AFRL RESEARCH LABORATORY SPACE TIME ADAPTIVE PROCESSING (RL-STAP) SIMULATION TOOL

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Agenda

- Background
- RLSTAP Simulation Tool
- Examples

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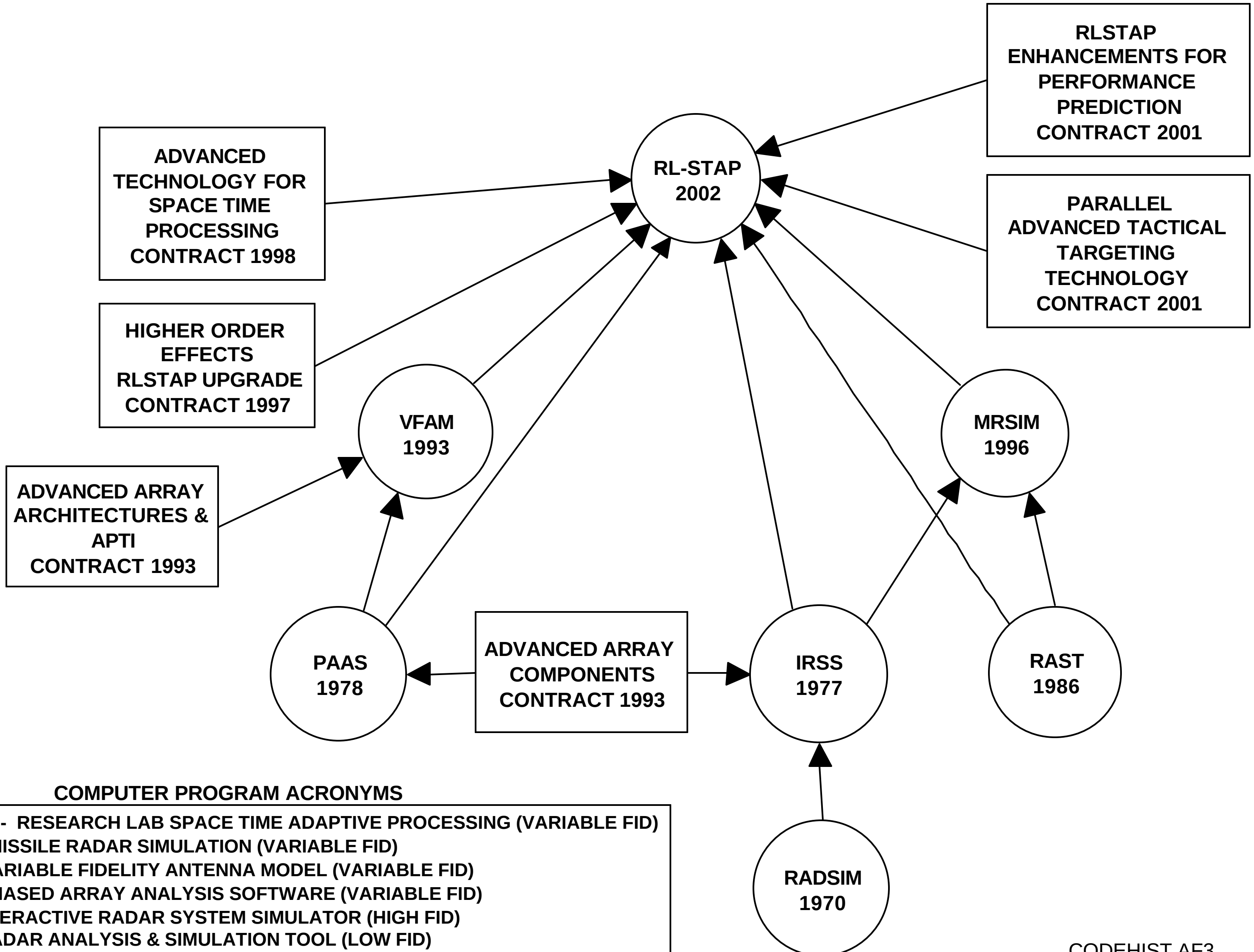
CAESOFT SIMULATION CODE HISTORY



COMPUTER PROGRAM ACRONYMS

RL-STAP - RESEARCH LAB SPACE TIME ADAPTIVE PROCESSING (VARIABLE FID)
MRSIM - MISSILE RADAR SIMULATION (VARIABLE FID)
VFAM - VARIABLE FIDELITY ANTENNA MODEL (VARIABLE FID)
PAAS - PHASED ARRAY ANALYSIS SOFTWARE (VARIABLE FID)
IRSS - INTERACTIVE RADAR SYSTEM SIMULATOR (HIGH FID)
RAST - RADAR ANALYSIS & SIMULATION TOOL (LOW FID)
RADSIM - RADAR SIMULATION PROGRAM (HIGH FID)

CODEHIST.AF3

SYSTEMS SUPPORTED BY CAESOFT SIMULATIONS

- AIRBORNE SURVEILLANCE
  - AWACS -- SENSORCRAFT
  - J-STARS / RTIP -- MP-RTIP (proposed)
  - AN/APS-137 -- E-2C Circular Array STAP (proposed)
- SPACE BASED
  - ISAT / XLSAT
  - DISCOVERER II
  - CONCEPTS FROM USAF SPONSORED STUDIES 1978 THRU 1988
- RADAR-GUIDED MISSILES
  - LCCMD MLI
  - ERINT (PAC-3 UPGRADE)
  - FOREIGN THREAT SAMS
  - PROPRIETARY PROGRAMS
- AIRBORNE WEAPON DELIVERY
  - ATF
  - AN/APQ-130
- AIRBORNE UNMANNED VEHICLE
  - GLOBAL HAWK J-STARS AUGMENTATION CONCEPT
- SHIP BASED
  - SPY-1B (Antenna only)
- GROUND BASED
  - RADAR SURVEILLANCE TECHNOLOGY EXPERIMENTAL RADAR(RSTER)
  - AN/FPS-111 LONG RANGE SURVEILLANCE
  - ADVANCED TACTICAL RADAR
  - FOREIGN THREAT FIRE CONTROL

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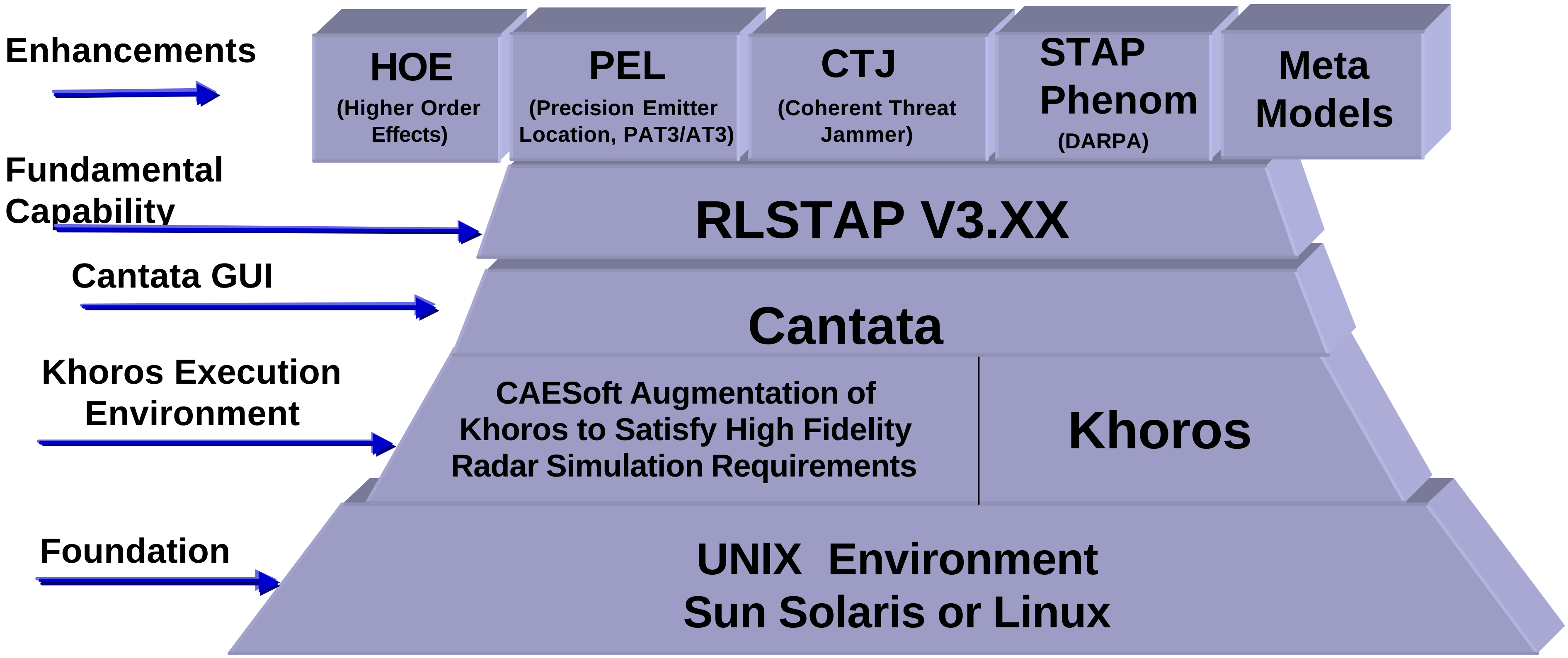
Simulation Approach



Note: Khoros Glyphs were not modified and are compatible with RLSTAP V3.XX Glyphs.

Khoros was <u>Not</u> modified but augmented to bridge known Khoros execution environment gaps to enable its application to an extensible High Fidelity Radar Simulation and to provide enhanced operability where needed

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SUMMARY OF CURRENT CAPABILITIES

- Antenna Modeling
  - General Phased Arrays
  - Multiple Subarrays, Beams
  - Non-overlapped/Overlapped
  - Single Polarization
- Platform Effects
  - Airframe, Radome (JSTARS, AWACS)
  - Yaw (Crab Angle), Pitch, Roll
- Transmitter/Receiver
  - Monostatic/Bistatic
  - Receiver Noise, Blanking
  - IF and PC Filtering, Range Folding
- Waveforms
  - Low, Medium, and High Fixed PRFs
  - LFM, Phase and Barker Coded
- Targets
  - Single/Multiple Scatterer
  - Not Shadowed by Clutter
  - Swerling Models (1 & 3)
- Earth
  - Spherical, Non-Rotating
  - WGS-84
- Platforms
  - Radars, Targets, Jammers
  - Linear Flight Paths
  - User-Specified via LUT
- Low Simulation Noise (High Fidelity)
  - (>80db Below Peak Signal Levels)
- Clutter
  - UHF through X-Band
  - Homogeneous/Site Specific
  - Importing of Sigma Zero vs Grazing Angle Curves
  - Bistatic Equivalence Theorem
- Jammers
  - Direct Path Noise Jammers Only
    Can Set Bandwidth and Location/Speed
  - CTJ
- Temporal Modeling
  - Updates Positions of All Platforms on Each Pulse
  - Models Range-Walk and Doppler-Walk
- Signal Processing
  - STAP Algorithms
  - CFAR Algorithms
  - Beamforming, DPCA, MTI
- Interfaces With Other Software
  - MATLAB - Signal Processing Flexibility
  - MATLAB - Visualization
  - CS-PAAS - More Complex Antenna Modeling
  - Import Antenna Patterns Generated by Third Party Software

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Higher Order Effects That can be Included

- Antenna
  - Radome and near field scattering cause elevated sidelobes, main beam defocusing, and spatial pattern mis-matching in multi-channel systems
  - Manifold and fabrication tolerances cause pattern degradation and spatial pattern mis-matching in multi-channel systems
  - Time dispersion due to unequal delays in manifolding and beamsteering
  - Correlated noise in Active ESA's due to element reuse where low noise amplifiers at the element level drive manifolds which form multiple receive beams

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Higher Order Effects (Cont.)

- Transmitter
  - Exciter Spectral purity (phase noise, synthesizer spurs)
  - Power amplifier stability
  - Timing jitter
- Receiver
  - local oscillator Spectral purity (phase noise, synthesizer spurs)
  - Frequency dispersion due to non-linearities
  - time dispersion (mainly due to filters)
  - channel to channel mismatch
  - Motion compensation errors due to imperfect ownship navigation data
  - Analog to digital converters

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Higher Order Effects (cont.)

