Implementing Digital Terrain Data In KA-STAP

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Agenda

- Introduction/Background
- Approach
- 200 meter NLCD (national land cover data) data – injected targets
- 30 meter NLCD data – moving target simulator (MTS) targets
- Seeing what the sensor sees
- 10 meter DEM data
- Agile Intelligent Radar System (AIRS)
- Summary/Future Plans

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Introduction/Background

- Can STAP performance be improved by choosing secondary data based upon a priori map data?
- Cell Averaging Symmetric Algorithm - choose secondary data plus and minus N/2 range rings from the test ring (omitting guard cells)
  – Implicit assumption - nearby range rings of the test ring are homogeneous with respect to terrain and are representative of the test ring.

    Conjectures:

    - Case I – Homogeneous Terrain Environment – Expect equal performance
    - Case II – Heterogeneous Terrain Environment – Expect improved performance

Objective/Proposed Algorithm

- Single-Bin Post-Doppler STAP
- Basic Assumption - Major clutter competing with the target cell is due to the patch of Earth within the same test ring that passes through the same Doppler filter
- Picking secondary range-Doppler cells that have the “same” terrain as the test cell will provide better performance than the cell averaging symmetric algorithm.

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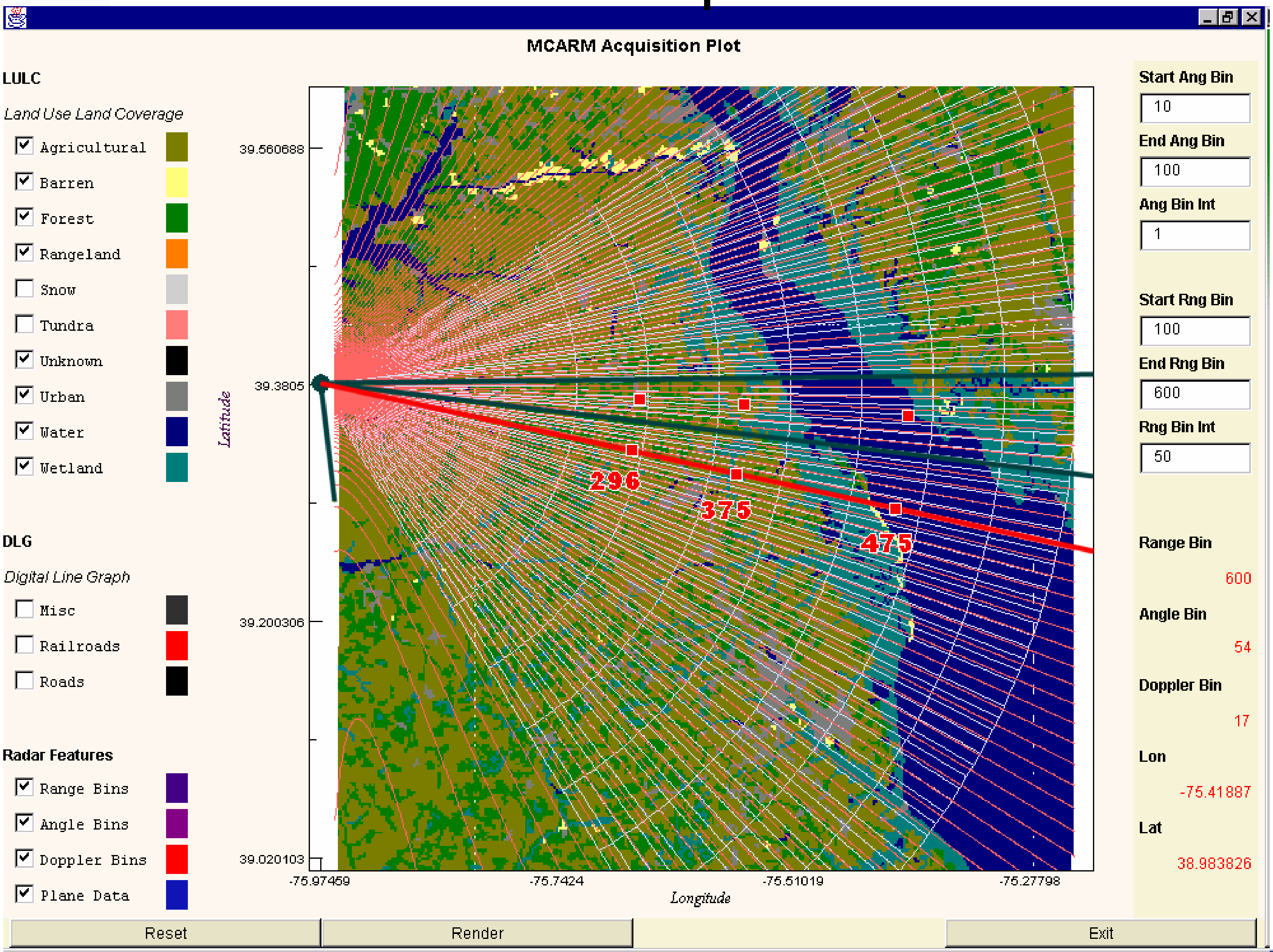
Multi-channel Airborne Radar Measurement (MCARM) Program

- USAF RL/SN Measurement program – mid 1990's
- Side looking L-Band radar
- 2 by 11 Channel linear array including sum and delta analog beamformers
- 120 Meter resolution with approximate 500 range bins
- 128 Pulses within a coherent processing interval (CPI)
- Returns were typically unambiguous in Doppler

Bac 1-11

MCARM Radar Registration With Map Data



Terrain Data Selection

- 21 terrain classifications were used, 200 meter (target injection) and 30 meter (MTS targets) resolution – National Land Cover Data (NLCD)
- Delmarva Peninsula is relatively flat – No elevation or digital line graph data were used
- Created a terrain vector from the 21 classification codes for each range-Doppler cell
- Accounted for differences in number of NLCD patches per range-Doppler cell
- Developed an algorithm to choose "like" range-Doppler cells by using a Euclidian distance measure between the normalized terrain vectors

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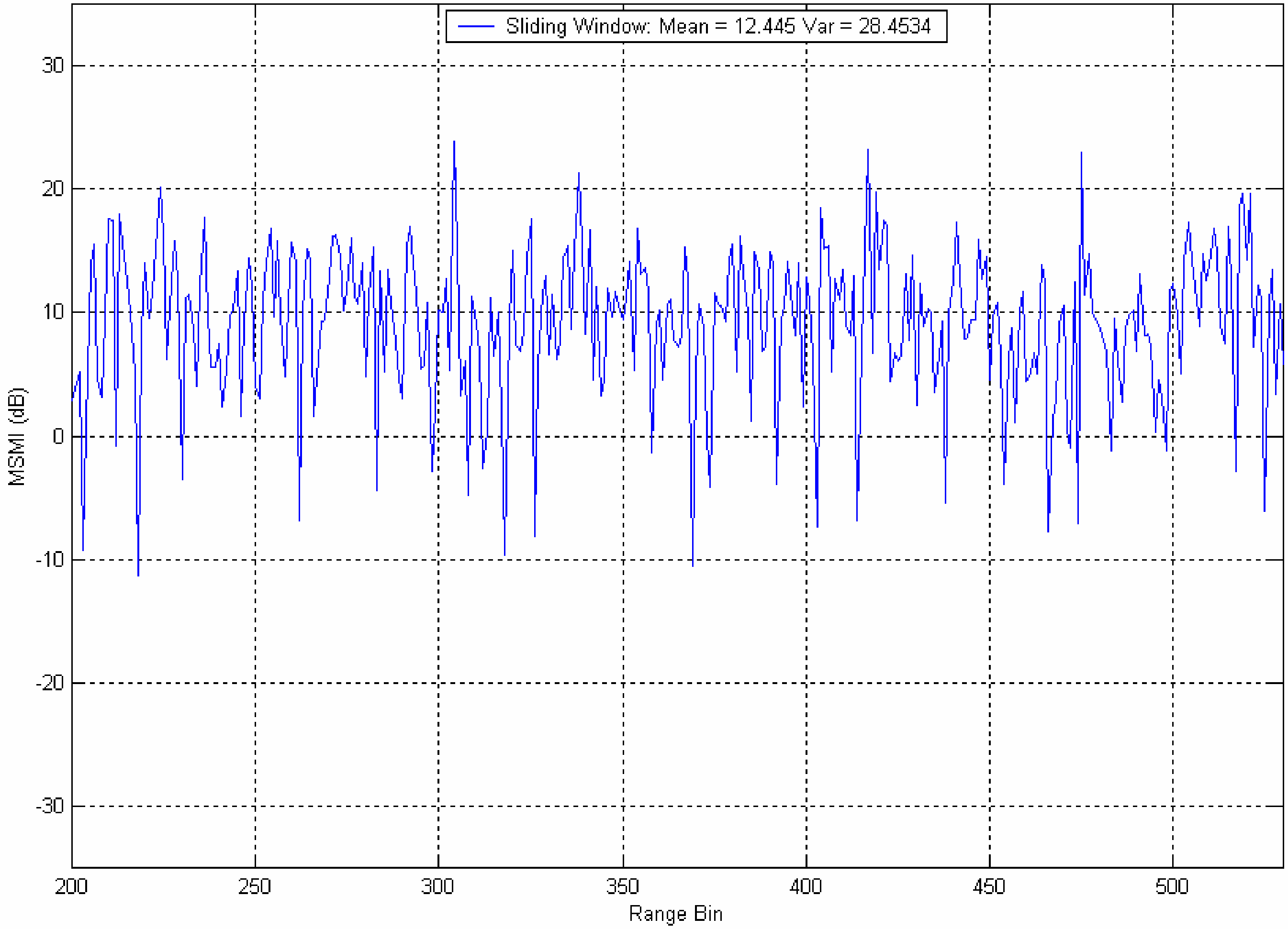
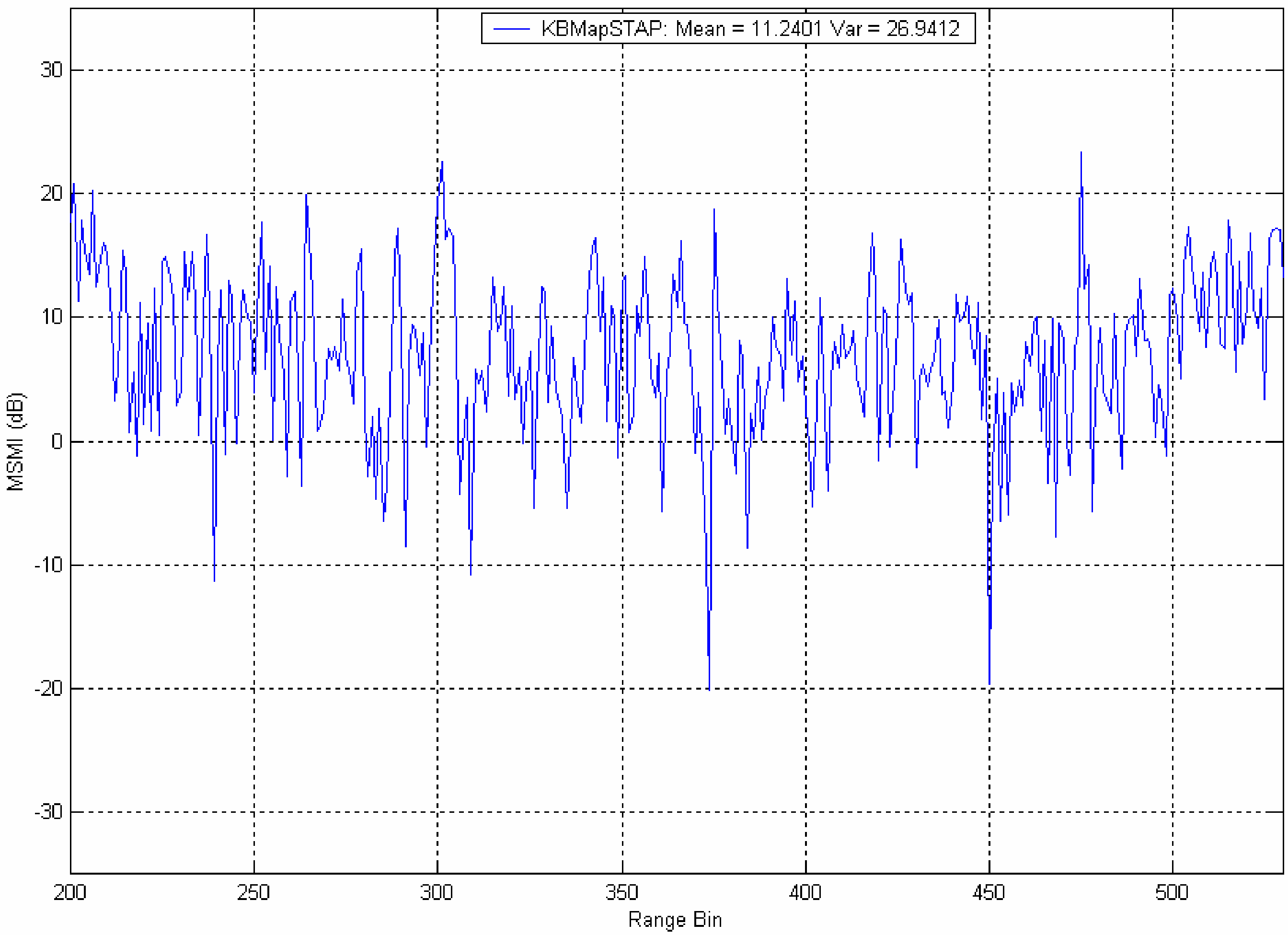
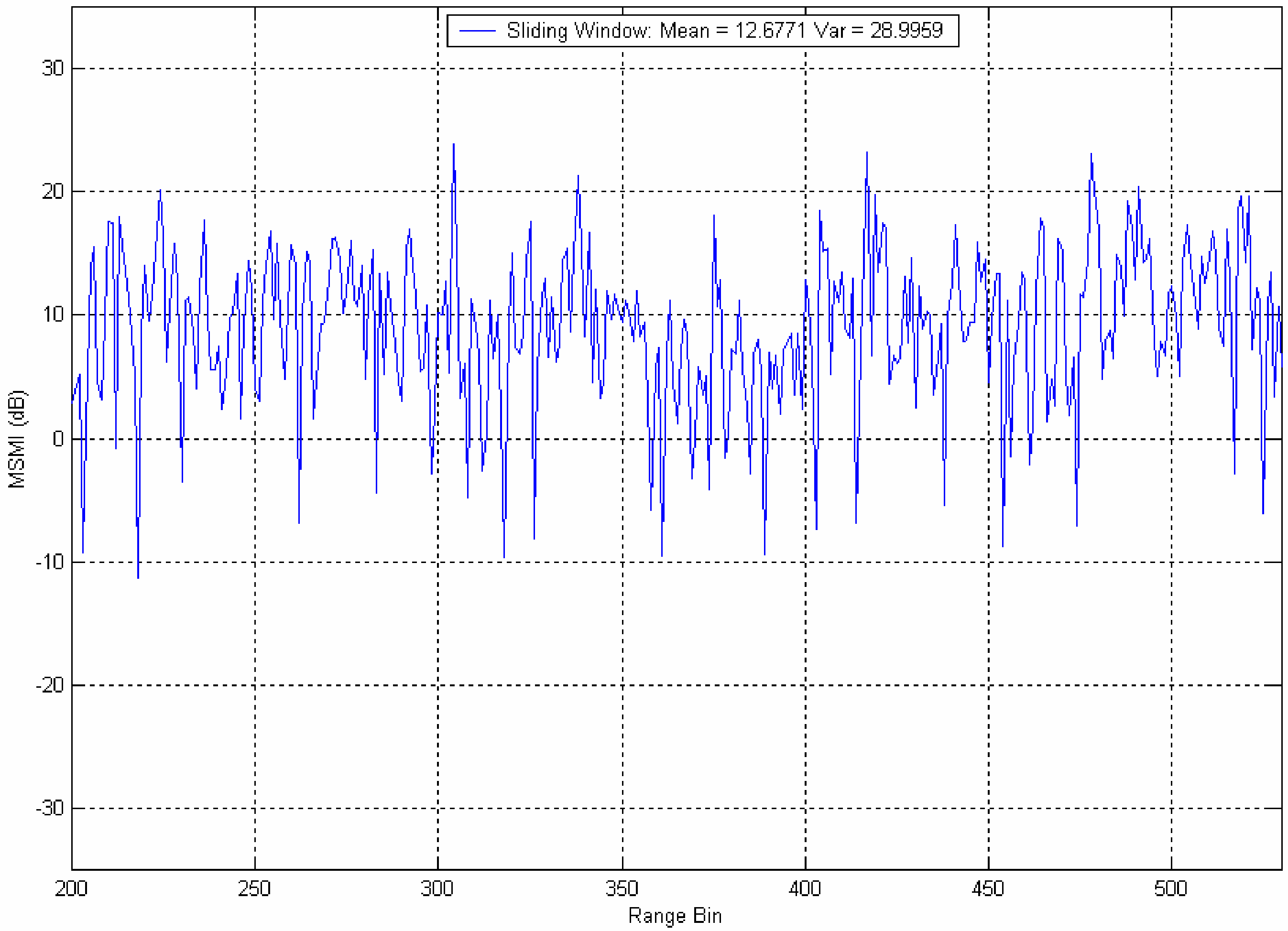
MSMI Output Using Sliding Window Algorithm With Injected Target At Range Bin 475



