



Simulation and Analysis of Adaptive Interference Suppression for Bistatic Surveillance Radars*

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13 March 2001

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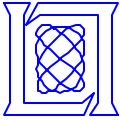
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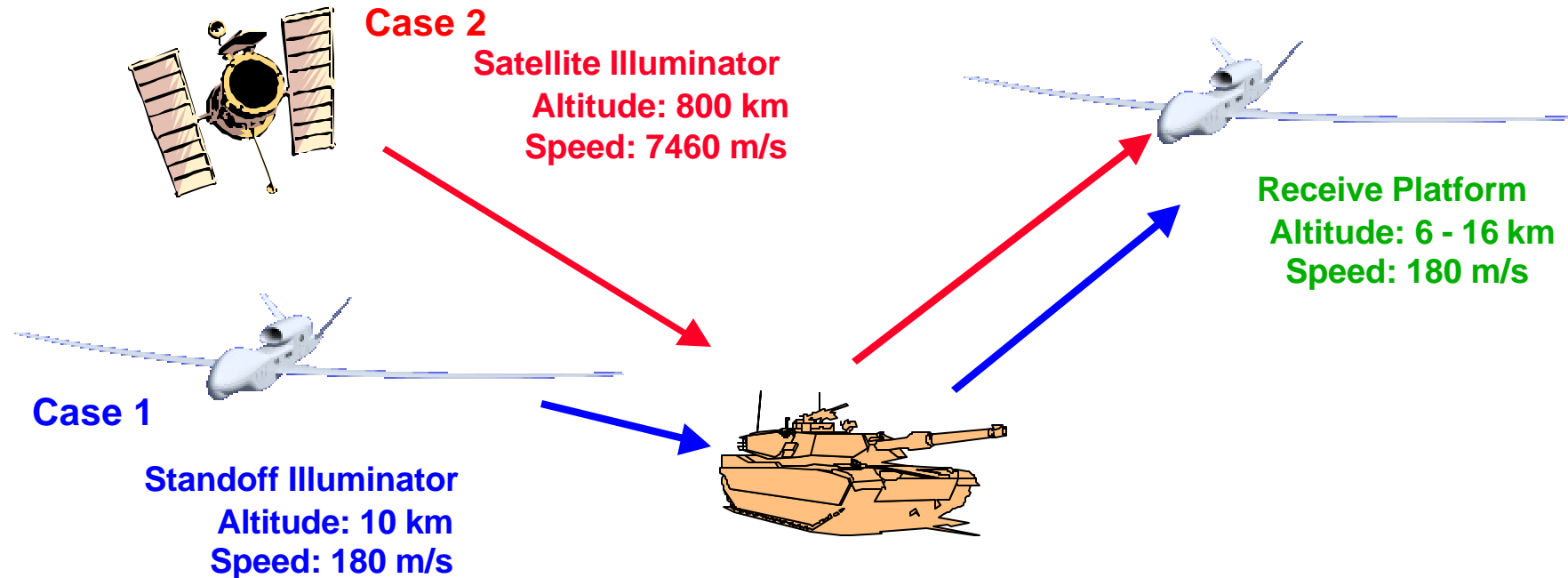
Outline

➔ Problem Overview

- Bistatic Algorithms - Description and Analysis
- Summary and Future Work



Problem Overview

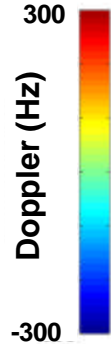
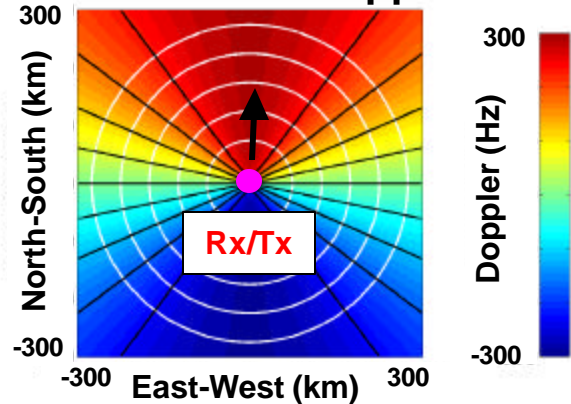


- **Bistatic geometry involves separate transmit and receive platforms**
 - Platforms are moving independently
- **Receive only platform for surveillance or strike**
 - Extend coverage area
 - Improve target localization
 - No transmitter on receive platform
 - Reduce size, weight, power
 - Improve stealthiness



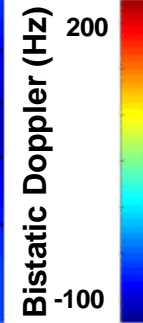
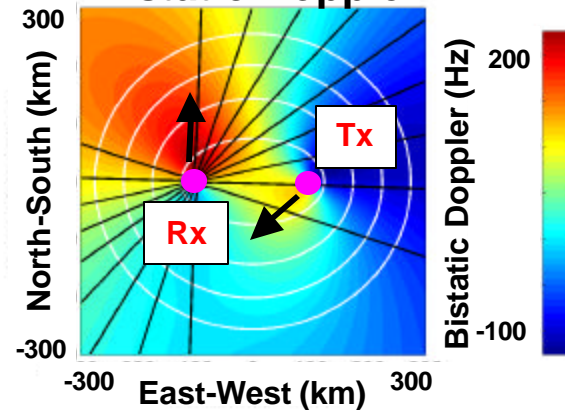
Challenges for Bistatic Operation

