Optimal Space-Time Transmit Signal Design For Multi-Static Radar

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Outline

- Motivation
- Approach
- Algorithm-1(Collective Projection Algorithm)
- Algorithm-2 (Individual Projection Algorithm)
- Numerical Results
- Radar Model
- Results using the Radar Model
- Conclusions and Future Work

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Objective

To develop Mathematical Algorithms that produce optimal space-time transmit signal, which would result in the responses from dissimilar targets to be as orthogonal as possible.

Motivation

- Why do we need the responses from dissimilar targets to be orthogonal to each other?
- REASON:

➢ The response signal of a radar in vector-matrix form is given as,

$$\boxed{\mathbf{r} = \sum_i \gamma_i \mathbf{H}_i \mathbf{s} + \mathbf{n} = \sum_i \gamma_i \boldsymbol{\rho}_i + \mathbf{n} = \mathbf{P}\boldsymbol{\gamma} + \mathbf{n}}$$

Where, $\mathbf{r}$ is the Measurement vector.

$\mathbf{H}_i$ is the Propagation matrix.

$\boldsymbol{\gamma}_i$ is the scattering coefficient of target-i.

$\mathbf{s}$ is the transmit signal.

$\boldsymbol{\rho}_i$ is the normalized response vector.

$$\boxed{\boldsymbol{\rho}_i = \mathbf{H}_i \mathbf{s}}$$

Estimators

• The response signal needs to be processed in order to estimate the scattering coefficients.

• <u>Matched Filter</u>

➢Most common and simple estimator.

➢The Scattering Estimate of a given target pixel using the Matched filter is given by,

$$\hat{\gamma}_i = \gamma_i + \sum_{i \neq j} \gamma_i \frac{\boldsymbol{\rho}'_i \, \boldsymbol{\rho}_j}{|\boldsymbol{\rho}_i|^2} + \frac{\boldsymbol{\rho}'_i \, \mathbf{n}}{|\boldsymbol{\rho}_i|^2}$$

➢ First term represents the desired estimate, second term is error due to clutter and the third term is error due to noise.

➢ Maximizes Signal to Noise Ratio (SNR), does nothing to suppress error due to clutter.

➢ A good estimate can be achieved if the responses from dissimilar target pixels are orthogonal to each other.

Hence in order to use the Matched filter and still get a good estimate we need,

$$\boldsymbol{\rho}'_i \boldsymbol{\rho}_j = 0 \quad \text{where} \quad i \neq j$$

Approach

- AIM : To come up with a space-time transmit signal that produces the response signals from dissimilar targets to be as orthogonal as possible.

- MINIMAX SOLUTION :

➢ Minimize the maximum correlation between two dissimilar targets.

➢ Try to find the “worst code” corresponding to the highest correlation.

➢ Find an orthogonal code to the worst code.

➢ This code reduces the maximum correlation.

- Based on this Minimax solution, an Optimization criteria (χ) is designed that helps in selecting the worst transmit codes.

Optimization Criteria χ

- A criteria is needed to help us select the worst codes and to come up with the desired transmit signal.
- The Optimization Criteria,

$$\chi = \frac{(\boldsymbol{\rho}'_i \boldsymbol{\rho}_i + \boldsymbol{\rho}'_j \boldsymbol{\rho}_j + \boldsymbol{\rho}'_i \boldsymbol{\rho}_j + \boldsymbol{\rho}'_j \boldsymbol{\rho}_i)}{(\boldsymbol{\rho}'_i \boldsymbol{\rho}_i + \boldsymbol{\rho}'_j \boldsymbol{\rho}_j)}$$

- Range of χ values is given by, $0 \leq \chi \leq 2$

$\chi = 0$ or $2 \rightarrow \boldsymbol{\rho}_i$ and $\boldsymbol{\rho}_j$ perfectly correlated.

$\chi = 1 \rightarrow \boldsymbol{\rho}_i$ and $\boldsymbol{\rho}_j$ perfectly orthogonal to each other.

Analysis of χ

- The optimization criteria in terms of the propagation matrices (**H**) is given as,

$$\chi = \frac{\mathbf{s}'(\mathbf{H}'_i\mathbf{H}_i + \mathbf{H}'_j\mathbf{H}_j + \mathbf{H}'_i\mathbf{H}_j + \mathbf{H}'_j\mathbf{H}_i)\mathbf{s}}{\mathbf{s}'(\mathbf{H}'_i\mathbf{H}_i + \mathbf{H}'_j\mathbf{H}_j)\mathbf{s}}$$

- Introducing two matrices **A** and **B** as,

$$\mathbf{A} = \mathbf{H}'_i\mathbf{H}_i + \mathbf{H}'_j\mathbf{H}_j + \mathbf{H}'_i\mathbf{H}_j + \mathbf{H}'_j\mathbf{H}_i$$
$$\mathbf{B} = \mathbf{H}'_i\mathbf{H}_i + \mathbf{H}'_j\mathbf{H}_j$$

- The optimization criteria can then be written as,

$$\chi = \frac{\mathbf{s}'\mathbf{A}\mathbf{s}}{\mathbf{s}'\mathbf{B}\mathbf{s}}$$

The C matrix

- Defining another matrix **C**, we can write χ as,

$$\boxed{\chi = \frac{\tilde{\mathbf{s}}'\mathbf{C}\tilde{\mathbf{s}}}{\tilde{\mathbf{s}}'\tilde{\mathbf{s}}}}$$

Where, $\mathbf{C} = \mathbf{B}^{-1/2}\mathbf{A}\mathbf{B}^{-1/2}$ and $\tilde{\mathbf{s}} = \mathbf{B}^{1/2}\mathbf{s}$

- The **C** matrix is a Positive-definite matrix, so Eigen analysis can be used.
- Representing **C** in its eigen values and eigen vectors we have,

$$\mathbf{C} = \sum_{n=1}^{\mathbf{N}} \lambda_n \hat{v}_n \hat{v}_n'$$

Where λ_n are the eigen values of the **C** matrix.

$\hat{v}_n$ are the eigen vectors of the **C** matrix.

$$\chi = \lambda_n = \frac{\hat{v}_n'(\mathbf{H}'_i\mathbf{H}_i + \mathbf{H}'_j\mathbf{H}_j + \mathbf{H}'_i\mathbf{H}_j + \mathbf{H}'_j\mathbf{H}_i)\hat{v}_n}{\hat{v}_n'(\mathbf{H}'_i\mathbf{H}_i + \mathbf{H}'_j\mathbf{H}_j)\hat{v}_n} = \frac{\hat{v}_n'\mathbf{C}\hat{v}_n}{\hat{v}_n'\hat{v}_n}$$

Correlation Coefficient (ξ)

- The Correlation Coefficient gives us the measure of similarity between two response signals.

$$\xi = \frac{\left|\boldsymbol{\rho}_i{}'\boldsymbol{\rho}_j\right|}{\left|\boldsymbol{\rho}_i\right|\left|\boldsymbol{\rho}_j\right|}$$

Minimize $\quad Max\{\xi\} \rightarrow 0$

- Relation between χ and ξ

$$\chi = 1 - \mathrm{Re}\left\{\frac{\boldsymbol{\rho}_i{}'\boldsymbol{\rho}_j}{\left|\boldsymbol{\rho}_i\right|\left|\boldsymbol{\rho}_j\right|}\right\}$$

$$\chi = 1 - \xi \rightarrow \mathrm{Im}\left\{\boldsymbol{\rho}_i{}'\boldsymbol{\rho}_j\right\} = 0$$

$$\chi \rightarrow 1;\ \ \xi \rightarrow 0$$

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Summary

- We intend to have $\boldsymbol{\rho}'_i \boldsymbol{\rho}_j = 0$ where $i \neq j$

- A solution **s**, such that, $\mathbf{s}'\mathbf{H}'_i \mathbf{H}_j \mathbf{s} = 0$

- The Optimization Criteria, $\chi = \dfrac{\mathbf{s}'(\mathbf{H}'_i \mathbf{H}_i + \mathbf{H}'_j \mathbf{H}_j + \mathbf{H}'_i \mathbf{H}_j + \mathbf{H}'_j \mathbf{H}_i)\mathbf{s}}{\mathbf{s}'(\mathbf{H}'_i \mathbf{H}_i + \mathbf{H}'_j \mathbf{H}_j)\mathbf{s}}$

Such that $\chi = 0$ or $2 \rightarrow \boldsymbol{\rho}_i$ and $\boldsymbol{\rho}_j$ are perfectly correlated.
$\chi = 1 \rightarrow \boldsymbol{\rho}_i$ and $\boldsymbol{\rho}_j$ are perfectly orthogonal to each other.

- Define **C** matrix, $\chi = \dfrac{\tilde{\mathbf{s}}'\mathbf{C}\tilde{\mathbf{s}}}{\tilde{\mathbf{s}}'\tilde{\mathbf{s}}}$ and $\mathbf{C} = \sum_{n=1}^{\mathbf{N}} \lambda_n \hat{v}_n \hat{v}_n'$

$$\chi = \lambda_n = \frac{\hat{v}_n'\mathbf{C}\hat{v}_n}{\hat{v}_n'\hat{v}_n}$$

- Correlation Coefficient, $\xi = \dfrac{|\boldsymbol{\rho}_i'\boldsymbol{\rho}_j|}{|\boldsymbol{\rho}_i||\boldsymbol{\rho}_j|}$

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Algorithm – 1 (Collective Projection Algorithm)

Inputs: H-matrices

$$\left.\begin{aligned} \mathbf{A}_{1j} &= (\mathbf{H}_1+\mathbf{H}_j)'(\mathbf{H}_1+\mathbf{H}_j) \\ \mathbf{B}_{1j} &= (\mathbf{H}_1'\mathbf{H}_1+\mathbf{H}_j'\mathbf{H}_j) \\ \mathbf{C}_{1j} &= \mathbf{B}^{-1/2}\mathbf{A}\mathbf{B}^{-1/2} \end{aligned}\right\} \quad j = 2 \text{ to T}$$

$$\mathbf{C}_{1j} = \sum_{n=1}^{\mathrm{N}} \lambda_n \hat{v}_n \hat{v}_n'$$

(N-1) worst eigen vectors picked

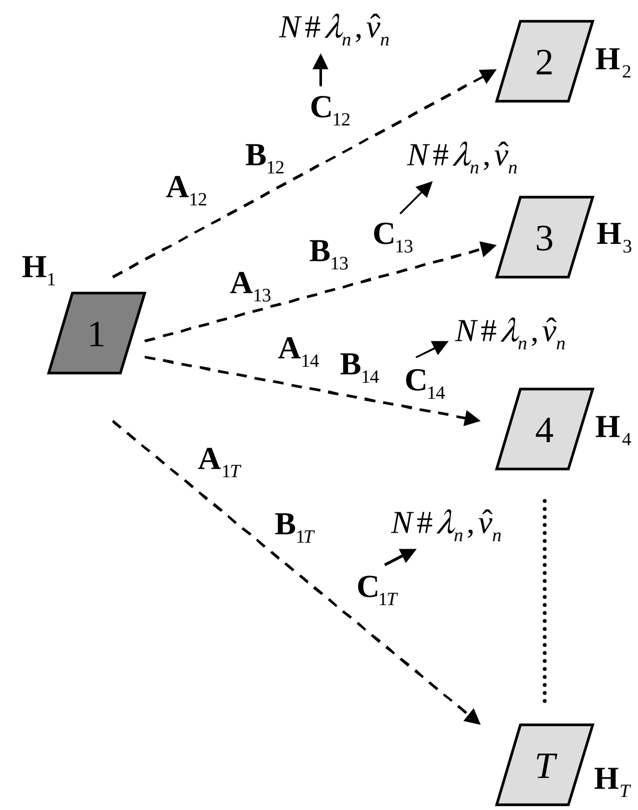
$$\tilde{\mathbf{W}} = [\tilde{\hat{v}}_1, \tilde{\hat{v}}_2, \tilde{\hat{v}}_3, \tilde{\hat{v}}_4 \ldots\ldots\tilde{\hat{v}}_{(N-1)}]^T$$

$$\mathbf{W.s} = 0$$

s → Transmit signal

Nth eigen value → bound

Worst Vec = $\hat{v}_n \longrightarrow$ Max or Min λ_n



(T-1) # **A**,**B**,**C** matrices

N(T-1)* # $\lambda_n, \hat{v}_n$

Numerical Analysis of Algorithm-1

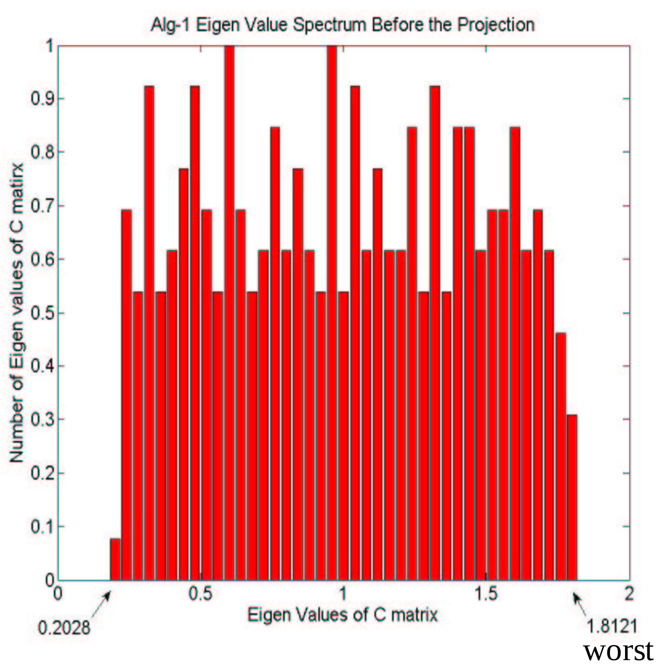
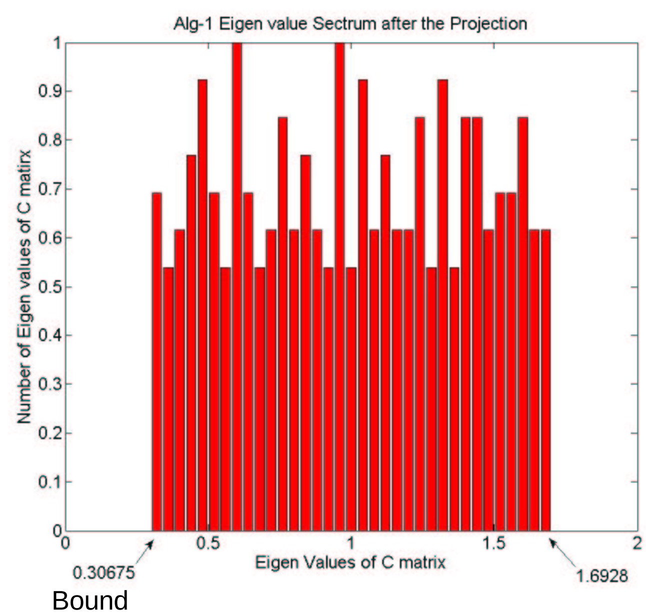
• The Propagation matrices (H-matrices) generated Randomly from a Gaussian Distribution of 0 mean and variance 1.

