Master's Thesis Defense

Illumination Optimized Transmit Signals for Space-Time Multi-Aperture Radar

Vishal Sinha

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Committee

Dr. James Stiles (Chair)
Dr. Chris Allen
Dr. Glenn Prescott

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OUTLINE

- **Introduction**
  - What are we doing?
  - Why are we doing it ?
  - What has been done before ?
  - How is our work different ?
- **Execution + Results**
  - How do we do it?
  - Is it good?
  - If yes, how much is it better than the work done previously?
- **More Observations**
  - How close do we reach to the goal we started with initially?
  - Is there anything more to it?
- **Conclusions and Future work**
  - What did we learn?
  - What more can be done?

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OBJECTIVE

- **To come up with illumination optimized transmit signals for a space-time multi-aperture radar**

- **Applications**
  - SAR
  - GMTI
  - AMTI

- **Why a distributed sensor ?**
  - More robust structure
  - Manageable power requirements
  - **Potential for space-time operation**

- **Project supported by AFRL**

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WHY IS IT IMPORTANT?

- **Objective of any radar – SAR, GMTI or AMTI: Accurate detection and estimation of Targets**
  - Place energy on the regions it is interested in (targets)
  - Not waste any energy on regions it is not interested in (clutter)
  - Also distribute the energy equally on all targets
  - Make returns from all targets as dissimilar or uncorrelated as possible

Illumination Optimization (Maximizes SINR)

Ambiguity Optimization (Maximizes estimation)

- **Ways to control the radar performance:**
  - Add more transmitters/receivers
  - Modify the antenna array
  - **Change the radar transmit signal**

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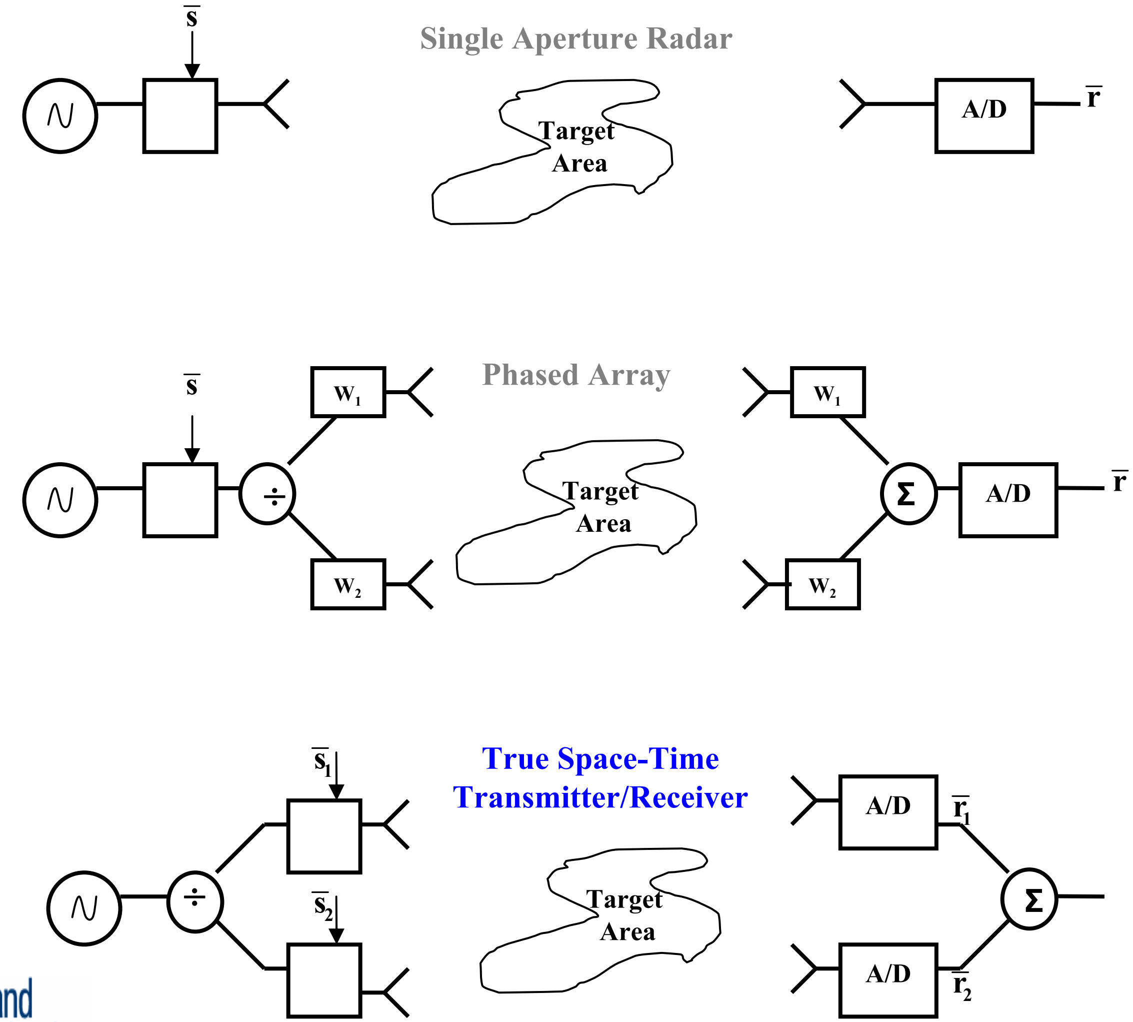
PRIOR WORK
OPTIMAL TRANSMIT SIGNAL CONSTRUCTION

- **Optimal transmit signals/codes for illumination optimization**
  - Time-frequency codes
  - Optimized for a single target
  - Compromise between SINR and quality of radar waveform
  - Pseudo space-time codes → Phased arrays, essentially plain spatial codes

- **Nothing on the True Space-Time Transmitter**

OUR APPROACH
A TRUE SPACE-TIME TRANSMITTER



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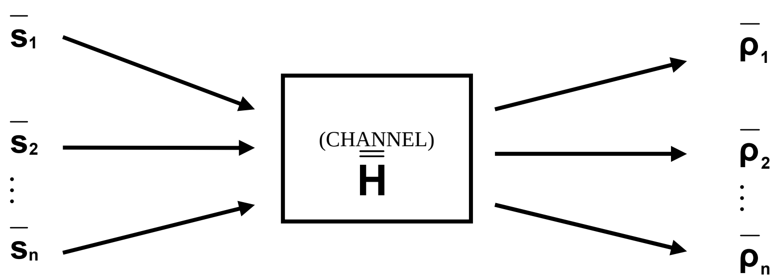
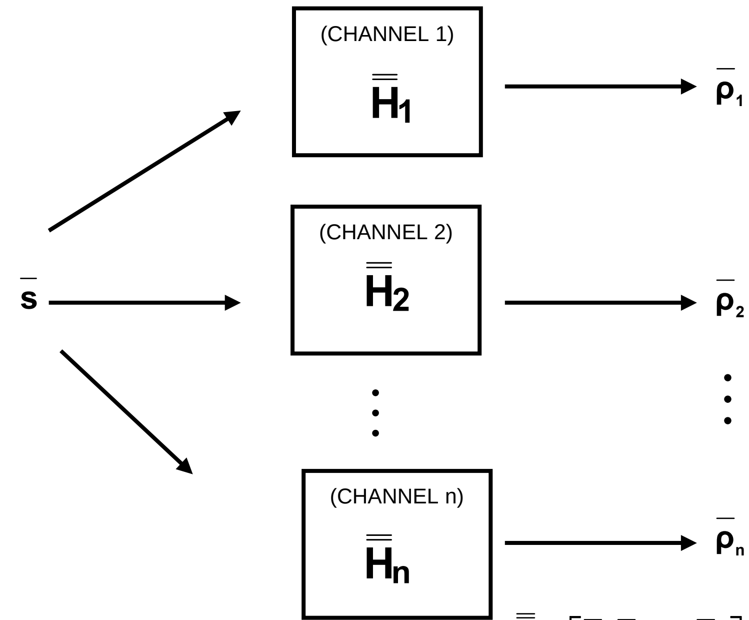
SPACE-TIME CODES IN COMMUNICATIONS

- **Space-time codes for communications**
  - A much easier problem



$\bar{\bar{P}} = \left[\bar{\rho}_1\, \bar{\rho}_2 \,....\, \bar{\rho}_n\right]$ **Goal** $\Rightarrow \bar{\bar{P}}^H \bar{\bar{P}} \approx I$

Space Time Codes for Communications



$\bar{\bar{P}} = \left[\bar{\rho}_1\, \bar{\rho}_2 \,....\, \bar{\rho}_n\right]$

Goal $\Rightarrow \bar{\bar{P}}^H \bar{\bar{P}} \approx I$

Space Time Codes for Radars

TRUE SPACE-TIME CODES - MOTIVATION

- **Better radar performance → Using same transmit power and radar resolution.**
- **Reduced receiver complexity**
- **Improved performance in multiple modes – e.g. SAR and GMTI**

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RADAR MODELS - THE BACKGROUND

- **We need radar models to:**
  - Simulate the space-time radar and the propagation from the transmitter to the targets
  - Model complex targets geometries consisting of any combination of point, distributed, stationary, moving, airborne and surface targets
  - Represent the radar transmit signal as a complex superposition of orthonormal basis functions
- **A transmission, target and propagation model and a transmit signal model were coded and implemented in MATLAB.**

TRANSMISSION, TARGET AND PROPAGATION MODEL

- **Space-Time Transmitter**
  - The radar transmit signal is modeled as a superposition of N basis functions ϕ_n $\longrightarrow$ $s(\bar{z}) = \sum_{n=1}^{N} s_n \, \phi_n(\bar{z})$
  - The basis functions ϕ are functions of 3-D space, time and frequency collectively spanning the entire timewidth, bandwidth and the spatial extent of the of the radar array $\longrightarrow$ $\bar{z} = \left[\, x \; y \; z \; t \; w \,\right]^T$
  - The vector **s** containing the complex weights s_n for each of the basis functions then represents the transmit signal completely. $\longrightarrow$ $\mathbf{s} = \left[\, s_1 \; s_2 \; s_3 \cdots s_N \,\right]^T$

TRANSMISSION TARGET AND PROPAGATION MODEL

- **Targets**

  - The joint target scattering response can also be modeled as a combination of N_t orthonormal basis functions ψ_t $\longrightarrow$ $\gamma(\bar{y}) = \sum_{t=1}^{N_t} \gamma_t \, \psi_t(\bar{y})$

  - The basis functions ψ are functions of 3-D space and radial velocity $\longrightarrow$ $\bar{y} = \left[\, x \; y \; z \; v_r \,\right]^T$