- Environment Generators (Physical Model)
  - Effect of platform motion during a CPI which may result in range walk, Doppler walk, and higher order migration terms
  - Effect of crab angle on clutter returns
  - Target and clutter glint and scintillation
  - Non-homogeneous clutter
  - Large clutter discretes
  - Large number of ground vehicles can be included to generate realistic backgrounds
  - Terrain Shadowing Terrain
  - Clutter Internal Motion
- Signal Processing
  - Pulse compression range sidelobes
  - Doppler sidelobes

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SIMULATION REQUIREMENTS & SELECTION

- MANY TASKS MUST BE SUPPORTED BY DESIGN AND SIMULATION TOOLS
- SPEED AND FIDELITY REQUIREMENTS:
  - DEPEND ON THE TASK
  - VARY OVER A WIDE RANGE
- THE FIGURES OF MERIT FOR A SIMULATION ARE RELATED TO HOW WELL IT SUPPORTS THE DEVELOPMENT PROCESS
  - HOW QUICK?
  - HOW ACCURATE?

THESE MUST BE TRADED OFF

- QUICK TURNAROUND WITH POOR ACCURACY IS OF NO VALUE
- VERY SLOW WITH HIGH FIDELITY IS INAPPROPRIATE FOR MANY PURPOSES
- POSSIBLE SOLUTIONS:
  - USE A SEPARATE SIMULATION FOR EACH TASK
  - USE A VARIABLE FIDELITY SIMULATION

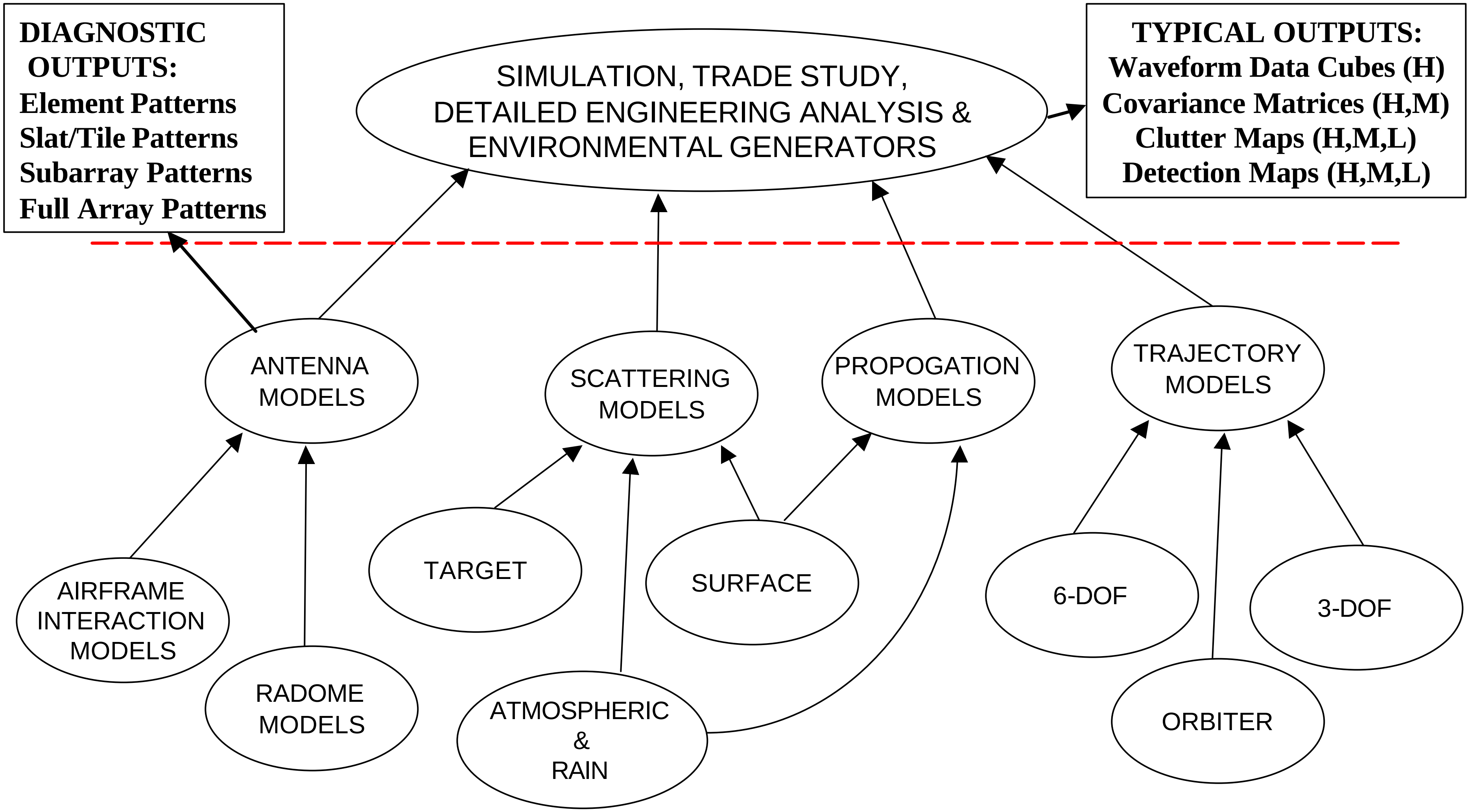
FEATURES VS FIDELITY LEVEL

- **CORE PROCESS DATA REPRESENTATION**
  - **LOW - POWER**
  - **MEDIUM - POWER OR SAMPLES COMPLEX VIDEO**
  - **HIGH - SAMPLED WAVEFORMS**
- **CORE PROCESS DATA SAMPLE RATE**
  - **LOW - DWELL**
  - **MEDIUM - CPI OR DWELL**
  - **HIGH - CHOSEN TO AVOID ALIASING; RESAMPLING PERFORMED AS REQUIRED TO MATCH WAVEFORM BANDWIDTH**
- **GEOMETRY UPDATE RATE**
  - **LOW - DWELL**
  - **MEDIUM - CPI**
  - **HIGH - PRI**
- **OUTPUT DATA**
  - **LOW - SNR, J/S, PD, PFA, PACQ, RMS RANGE, ANGLE, AND DOPPLER TRACK ACCURACIES**
  - **MEDIUM - SNR, SIR, J/S, PD, PF, PACQ, CA, SCV, PEAK CLUTTER, DYNAMIC RANGE REQUIRED, CLUTTER MAPS, ESTIMATED TARGET ANGLE OFF BORESIGHT, ESTIMATED TARGET RANGE AND DOPPLER**
  - **HIGH - SAMPLED WAVEFORMS AT ANY POINT IN SIMULATED SYSTEM**

FEATURES VS FIDELITY (Cont.)

- **SCOPE**
  - **LOW - FOR INITIAL DESIGN PROCESS BASED ON NOISE LIMITED PERFORMANCE ESTIMATION**
  - **MEDIUM - FOR DETAILED ANALYSIS AND DESIGN TRADE-OFF STUDIES. INCLUDES INTERFERENCE INVESTIGATIONS AND HOW OTHER PHENOMENA AFFECT SEEKER PERFORMANCE**
  - **HIGH - FOR DETAILED SIMULATION OF SPECIFIC SYSTEM DESIGN**
- **METHODOLOGY**
  - **LOW - USES CLOSED FORM SOLUTIONS AND LOOK-UP TABLES**
  - **MEDIUM - COMBINES CLOSED FORM SOLUTIONS, INTERATIVE TECHNIQUES, NUMERICAL INTEGRATION, AND LOOK-UP TABLES TO PREDICT SYSTEM PERFORMANCE**
  - **HIGH - COMBINES ACCURATE EMULATION MODELS OF RADAR COMPONENTS WITH ENVIRONMENT STIMULATORS**
- **HARDWARE CHARACTERIZATION**
  - **LOW - PARAMETERS, LOOK-UP TABLES**
  - **MEDIUM - PARAMETERS, LOOK-UP TABLES, AND SIMPLE MODELS**
  - **HIGH - CHARACTERIZED VIA EMULATORS DESIGNED TO ACCURATELY SIMULATE HARDWARE DEVICES**

TRUTH SUB-MODELS ARE THE LOWEST LEVEL ROUTINES
THEY ARE COMMON TO ALL FIDELITIES
(REQUIRE STANDARD OPERATIONAL INTERFACES)



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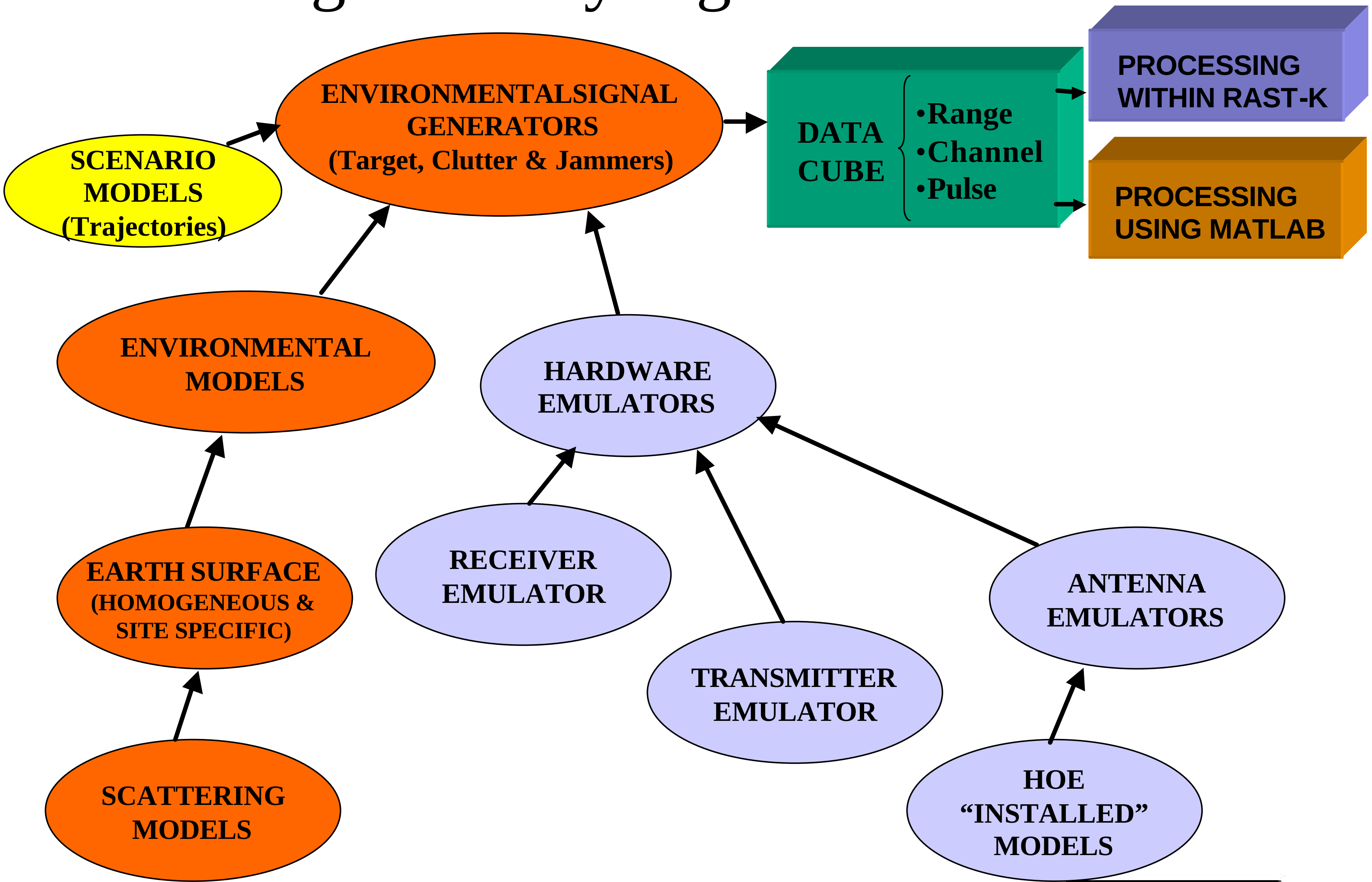
High Fidelity Signal Generation