MSMI Output Using KBMapSTAP Algorithm With Injected Target At Range Bin 475



MSMI Output Using Sliding Window Algorithm With Injected Target At Range Bin 375



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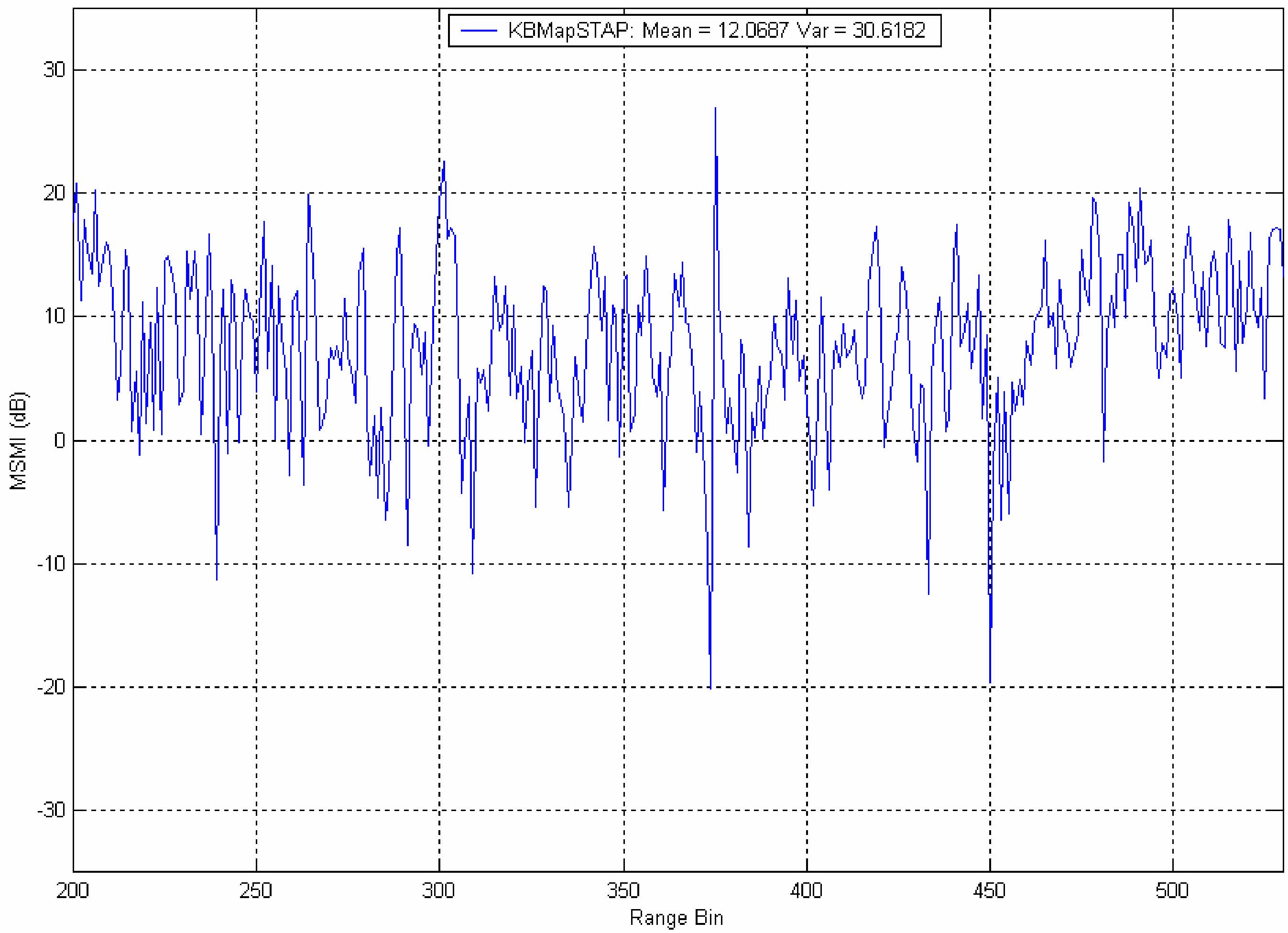
MSMI Output Using KBMapSTAP Algorithm With Injected Target At Range Bin 375



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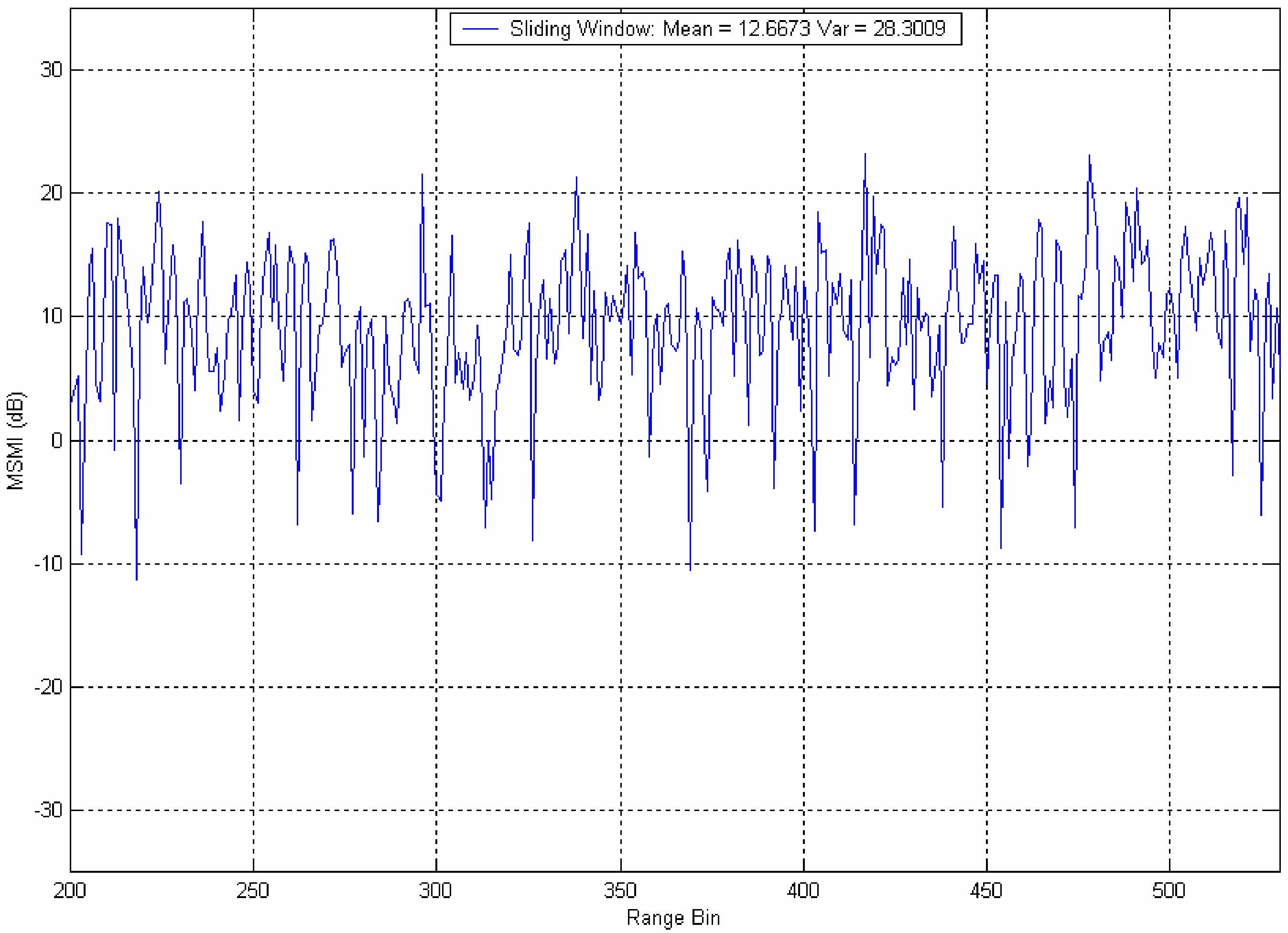
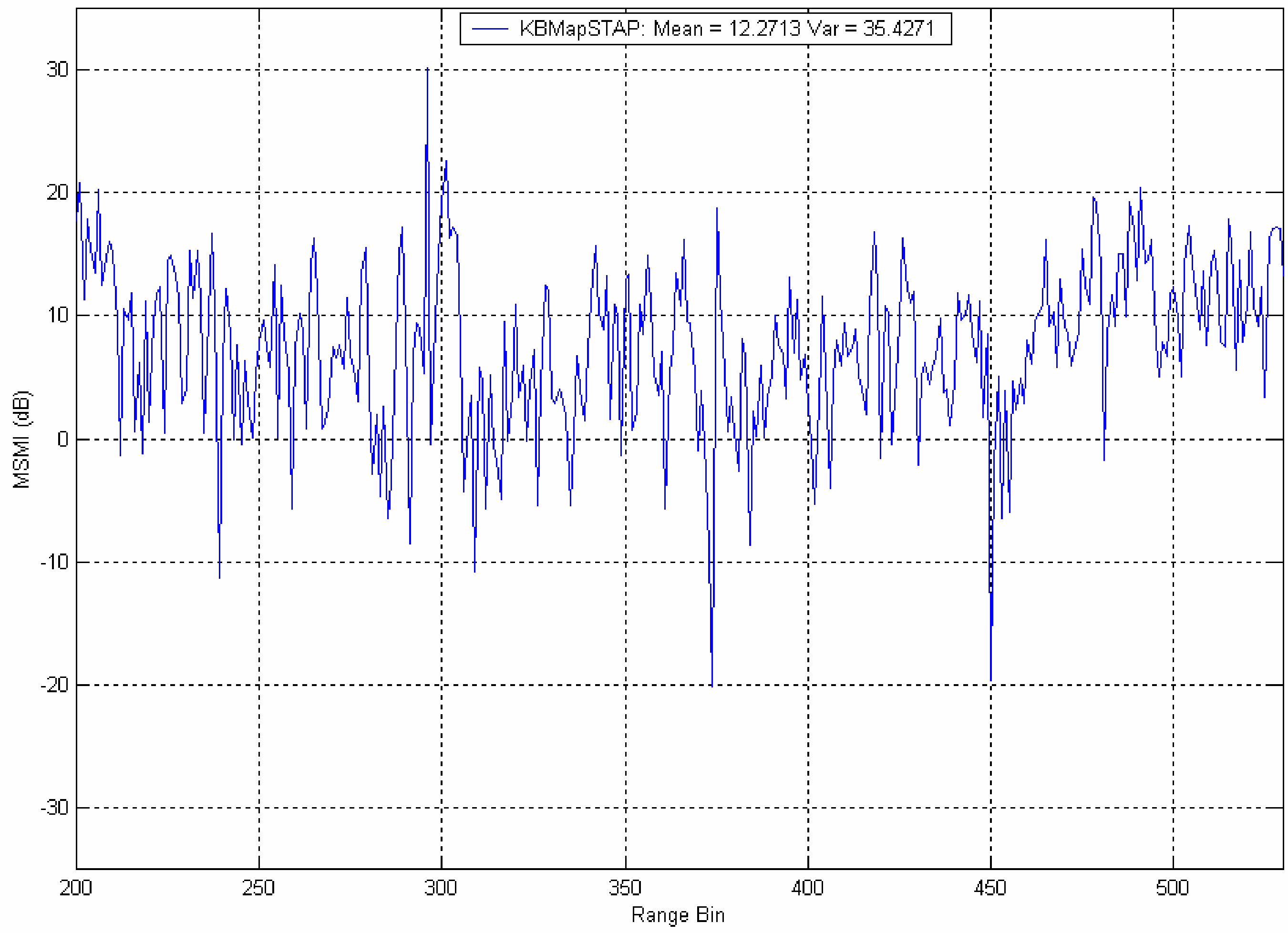
MSMI Output Using Sliding Window Algorithm With Injected Target At Range Bin 296



MSMI Output Using KBMapSTAP Algorithm With Injected Target At Range Bin 296



Early Assessment

- Outperformed standard windowing approach within heterogeneous environments (up to 9 dB improvement)
- Performed the same as standard windowing approach within homogeneous environments
- However, there are issues with this approach
  - Map data accuracy – data are not always current
  - Digital elevation data needed in mountainous terrains– shadowing effects
  - Weather data is time dependent
  - Time of year – e.g. snow covered terrain
  - <u>Registration and calibration errors must be assessed</u>
  - <u>Variability in STAP results compared to sliding window</u>
- Need to "see what the radar is seeing"
- Map data is necessary but not sufficient for filtering and detection– also need mapping data for tracking (e.g. roads and railroads)

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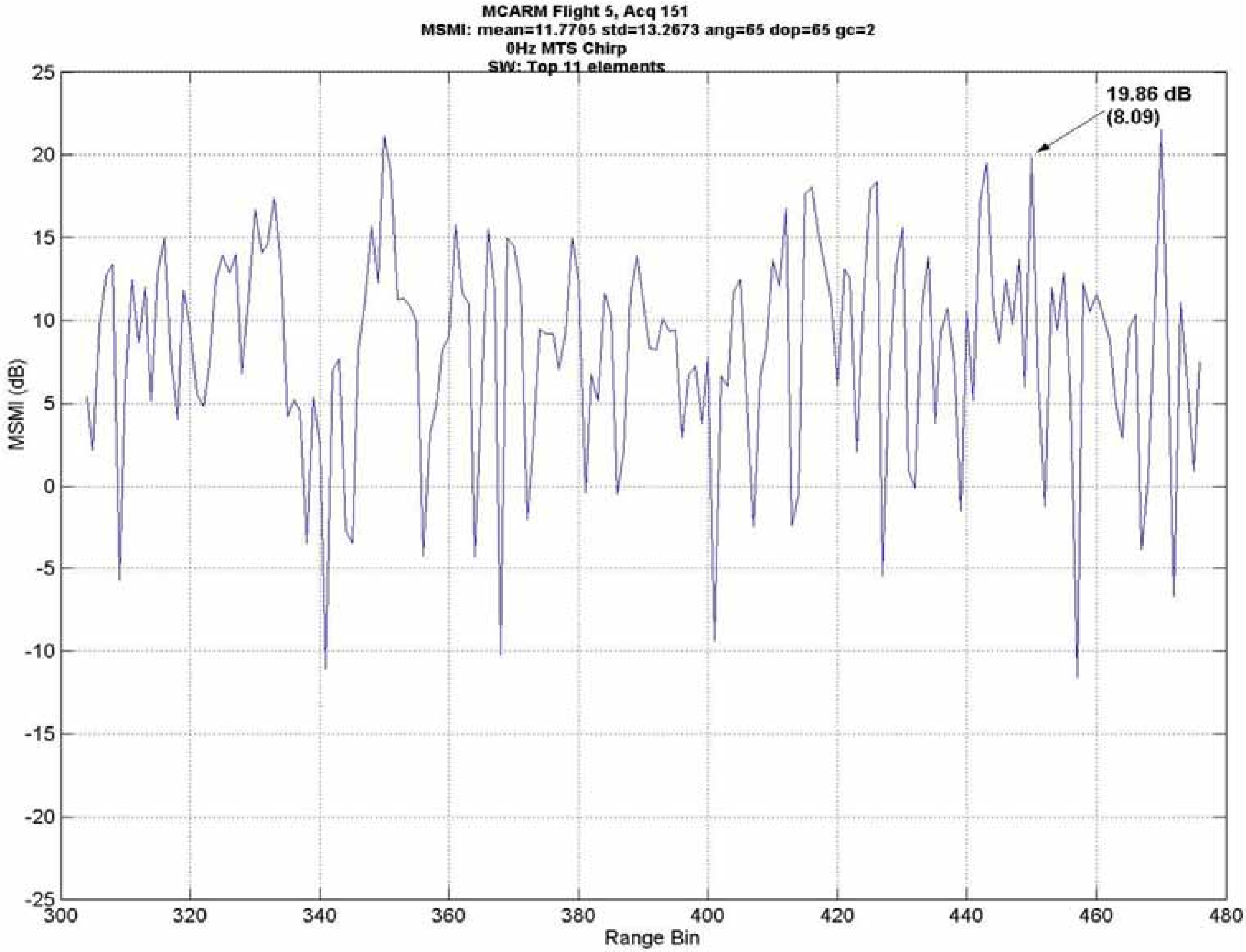
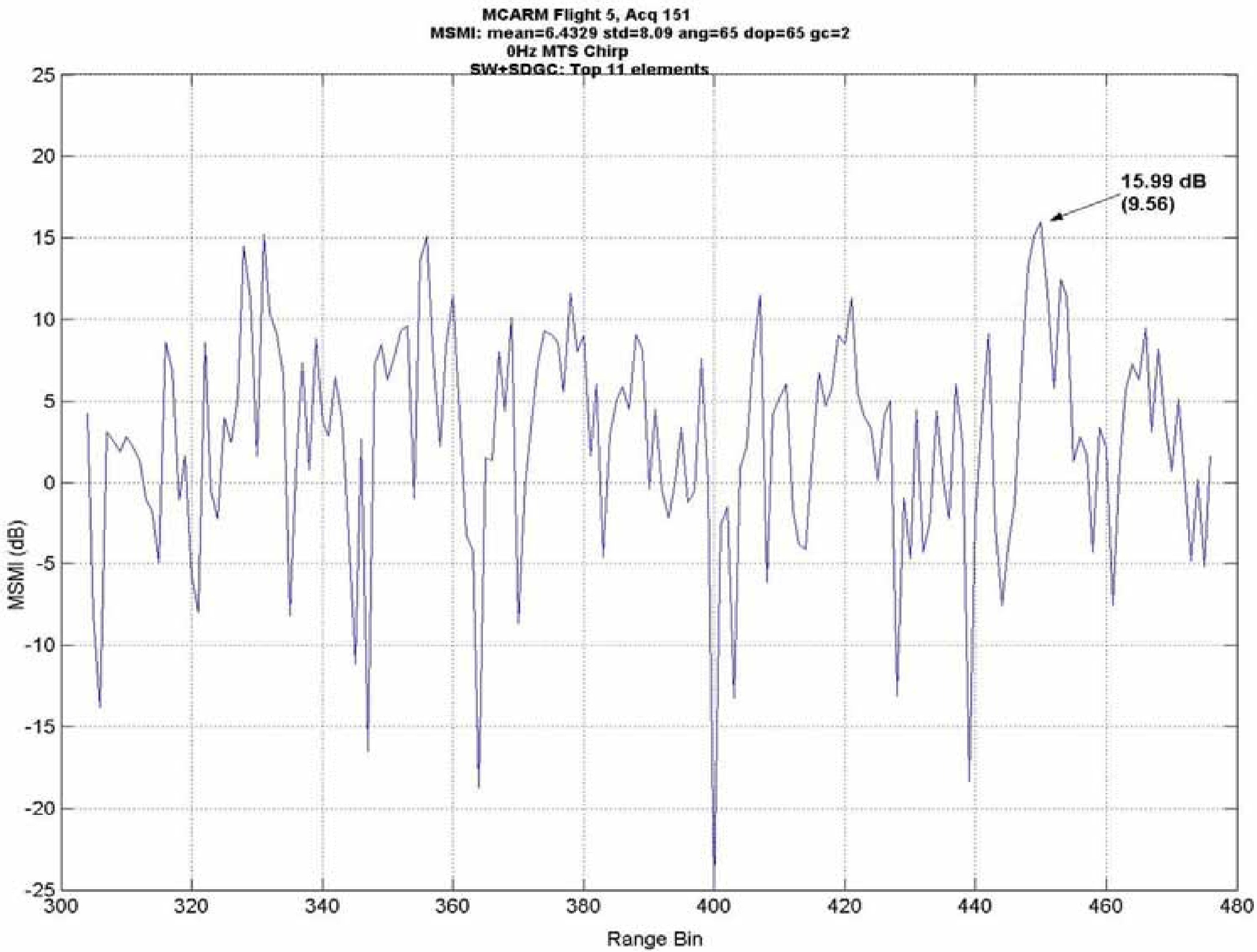
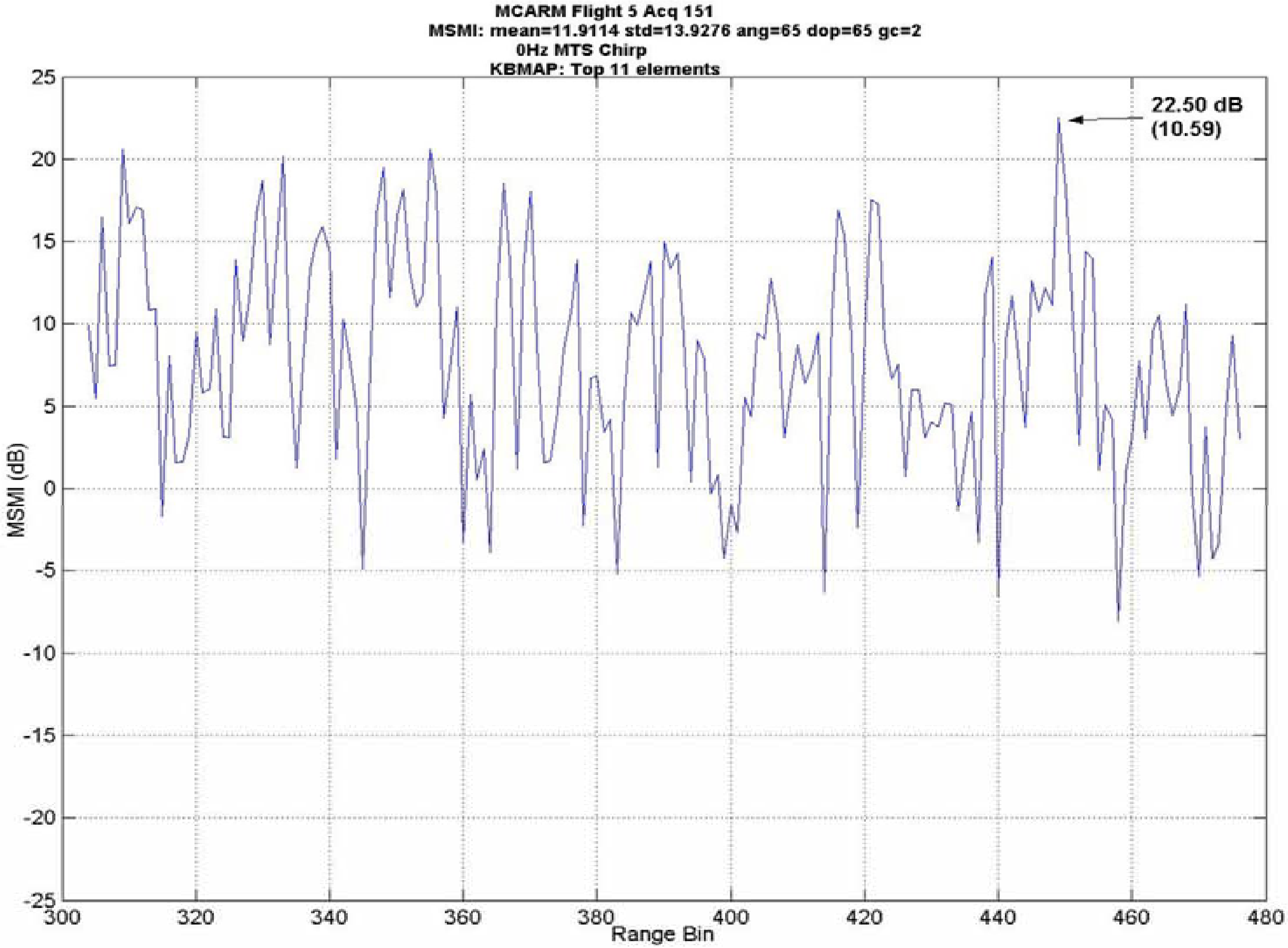
Secondary Data Guard Cells

