Phased Array design using Kyesight SystemVue

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Keysight Technologies Japan	

KEYSIGHT TECHNOLOGIES

Agenda

13:00～16:00

- SystemVue Phased Array Analysis overview
- Lab 1: Beam Pattern
- Lab 2: Beamform and Magnitude/Phase Error
- Lab 3: Phased Array Analysis for RF design
- Lab 4: Monte Carlo Analysis

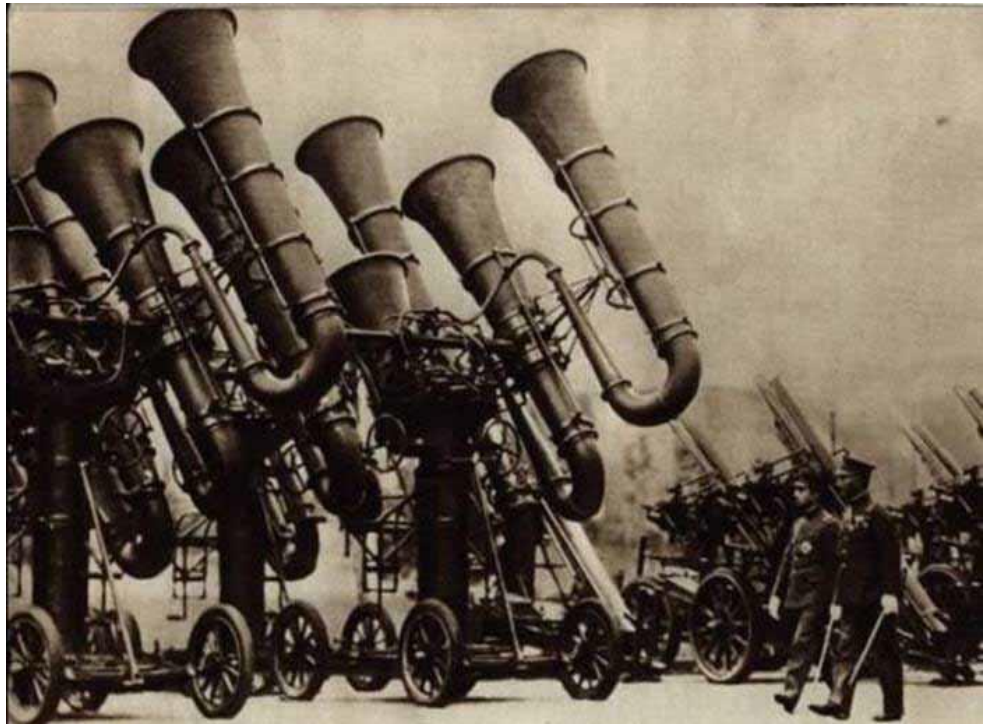
Appendix:

- Array Antenna Design and Verification with SystemVue and EMPro
- Simulation Capacity : EMPro FEM vs FDTD

Phased Array : Past and Present

Early day phased array

WW I ACOUSTIC ARRAY



Largest phased array

Space Fence

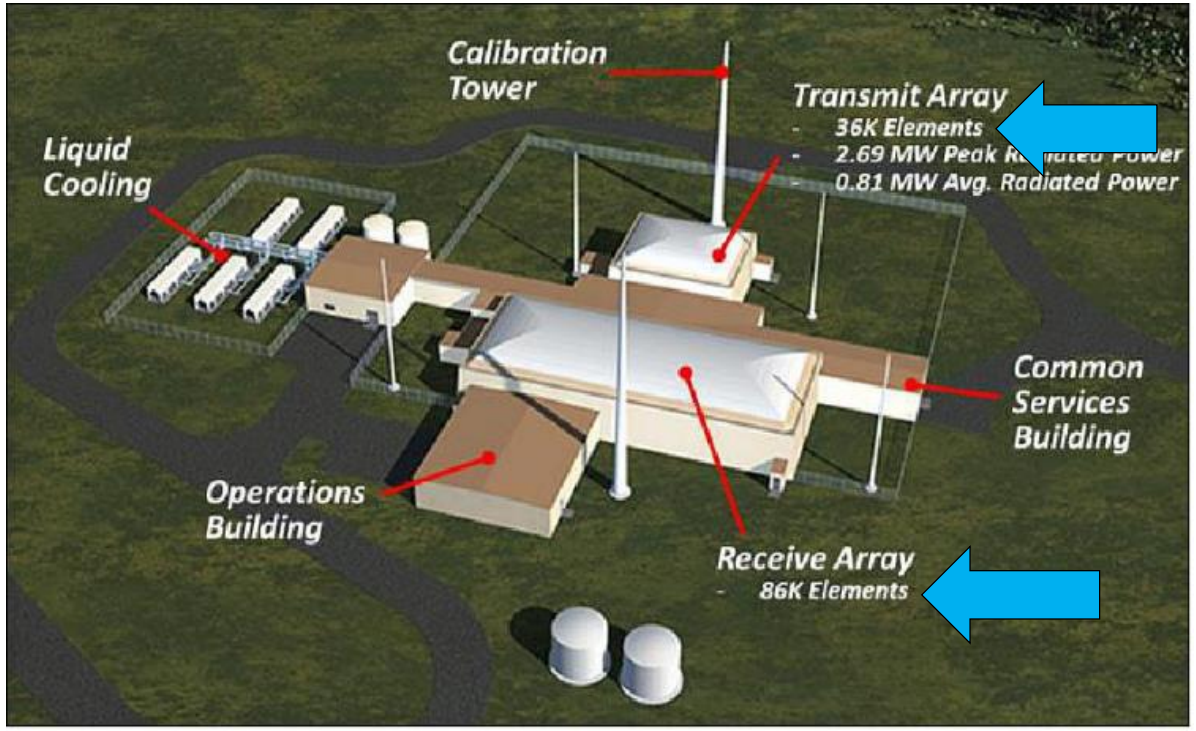
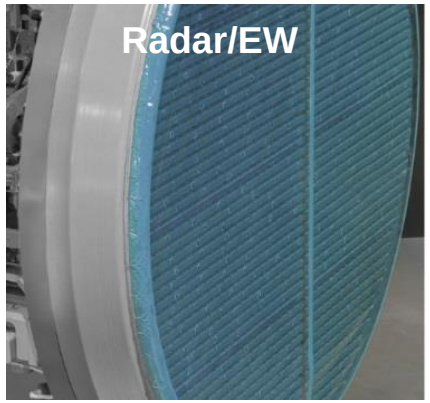


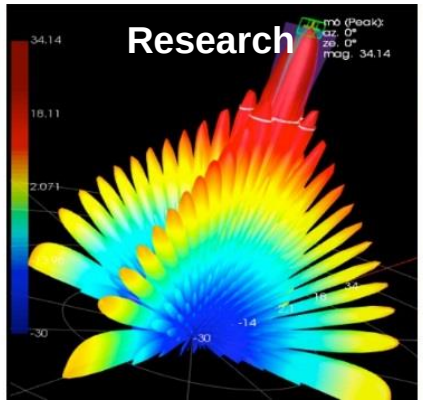
Figure 10: Space Fence Sensor Site Facility on Kwajalein Island (image credit: Lockheed Martin)

https://directory.eoportal.org/web/eoportal/satellite-missions/s/space-fence

Industry drivers for Multi-Channel Phased Array Architectures

Goal: Provide higher service levels in less cost





Why use beamforming?

- Reduce Interference
- Increase Range
- Multiple, dynamic services
- Improve security

Why now?

- Semiconductor advances
- Demand for services
- Shorter mm wavelengths

Key challenges

- Crosses multiple disciplines
- Disjointed tool set
- One-directional, not predictive
- Difficult to co-validate
- High skill levels, IP
- Time-to-market, Risk
- Low budget for “overhead”

New Approach: System-level flow for Phased Array architectures

A common "cockpit" across multiple disciplines : BB, RF, System, Application, T&M

Application/Scenario Layer (Dataflow)

5G/Comms Mod, Coding Control

Radar Multiple TX RX

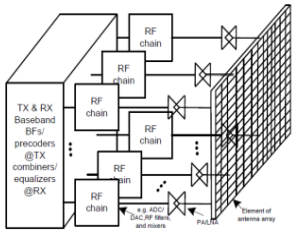
Satellite NewSpace

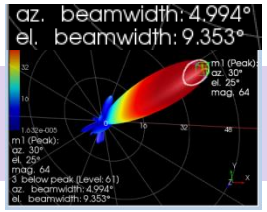
WLAN WPAN

3rd Party environments

Inertial position, velocity, attitude

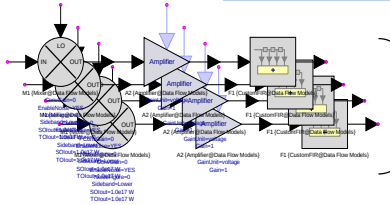
System / PHY Layer (Dataflow)





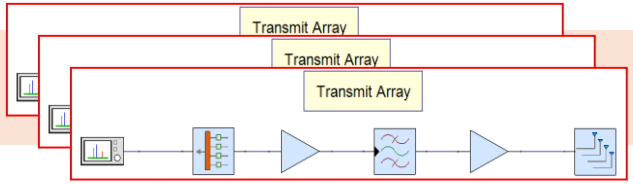
T&M Connect to test

Multi-Channel RF_LINK (Dataflow)

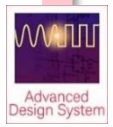


N paths

RF Architecture Layer (RF System / Spectrasys)



S



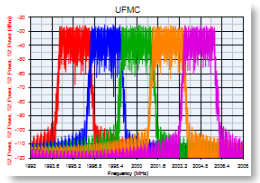
X

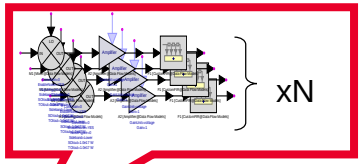
Element Pattern

SystemVue

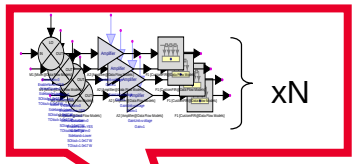
New Approach: System-level flow for Phased Array architectures

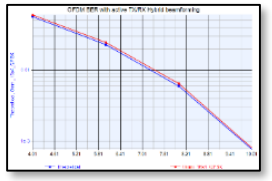
5G



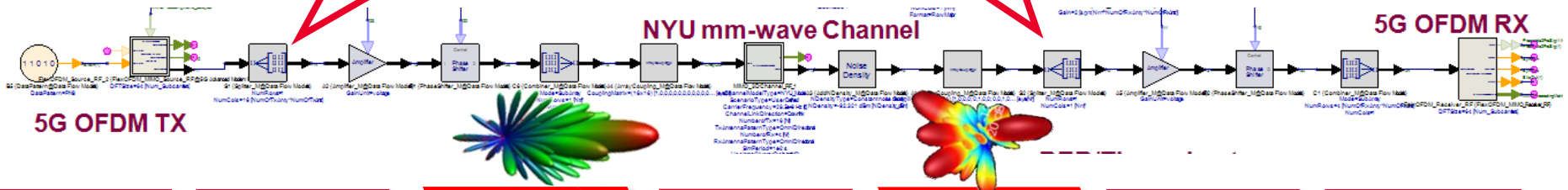


Beamforming



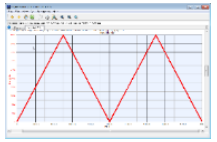


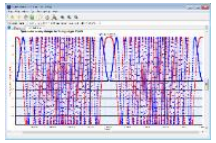
Throughput, Sensitivity

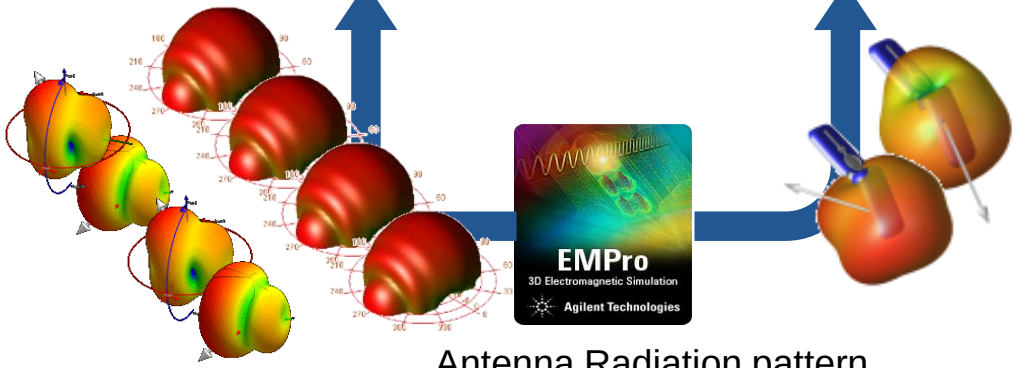


Signal Generation → Transmitter → **Tx Array** → Channel / Target → **Rx Array** → Receiver → Signal Analysis

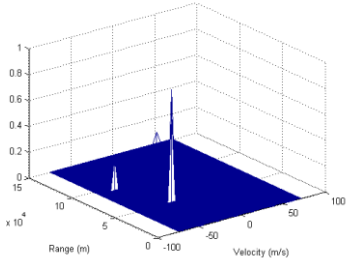
FMCW Radar







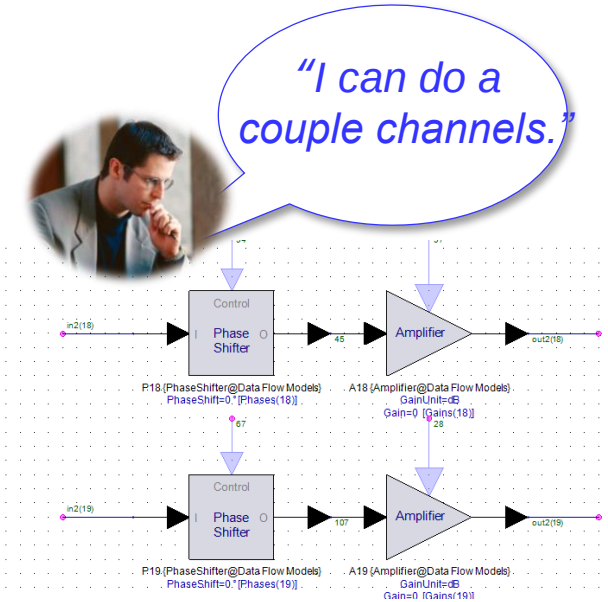
Antenna Radiation pattern

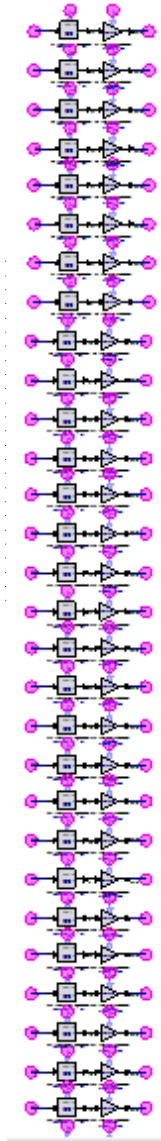


Target Detection

Dataflow (Time Domain): Traditional vs Array Models

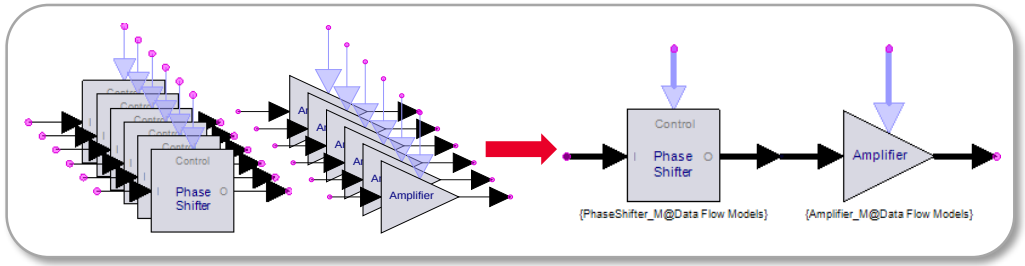
Array models replace thousands of channels





"But how do I <u>even draw</u> **1000** channels?"

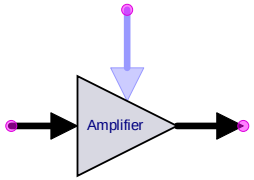
Array model of "N" channels



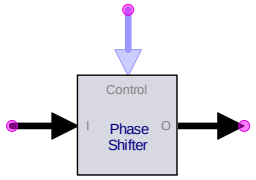
- ✓New datatype: "Envelope Matrix"
- ✓Saves drawing *massive* schematics, GUI complexity
- ✓Dramatically reduced simulation overhead, RAM
- ✓Faster parallel threading on multi-core machines

Beam Forming/Phased Array Design Kit (W1720)

Gain, Phase Shifter, RF_Link, Antenna, OTA_Test (for 5G)



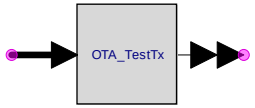
A4 {Amplifier_M@Data Flow Models}
GainUnit=voltage



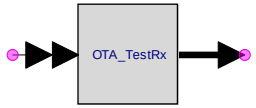
P1 {PhaseShifter_M@Data Flow Models}

A2 {AntennaArrayTx@Data Flow Models}
Configuration=Uniform Rectangular Array
NumElementsX=8
NumElementsY=8
DistanceUnit=Wavelengths
DistanceX_in_Wavelengths=0.5
DistanceY_in_Wavelengths=0.5
CenterArrayAtOrigin=NO
RotateArray=NO
NumAntennasPerLocation=1
SaveAntennaLocation=NO
ElementPatternType=Isotropic
TimeDelayOption=Phase Shift
ElementFailure=None
ThetaAngles=0 °
PhiAngles=0 °

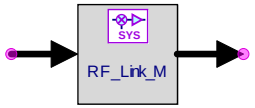
A3 {AntennaArrayRx@Data Flow Models}
Configuration=Uniform Rectangular Array
NumElementsX=8
NumElementsY=8
DistanceUnit=Wavelengths
DistanceX_in_Wavelengths=0.5
DistanceY_in_Wavelengths=0.5
CenterArrayAtOrigin=NO
RotateArray=NO
NumAntennasPerLocation=1
SaveAntennaLocation=NO
ElementPatternType=Isotropic
TimeDelayOption=Phase Shift
ElementFailure=None
ThetaAngles=0 °
PhiAngles=0 °



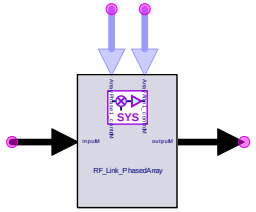
O1 {OTA_TestTx@Data Flow Models}
Configuration=Uniform Rectangular Array
NumElementsX=8
NumElementsY=8
DistanceUnit=Wavelengths
DistanceX_in_Wavelengths=0.5
DistanceY_in_Wavelengths=0.5
RotateArray=NO
NumAntennasPerLocation=1
SaveAntennaLocation=NO
ElementPatternType=Isotropic
Etheta=1
Ephi=0
TimeDelayOption=Phase Shift
ElementFailure=None
ProbeDistanceUnit=Wavelengths
ProbeLocationX_in_Wavelengths=0
ProbeLocationY_in_Wavelengths=0
ProbeLocationZ_in_Wavelengths=1
ProbeNumAntennasPerLocation=1
ProbePatternType=Isotropic
ProbeEtheta=1
ProbeEphi=0
PolarizationMismatch=NO
Normalization=NO
DynamicControl=None



O2 {OTA_TestRx@Data Flow Models}
Configuration=Uniform Rectangular Array
NumElementsX=8
NumElementsY=8
DistanceUnit=Wavelengths
DistanceX_in_Wavelengths=0.5
DistanceY_in_Wavelengths=0.5
RotateArray=NO
NumAntennasPerLocation=1
SaveAntennaLocation=NO
ElementPatternType=Isotropic
Etheta=1
Ephi=0
TimeDelayOption=Phase Shift
ElementFailure=None
ProbeDistanceUnit=Wavelengths
ProbeLocationX_in_Wavelengths=0
ProbeLocationY_in_Wavelengths=0
ProbeLocationZ_in_Wavelengths=1
ProbeNumAntennasPerLocation=1
ProbePatternType=Isotropic
ProbeEtheta=1
ProbeEphi=0
PolarizationMismatch=NO
Normalization=NO
DynamicControl=None



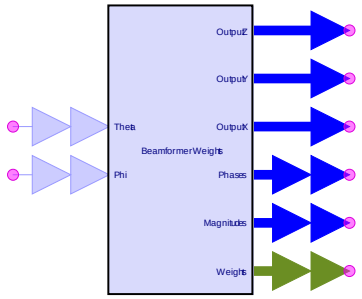
R2 {RF_Link_M@Data Flow Models}
Schematic=RFSch
FreqSweepSetup=Automatic
EnableNoise=NO
CalcPhaseNoise=NO



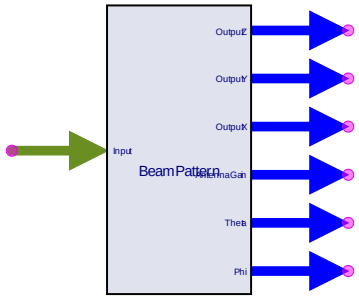
R1 {RF_Link_PhasedArray@Data Flow Models}
Schematic=RFSch_Beamform
RxTx=Rx

Beam Forming/Phased Array Design Kit (W1720)

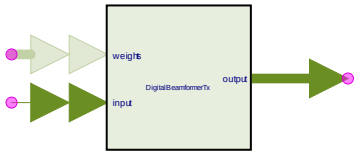
Beamformer, Beam Measurement, 3D Plot



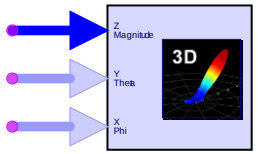
B1 {BeamformerWeights@Data Flow Models}
Configuration=Uniform Rectangular Array
NumElementsX=8
NumElementsY=8
DistanceUnit=Wavelengths
DistanceX_in_Wavelengths=0.5
DistanceY_in_Wavelengths=0.5
CenterArrayAtOrigin=NO
RotateArray=NO
NumAntennasPerLocation=1
SaveAntennaLocation=NO
Phi=0 °
Theta=0 °
MultiUser=Shared Array
Window=None



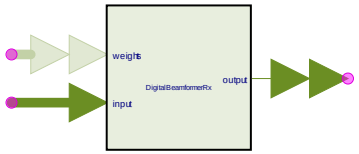
B3 {BeamPattern@Data Flow Models}
Configuration=Uniform Rectangular Array
NumElementsX=8
NumElementsY=8
DistanceUnit=Wavelengths
DistanceX_in_Wavelengths=0.5
DistanceY_in_Wavelengths=0.5
CenterArrayAtOrigin=NO
RotateArray=NO
NumAntennasPerLocation=1
SaveAntennaLocation=NO
ElementPatternType=Isotropic
OutputPolarizationPatterns=NO
ArrayRadiation=Full Sphere
Resolution=1 °
ThetaRange=90 °



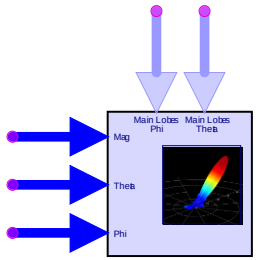
D1 {DigitalBeamformerTx@Data Flow Models}
Weights=1
MultiUser=Shared Array



D3 {Dynamic3D@Data Flow Models}
CoordinateSystem=Cartesian
ScatterPlot=NO



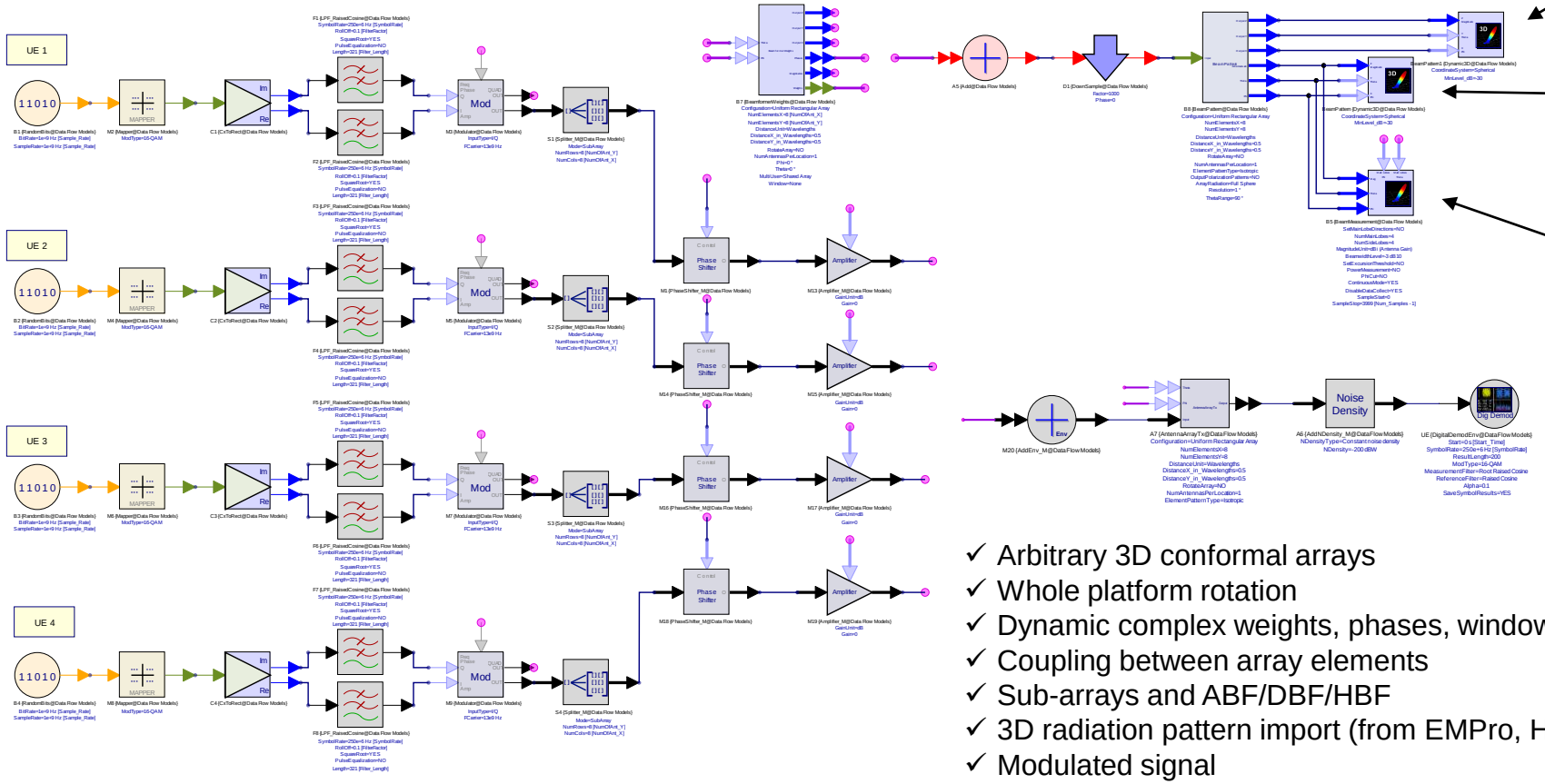
D2 {DigitalBeamformerRx@Data Flow Models}
Weights=1
MultiUser=Shared Array

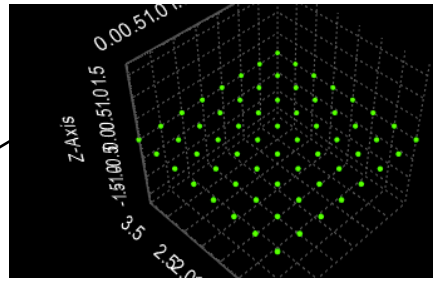


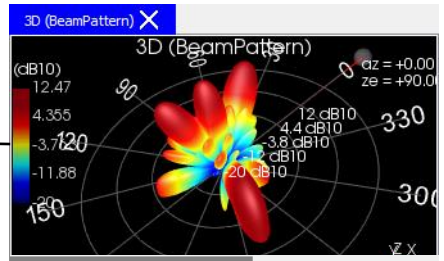
B2 {BeamMeasurement@Data Flow Models}
SetMainLobeDirections=NO
NumMainLobes=1
NumSideLobes=1
MagnitudeUnit=dBi (Antenna Gain)
BeamwidthLevel=-3 dB10
SetExcursionThreshold=NO
PowerMeasurement=NO
PhiCut=NO
ContinuousMode=YES
DisableDataCollect=YES

Dataflow: Multi-Beam System-Level Phased Array Analysis

4 User 16QAM 8x8 URA RF-BF Shared Array

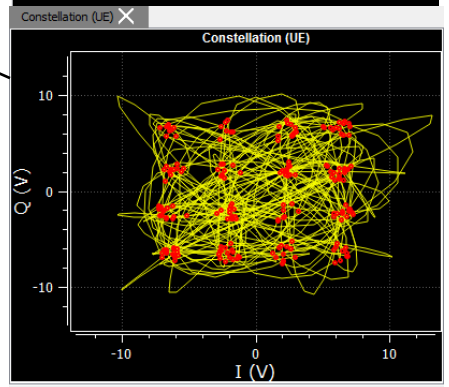






3D Beam Measurement (B5)

Main Lobes	Lobe 1	Lobe 2
Azimuth	65 °	157 °
Zenith	1 °	22 °
Magnitude	12.47 dBi	12.42 dBi
3dB Azimuth Beamwidth	11.79 °	13.38 °
3dB Zenith Beamwidth	13.01 °	13.53 °
Side Lobes	**Lobe 1**	**Lobe 2**
Azimuth	104 °	273 °
Zenith	90 °	60 °
Ratio to Max Lobe	-9.628 dB	-10 dB



Errors Summary (UE)

EVM	=	7.881	%rms	16.44	% pk
Mag Err	=	5.547	%rms	-13.68	% pk
Phase Err	=	5.763	° rms	19.44	° pk
Freq Err	=	2119	Hz		
IQ Offset	=	-46.75	dB20		
Quad Err	=	0.1978	°		
Gain Imb	=	-0.04451	dB20		
Droop	=	-0.0003861	dB20		