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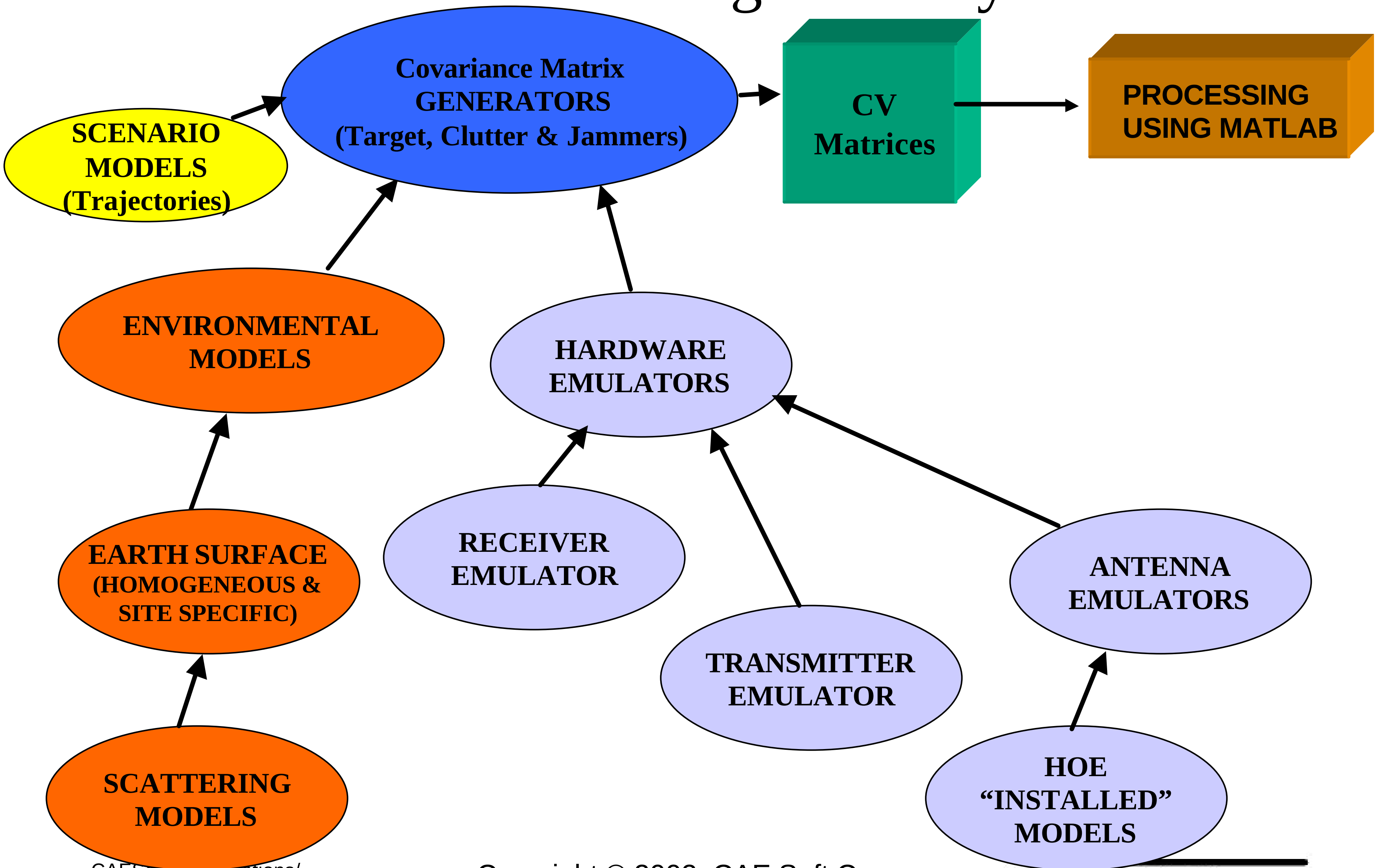
Covariance Matrix Generation uses same interface as High Fidelity



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Example Illustrating some Higher order effects

- Site Specific Non-Homogeneous Clutter Background with and without ICM
- Simple Example Illustrating Clutter Glint Effects

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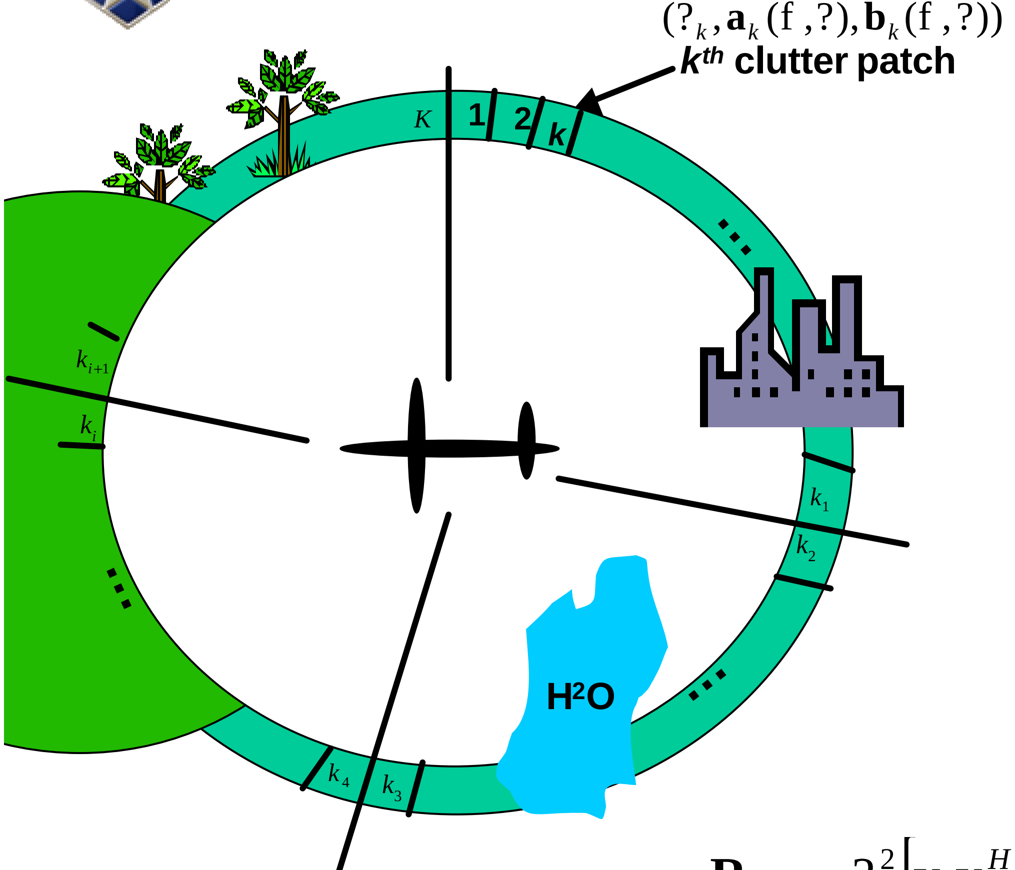
ACM Results 3/27/02
Salt Lake City Area

Peter Zulch
Signal Processing Branch (SNRT)
Sensors Directorate
Air Force ResearchLaboratory

Varied ICM Properties Around a Range Ring



ICM Can Vary From
Region to Region
Depending On Clutter Type

Spatial Steering Vector

$$\mathbf{a}_k = \exp(j2p(0:N-1)\frac{d}{l}\sin(f_k)\cos(q_k))$$

Temporal Steering Vector

$$\mathbf{b}_k = \exp(j2p(0:M-1)\frac{2v}{l \bullet prf}\sin(f_k + f_{vma})\cos(q))$$

Space Time Steering Vector

$$\mathbf{v}_k = (\mathbf{b}_k \otimes \mathbf{a}_k) \in C^{NM\times 1}$$

Analytic Covariance Matrix Calculation

$$\mathbf{R} = \sum_{k=1}^{K} ?_k^2 \mathbf{v}_k \mathbf{v}_k^H$$

Covariance with ICM

$$\mathbf{R}_{icm} = \mathbf{R} \circ \mathbf{T}_{ST} = \left[\sum_{k=1}^{K} ?_k^2 \mathbf{v}_k \mathbf{v}_k^H\right] \circ \mathbf{T}_{ST}$$

$$\mathbf{R}_{icm} = ?_1^2\left[\mathbf{v}_1\mathbf{v}_1^H\right]\circ\mathbf{T}_{ST} + ?_2^2\left[\mathbf{v}_2\mathbf{v}_2^H\right]\circ\mathbf{T}_{ST} + \cdots + ?_K^2\left[\mathbf{v}_K\mathbf{v}_K^H\right]\circ\mathbf{T}_{ST}$$

Can be more specific as to the ICM for the *k^{th} patch*

$$\mathbf{R}_{icm} = ?_1^2\left[\mathbf{v}_1\mathbf{v}_1^H\right]\circ\mathbf{T}_{ST,1} + ?_2^2\left[\mathbf{v}_2\mathbf{v}_2^H\right]\circ\mathbf{T}_{ST,2} + \cdots + ?_K^2\left[\mathbf{v}_K\mathbf{v}_K^H\right]\circ\mathbf{T}_{ST,K}$$

Internal Clutter Motion (ICM)

- Method Based on Covariance Matrix Tapers

Billingsley Model

Spectrum

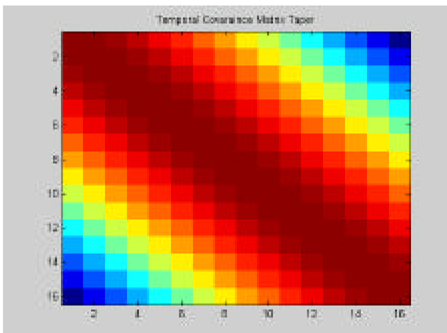
$$P_c(f) = \frac{r}{r+1} d(f) + \frac{1}{r+1}\frac{bl}{4}\exp\left(-\frac{bl}{2}|f|\right)$$

$\rightarrow \mathfrak{I}^{-1} \rightarrow$

Correlation Function

$$r_c(t) = \frac{r}{r+1} + \frac{1}{r+1}\frac{(bl)^2}{(bl)^2 + (4\pi t)^2}$$

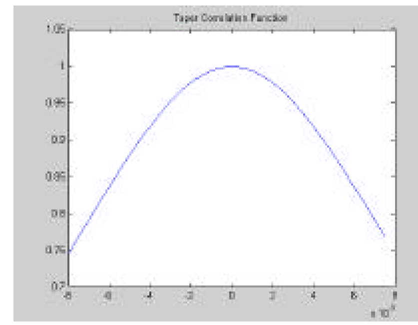
$\mathbf{T} \equiv$



$$10\log r = -15.5\ \log w - 12.1\ \log f_c + 63.2$$

$$\mathbf{T}_{ST} = \mathbf{T} \otimes \mathbf{1}_{N\times N}$$

$$\mathbf{R}_{icm} = \mathbf{T}_{ST} \circ \mathbf{R}$$



$\mathbf{T} \in R^{[M\times M]}$ $\quad$ $\mathbf{T}_{ST} \in R^{MN\times MN}$ $\quad$ $\mathbf{R} \in C^{MN\times MN}$

- Can apply time modulation directly to range sample

$$(\mathbf{U}, \Lambda) = \mathrm{EIG}(\mathbf{T})$$

$$\tilde{\mathbf{z}} = \left(\mathbf{U}\Lambda^{1/2}\right)\mathbf{z}, \quad \mathbf{z} \in C^{M\times 1}$$

$$\tilde{\mathbf{x}}_{r,icm} = \sum_{p=1}^{P_{cc}} x\left(\mathbf{v}(f,q) \bullet (\tilde{\mathbf{z}} \otimes \mathbf{1}_N)\right)$$

Reference: Techau, Paul M., Bergin, Jameson S., and Guerci, Joseph R., "Effects of Internal Clutter Motion on STAP in a Heterogeneous Environment," *Proceedings of the IEEE Radar Conf.*, Atlanta, GA, May 1-3, 2001

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RSTER UHF Example Parameters

Parameter	Value	
Transmit Frequency	435 MHz	
Pulse Width	1e-5 sec	
3 dB Bandwidth	0.6 MHz	
PRF	625	
Transmit Peak directive Gain	29 dBi	
Receive Peak directive Gain	17 dBi	
Transmit Power	128 Kwatts	
Boresight	Broadside (Starboard)	
# Receive Channels	14 subarrays	
# Transmit Pulses	16	
Platform Heading	North	
Platform Velocity	175 m/s	
Platform Altitude	9 Km	
Platform Location	41 deg. N Lat, 112.57 W Lon	
Range Resolution Cell Size	150 m	