  - The vector $\boldsymbol{\gamma}$ of complex scattering coefficients γ_t then defines the set of illuminated targets completely $\longrightarrow$ $\boldsymbol{\gamma} = \left[\, \gamma_1 \, \gamma_2 \, \gamma_3 \cdots \gamma_{N_t} \,\right]^T$

TRANSMISSION, TARGET AND PROPAGATION MODEL

- **Space-Time Receiver**
  - The received signal can be also be represented as a weighted superposition of *M* orthonormal space-time basis functions φ_m $\longrightarrow r(\bar{x}) = \sum_{m=1}^{M} r_m \, \varphi_m(\bar{x})$
  - The basis functions φ are again functions of 3-D space, slow time and fast frequency. $\longrightarrow \bar{x} = \begin{bmatrix} x \; y \; z \; t \; w \end{bmatrix}^T$
  - The vector **r** of complex weights r_m completely defines the received space-time signal. $\longrightarrow \mathbf{r} = \begin{bmatrix} r_1 \; r_2 \; r_3 \cdots r_M \end{bmatrix}^T$

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TRANSMISSION TARGET AND PROPAGATION MODEL

- **Propagation**
  - The transmitted, target and receive functions are related by the following convolution integral through the dyadic Green's propagation functions

$$r(\bar{x})=\int \vec{\vec{H}}(\bar{x};\bar{y}).\gamma(\bar{y}).\int \vec{\vec{G}}(\bar{y};\bar{z}).s(\bar{z})\,d\bar{z}\,d\bar{y}$$

  - Also since,

$$r_m = \int r(\bar{x})\,\varphi_m(\bar{x})\,d\bar{x}$$

  - We can simplify as follows

$$r_m = \int \varphi_m(\bar{x}) \int \vec{\vec{H}}(\bar{x};\bar{y}).\gamma(\bar{y}).\int \vec{\vec{G}}(\bar{y};\bar{z}).s(\bar{z})\,d\bar{z}\,d\bar{y}\,d\bar{x}$$

$$r_m = \sum_{t=1}^{N_t} \gamma_t \sum_{n=1}^{N} s_n \int \varphi_m(\bar{x}) \int \vec{\vec{H}}(\bar{x};\bar{y}).\psi_t(\bar{y}).\int \vec{\vec{G}}(\bar{y};\bar{z}).\phi_n(\bar{z})\,d\bar{z}\,d\bar{y}\,d\bar{x}$$

$$\boxed{r_m = \sum_{t=1}^{N_t} \gamma_t \sum_{n=1}^{N} s_n\, H_{mn}^t}$$

$$where, H_{mn}^t = \int \varphi_m(\bar{x}) \int \vec{\vec{H}}(\bar{x};\bar{y}).\psi_t(\bar{y}).\int \vec{\vec{G}}(\bar{y};\bar{z}).\phi_n(\bar{z})\,d\bar{z}\,d\bar{y}\,d\bar{x}$$

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TRANSMISSION TARGET AND PROPAGATION MODEL

$$\mathbf{r} = \sum_{t=1}^{N_t} \gamma_t \, \mathbf{H}_t \, \mathbf{s} + \mathbf{n}$$

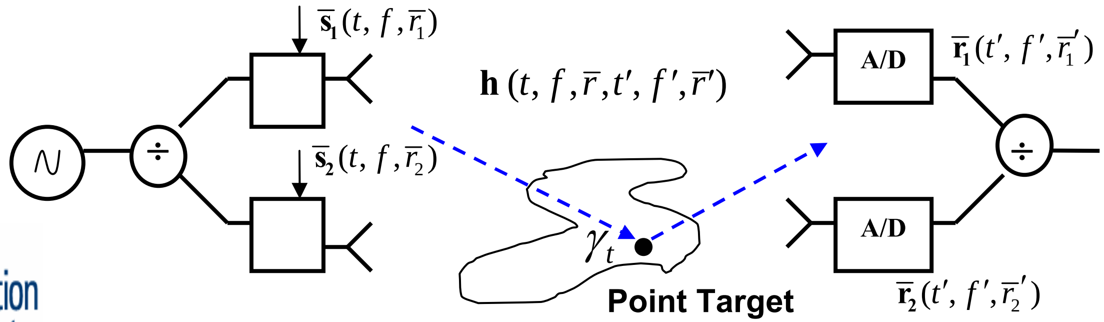
s → is the transmit signal vector completely representing the transmitted signal

r → is the received signal vector completely representing the received signal

γ_t → is the scattering coefficient for each target

n → measurement noise vector

$\mathbf{H}_t$ → is a 2-D matrix relating the *N* transmitted samples to the *M* received samples for the t^{th} target – analogous to the convolution function of a two port network



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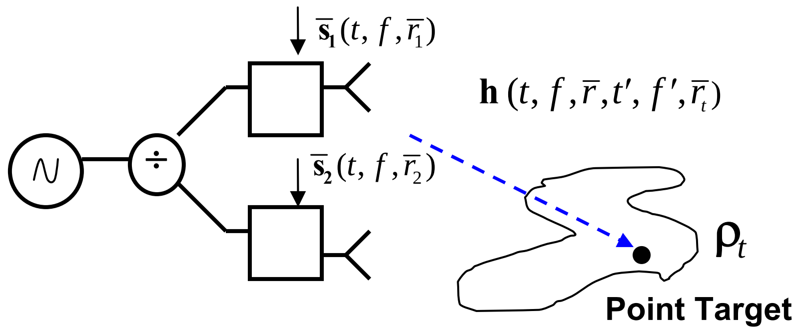
ADJUSTMENT FOR THE ILLUMINATION OPTIMIZATION PROBLEM



- For the illumination optimization problem we just need to model the propagation from the transmitter to the targets
- The propagation matrix for each target $\mathbf{H}_t$ is modified accordingly
- The normalized response at the target due to a transmit signal **s** is given by

$$\boxed{\rho_t = \mathbf{H}_t\,\mathbf{s}}$$

- The set of N_t propagation matrices $\mathbf{H}_t$, and normalized responses $\boldsymbol{\rho}_t$ are critical parameters for all our algorithms and optimization procedures.

TRANSMIT SIGNAL MODEL

- **Required for expanding the transmit signal as a weighted superposition of space-time orthonormal basis functions**
- **A time-frequency basis function consist of a train of *U* wideband pulses – the same pulse train is present at each antenna resulting in a space-time basis function**
- **The pulse trains at the same antenna have different delays and/or different phase weightings - ∴ the basis functions form an orthonormal set**
- **The different delays and phase weightings characterize the different fast and slow time basis functions available**
- **Each basis function has wide timewidth and bandwidth, and would make an adequate radar signal in itself**
- **Choice and number of time-frequency basis functions are important**

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TRANSMIT SIGNAL MODEL

- **Inputs to the model**

  - f_c = *carrier frequency (Hz)*
  - B = *transmit signal bandwidth (Hz)*
  - f_o = *pulse repetition frequency – PRF (Hz)*
  - U = *integer number of pulses transmitted as part of the transmit signal*
  - Q = *odd number of 'fast-time' basis functions*
  - P = *odd number of 'slow-time' basis functions*
  - $g_s(t)$ = *a 'mother function' used to generate new slow-time basis functions*
  - $G_f(w)$ = *a 'mother function' used to generate new fast-time basis functions*
  - $\{ \tau_q \}$ = *Q time delay values used to generate all the fast-time basis functions*
  - $\{ w_p \}$ = *P frequency shift values used to generate all the slow-time basis functions*

  - $1/f_o = T_o$ = *pulse repetition interval – PRI (sec)*
  - $UT_o = T$ = *transmit signal timewidth (sec)*
  - $w_o = 2\pi f_o$ = *angular pulse repetition frequency (radians/sec)*
  - $w_c = 2\pi f_c$ = *angular carrier frequency (radians/sec)*

TRANSMIT SIGNAL MODEL

- **Any real valued temporal signal can be expressed as** $v_s(t) = \mathrm{Re}\{S(t)e^{-jw_c t}\}$
- ***S(t)* can be written as a weighted superposition of *PQ* complex basis functions**

$$S(t) = \sum_p \sum_q S_{pq} \psi_{pq}(t) \qquad \psi_{pq}(t) = s_p(t) \sum_u f_q(t - uT_o) e^{jw_c uT_o}$$

$$f_q(t) = g_f(t - \tau_q) e^{jw_c \tau_q}, \text{ where } \tau_q << T_o$$

$$S_p(w) = G_s(w - w_p), \text{ where } w_p << w_o$$

$$S_p(w) = \int_{-\infty}^{+\infty} s_p(t) e^{-jwt}\, dt \quad \text{and} \quad G_s(w) = S_0(w) \quad Q\tau_q \le T_0 \quad P w_p \le w_0$$

- **Sampled Windowed Fourier Transform of *S (t)*** $S(t) = \sum_p \sum_q S_{pq} e^{j\omega_p t} g_s(t) \sum_u f_q(t - uT_o) e^{j\omega_c uT_o}$

$$s(uT_o, \omega) = \sum_p g_s(uT_o) e^{ju\omega_p T_o} \sum_q S_{pq} G_f(\omega) e^{-j\omega u T_o} e^{-j(\omega - \omega_c)\tau_q}$$

$$s_{uv} = \sum_p g_s(uT_o) e^{ju\omega_p T_o} \sum_q S_{pq} G_f\left(\frac{v\omega_o}{2}\right) e^{-j\left(\frac{v\omega_o}{2} - \omega_c\right)\tau_q}$$

- **Defining** $\psi_{uv}^{pq} = g_s(uT_o) e^{ju\omega_p T_o} G_f\left(\frac{v\omega_o}{2}\right) e^{-j\left(\frac{v\omega_o}{2} - \omega_c\right)\tau_q}$ **we get** $\boxed{s_{uv} = \sum_p \sum_q \psi_{uv}^{pq} S_{pq} \ \text{ or, } \ \mathbf{s}^t = \boldsymbol{\psi}\mathbf{S}^t}$