Monostatic Doppler

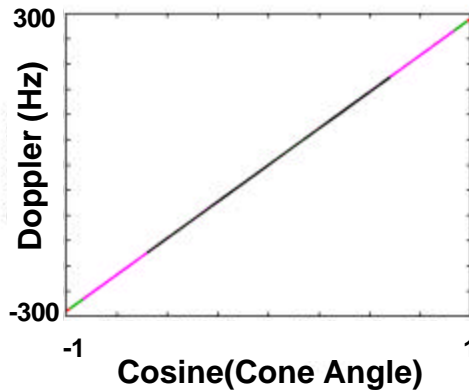


— Iso-cone
— Iso-range

Bistatic Doppler

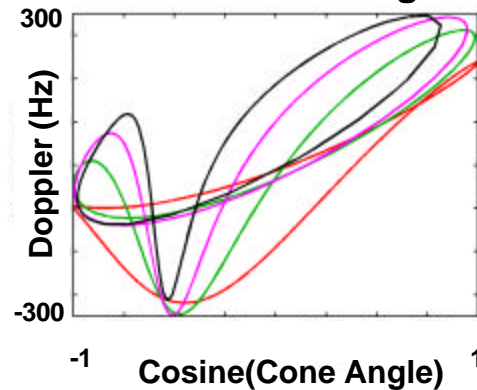


Monostatic Clutter Ridges



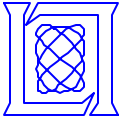
Two-way range
25 km
50 km
100 km
300 km

Bistatic Clutter Ridges

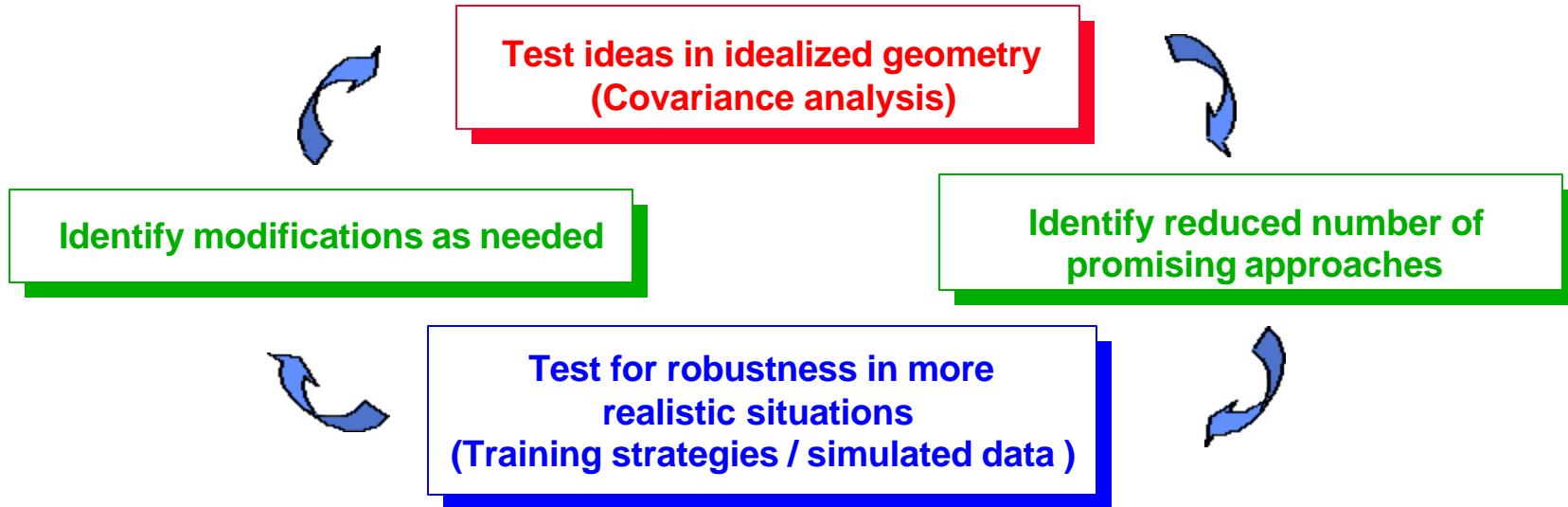


Bistatic Range
225 km
250 km
300 km
500 km

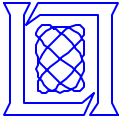
- Benefits of bistatic operation come at a price
 - Azimuth / Doppler structure of clutter interference varies with range
- Challenge is to find training strategies to estimate covariance R



Algorithm Development Approach

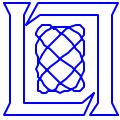


- **Covariance model is used to compare algorithms with**
 - large number of geometries
 - coarse range sampling
- **Modeling goal is to quickly survey algorithm performance**
 - simplified scattering model
- **Time series model is used to compare algorithms with**
 - small number of geometries
 - fine scale range sampling
- **Designed to examine “real world” effects on algorithm performance**