- ✓ Arbitrary 3D conformal arrays
- ✓ Whole platform rotation
- ✓ Dynamic complex weights, phases, windowing
- ✓ Coupling between array elements
- ✓ Sub-arrays and ABF/DBF/HBF
- ✓ 3D radiation pattern import (from EMPro, HFSS, CST)
- ✓ Modulated signal
- ✓ Dynamic plots and measurements (3D, beam, EVM)

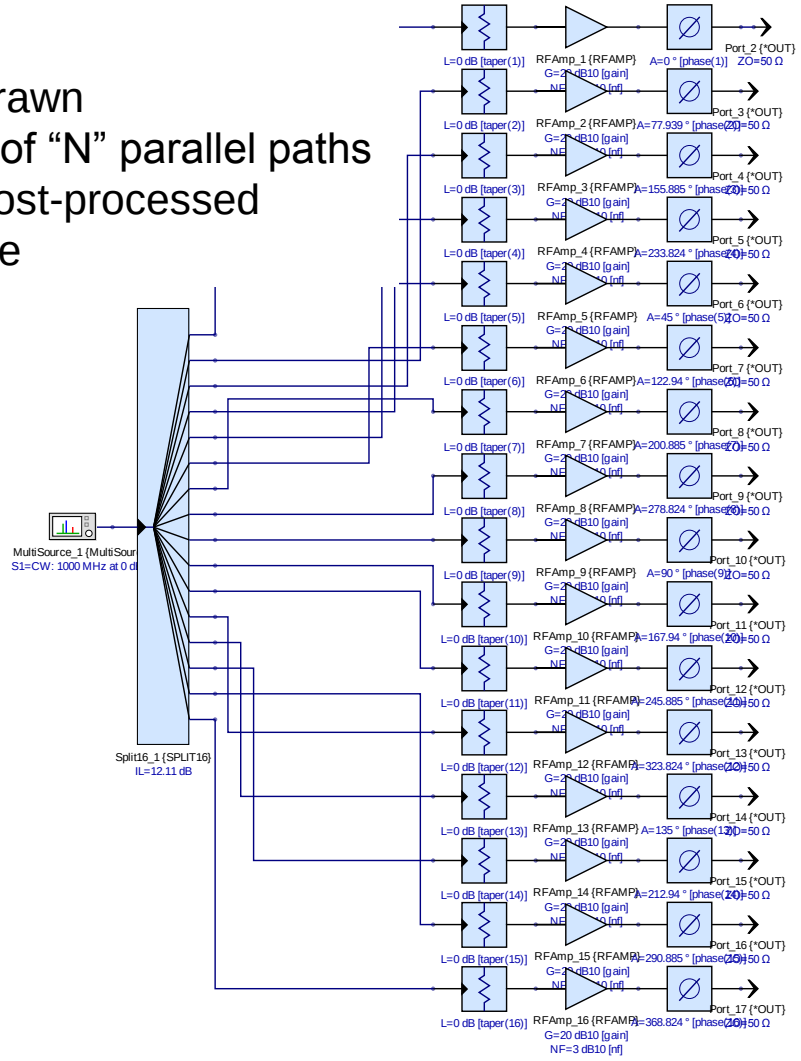
KEYSIGHT TECHNOLOGIES

RF Phased Array Design: Traditional vs New Approach

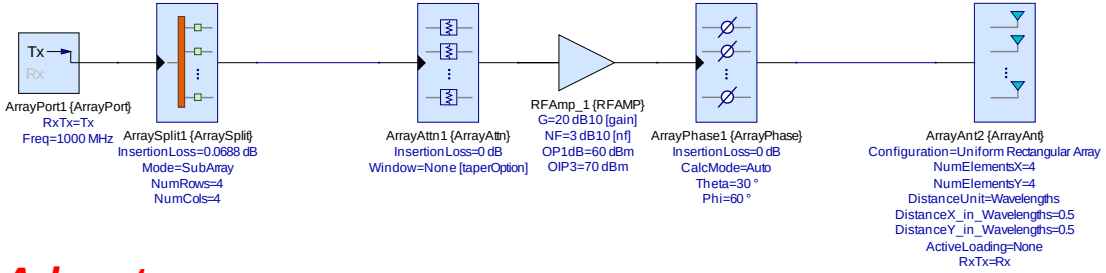
Fast design and simulation for phased array of any size

- Brute force
- Manually drawn
- “M” stages of “N” parallel paths
- Manually post-processed
- Not scalable

Traditional Spectrasys



- Special “**Phased Array**” analysis (frequency domain)
- Draw **one chain**
- Abstracted to handle “M” stages, “N” paths
- Pre-defined beam and array measurements

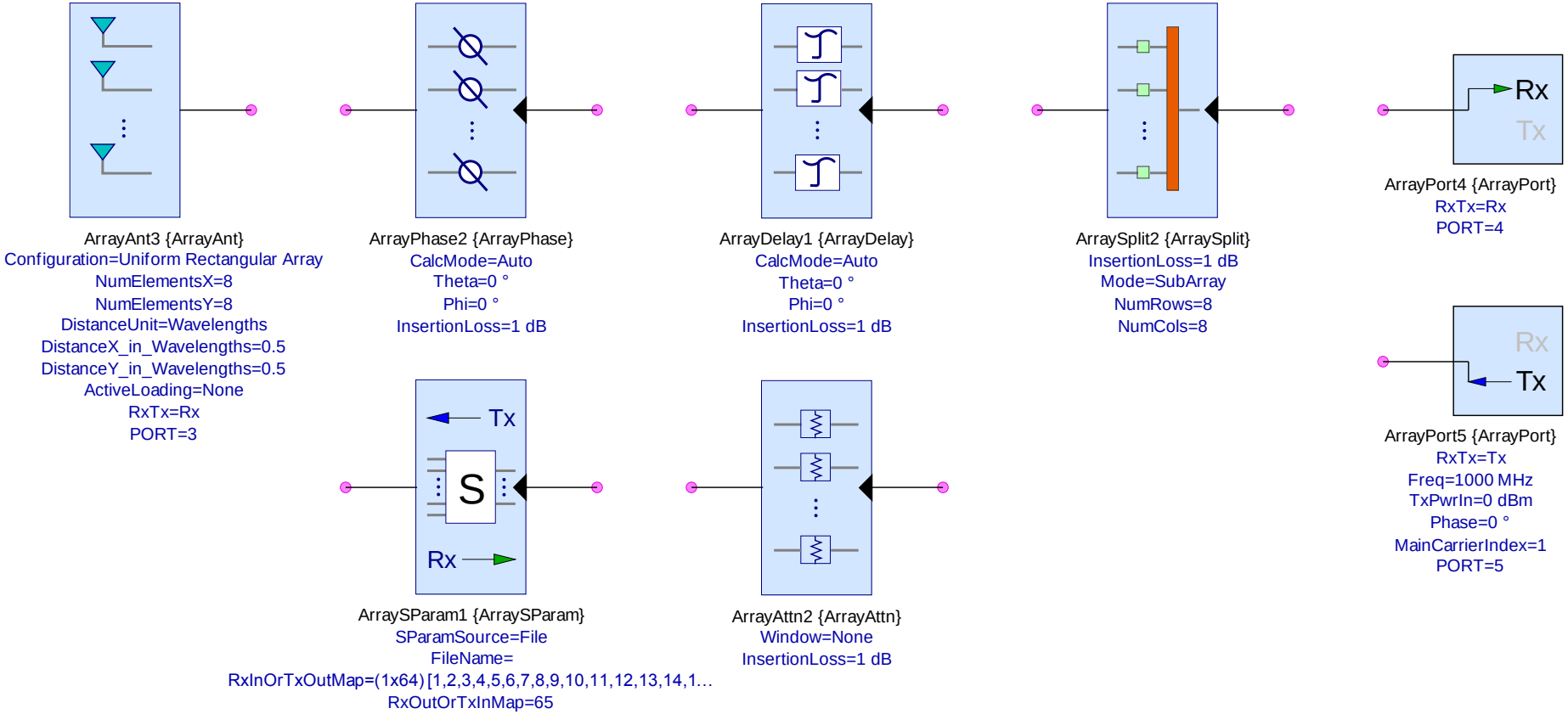


Advantages

- *Easy to draw*
- *Topology easy to change*
- *Import antenna element pattern*
- *Fast and “tunable”*
  - *100x100 RF array is ~2 seconds*
  - *Monte Carlo and Frequency Sweep in minute(s)*
- *Can use S-parameters, X-parameters, Sys-parameters, etc*

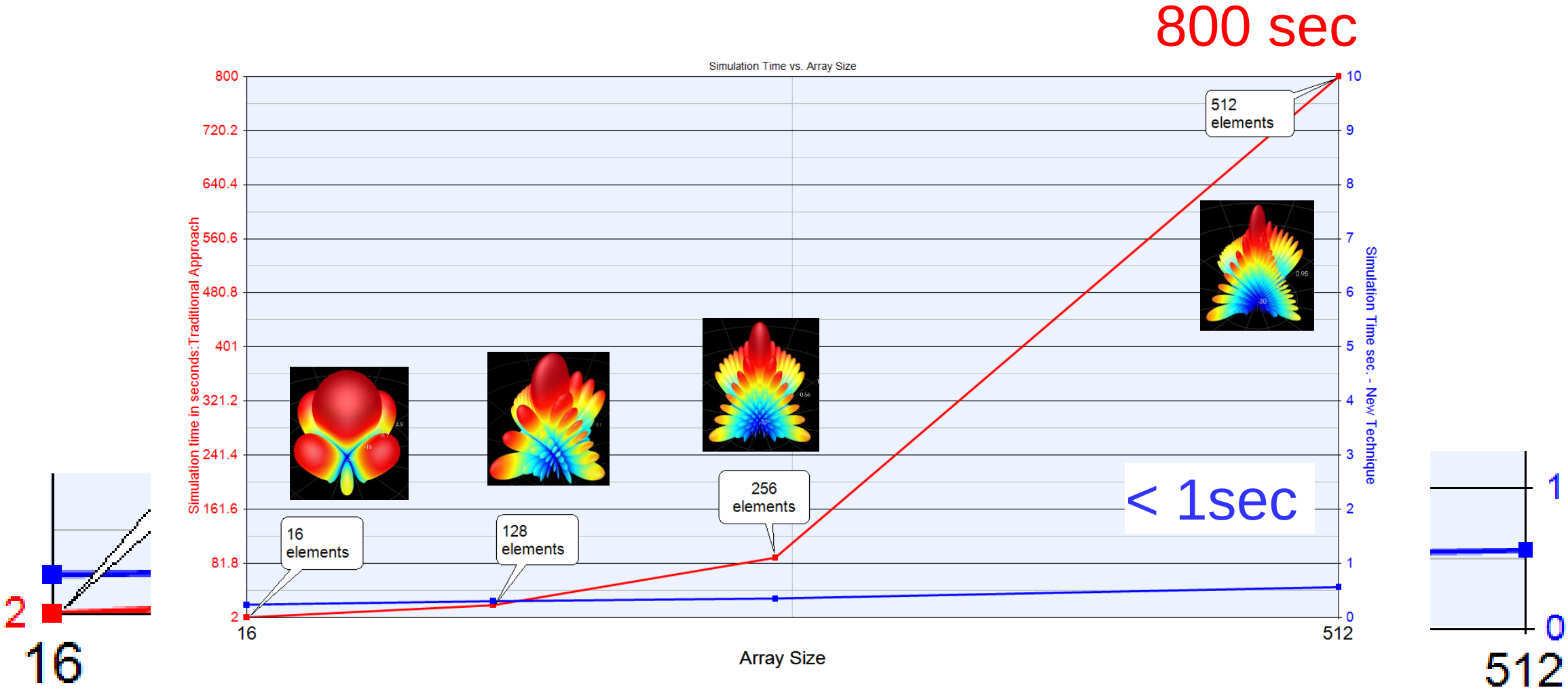
Beam Forming/Phased Array Design Kit (W1720)

Antenna, Gain, Phase Shifter, Time Delay, Sparam, Splitter/Combiner, Port

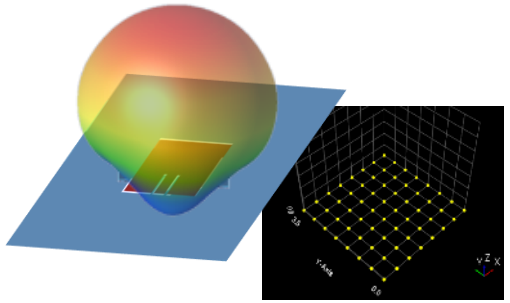


Simulation Time: Traditional vs New Approach

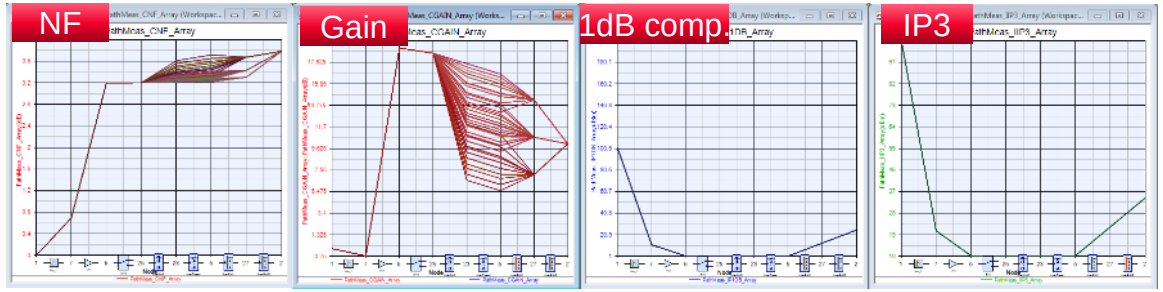
Fast design and simulation for phased array of any size



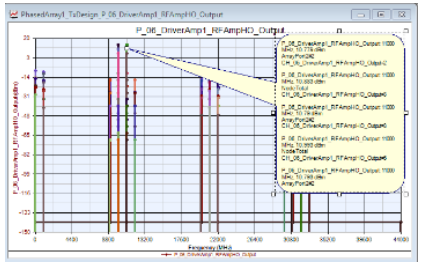
Designing RF Phased Array Systems of Any Size



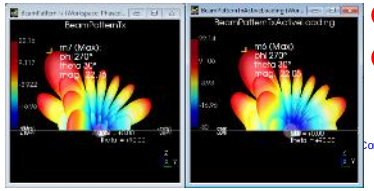
EM simulation

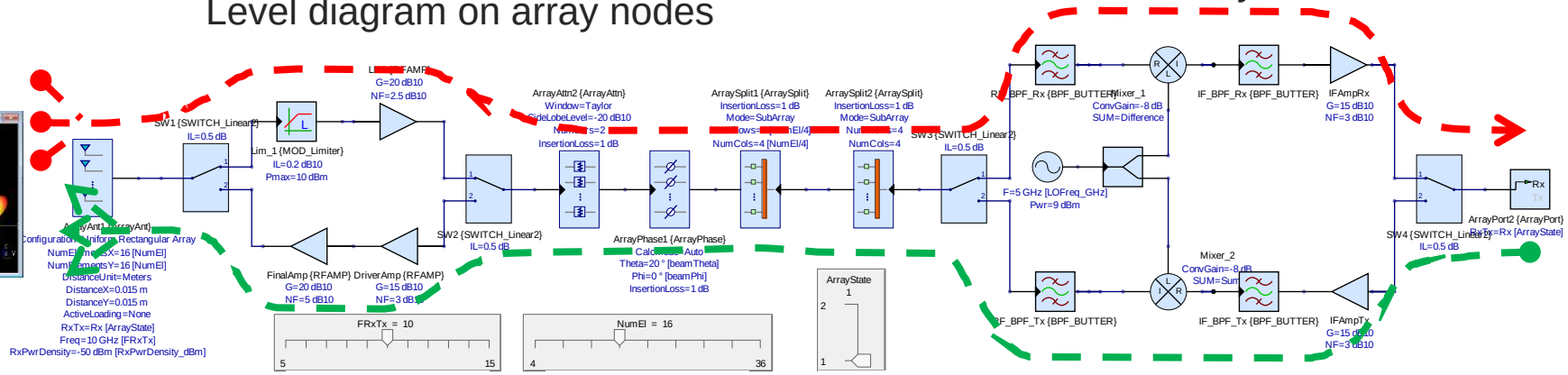


Level diagram on array nodes



Root-cause analysis at arbitrary node



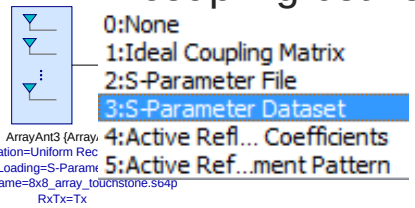


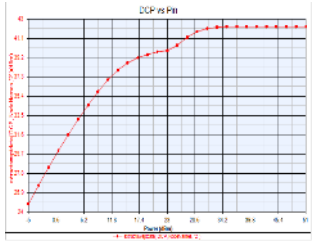
Active Loading: coupling between elements

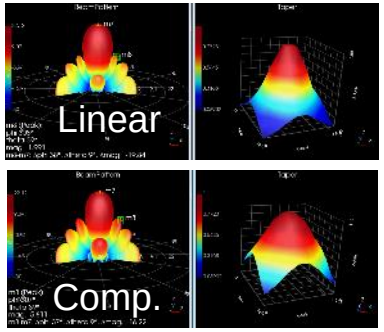
Center Freq

Number of Elements (NxN)

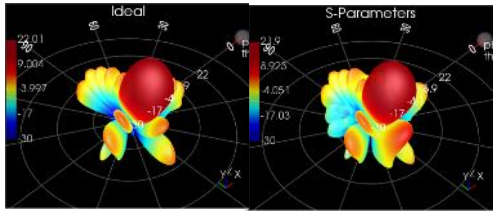
MODE:
TX=2
RX=1







Nonlinearity effect

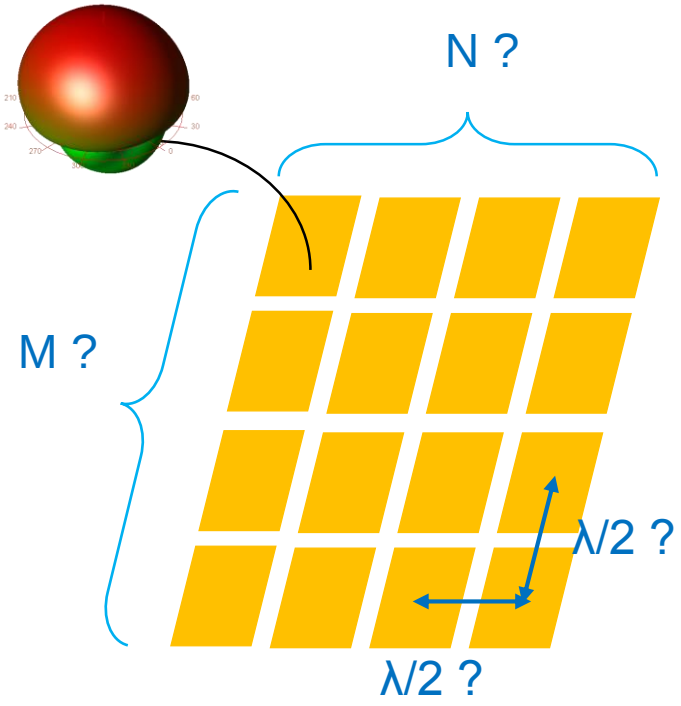


COTS Sparameter

Lab 1 : Beam pattern

Key Parameters of Phased Array

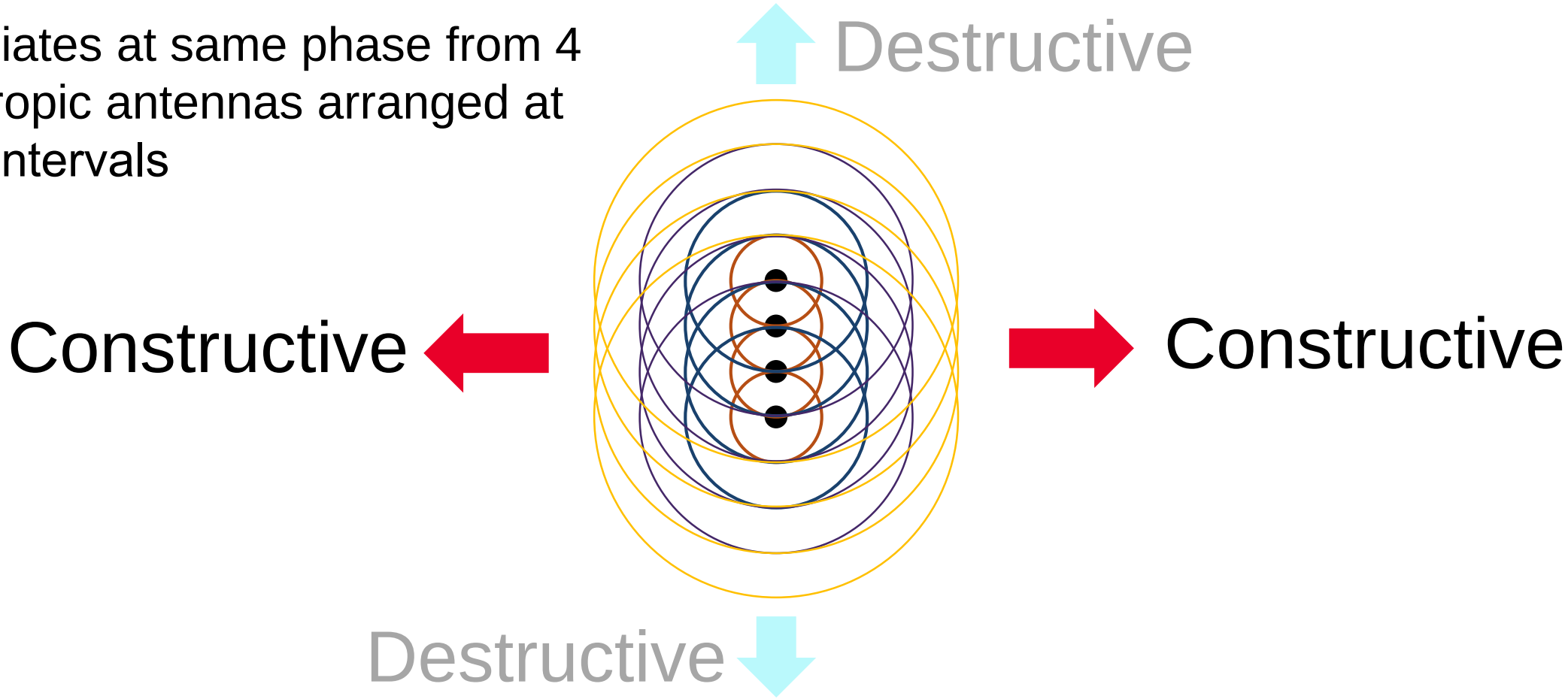
1. Number of array elements
2. Distance between elements (usually <λ/2)
3. Arrangement of array（UL, UR, Circular, Hexagonal, …）
4. Frequency
5. Radiation pattern of each elements



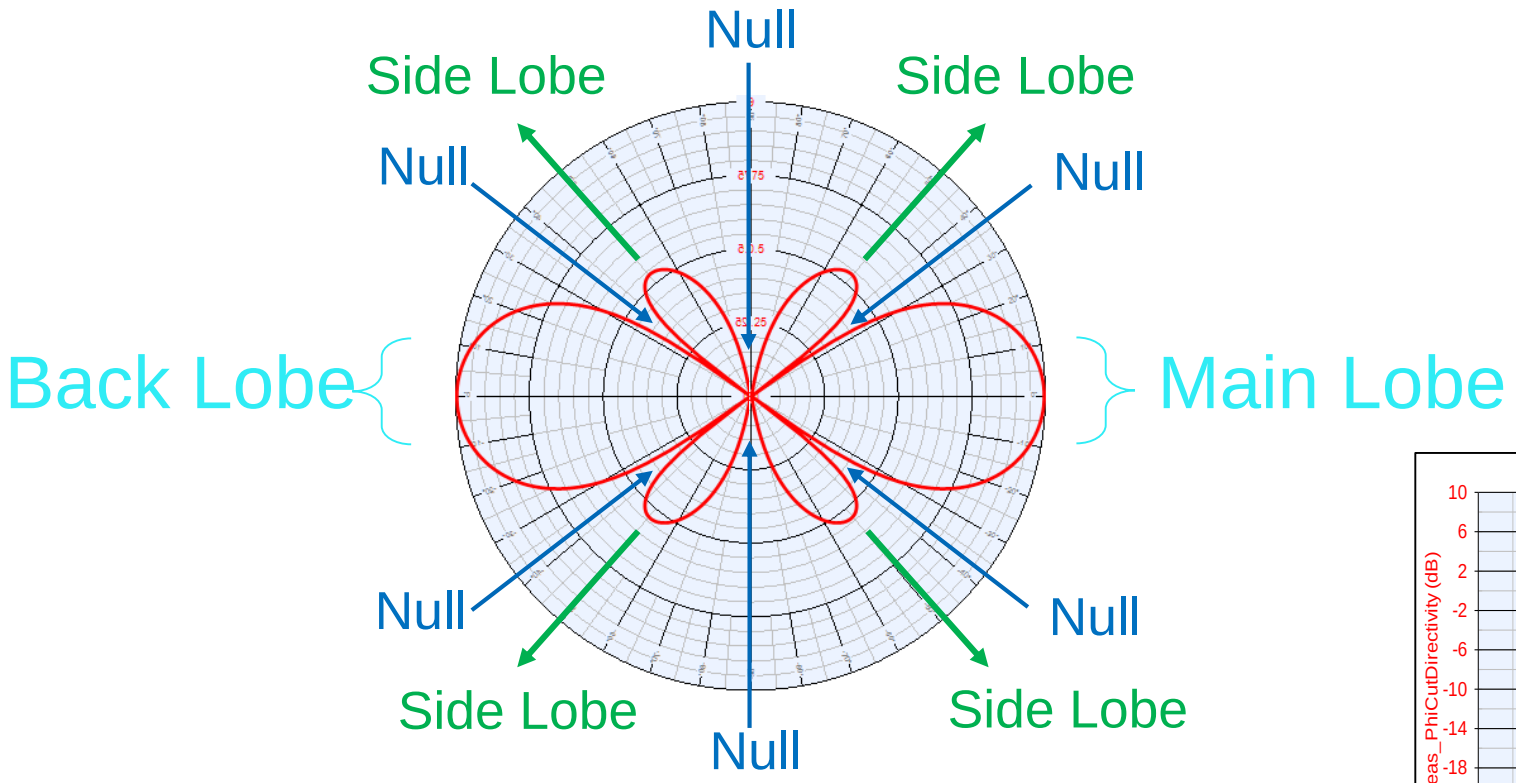
→ Radiation beam pattern by selecting these items properly

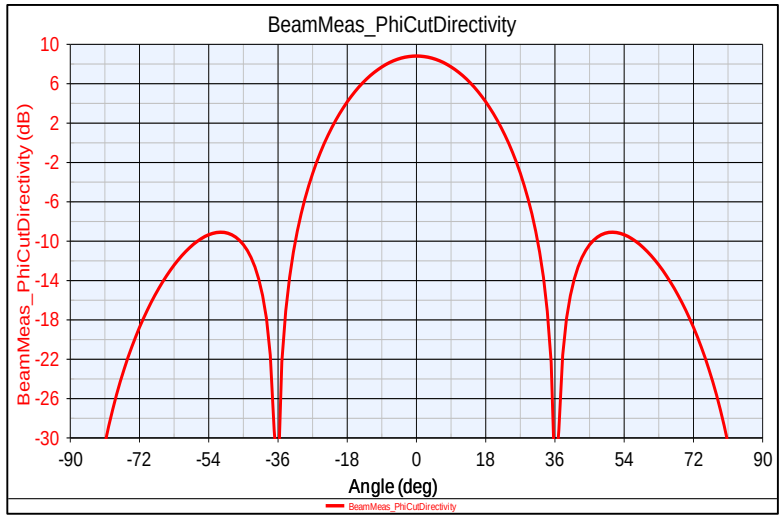
E.g. Uniform Linear 4 Element Array

- Radiates at same phase from 4 isotropic antennas arranged at $\lambda/2$ intervals



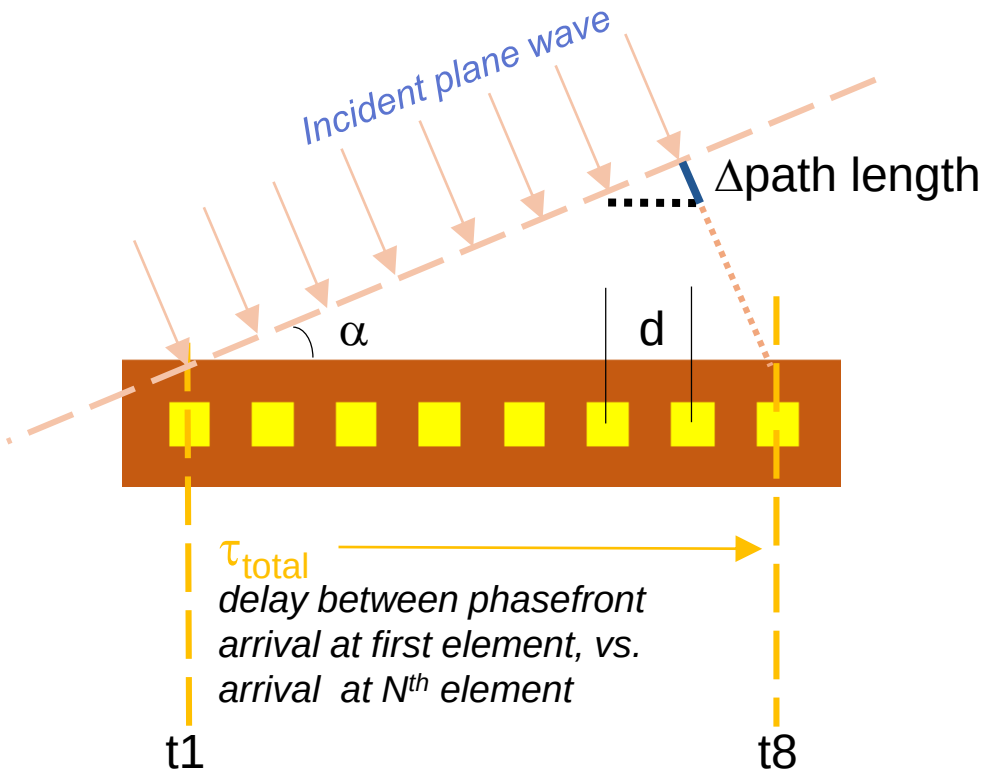
2D Radiated Pattern





Phased Array fundamentals: Phase fronts and Beamsteering

Recreating a "plane wave": Time Delays vs. Phase Shifts



Δ Time Delay @N^{th} element: $e^{-j2\pi F_c N \Delta\tau}$

- $\Delta\tau$ = (Δpath length) / (speed of light / $\sqrt{\varepsilon_{r,eff}}$)
- Δpath length = d sin(α)
- More accurate, but freq-dependent