- Analysis of early results were suspect
- Analysis of Moving Target Simulated (MTS) data indicated range-Doppler spread
  - Potentially violating i.i.d. criteria in STAP processing
- Excluded range cells around secondary data cells to mitigate the affects of range-Doppler spreading
- Due to number of required range cells, total number of range cells available, and the number of guard cells:
  - Tried to use full array (22 elements) – Not enough samples
  - Used upper row array (11 elements)


MCARM Flight 5, Acq 151
MSMI: mean=11.7705 std=13.2673 ang=65 dop=65 gc=2
0Hz MTS Chirp
SW: Top 11 elements
19.86 dB
(8.09)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480


MCARM Flight 5, Acq 151
MSMI: mean=6.4329 std=8.09 ang=65 dop=65 gc=2
0Hz MTS Chirp
SW+SDGC: Top 11 elements
15.99 dB
(9.56)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480


MCARM Flight 5 Acq 151
MSMI: mean=11.9114 std=13.9276 ang=65 dop=65 gc=2
0Hz MTS Chirp
KBMAP: Top 11 elements
22.50 dB
(10.59)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
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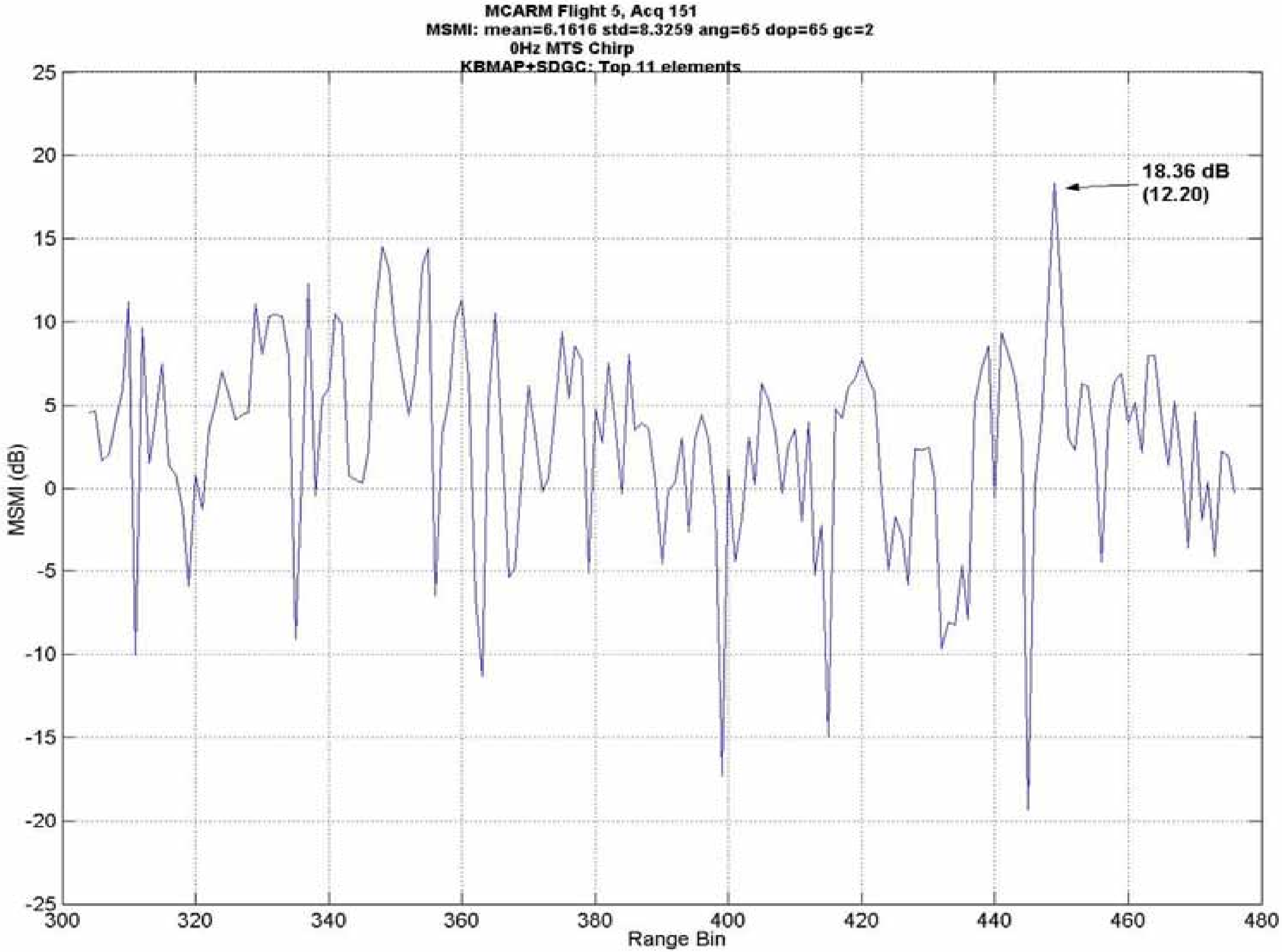

MCARM Flight 5, Acq 151
MSMI: mean=6.1616 std=8.3259 ang=65 dop=65 gc=2
0Hz MTS Chirp
KBMAP+SDGC: Top 11 elements
18.36 dB
(12.20)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
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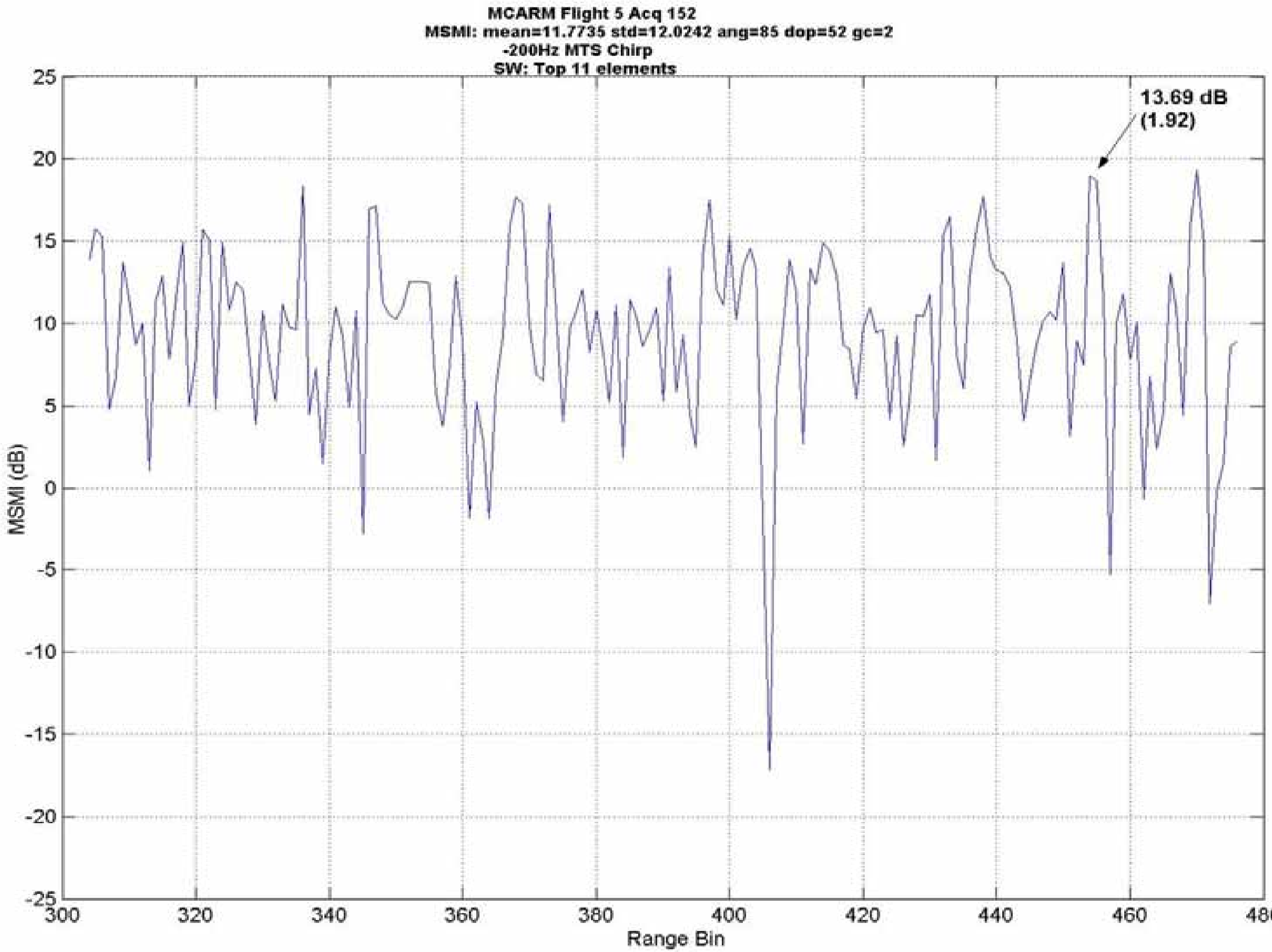
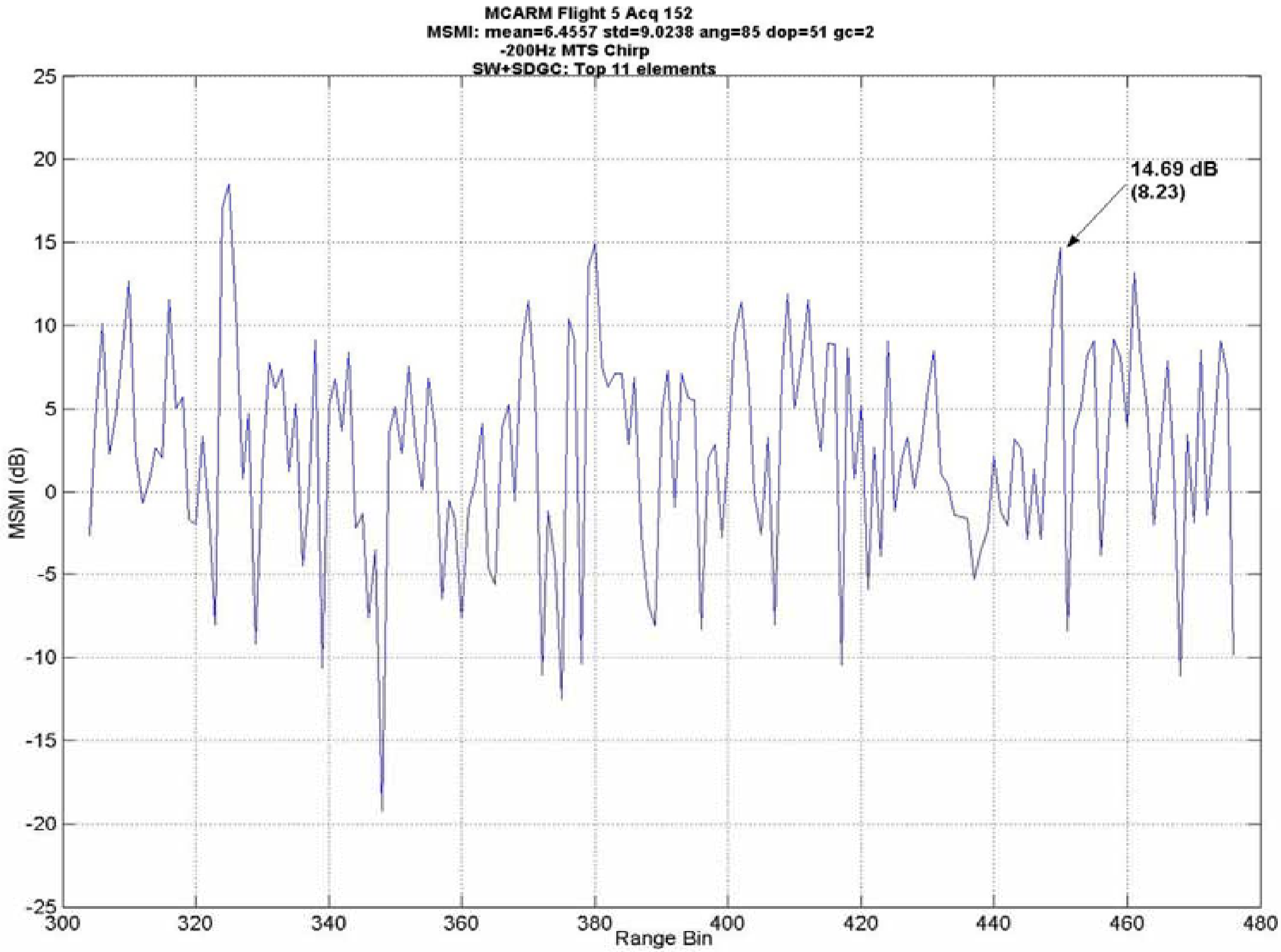


MCARM Flight 5 Acq 152
MSMI: mean=11.7735 std=12.0242 ang=85 dop=52 gc=2
-200Hz MTS Chirp
SW: Top 11 elements
13.69 dB
(1.92)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480