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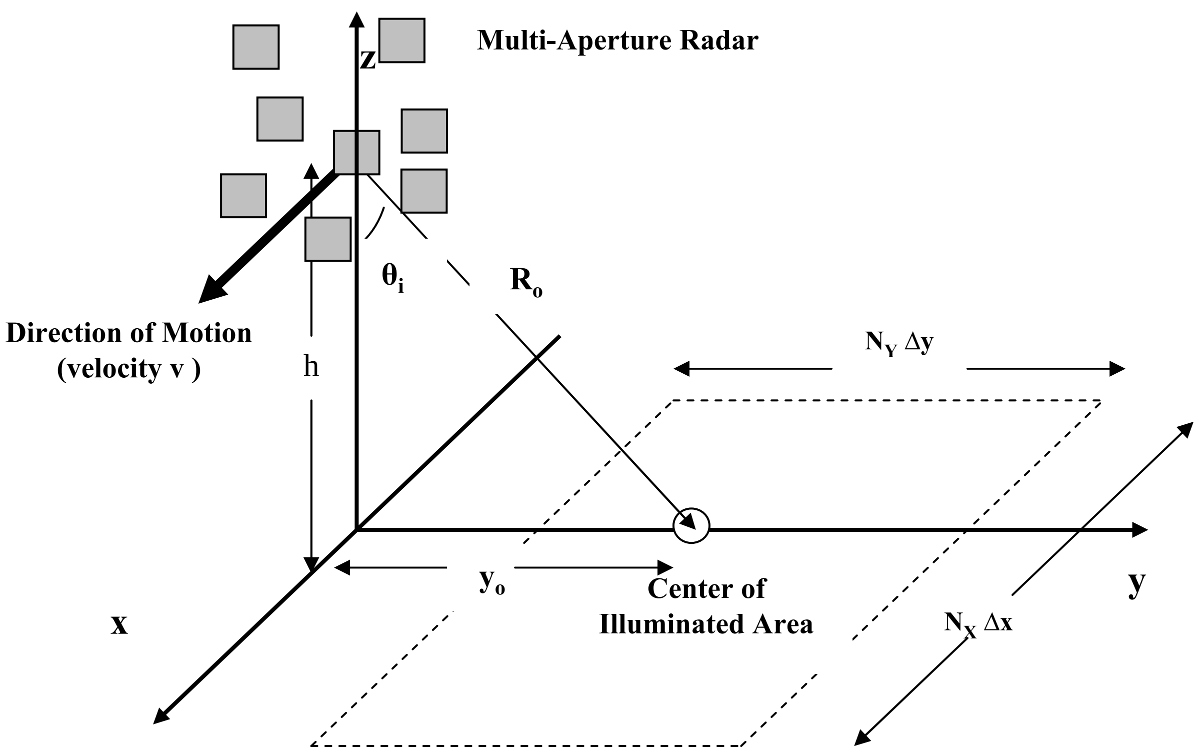
RADAR GEOMETRY



Radar Parameters

Radar height (h)	183 km
Radar velocity (v)	780 m/sec
Look angle (θ_i)	45 degrees
Carrier frequency (f_c)	10 GHz
Horizontal distance to the center of target grid	183 km
Actual distance to the center of target grid (R_o)	258.8 km

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SPACE-TIME ILLUMINATION OPTIMZATION
– THE PROCESS

- **If all scatterers are classified into two sets:**
  - **Targets**: Scatterers we wish to illuminate or estimate
  - **Clutter**: Scatterers we do not wish to illuminate

- **Then the perfect transmit code would:**
  - Illuminate all targets
  - Not illuminate any clutter objects
  - Distribute energy equally amongst all targets
  - Make responses from all targets mutually orthogonal

Illumination Optimization

- **Unfortunately such a perfect transmit code does not exist!!**

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SPACE-TIME ILLUMINATION OPTIMZATION
– OPTIMIZATION CRITERIA

- **Instead we define a number of optimization criteria and try to satisfy them to the greatest possible extent**

- **If not perfect, then at least an optimal code**

- **Example of optimization criteria can be:**
  - Maximize the total energy on all targets
  - Minimize the total energy on all clutter objects
  - Maximize the ratio of total signal (target) to clutter energy – SCR
  - Maximize the SCR for the target receiving the minimum SCR
  - Minimize the maximum correlation between any two targets

Illumination Optimization

BASIC OPTIMIZATION CRITERIA
MAXIMUM TARGET ENERGY

- Total Energy on all target objects is given as

$$E_{targets} = \sum_{\substack{i \in \\ targets}} \rho_i' \rho_i = \boxed{\mathbf{S}'\mathbf{A}\mathbf{S}}$$

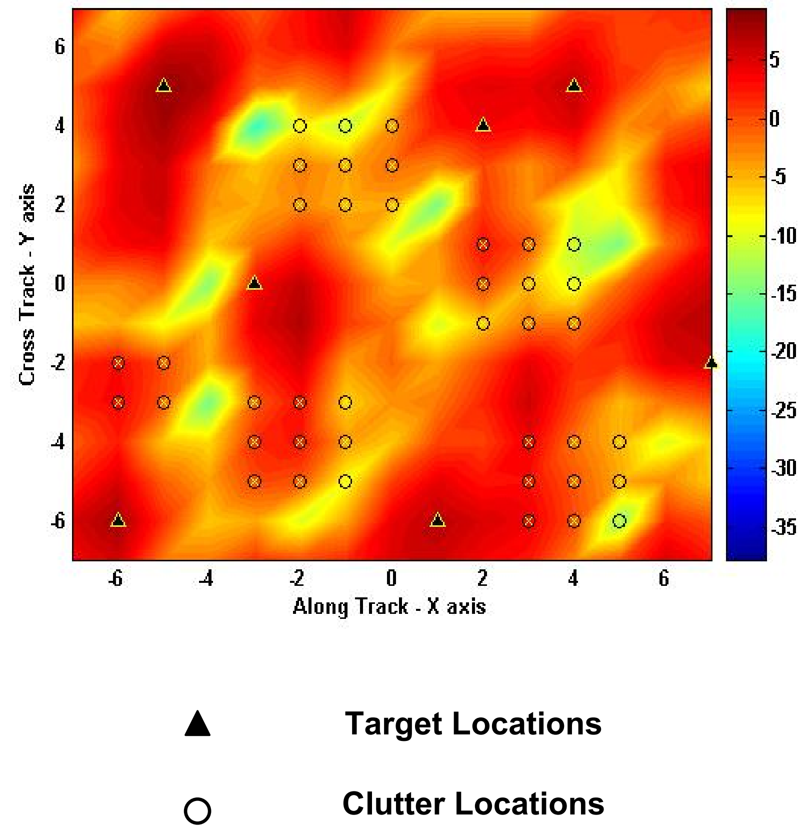
$$\text{where } \mathbf{A} = \sum_{\substack{i \in \\ targets}} \mathbf{H}_i'\mathbf{H}_i$$

- This energy is maximized when the eigen vector associated with the largest eigen value of the non-negative definite matrix **A** is selected as the transmit code **S**

$$\mathbf{A} = \sum_n \lambda_n^a \hat{e}_n^a \hat{e}_n^{a\prime}$$

$\therefore$ **S** = $\hat{e}_n^a$ associated with $(\lambda_n^a)_{\max}$

NOTE: For all cases 14 transmit antennas and 9 time-frequency basis functions, or a transmit signal dimension of 126



BASIC OPTIMIZATION CRITERIA
MINIMUM CLUTTER ENERGY

- Total Energy on all clutter objects is given as

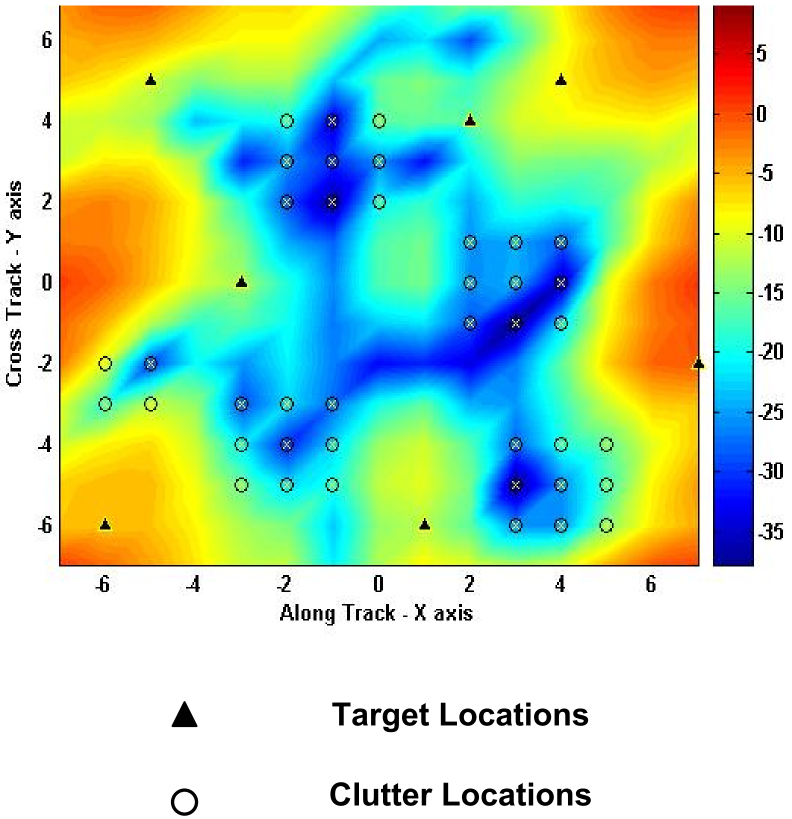
$$E_{clutter} = \sum_{j \in clutter} \rho_j' \rho_j = \boxed{\mathbf{S'BS}}$$

$$\text{where } \mathbf{B} = \sum_{i \in clutter} \mathbf{H}_j' \mathbf{H}_j$$

- This energy is minimized when the eigen vector associated with the smallest eigen value of the non-negative definite matrix **B** is selected as the transmit code **S**

$$\mathbf{B} = \sum_n \lambda_n^b \hat{e}_n^b \hat{e}_n^{b\prime}$$

$\therefore$ **S** = $\hat{e}_n^b$ associated with $(\lambda_n^b)_{\min}$



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BASIC OPTIMIZATION CRITERIA
MAXIMUM SCR

- The ratio of the signal to clutter energy is given as

$$\mathrm{SCR} = \frac{E_{targets}}{E_{clutter}} = \frac{\mathbf{S}'\mathbf{A}\mathbf{S}}{\mathbf{S}'\mathbf{B}\mathbf{S}} = \boxed{\frac{\tilde{\mathbf{S}}'\mathbf{C}\tilde{\mathbf{S}}}{\tilde{\mathbf{S}}'\tilde{\mathbf{S}}}}$$