Δ Phase @N^{th} element: $e^{jN\Delta\phi}$

- $\Delta\phi = -2\pi F_c \Delta\tau$
- Distances normalized to the spacings (λ/2 at F_{center})
- Constant phase shift at all frequencies in BW
- Easier to implement in DSP/RF, but narrowband

Steer array to the side by $\alpha=10^o$:

[0° 10° 20° 30° 40° 50° 60° 70°]

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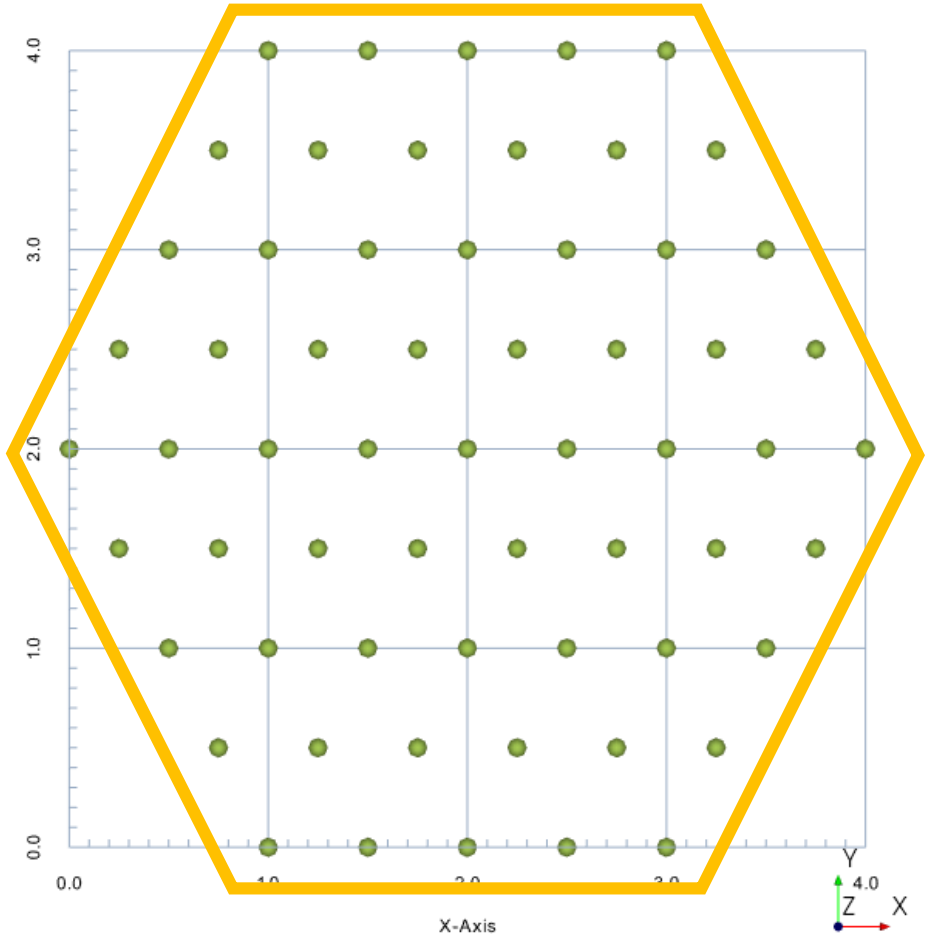
How about Hexagonal 61 elements array?

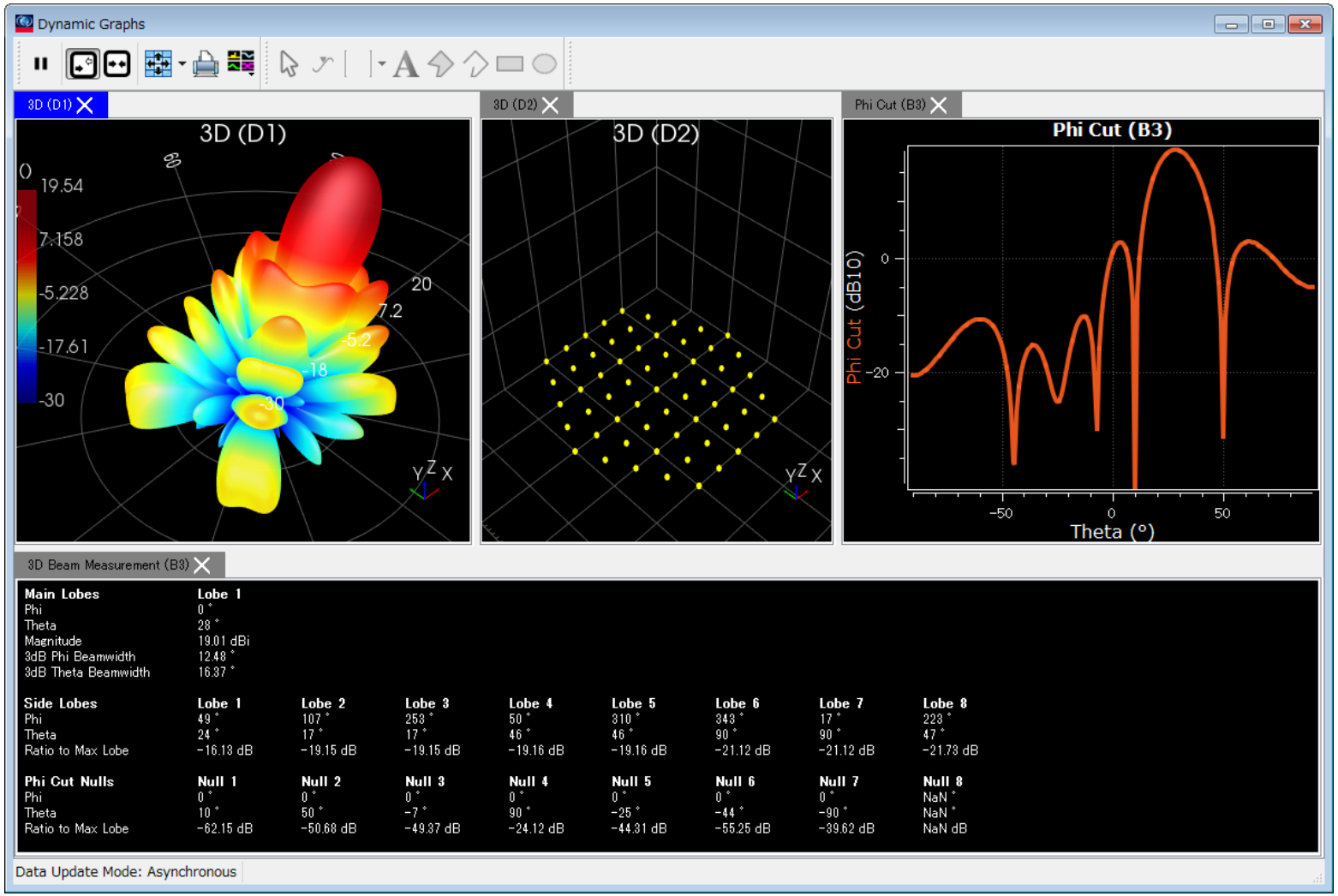


Which direction?
- Main Lobe
- Side Lobe
- Null

What if change Main Lobe direction??

How about Hexagonal 61 elements array

Main Lobe = Θ : 28°, φ : 0°

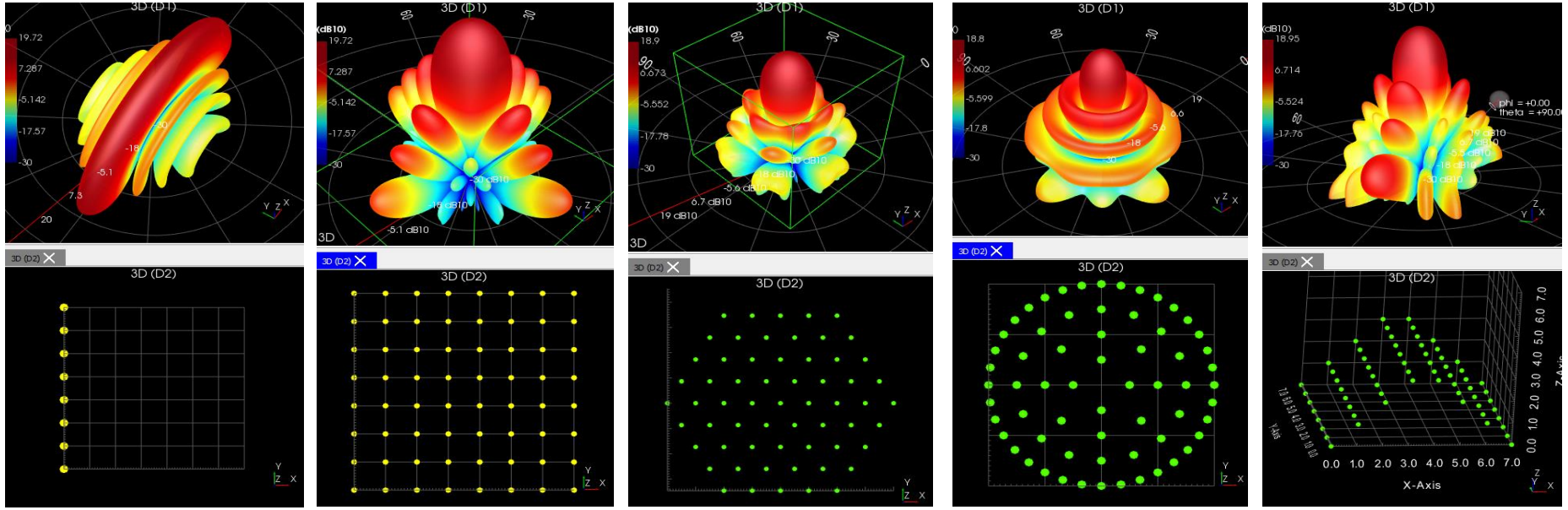


Designing a Phased Array Antenna

Define Configuration, Size, Element patterns, Scan angle, Amplitude taper

- SystemVue can do this easily and you may find it fun to experiment since it is so fast
  - Conformal array defined by x,y,z coordinates and rotation of each element

Uniform Linear | Uniform Rect. | Triangular | Circular | 3D/Conformal



4G Basestations
Automotive Radar

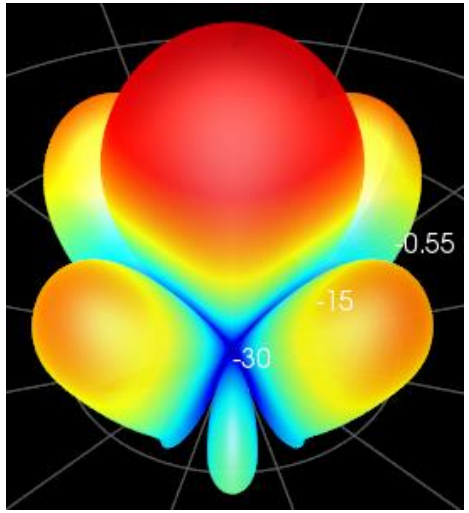
SatComm, 5G, Radar
General purpose

Mobility
applications

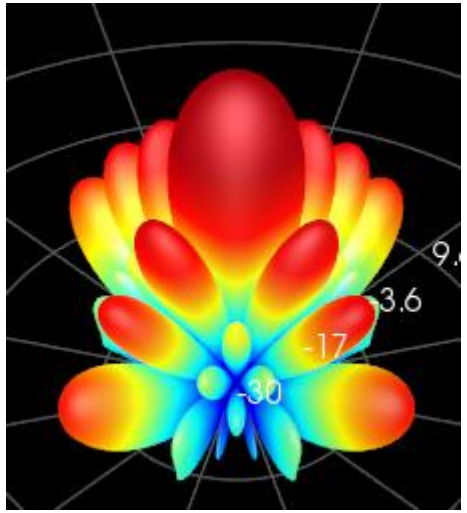
>180º coverage

Explore Array of Any Size

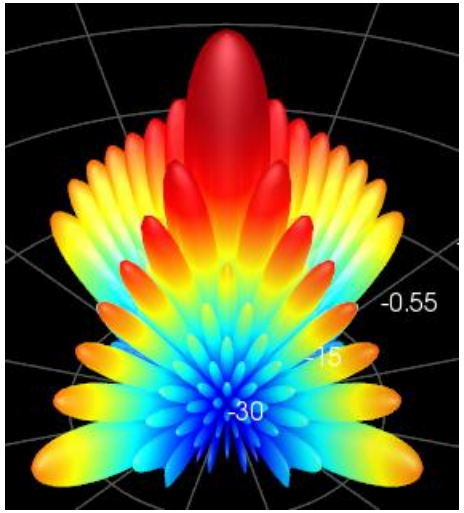
Effect of array size on beam pattern



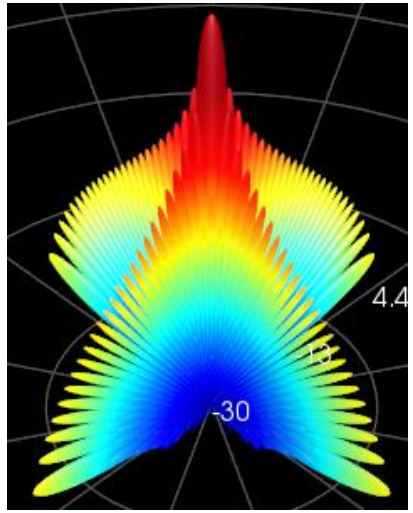
4x4 URA
16.52dBi
26.3°



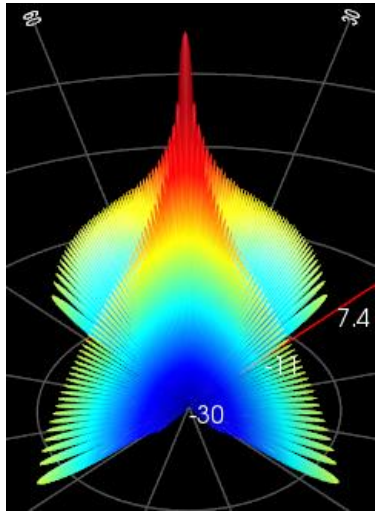
8x8 URA
22.75 dBi
12.9°



16x16 URA
28.9 dBi
6.4°



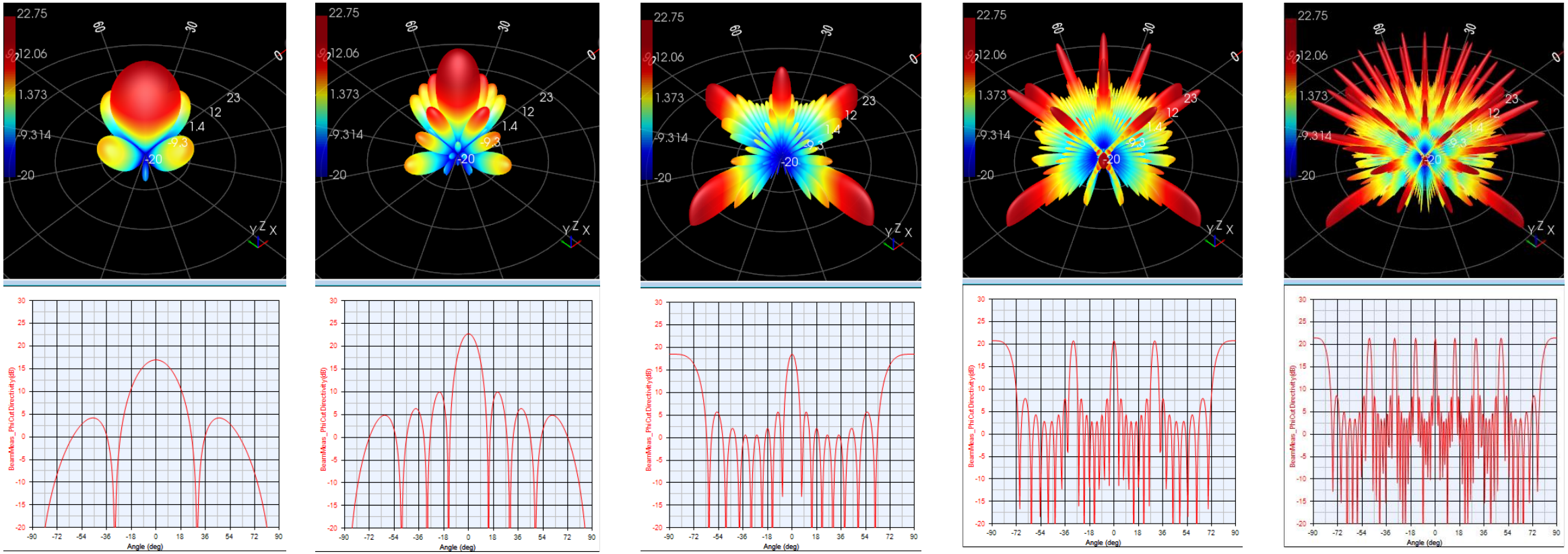
50x50 URA
38.88 dBi
2.0°



100x100 URA
44.89 dBi
1.0°

Explore Effects of Element Spacing

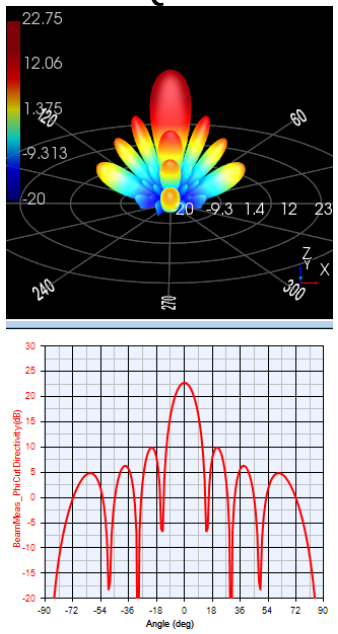
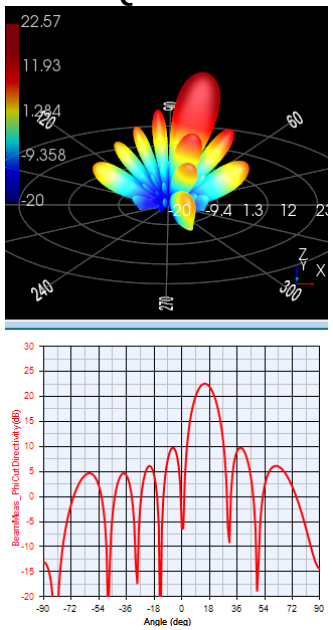
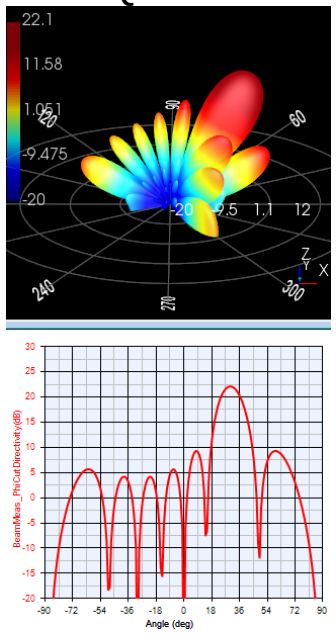
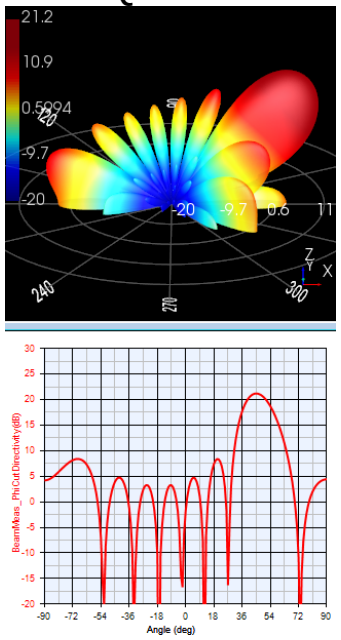
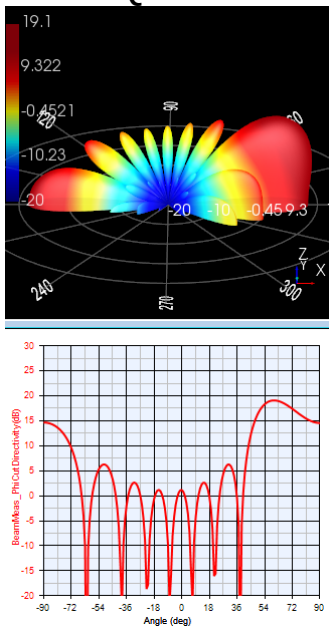
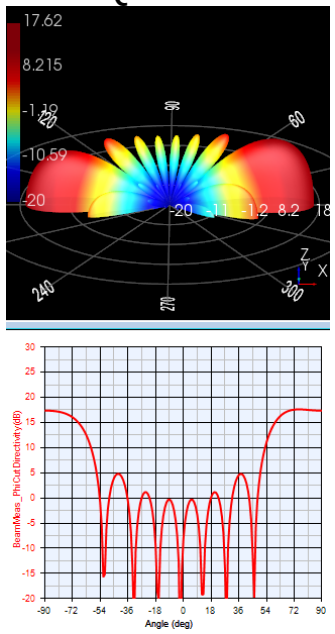
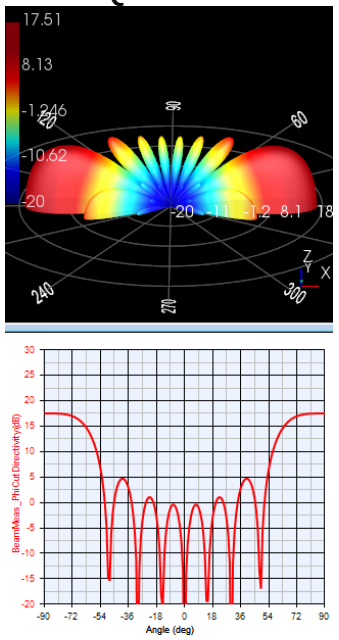
8x8 array with elements at 0.25l, 0.5l, 1.0l, 2.0l, 4.0l separation



As element spacing increases:

- Effective cross-section area increases → higher gain, narrower beam
- Used for multi-function interleaved arrays
- Unwanted spatial “images” due to “spatial undersampling”
- Much more frequency-sensitive

Explore Scan Angle vs Beam Pattern

Q=0º	Q=15º	Q=30º	Q=45º	Q=60º	Q=75º	Q=90º
						
D=22.75dBi QBW=12.75º	D=22.57dBi QBW=13.23º	D=22.10dBi QBW=14.83º	D=21.20dBi BW=18.37º GLL=-12.8dB	D=19.09dBi BW=28.95º GLL= -4.42dB	D=17.62dBi GLL= -0.24dB	D=17.51dBi GLL= 0dB

As scan angle increases:

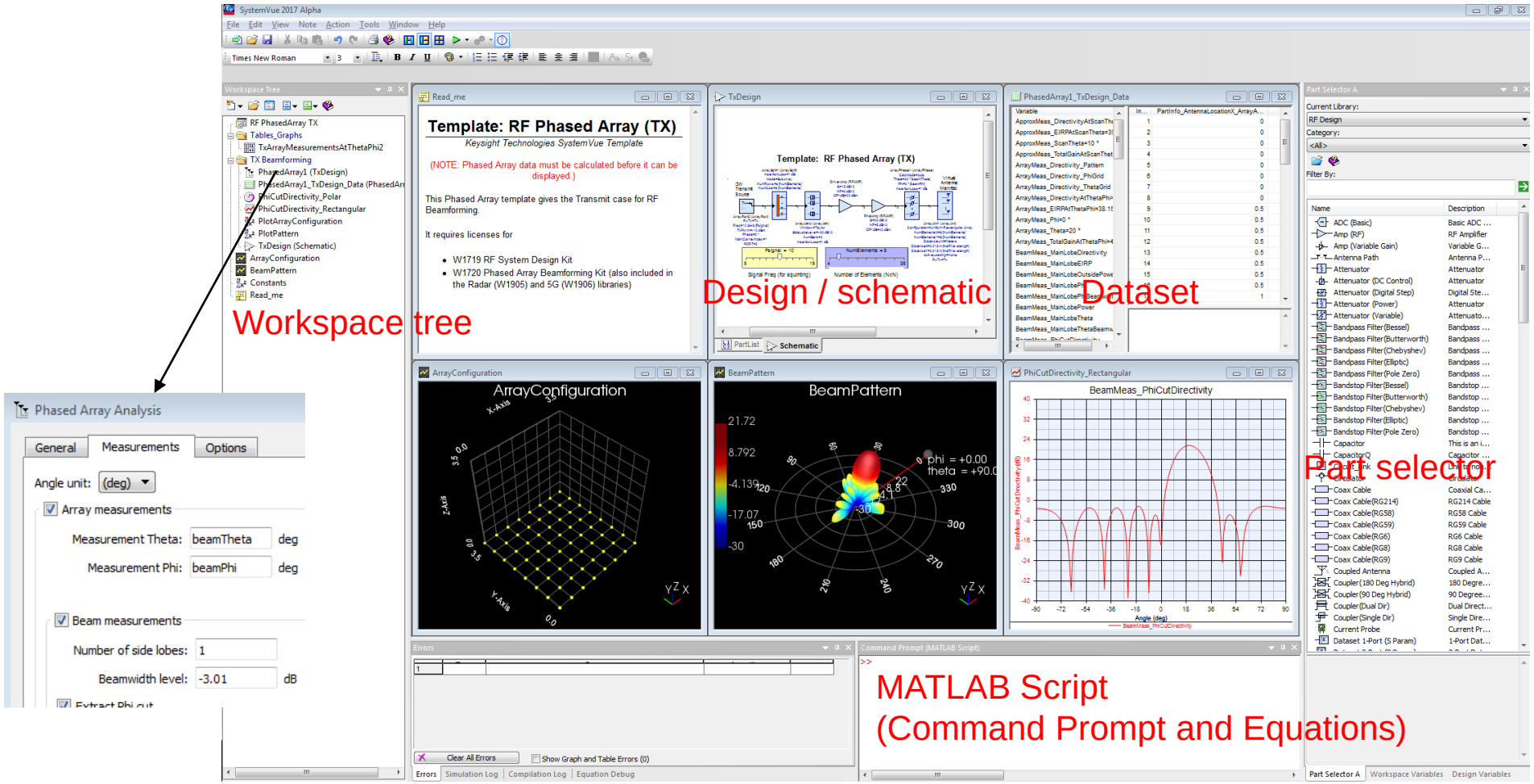
- Effective cross-section area decreases
- Less power to main lobe, lower peak directivity, wider beam
- More energy goes to grating lobes (scan to far)

PA loading & impedance changes

- Affects beam shape, in extreme case can create blind spots

Lab 1 : Exercise

SystemVue Environment for Phased Array Design



Templates:

- RF Phased Array Tx
- Dataflow RF Beamforming Tx

Examples:

- Examples¥Beamforming
- Examples¥RF Architecture Design¥Phased Array Analysis

Videos:

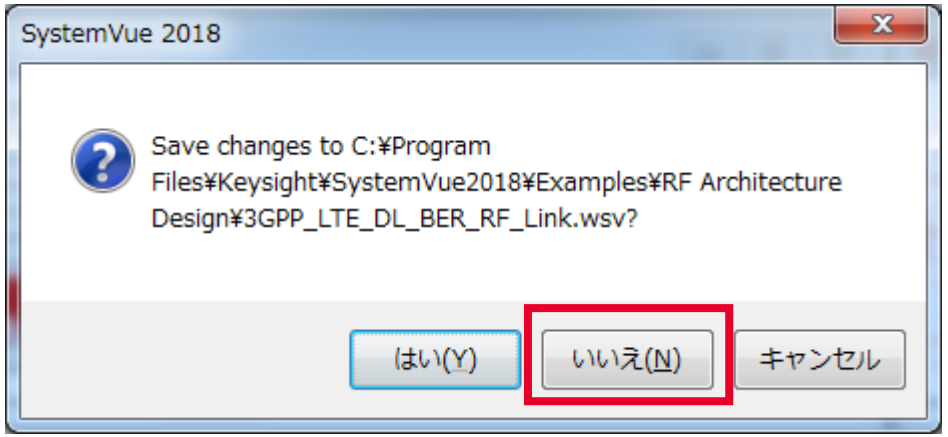
- https://www.youtube.com/playlist?list=PLtq84kH8xZ9E8_CtYsQx5Gx-w-ieA_Olt

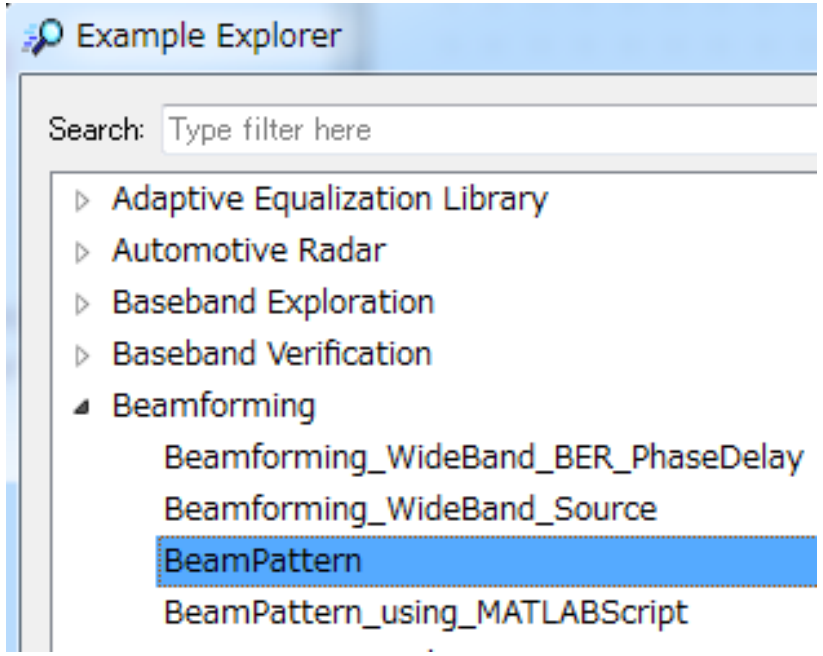
Lab 1: Beam pattern

➢Help > Example Explorer

Open Beamforming > BeamPattern

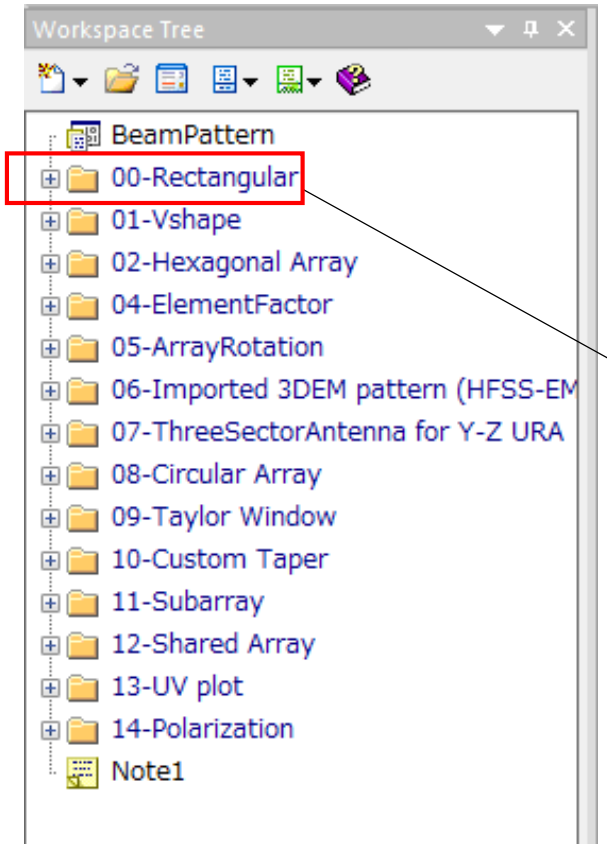
!! Choose “No” not to save current workspace !!