MCARM Flight 5 Acq 152
MSMI: mean=6.4557 std=9.0238 ang=85 dop=51 gc=2
-200Hz MTS Chirp
SW+SDGC: Top 11 elements
14.69 dB
(8.23)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
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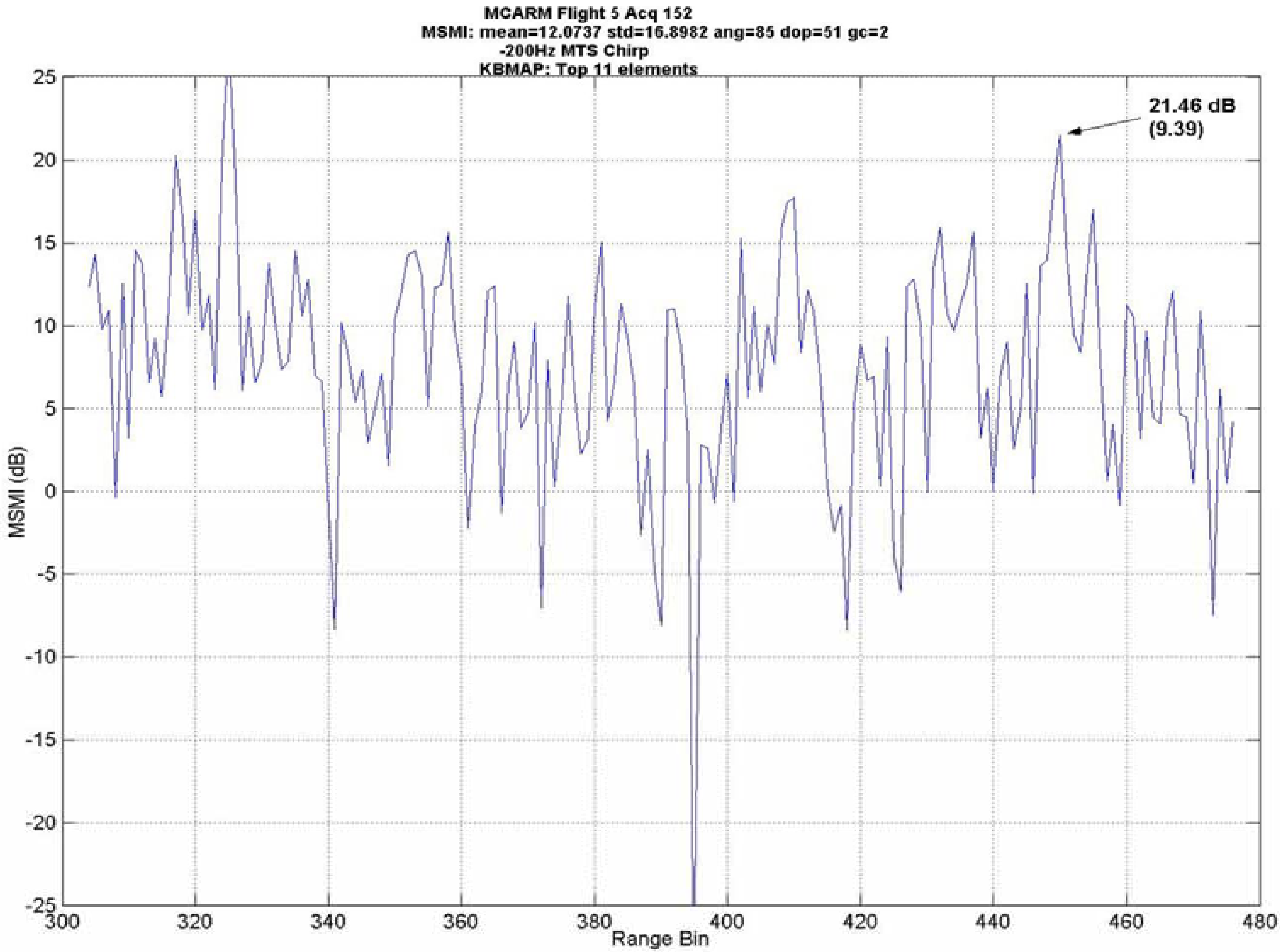
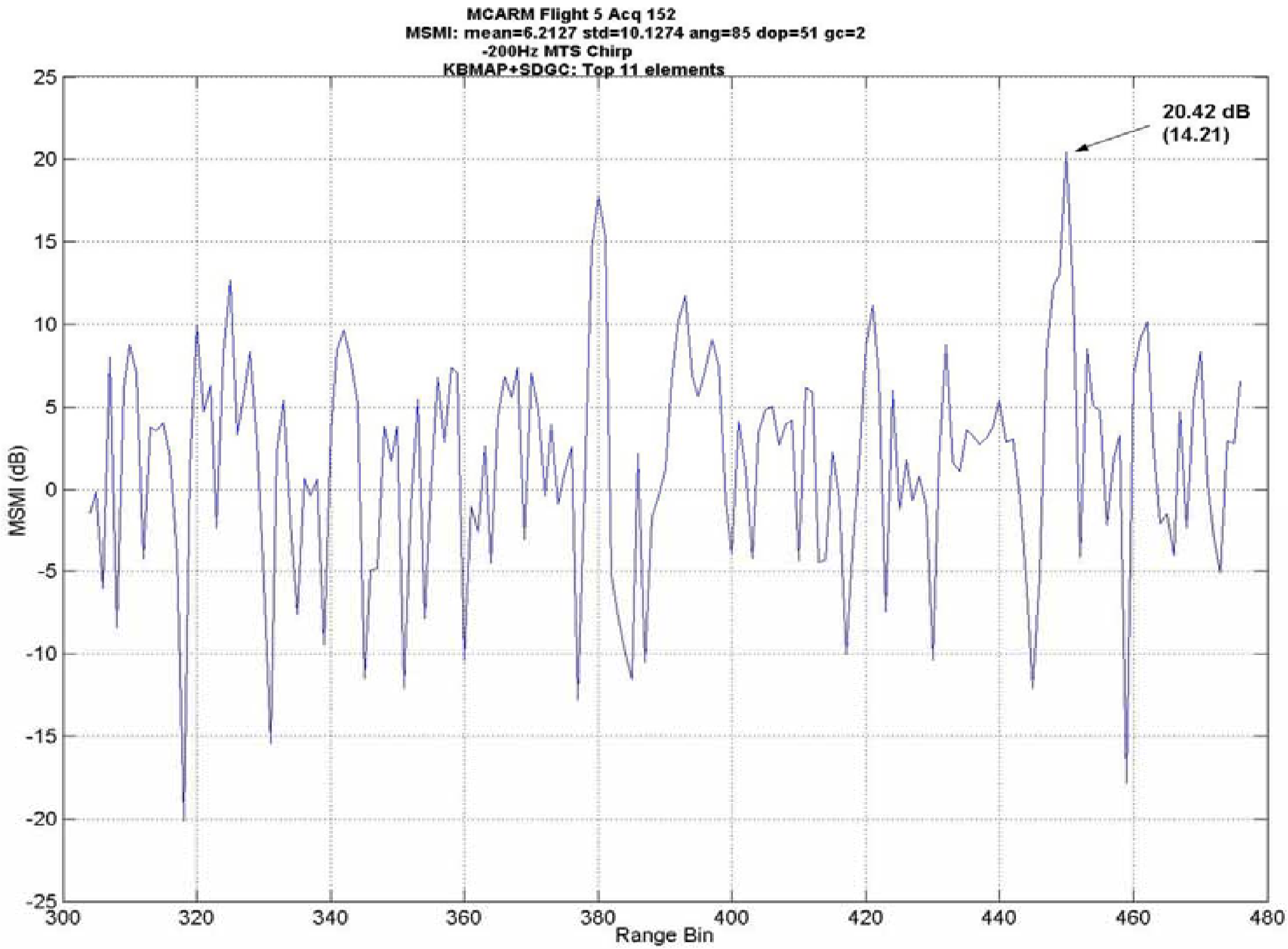
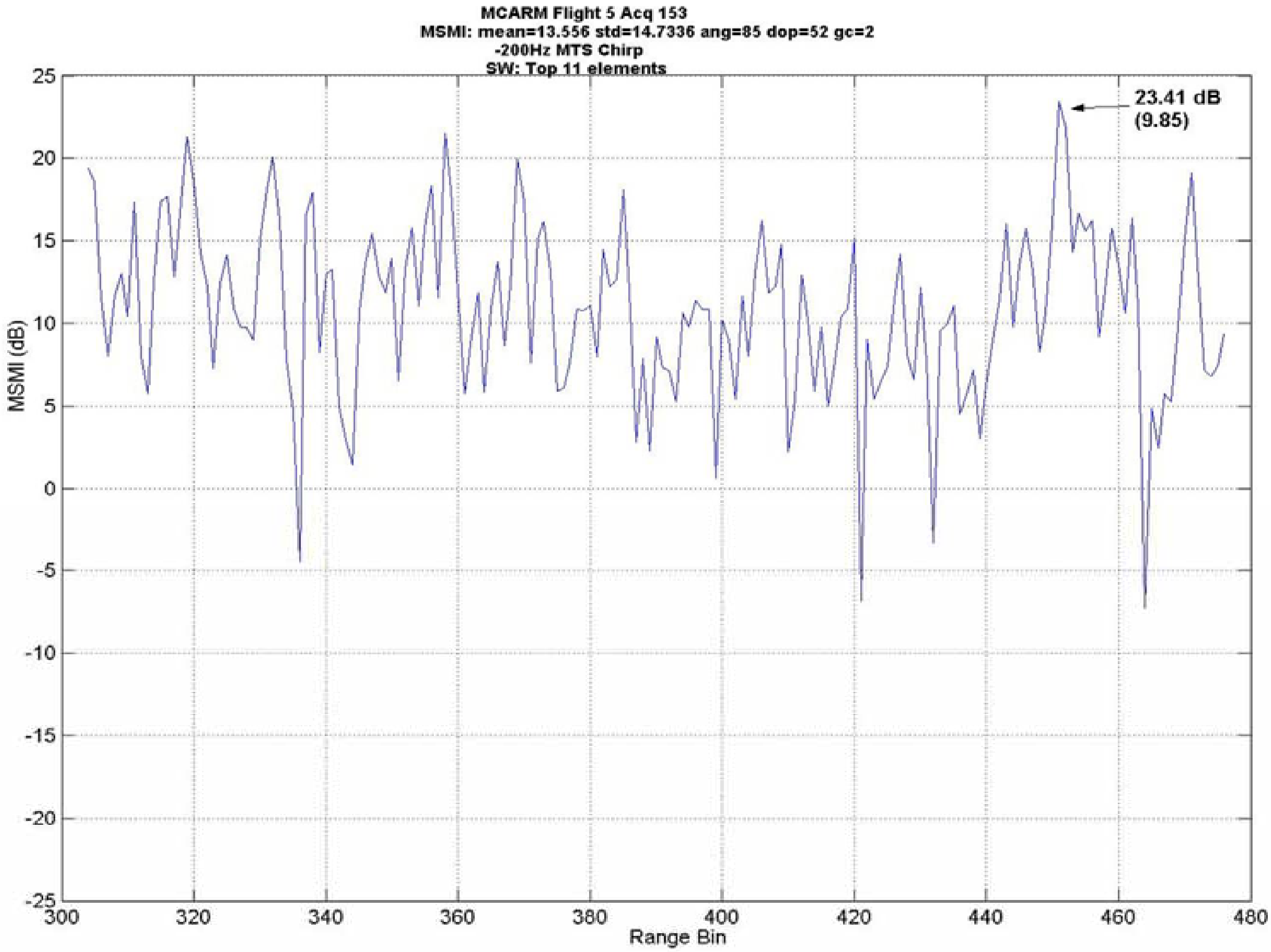
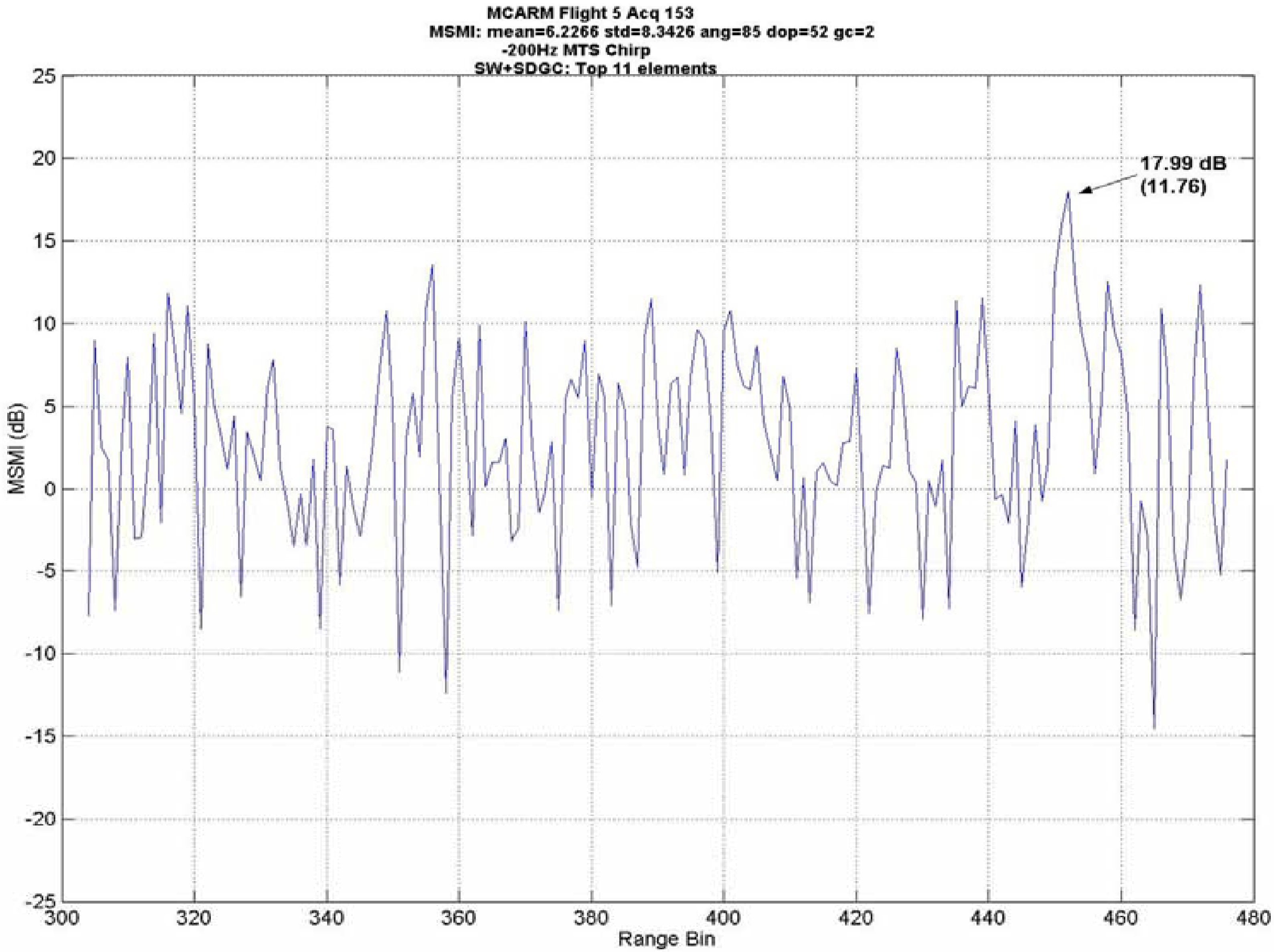
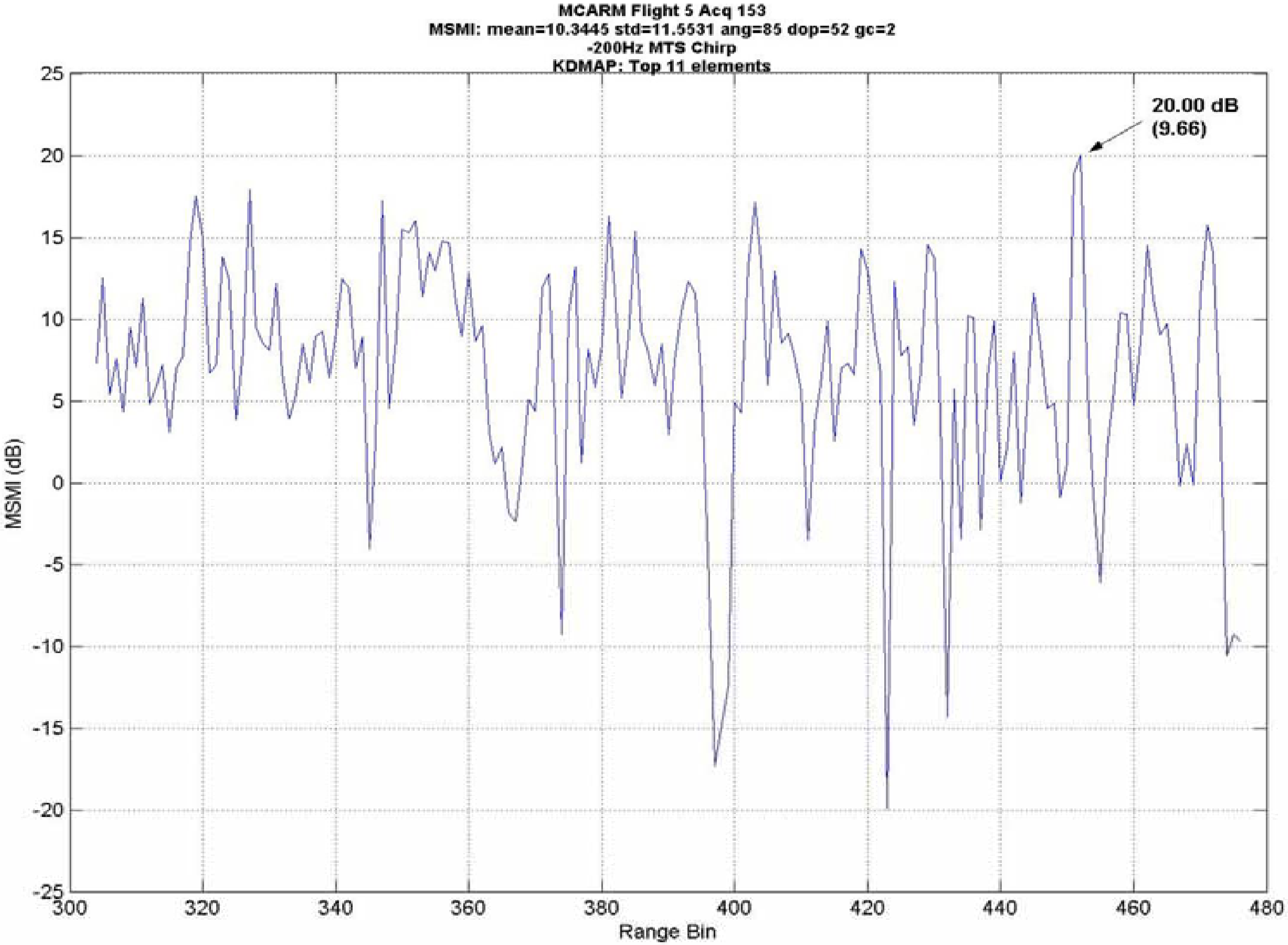
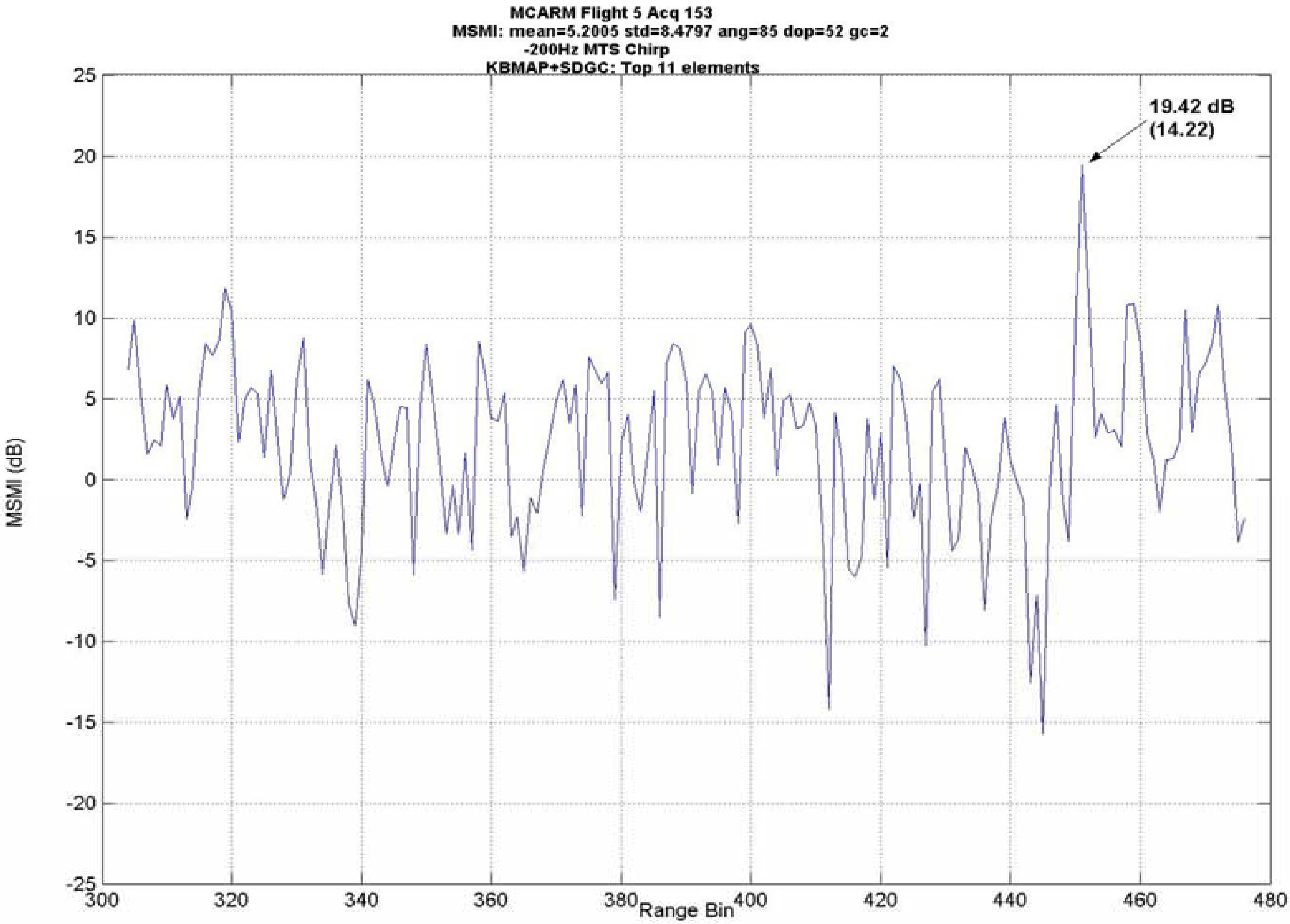