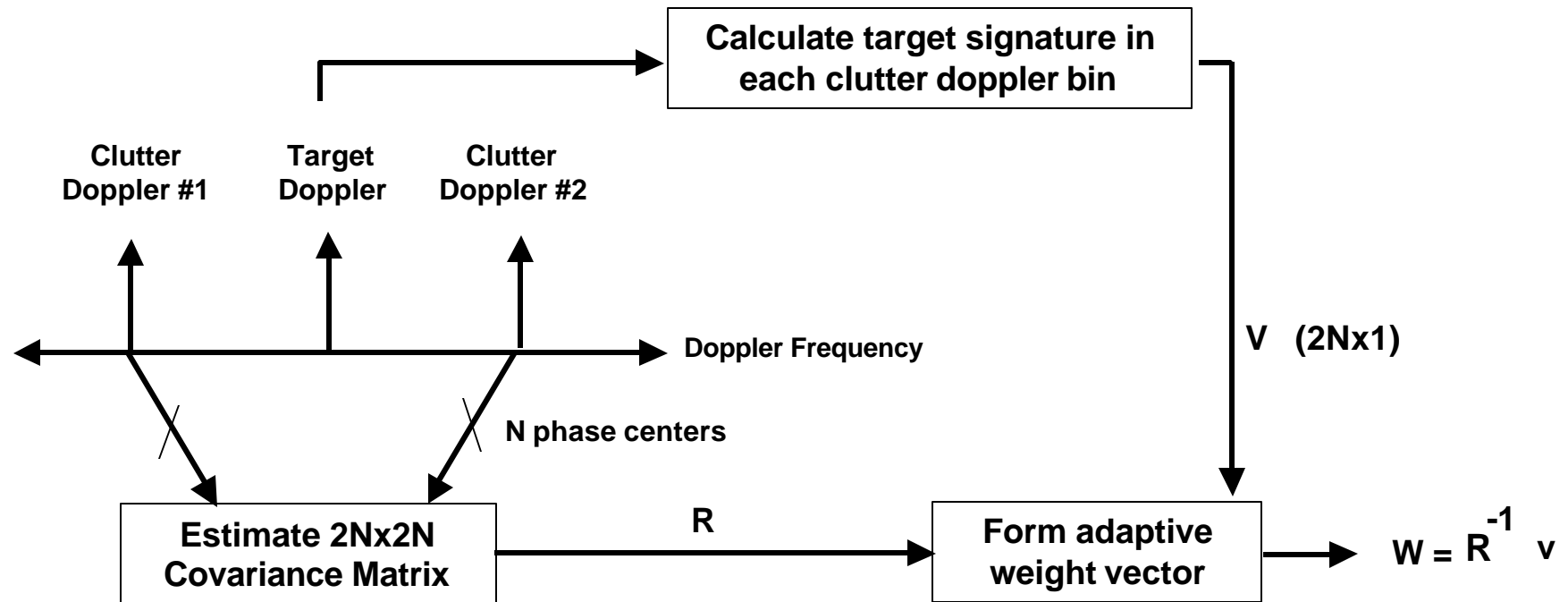


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- Problem Overview
- Bistatic Algorithms - Description and Analysis
 - Algorithm description
 - “Standard” 2 - bin Post - Doppler
 - 2 - bin Post - Doppler with Derivative Based Updating (DBU)
 - *Uses only radar data but doubles the degrees of freedom (DOF's)*
 - *Requires increased sample support*
 - 2 - bin Post - Doppler with High Order Doppler Warping (HODW)
 - *Uses knowledge of bistatic clutter ridge*
 - *Receiver must know position and velocity of transmitter*
 - Algorithm performance
- Summary and Future Work



2 - Bin Post - Doppler Algorithm

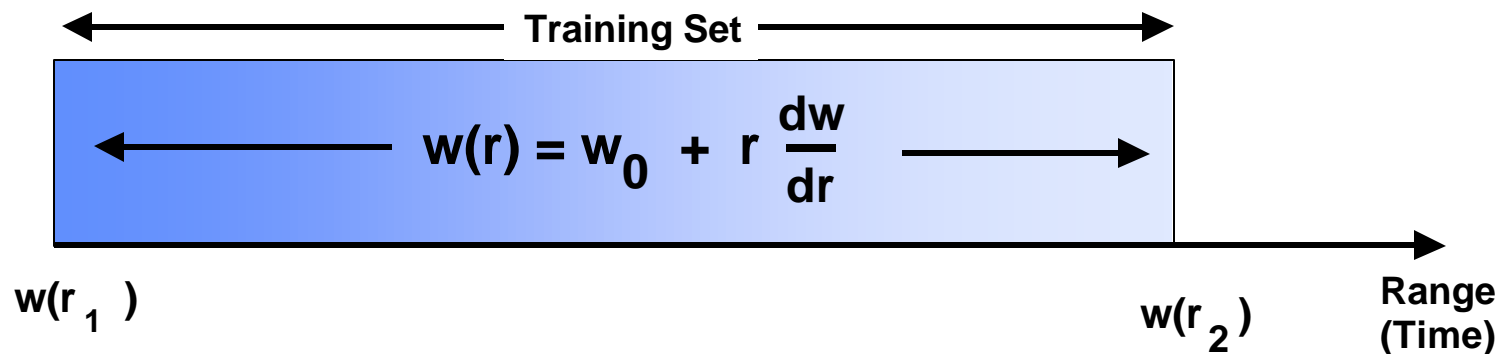


- **Two-Bin nulling algorithm:**
 - Train on clutter in Doppler bin #'s 1 and 2 to null clutter at the target Doppler frequency
- **Well established approach for monostatic STAP applications**
 - Typically assume *range invariance* and estimate covariance with *range average*

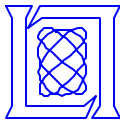


Derivative-Based Updating Algorithm

- **Derivative-Base Updating Algorithm (DBU):**
 - Hayward (1996), Zatman & Kogon (2000 ASAP), Zatman (2001 ASAP)



- **Assumes weight vector varies linearly with range**
 - Effectiveness depends on accuracy of weight vector model
- **Doubles the number of degrees of freedom (DOF) in the STAP problem**
 - Covariance matrix size is doubled
 - Number of training samples required to estimate covariance is doubled



Derivative Based Updating - Interpretation

- Assume optimal filter $w_k = w_0 + k w'$ (at k^{th} relative range gate)
- $w_k^H x_k = w_0^H x_k + k w'^H x_k = [w_0^H \ w'^H] [x_k; k x_k]$
- Form sample set based on extended vector $[x_k; k x_k]$ to obtain *extended covariance*

$$R_{\text{est}} = (1/N) \begin{bmatrix} \sum_k x_k x_k^H & \sum_k k x_k x_k^H \\ \sum_k k x_k x_k^H & \sum_k k^2 x_k x_k^H \end{bmatrix} \rightarrow \begin{bmatrix} R_0 & a R' \\ a R' & a R_0 \end{bmatrix} \quad \left(a = \sum_k k^2 \right)$$

$$[w_0^H \ w'^H] [x_k; k x_k] = [v^H \ 0] (R_{\text{est}})^{-1} [x_k; k x_k] = v^H D_k^{-1} x_k$$