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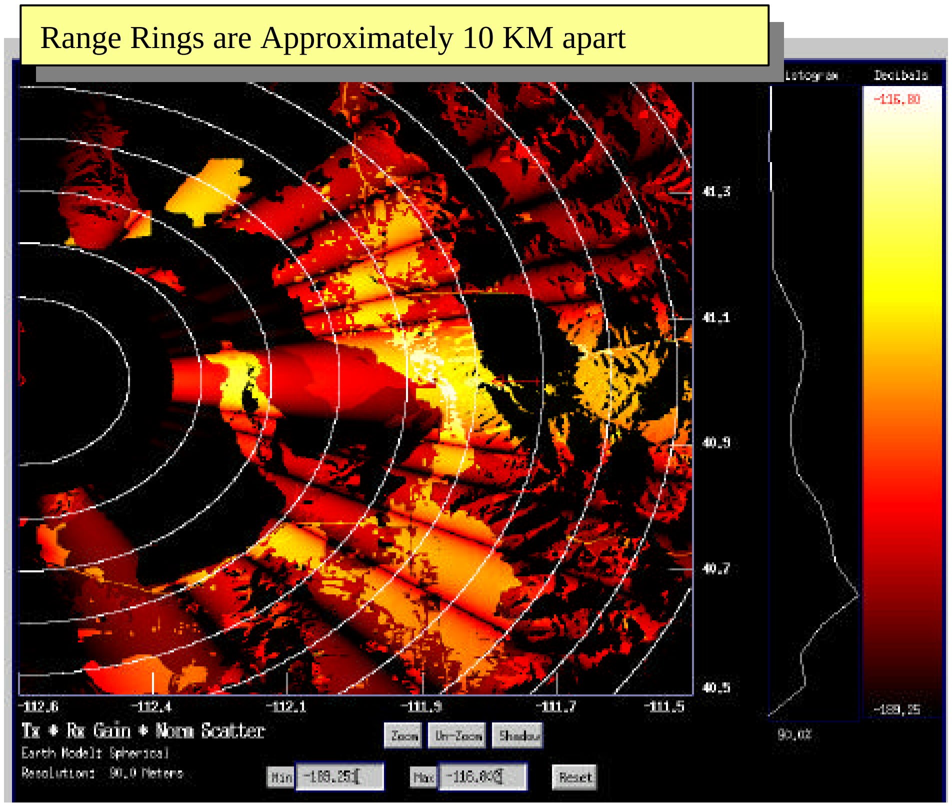
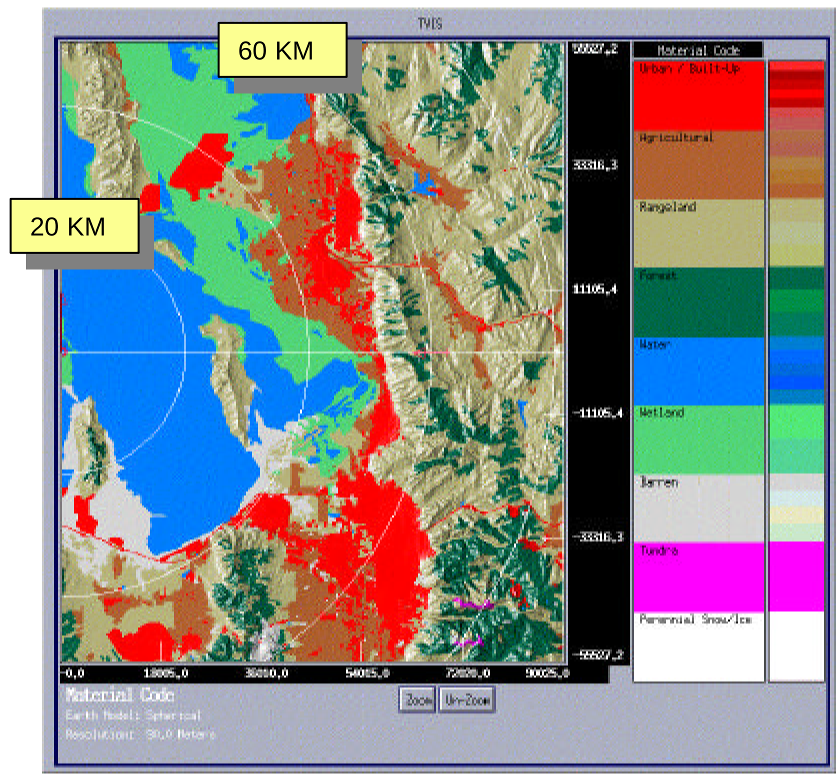
Salt Lake City Area

- Radar positioned just on left border of plot, ½ way down plot
- Looking out over Great Salt Lake towards SLC and Wasatch Mt. Range

Clutter Power



Land Cover



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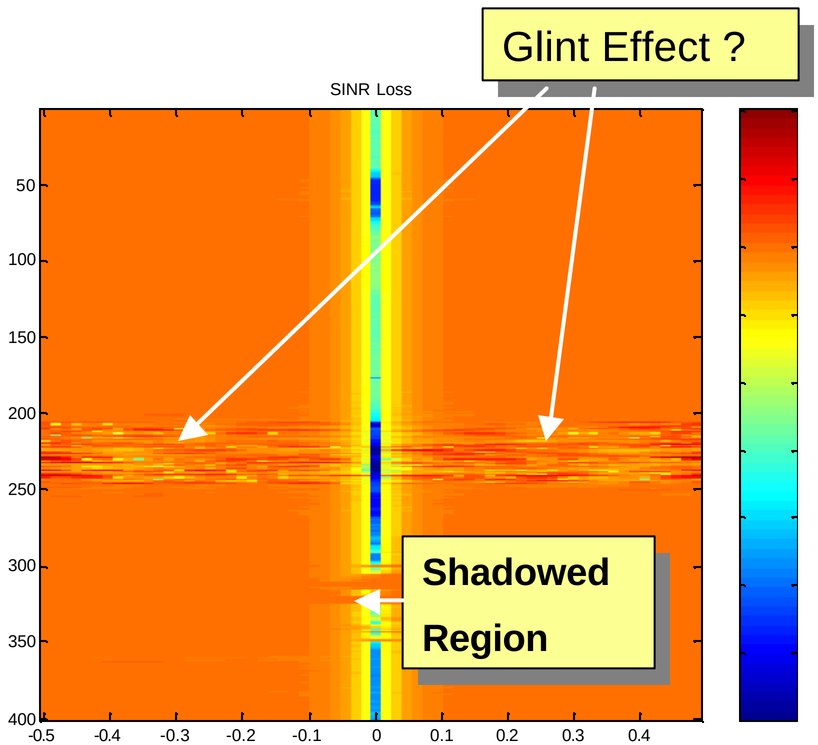
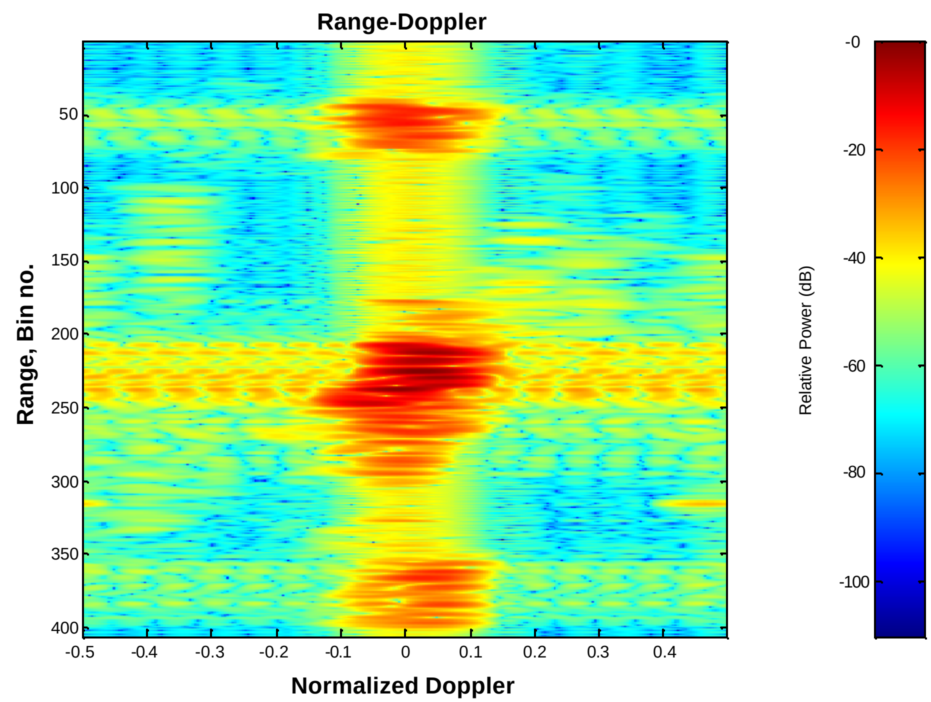
SINR vs. Range Doppler Comparison No ICM

- Rng. Dop plot after conventional beamforming and Doppler processing (30 dB Dolph-chebychev weights)





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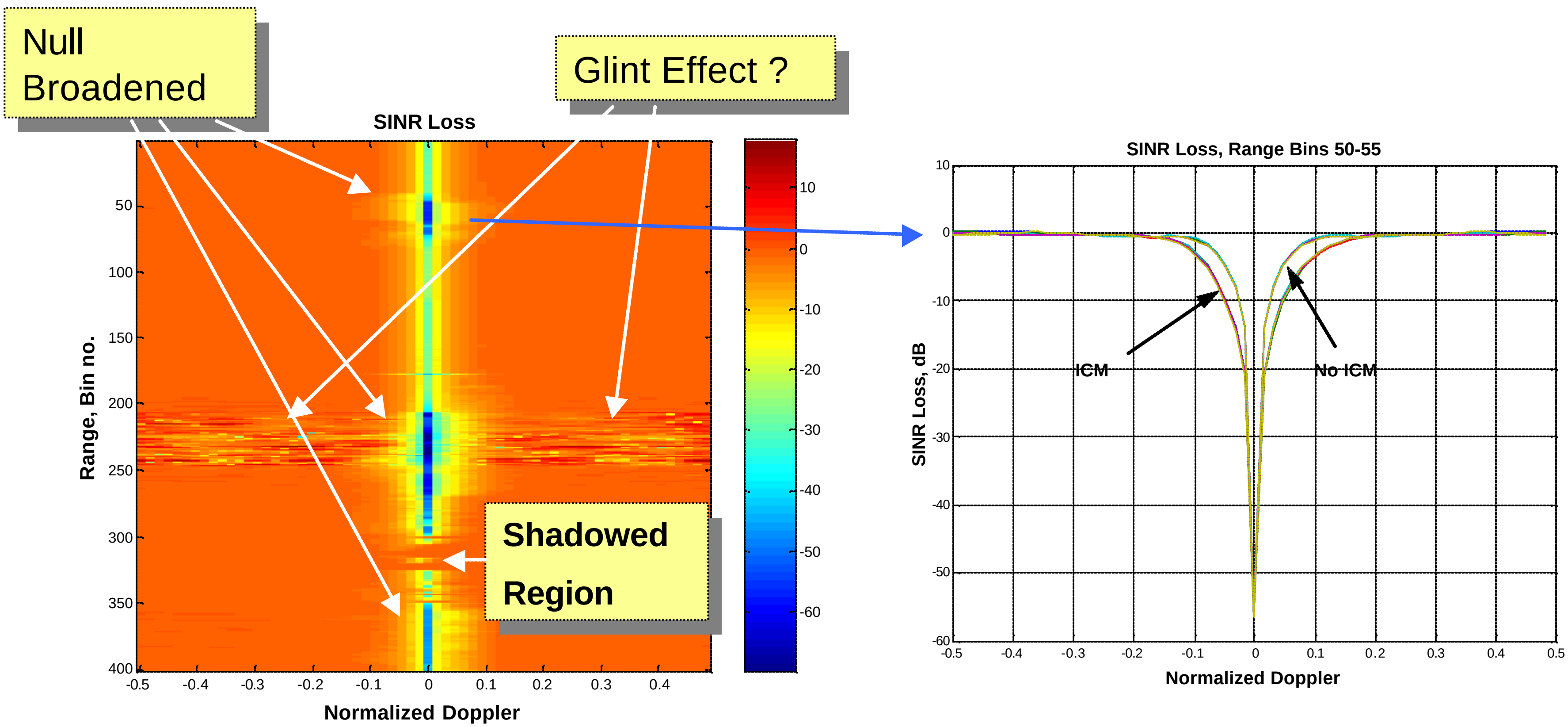
SINR Analysis – Clutter plus Noise ICM Included

- Included ICM where correlation properties differ from one cover type to another
- Used combination of Billingsley and Simkins Temporal Correlation Models