MCARM Flight 5 Acq 152
MSMI: mean=12.0737 std=16.8982 ang=85 dop=51 gc=2
-200Hz MTS Chirp
KBMAP: Top 11 elements
21.46 dB
(9.39)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480


MCARM Flight 5 Acq 152
MSMI: mean=6.2127 std=10.1274 ang=85 dop=51 gc=2
-200Hz MTS Chirp
KBMAP+SDGC: Top 11 elements
20.42 dB
(14.21)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480


MCARM Flight 5 Acq 153
MSMI: mean=13.556 std=14.7336 ang=85 dop=52 gc=2
-200Hz MTS Chirp
SW: Top 11 elements
23.41 dB
(9.85)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480


MCARM Flight 5 Acq 153
MSMI: mean=6.2266 std=8.3426 ang=85 dop=52 gc=2
-200Hz MTS Chirp
SW+SDGC: Top 11 elements
17.99 dB
(11.76)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480

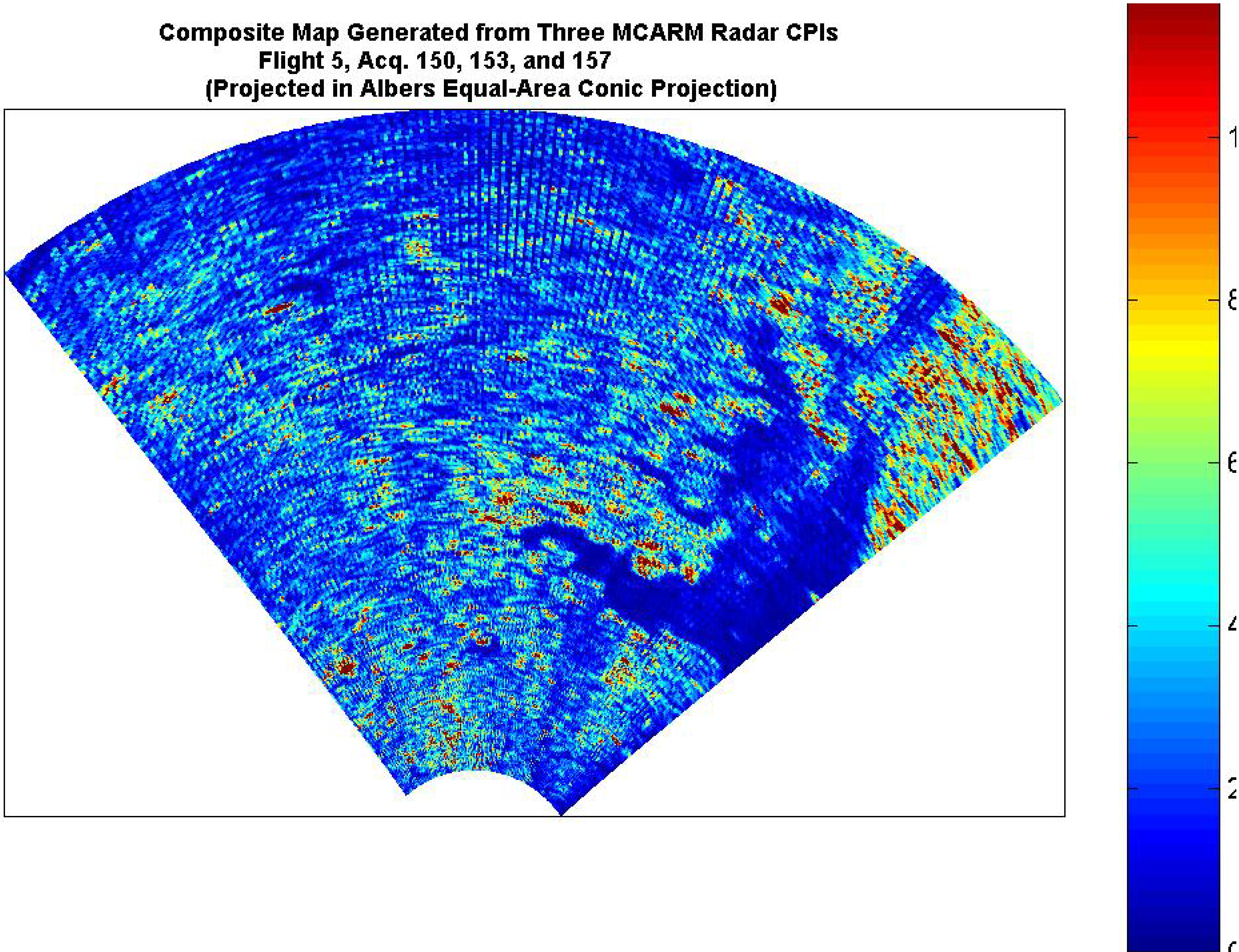

MCARM Flight 5 Acq 153
MSMI: mean=10.3445 std=11.5531 ang=85 dop=52 gc=2
-200Hz MTS Chirp
KDMAP: Top 11 elements
20.00 dB
(9.66)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480

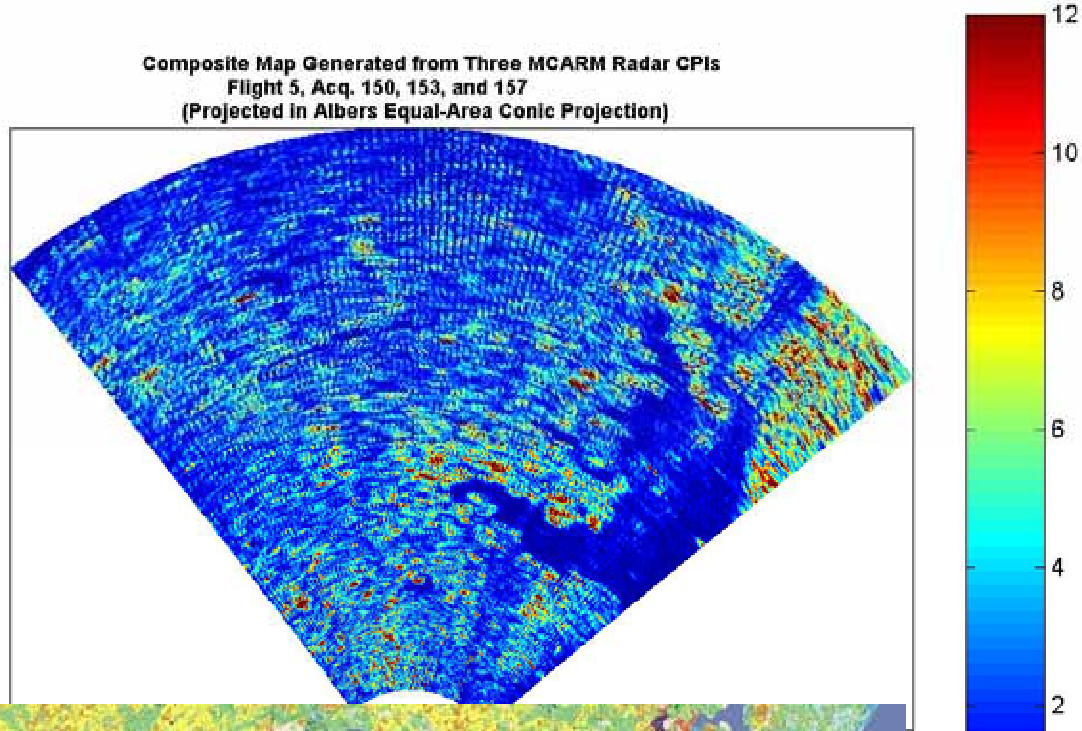

MCARM Flight 5 Acq 153
MSMI: mean=5.2005 std=8.4797 ang=85 dop=52 gc=2
-200Hz MTS Chirp
KBMAP+SDGC: Top 11 elements
19.42 dB
(14.22)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480

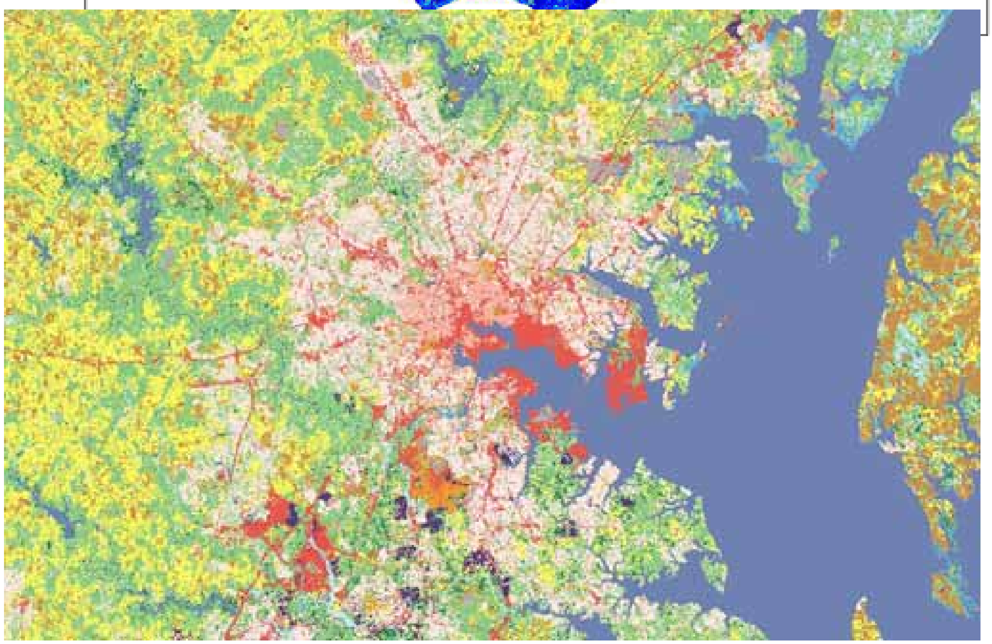
Results

- Knowledge-aided approach performed 3-7 dB better than cell averaging symmetric (sliding window) method in non-homogeneous terrain environments
- Used modified sample matrix inversion (MSMI) – as our test statistic
- MTS target at range bin 450
- Ratio of MSMI of target to average MSMI, over all ranges, is our preferred performance measure (PPM)

Seeing What the Sensor Sees


Composite Map Generated from Three MCARM Radar CPIs
Flight 5, Acq. 150, 153, and 157
(Projected in Albers Equal-Area Conic Projection)


Composite Map Generated from Three MCARM Radar CPIs
Flight 5, Acq. 150, 153, and 157
(Projected in Albers Equal-Area Conic Projection)
12
10
8
6
4
2
0



Digital Elevation Model (DEM) Data

DEM Data Algorithm Development

- Chose a mountainous region
- A real radar with multiple CPIs
- Real truth data – more than MTS data
- Minimal variation in NLCD data – not included in algorithm
- Algorithm is automated in MATLAB (based upon % shadowing and reflection angle statistics per range ring)

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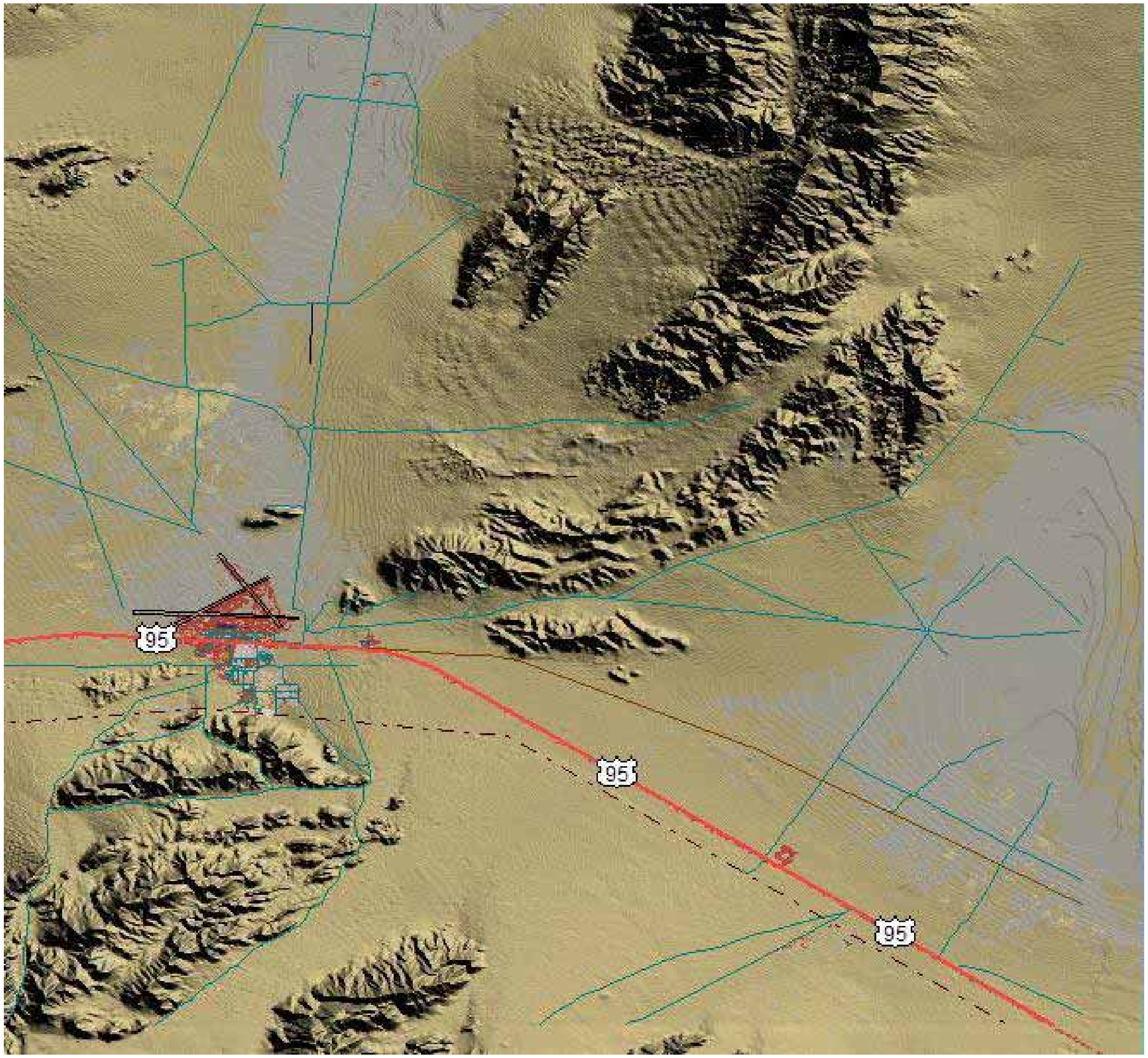
Scene with DEM, LULC and DLG Terrain Data