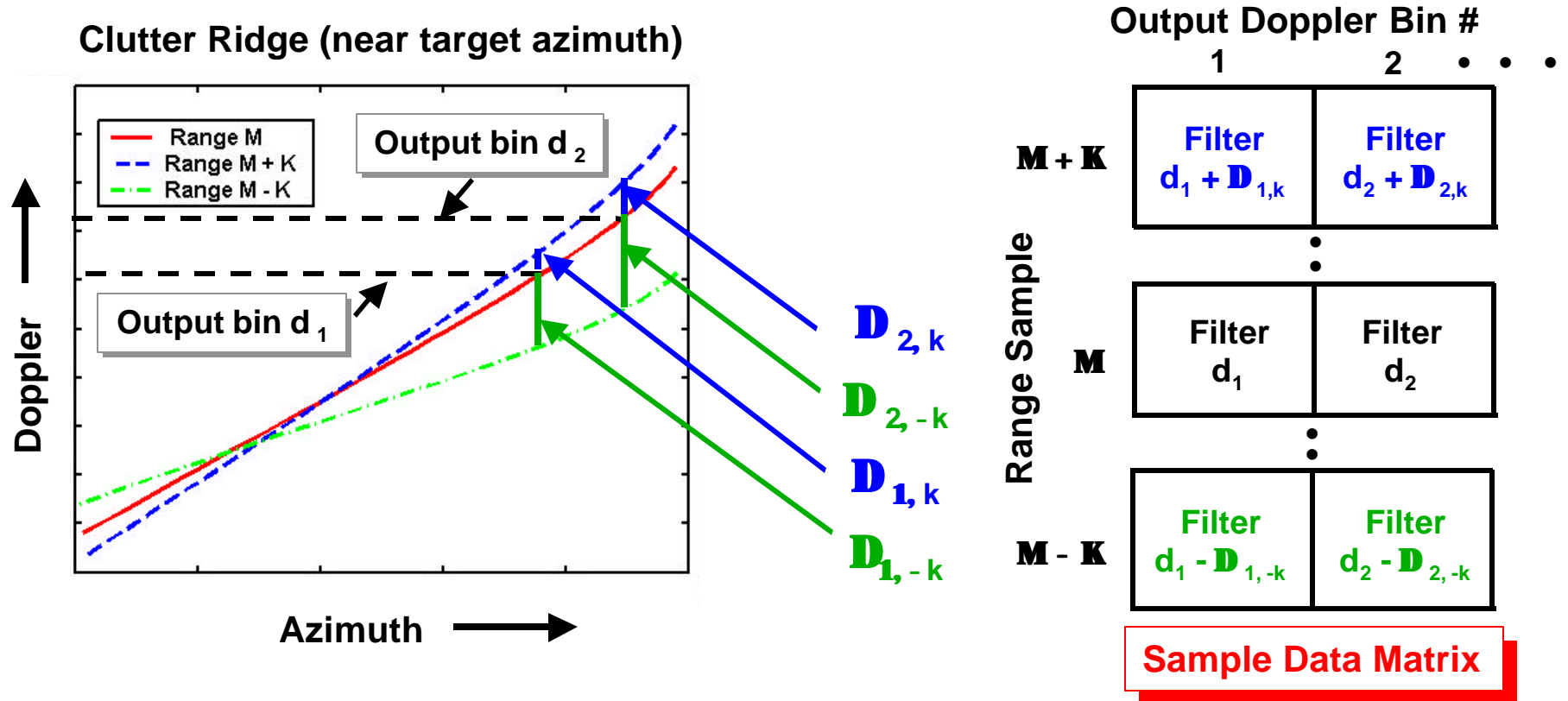
(have used sample set symmetry ($\sum_k k = 0$) and $R_k = \langle x_k x_k^H \rangle = R_0 + k R'$)

*DBU equivalent to applying filter $w_k = D_k^{-1} v$
with $D_k^{-1} = (I - k R_0^{-1} R') (R_0 - a R' R_0^{-1} R')^{-1}$*

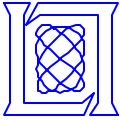
- First order perturbation: $R_k^{-1} = (R_0 + k R')^{-1} \approx (I - k R_0^{-1} R') R_0^{-1}$
 - DBU matches perturbation up to terms quadratic in R'
 - the a term grows quadratically with the size of training set



High Order Doppler Warping (HODW)