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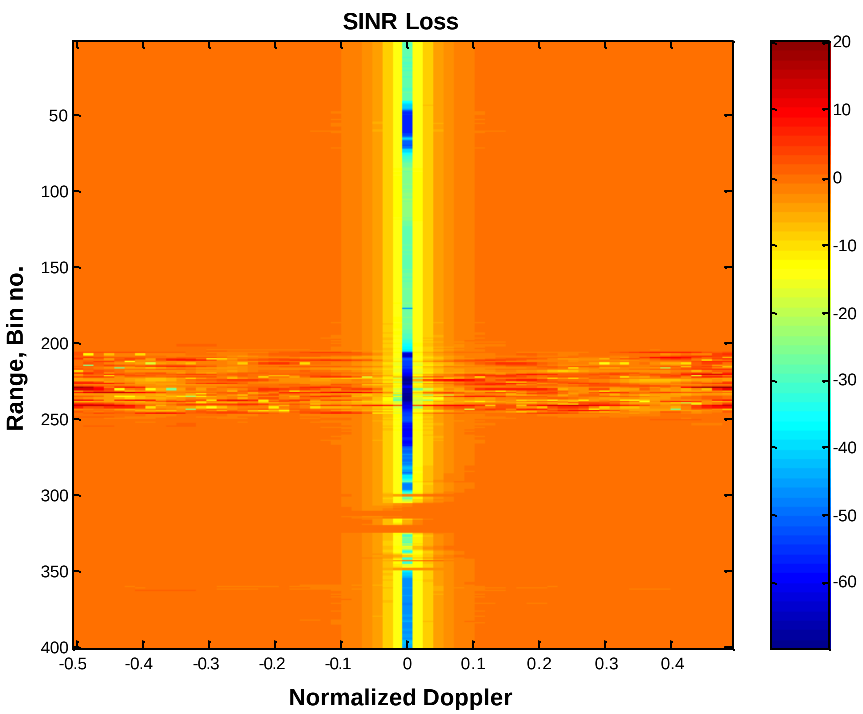
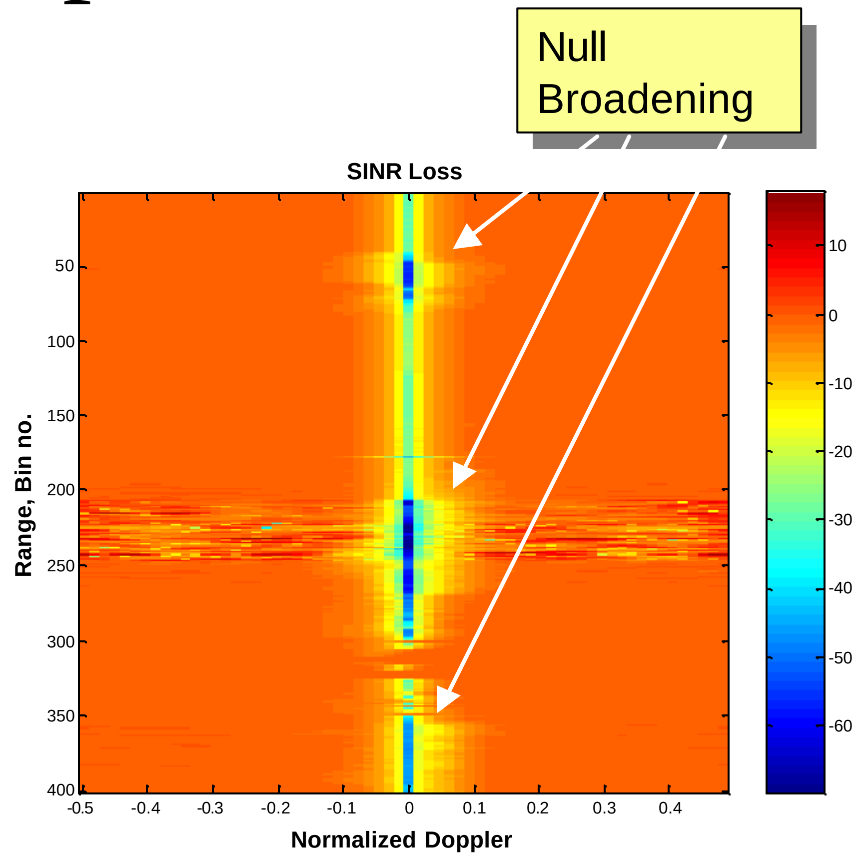
SINR Comparison



Without ICM



With ICM

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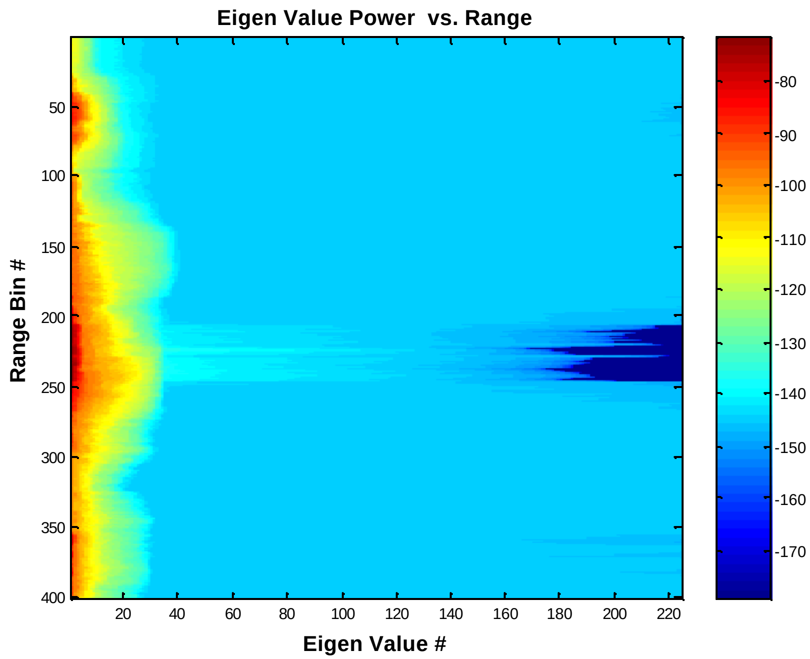
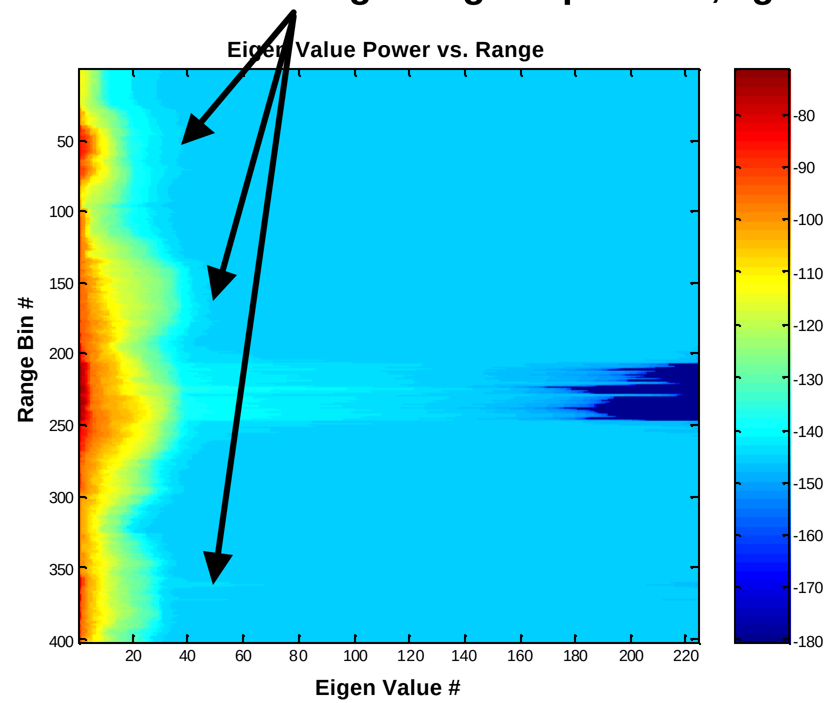
Eigen Analysis

- All 401 range cells
- Analytic covariance matrices used

Broadening of Eigen Spectrum, light blue



Without ICM



With ICM

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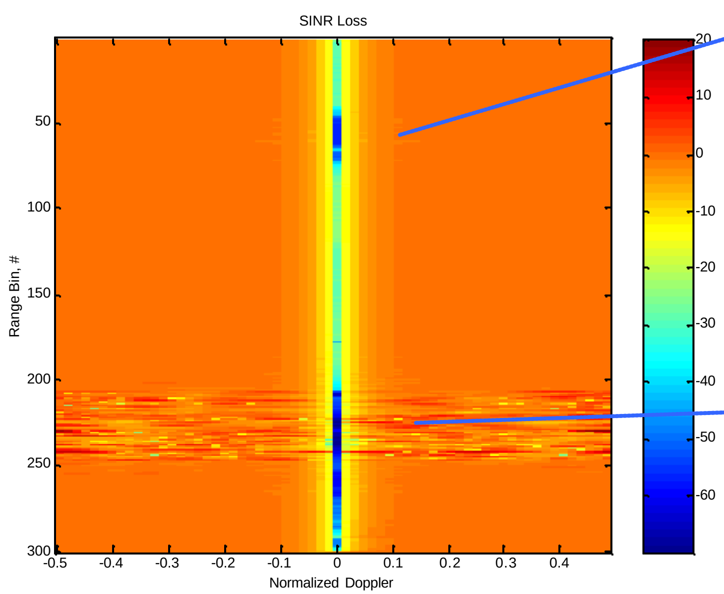
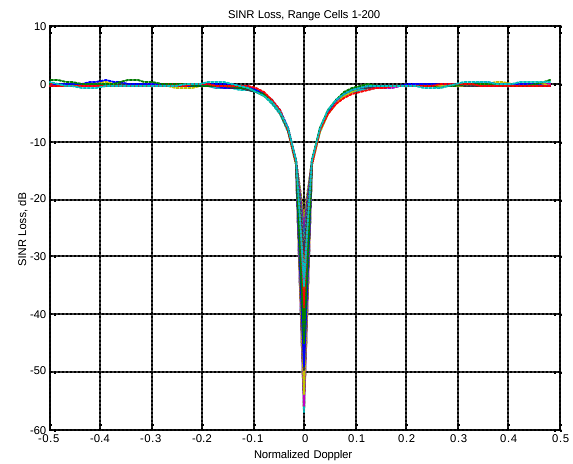
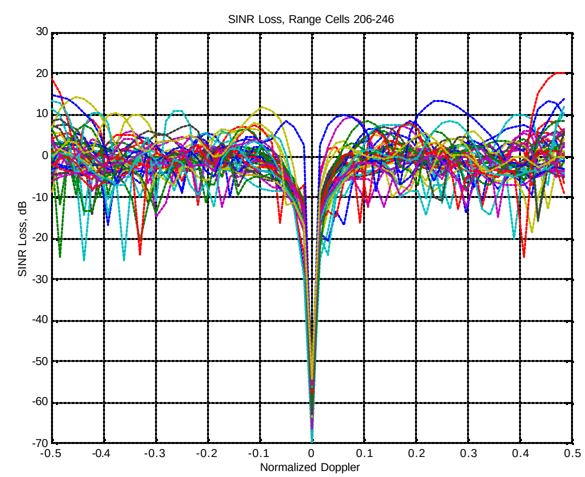
SINR Analysis – Clutter plus Noise (No ICM)

- Cuts show SINR overall shape does not change much except between range cells 200 and 240







Clutter Scintillation and Glint

- Coherent Superposition causes Constructive and Destructive Interference between multiple clutter scatterers at the Antenna
  - Scintillation is the temporal effect
  - Glint is the spatial effect
- Is always present when more than one clutter scattering object reside in a range bin
- Degrades
  - SAR Imagery – Speckle
  - Adaptive Processing – Sub-Space Leakage