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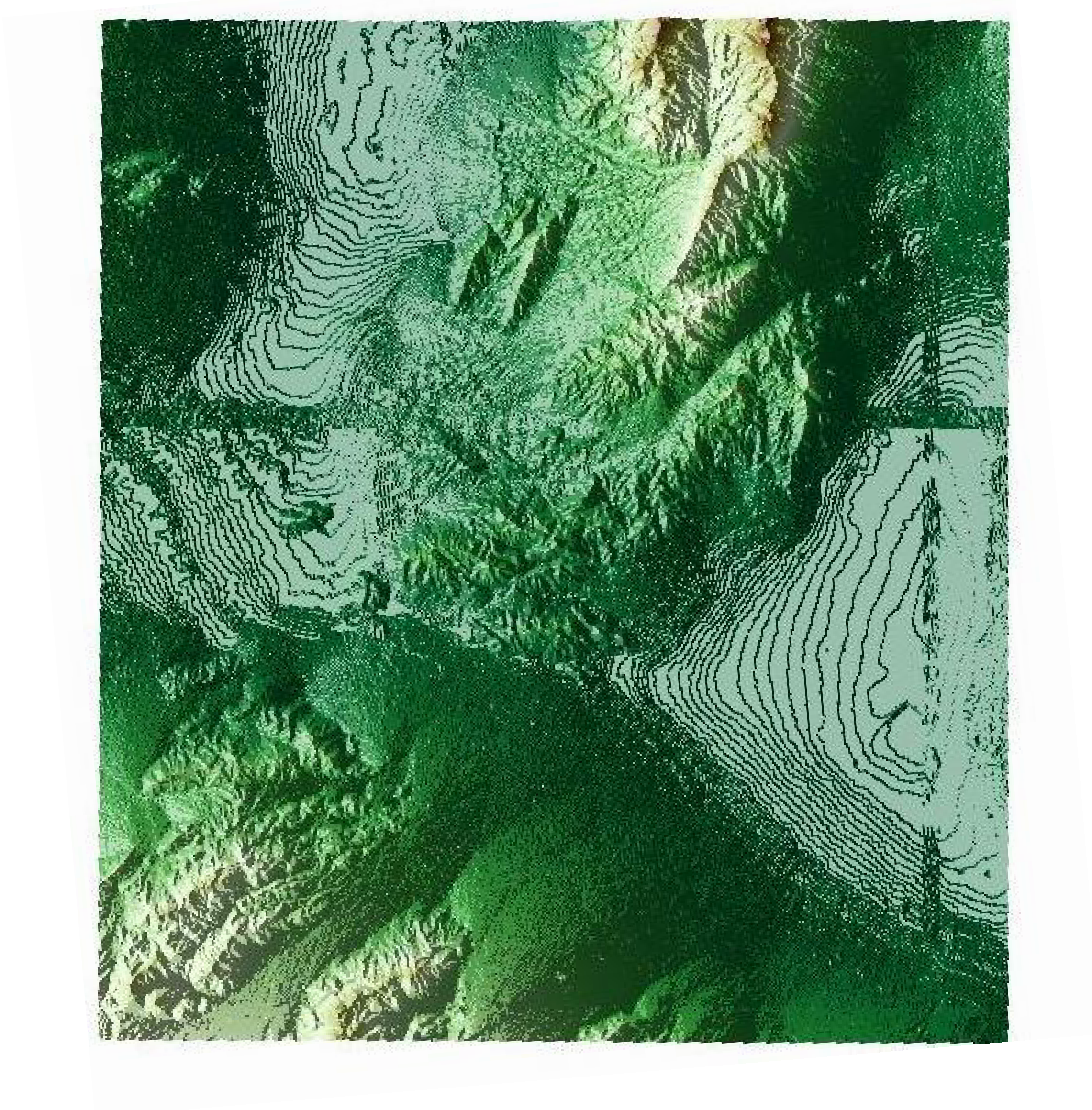
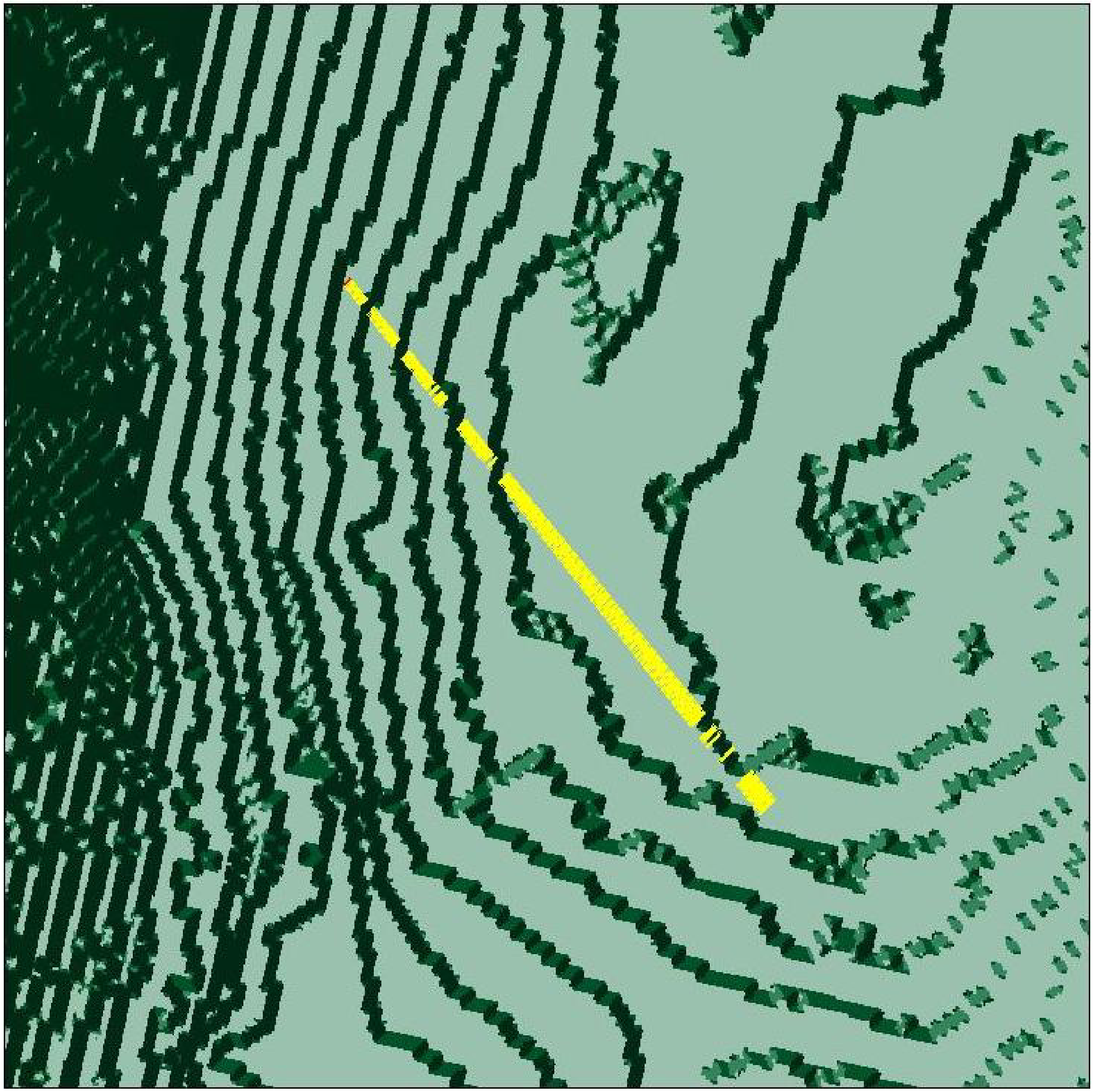
Scene with 10 Meter DEM Terrain Data in MATLAB



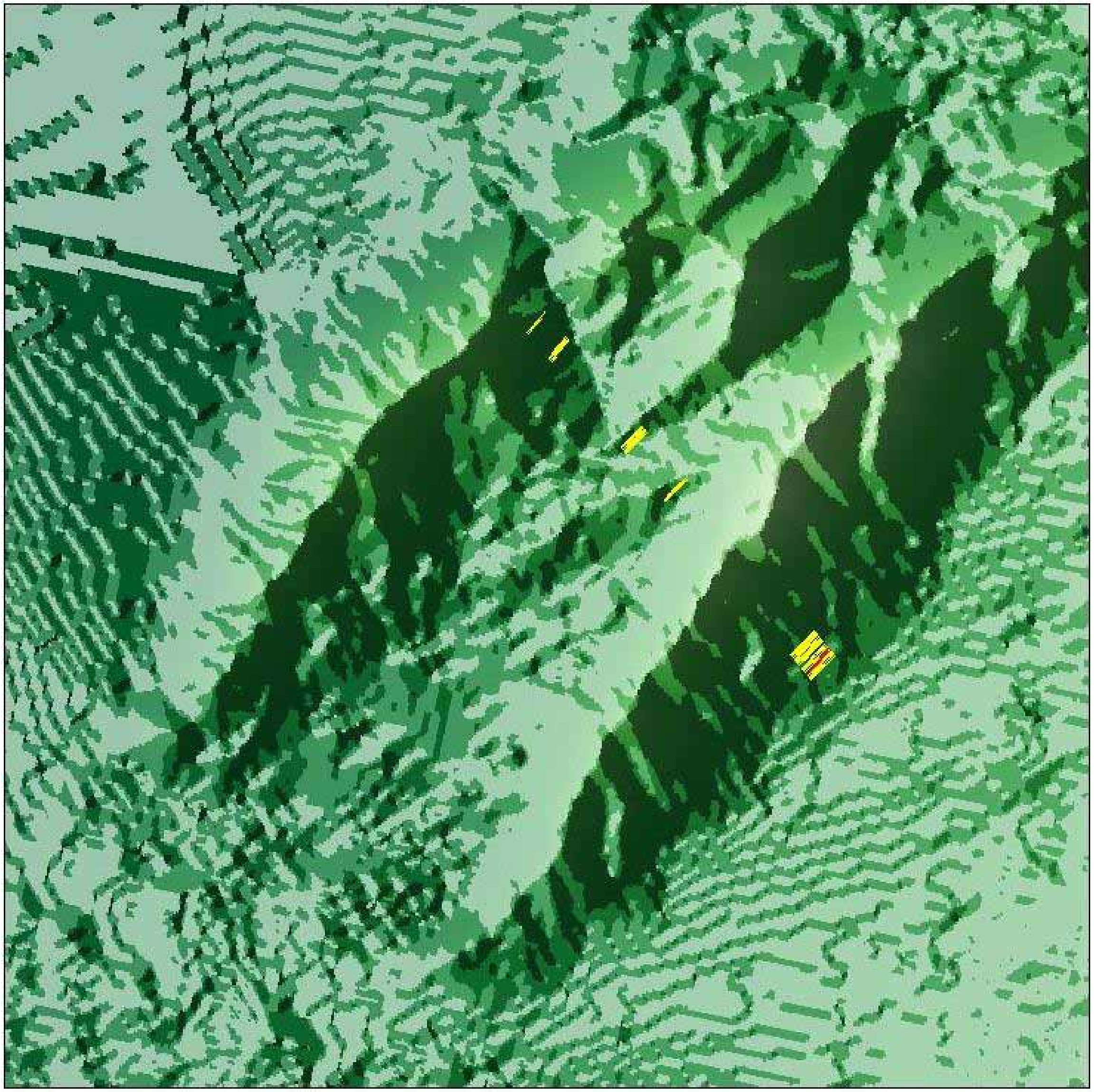
Chosen Range Bins on Flat Terrain

(Test Cell Red, Sample Cells Yellow)

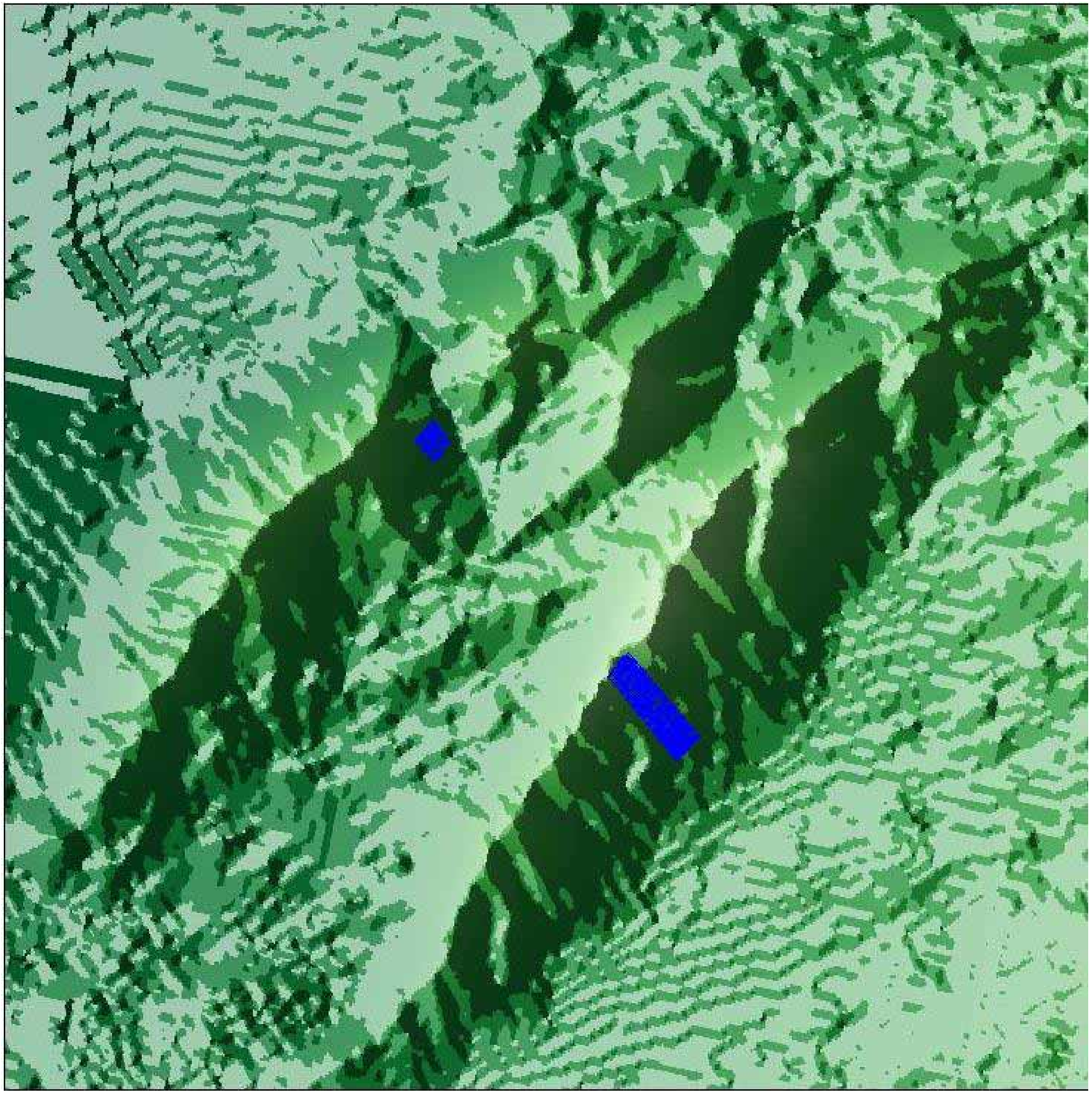


Chosen Range Bins on Mountainous Terrain

(Test Cell Red, Sample Cells Yellow)



Shadowed Range Cells Shown in Blue



Agile Intelligent Radar System (AIRS)

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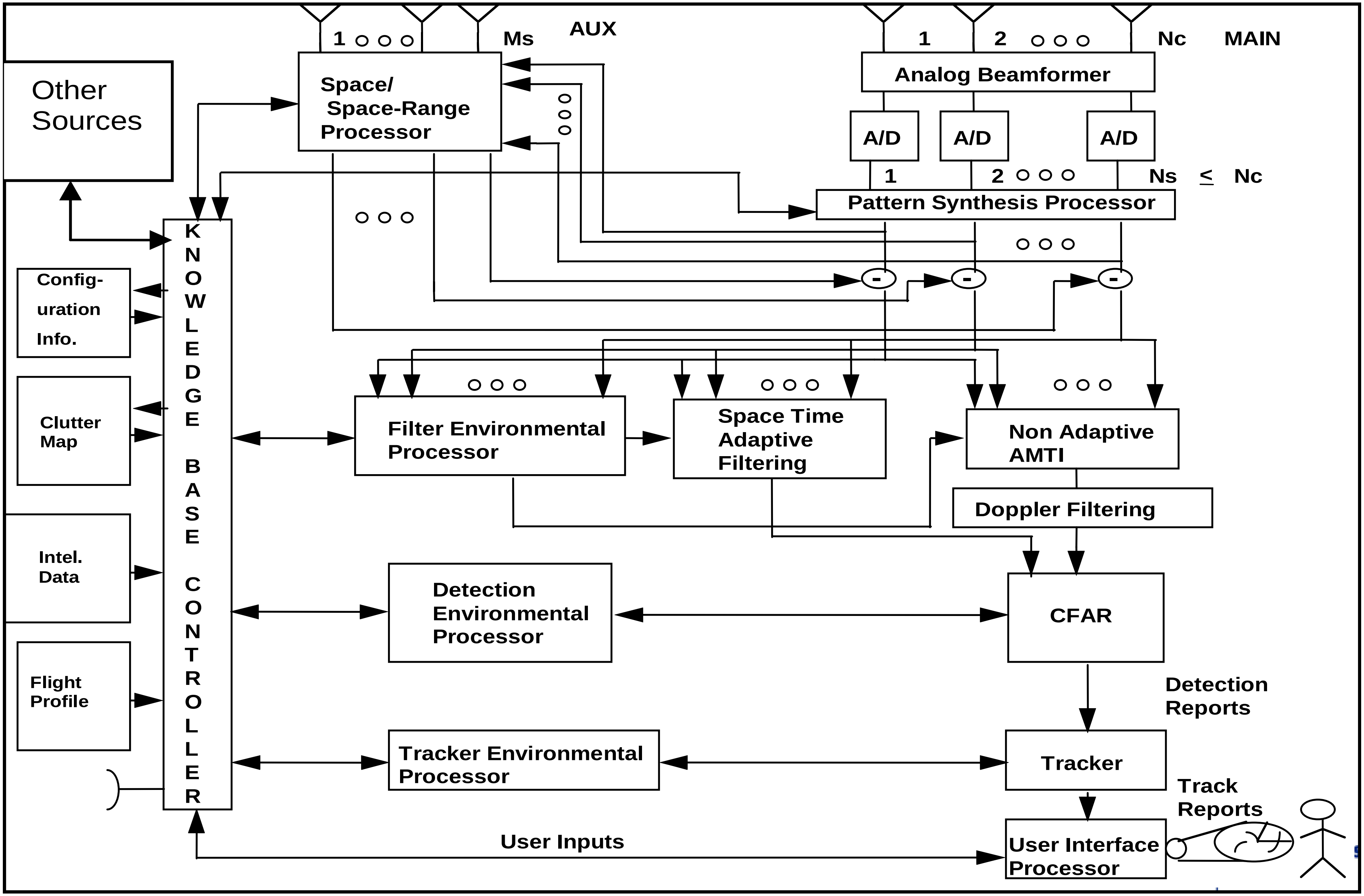
AIRS Architecture



An Agile Intelligent Radar System (AIRS)

- The KB Signal and Data Processing portion of the Intelligent Sensor System
- KB Controller (KBC), processors, outside data sources, communications, user interface, and pre-loaded data
- Processors work independently and cooperatively
- The KBC handles all interrupts, assigns tasks, manages processors, communicates results, and interfaces with the user

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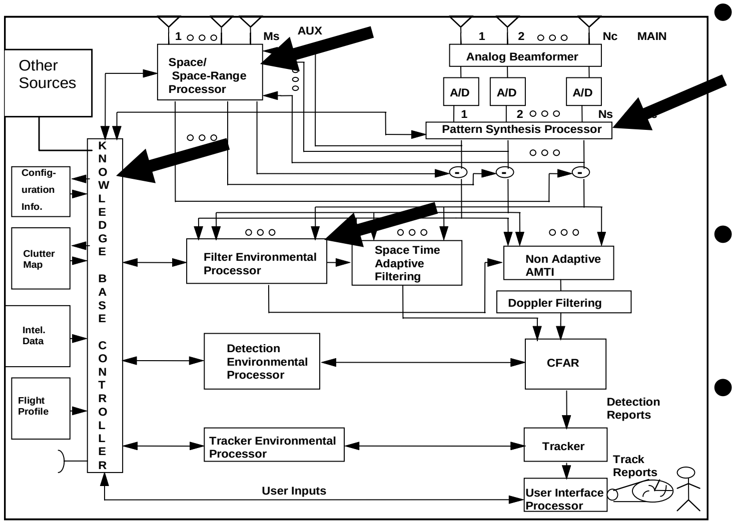
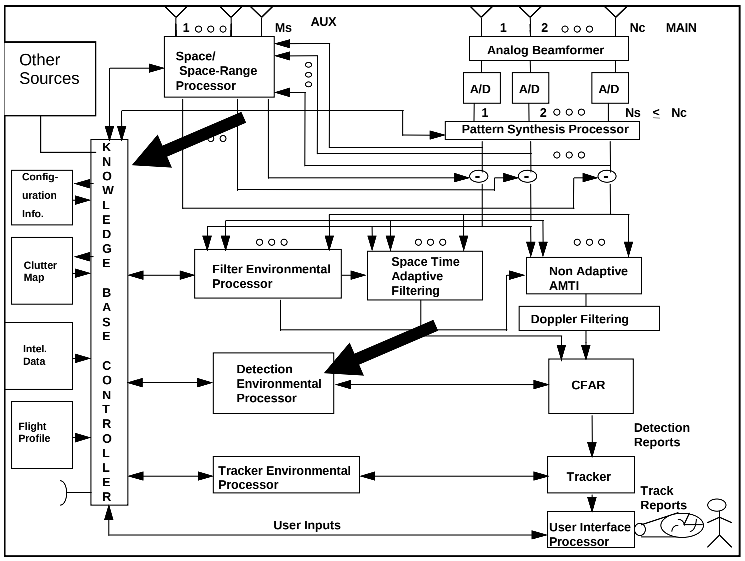
Space/Space-Range Processor (SSRP), Pattern Synthesis Processor (PSP), Filter Environmental Processor (FEP) and KBC Interfaces