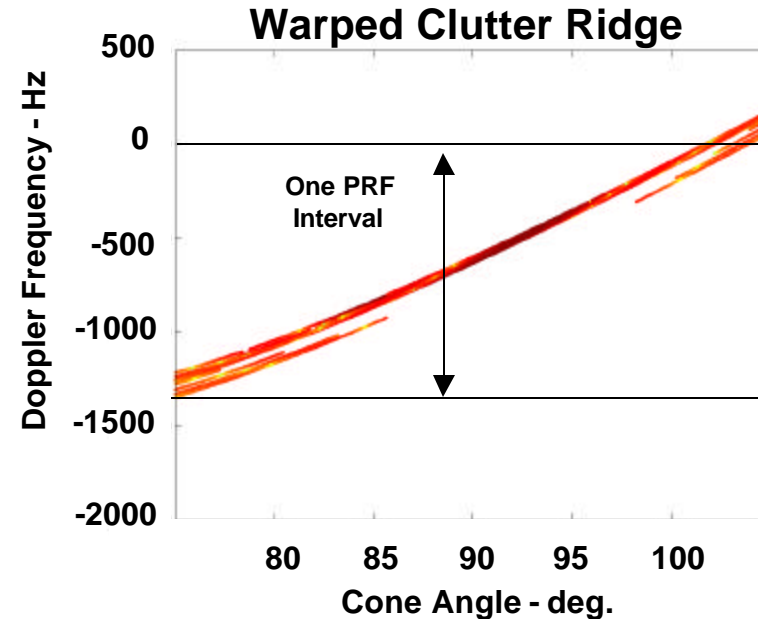
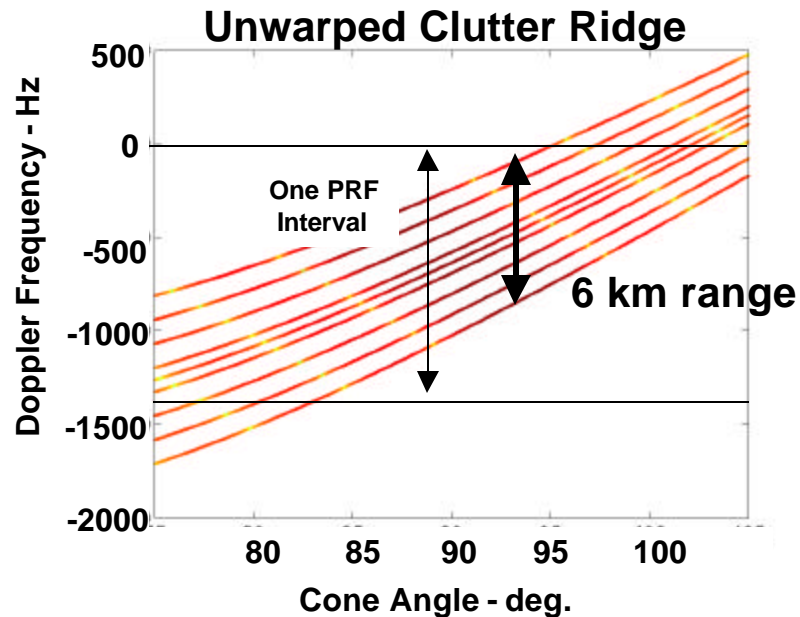
- In each Doppler filter apply a range-dependent Doppler frequency shift
 - Shift is different in each Doppler filter, at each range
 - Original warping algorithm used same shift in each Doppler filter
 - *Interference structure nearly homogeneous in range for each output Doppler bin*
- Clutter ridge calculation requires knowledge of transmitter position and velocity*



High-Order Doppler Warping

Bistatic Space to Air Example

Clutter Ridges Over 6 km at Target Range

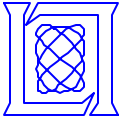


- Frequency shift is derived from the clutter ridge geometry
 - Clutter ridge multiplicity (front lobe / back lobe, aliasing) resolved by choosing highest transmit power branch
- “High Order” Warping has made the clutter interference *range invariant*” on a *bin by bin* basis



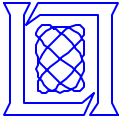
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 - “Standard” 2-bin Post - Doppler
 - Derivative Based Updating
 - High Order Doppler Warping
 - **Algorithm performance**
- **Summary and Future Work**



Measuring Performance

- Standard measure of performance is **SINR Loss**
- For signal element response vector \mathbf{v} ($|\mathbf{v}|^2 = 1$) and filter \mathbf{w} :
 - $SINR = |s|^2 |\mathbf{w}^H \mathbf{v}|^2 / (\mathbf{w}^H \mathbf{R} \mathbf{w})$
where \mathbf{R} is the true “interference + noise” covariance matrix $\langle \mathbf{x} \mathbf{x}^H \rangle$
and s is the signal amplitude
- For uncorrelated noise (unit power) $\langle \mathbf{n} \mathbf{n}^H \rangle = \mathbf{I}$ and with $\mathbf{w} = \mathbf{v}$
 - $SNR = |s|^2 |\mathbf{v}^H \mathbf{v}|^2 / (\mathbf{v}^H \mathbf{v}) = |s|^2$
- For correlated noise $\langle \mathbf{n} \mathbf{n}^H \rangle = \mathbf{N}$ and with $\mathbf{w} = \mathbf{N}^{-1} \mathbf{v}$
 - $SNR = |s|^2 |\mathbf{v}^H \mathbf{N}^{-1} \mathbf{v}|^2 / (\mathbf{v}^H \mathbf{N}^{-1} \mathbf{v}) = |s|^2 \mathbf{v}^H \mathbf{N}^{-1} \mathbf{v}$
- Ratio is $SINR\ Loss = |\mathbf{w}^H \mathbf{v}|^2 / ((\mathbf{w}^H \mathbf{R} \mathbf{w}) (\mathbf{v}^H \mathbf{N}^{-1} \mathbf{v})) \leq 1$
 - Optimal $\mathbf{w} = \mathbf{R}^{-1} \mathbf{v}$ and $max(SINR\ Loss) = \mathbf{v}^H \mathbf{R}^{-1} \mathbf{v} / (\mathbf{v}^H \mathbf{N}^{-1} \mathbf{v})$
 - In practice use estimated \mathbf{R}_{est} and $\mathbf{w} = \mathbf{R}_{est}^{-1} \mathbf{v}$