• Total Number of Measurements *(M)* =100

• Total Dimensions of the Tx signal *(N)* = 40

• Total Number of Targets *(T)* = 10

• **H** → *M x N x T*

<table>
<tr><th>Eigen value Spectrum Before Projection</th><th>Eigen value Spectrum After Projection</th></tr>
<tr><td>
</td><td>
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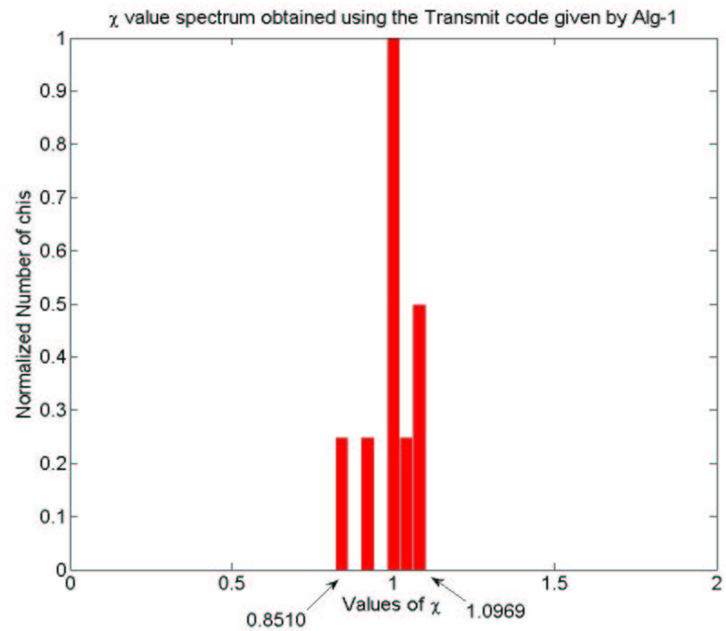
</table>

Conclusions from Algorithm-1

- **s** is a vector orthogonal to *(N-1)* vectors.



Eigen Value spectrum obtained using the s vector

- The χ values are well within the bound of 0.30675.

Conclusions:

- Tightened the χ-value bound from 1.8121 to 0.30675.

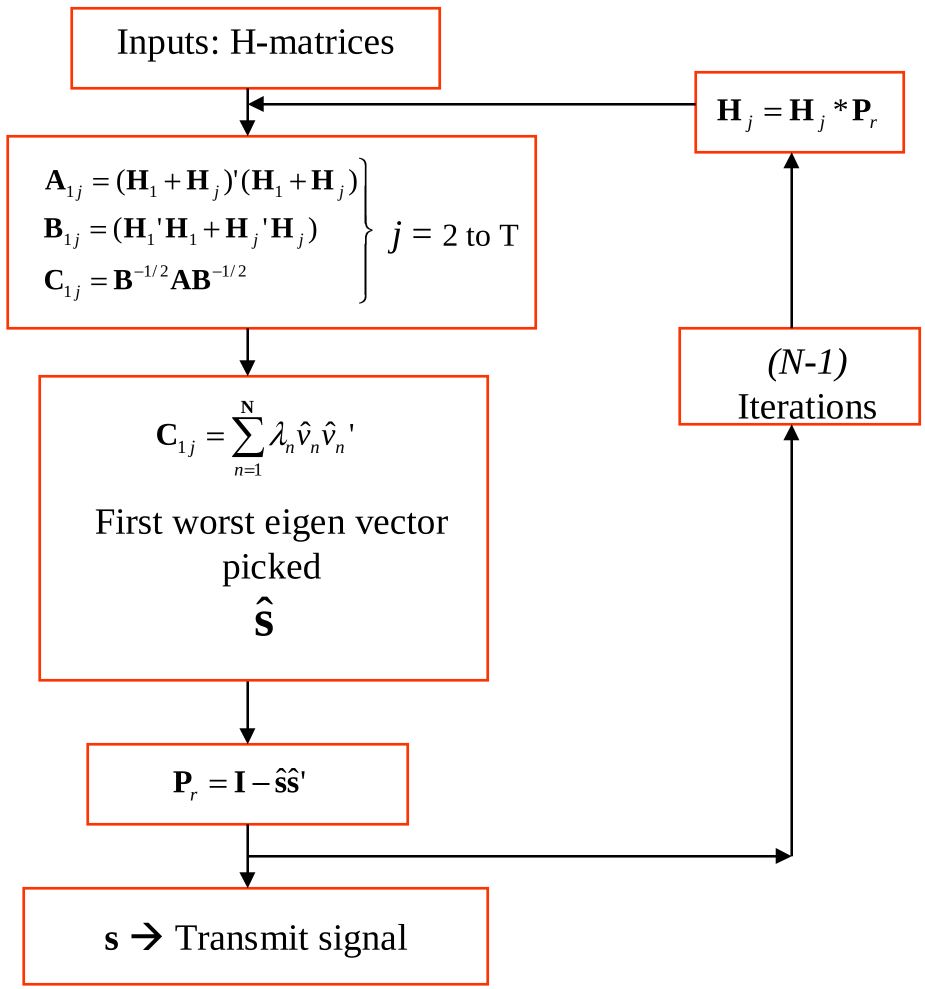
Problem :

- Correlation among *(N-1)* worst vectors.

Solution

- Algorithm-2

Algorithm-2 (Individual Projection Algorithm)



Numerical Analysis of Algorithm-2

• The Propagation matrices (**H**-matrices) generated Randomly from a Gaussian Distribution of 0 mean and variance 1.

• Total Number of Measurements *(M)* =100

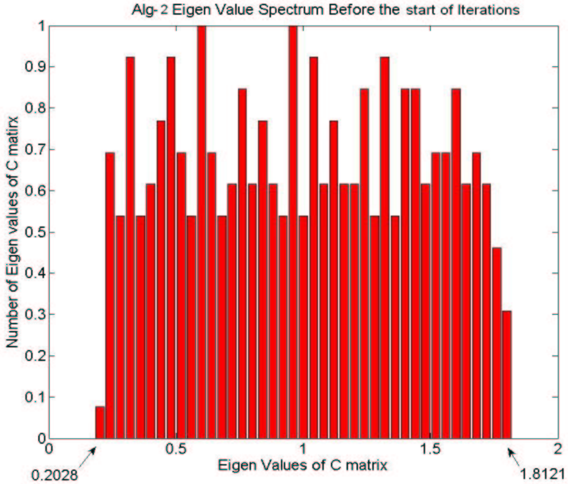
• Total Dimensions of the Tx signal *(N)* = 40

• Total Number of Targets *(T)* = 10

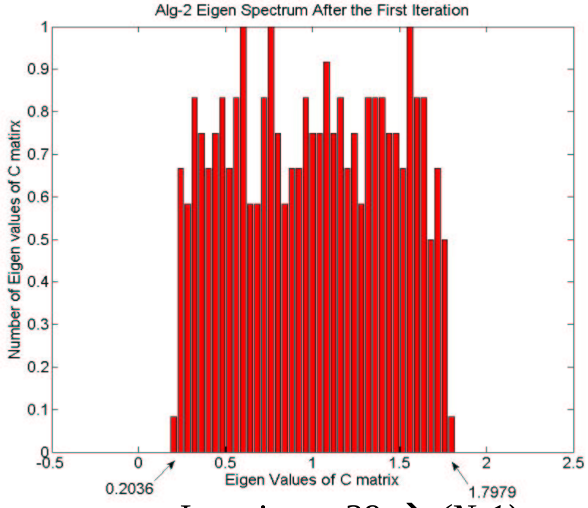
• The propagation matrices are given as inputs to the Algorithm.

Numerical Analysis of Algorithm-2

Before the start of the Iterations

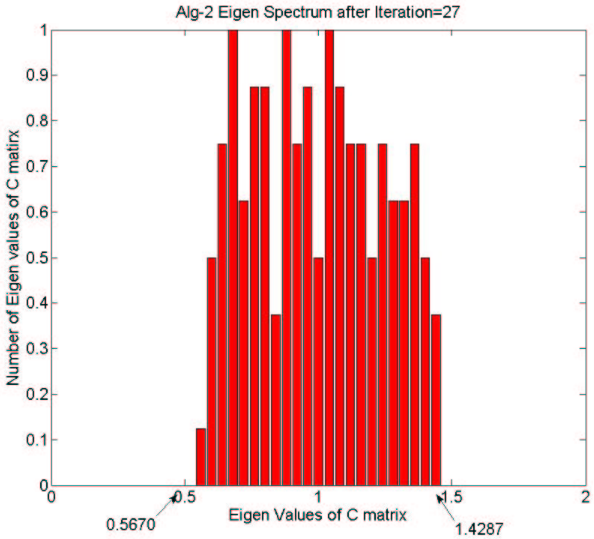


Iteration =1

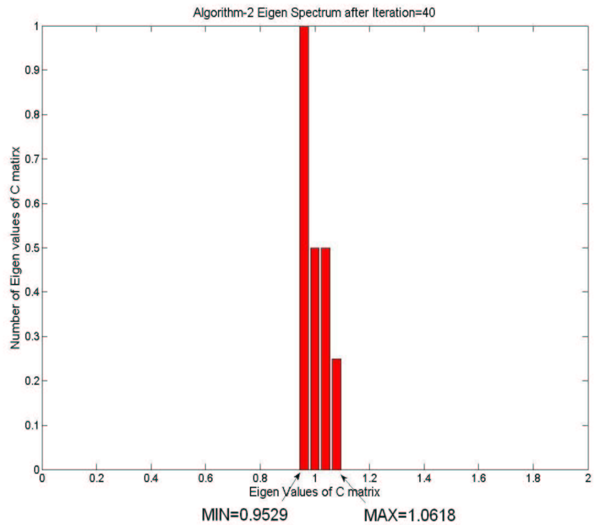


- Worst χ value has been improved from 1.8121 to 1.0167.
- No bound unlike Algorithm-1.