Lab 1: BeamPattern.wsv

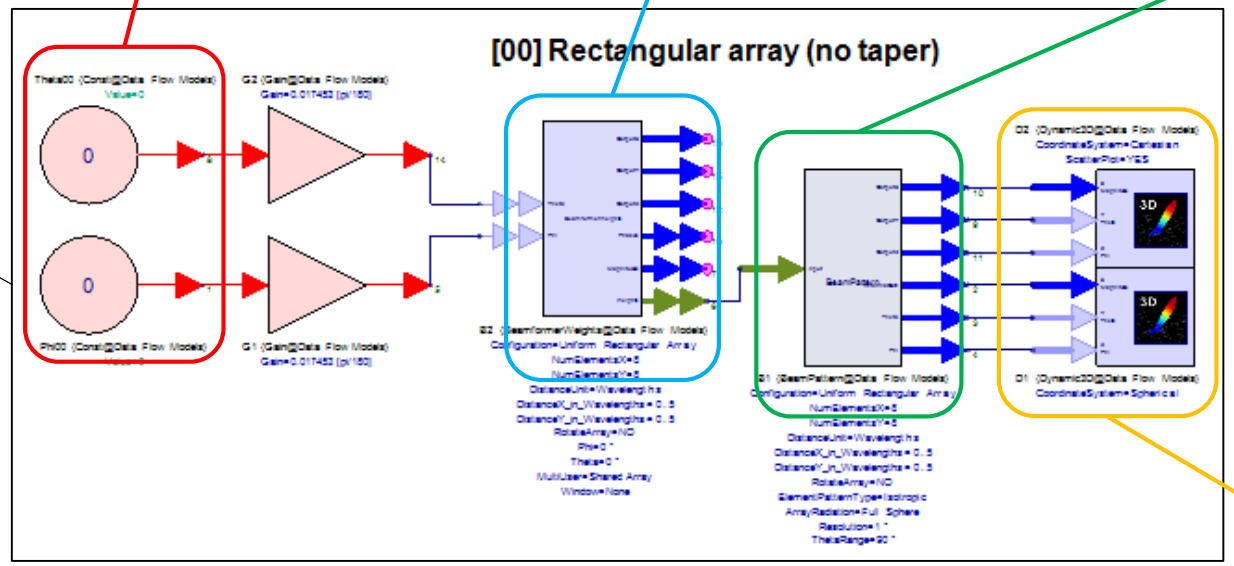
- 00 ~ 14: Different types of array pattern or window(weight) pattern



Theta / Phi control beam direction

Calculate weight(*) of array element

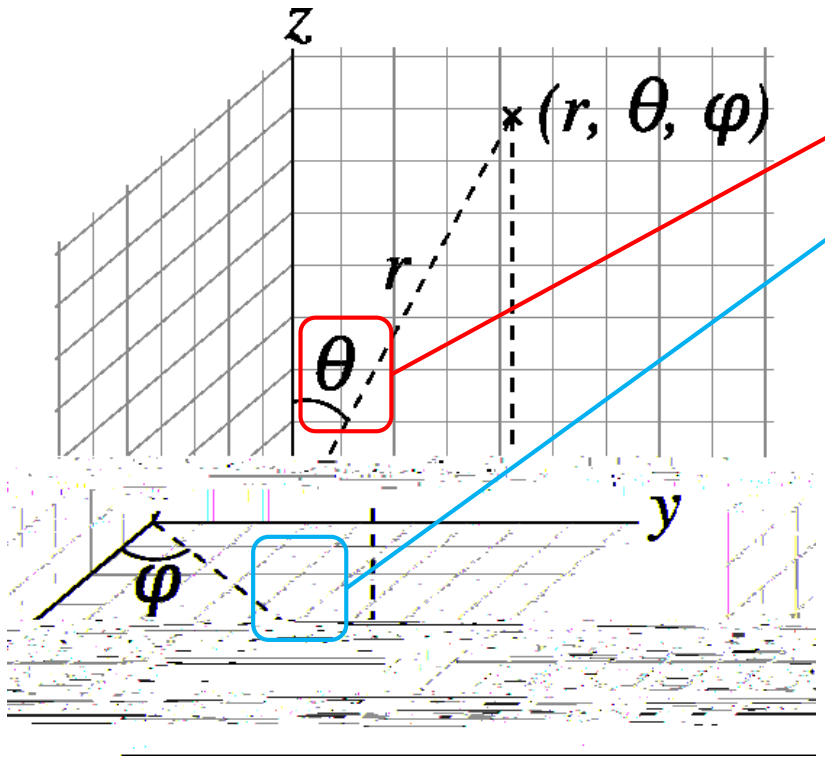
Calculate beam pattern

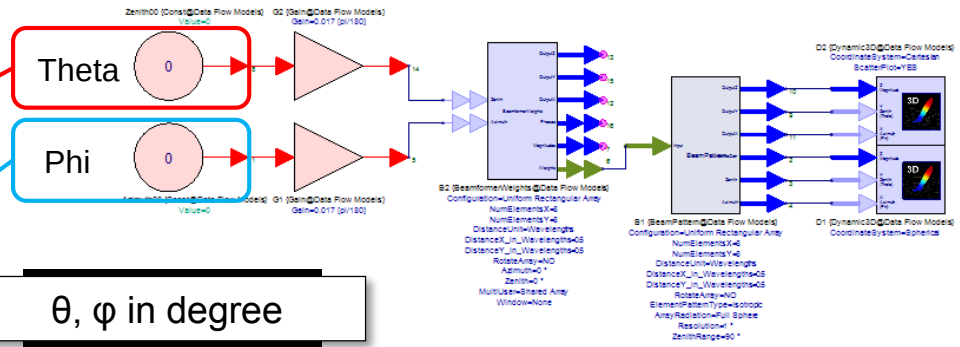


3D plot of array position and beam pattern

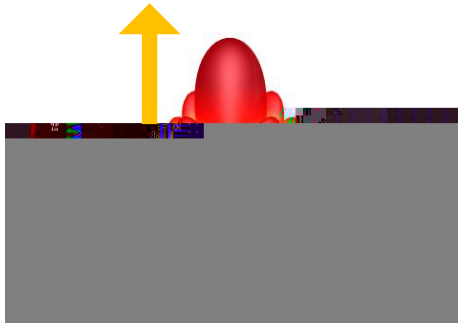
* Weight is complex data of magnitude and phase for each array element
Weight can be output as magnitude or phase separately

Lab 1: θ (Theta), φ (Phi) and Coordinate





θ, φ in degree

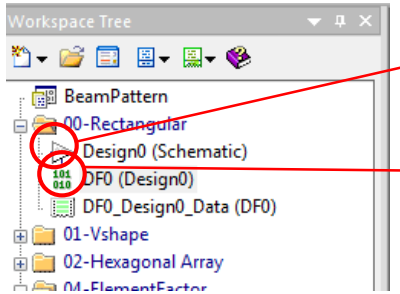


Arrange antenna array on x-y plane
Set direction : θ=0°, φ=0°

Beam direction : +Z axis

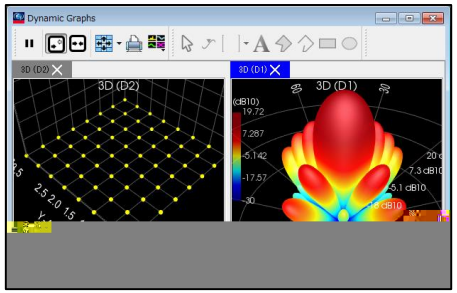
Lab 1: 00-Rectrangular ～ Number of array, arrangement

[A] Rum simulation as it is



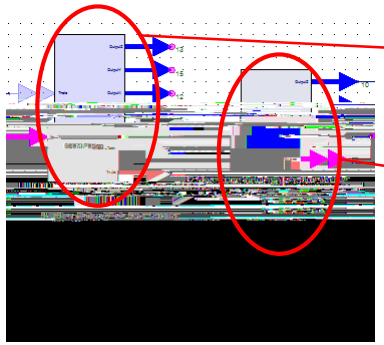
①Open Design0

②Run DF0



8x8 Uniform Rectangular Array beam pattern

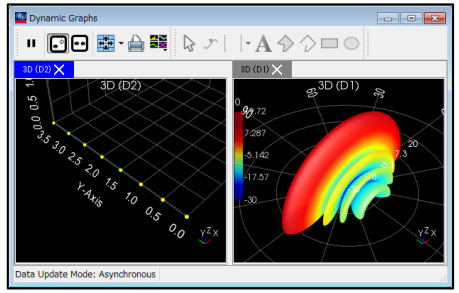
[B] Arrange 1D array（x=1, y=8） and run DF0



③ Number of X Elements: 8→1 in BeamformerWeights property

④ Number of X Elementsを8→1 in BeamPattern property

⑤Run DF0



1x8 Uniform 1D Array beam pattern

[C] Increase number of array elements (x=16, y=16) 実行

⑥In BeamformerWeights property
Number of X Elements : 1→16
Number of Y Elements : 8→16

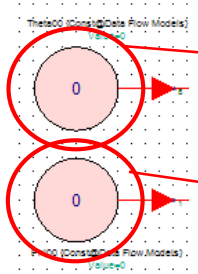
⑦In BeamPattern property
Number of X Elements : 1→16
Number of Y Elements : 8→16

⑧Run DF0

Beam pattern???

Lab 1: 00-Rectrangular ～ Beam Direction (θ, φ)

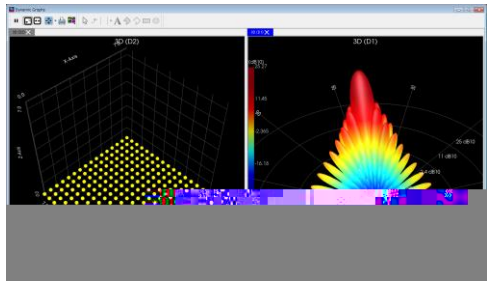
[D] Change θ, φ and check beam direction



⑨Theta00(Const) Value : 0→30

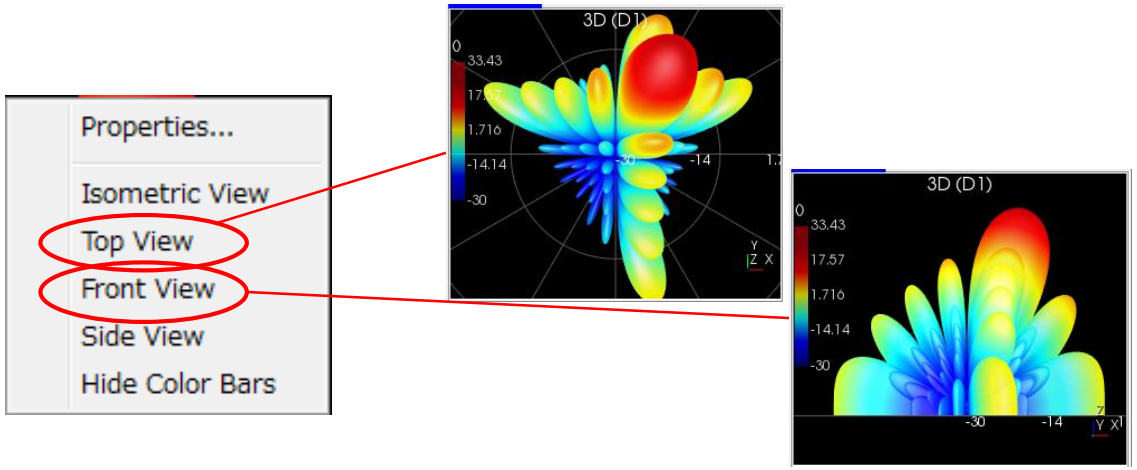
⑩Phi00(Const) Value : 0→60

⑪Run DF0



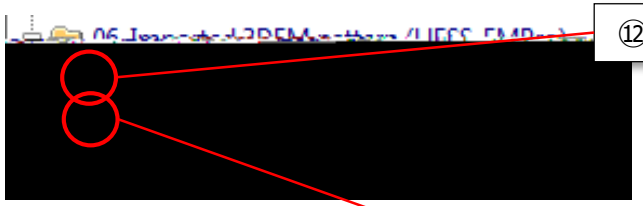
Observe beam pattern changing θ, φ as you like

Tips :
Right mouse click to specify view direction on 3D plot.



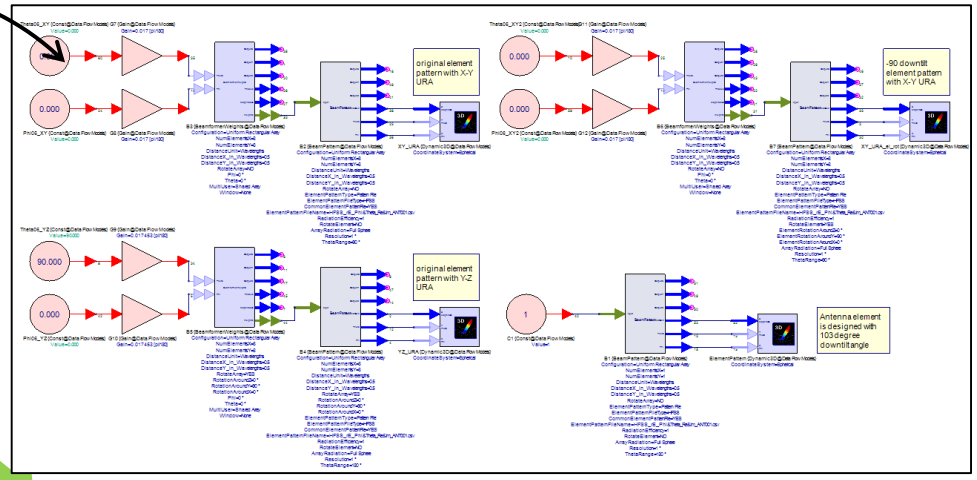
Lab 1: 06-Imported 3DEM pattern (HFSS-EMPro)

[E] Import antenna pattern file (by 3DEM simulation or measurement)



⑫Open Design6

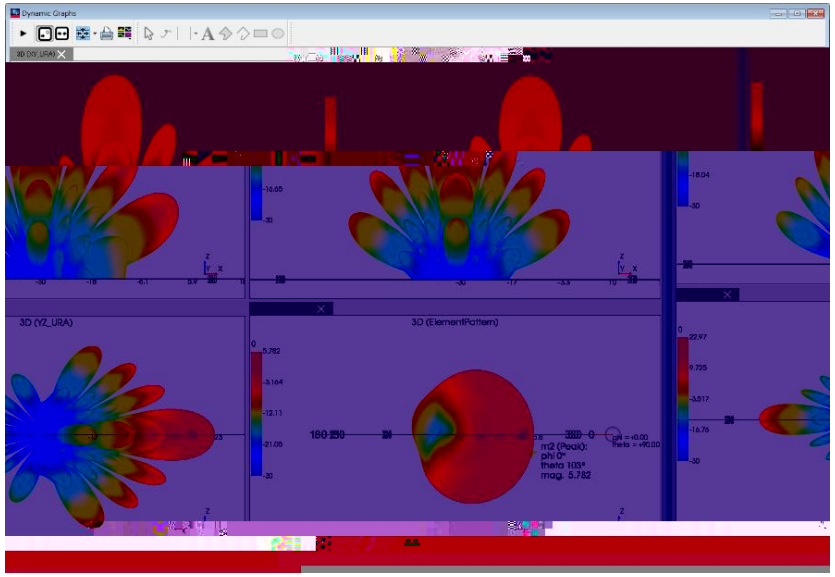
⑬Run DF6



- Specify beam direction
- Rotate arrangement coordinate
- Rotate element antenna pattern

Beam direction:
θ=0°, φ=0°
Array arrangement:
X-Y plane

Beam direction:
θ=90°, φ=0°
Array arrangement:
Z-X plane

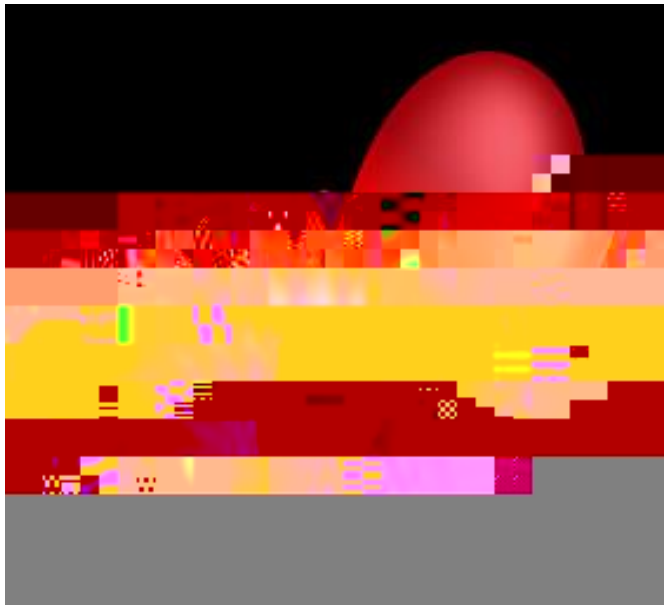


Beam direction:
θ=0°, φ=0°
Array arrangement:
X-Y plane
Antenna pattern:
-90°rotation around Y-axis

Imported antenna pattern of element
103°Downtilt

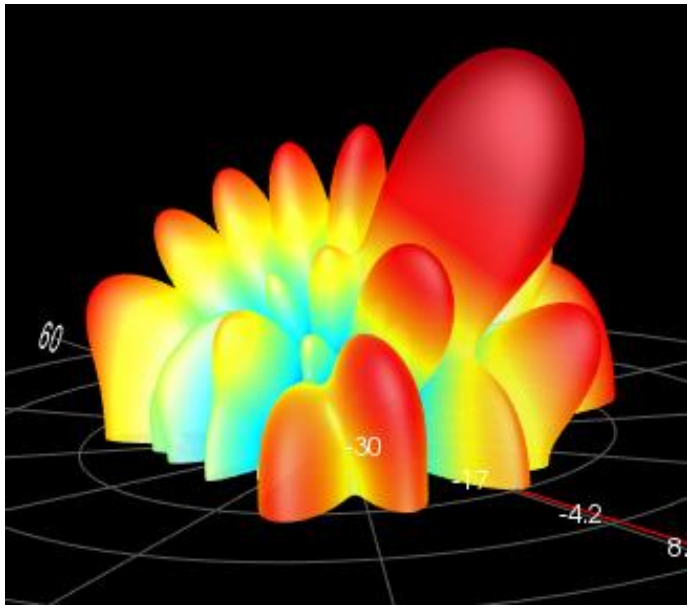
Lab 2 : Beamform and Magnitude/Phase Error

Finite Quantized states of amplitudes and phases



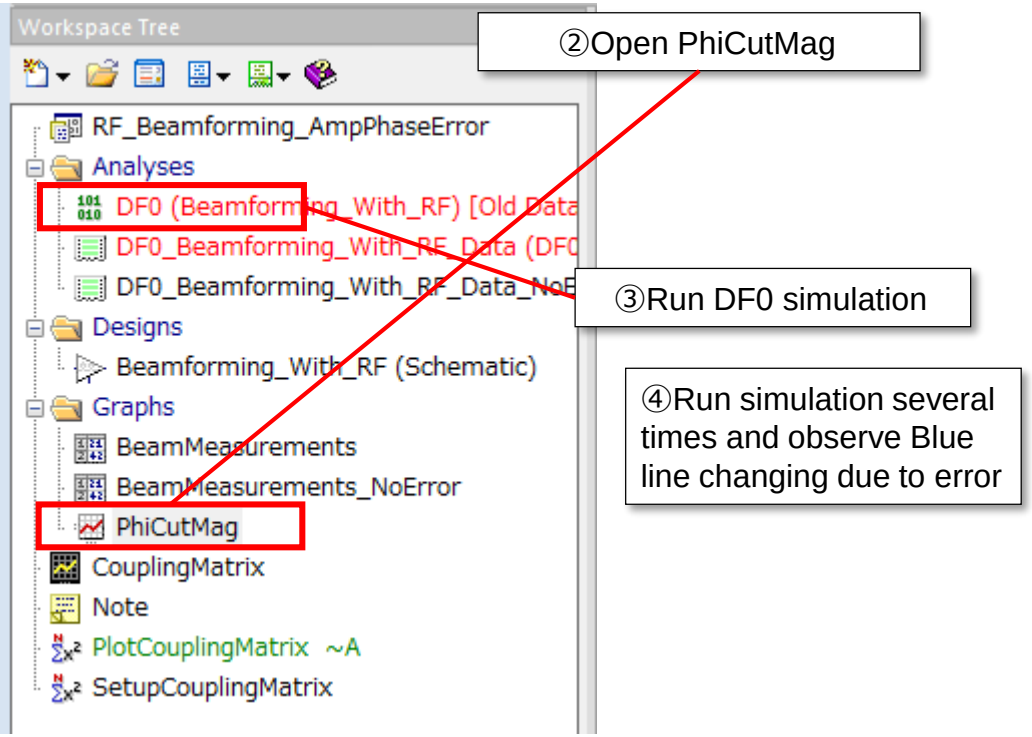
No quantization

5 bit quantization



3 bit quantization

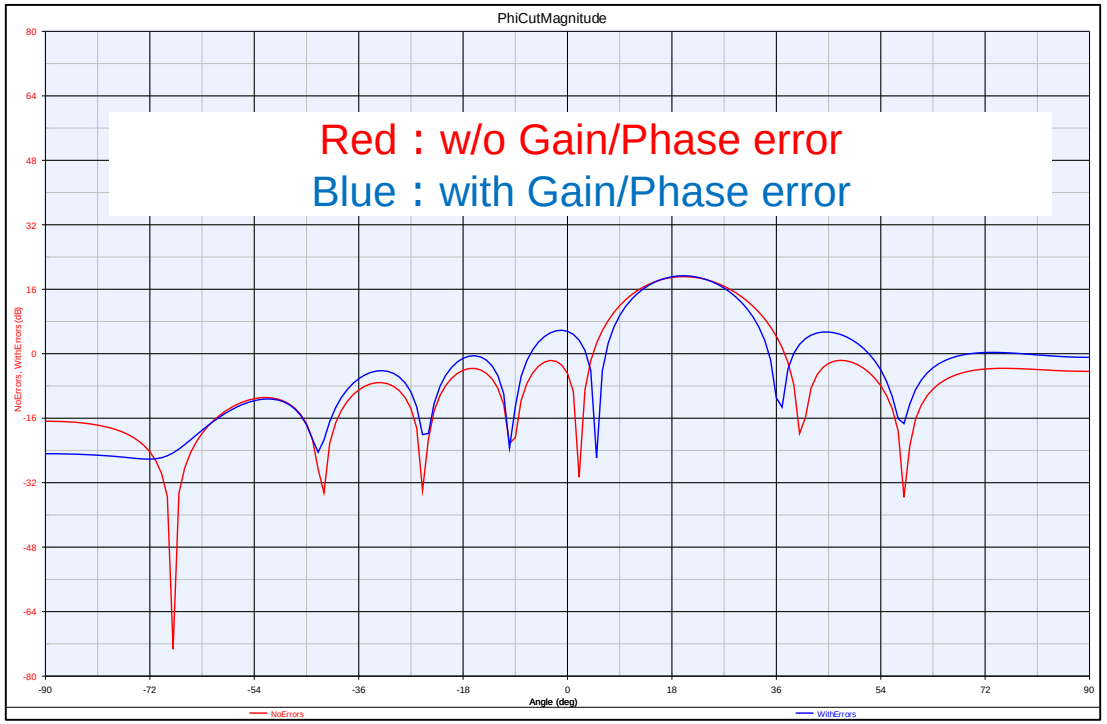
Lab 2: Run simulation and check PhiCutMag plot



②Open PhiCutMag

③Run DF0 simulation

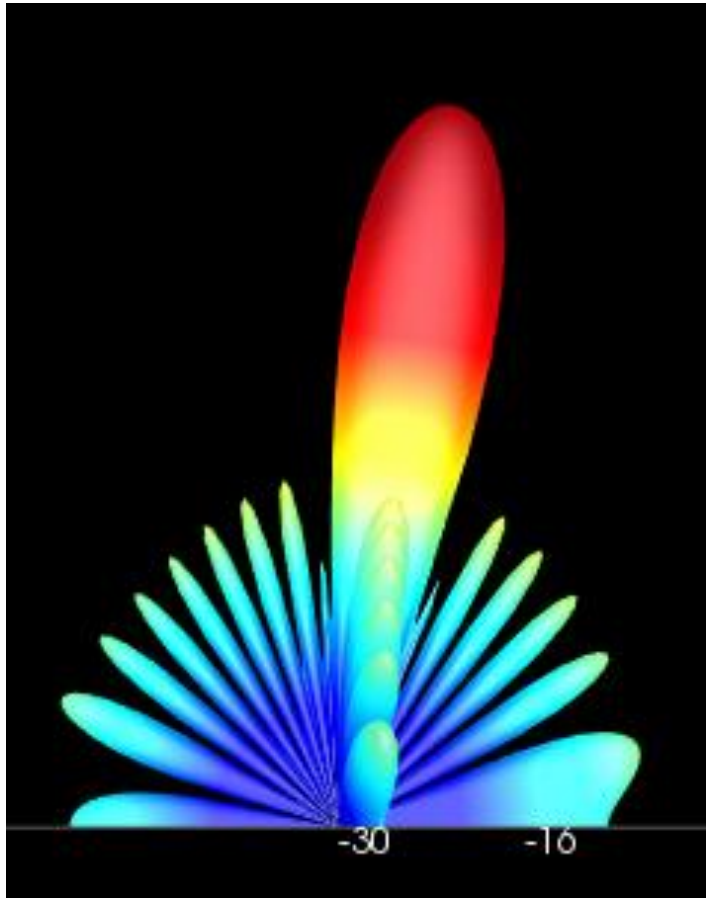
④Run simulation several times and observe Blue line changing due to error



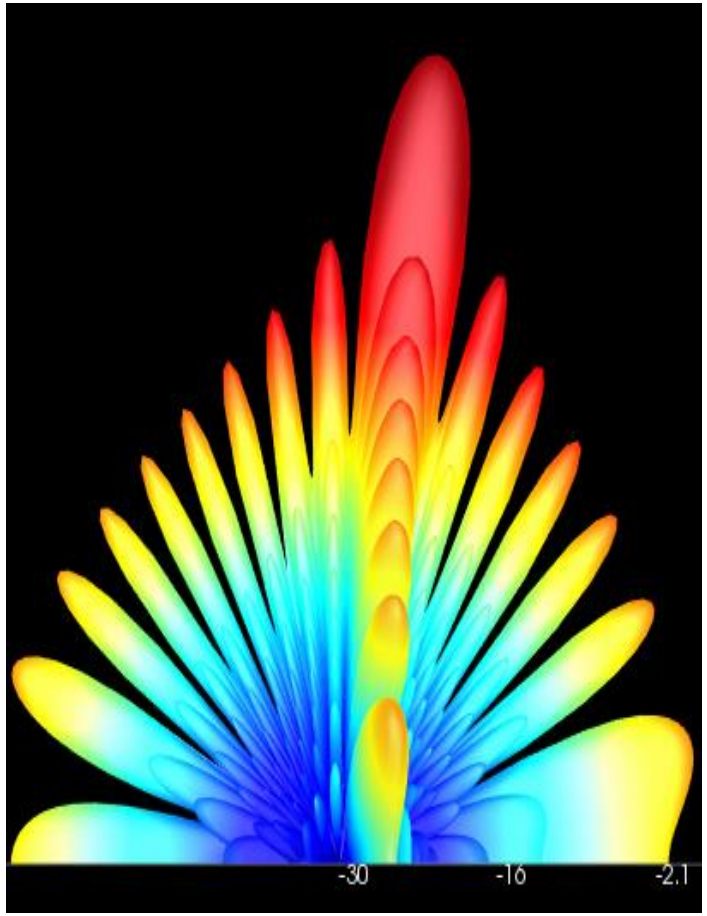
Magnitude or angle of side lobe and null will vary due to gain/phase error
The value of side lobe and null can be checked in the Dataset list.