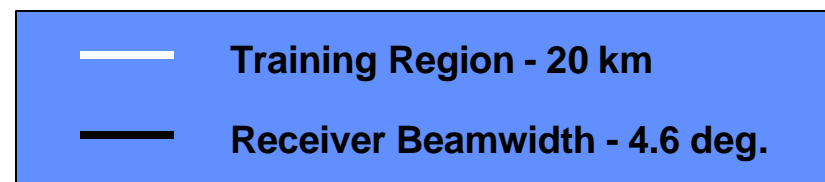
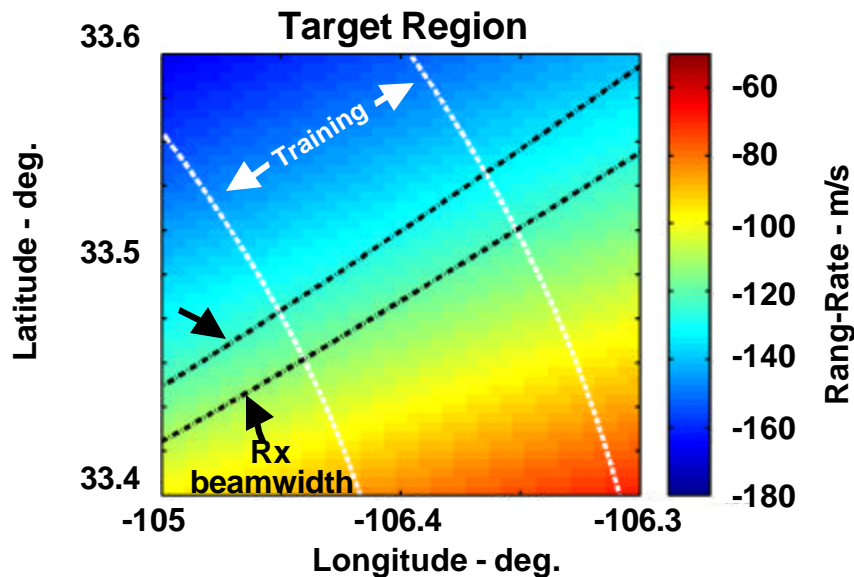
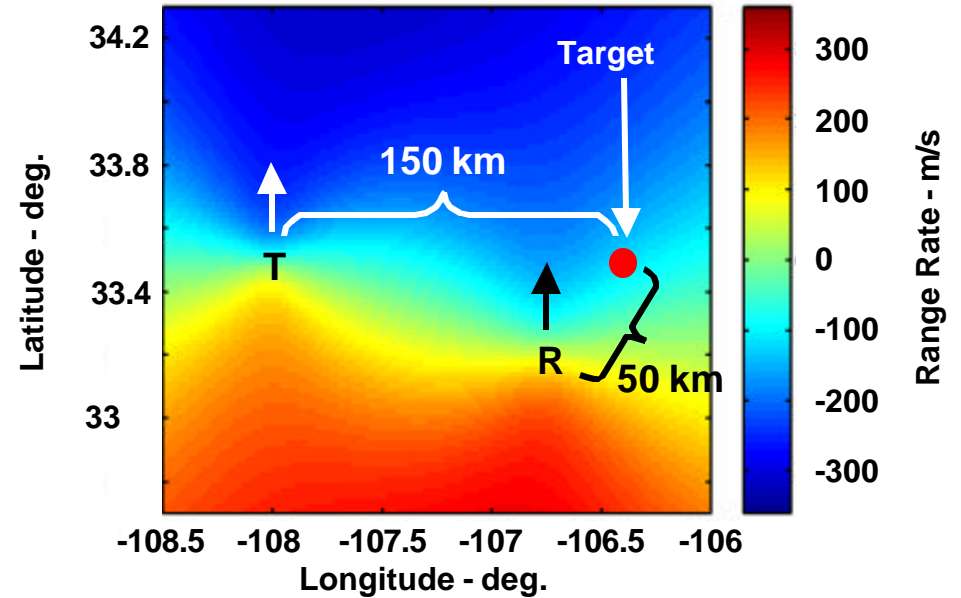
Case 1: Air to Air Geometry

Transmitter

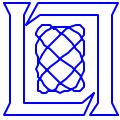
Altitude	10 km
Speed	180 m/s
Heading	North
Freq.	5.2 GHz
Bandwidth	5 MHz
Array Elements	8 Hor. X 24 Ver.

Receiver

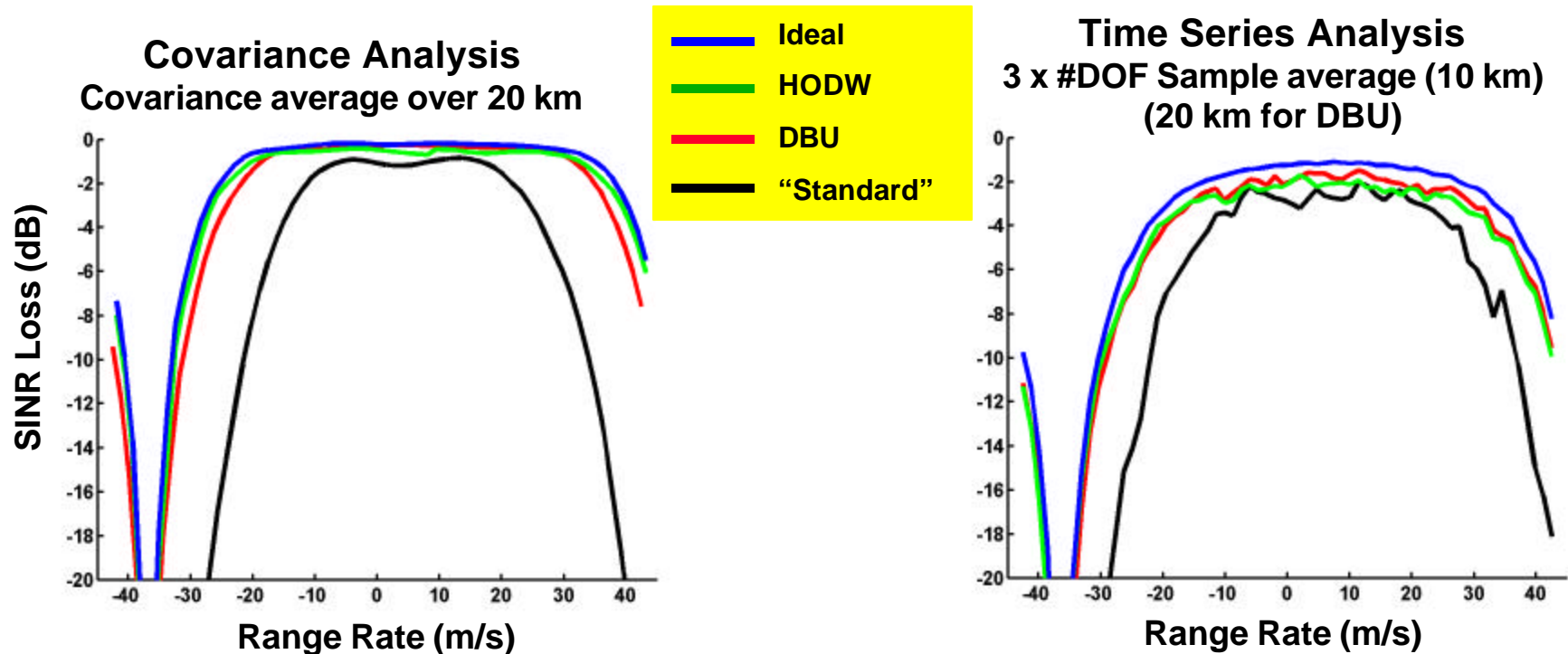
Altitude	16 km
Speed	180 m/s
Heading	North
Array Elements	32 Hor. X 1 Ver.
# DOFs	32