Iteration =27



Iteration = 39 → *(N-1)*

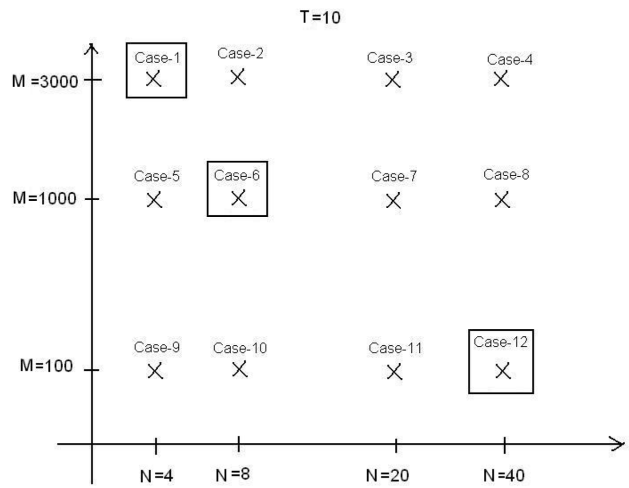


Comparison of Alg-1 and Alg-2

- Performances of Algorithm-1 (Collective Projection) and Algorithm-2 (Individual Projection) are compared.
- The Propagation Matrices (H-matrices) are generated randomly from 0 mean and variance 1 Gaussian Distribution.
- Monte Carlo Loop = 20
- The histograms of the χ values and Maximum Correlation Coefficient values are compared

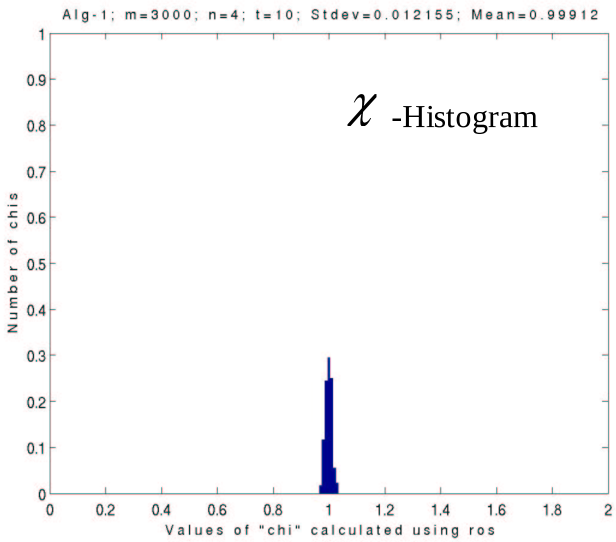
$$\chi = \frac{\tilde{\mathbf{s}}'\mathbf{C}\tilde{\mathbf{s}}}{\tilde{\mathbf{s}}'\tilde{\mathbf{s}}} \qquad \xi = \frac{|\boldsymbol{\rho}_i'\boldsymbol{\rho}_t|}{|\boldsymbol{\rho}_i||\boldsymbol{\rho}_t|}$$

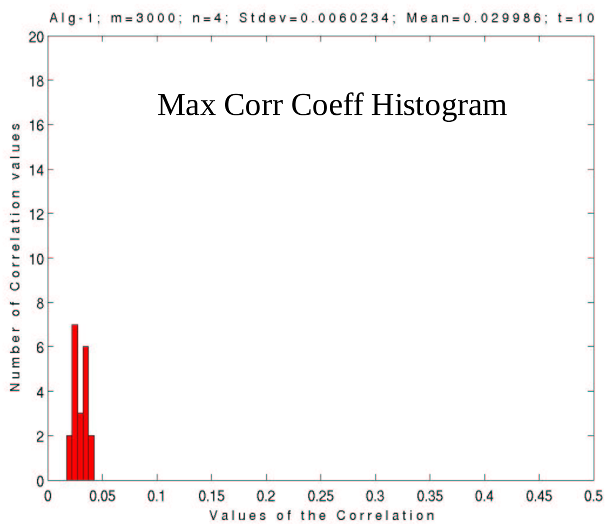
Different Cases for which the Algorithms have been compared