Lab 3: Phased Array Analysis for RF design

What is a good beam and what is not?



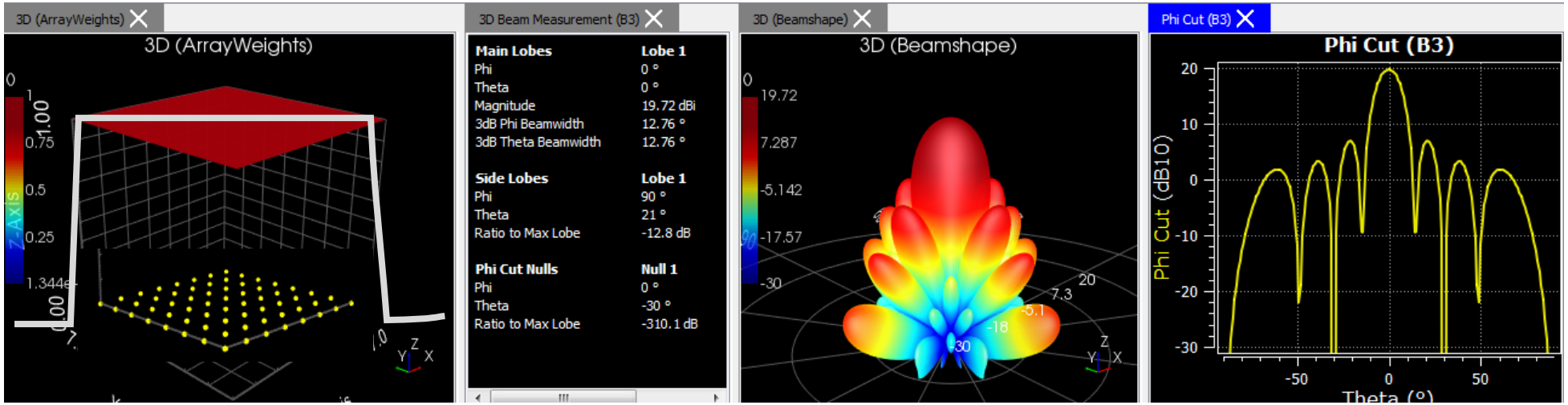
Good: lower side lobes



Bad: higher side lobes

Suppressing Sidelobes with Amplitude Tapering

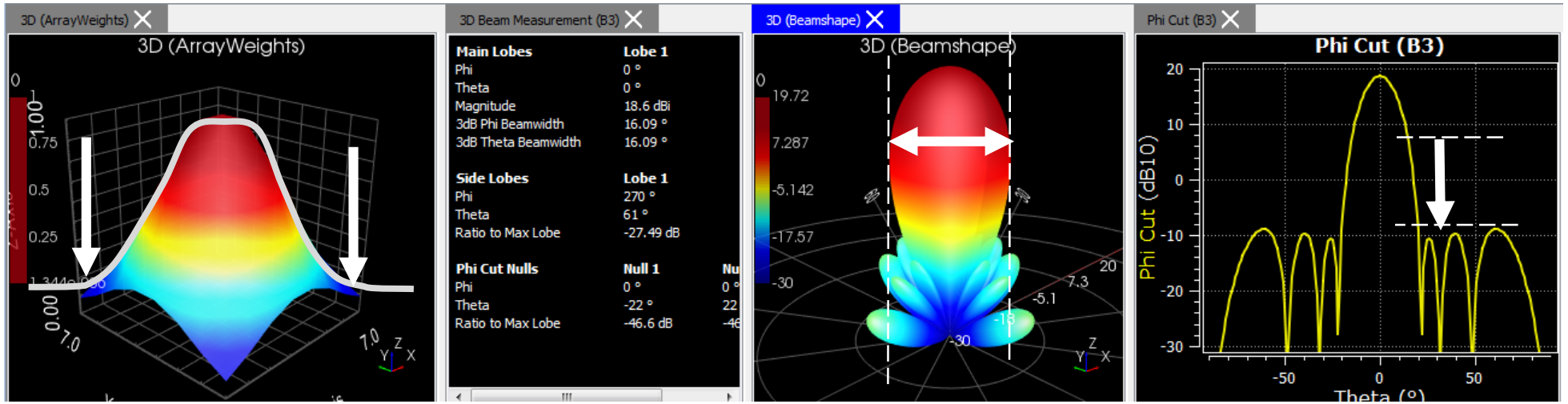
No window



"Ringing"

Unwanted energy waste (or leakage)

2-D "Taylor" window



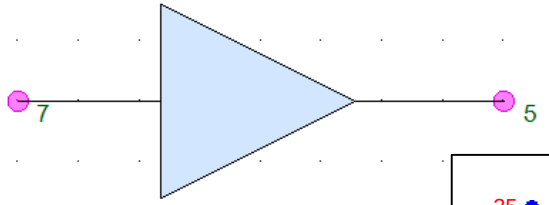
Sidelobe Suppression

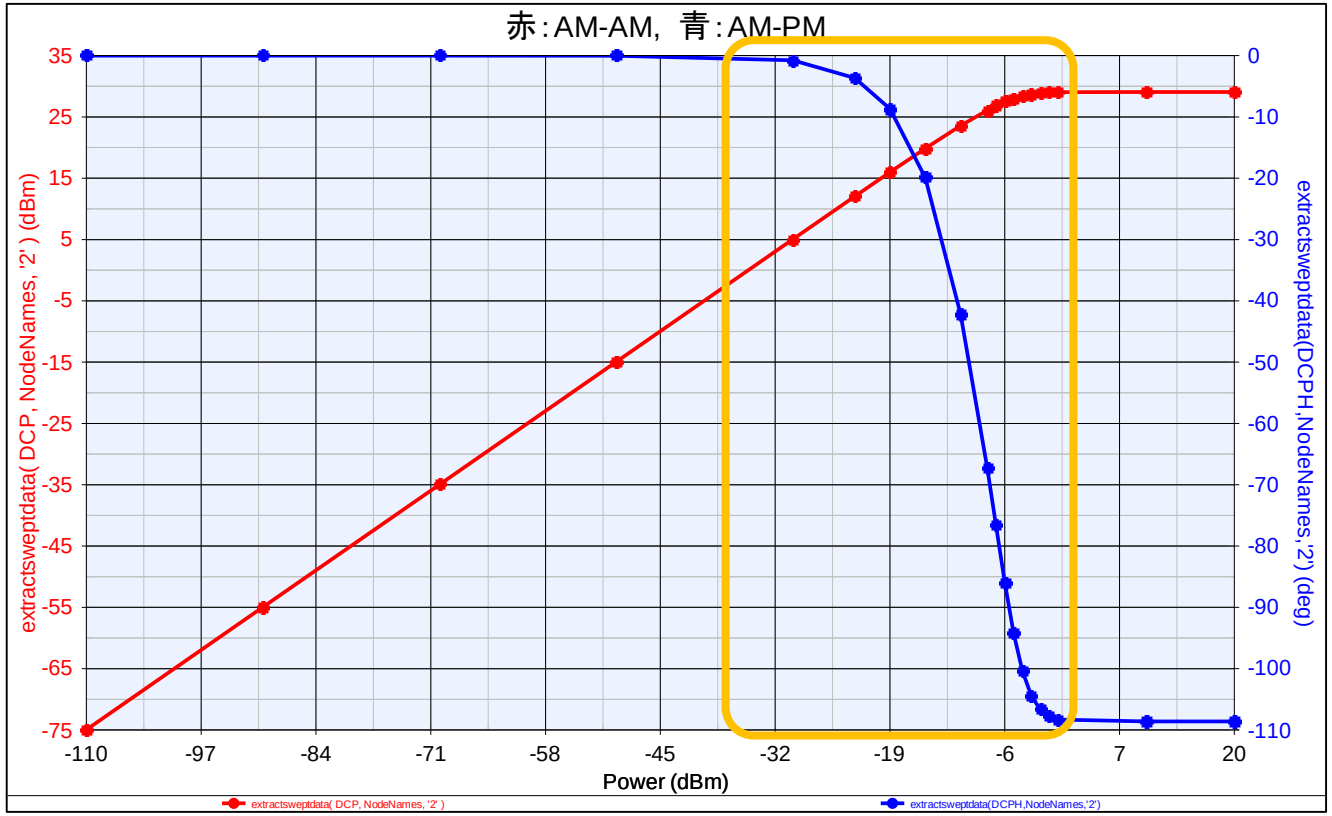
from -12.8dBc to -27.5dBc

Wider beamwidth

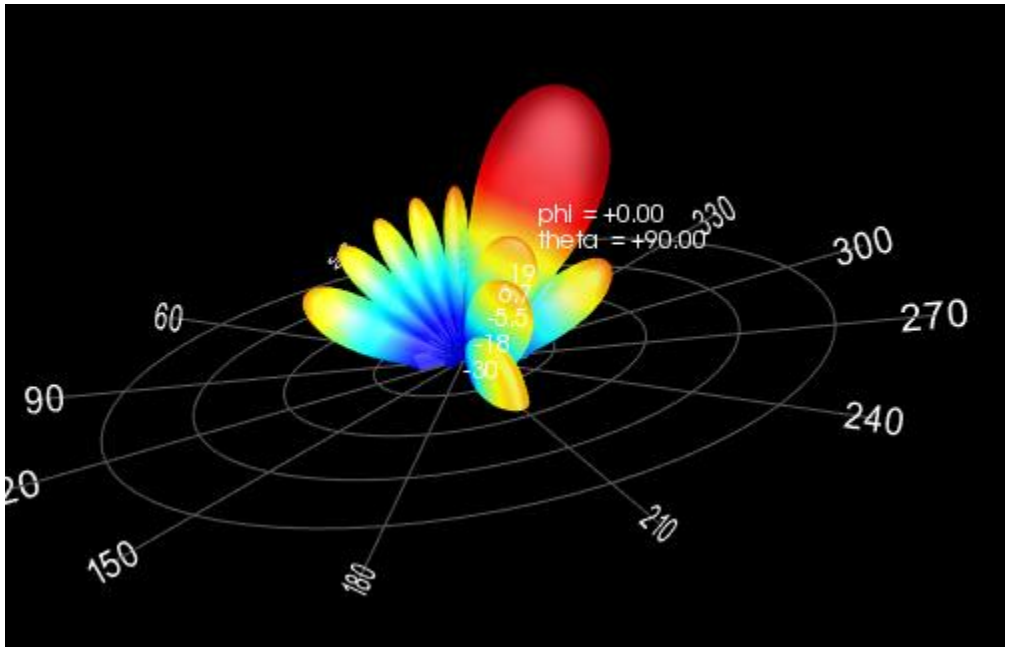
from 12.8º to 16.1º

Amplifier AM-AM, AM-PM

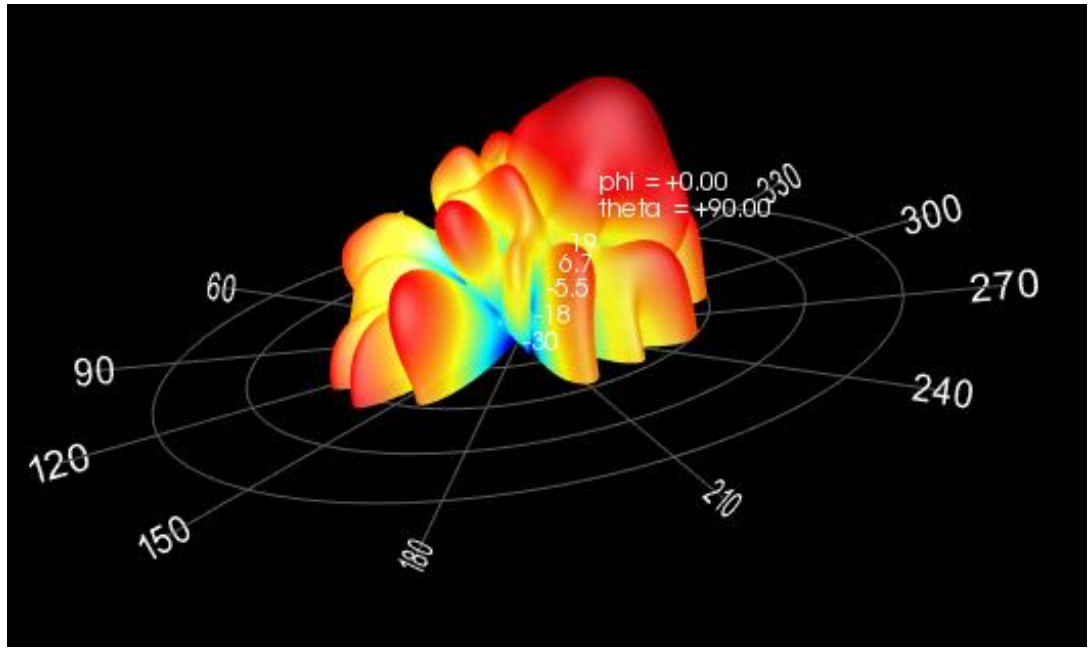




What is a good beam and what is not?



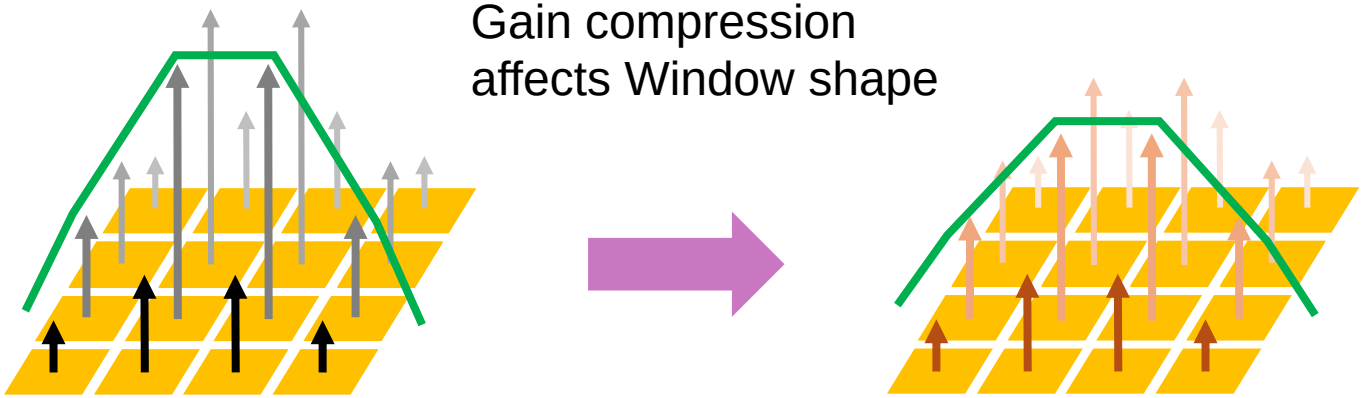
Good



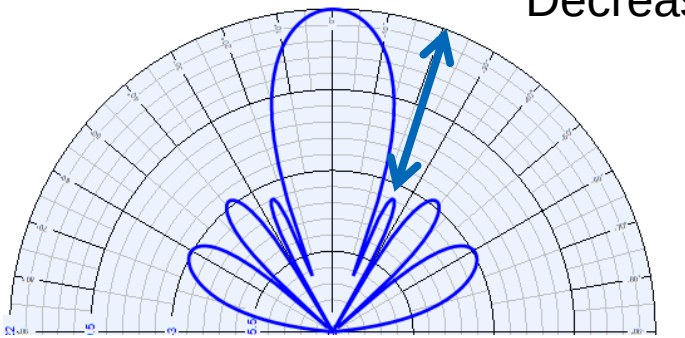
Bad
Amplifier AM-PM effect

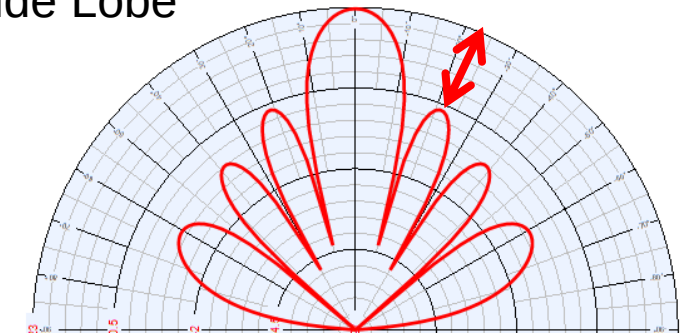
Nonlinear Distortion also degrades Window(taper)

Gain compression
affects Window shape



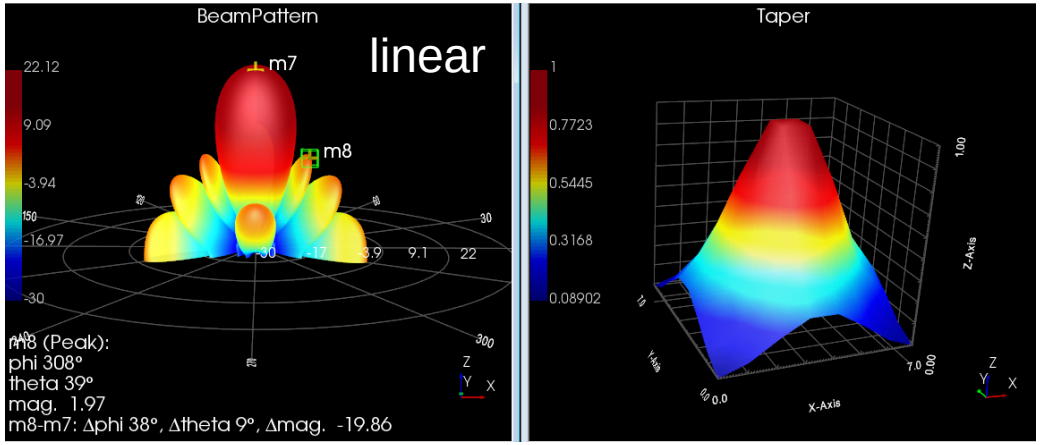
Decrease Main/Side Lobe
ratio

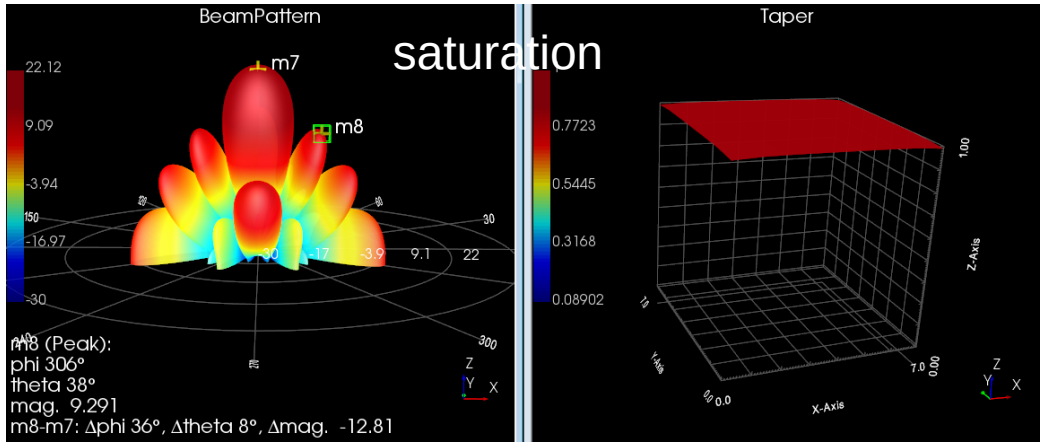


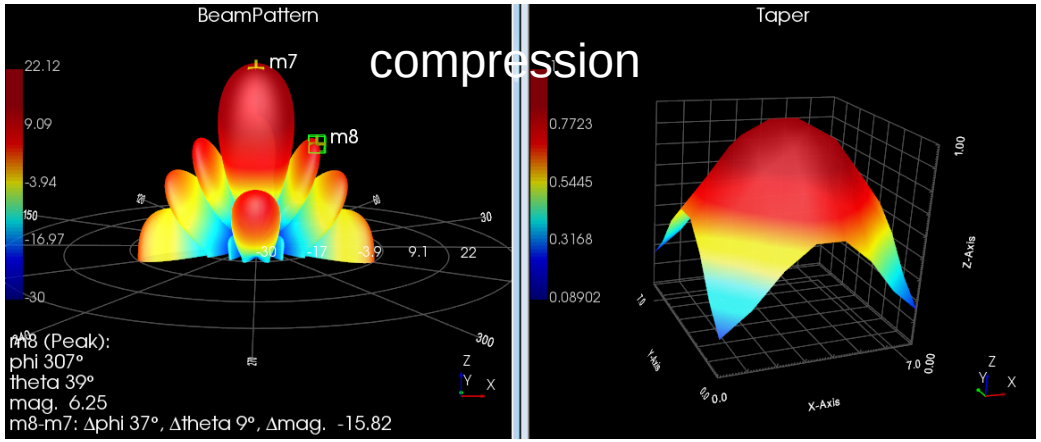


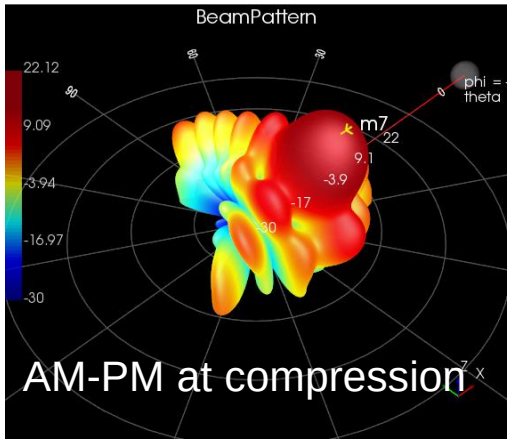
Impact of Nonlinear Devices on Beam Patterns

8x8 URA Taylor (-20dB) Nonlinear Amp vs Input Power









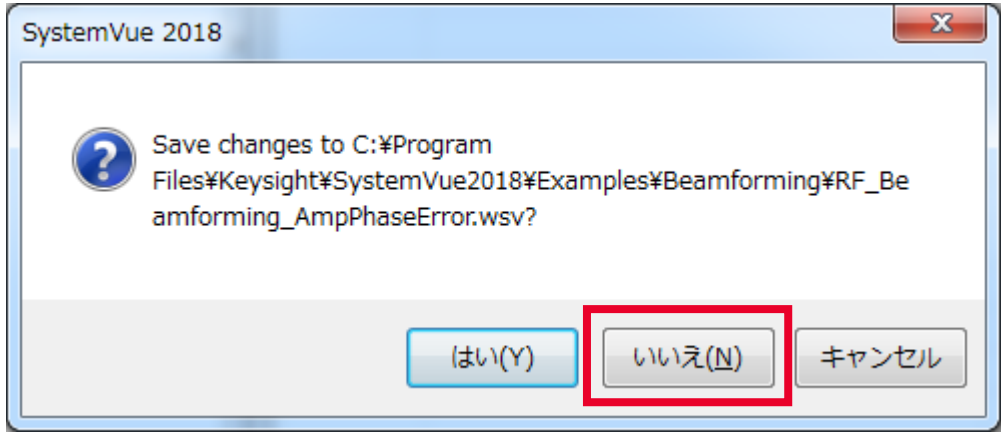
Lab 3 : Exercise

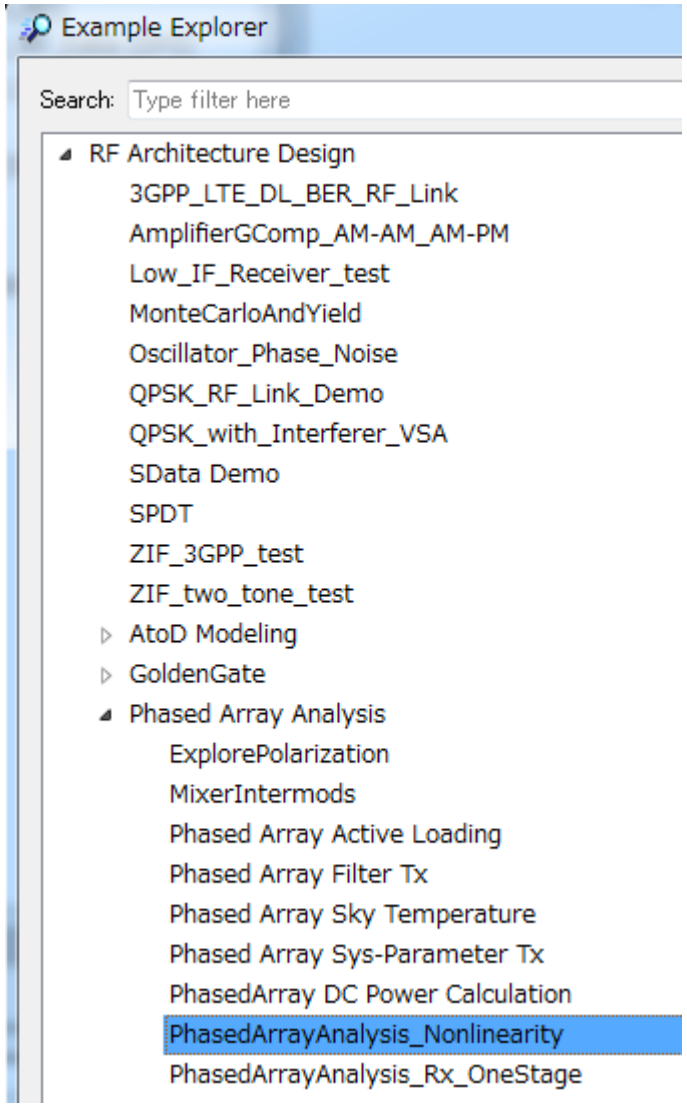
Lab 3: Phased Array Analysis for RF design

➢Help > Example Explorer

Open RF Architecture Design > Phased Array Analysis > PhasedArrayAnalysis_Nonlinearity

!! Choose “No” not to save current workspace !!