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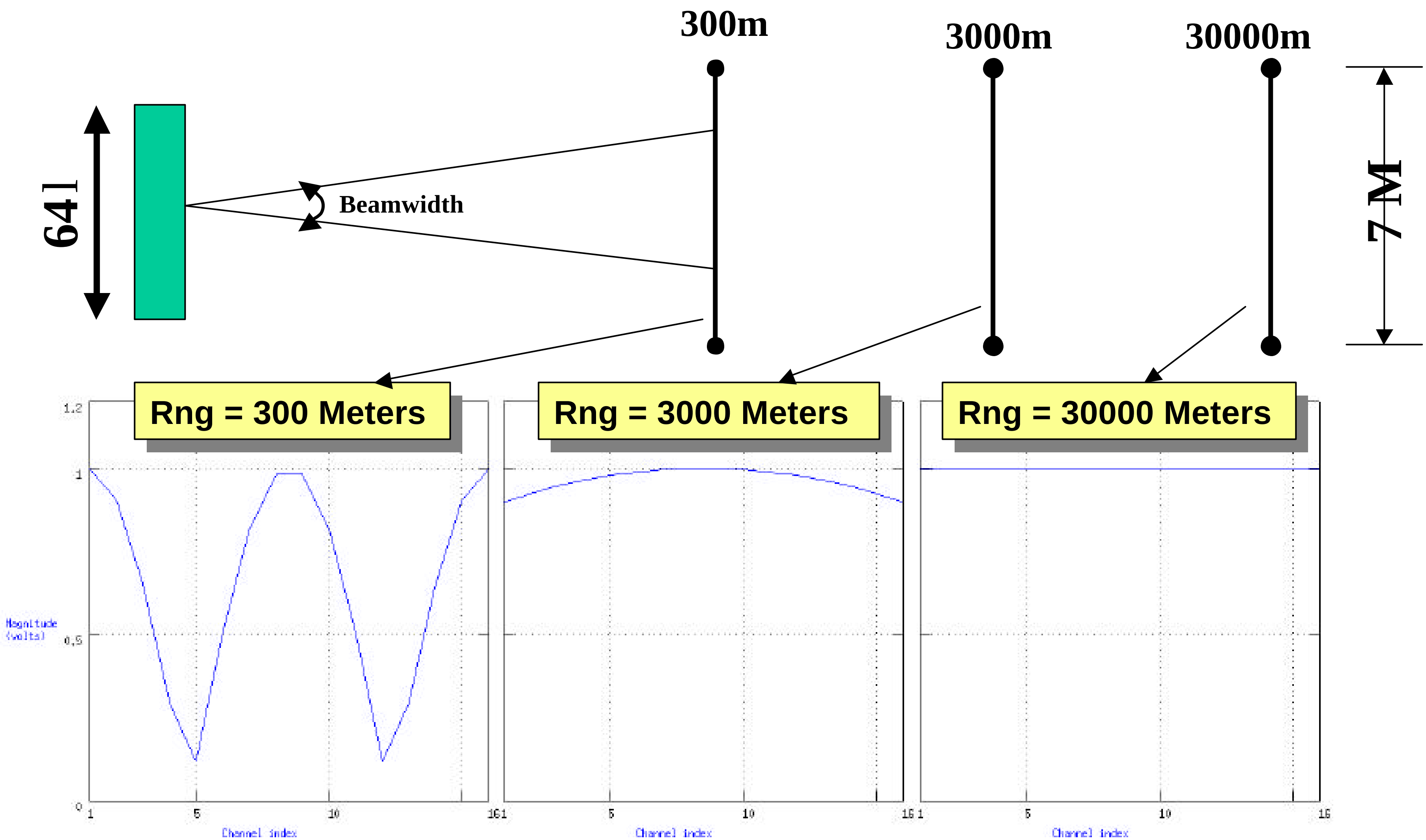
Clutter Glint Simple Example



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KASSPER03Apr02.ppt

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Scenario Description

- Rectangular Scatterer field:
  - 110 Meters wide (cross-range)
  - 110 KM long (down-range)
- Scatterer locations were randomized
- Width of scatterer field ensures it is in main beam of TX and RX patterns
- CluGlint-r1e.wk

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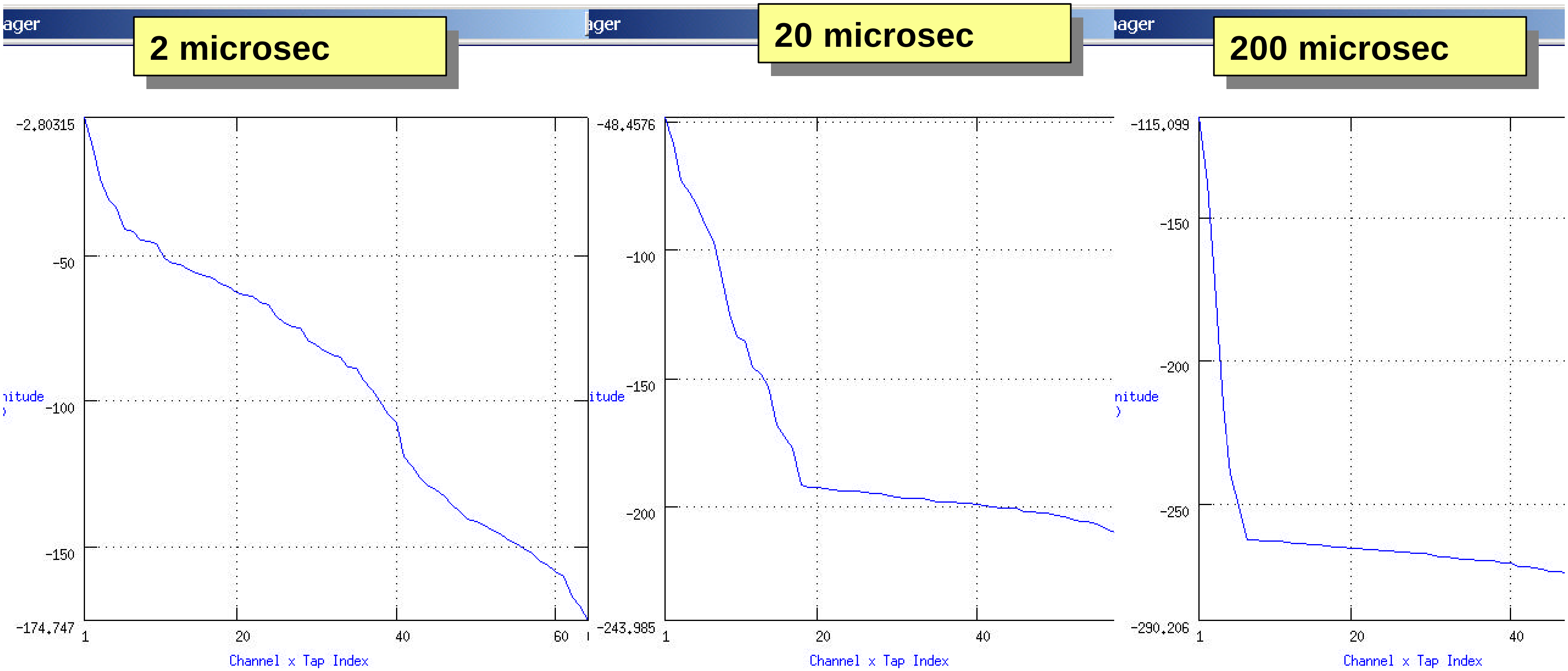
Eigen-Spectra Computation

- 16 channels, 4 pri taps
- Covariance matrices were computed for each range bin and summed together in groups of 10
- Case 1 Crab angle is 0.0
- Case 2 Same as case 1 with non-zero crab angle

Case 1 no crab angle



Notice the clutter eigen-spectrum is relatively wide for the close-in range bins and decreases as we go out in range where glint is less significant.

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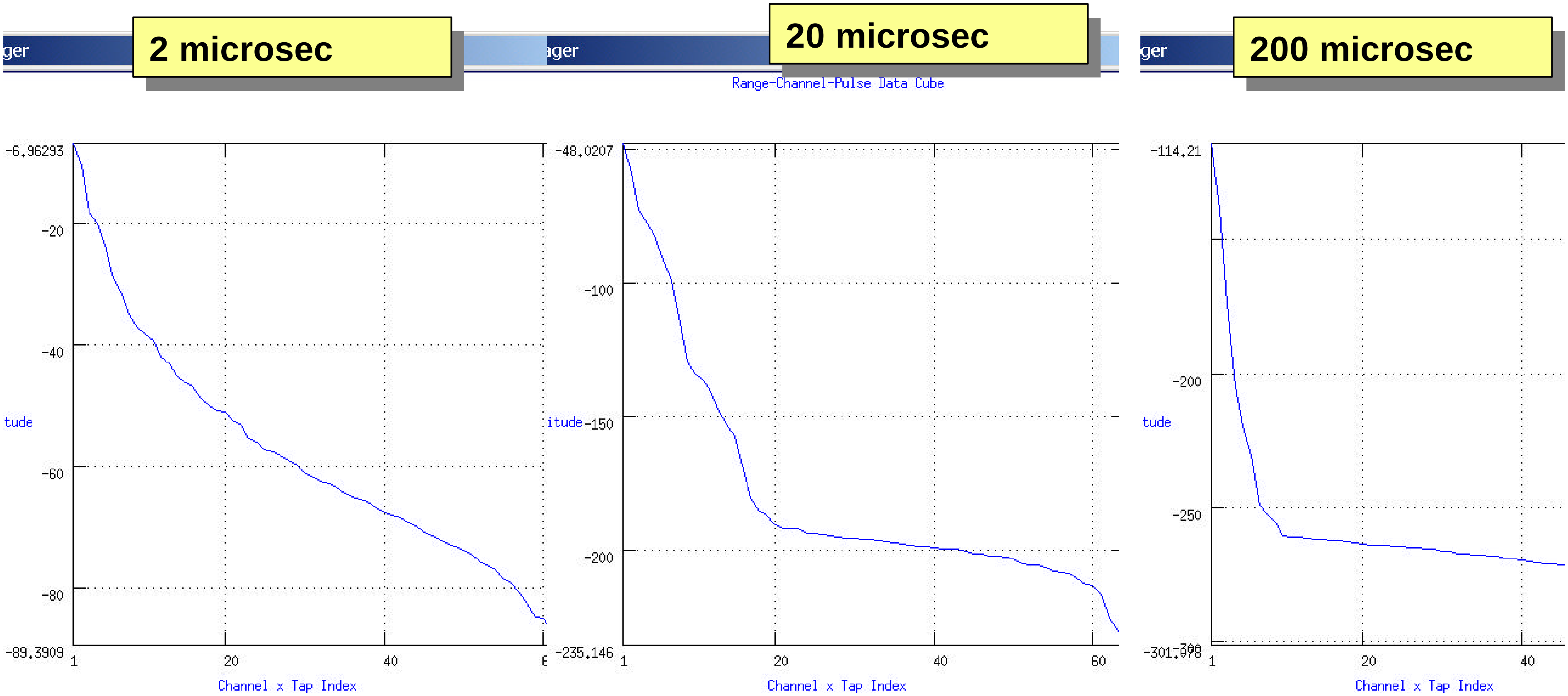
Case 2 with crab angle



Only change was to modify the velocity components so the phase centers no longer lined up along the velocity vector, i.e. Non-zero crab angle.

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BACKUPS

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RLSTAP V3.18 GLYPH LIST (March 2002)

ANTENNA	**PLATFORM**	**RADAR**	**TARGET**	**CLUTTER**	**PEL**
Synthesis:	*GVS PlatformLUT*	**Transmitter:**	**Initialization:**	**Scattering:**	**Initialization:**
AmplitudeTaper	*PlatformLUT*	*TX Init*	*TgtInit*	*AddCluCorrLUT*	*PEL EmInitEsaAzScanOnly*
CBFTODVR	*PointMass*	*Gen LFM Wvf*	*TgtInitMany*	*AddDisScat*	*PEL EmInitMechAzScanOnly*
CorporateFeed	*PlatCollector*	*Gen PC*	*TgtDSInit*	*CorrelationLUT*	*PEL EmInitWaveformGeneric*
ElemCtrl	*NavModel*	*Gen PC Wvf*	**Waveform:**	*CorrelationModels*	*PEL EmInitWaveformLUT*
ElementLocations	*TrajGen*	*Gen Pls Wvf*	*TgtWvfGen*	*HF CWG Prescan*	*PEL EmitterCollector*
ExcFailures		**Receiver:**	**Covariance:**	*InsertImage*	*PEL PlatformLUT*
ExcGainErrors	**SIMULATION CONTROL**	*RX Init*	*MF Tgt ACM Gen*	*PolarHomoScat*	*PEL RxInit*
ExcPhaseErrors	*SIMCON*	*Add Noise*		*RectHomoScat*	***Simulation Control:***
FreqResponse	*CPICON*	*FiltIIRA*	**Jammer**	*RSS Sigma0 Curve*	*PEL SIMCON*
GenLinArray	*MEASCON*	*HF CorrNoisGen*	**Initialization:**	*Sigma0 Curve*	*PEL MEASCON*
GenRectArray	*PD Mode Control*	*MF Nois ACM Gen*	*JAM Init*	*Sigma0 LUT*	*PEL ModeControl*
GenSubApertures	*Spotlight SAR Mode*	*LFM PulseComp*	*CTJ Init*	*SiteSpecificScat*	***Waveform:***
ImpulseResponse	*Staggered PRI Cont*	*Rcvr BP*	**Waveform:**	*UserScat*	*PEL HF EmitWvfGen*
InitBeamFormDef		*Rcvr Gain*	*AddCTJ*	*UserScat2*	***Utilities:***
TimeDelayAdj		*RngAxisLmpErr*	*AddJamNoise*	**Analysis:**	*PEL CAF Gen*
Servers:		*RX Blanking*		*MonoCluParm*	*PEL EmitGeoParm*
AntennaLUT		**Propagation:**		**Waveform:**	
AntennaServer		*DirectPath*		*HF CWG*	
Time Dispersion:				*HF CWG SHM*	
AddTimeDispersion				**Covariance:**	
Import AES:				*MF Clu ACM Gen*	
AntennaCollector					
Visualization					
AntPatGen					