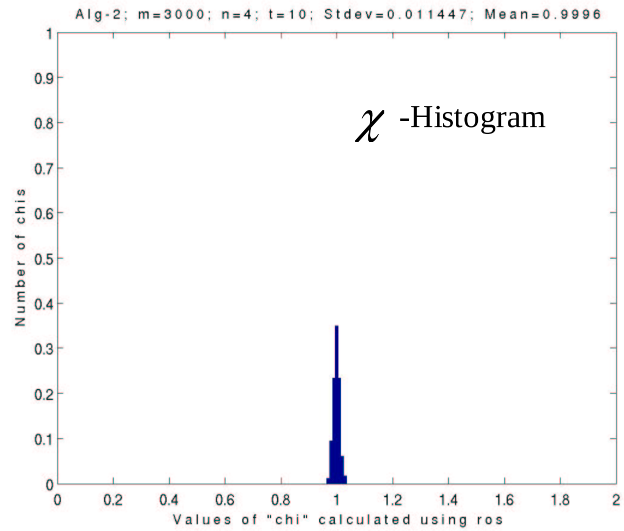
Case-1: **M=3000**; **N=4**; T=10

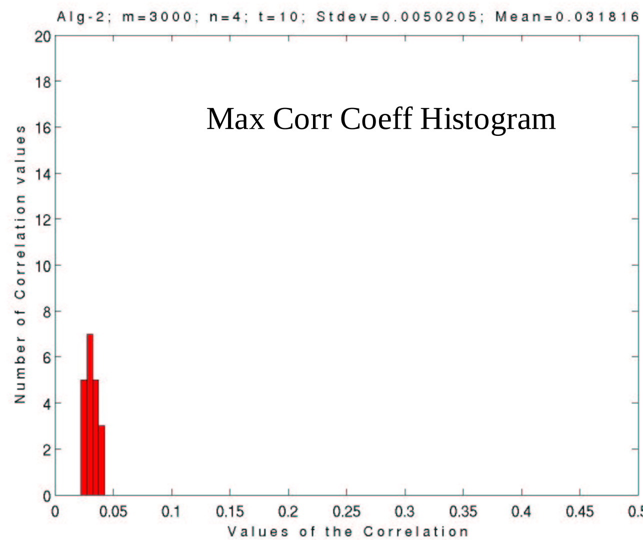
Algorithm-1





Algorithm-2





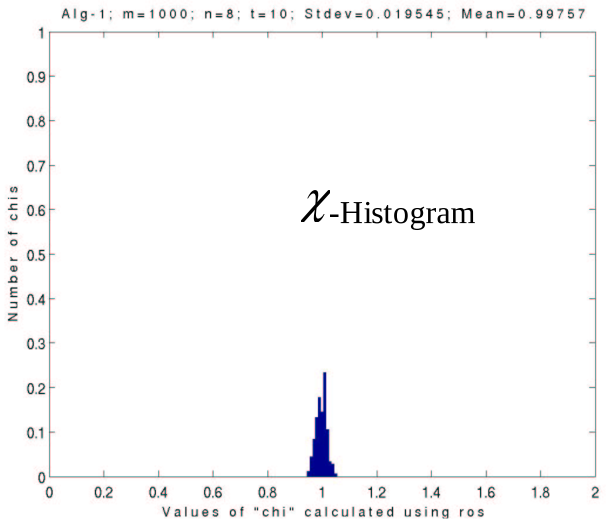
Ratio of χ Std

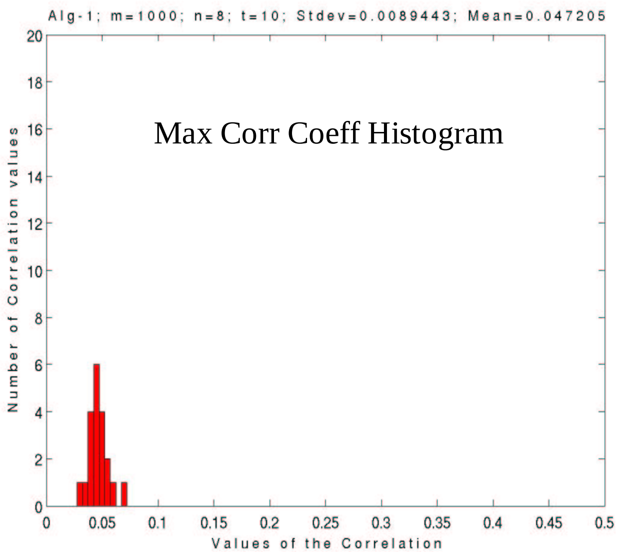
Alg1 / Alg2 = 1.06

Ratio of Means of Max ξ Alg1/ Alg2= 0.9424

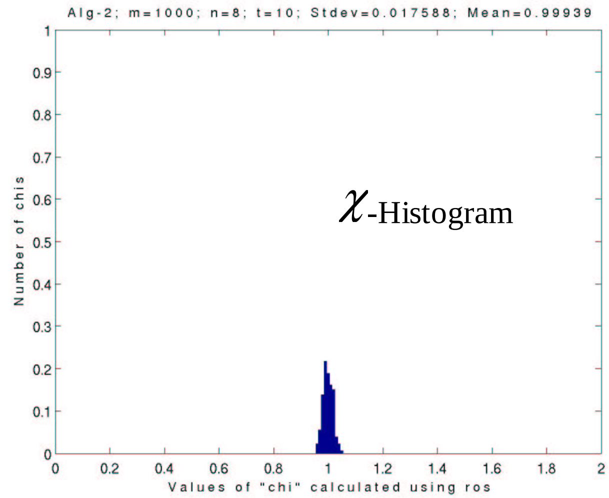
Case-6: **M=1000**; **N=8**; T=10

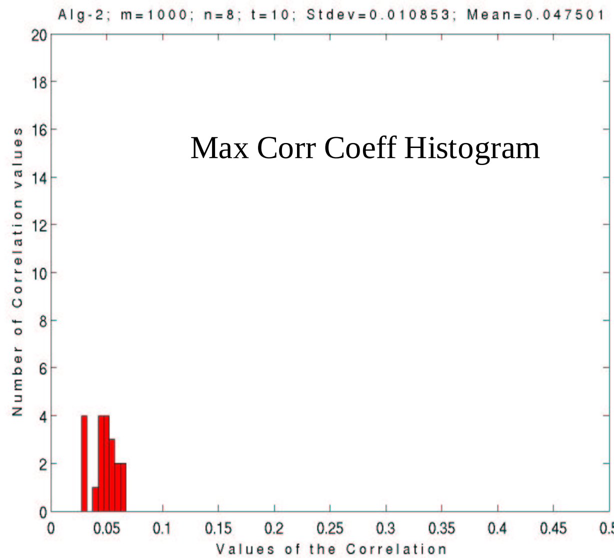
Algorithm-1





Algorithm-2





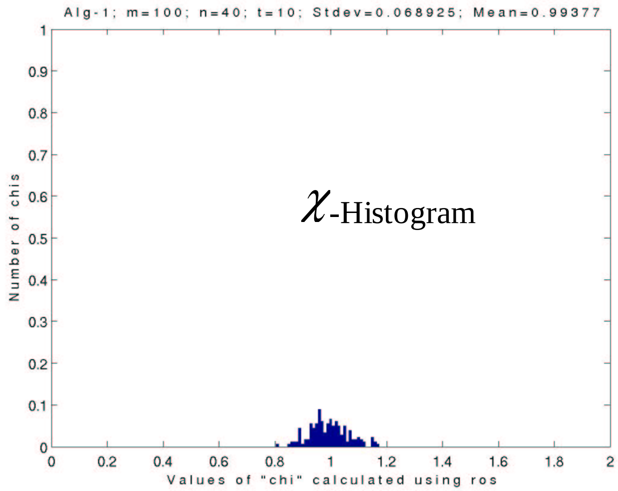
Ratio of χ Std

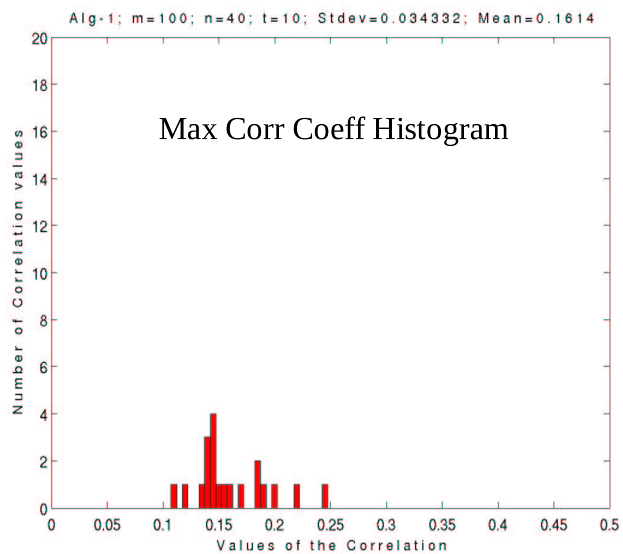
Alg1 / Alg2= 1.11

Ratio of Means of Max ξ Alg1 / Alg2= 0.99

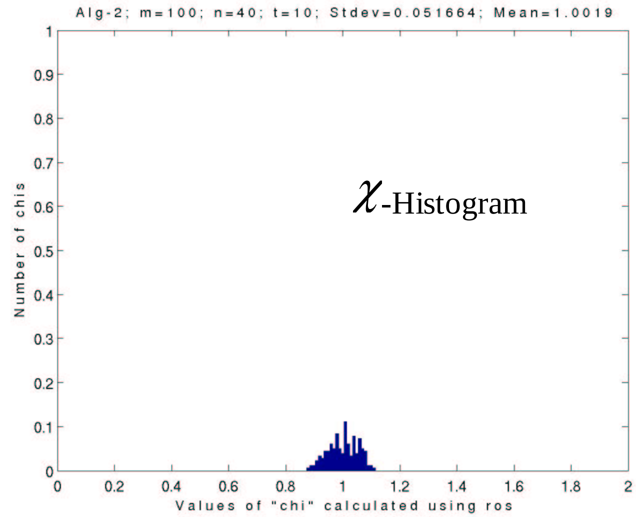
Case-16: **M=100**; **N=40**; T=10

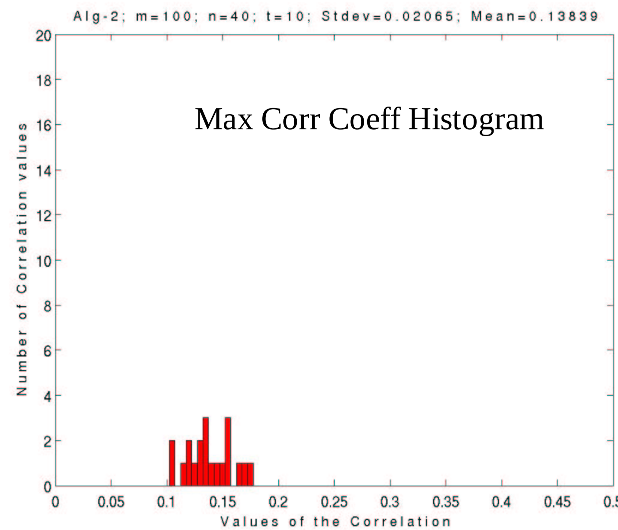
Algorithm-1





Algorithm-2





Ratio of χ Std

Alg1 / Alg2= 1.33

Ratio of Means of Max ξ Alg1 / Alg2= 1.165

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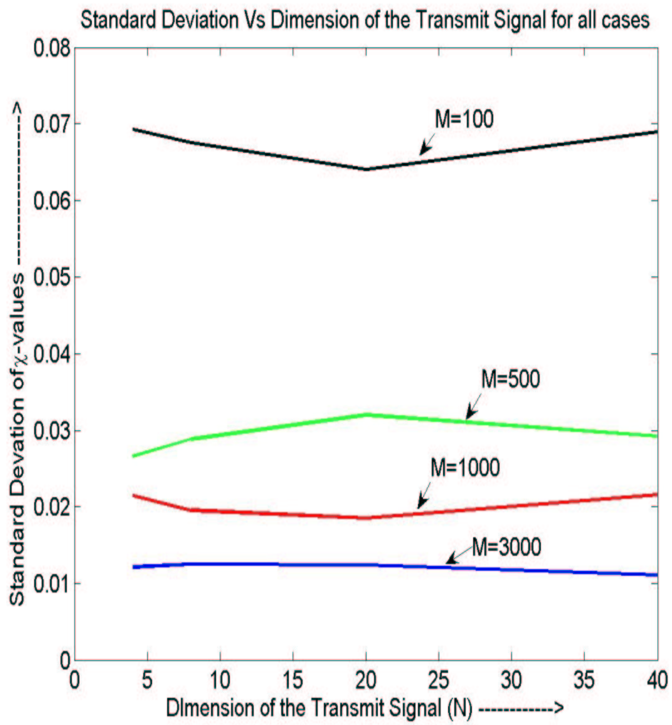
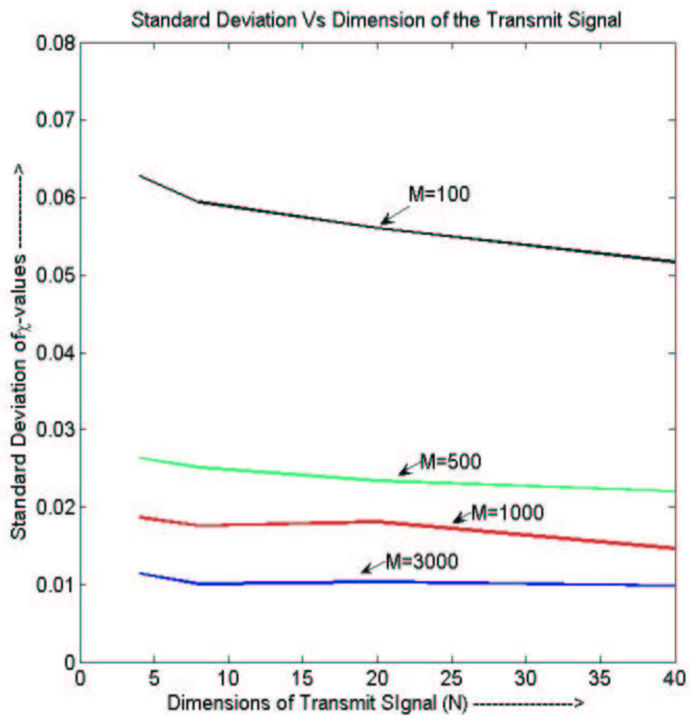
Summary of All the Cases

• Plots summarizing the standard deviation of χ values for all the cases.

Algorithm-1



Algorithm-2

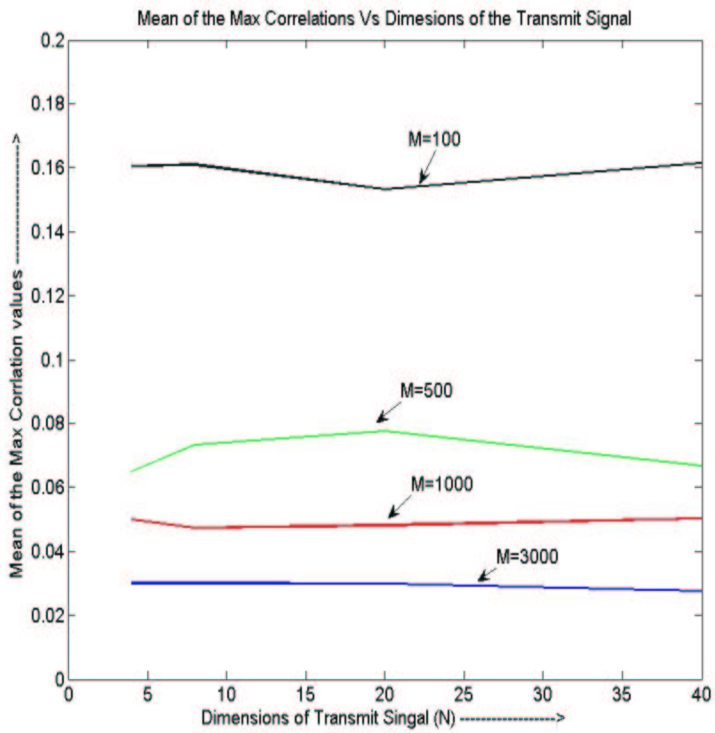


• Not much improvement in performance of Alg-2 compared to Alg-1, when constant-H matrices are used.

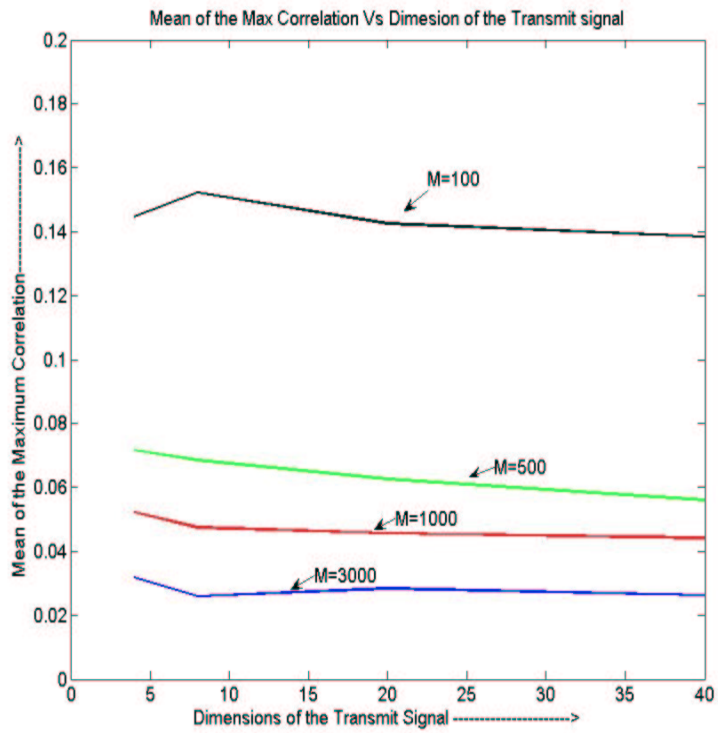
Summary of All the Cases

• Plots Summarizing the Means of Max Correlation Coefficient Values for all the cases.

Algorithm-1



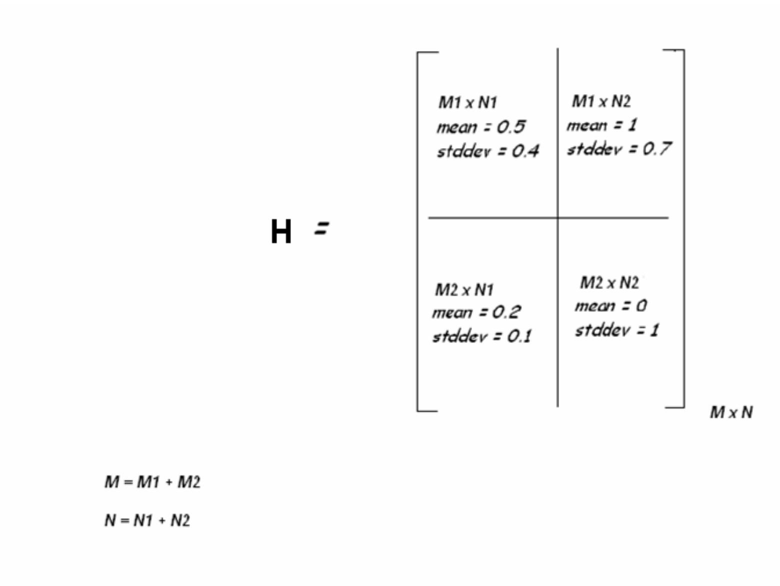
Algorithm-2



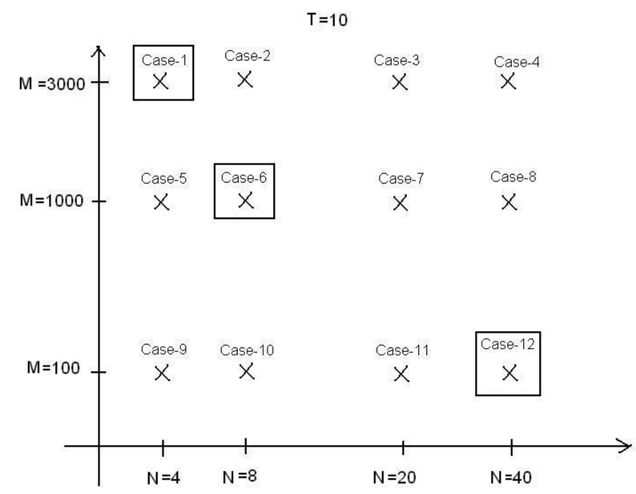
• Not much improvement in performance of Alg-2 compared to Alg-1, when constant-H matrices are used.

Varying Propagation Matrices (**H**-matrices)

• H-matrices are generated from four different Gaussian distributions.



Composition of **H**-matrix



Different Cases of comparison

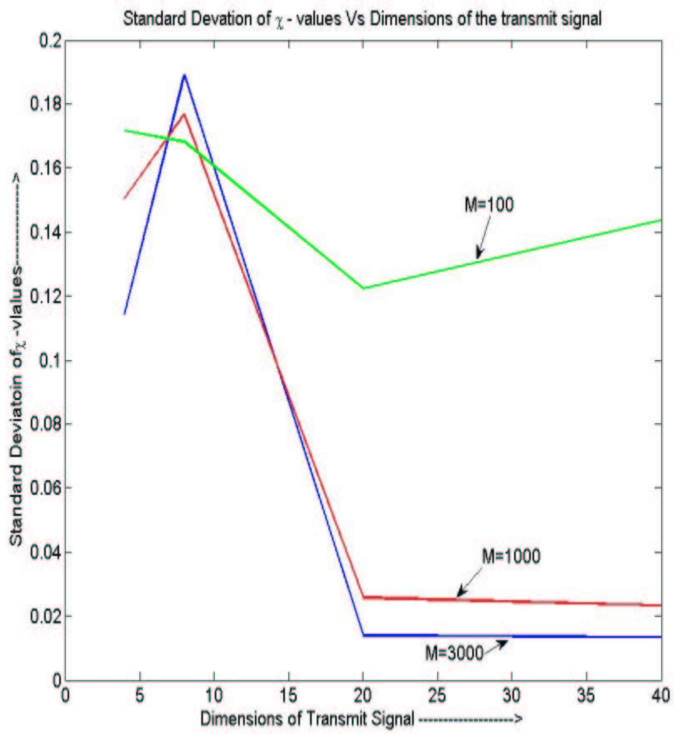
• These varying **H**-matrices are used as inputs to the Algorithms.

• Performance of the Algorithms are compared for the same cases as in previous slides.

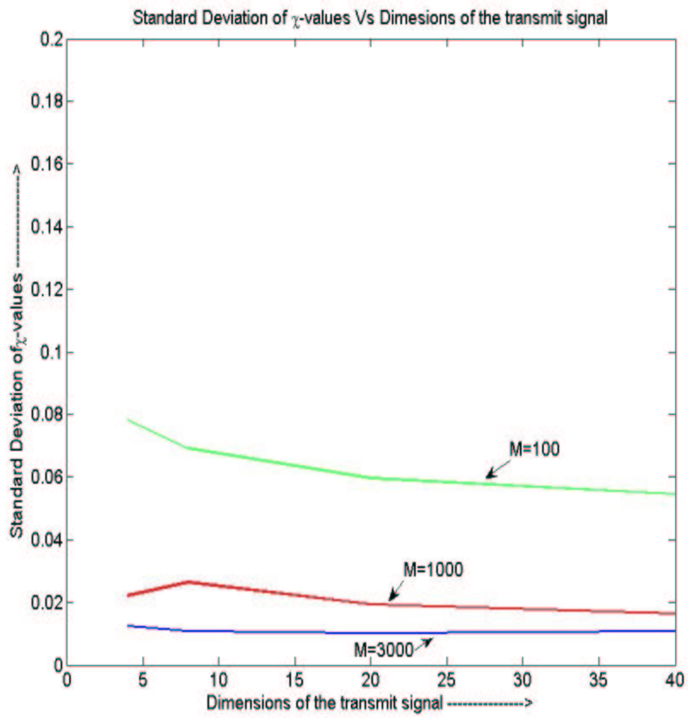
Summary of All the Cases

• Plots Summarizing the standard deviation of χ values for all the cases.

