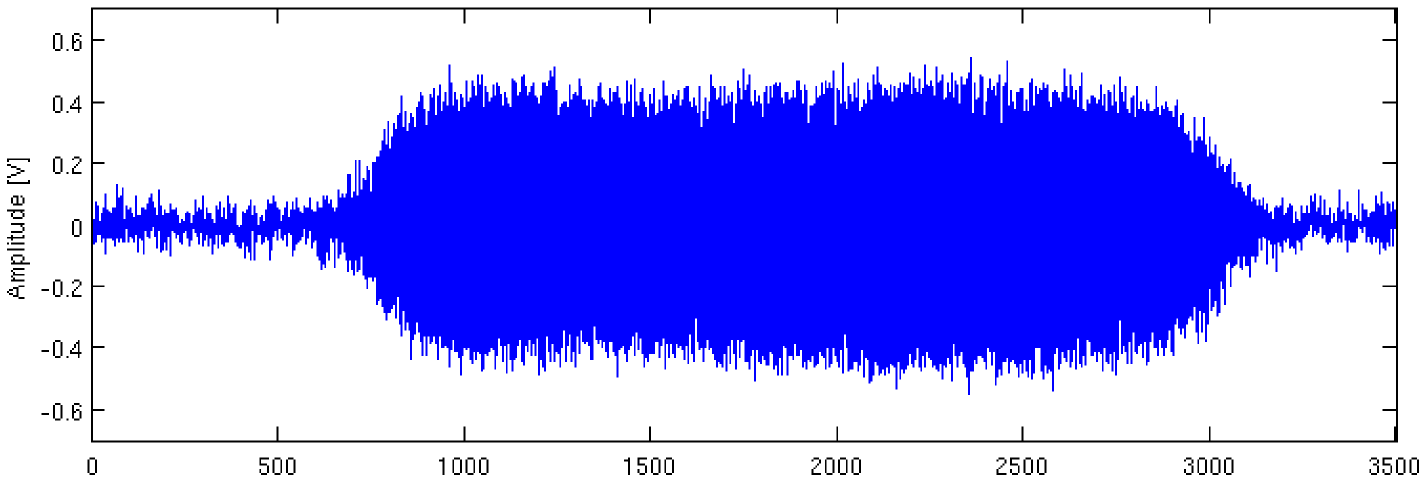


Compressed Data

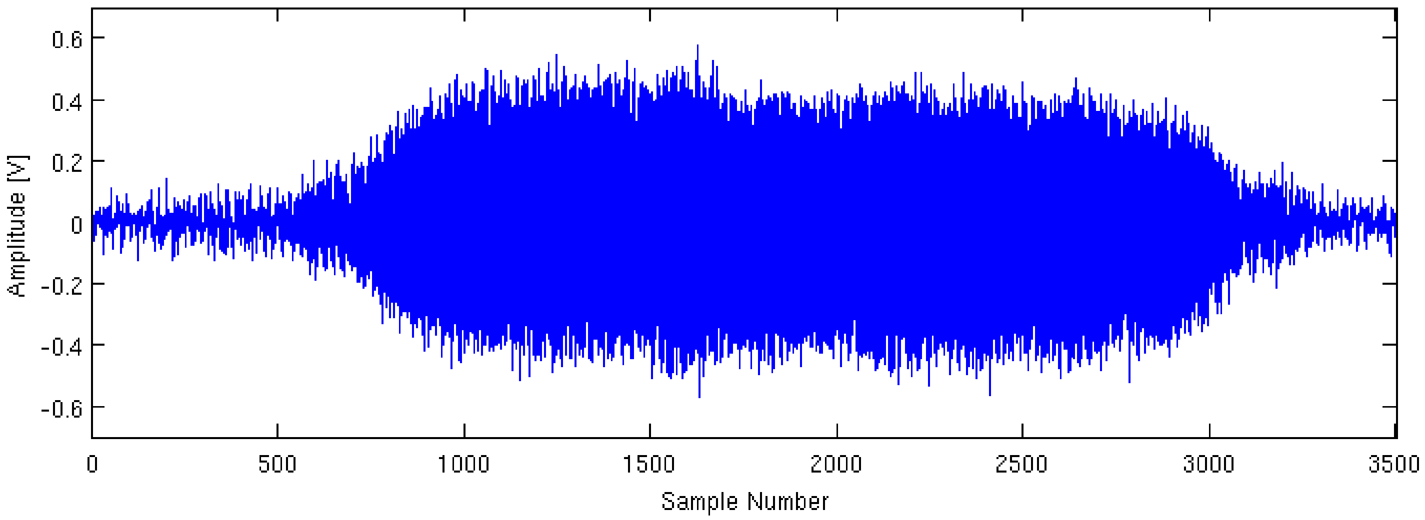

Compressed Observations in the DCT Basis


Compressed Observations in the DFT Basis

Recovered Signals



Time Series Data recovered for DCT Domain Compression



Time Series Data recovered for DFT Domain Compression

Post Recovery Analysis

- Sparsity
  - DCT basis sparsity 12.94 % (resultant data rate of 32.5 MSps)
  - DFT basis sparsity 5.66 % (resultant data rate of 15 MSps)
- Mean recovery error
  - DCT basis = 0.049
  - DFT basis = 0.058
- Recovery of pulse edges not desirable
  - Due to high frequency coefficients considered to be sparse
- Low recovery loss may be tolerated
  - Traditional parameter estimation will still work

Concluding Remarks

- Compressive sensing shows a great deal of promise at least in the transport of data at lower rates
    - If feasible in hardware it may solve the high data rate problem
- The Nyquist criterion is not violated
    - Initial sampling is still subject to it
    - Sampled data are compressed
- Literature suggests that signal processing and classification are possible using compressed observations of signals
    - Signals may only be recovered if required
    - Disqualifies popular data compression eg. Bzip2

Thank You

Any Questions?

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