DIGITAL SIGNAL PROCESSING	**STAP**	**DIGITAL DATA PROCESSING**	**VISUALIZATION**	**DATA MANIPULATION**	**DIAGNOSTICS**	**IMPORT/ EXPORT**
BlankMap	*ADPCA*	*Cell Averager*	*AES Plot*	*ExtractWvf*	*DOBJ Viewer*	*KDF to MAT*
Digital Beamforming	*FST*	*Greatest Of*	*Plotter*	*PatchFPB*	*FPB Viewer*	*MAT to KDF*
Dec PRBS	*FTS*	*Ordered Statistic*	*Tvis*	*PostAttr*		*PSV to ASC*
Filt MTI Amp	*JD*	*Trimmed Mean*		*PostFPB*		
Filt PD ARY	*JD Diagn*			*RCtoRCP*		
HF Sample CM Gen	*JDNG*			*RngFldWvf*		
ImageFormationProc				*Voltage to dB*		
PD MoComp						
SarMoComp						
SarPhasMoComp						
WvfTimeDelayAdj						

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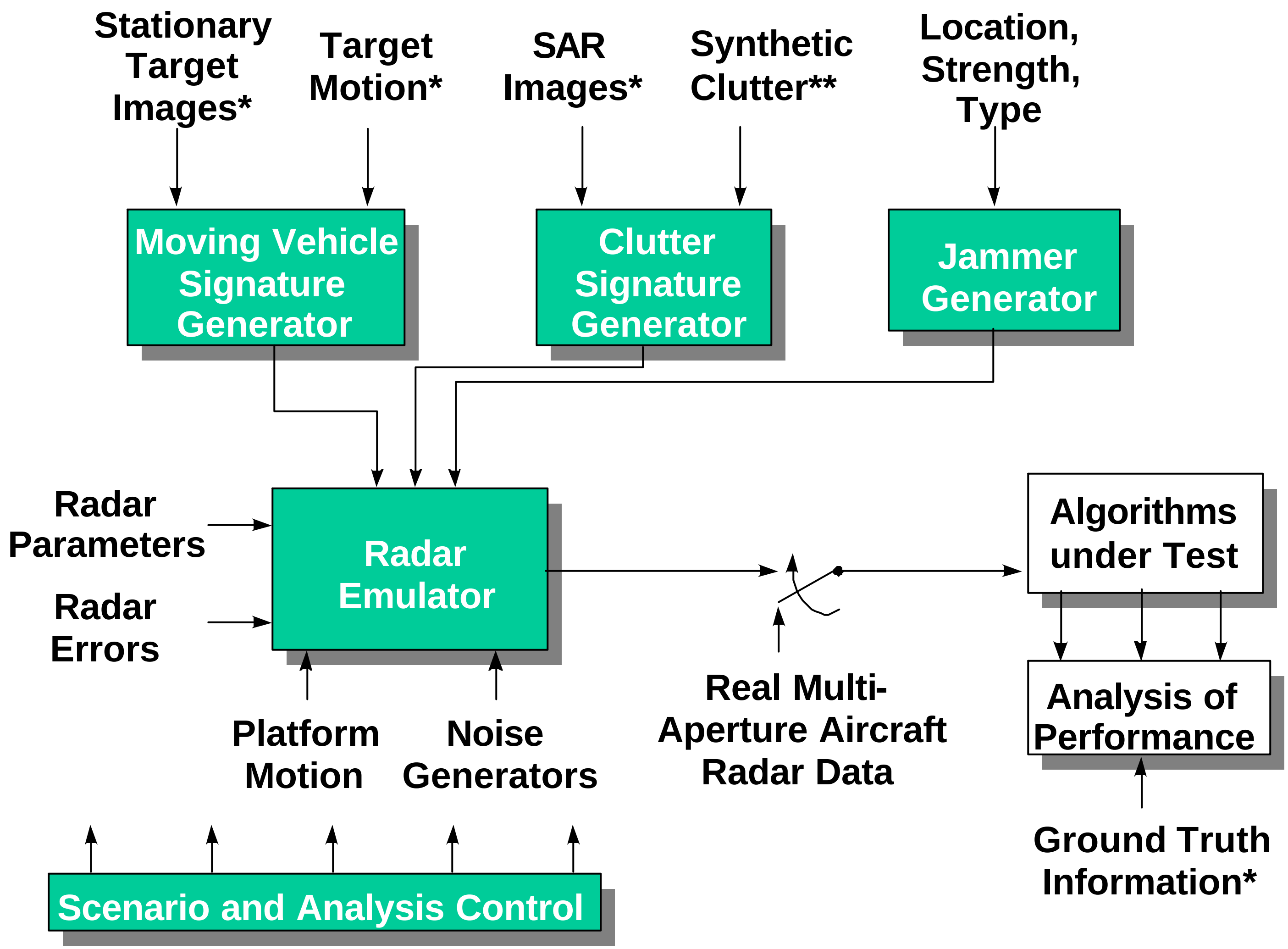
LINCOLN LAB ALGORITHM TESTBED CONCEPT USING RLSTAP



Notes: * Real or Simulated ** Synthetic Clutter for Far Sidelobes and Internal Motion

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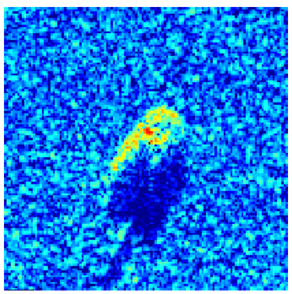
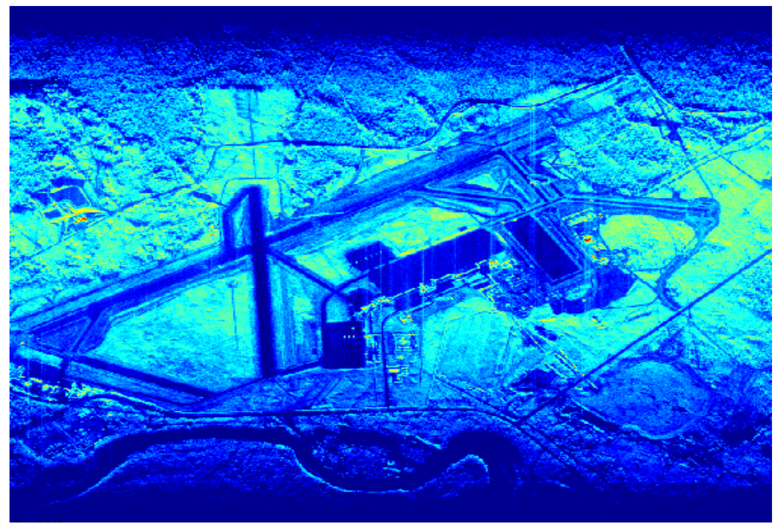
EMULATION APPROACH

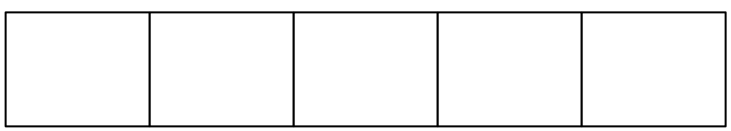
- **EMULATE COMPLEX DATA FOR MULTI-CHANNEL ARRAY USING SINGLE CHANNEL COMPLEX SAR CLUTTER AND TARGET DATA**



+



$\mathbf{V_t}$



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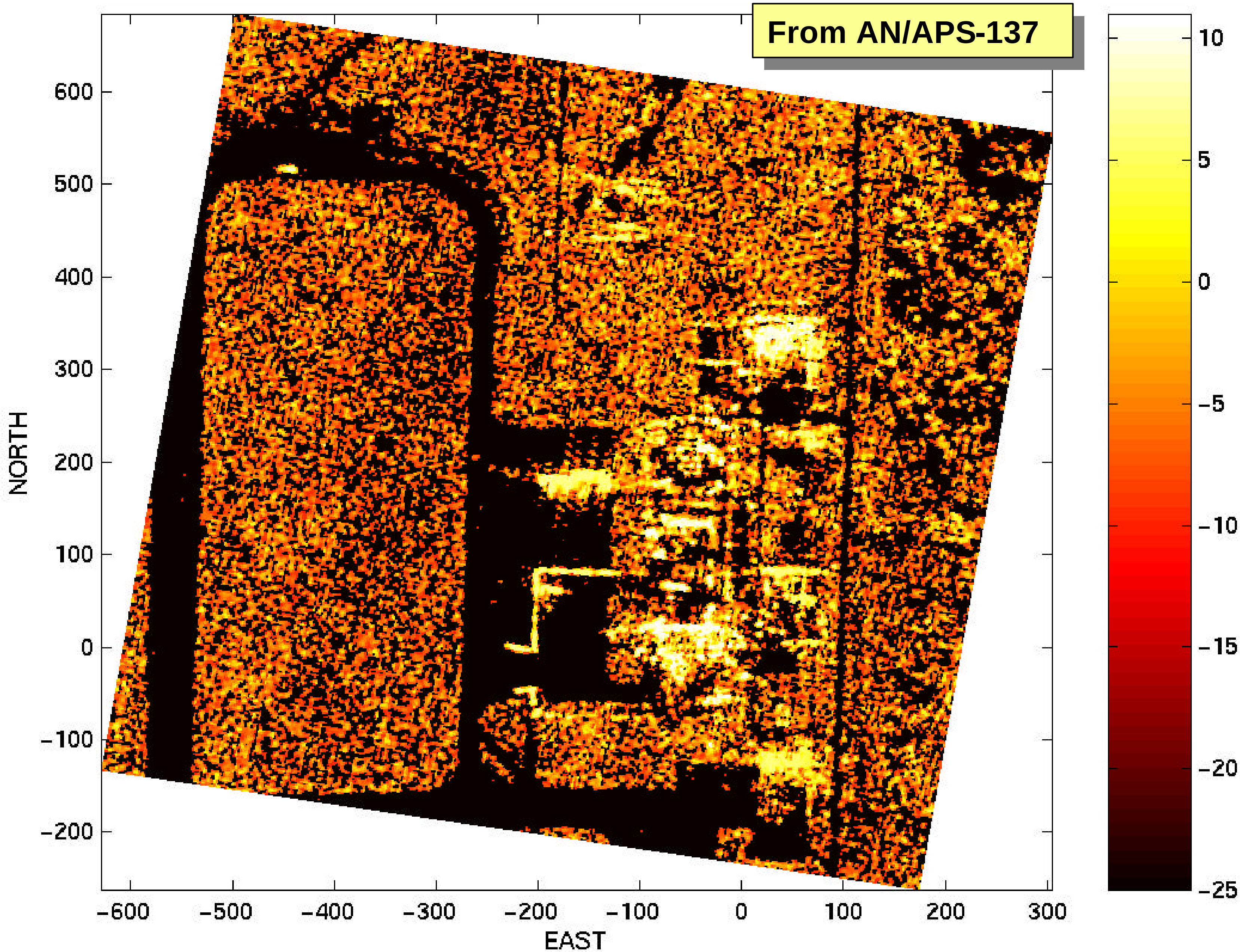
EXAMPLE OF PROCESSED SAR DATA USED TO SPECIFY CLUTTER BACKGROUND



Description of Simulation used to Illustrate Clutter Glint Effects

Parameters

- **Workspace = CluGlint-r1e.wk**
- **Radar General:**
  - **Center Frequency = 10 GHz**
  - **CPI Length = 34 pulses**
- **Simulation General:**
  - **Sample Rate = 20 MHz**
  - **TX Wvf Oversample Ratio = 4**
  - **Min Range = 0.0 Meters**
  - **Max Range = 80000 Meters (43.2 NM)**
  - **Start Time = 0.0 Sec**

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Parameters (cont.)

- **Antenna:**
  - **TX Mode:**
    - **Width = 3.84 meters (256 elements), spacing = 0.015 meters**
    - **Height = 0.02 meter (1 element)**
  - **RX Mode:**
    - **16 subapertures spaced 0.24 meters apart horizontally**
    - **each subaperture:**
      - **Width = 0.24 meters (16 elements), elem. spacing = 0.015 meters**
      - **Height = 0.02 meter (1 element)**
  - **Mechanical boresight**
    - **Az = 90.0**
    - **El = -10.0**
  - **Electronic steering: boresight**

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Parameters (cont.)