Algorithm-1



Algorithm-2

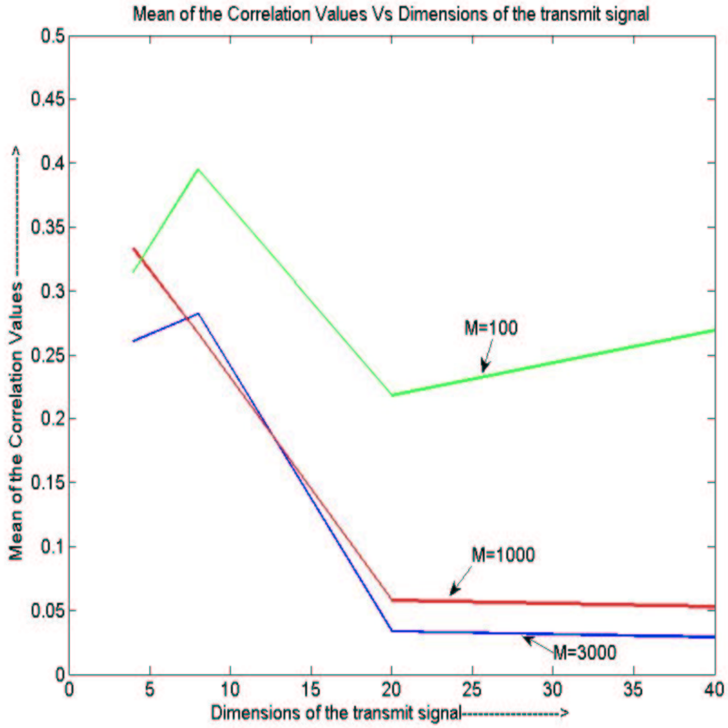


• Significant improvement in the performance of Algorithm-2 compared to Algorithm-1

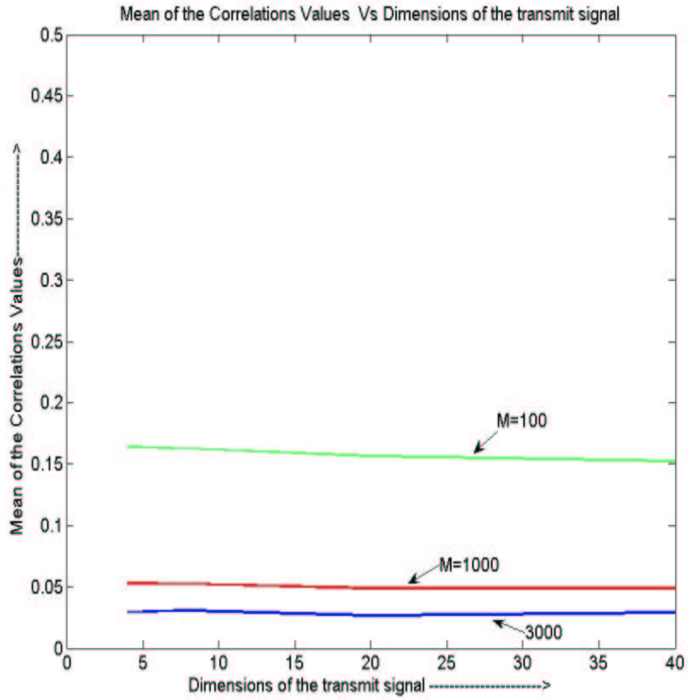
Summary of All the Cases

• Plots Summarizing the Means of Max Correlation Coefficient Values for all the cases.

Algorithm-1



Algorithm-2



• Significant improvement in the performance of Algorithm-2 compared to Algorithm-1

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Conclusions from the Comparisons

- Higher the total number of measurements (M), and higher the total number of dimensions (N), better is the performance of both Algorithms.

- The performance of Algorithm-2 largely depends on the structure of **H**-matrices.

- Hence, the performance of Algorithm-2 is either same or better than Algorithm-1.

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Question : How good is the result given by Algorithm-2 in general ??

Or

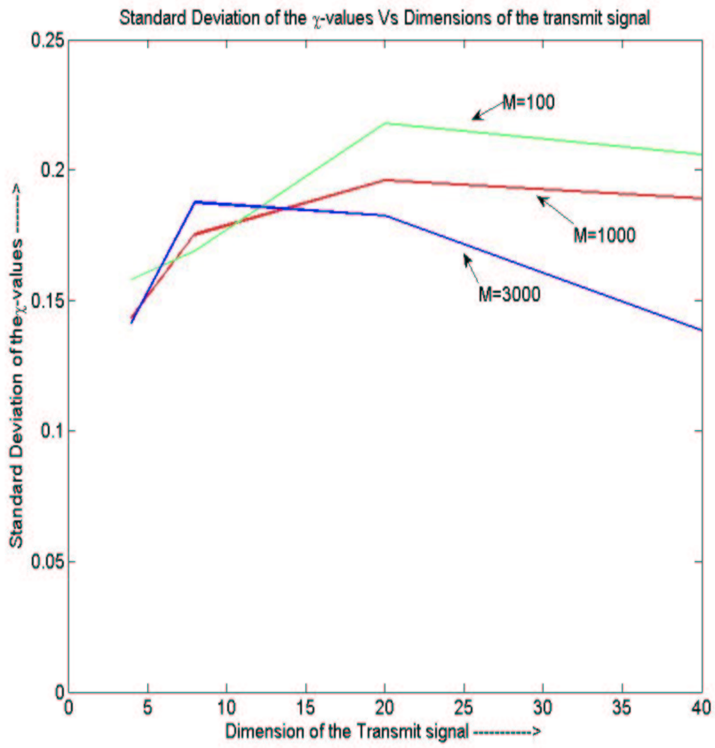
Is there a yardstick to measure the performance of the Algorithm?

Answer : Compare the performance with ***Random code*** and code given by ***Genetic Algorithm***

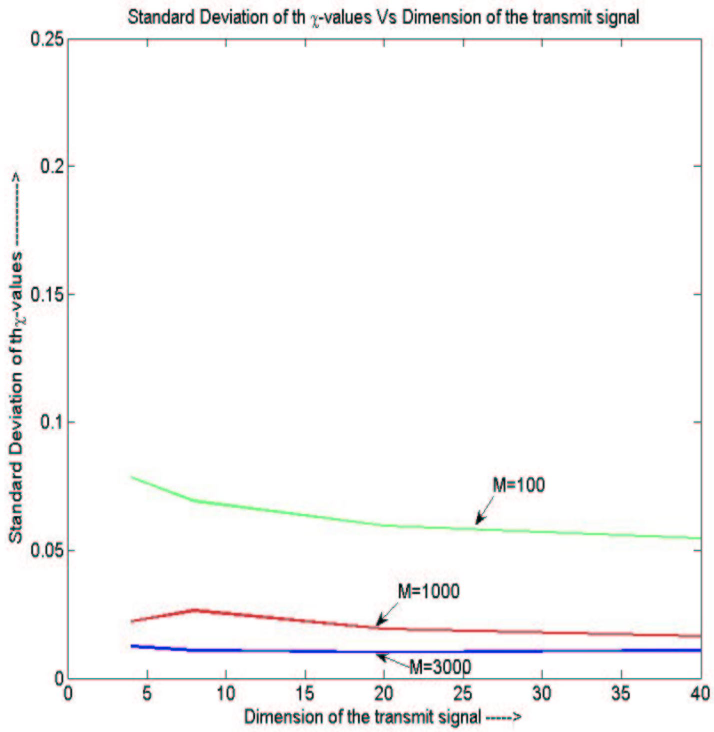
Comparison of Algorithm-2 with Random Code

• Plots Summarizing the standard deviation of χ values for all the cases.

Random Code



Algorithm-2

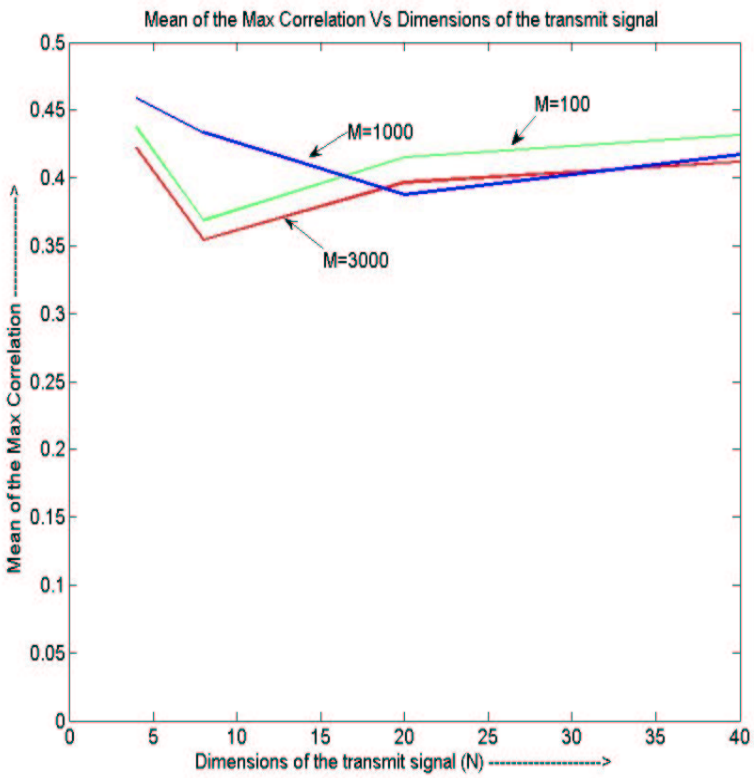


• Algorithm-2 performs much better than a randomly chosen code.

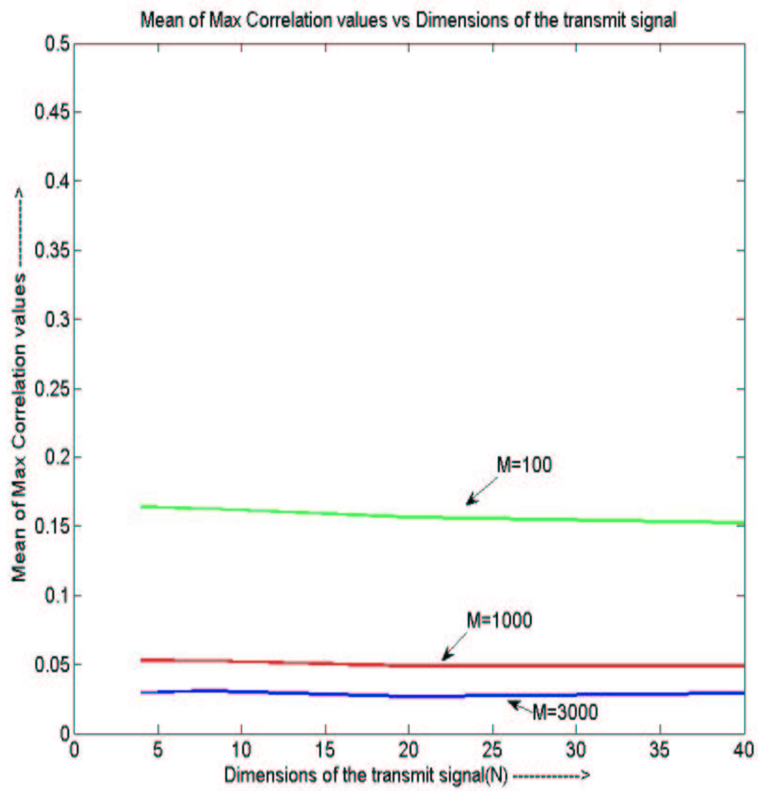
Comparison of Algorithm-2 with Random Code

• Plots Summarizing the Means of Max Correlation Coefficient Values for all the cases.

Random Code



Algorithm-2



• Algorithm-2 performs much better than a randomly chosen code.

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Comparison with Genetic Algorithm

- **Genetic Algorithm** (Master's Project by Fernando Soto)

➢ A group of possible codes is considered.

➢ A new group of fit solutions is selected out of the old group and are combined.

➢ This process is continued till there is no improvement in the criteria.

- Varying-**H** matrices were used with *M*=100; *N*=8; *T*=10
- Criteria given to the Genetic Algorithm
- **s** – solution that minimizes the largest β_t value.

$$\beta_t = \frac{|\boldsymbol{\rho}_1{}'\boldsymbol{\rho}_t|^2}{|\boldsymbol{\rho}_1|^2|\boldsymbol{\rho}_t|^2} = \frac{|\mathbf{s}'\mathbf{H}'_1\mathbf{H}_t\mathbf{s}|^2}{|\mathbf{H}_1\mathbf{s}|^2|\mathbf{H}_t\mathbf{s}|^2} \qquad \text{Where,} \quad t \in \{2,3,4........,T\}$$

Comparison with Genetic Algorithm

Genetic Algorithm

T	β_t
Target-2	0.0001
Target-3	0.0000
Target-4	0.0002
Target-5	**0.0011**

Target-6	0.0002
Target-7	0.0002
Target-8	0.0002
Target-9	0.0000
Target-10	0.0008

Max β_t = 0.0011 = -30dB

Algorithm-2

T	β_t
Target-2	0.0162
Target-3	0.0021
Target-4	0.0092
Target-5	0.0041

Target-6	0.0003
Target-7	**0.0175**
Target-8	0.0019
Target-9	0.0057
Target-10	0.0124

Max β_t = 0.0175 = -18dB

- Genetic Algorithm is better by 12 dB compared to Algorithm-2

Disadvantages of Genetic Algorithm

- No mathematical basis for the Algorithm.
- Takes huge amount of time compared to Algorithm-2.
- Cannot be used where processing time is an important factor.

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Radar Model

Performance of the Algorithm using the Radar Model.

Radar Model

• The Radar Model has been defined in three major parts.

➢ Transmit signal.

➢ Target set

➢ Received Measurements.

• **Transmit Signal**

➢ Defined as a set of complex valued samples in a 5 dimensional space.

$$\bar{z}_{jk} = [x_j, y_j, z_j, t_k, \omega_k]^T$$

Where, $J \rightarrow$ total number of spatial samples (Total number of transmit elements).