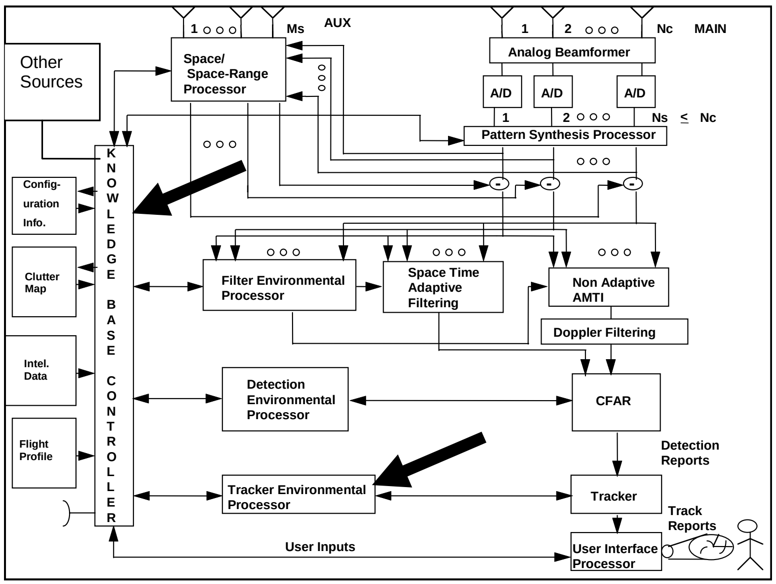
- KBC provides tasking and the location of jammers, discretes, unintentional interferers, etc.
- Processors will "optimize" the KBC tasking
- Data exchange and feedback on results are passed between the processors and the KBC (dB attenuation, gain/loss, algorithms & parameter values)
- KBC will provide control and satisfy operational requests e.g. user wishes to exercise multiple algorithms

Detection Environmental Processor (DEP) and KBC Interface



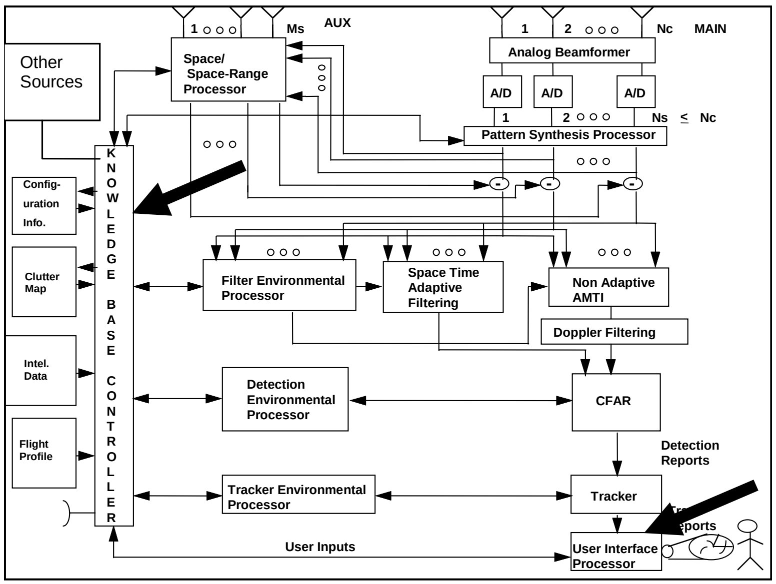
- KBC provides filter data, clutter map and tracker data to the DEP
- DEP uses these data for selecting its CFAR algorithm and setting of thresholds based on “targets” and clutter data
- DEP provides PD, PFA, algorithms, and parameters used
- KBC tasks DEP processing

Tracker Environmental Processor (TEP) and KBC Interface



- KBC provides the TEP priority of targets, results of DEP, control and tasking
- TEP uses these data along with terrain data for declaring and managing tracks
- TEP provides all track data (track i.d., track probability or certainty, lost tracks, etc.) algorithms, and parameters used
- KBC tasks TEP processing

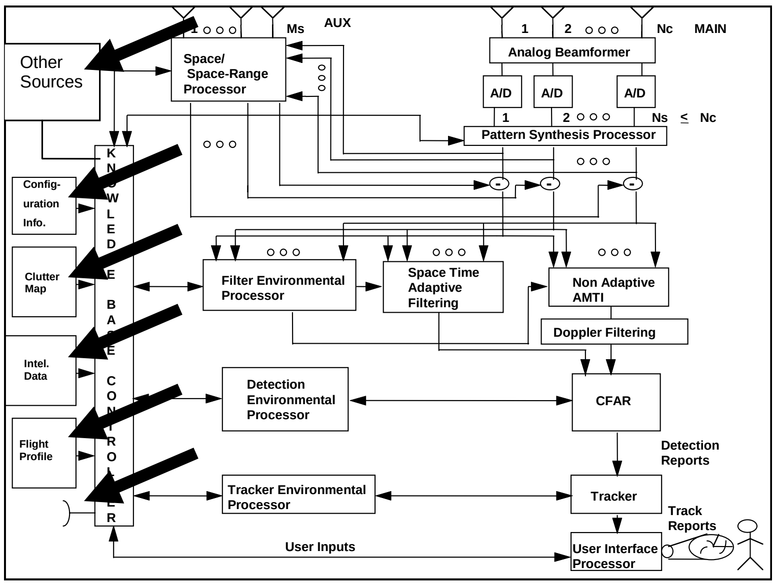
User Interface Processor (UIP) and KBC Interface



*Process Manager and Data Manager are not shown in architecture

- KBC provides the UIP with processed data – intermediate results, performance measures, what and why decisions were made, and assist user in configuring the antenna and processors
- UIP tasks the KBC
- KBC tasks the Process Manager and Data Manager* to configure all computers & algorithms for next iteration

Additional KBC Interfaces



Process Manager and Data Manager store and manage most of these data for the user and the KBC

- Configuration Information e.g. radar description, radar location, and antenna, Rx, & Tx characteristics
- Clutter Map i.e. data required by algorithms e.g. DEM, NLCD, DLG, etc.
- Intelligence data e.g. location of jammers, other radar systems, target kinematics and parameters
- Flight Profile
- Antenna – communications link for obtaining and providing information

AIRS State Processing

- State 1 – pre-flight loading of intelligence, mission, and terrain data
- State 2 – initial transient state e.g. 0 - 4 CPIs
- State 3 – correlation, performance, assessment and learning state e.g. 4 – 20+ CPIs
- State 4 - steady state e.g. after 1 to 2 flights over area (e.g. race track routes)
- Partitioned KBC into a KB performance processor and a KB control processor

System States Versus Processors

System States / Processors	**Pre-Flight**	**Initiate System & Initial Transient States (4 to 20+ CPIs)**	**Correlation, Assessment, Learning (1 to 2 Complete Race Tracks of a Defined Scene/Area)**	**Steady State**
K B Performance Processor	1- Locate and load all Potential Discretes, Clutter Boundaries, Shadow Regions, Jammers, Obstacles - Set System Parameters	6- Monitor System	11- Correlate Discretes, Clutter Boundaries, Shadow Regions, Potential Jammers, Obstacles - Evolve Rules - Insert Synthetic Targets - Measure Performances	16- Insert Synthetic Targets - Measure Performances - Change Rule Sets Accordingly
K B Controller	2- Locate and load all Potential Discretes, Clutter Boundaries, Shadow Regions, Jammers, Obstacles - Set System Parameters	7- Initiate System and Monitor	12- Correlate Discretes, Clutter Boundaries, Shadow Regions, Potential Jammers, Obstacles - Evolve Rules	17- Measure Performances - Change Rule Set Accordingly

System States Versus Processors (Continued)

	Pre-Flight	- Initiate System	- 1 to 2 Race Tracks	- Steady State
Intelligent Filter Environmental Processor	3- Define initial settings and performance measure thresholds	8- Execute Non-STAP Algorithm - Compute No of Secondary Rings - Run NHD - Compute Beam Performance, Determine Null Weights - Determine STAP feasibility	13- Compute Number of Sec. Rings, Run NHD, Compute Beam Performance Measures, Set Nulls, Determine When and Where STAP is Feasible - Evolve Rules	18- Measure Performances - Change Rule Set Accordingly
Intelligent Detector Environmental Processor	4- Define initial settings and Thresholds for Pfa	9- Compute and Adjust Thresholds for Pfa	14- Compute Detections – Re-compute and Adjust Pfa Thresholds - Evolve Rules	19- Measure Performances - Change Rule Set Accordingly
Intelligent Tracker Environmental Processor	5- Locate all Potential Discretes, Clutter Boundaries, Shadow Regions, Jammers, Obstacles - Define initial settings and performance measure thresholds	10- Initiate Tracks - Compute Performance Measures (Number of Correct Tracks, Number of Dropped Tracks, Number of Incorrect Tracks)	15- Correlate FAA Data with Tracks - Compute Performance Measures - Number of Tracks, Number of Dropped Tracks, Number of Incorrect Tracks - Evolve Rules	20- Measure Performances - Change Rule Set Accordingly

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Summary/Future Plans

- Introduction/Background
- Approach
- 200 meter NLCD (national land cover data) data – injected targets
- 30 meter NLCD data – moving target simulator (MTS) targets
- Seeing what the sensor sees
- 10 meter DEM data
- Agile Intelligent Radar System (AIRS)
- Future Plans
  - DEM model development and test in SPEAR facility
  - Continue with image map development – seeing what the sensor sees
  - Integrate NLCD, DEM, and DLG data
  - Extend KB control logic design for the total processing chain - AIRS
- Acknowledgements

References

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- Mr. Mark Novak – AFRL/SNRT
- Dr. Michael Wicks – AFRL/SN

Supplemental Slides

Performance Measure
Modified Sample Matrix Inversion

$$\mathrm{MSMI}_i = \frac{\left| s^H \hat{R}^{-1} x_i \right|^2}{s^H \hat{R}^{-1} s}$$

where: $\hat{R}$ is an estimate of the clutter covariance matrix,

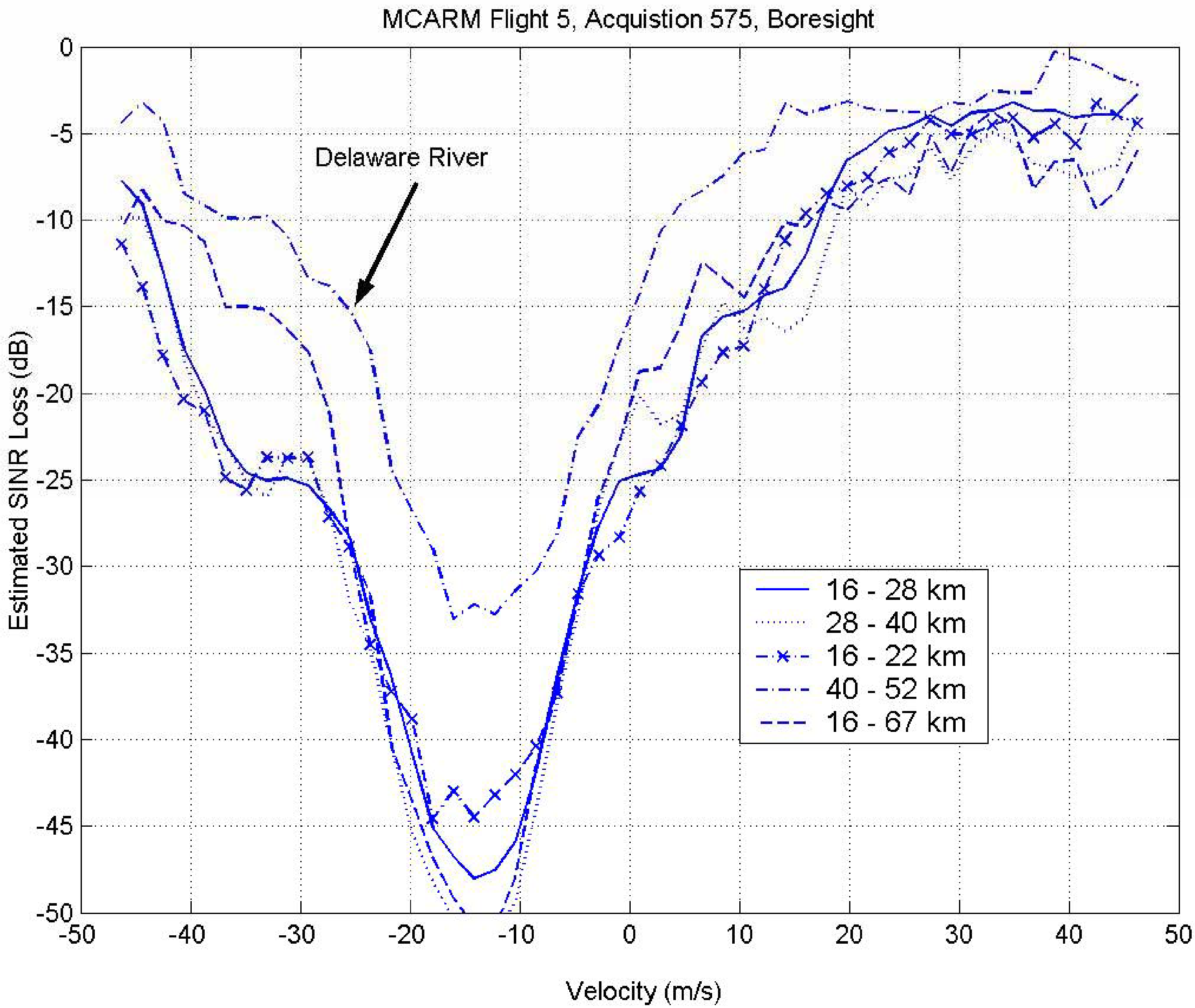
s is the steering vector,

s^H is the complex conjugate transpose of the steering vector,

χ_i is the radar return vector from the ith range ring,

$\hat{R}^{-1}$ is the inverse of the estimate of the clutter covariance matrix.

MSMI is computed for each range ring - has a thresholding or detection quality, similar to CFAR.



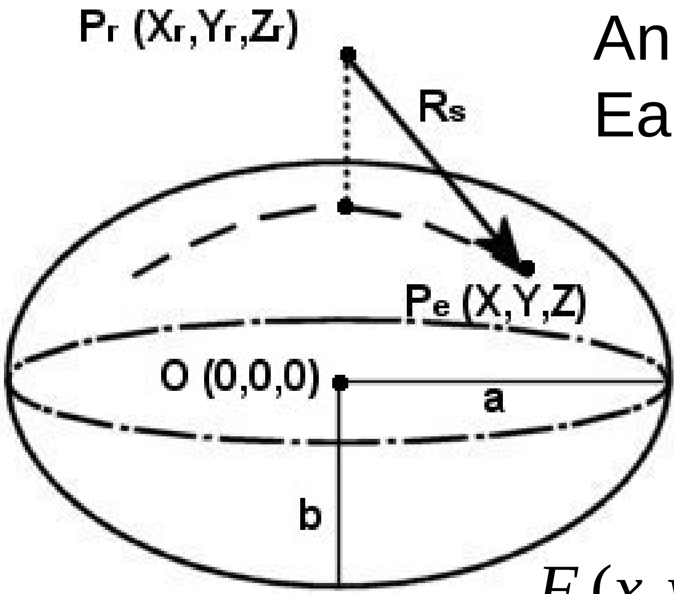
MCARM Flight 5, Acquistion 575, Boresight
Delaware River
Estimated SINR Loss (dB)
Velocity (m/s)
16 - 28 km
28 - 40 km
16 - 22 km
40 - 52 km
16 - 67 km
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-40
-30
-20
-10
10
20
30
40
50

In estimating the covariance matrix, if one wishes to maintain an **average** loss, compared to the optimum, of better than one-half (less than 3 dB), at least 2N samples of data are needed.

I. S. Reed, J. D. Mallet, and L. E. Brennan, "Rapid Convergence Rate in Adaptive Arrays," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 10, No. 6, pp. 853-863, November, 1974.

- In order to demonstrate that knowledge-aided approaches improve STAP performance we need to use real radar data since similar knowledge sources are used to produce simulated radar data.
- If we use real radar data we have no way of knowing what the true covariance matrices are and, therefore, a reliable performance metric is hard to obtain.
- We need to develop a statistical performance measure, when using real radar data, to evaluate STAP algorithms properly. A couple of data points are not sufficient to prove that new approaches are better than current ones.
- However, a statistical performance measure would require a large collection of radar data with accurate truth information about embedded targets.

Registration



An oblate spheroid (elliptical) model of the Earth was used.

Newton-Raphson Iterative Method of solution used to solve registration equations.

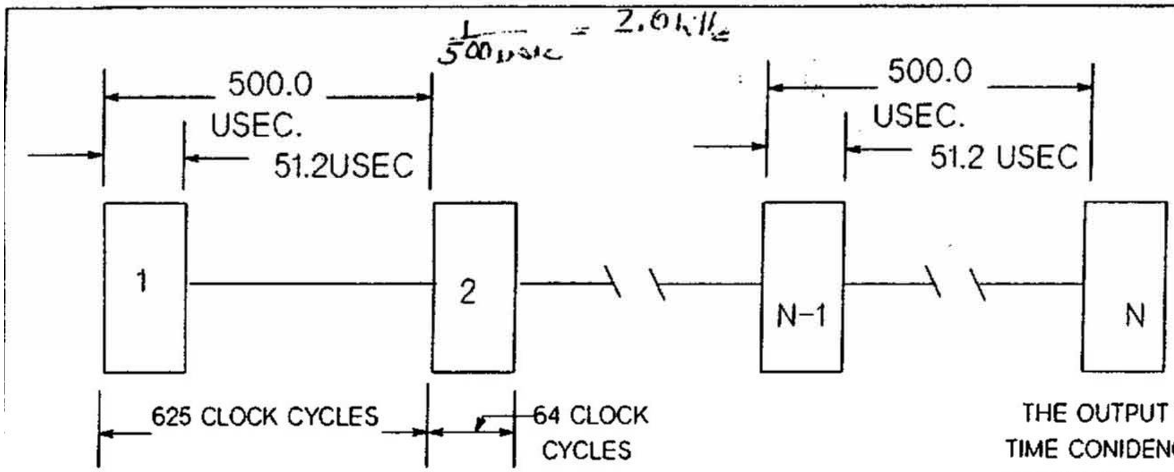
$$F_1(x,y,z)=(x-x_r)^2+(y-y_r)^2+(z-z_r)^2-R_s^{\,2}=0$$

$$F_2(x,y,z)=(x-x_r)v_{rx}+(y-y_r)v_{ry}+(z-z_r)v_{rz}-\frac{f_d\lambda R_s}{2}=0$$

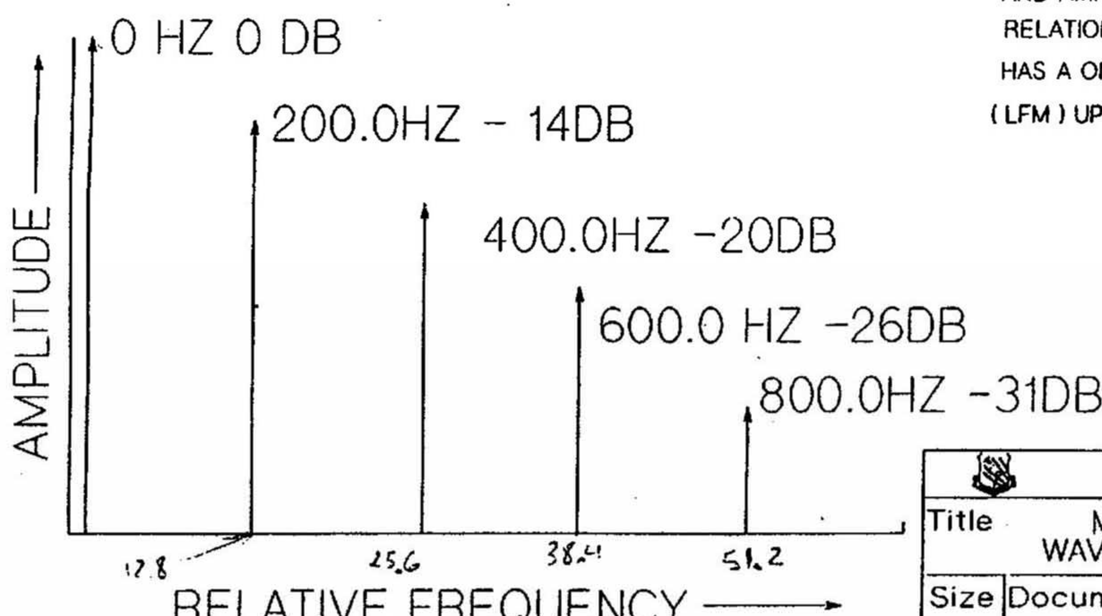
$$F_3(x,y,z)=\frac{x^2}{a^2}+\frac{y^2}{a^2}+\frac{z^2}{b^2}-1=0$$

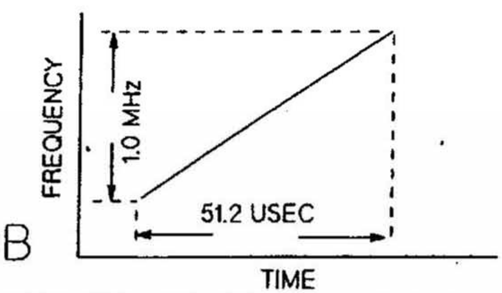
caprao technologies inc.