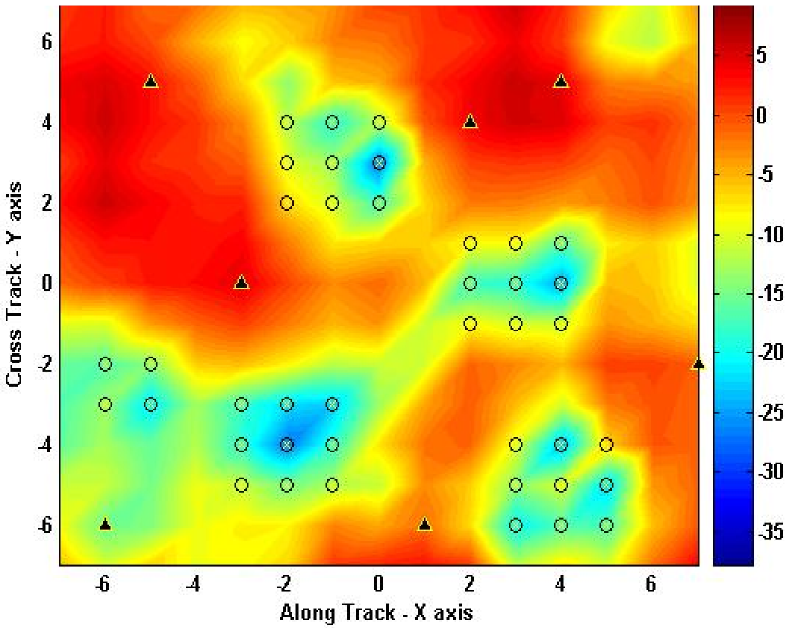
where $\mathbf{C} = (\mathbf{B}^{-1/2})'\,\mathbf{A}\,(\mathbf{B}^{-1/2})$ and $\tilde{\mathbf{S}} = \mathbf{B}^{1/2}\mathbf{S}$

- The SCR is maximized when the eigen vector associated with the largest eigen value of the non-negative definite matrix **C** is selected, and the transmit code **S** is determined from it

$$\mathbf{C} = \sum_n \lambda_n^c \, \hat{e}_n^c \, \hat{e}_n^{c\prime}$$

$\therefore \quad \tilde{\mathbf{S}} \quad \hat{e}_n^c$ associated with $(\lambda_n^c)_{\max}$

and $\mathbf{S} = \mathbf{B}^{-1/2}\tilde{\mathbf{S}}$



▲ Target Locations

○ Clutter Locations

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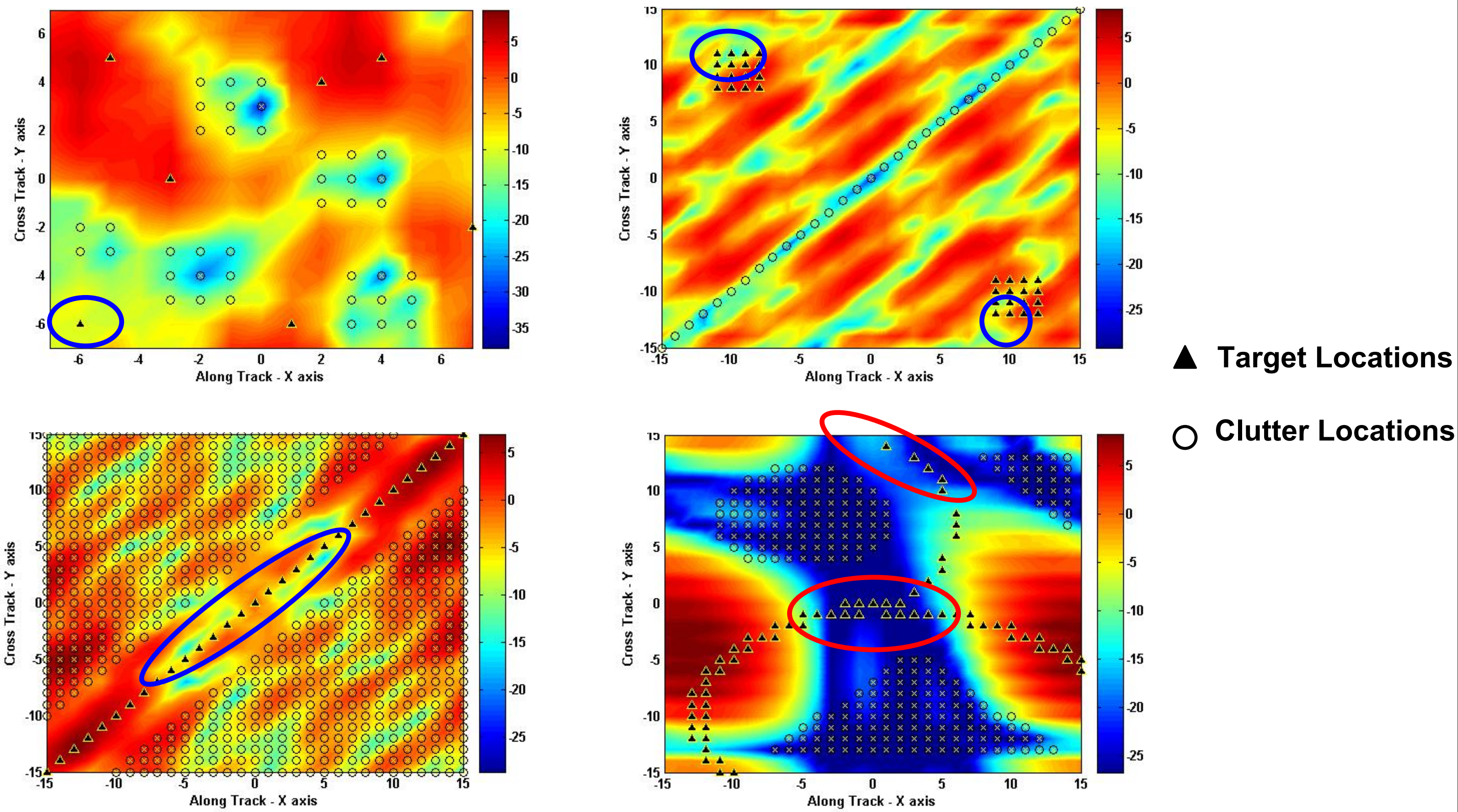
THE ORPHAN PROBLEM



NEED FOR AN ADVANCED CRITERIA
MAXI-MIN OR MINI-MAX

- We can define the alternate **maxi-min** or the **mini-max** criteria as:

The code which **maximizes** the **smallest** energy received by any target

The code which **minimizes** the **largest** energy received by any clutter object

The code which **maximizes** the SCR for the target with the **worst SCR**

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THE MAXI-MIN PROCEDURE

- Finding the best maxi-min solution is difficult, finding the worst maxi-min is easy
- Project out enough of these worst dimensions from the finite dimensional transmit signal space → Converge to a good solution
- The SCR received by each target is defined by it's individual $\mathbf{C}_i$ matrix:

$$SCR_i = \frac{E_a^i}{E_b} = \frac{\mathbf{S}'\mathbf{A}_i\mathbf{S}}{\mathbf{S}'\mathbf{B}\mathbf{S}} = \frac{\tilde{\mathbf{S}}'\mathbf{C}_i\tilde{\mathbf{S}}}{\tilde{\mathbf{S}}'\tilde{\mathbf{S}}}$$

- The smallest eigen value of a $\mathbf{C}_i$ matrix -λ_i^{min} provides the worst SCR that the i^{th} target can receive, and the corresponding eigen vector $\tilde{e}^{min}$ is the worst SCR solution for that particular target.
- Overall worst solution is then simply the $\tilde{e}^{min}$ associated with the smallest of all individual minimum eigen values: $\lambda_{smallest}^{min}$ → lower bound on SCR_{min}
- The lower bound on SCR_{min} is raised by restricting our solutions to an orthogonal subspace:

$$\mathbf{P}_\perp(l) = \mathbf{I} - \tilde{e}^{min}\,\tilde{e}^{min\prime} \qquad \mathbf{C}_i(l+1) = \mathbf{P}_\perp{}'(l)\,\mathbf{C}_i(l)\,\mathbf{P}_\perp(l)$$

THE MAXI-MIN PROCEDURE

- Again look for the worst solution in the new subspace and project orthogonal to it
- All projections are orthogonal to each other → the lower bound on $SCR_{\min}$ monotonically increases
- We continue with this process till we are left with a single dimension – a vector
- This vector forms our optimal maxi-min transmit solution **S**
- The process is mathematically defensible – hence called the **True Maxi-min**

HEURISTIC MAXI-MIN

- Upper bound on $SCR_{\min}$ is given by the smallest of all maximum eigen values for individual C_i matrices:

$$\lambda_{\text{smallest}}^{max} = \min\left\{\lambda_1^{max}, \lambda_2^{max}, \lambda_3^{max}, \cdots \lambda_{N_t}^{max}\right\} \geq SCR_{\min}$$

- The upper bound also comes down with every projection

- An alternative approach can be to try and keep the upper bound on $SCR_{\min}$ as high as possible:
  - Find the weakest target ***'t'***, or the one with the smallest maximum eigen value $\lambda_{\text{smallest}}^{max}$
  - Find the worst solution for this target $\tilde{e}_t^{min}$ i.e. the vector corresponding to the smallest eigen value of it's **C** matrix
  - Use this vector to form the projection matrix and repeat all steps as before

- This approach is called the ***HEURISTIC MAXI-MIN*** as it is not guaranteed to improve or preserve any bound, but is often seen to perform well - in fact most often even better than the earlier mathematically defensible ***TRUE MAXI-MIN***

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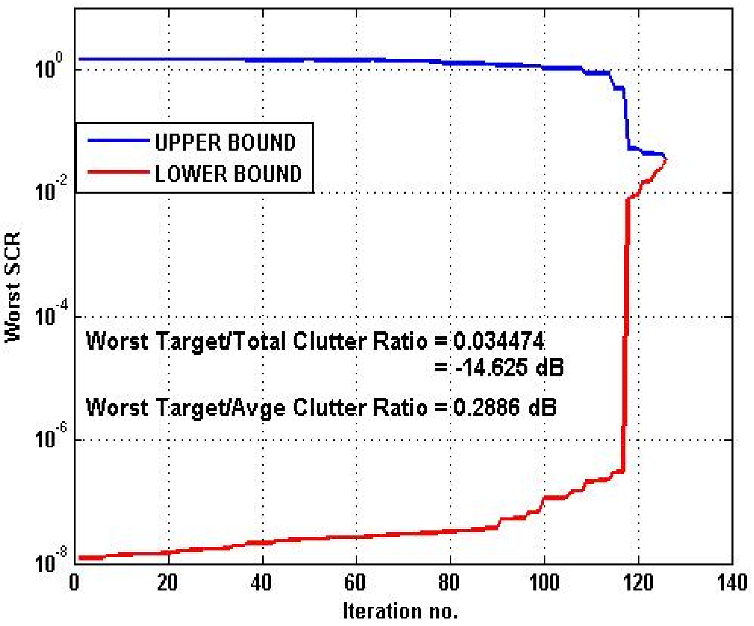
UPPER/LOWER BOUND CONVERGENCE