$K \rightarrow$ total number of temporal samples.

Radar Model

- Further, the transmit signal is defined as, a superposition of wide timewidth and wide bandwidth orthonormal basis functions.
- Slow time functions *(P)* and Fast time functions *(Q)*
- Total # of orthonormal basis functions = *PQ*
- The response vector is transformed as,

$$\boldsymbol{\rho}_i = \mathbf{H}_i \mathbf{s} = \mathbf{H}'_i \mathbf{S}$$

- The $\mathbf{H}'_i$ matrices which relate the received signal to the weights of the basis functions are used as inputs to the Algorithm.
- Algorithm works to find the best weight vector for the basis functions.

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Radar Model

- **Target set**

➢ A total of N_t number of targets are considered.

➢ A grid of N_x x N_y is defined such that $N_t = N_x N_y$.

➢ The target position vector is defined in 4 dimensional subspace and is given as,

$$\bar{y}_t = [x_t, y_t, z_t, v_t]^T$$

➢ The spacing between the targets is set equal to the Doppler resolution and Range resolution in *x* and *y* directions respectively.

Radar Model

- **Received Measurements**

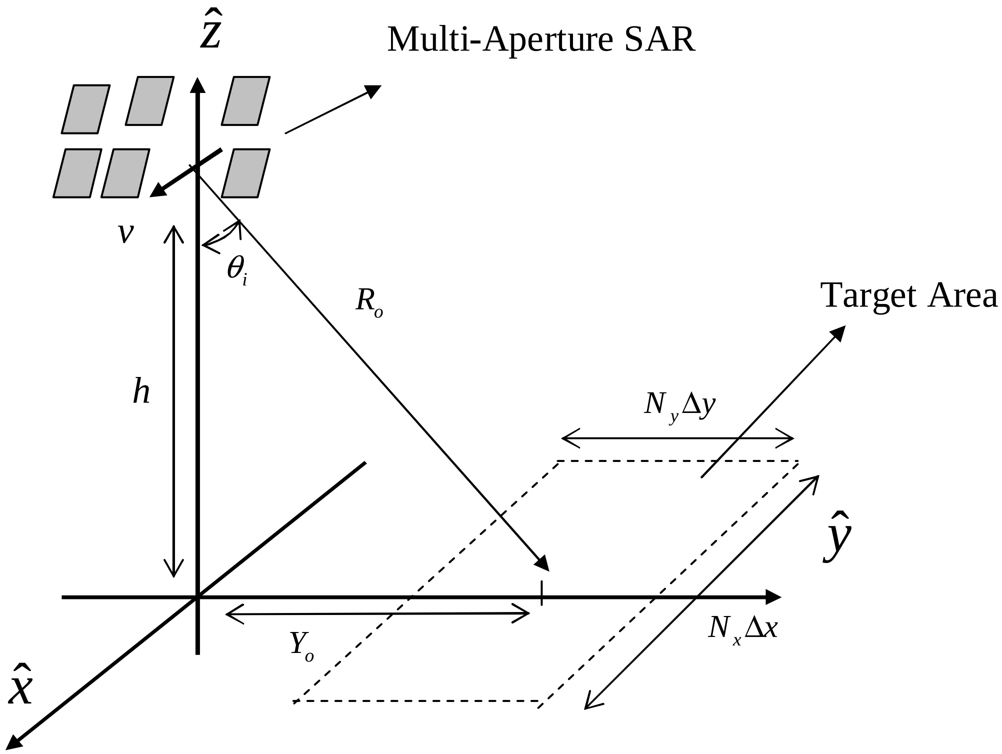
➢ Defined as a set of complex valued samples in a 5 dimensional space.

$$\bar{x}_{ik'} = [x_i, y_i, z_i, t_{k'}, \omega_{k'}]^T$$

Where, *I* → total number of spatial samples (Total number of Receive elements).

K' → total number of temporal samples.

Radar Model



The Radar Model setup

Assumed Default Values

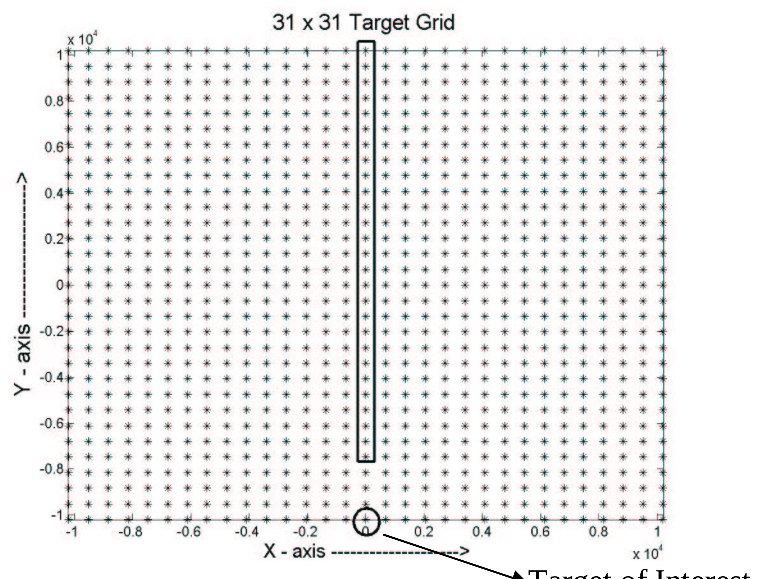
$$c = 3 \times 10^8 \ m/s$$
$$h = 183 \ km$$
$$v = 7.8 \ km/s$$
$$f_c = 10 \ GHz$$
$$\theta_i = 45^o$$

- A target grid of 31 x 31 has been chosen based on the system memory and processing time.

$$N_x = 31; N_y = 31$$
$$N_t = 961$$

Analysis of the Algorithm using the Model.

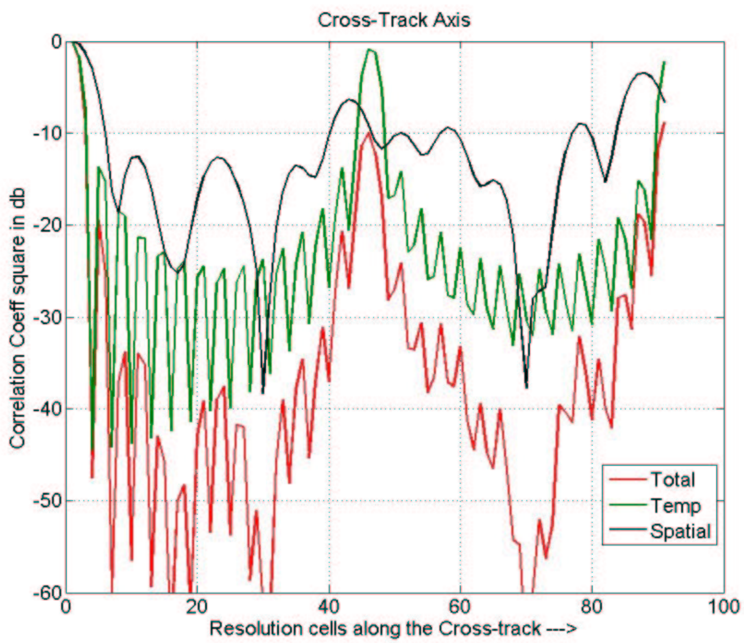
- H-matrices from the Model are used as Inputs.
- Total # of Transmit elements *(J)* = 1
- Total # of Receive elements *(I)* = 15
- Total number of slow-time functions *(P)* and Total number of fast-time functions *(Q)* - $P = 1$; $Q = 1$ to $P = 11$; $Q = 11$
- Performance of the Algorithm with varying number of basis functions.



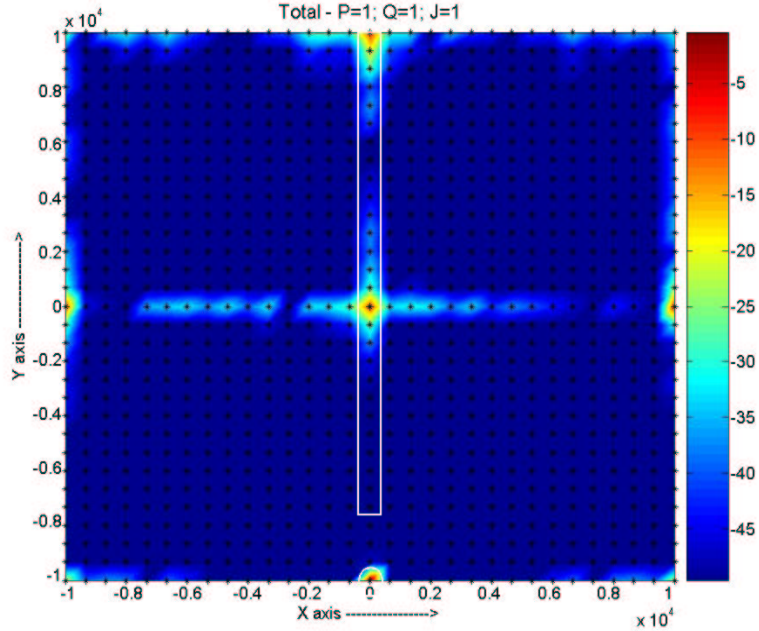
Target Grid

Tx element *(J)*=1; Slow-Time Fn *(P)*=1; Fast-Time Fn. *(Q)*=1

Correlation along the Range axis



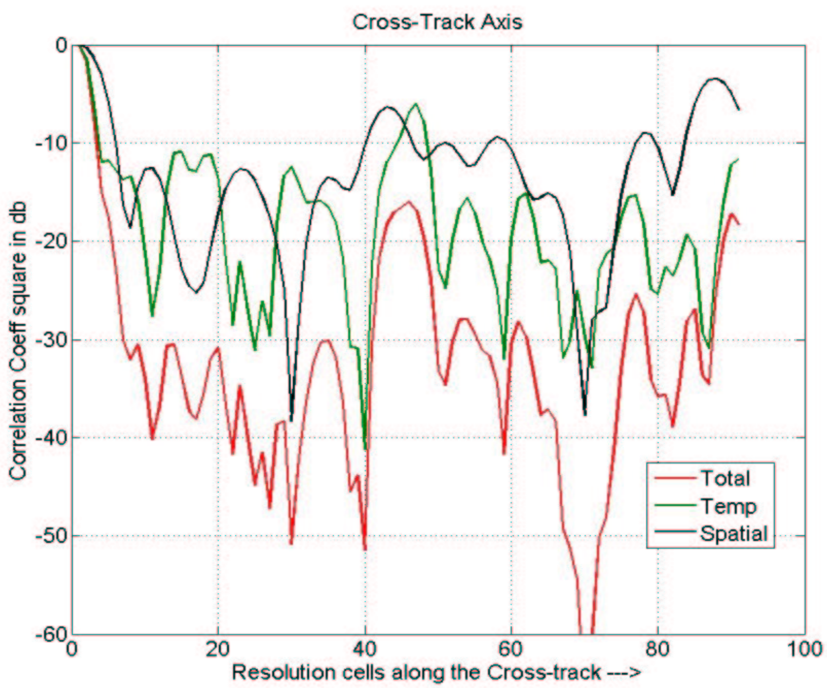
Total Correlation of the entire grid



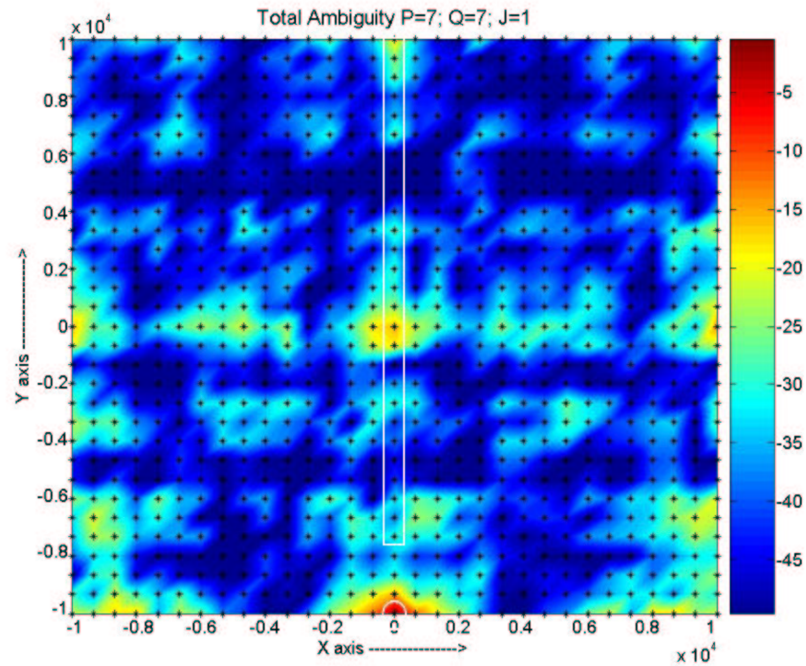
- Green → Temporal; Black → Spatial; Red → Total
- Total Maximum Correlation = -9dB
- Not much freedom to the Algorithm.