- **Transmitter:**
  - **Peak Power = 10,000 watts**
  - **PulseWidth = 5 MicroSec**
  - **PRI = 950 MicroSec**
  - **Intra-pulse Modulation = none**
- **Radar Platform:**
  - **Reference Point: Lat, Long = 0.0 N, 0.0 E**
  - **Starting Location: 0.0 Meters N, 0.0 Meters E**
  - **Altitude = 300 Meters**
  - **Velocity = 252.63 M/S**

Parameters (Cont.)

- **Receiver:**
  - **Noise Figure = 3 dB (The noise injection in the count loop was disabled)**
  - **ADC Clock = 10 MHz**
- **Filter:**
  - **Low-pass Butterworth, 8 poles, bandwidth = 6 MHz**

Parameters (Cont.)

- **Target:**
  - **None**
- **Clutter from HomoScat:**
  - **Spanned approximately 110 meters cross range and 110,000 meters down range**
  - **2001 x 41 scatterer field on rectangular grid**
    - **Horizontal spacing = 0.0005 degrees (approx. 55.5 Meters)**
    - **Vertical spacing = 0.00001 degrees (approx. 1.11 Meters)**
  - **Center of scatterer field: Lat, Long = 0.0º N, -0.5º E**
  - **Material Code: open ocean**

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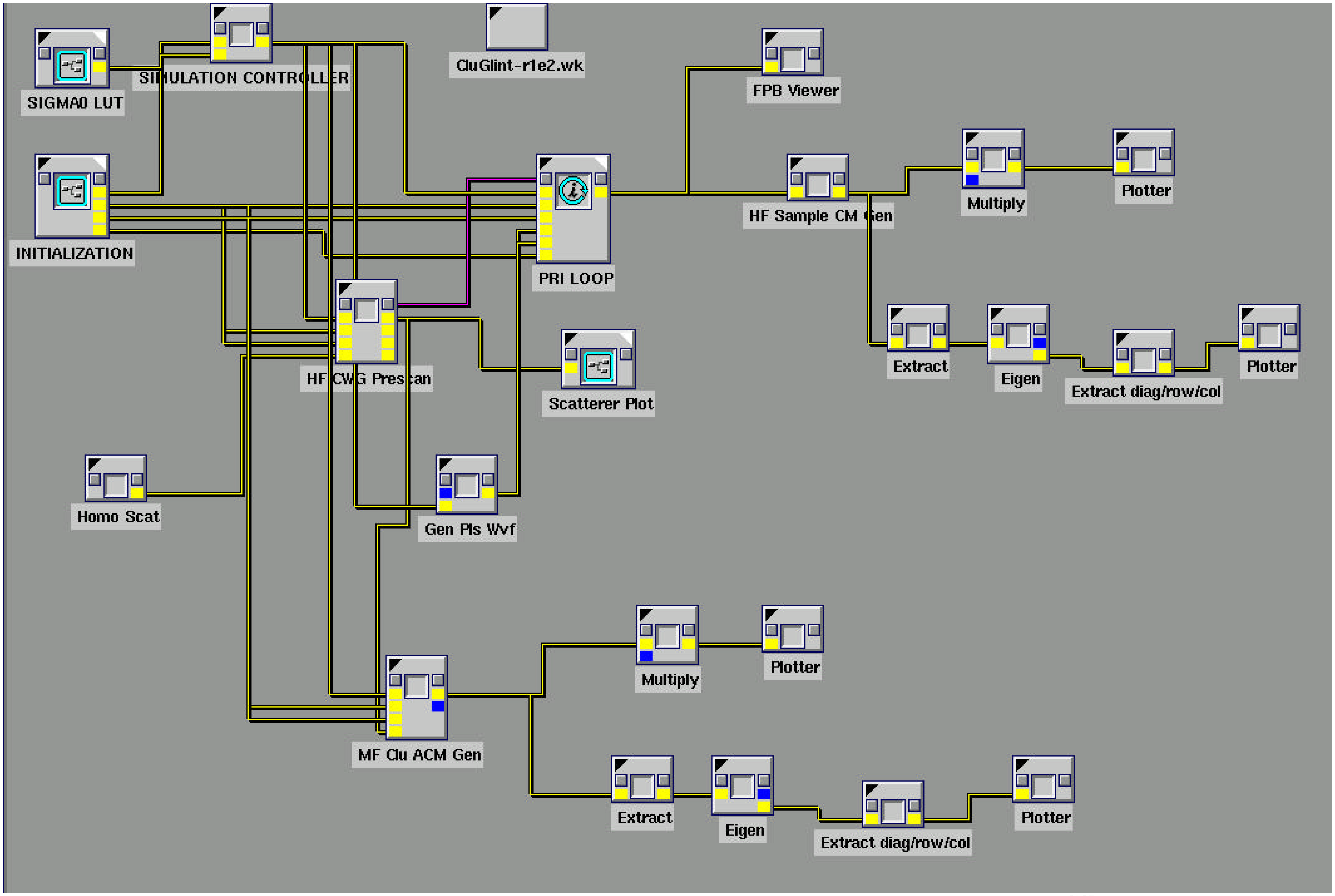
Top Level Workspace



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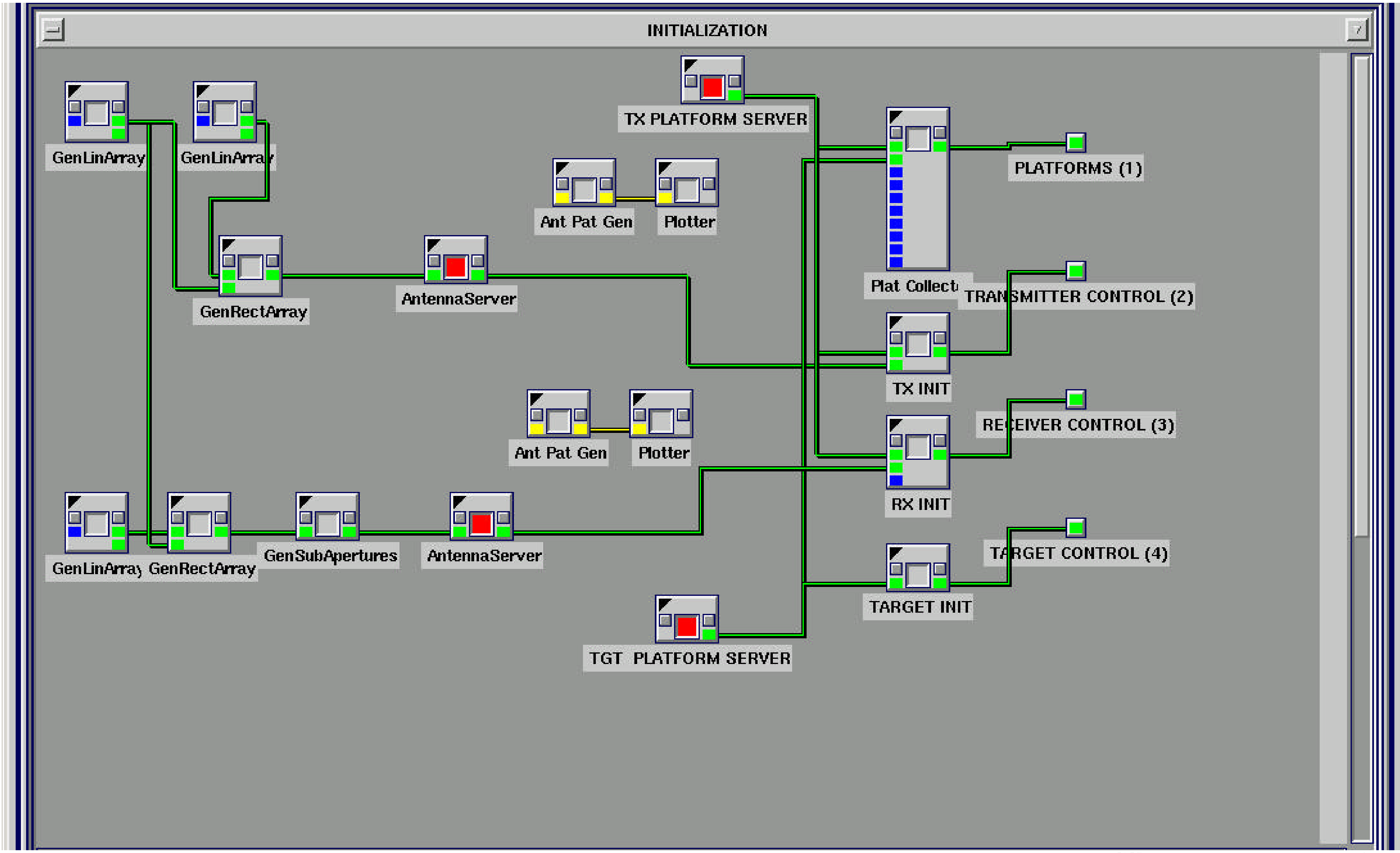
Initialization Workspace



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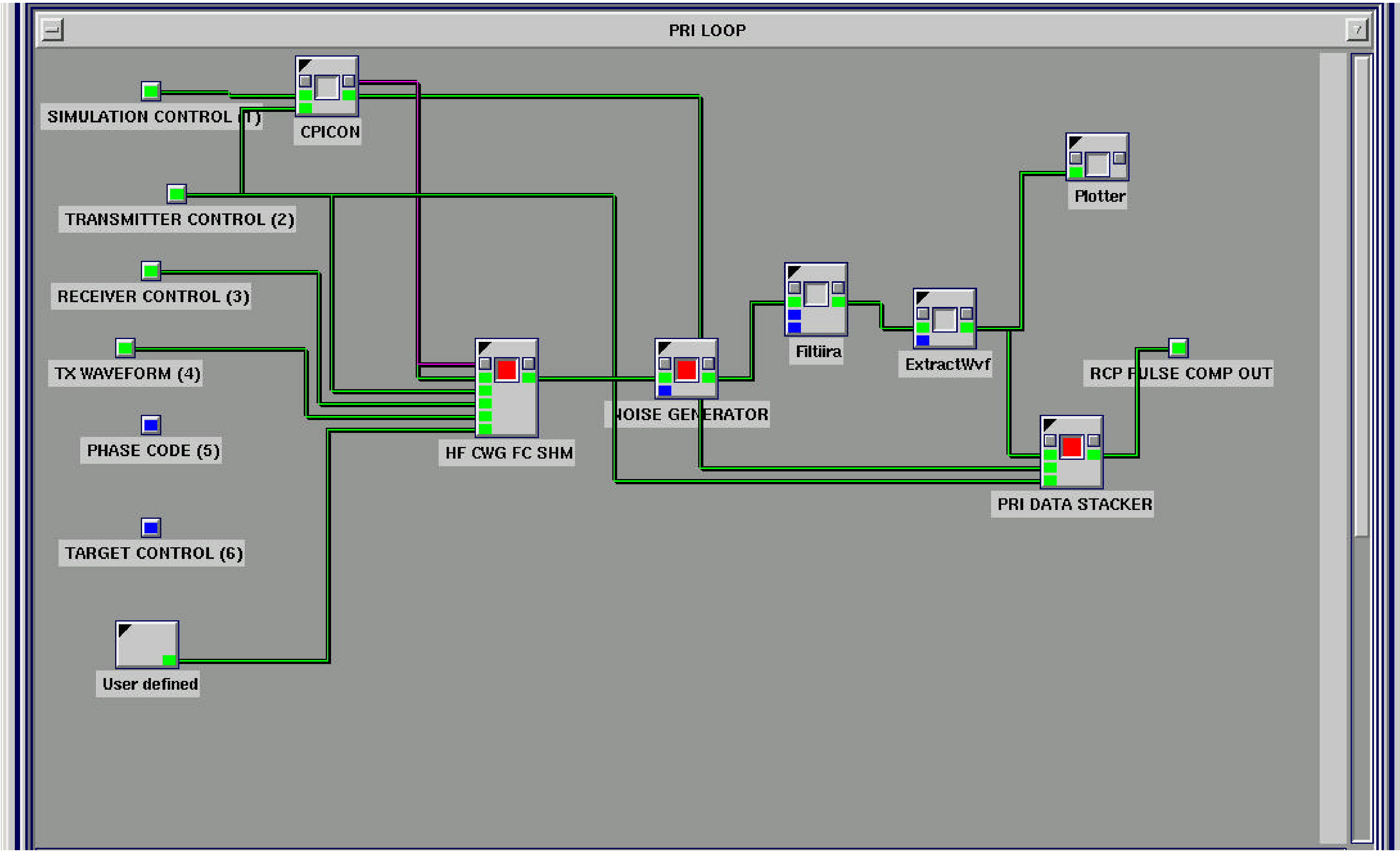
Count Loop



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