Lab 3: Phased Array Analysis for RF design

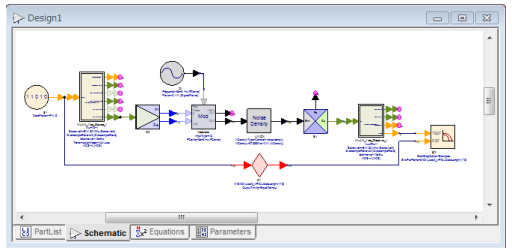
➢ Dedicated simulation in frequency domain for Phased Array

Lab 1/2

Data Flow Controller

Design1 Analysis (Design1)

Schematic



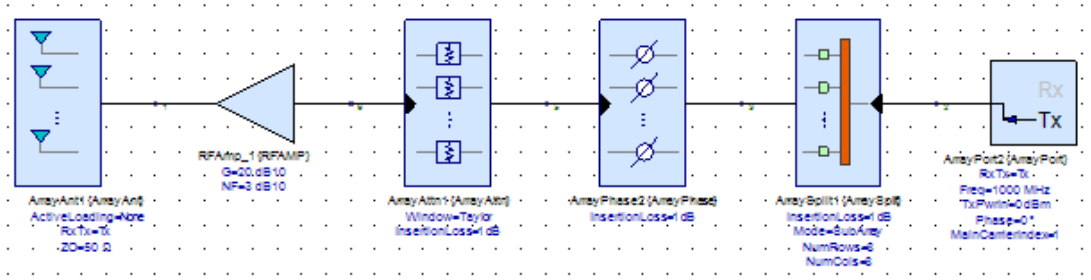
Time Domain Simulation

Lab 3/4

Phased Array Controller

PhasedArray1 (Sch1)

Schematic



Antenna array | Amplifier | Attenuator | Phase Shifter | Splitter (Tx) Combiner (Rx) | Port (Tx/Rx)

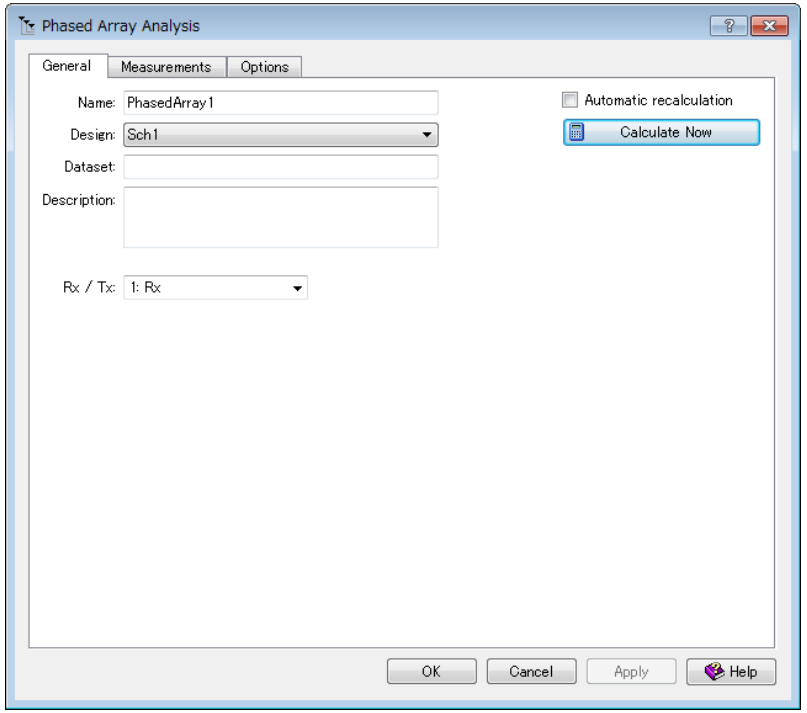
Can simulate MxN array by setting parameter on the same schematic

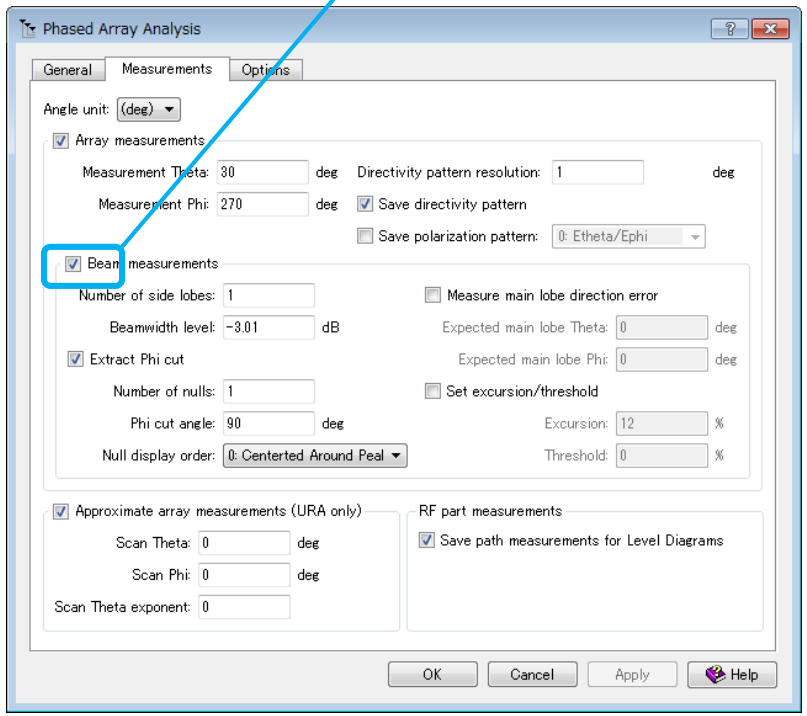
Frequency Domain Simulation

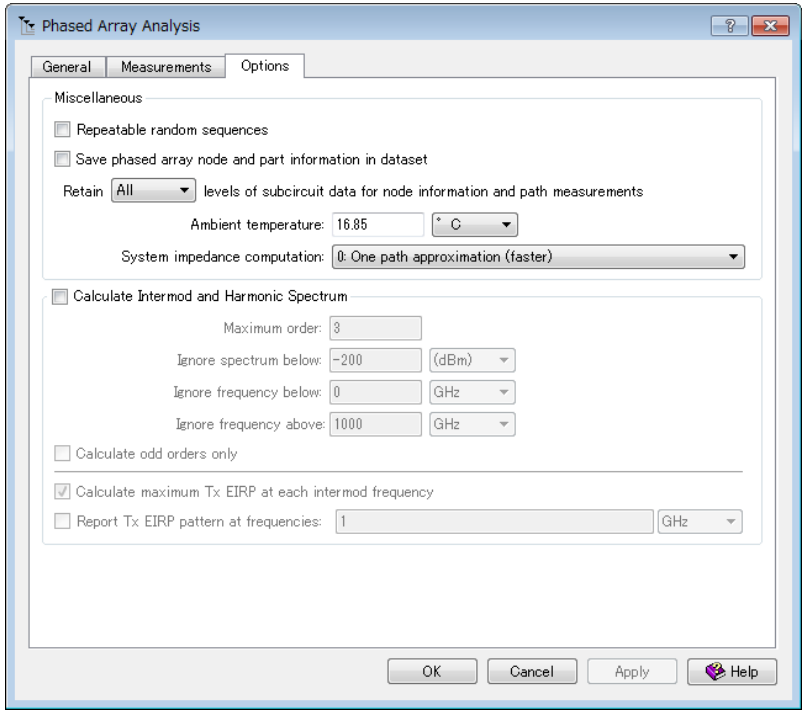
Lab 3: Phased Array Controller

- Open PhasedArray1 controller

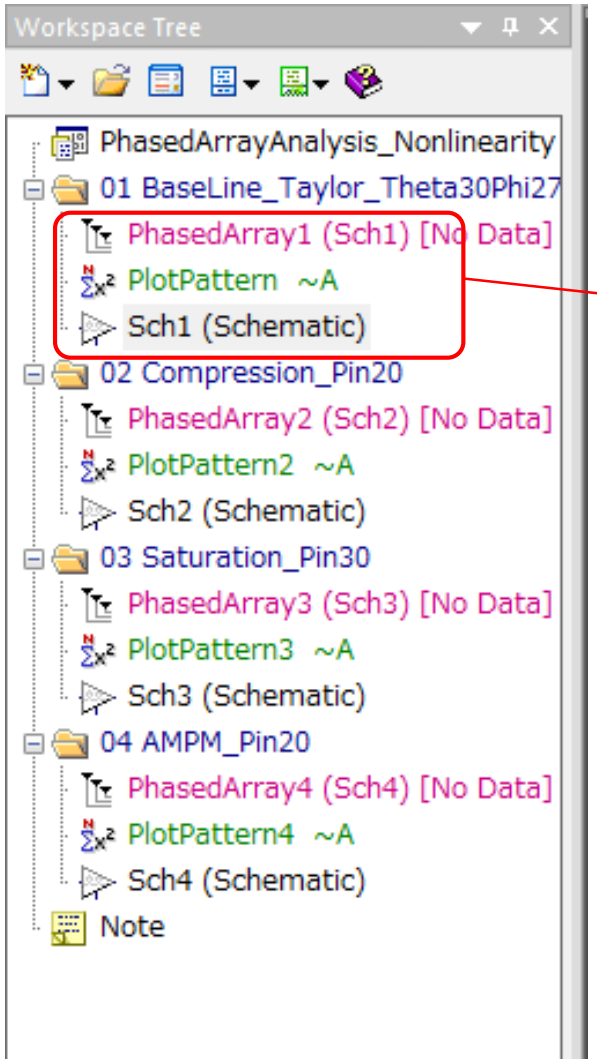
Check for main lobe power, etc. of beam measurement







Lab 3: Workspace Overview

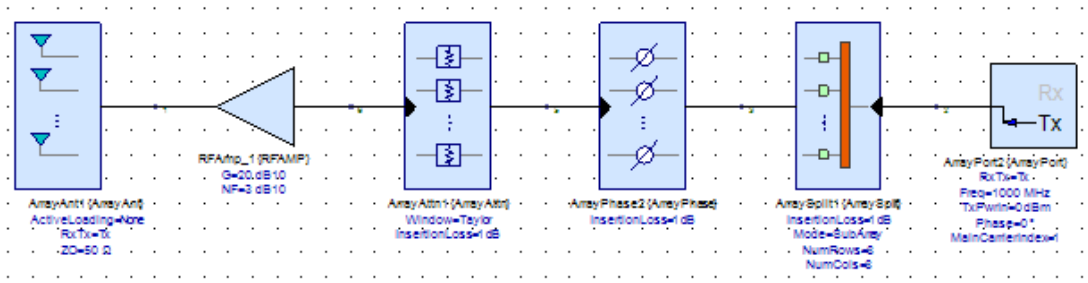


- Transmitter by Phased Array analysis
- 8x8 Uniformed Rectangular Array
- Verify amplifier nonlinearity effect on beam pattern
- Sch1 is ideal pattern (for reference)

01～04 folder has same structure except simulation setting or parameters

- PhasedArray_ : Controller
- PlotPattern_ : Equation for 3D plot after simulation
- Sch_ : Schematic design as follows

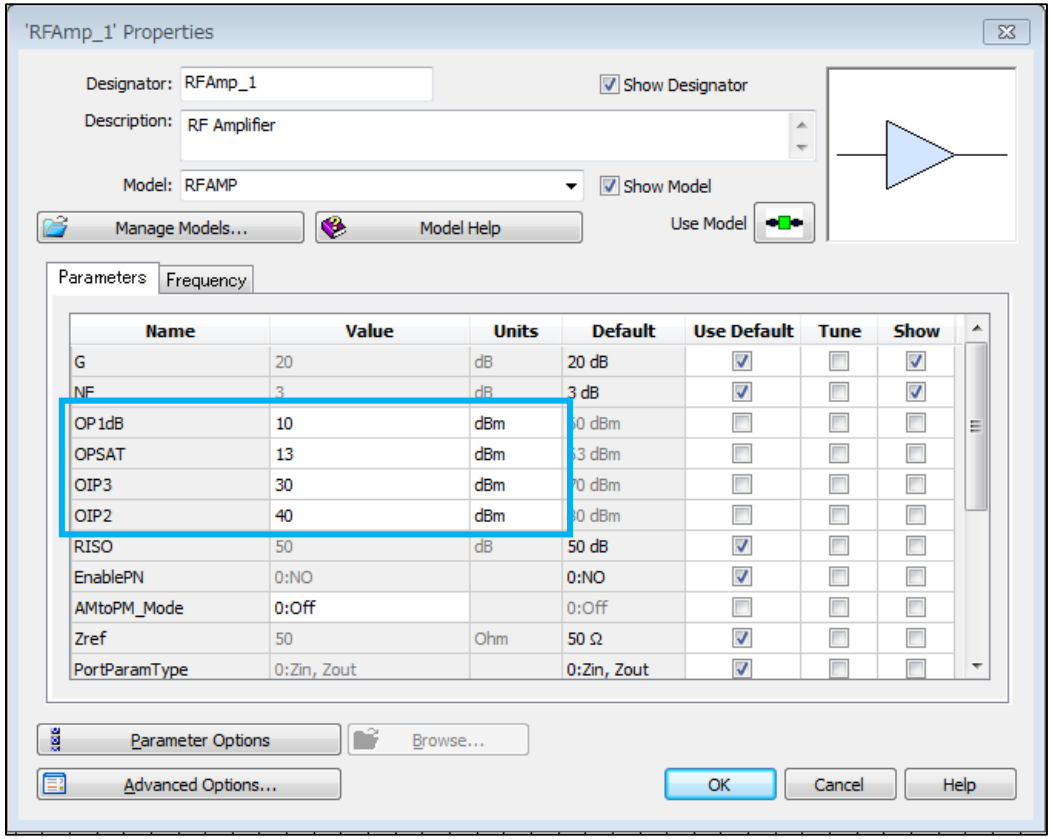
Sch1 ~ 4 is same design except parameter values



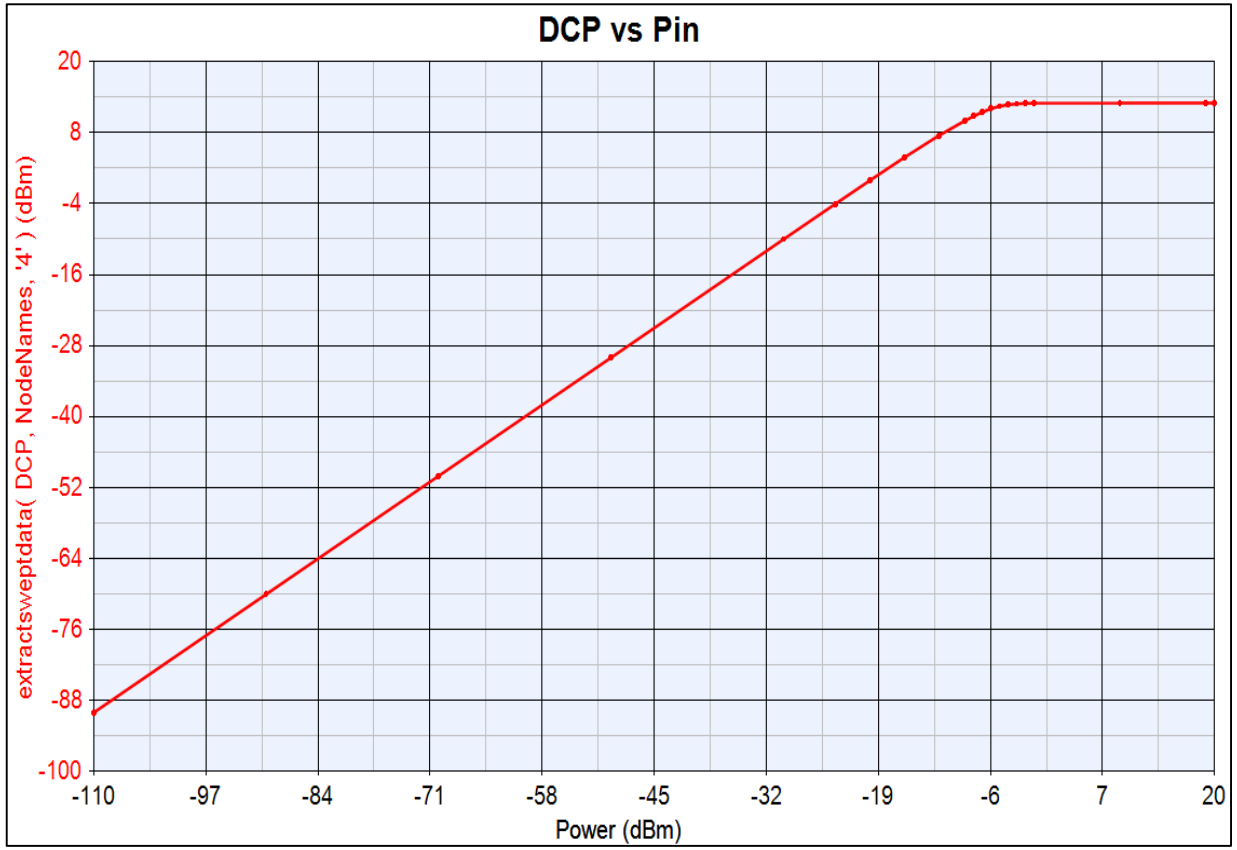
Antenna array | Attenuator | Amplifier | Phase Shifter | Splitter (Tx) | Port (Tx)

【Ref.】Gain Compression of Amplifier

- RF Amplifier model has nonlinear parameters as following images
  # Right plot is calculated by other simulation than this Lab

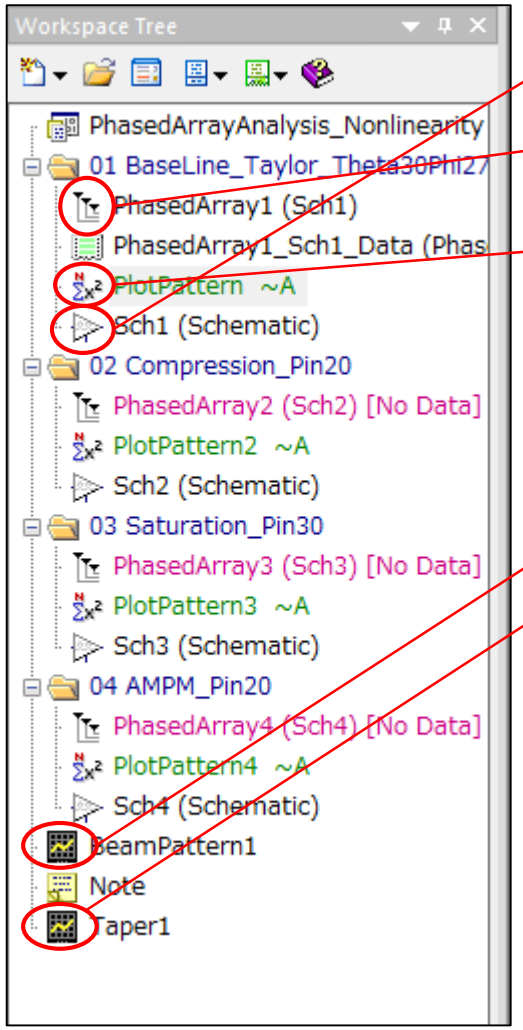


Name	Value	Units	Default	Use Default	Tune	Show
G	20	dB	20 dB	✓		✓
NF	3	dB	3 dB	✓		✓
OP1dB	10	dBm	0 dBm			
OPSAT	13	dBm	3 dBm			
OIP3	30	dBm	70 dBm			
OIP2	40	dBm	0 dBm			
RISO	50	dB	50 dB	✓		
EnablePN	0:NO		0:NO	✓		
AMtoPM_Mode	0:Off		0:Off			
Zref	50	Ohm	50 Ω	✓		
PortParamType	0:Zin, Zout		0:Zin, Zout	✓		



Lab 3: 01 BaseLine_Taylor_Theta30Phi270_Pin0

- Sch1 is for reference (= No errors, degrade) design



①Open Sch1

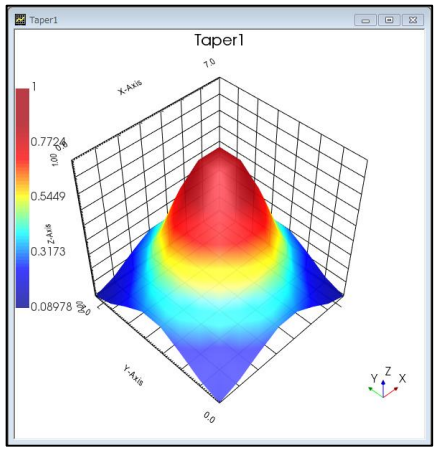
②Run PhasedArray1

③Run PlotPattern
（Right mouse click > Run Equations）

④Open BeamPattern1

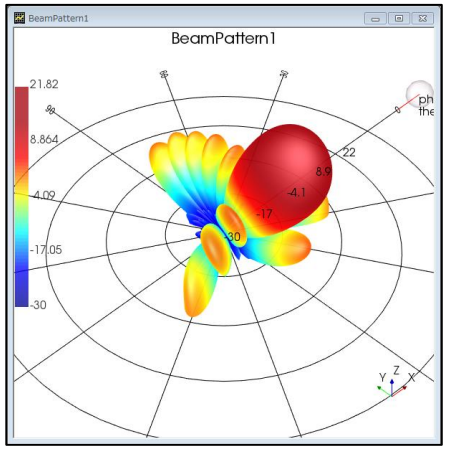
⑤Open Taper1

8x8 URA @ direction θ=30°, φ=270° (BeamPattern1)
Side Lobe level is -20dB by Taper1(Taylor Window)



Taper plot shows magnitude of each array elements

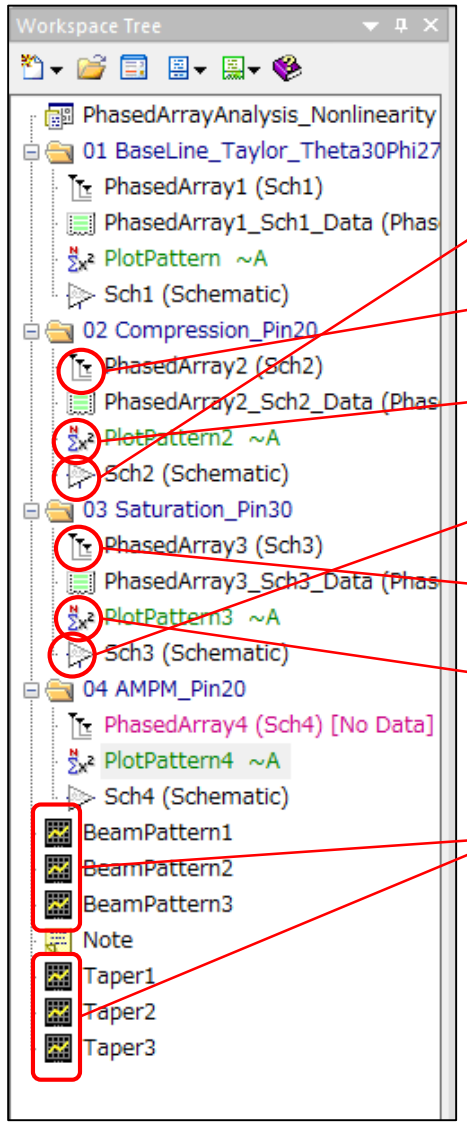
This plot is ideal:
Ideal Taylor Window shape set at ATT component



Reference beam pattern to be compared with pattern by Sch2 ~ Sch4.

Lab 3: Run 02, 03 and compare with 01

- Run and compare Sch2, Sch3 result with Sch1
- Beam Pattern and Taper plot is changed due to P1dB compression and PSaturation



⑥Open Sch2

⑦Run PhasedArray2

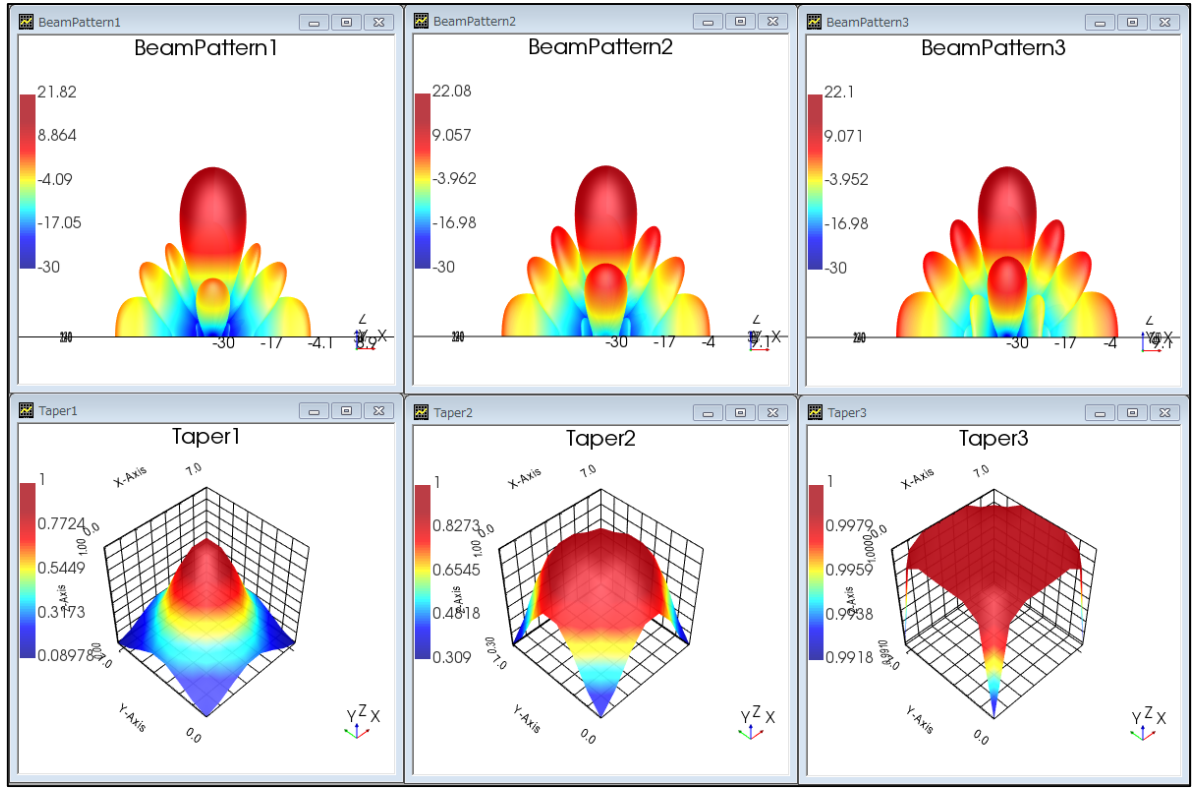
⑧Run PlotPattern2
(Right mouse click > Run Equations)

⑨Open Sch3

⑩Run PhasedArray3

⑪ Run PlotPattern3
(Right mouse click > Run Equations

⑫BeamPattern1～3
Taper1～3

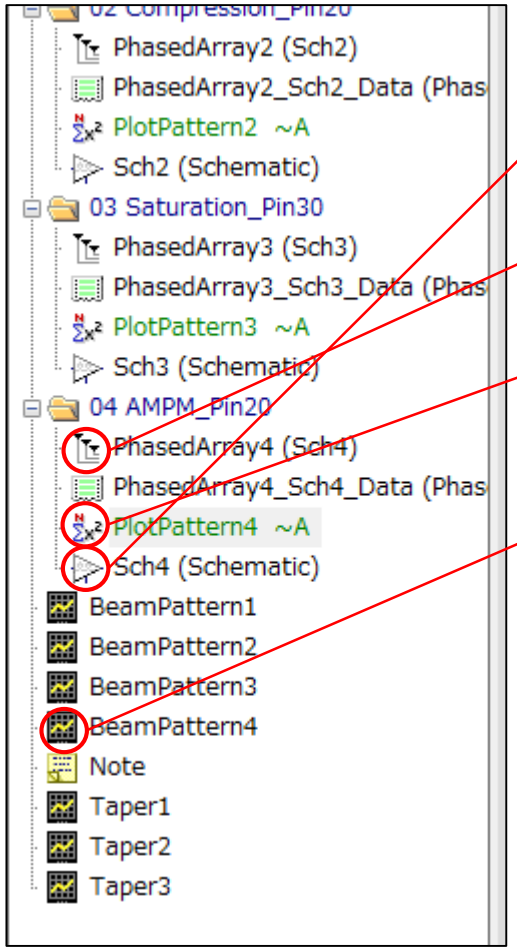


TxPwrIn = 0dBm TxPwrIn = 20dBm TxPwrIn = 30dBm

BeamPattern and Taper Plot

Lab 3: 04 AMPM_Pin20

➢ Sch4 simulates AM-PM conversion added to AM-AM at Amplifier

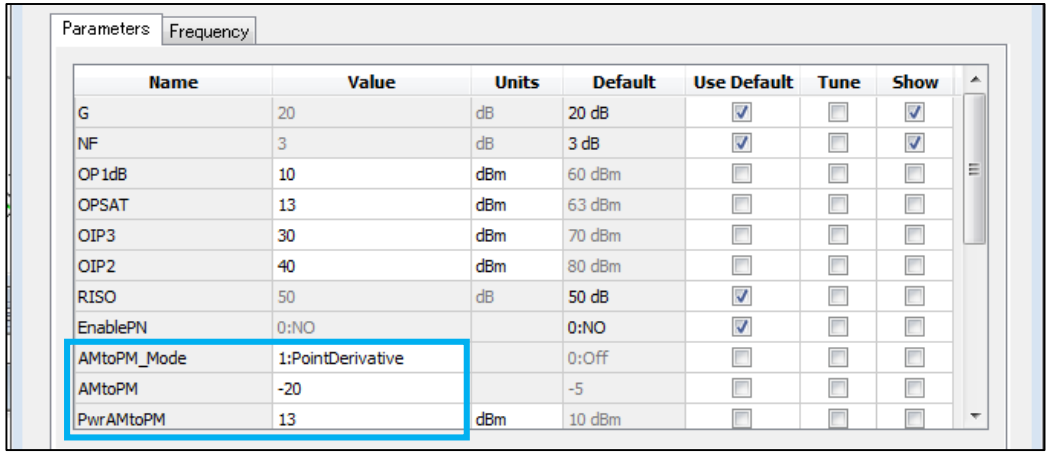


⑬Open Sch4

⑭Run PhasedArray4

⑮Run PlotPattern4
(Right mouse click > Run Equations)

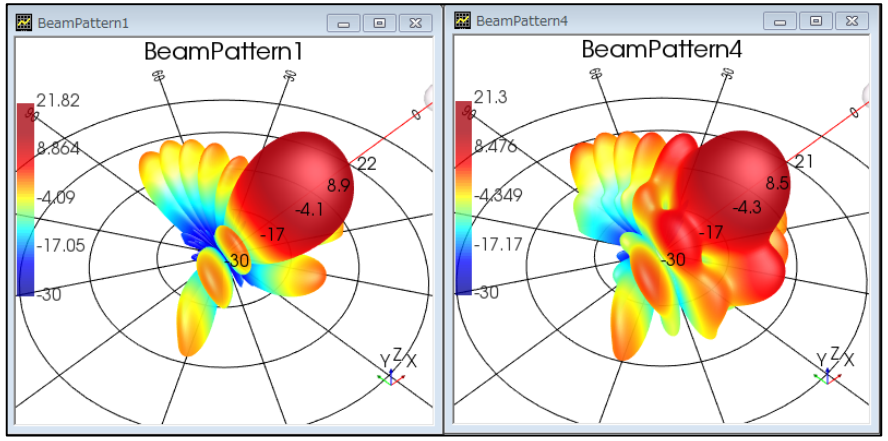
⑯Open BeamPattern4



Parameters | Frequency

Name	Value	Units	Default	Use Default	Tune	Show
G	20	dB	20 dB	☑	☐	☑
NF	3	dB	3 dB	☑	☐	☑
OP1dB	10	dBm	60 dBm	☐	☐	☐
OPSAT	13	dBm	63 dBm	☐	☐	☐
OIP3	30	dBm	70 dBm	☐	☐	☐
OIP2	40	dBm	80 dBm	☐	☐	☐
RISO	50	dB	50 dB	☑	☐	☐
EnablePN	0:NO		0:NO	☑	☐	☐
AMtoPM_Mode	1:PointDerivative		0:Off	☐	☐	☐
AMtoPM	-20		-5	☐	☐	☐
PwrAMtoPM	13	dBm	10 dBm	☐	☐	☐

Amplifier parameter in Sch4

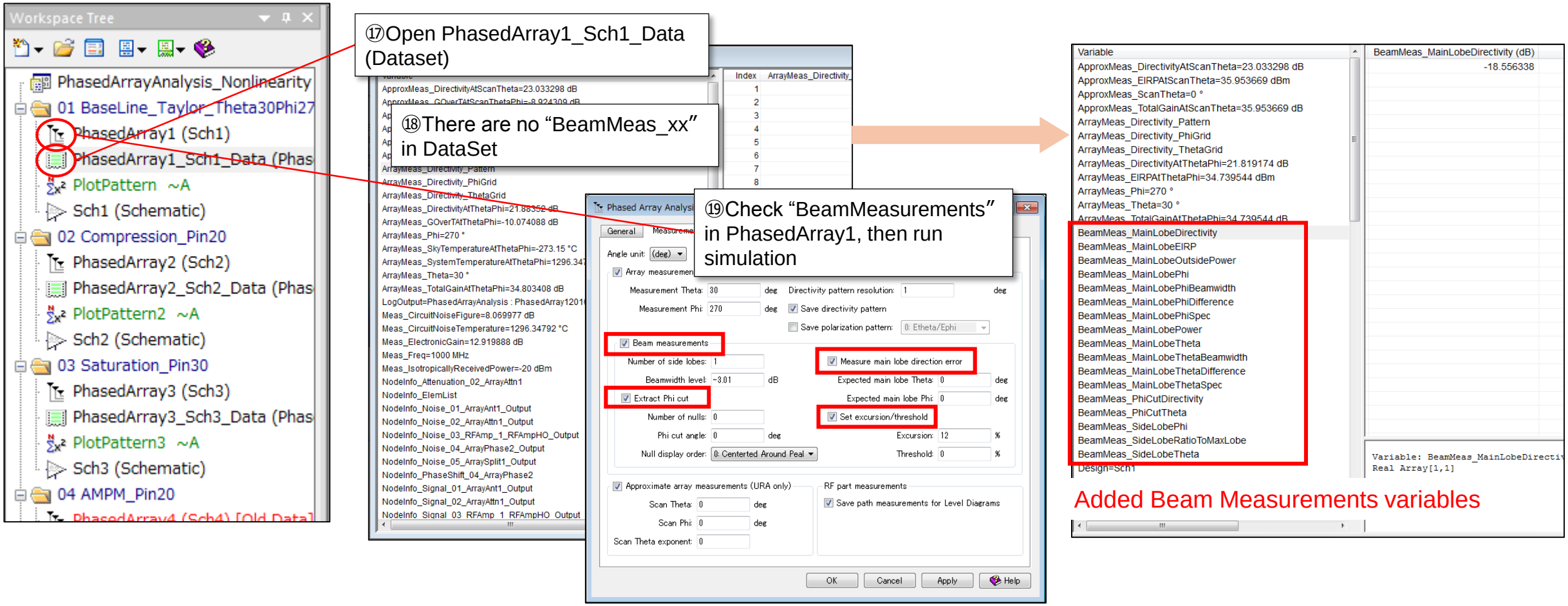


Amplitude distortion (Sch2/3):
→ Only main lobe to side lobe magnitude ratio.
It cancels taper effect.