Tx element ***(J)*=1**; Slow-Time Fn ***(P)*=7**; Fast-Time Fn. ***(Q)*=7**

Correlation along the Range axis



Total Correlation of the entire grid

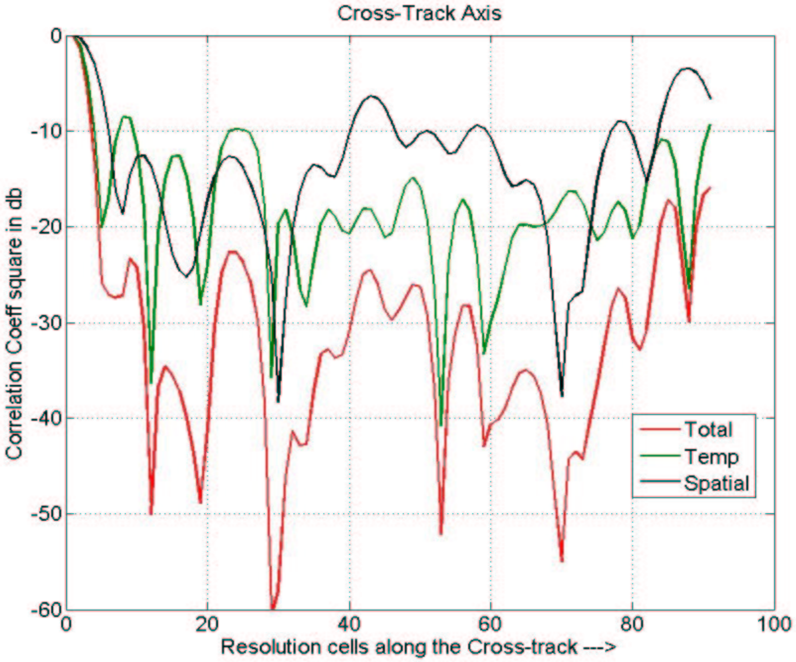


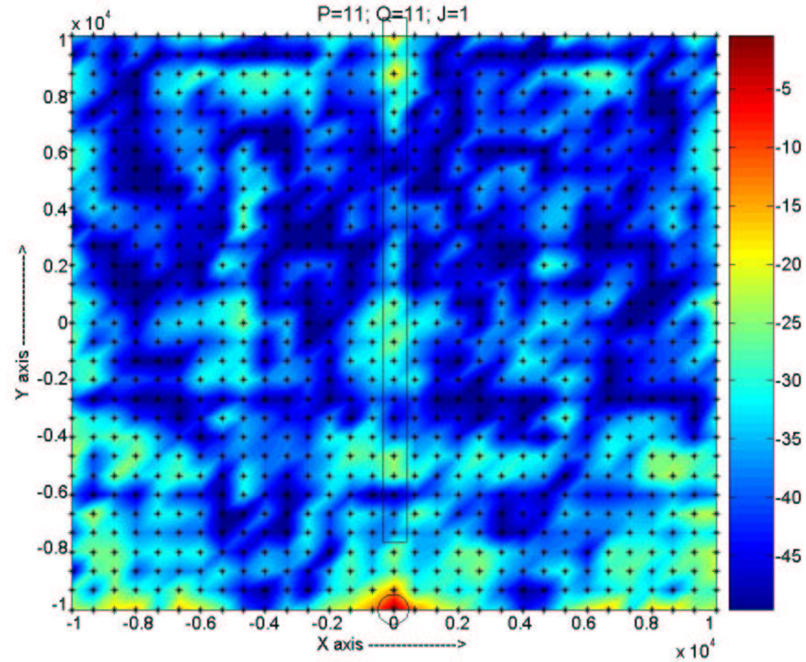
- Total Maximum Correlation = -16dB

Tx element ***(J)*=1**; Slow-Time Fn ***(P)*=11**; Fast-Time Fn. ***(Q)*=11**

Correlation along the Range axis

Total Correlation of the entire grid





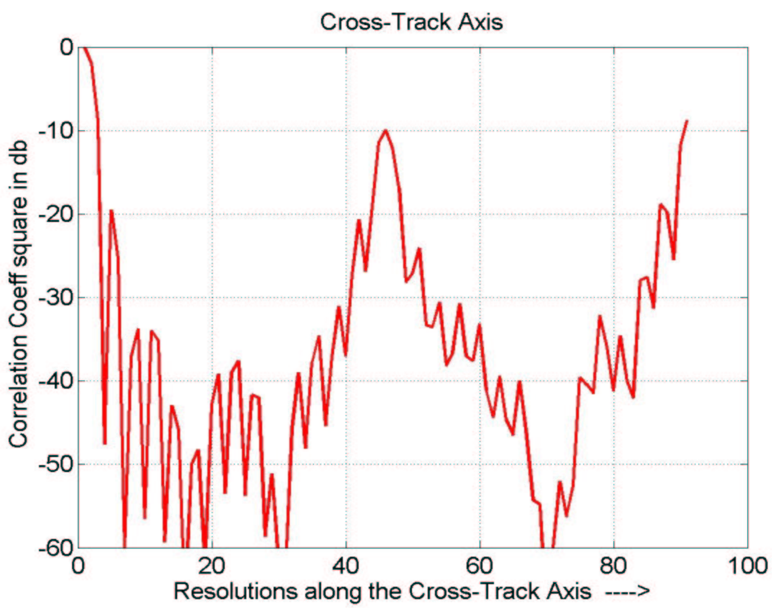
• Total Maximum Correlation = -16dB

Transmit Elements *(J)*

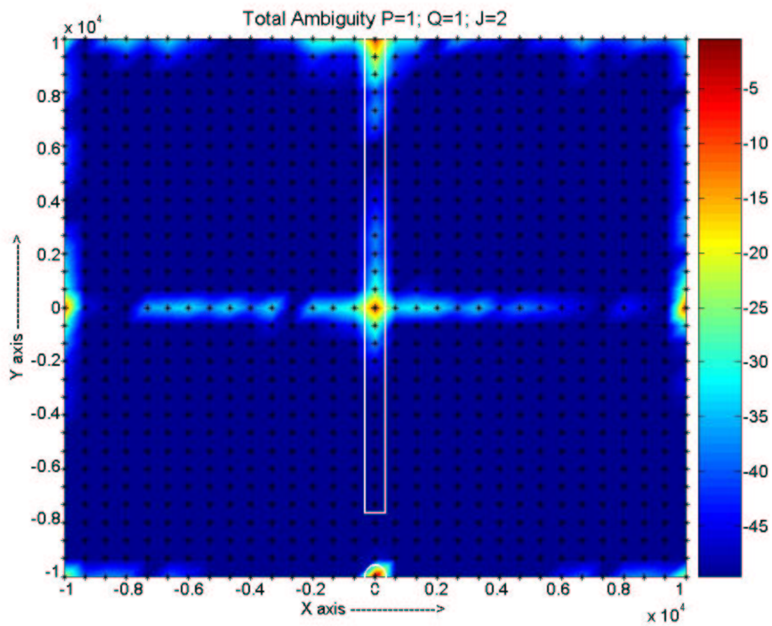
- The Number of Transmit Elements *(J)* are increased from 1 to 2.
- Algorithm analyzed by varying the total number of basis functions.

Tx element ***(J)*=2**; Slow-Time Fn ***(P)*=1**; Fast-Time Fn. ***(Q)*=1**

Correlation along the Range axis



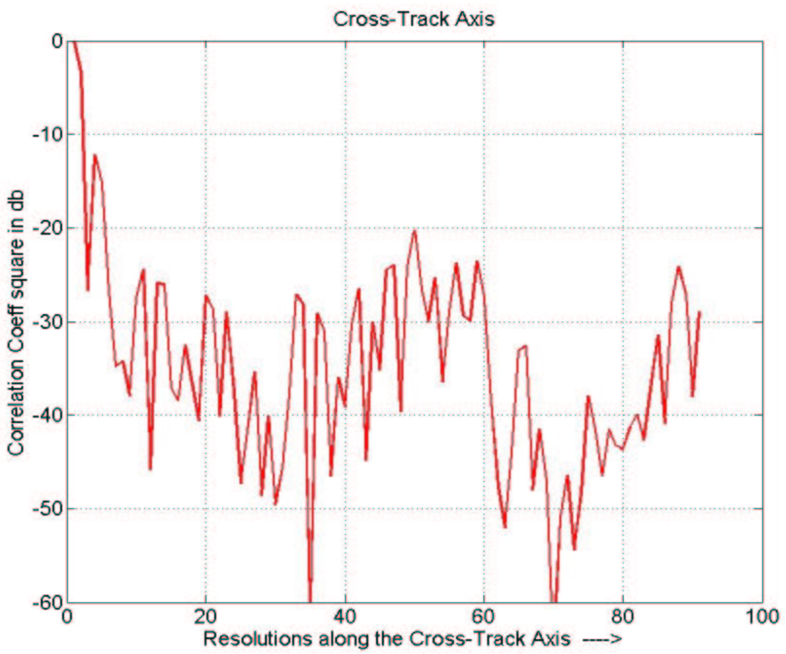
Total Correlation of the entire grid



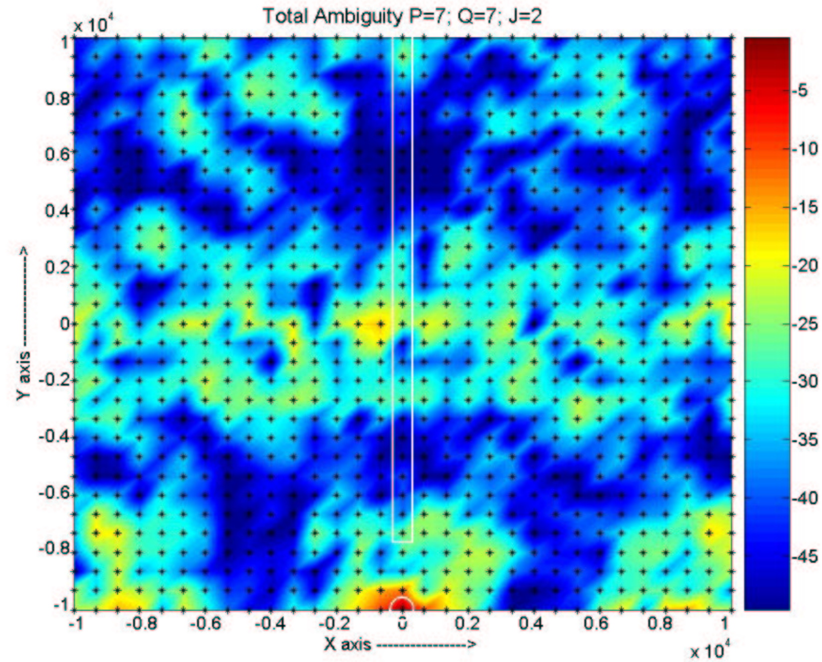
• Total Maximum Correlation = -9dB

Tx element *(J)*=2; Slow-Time Fn *(P)*=7; Fast-Time Fn. *(Q)*=7

Correlation along the Range axis



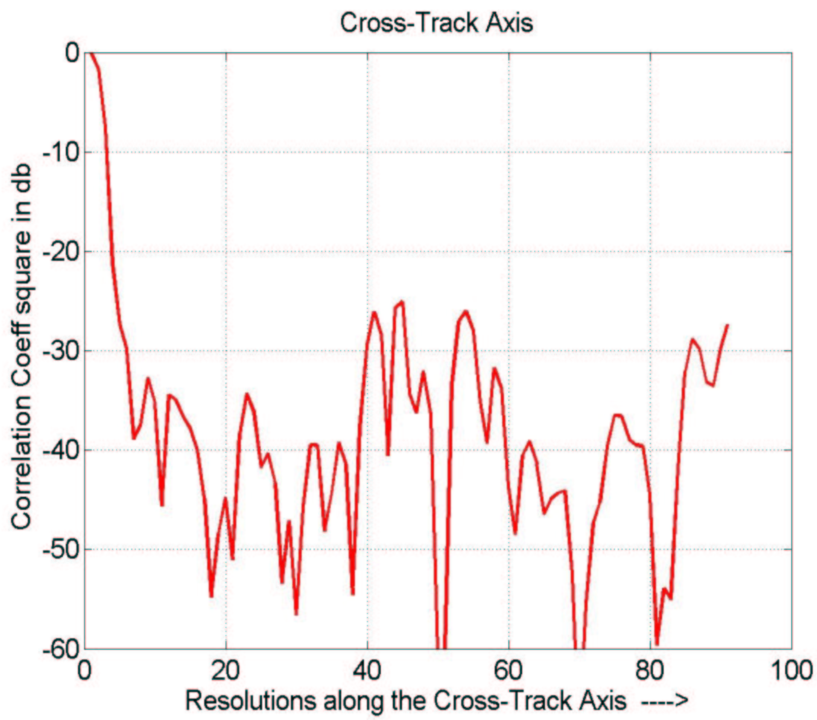
Total Correlation of the entire grid



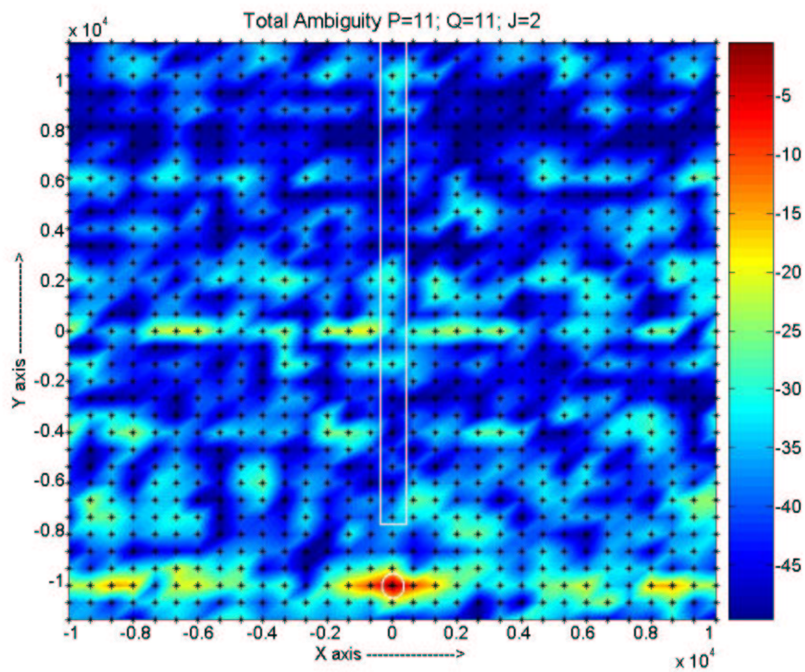
- Total Maximum Correlation = -24dB
- Improvement of 8dB compared to *J=1; P=7; Q=7* case.