- The ***TRUE*** algorithms just aim to increase the lower bound on SCR_{min} after each step

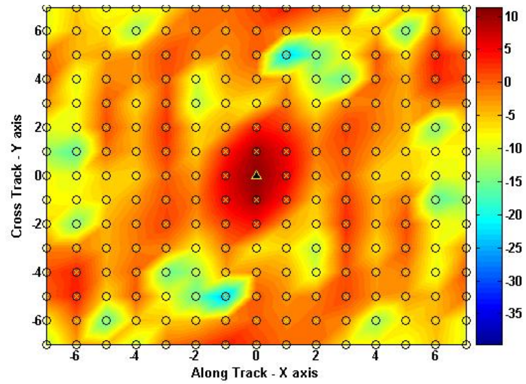
- However for most case, the upper bound turns out to be the more critical of the two bounds

- Thus the ***HEURISTIC*** algorithms are usually seen to be more effective than the ***TRUE*** algorithms



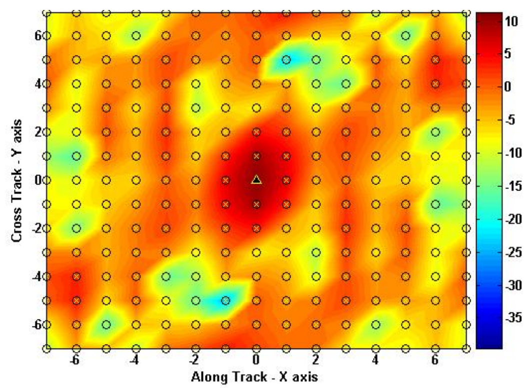
HEURISTIC AND TRUE SCR CONVRGENCE

True Maxi-min

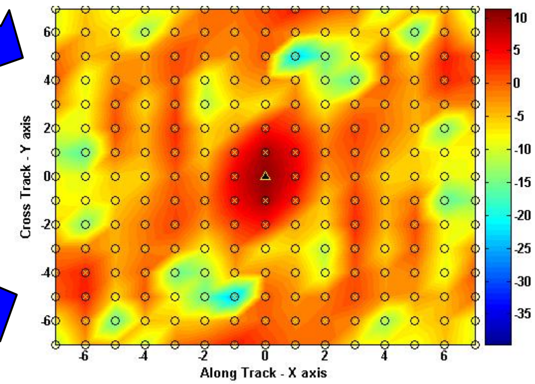


True SCR Convergence

Heuristic Maxi-min



Heuristic SCR Convergence



Maximum SCR

▲ Target Locations

○ Clutter Locations

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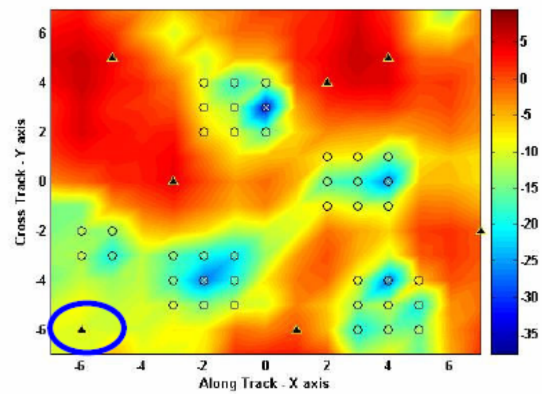
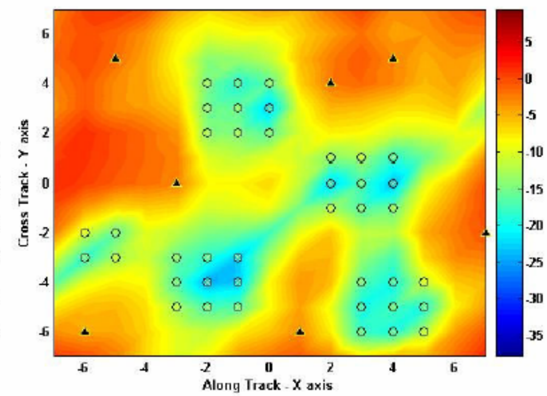
ORPHAN PROBLEM SOLUTION

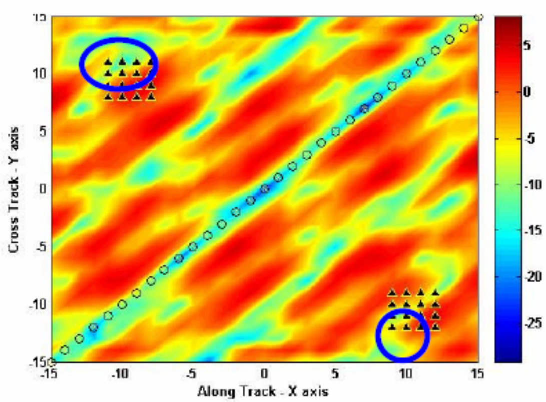
Maximum SCR | **Heuristic SCR Convergence**



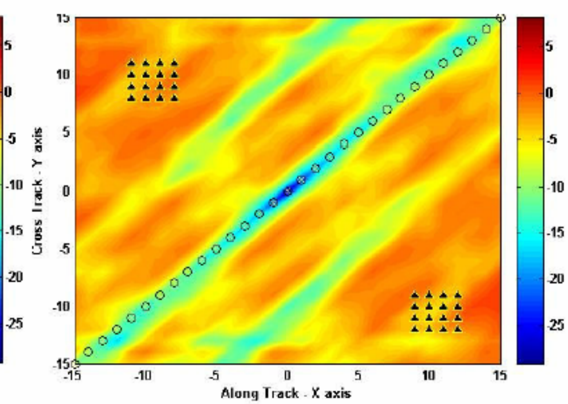
SCR_{min} = -2.73 dB



SCR_{min} = 11.38 dB



SCR_{min} = -2.21 dB



SCR_{min} = 8.84 dB

▲ **Target Locations**

○ **Clutter Locations**

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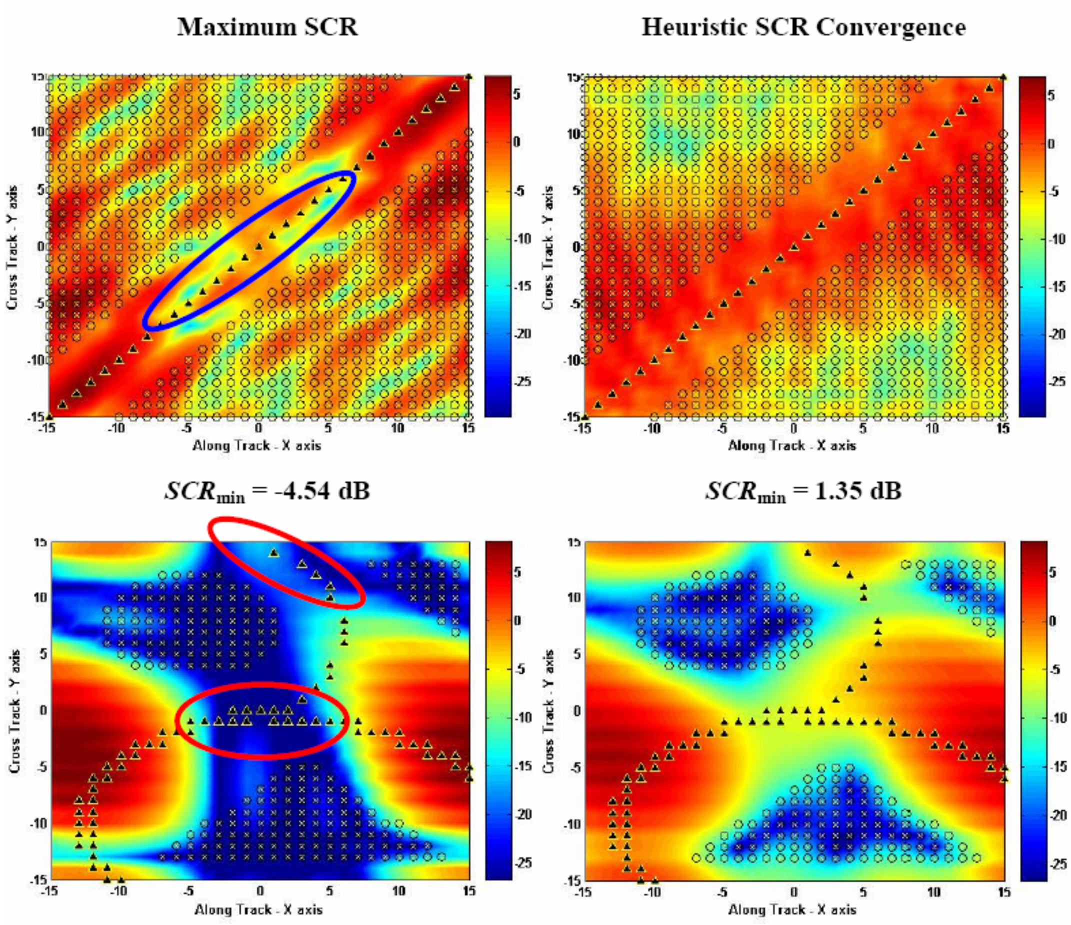
ORPHAN PROBLEM SOLUTION