Phase distortion (Sch4):
→ Affects beam pattern itself

Lab 3. Beam Measurements and DataSet

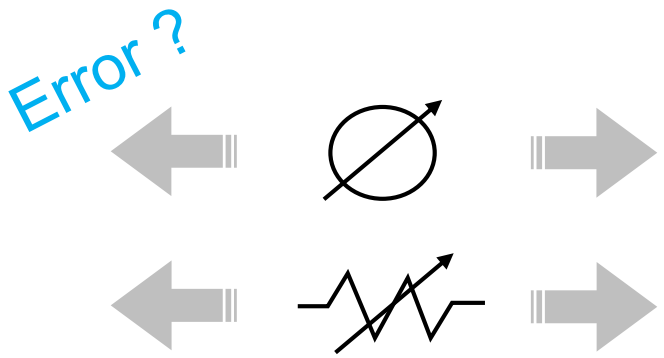
- If turning ON: Beam Measurements in Phased Array controller, Dataset contains Beam Measurement variables



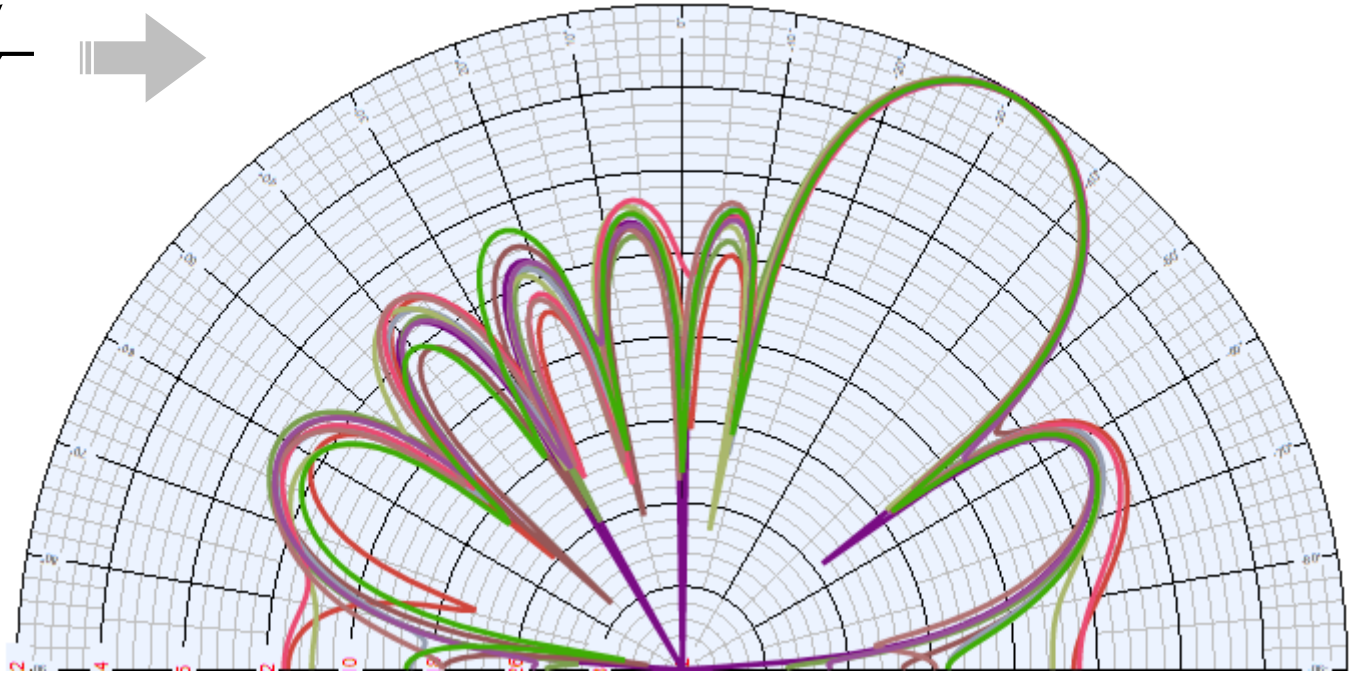
Added Beam Measurements variables

Lab 4: Monte Carlo Analysis

Lab 4: Monte Carlo Analysis



Phase Error : Std. Dev. 10 deg.
Attenuation Error : Std. Dev. 1dB
各々Normal(Gaussian)分布で設定



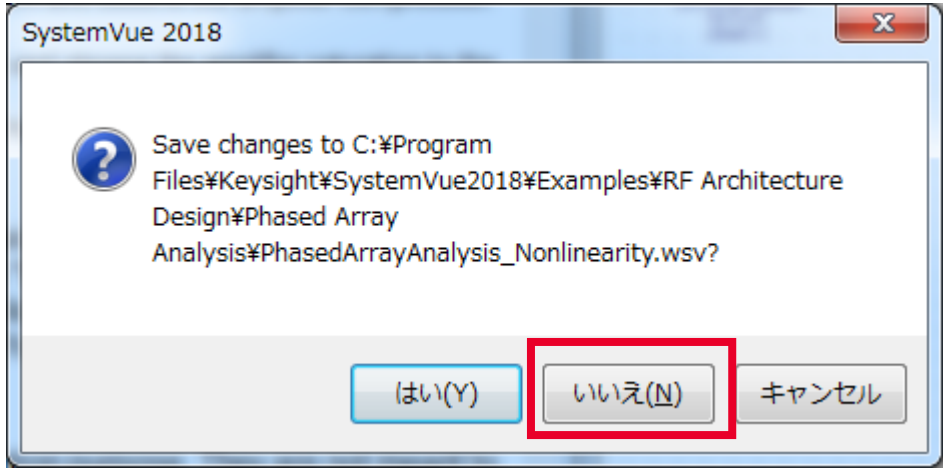
Lab 4 : Exercise

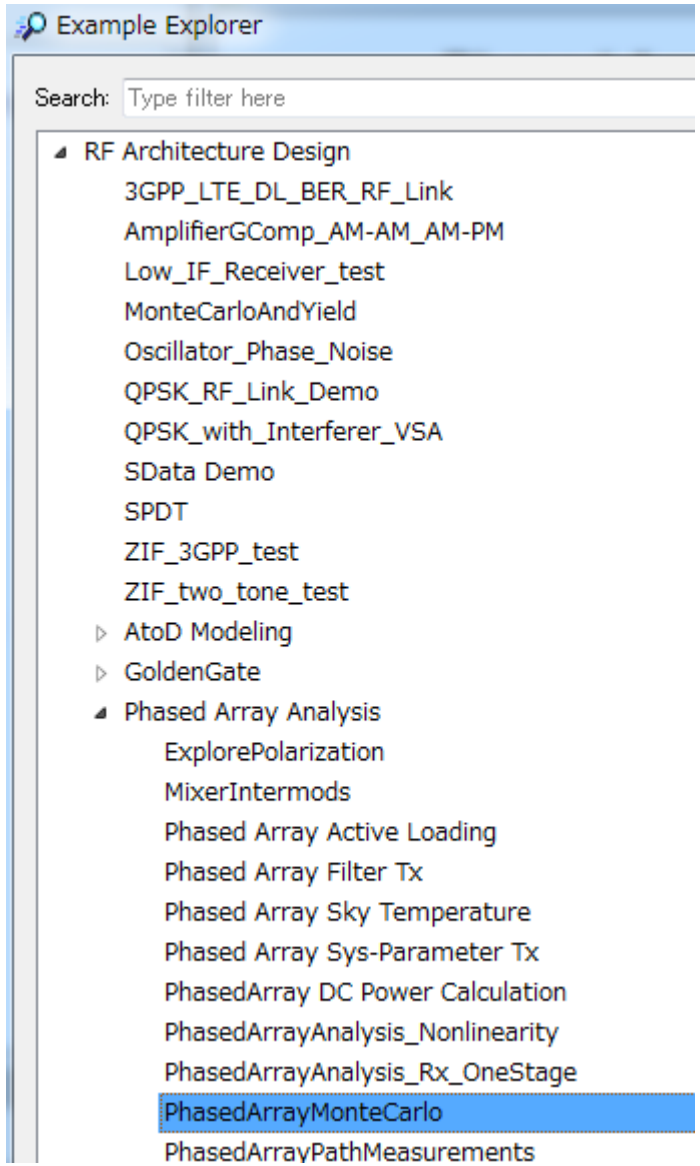
Lab 4: Monte Carlo Analysis

➢Help > Example Explorer

Open RF Architecture Design > Phased Array Analysis > PhasedArrayMonteCarlo

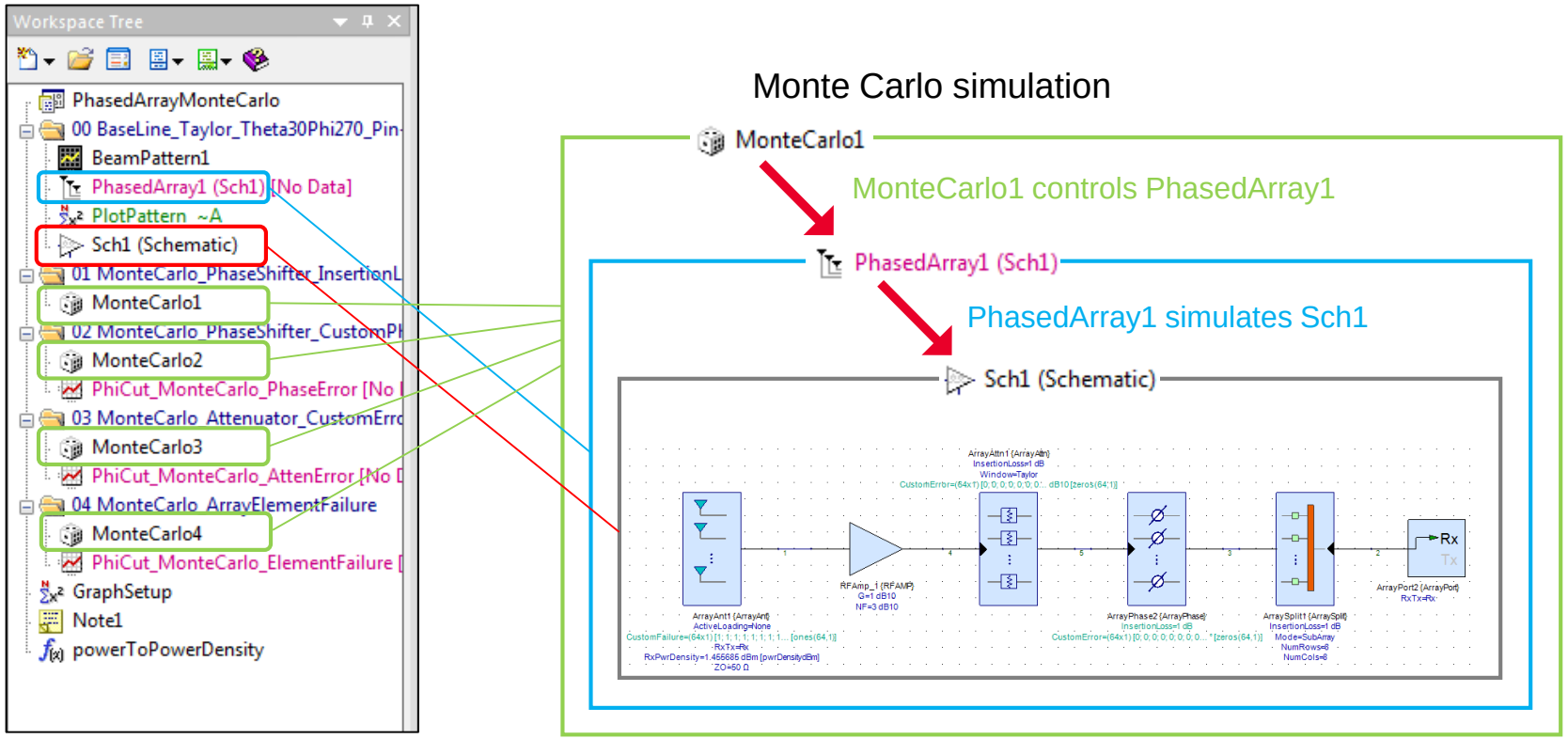
!! Choose “No” not to save current workspace !!



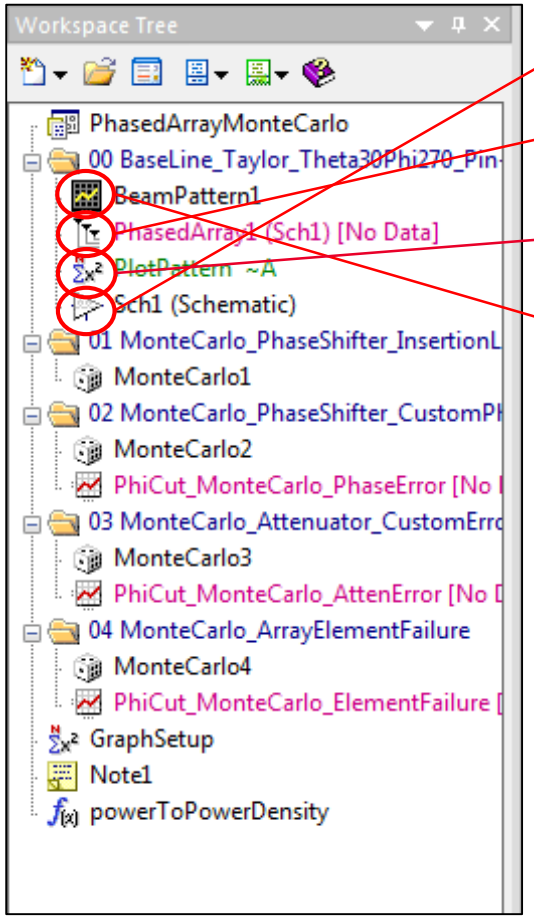


Lab 4: Workspace Overview

- Reciever by Phased Array analysis
- 8x8 Uniformed Rectangular Array
- Sch1 is the design to be simulated (ideal pattern for reference)
- MonteCarlo1~4 simulates deviation effect of different parameters



Lab 4: Run PhasedArray1 (No Error)

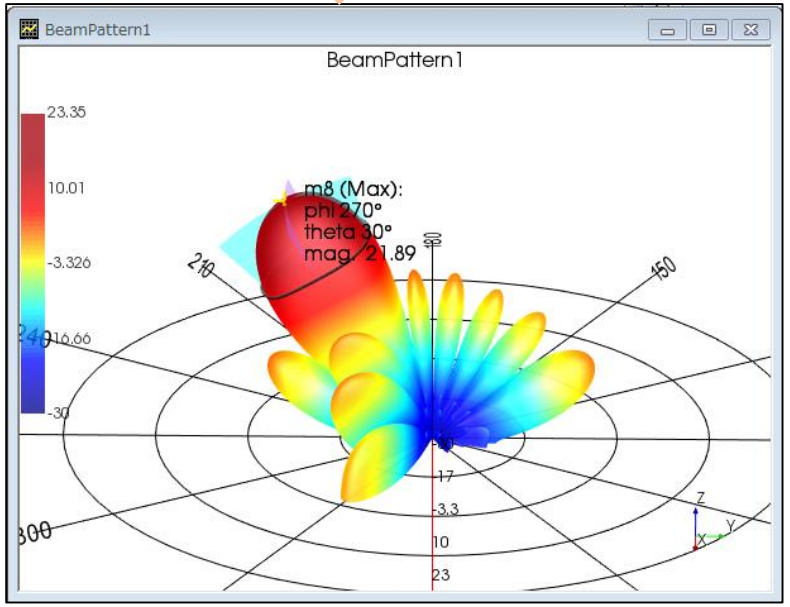


①Open Sch1

②Run PhasedArray1

③Run PlotPattern
(Right mouse click > Run Equations)

④Open BeamPattern1



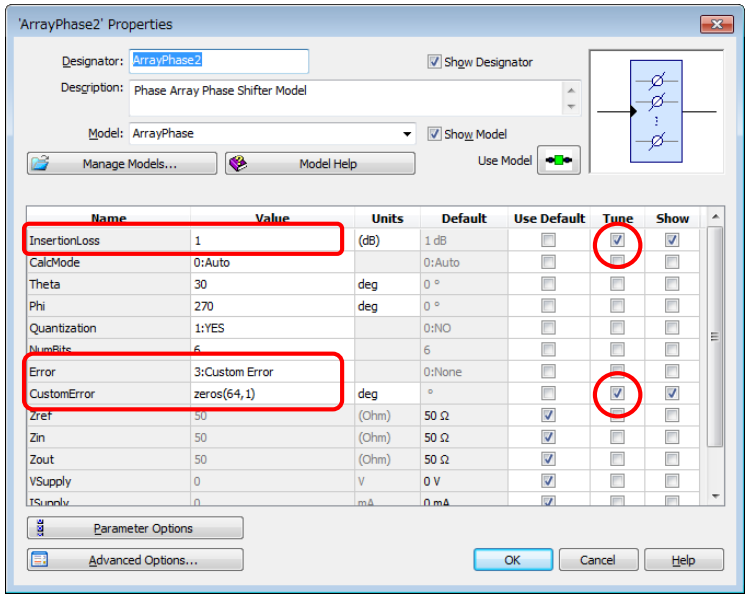
Beam pattern without error

8x8 URA
Beam direction : θ=30°、φ=270°
Side Lobe : -20dB by Taylor Window

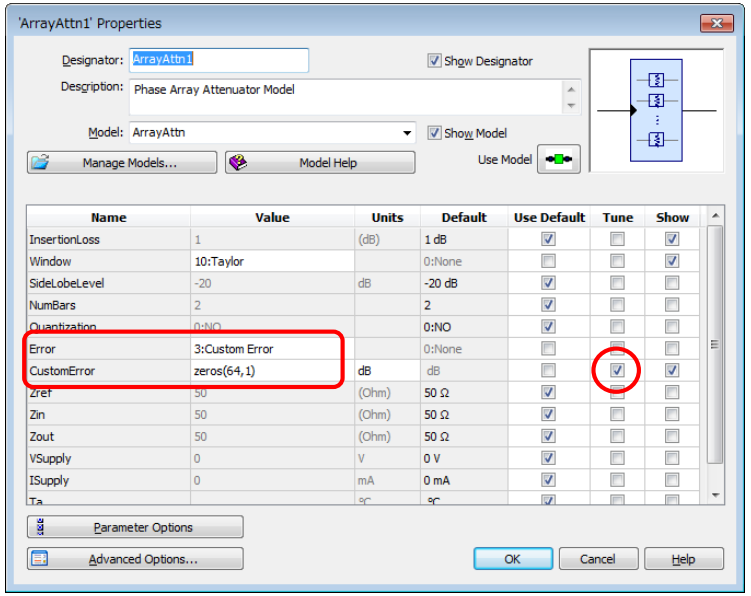
Lab 4: Error Configuration (#Check Only)

- Check Error parameters to be tuned by MonteCarlo of following components
- CustomError means “MonteCalro controls the value” (#refer next page)

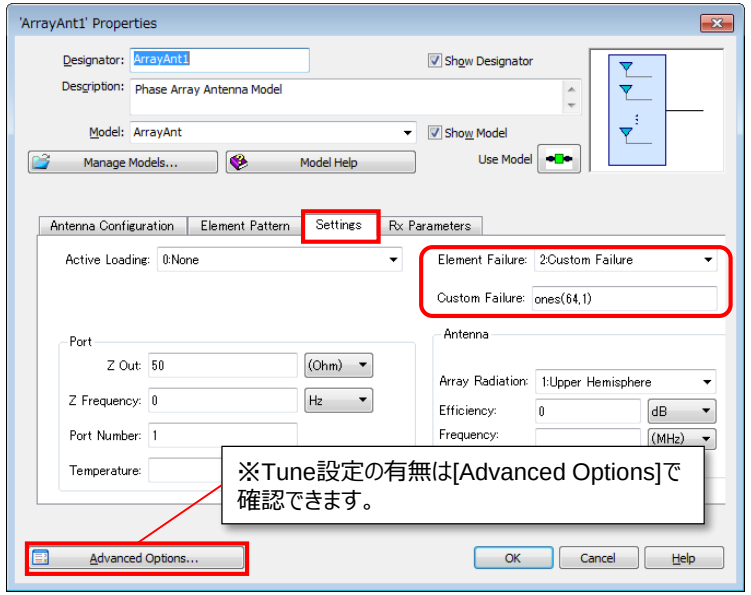
ArrayPhase2



ArrayAttn1



ArrayAnt1



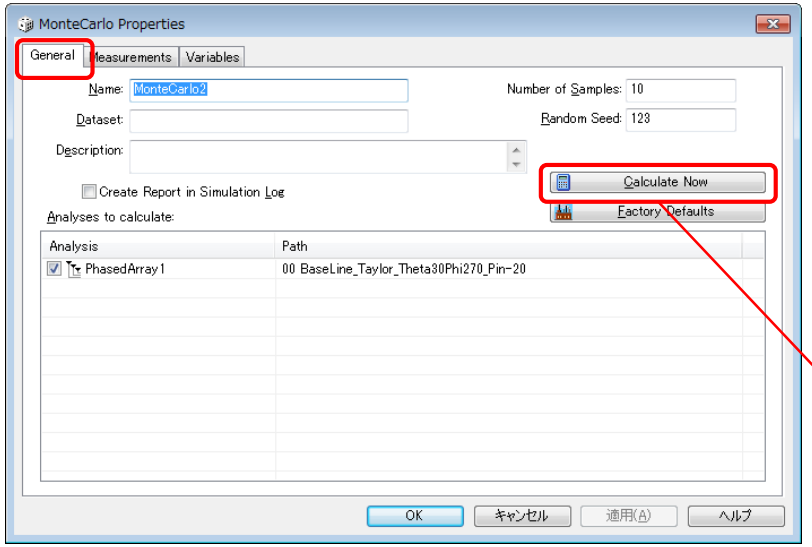
Lab 4: MonteCarlo Controller

➢ Open property of MonteCarlo2 and confirm the settings

⑤Open MonteCalro2 controller

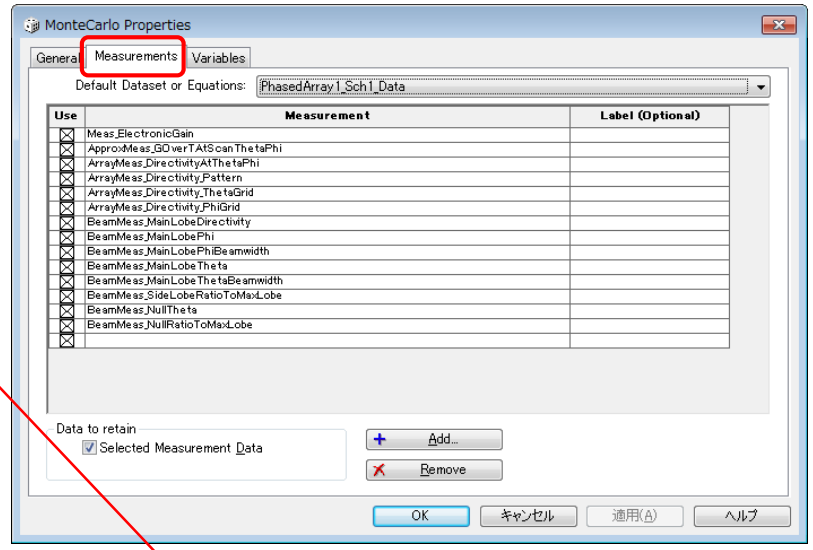
General

Specify simulation controller and number of simulations



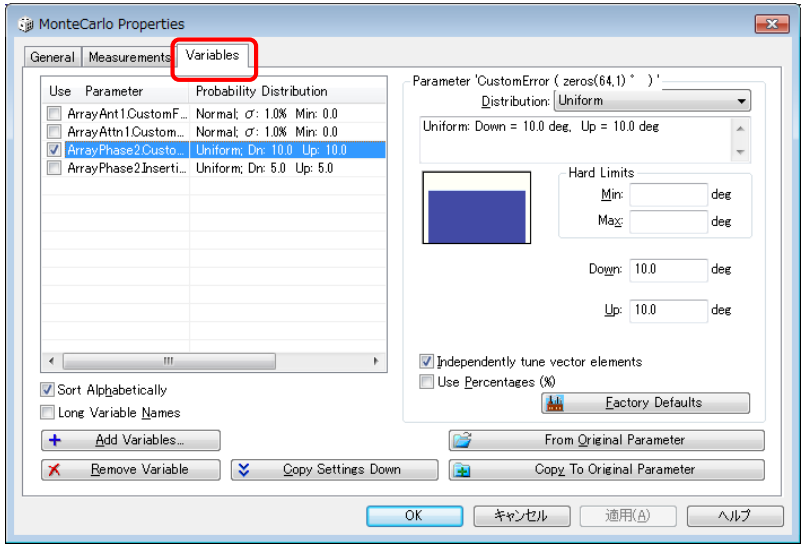
Measurements

Specify items in Dataset to be saved as MonteCalro result



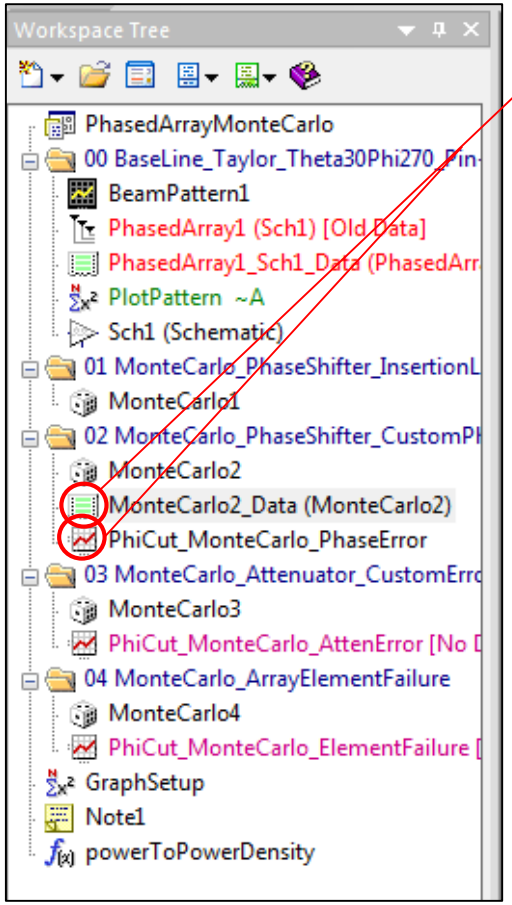
Variables

Set distribution of each parameters
E.g. Phase error → 10% uniform distribution



⑥Run MonteCarlo after confirming settings

Lab 4: Dataset and Plot by MonteCarlo2

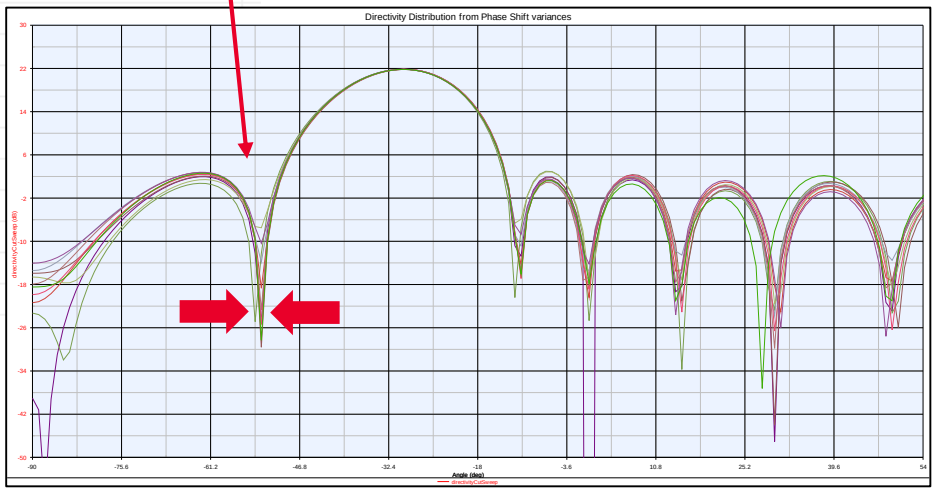


⑦Open MonteCarlo2_Data and PhiCut_MonteCarlo_PhaseError

Variable	Index	round_Swp	BeamMeas_NullTheta (°)
ApproxMeas_GOverTAtScanThetaPhi	1	1	-53
ArrayMeas_Directivity_Pattern	2	2	-54
ArrayMeas_Directivity_PhiGrid	3	3	-53
ArrayMeas_Directivity_ThetaGrid	4	4	-53
ArrayMeas_DirectivityAtThetaPhi	5	5	-53
BeamMeas_MainLobeDirectivity	6	6	-53
BeamMeas_MainLobePhi	7	7	-53
BeamMeas_MainLobePhiBeamwidth	8	8	-53
BeamMeas_MainLobeTheta	9	9	-53
BeamMeas_MainLobeThetaBeamwidth	10	10	-53
BeamMeas_NullRatioToMaxLobe			
BeamMeas_NullTheta			
BeamMeas_SideLobeRatioToMaxLobe			
Meas_ElectronicGain			
round_Swp			
round_Swp_Rounds			
Rounds			
Setting_ArrayPhase2_CustomError			
Settings			
VarLongNames			
VarNames			