Tx element ***(J)*=2**; Slow-Time Fn ***(P)*=11**; Fast-Time Fn. ***(Q)*=11**

Correlation along the Range axis



Total Correlation of the entire grid



- Total Maximum Correlation = -28dB
- Improvement of 12dB compared to *J=1; P=11; Q=11* case.

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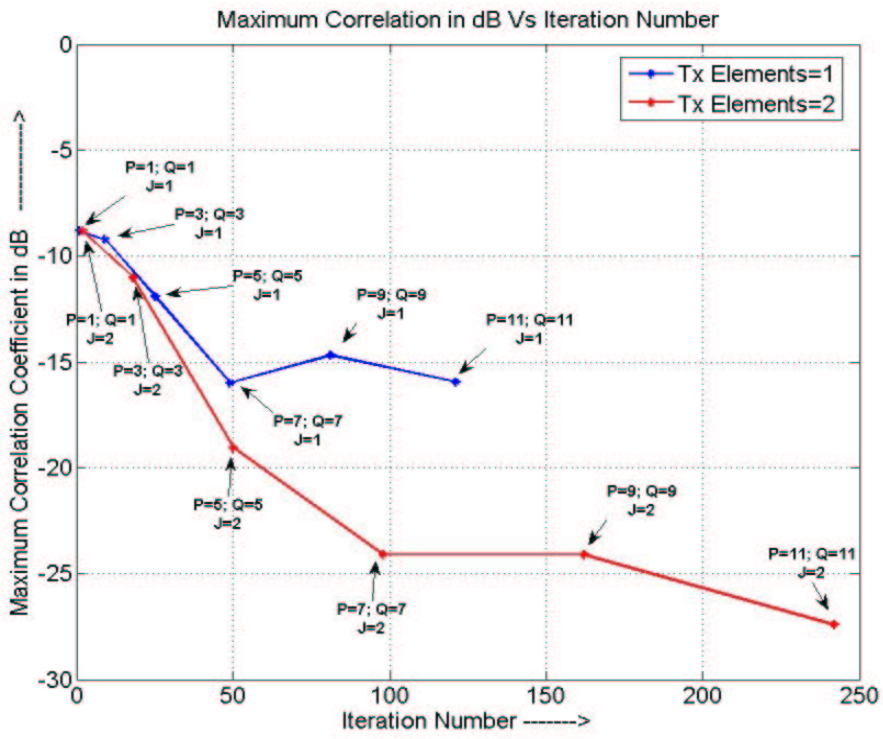
Summary of all the cases for *J=1* and *J=2*

Maximum Correlation Vs Iteration Number



• Higher the total number of basis functions, more is the flexibility provided to the algorithm to come up with a better code

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Efficacy of the best result.

Question: How good is the best result that is obtained?

Answer: Comparison with Standard code and Random Codes

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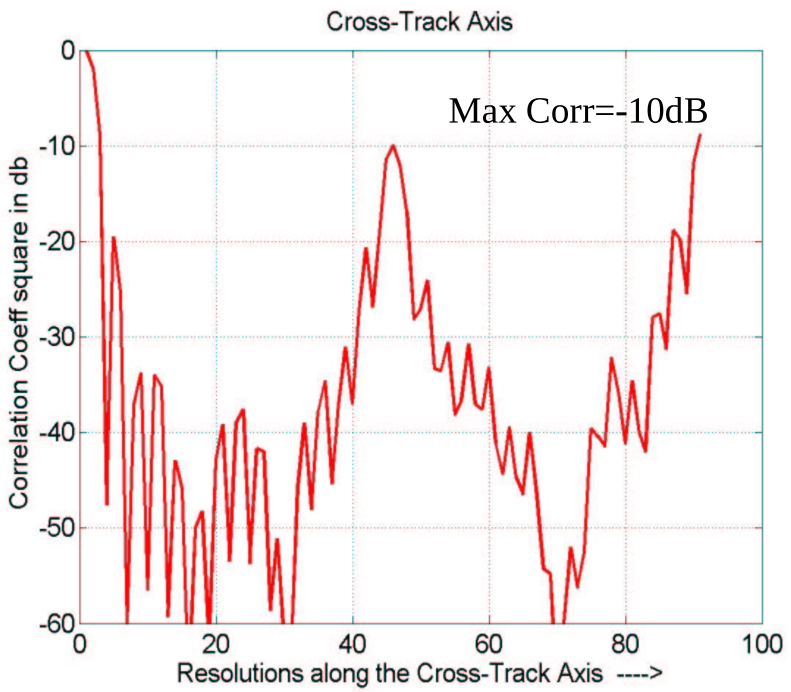
Comparison of the best result with Standard code

Best Code : J=2; P=11; Q=11

Standard Code : J=1; P=1; Q=1



- Algorithm code is 18dB better than a standard code.

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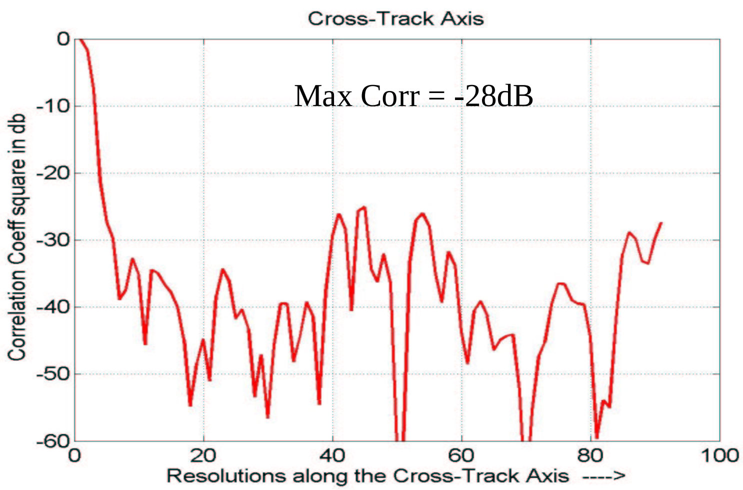
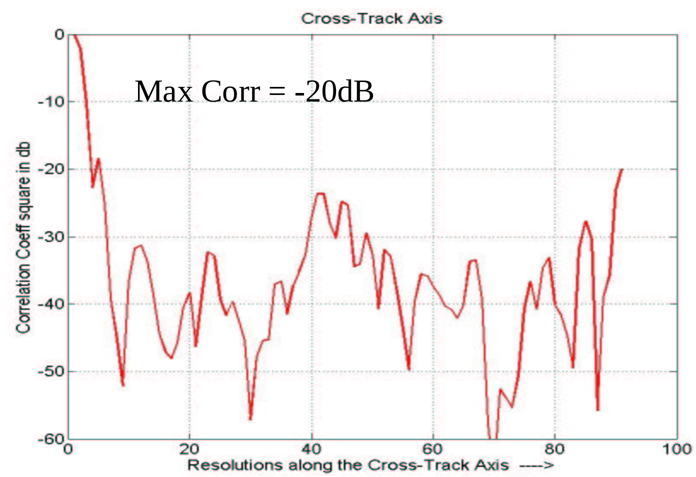
Comparison of the best result with Random codes

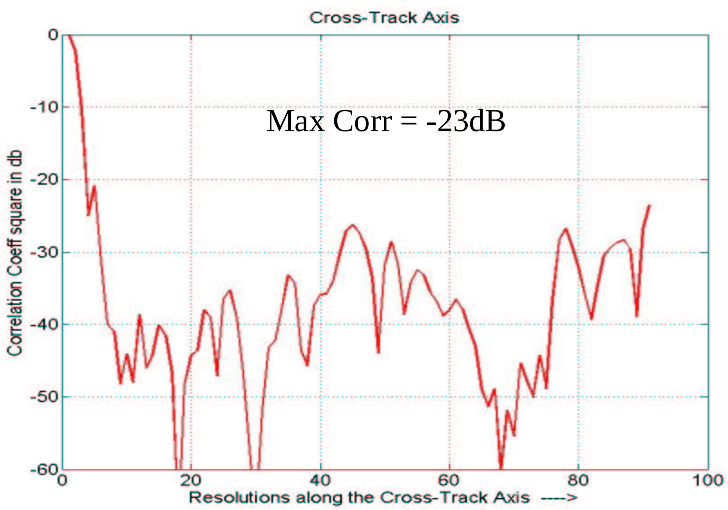
Algorithm Code



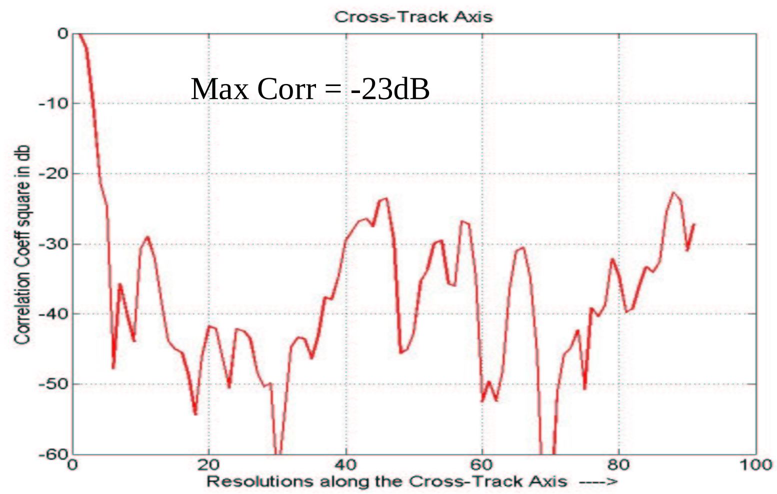
Random Code 1



Random Code 2



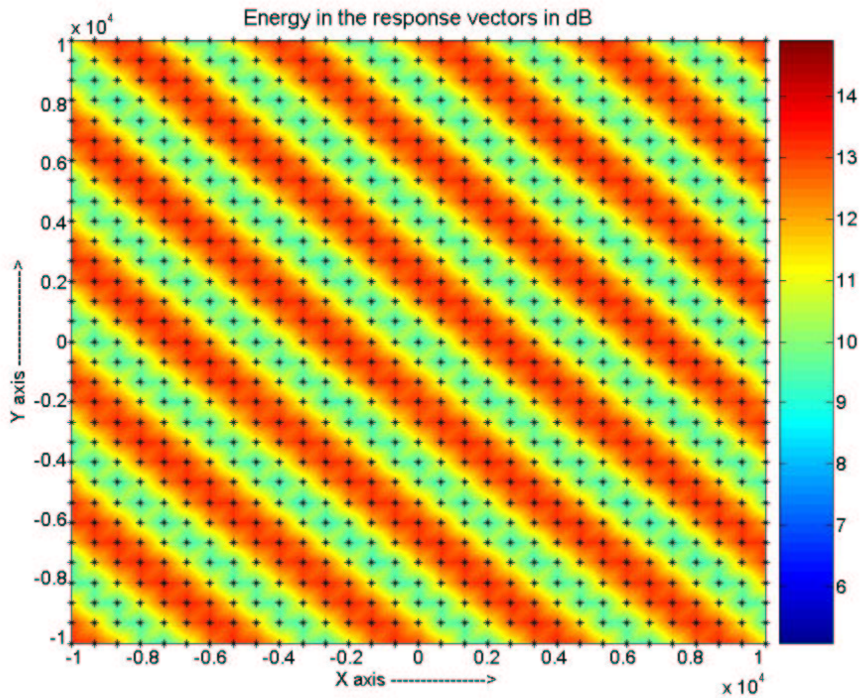
Random Code 3



Energy in the Response vector

- The condition $\boldsymbol{\rho}'_i \boldsymbol{\rho}_j = 0$ can still be satisfied if,

Energy in $\boldsymbol{\rho}_i$ or $\boldsymbol{\rho}_j = 0 \rightarrow$ Not desired



Max Energy = 14 dB

Min Energy = 9 dB

Plot showing the energy in the response vectors for all the targets in dB.

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Conclusions

• Proved that Space-Time transmit signal can be designed in order to reduce the maximum correlation.

• Higher the total number of measurements *(M)*, higher the total number of dimensions of the transmit signal *(N)*, better is the performance of the Algorithms.

• The performance also depends on the structure of the **H**-matrices or, the radar scenario.

• As the total number of basis functions are increased, more flexibility is provided to the Algorithm to come up with the best code.

• As the total number of transmit elements are increased from 1 to 2, the maximum ambiguity is reduced to a great extent.

Future Work

- The performance needs to be evaluated in the Doppler direction.
- The ambiguity function is not invariant for $J=2$. Therefore a new algorithm needs to be developed to come up with a transmit code.
- The Algorithm needs to be modified accordingly when we use more than 2 transmit elements.

- Thank You !!
- Questions ??