SCR_{min} = -4.54 dB

SCR_{min} = 1.35 dB

SCR_{min} = -13.82 dB

SCR_{min} = 6.96 dB

▲ Target Locations

○ Clutter Locations

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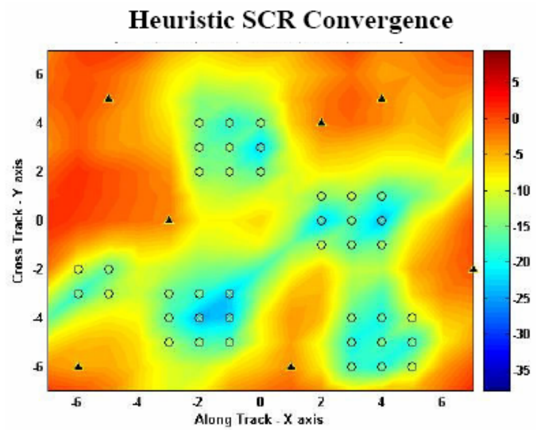
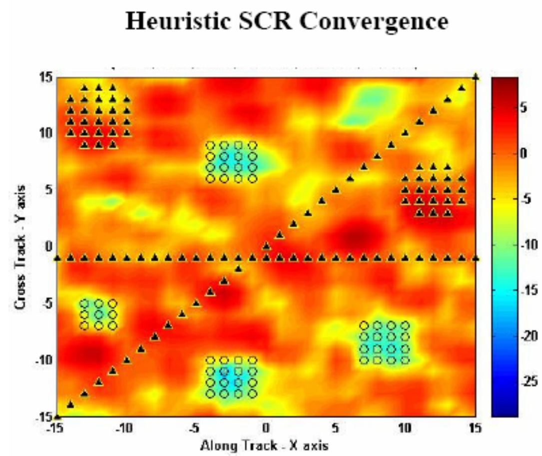
COMPARISON OF BOTH MAXI-MINS



$SCR_{min} = 11.38$ dB

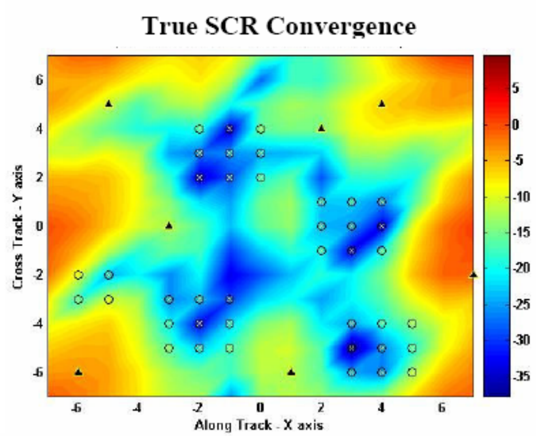


$SCR_{min} = 2.51$ dB

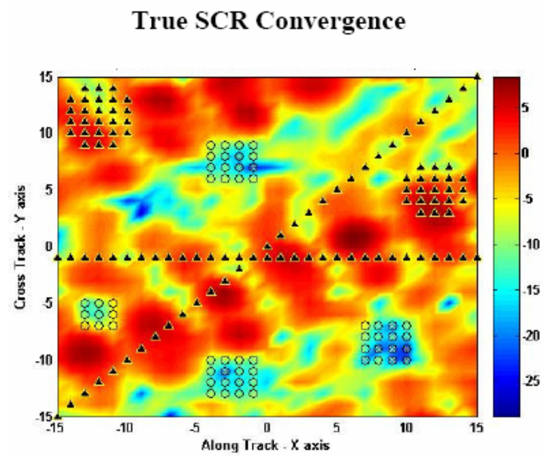
Maximum SCR
$SCR_{min} = -2.73$ dB

BETTER

Maximum SCR
$SCR_{min} = -4$ dB



$SCR_{min} = 4.29$ dB



$SCR_{min} = -1.47$ dB

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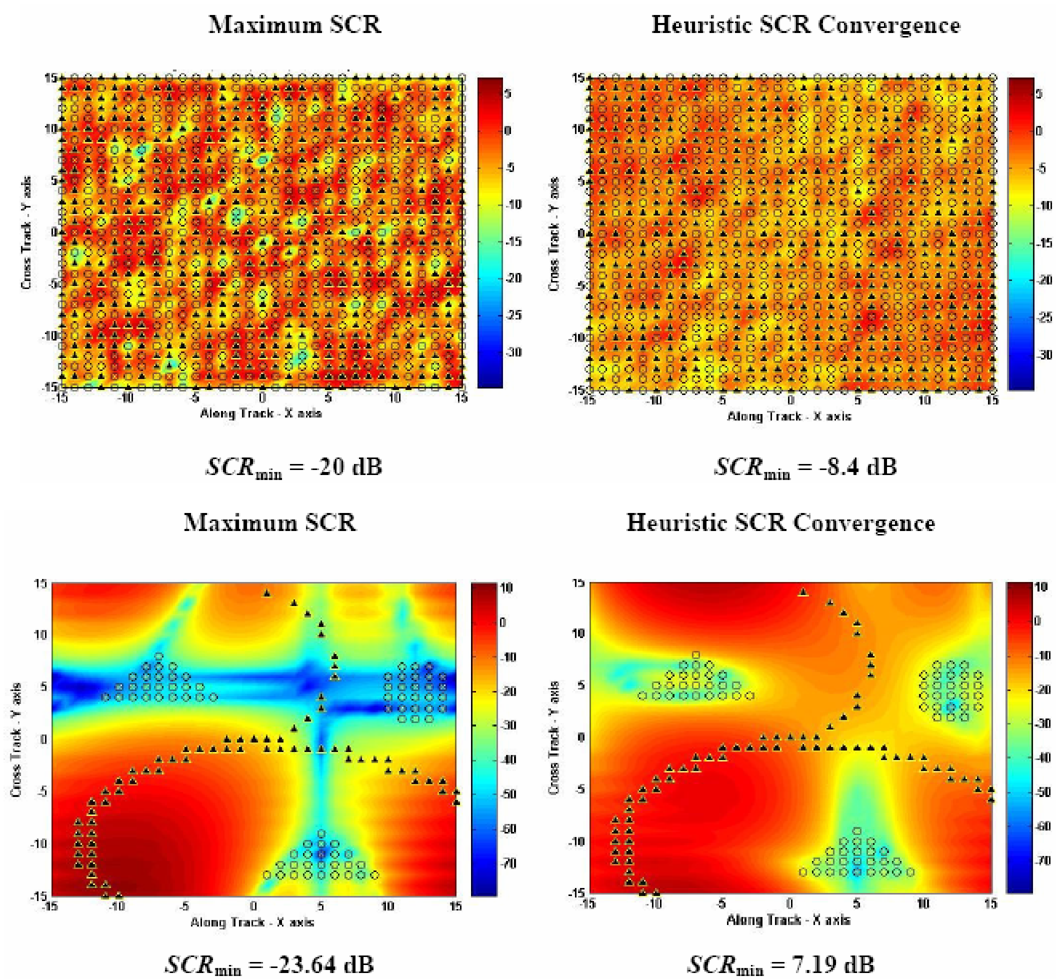
PERFORMANCE ANALYSIS

- Champion Algorithm → Heuristic SCR Convergence

DEPENDENCE ON TARGET SCENARIO



▲ Target Locations

○ Clutter Locations

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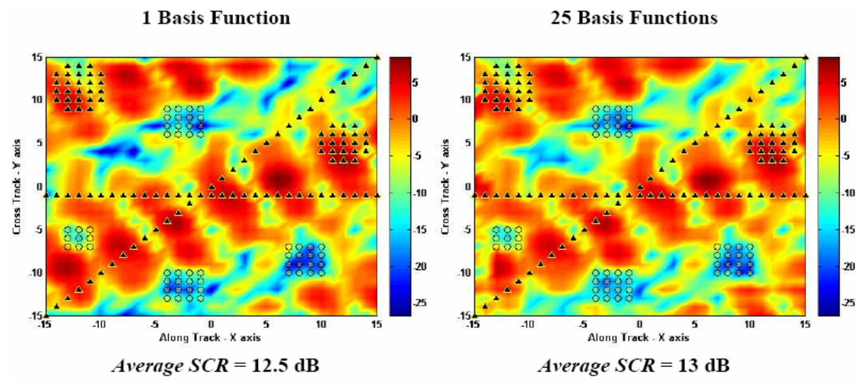
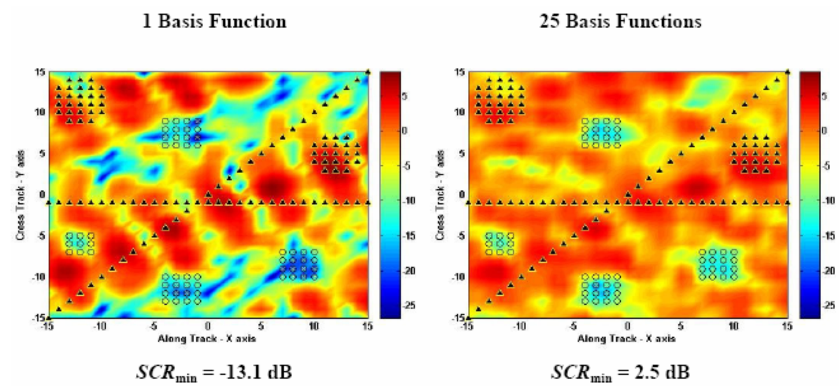
DEPENDENCE ON NUMBER OF BASIS FUNCTIONS (SIGNAL DIMENSION)

- **Standard code performance is fairly insensitive to the increase in the number of time-frequency basis functions → spatial beamforming**
- **Maxi-min performance depends greatly on the number of basis functions → true space-time solutions**



Maximum SCR



Heuristic SCR Convergence

Note: 1 basis function case essentially implies a spatial code

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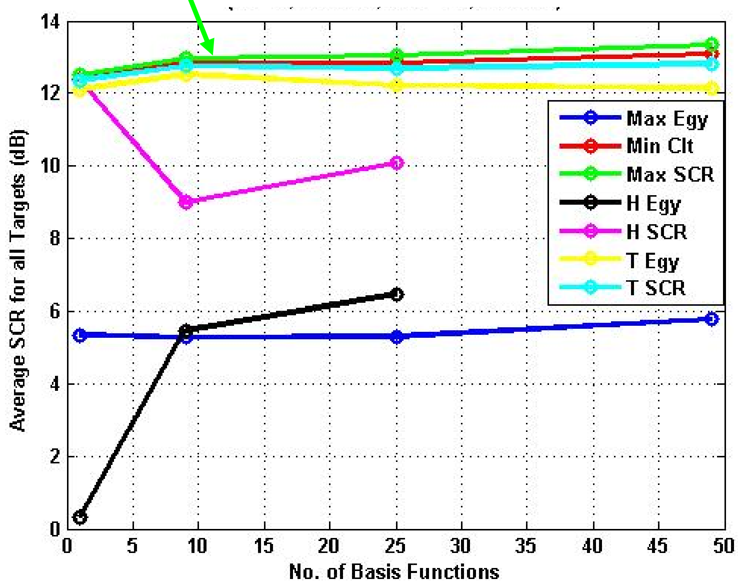
EFFECT OF INCREASING THE NUMBER OF BASIS FUNCTIONS ON DIFFERENT CODES