- Moderate variation of clutter ridge with range



Algorithm Performance - Bistatic Air to Air (Case 1)



- **Standard Sample Covariance Matrix approach significantly degraded**
 - Only moderate variation of clutter interference structure across training region
 - Standard approach preserves 60% of useable Doppler space (UDSF)
- **Both DBU and HODW methods yield near - ideal performance**
 - DBU preserves 80% UDSF, HODW 85%, Ideal 85%



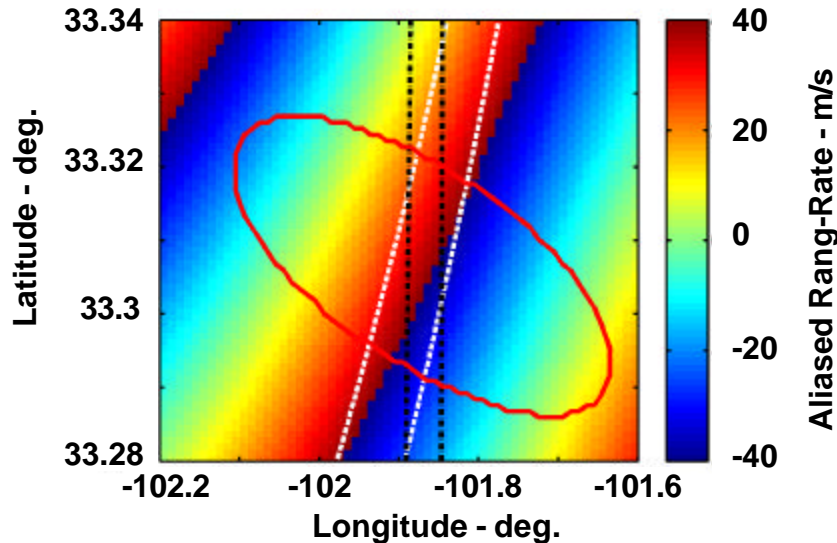
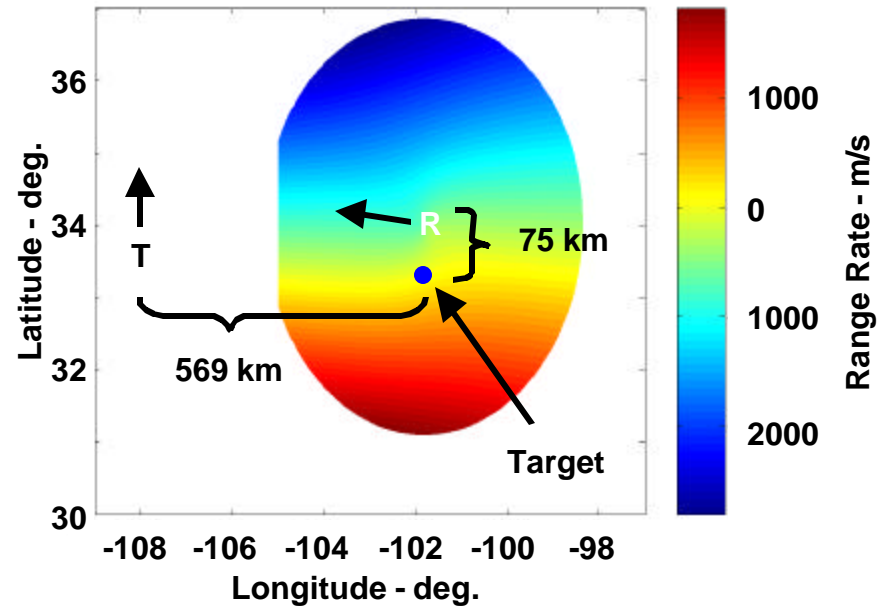
Case 2: Space to Air Geometry

Transmitter

Altitude	800 km
Speed	7540 m/s
Heading	North
Freq.	5.2 GHz
Bandwidth	12 MHz
Array Elements	501 Hor. X 51 Ver.