Monostatic, MTS tones



THE OUTPUT WAVEFORM IS COMPOSED OF FIVE (5) TIME CONIDENCE PULSES,(ie 5 DIFFERENT TARGETS IN THE SAME RANGE CELL) HAVING THE FREQUENCY AND AMPLITUDE, (ie RELATIVE DOPPLER AND RCS) RELATIONSHIP SHOWN AT THE LEFT.EACH PULSE ALSO HAS A ONE (1.0) MHz LINEAR FREQUENCY MODULATION (LFM) UP CHIRP.(SEE DIAGRAM BELOW)

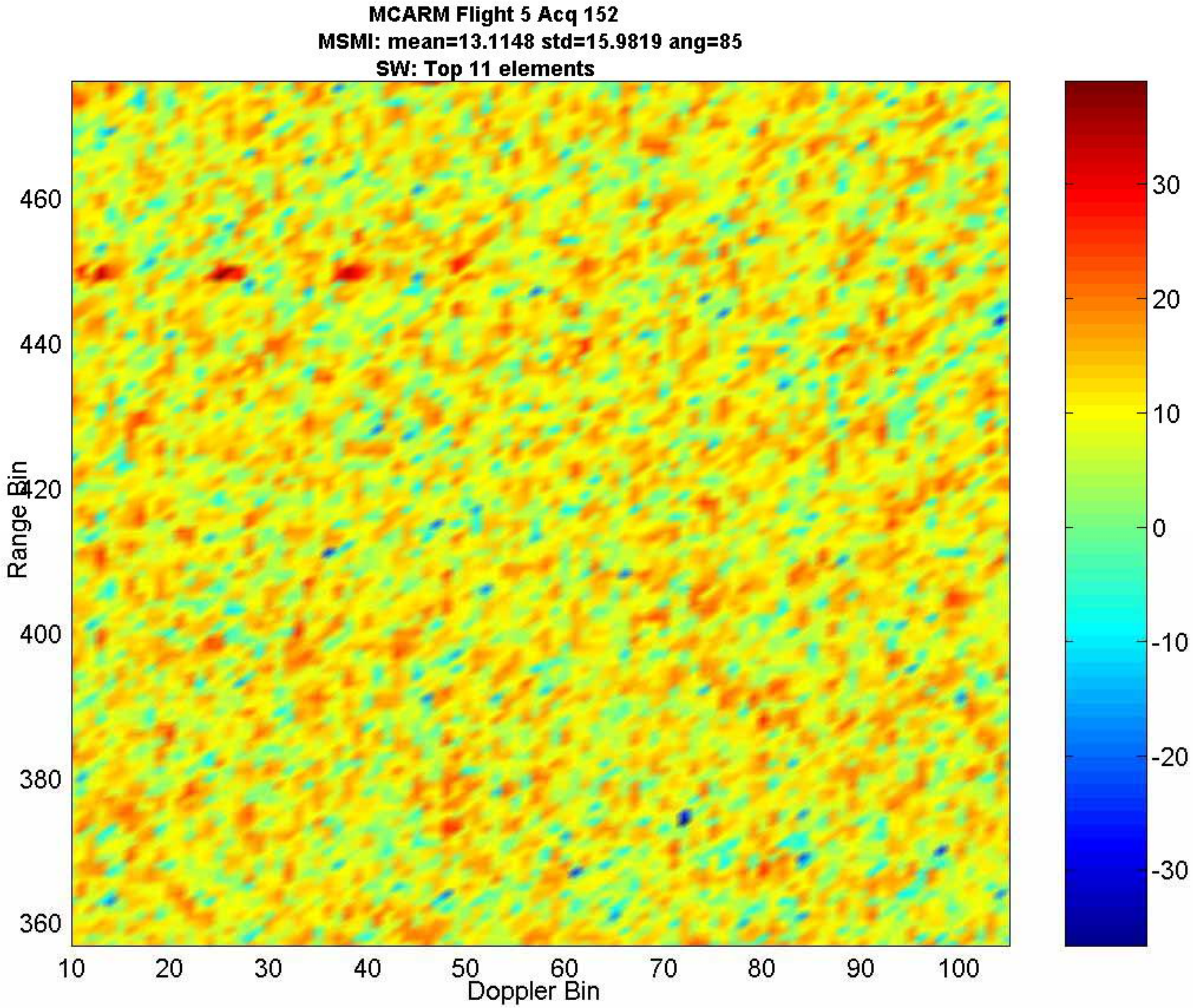




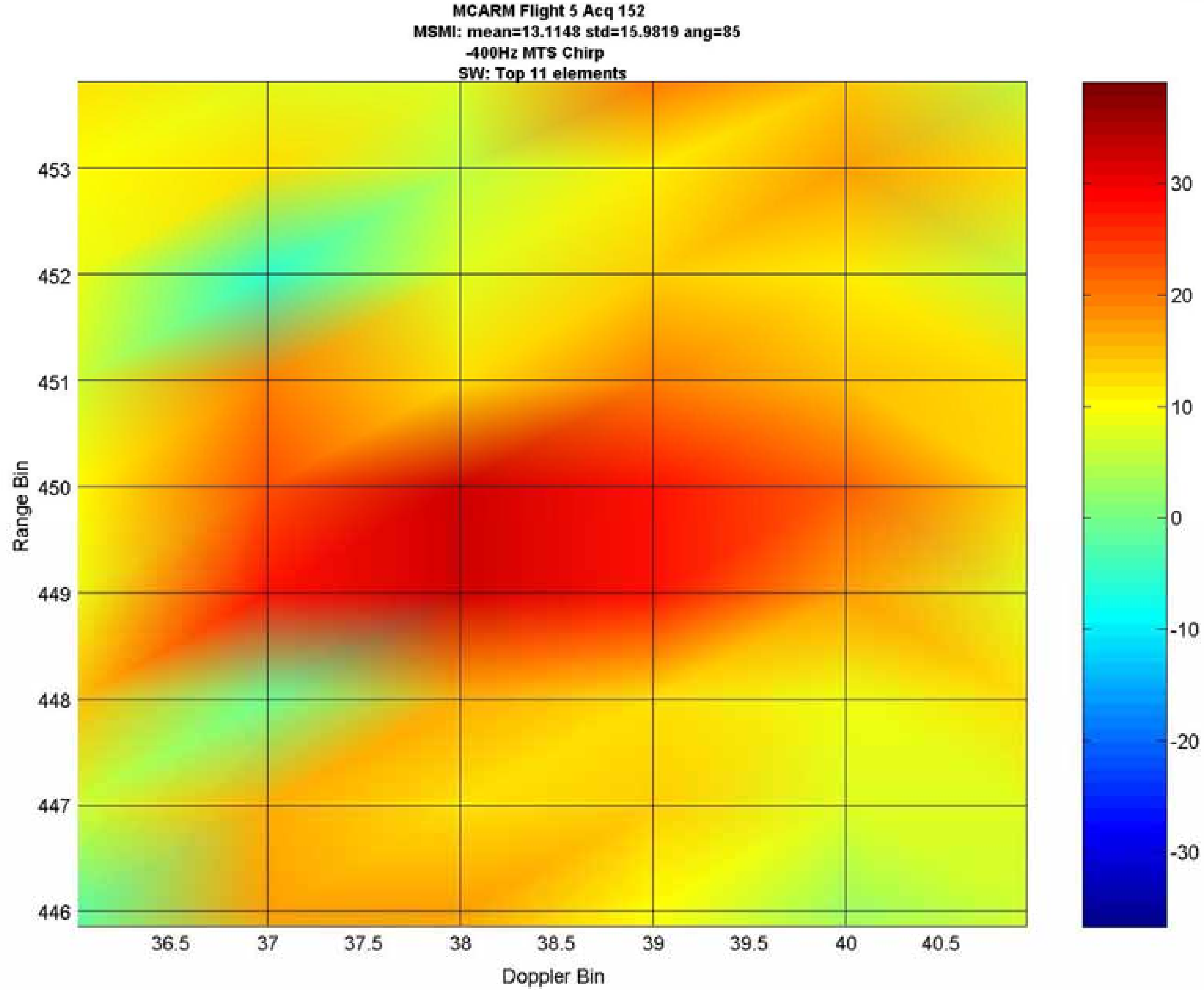
0 Hz RELATIVE FREQUENCY CORRESPONDS TO 1240.000000 MHz

Rome Laboratory		
Title	MOVING TARGET SIMULATOR WAVEFORM PARAMETERS MCARM	
Size	Document Number MTS7.GAL	REV
Date: 2 JUNE 1995		Sheet 7 of 8

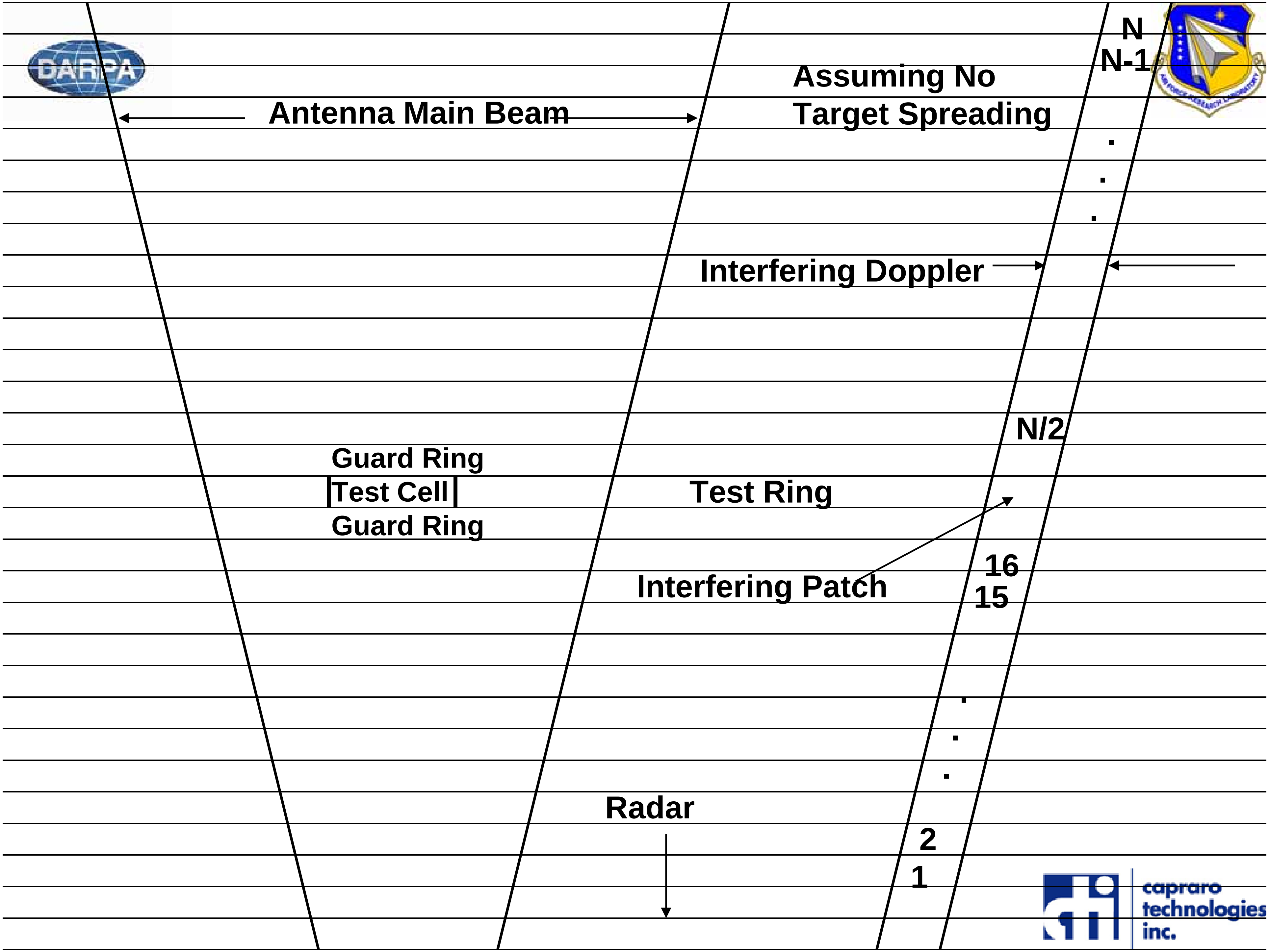
gies



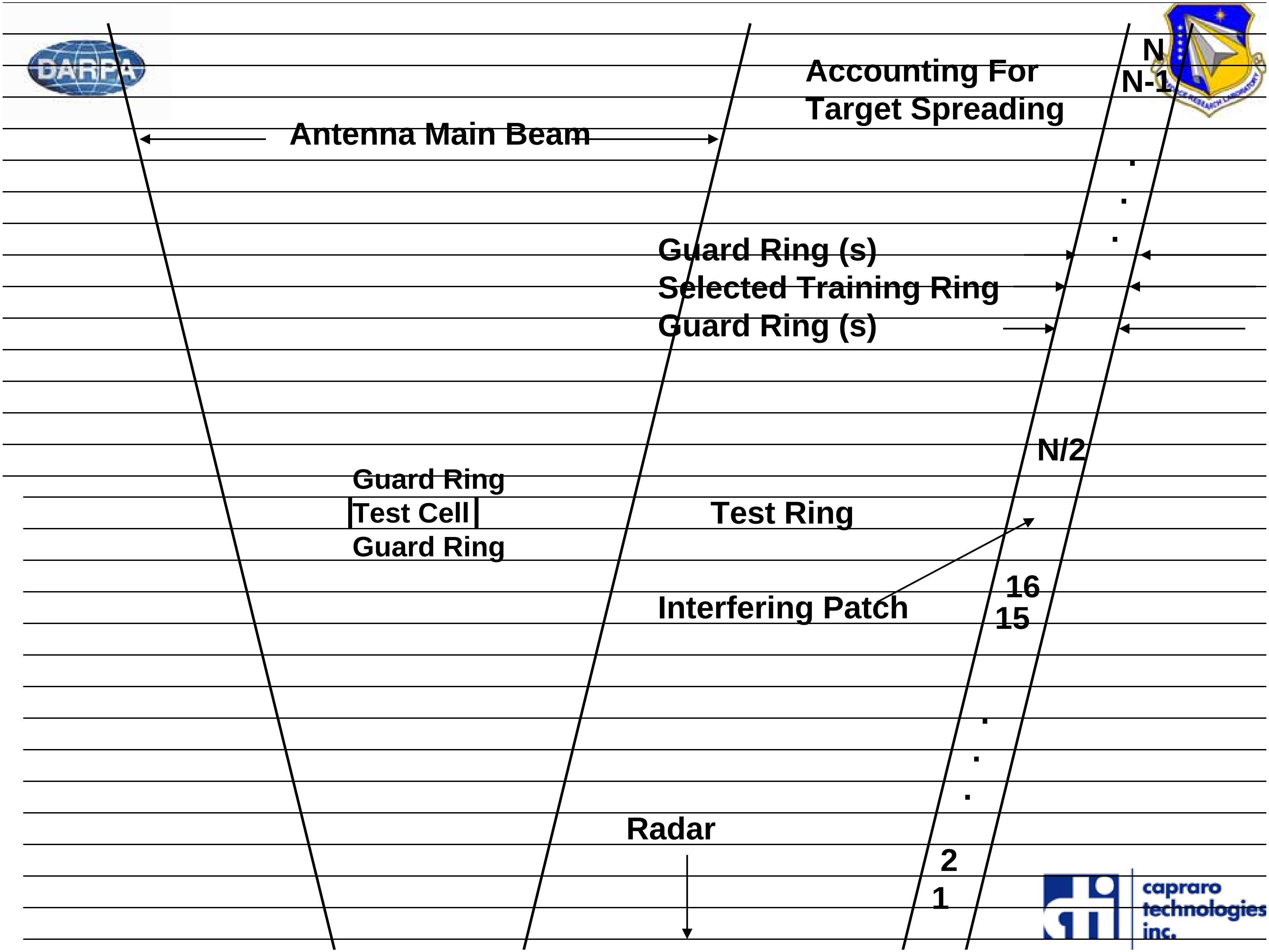
iro technologies inc.


MCARM Flight 5 Acq 152
MSMI: mean=13.1148 std=15.9819 ang=85
-400Hz MTS Chirp
SW: Top 11 elements
Range Bin
453
452
451
450
449
448
447
446
36.5
37
37.5
38
38.5
39
39.5
40
40.5
Doppler Bin
30
20
10
0
-10
-20
-30

Bac 1-11



N
N-1
Assuming No
Target Spreading
Antenna Main Beam
Interfering Doppler
N/2
Guard Ring
Test Cell
Guard Ring
Test Ring
16
15
Interfering Patch
Radar
2
1
capraro
technologies
inc.



Accounting For
Target Spreading
N
N-1
Antenna Main Beam
Guard Ring (s)
Selected Training Ring
Guard Ring (s)
N/2
Guard Ring
Test Cell
Guard Ring
Test Ring
Interfering Patch
16
15
Radar
2
1
DARPA
capraro
technologies
inc.