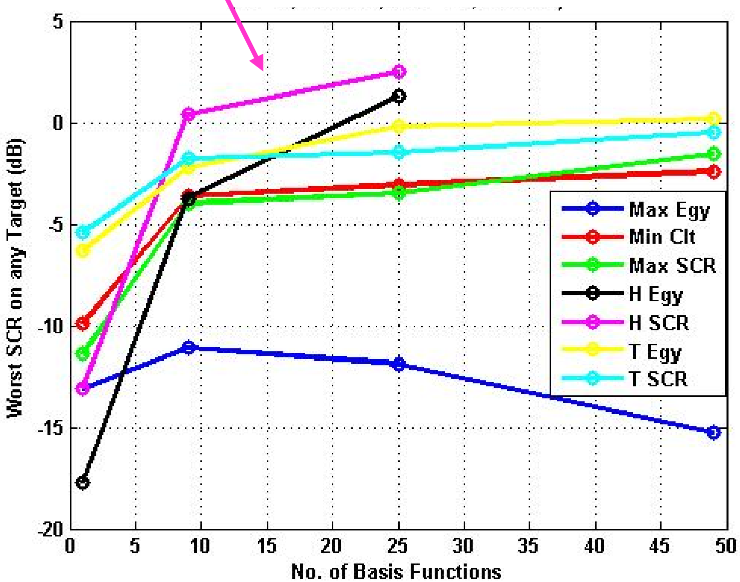
Not affected by increase in basis fn's – Spatial Beamforming equally effective

Greatly affected by increase in basis fn's – Spatial Beamforming not as good

Average SCR



Worst SCR



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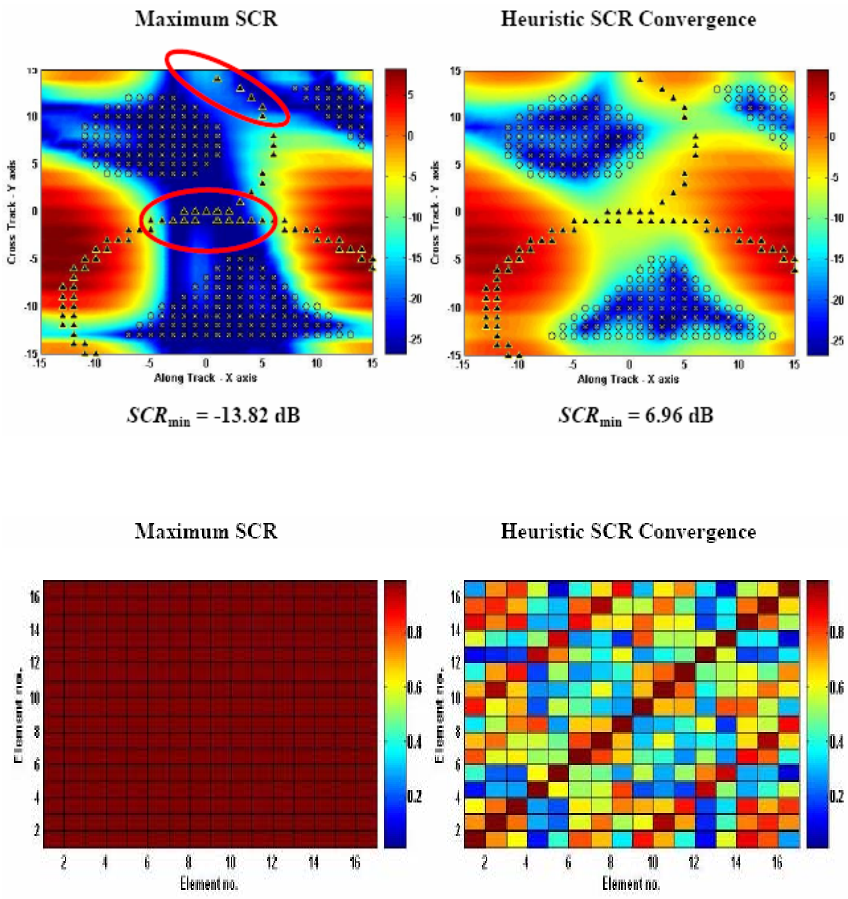
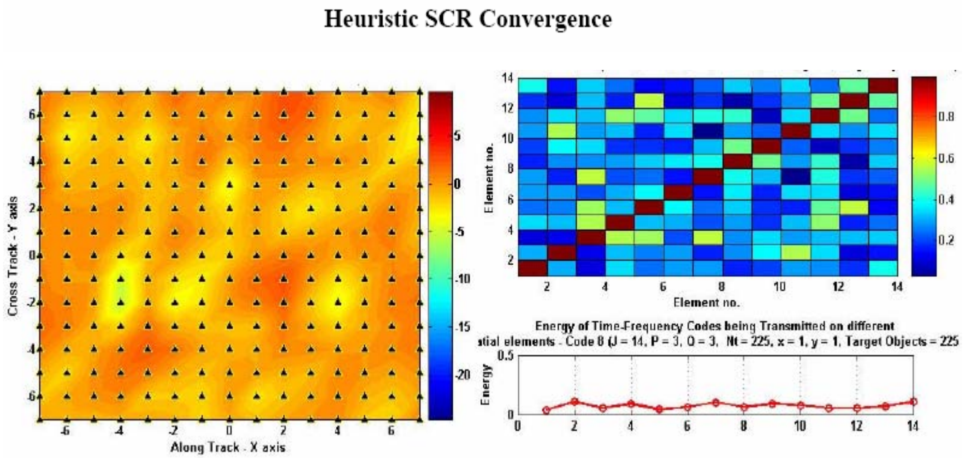
FORM OF THE TRANSMIT SIGNAL

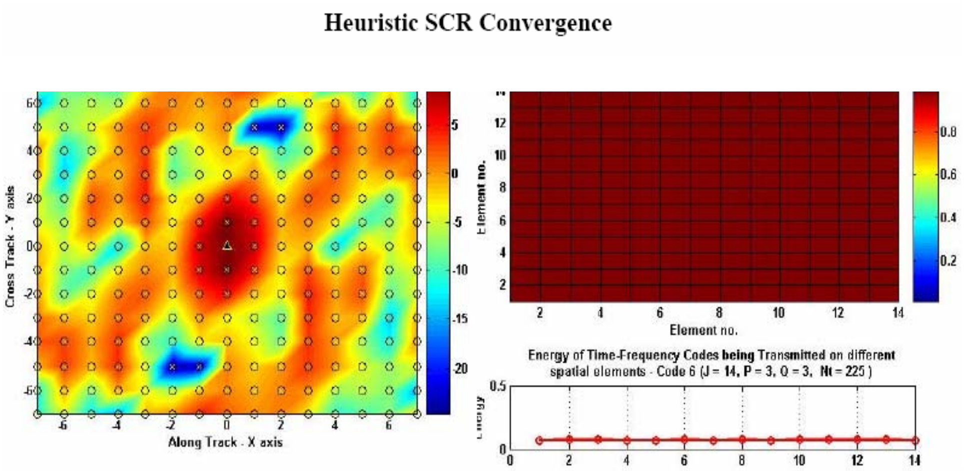
- Recall our initial goal – To come up with optimal and true space-time codes, i.e. *different time-frequency signals propagate* on *different transmitters*
- How close do we reach to this goal ?
- Results show that for the basic codes the temporal signals on the different elements are perfectly correlated – i.e. **pure spatial beamforming**
- While for the maxi-mins the individual signals are typically only partially correlated – **true space-time operation**



FORM OF THE TRANSMIT SIGNAL

- Nothing in the algorithm tells it what solutions to converge to
- The structure that exists can be used for synthesizing both spatial and space-time solutions
- It just converges to the optimal solution for the particular case
- **Any other means to synthesize identical illumination patterns (except by transmitting dissimilar transmit signals on different antennas) is not possible**





FORM OF THE INCIDENT SIGNAL ON TARGETS

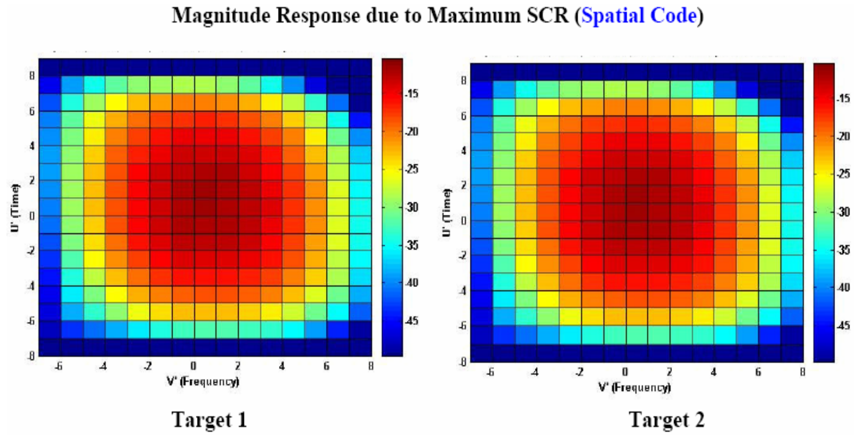
- More interesting than the form of transmit signal is the form of incident signals on the targets

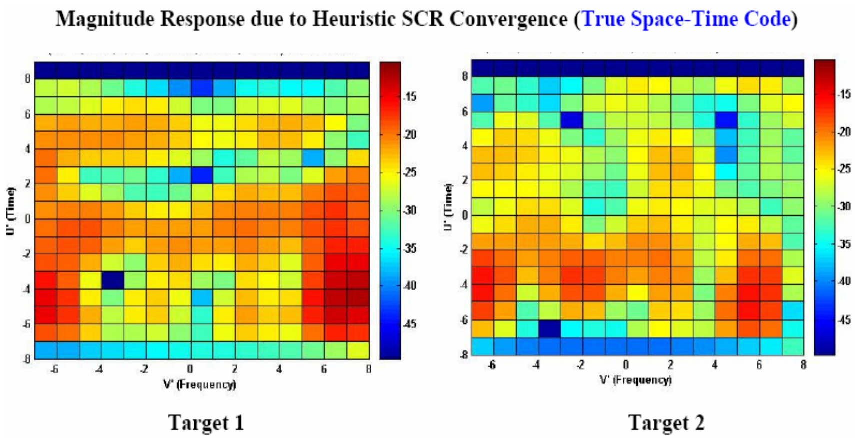
- Resulting signal at any target is due to the coherent summation of all the individual temporal signals of different transmitters

- **Separable or spatial codes**
  - Individual temporal signals identical
  - ***Resulting time-frequency spectra also identical at the different target locations***

- **Non-separable or space-time codes**
  - Coherent summation of *dissimilar* temporal signals of different antennas
  - ***Time-frequency spectra completely different at different target locations***

- **Potential for target resolution**





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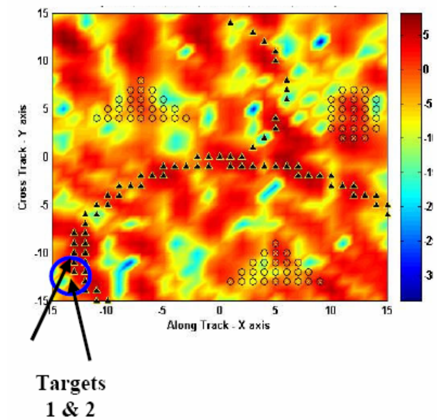
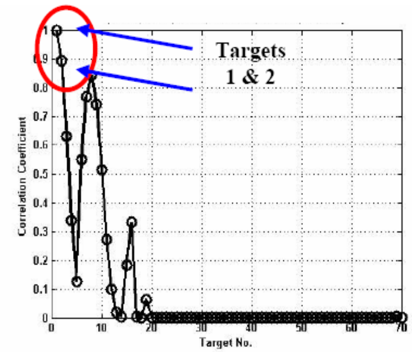
FORM OF THE SIGNAL INCIDENT ON TARGETS – ANOTHER PROSPECT

- Owing to the dissimilar magnitude responses, the cross-correlation between even those targets can be reduced that are non-resolvable in delay and doppler.