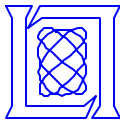
Receiver

Altitude	6 km
Speed	200 m/s
Heading	-86° wrt North
Array Elements	36 Hor. X 24 Ver.
# DOFs	36
CNR	40 dB

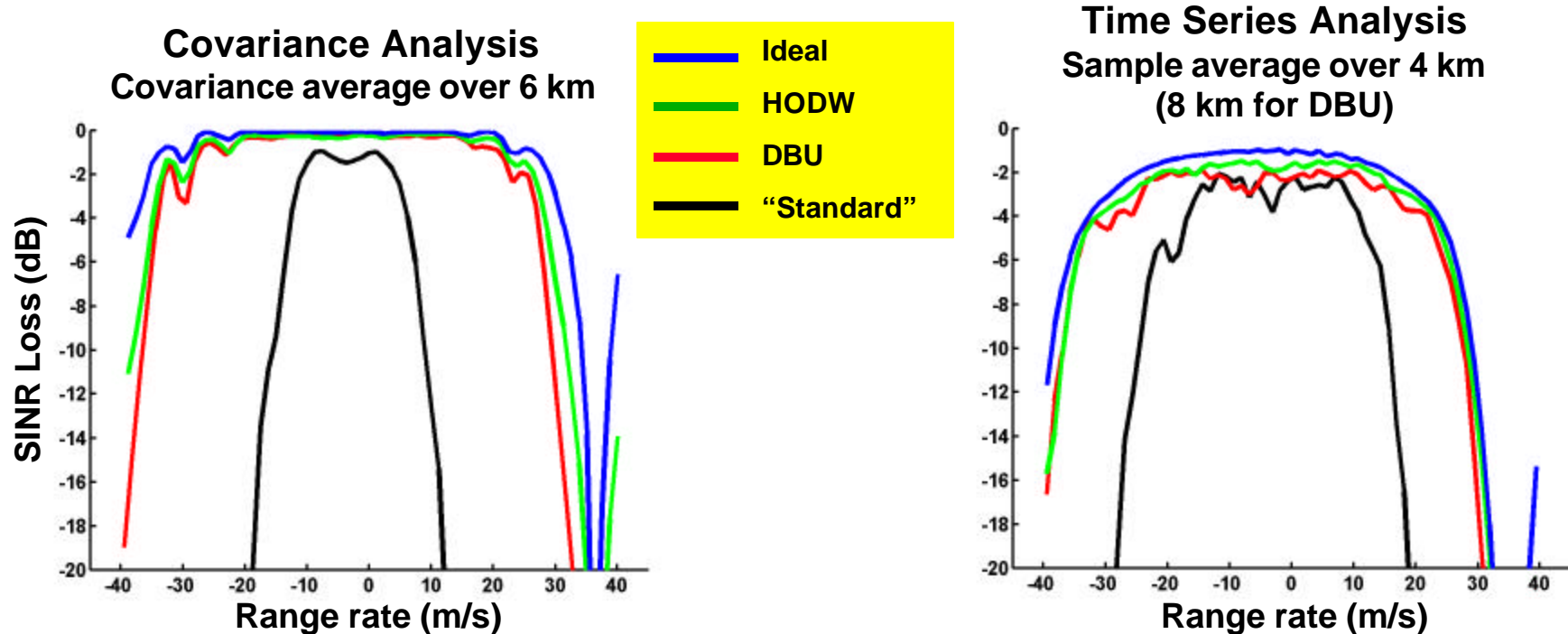


- Training Region - 4 km
- Receiver Beamwidth - 2.8 deg.
- 3 dB Transmitter Beamwidth

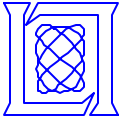
• Clutter ridge varies rapidly with range



Algorithm Performance - Bistatic Space to Air Case 2



- **Standard Sample Covariance Matrix approach performs poorly**
 - Very rapid variation of clutter interference structure across training region
 - Much worse performance than in air to air case
 - UDSF degrades from 45% with 4 km training to 25% with 6km training
- **Both DBU and HODW methods again yield near - ideal performance**
 - UDSF is 80% for both DBU and HODW, UDSF for ideal is 90%



Bistatic STAP Algorithms - Recap

- **Standard training approach for STAP works poorly**
 - Poor choice for non - stationary interference
- **DBU approach**
 - **Advantages**
 - No knowledge of transmitter position and velocity required
 - **Disadvantages**
 - Doubles the STAP degrees of freedom
 - Doubles the number of training samples required
 - Increases cost of weight computation by factor of 8
 - No significant impact on weight application computation
- **HODW Approach**
 - **Advantages**
 - No increase in degrees of freedom required
 - Fully adaptive in spatial dimension
 - **Disadvantages**
 - Requires knowledge of transmitter position and velocity
 - Increased complexity of Doppler filtering
 - FFT techniques may not be possible



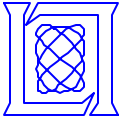
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Summary

- **Bistatic clutter interference suppression poses new challenges**
 - Clutter interference exhibits strongly range dependent structure
- **Doppler warping technique generalized**
 - “High Order Doppler Warping” algorithm
- **2-bin Post- Doppler Algorithms examined both with covariance analysis and more realistic direct time series analysis**
- **Preliminary assessments of selected algorithms in Air - to - Air and Space - to - Air bistatic scenarios presented**
 - All algorithms rely on sample average over range to estimate clutter interference covariance
 - **Standard training - POOR**
 - (no attempt to address range variation)
 - **Derivative Based Updating (DBU) - GOOD**
 - Requires doubling problem dimensionality
 - **High Order Doppler Warping (HODW) - GOOD**
 - Requires knowledge of transmitter position and velocity
 - Doppler filter implementation more complex



Future Directions

- **Extend analyses to other engagement geometries**
- **Assess impact of imperfections**

- **Array element calibration uncertainties**

Both DBU and HODW are fully data adaptive in the spatial dimension

No deterministic spatial transformations

Anticipate impact similar to that on monostatic STAP

- **Engagement geometry uncertainties**

HODW requires *a priori* knowledge of transmitter position and velocity

- **Develop computational complexity estimates for HODW**
 - **Determine optimal implementation strategy**