- Or the main lobe of the time-frequency ambiguity function can be narrowed

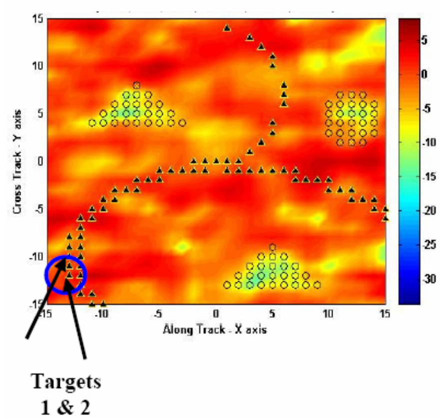
Maximum Energy (Spatial Code)

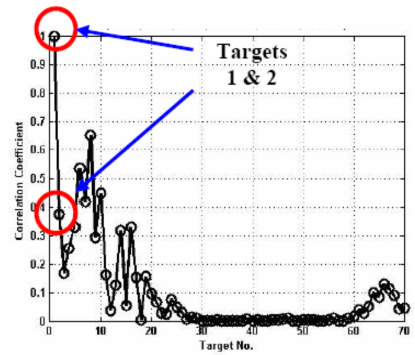




Correlation coefficient between response of Target 1 and other Targets

Heuristic SCR Convergence (Space-Time Code)





Correlation coefficient between response of Target 1 and other Targets

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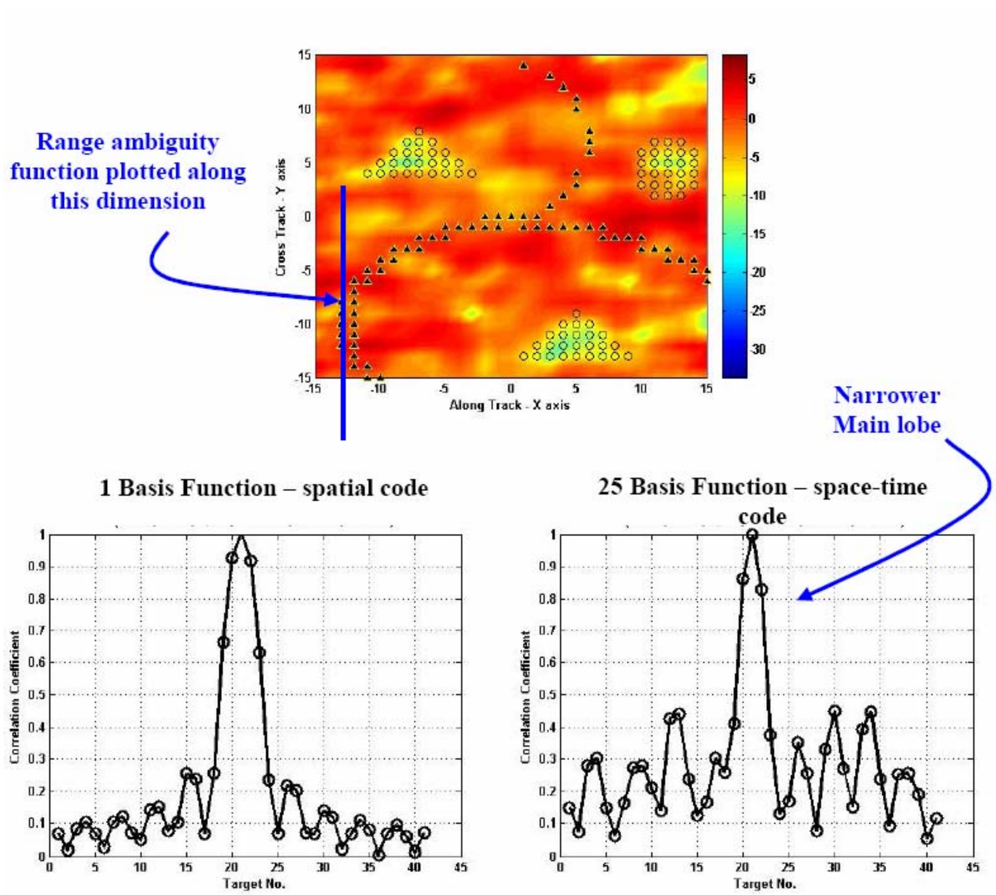
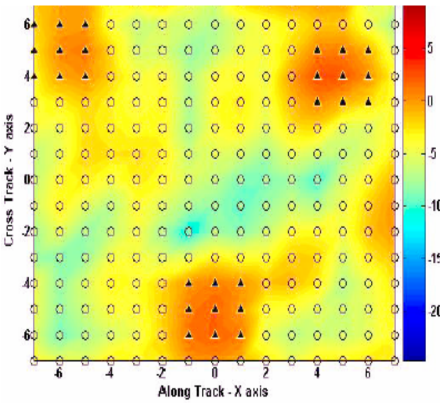
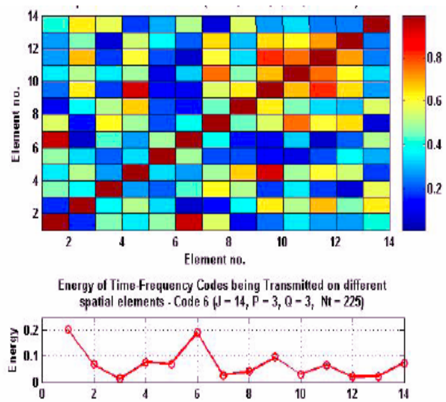
SPACE-TIME CODES

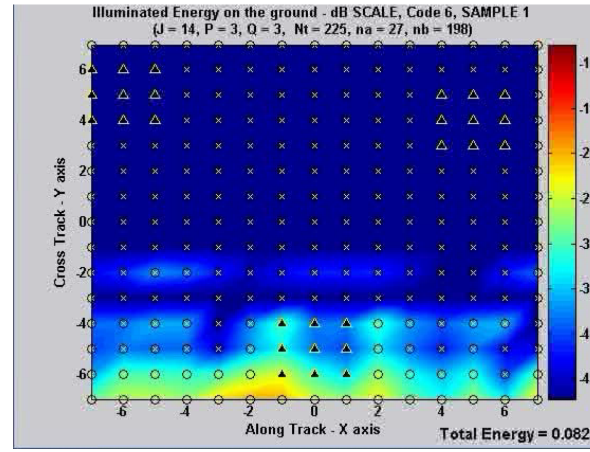
AMBIGUITY FUNCTION MAIN LOBE WIDTH REDUCTION



SPACE-TIME CODES
ONE FINAL PERSPECTIVE







- ***True Space Time Codes*** - the illumination pattern can change from pulse to pulse or frequency to frequency or even sample to sample, giving it additional versatility

- ***Spatial Codes*** - all antennas propagate the same temporal signal, and thus their coherent summation results in a constant illumination pattern with respect to time and frequency on the ground

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CONCLUSIONS

- For exploiting the true potential of a multi-aperture radar, dissimilar temporal signals needs to propagate on the different spatial elements.
- True space-time signals were successfully constructed for several illumination optimization criteria, using a union of vector-matrix radar models and linear algebraic techniques.
- Further, space-time codes that distribute energy appropriately across the available timewidth and bandwidth for different targets can potentially be constructed - and thus a range of radar requirements satisfied.

FUTURE WORK

- **Improve the computational efficiency of our algorithms**
- **Adaptive Space-Time codes**
  - Information theoretic selection criteria
- **Hybrid or Multi-Mode operation**
  - Different radar modes across different spatial locations
- **GMTI and AMTI applications**
- **Unification with Space-Time Ambiguity Optimization**
- **Algorithm performance evaluation for other basis functions and spatial array arrangements.**

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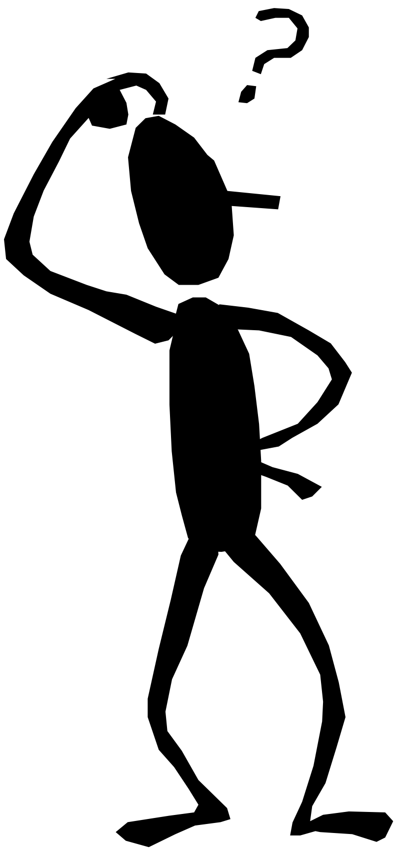
PUBLICATIONS

- Jim Stiles, Vishal Sinha, Atulya Deekonda. **“Optimal Space-Time Transmit Signals for Multi-Mode Radar”,** *2006 International Waveform Diversity & Design Conference, Lihue, Hawaii, USA, Jan 22-27*

THANK YOU!



QUESTIONS ??

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