Phase of Null varies by 1°

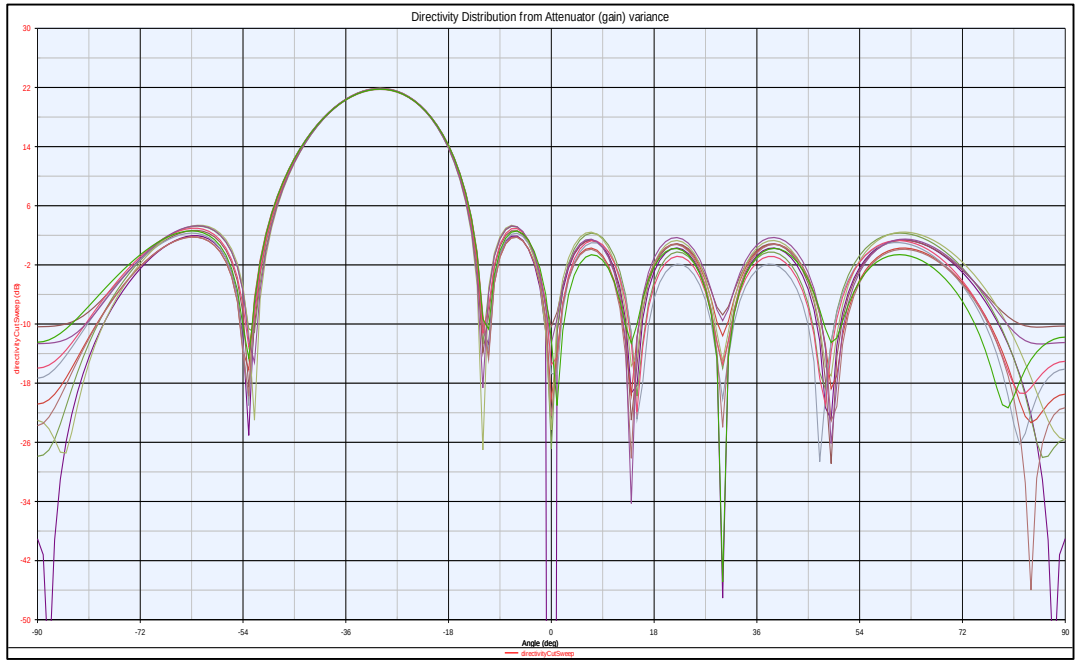
MonteCarlo2
Directivity distribution from
Phase shift variances



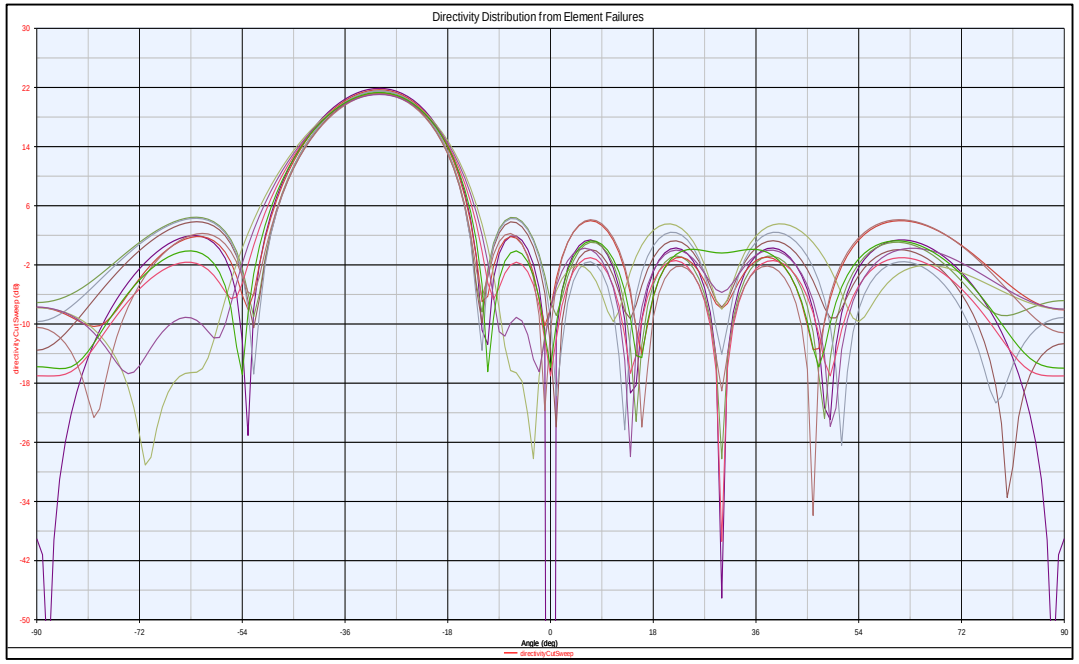
Lab 4: MonteCarlo3/4

- Check/Run MonteCarlo3, MoteCarlo4 and compare the plots

MonteCarlo3
Directivity distribution from Attenuator(Gain) variances



MonteCarlo4
Directivity distribution from Element Failures

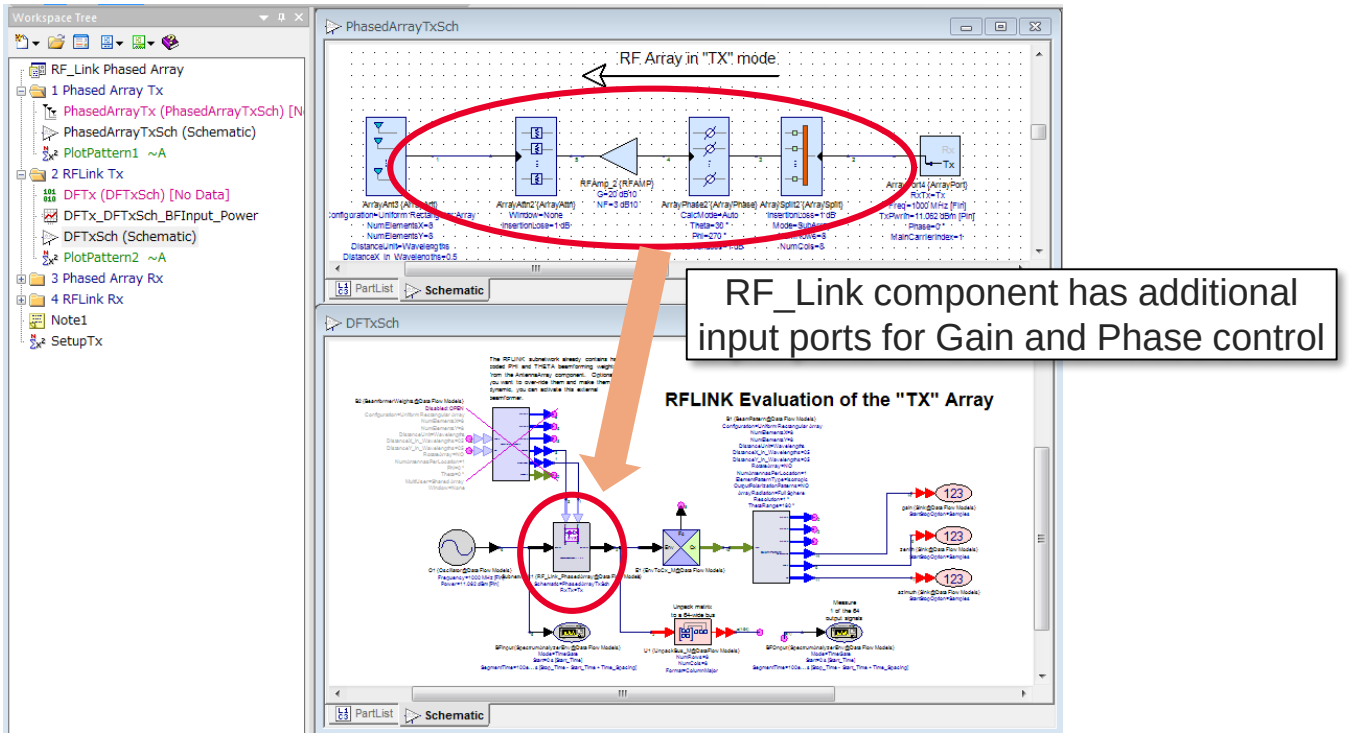


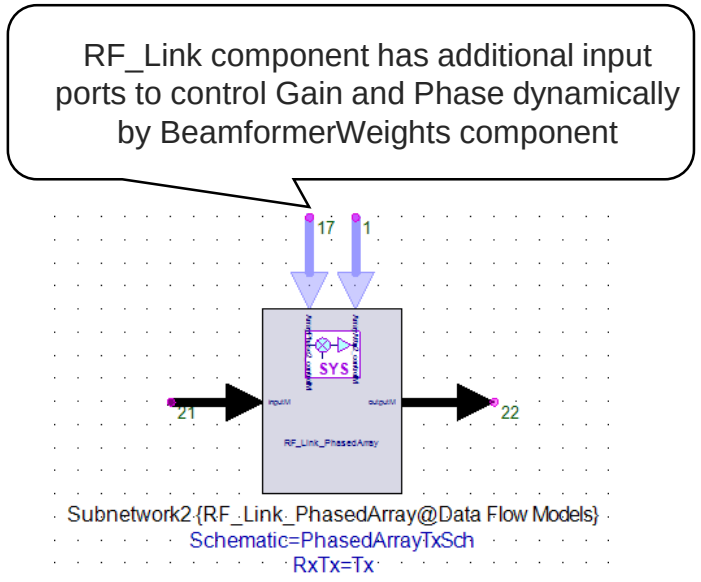
Monte Carlo can be applied to Data Flow simulation

【Ref.】RF_Link for Phased Array design

➢Help > Example Explorer

Open RF Architecture Design > Phased Array Analysis > RF_Link Phased Array.wsv



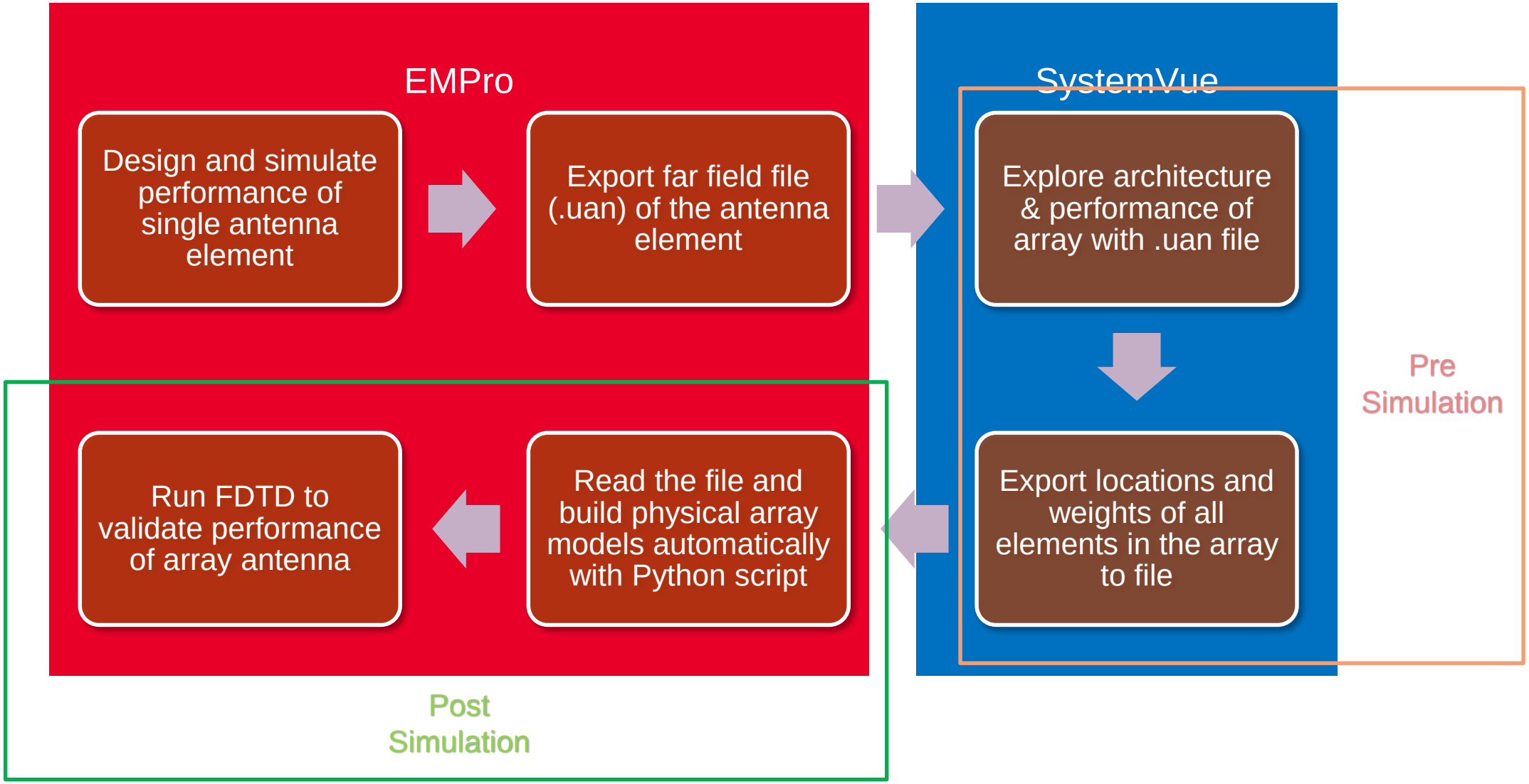


RF_Link for Phased Array design

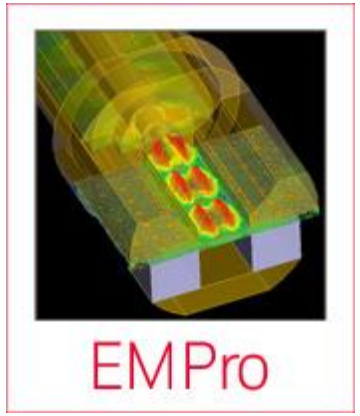
Array Antenna Design and Verification with SystemVue and EMPro

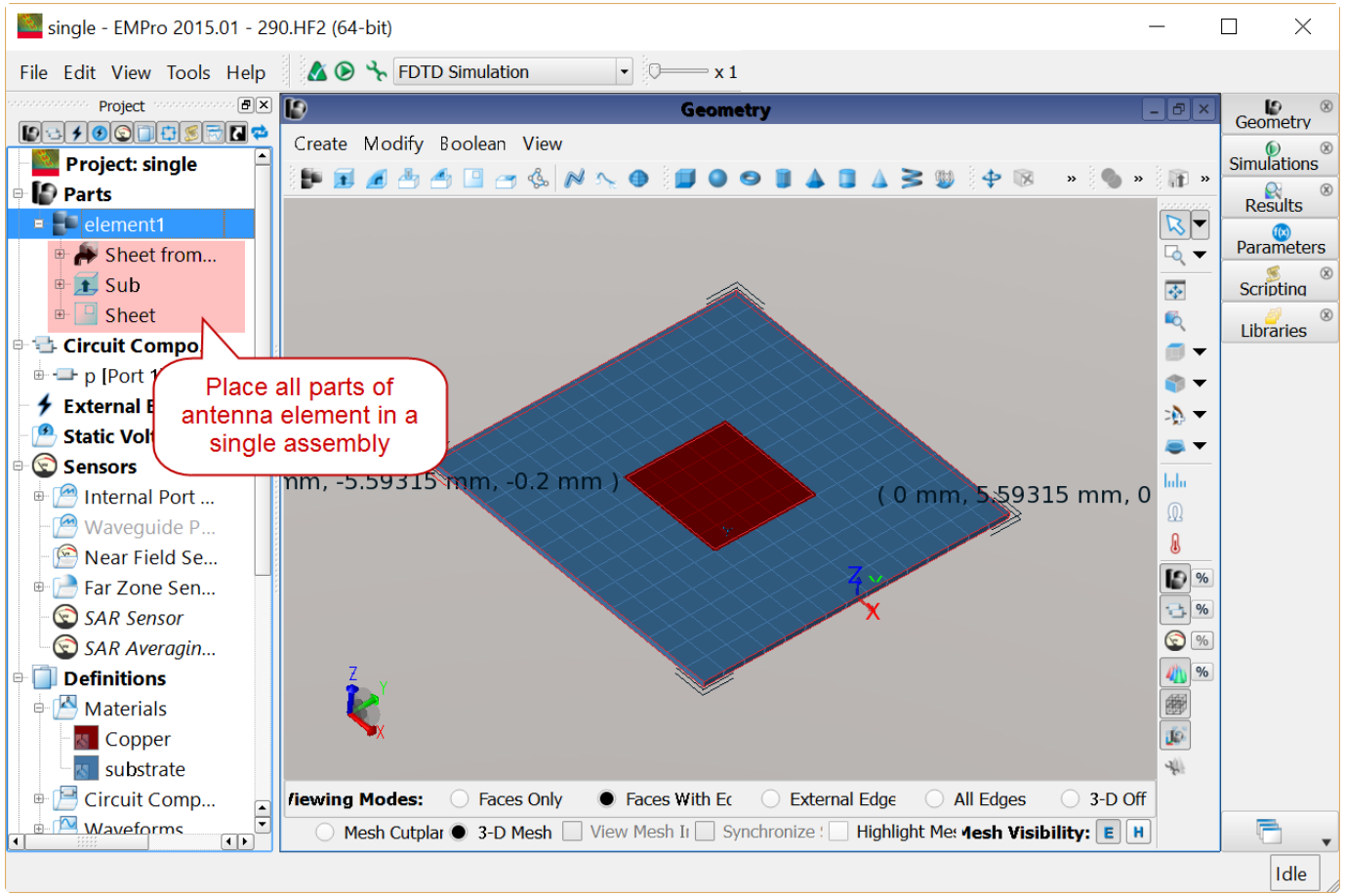
APPENDIX

EMPro–SV Array Design Flow

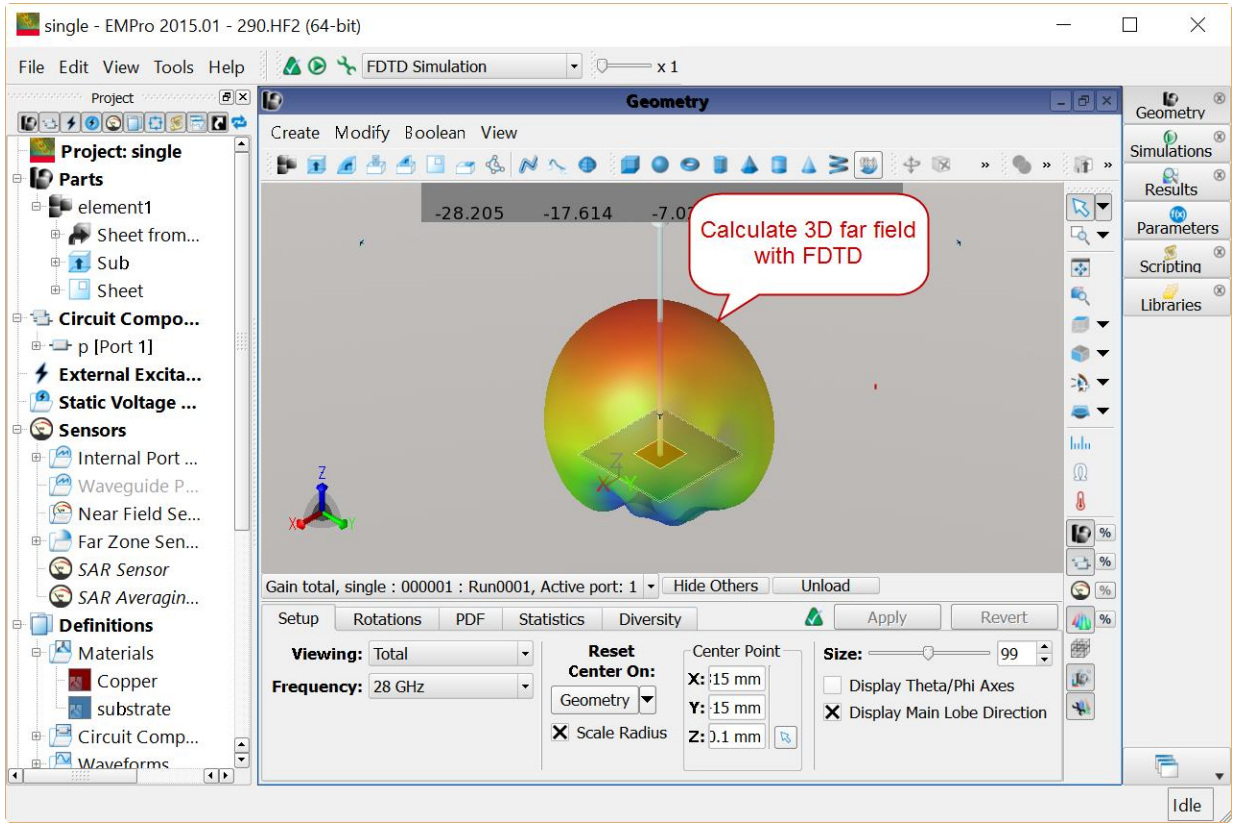


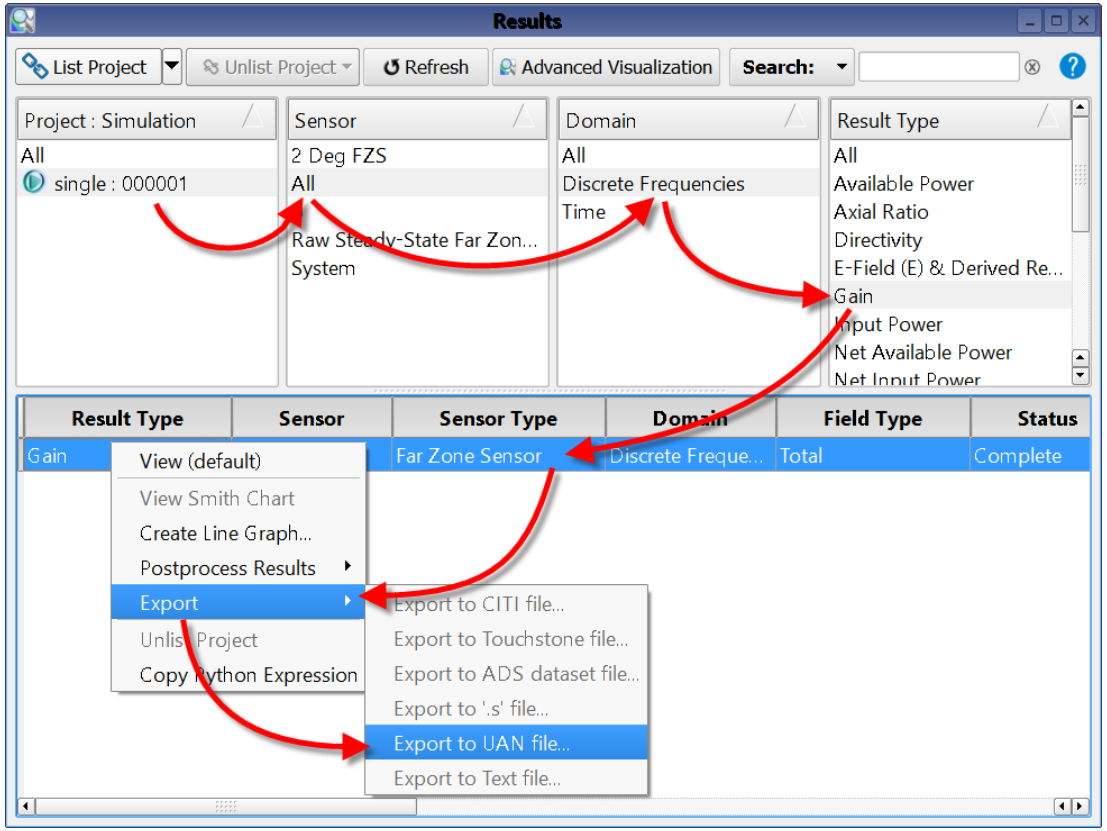
Complete Setting of Antenna Element in EMPro





Calculate 3D Far Field with EMPro

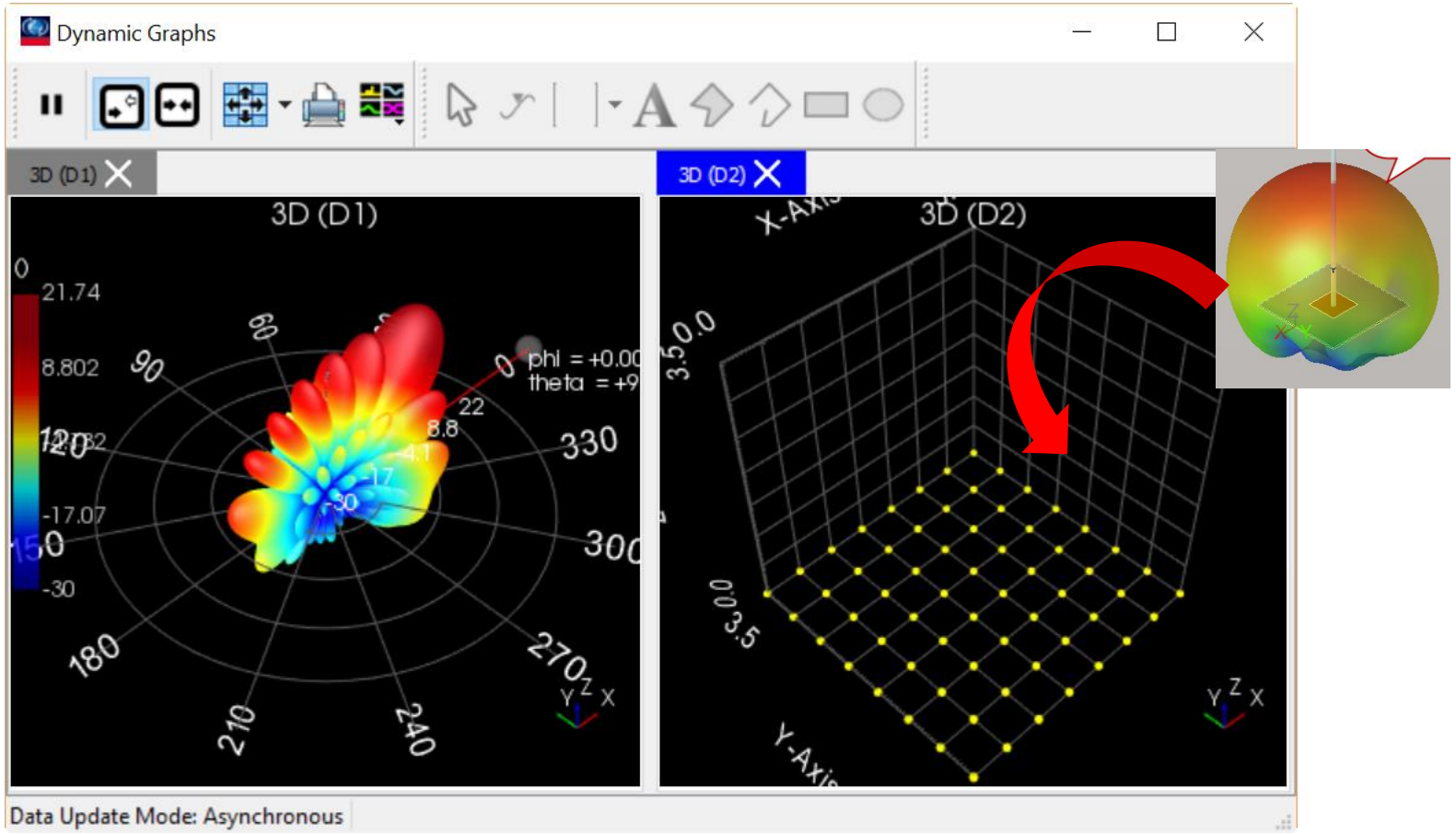


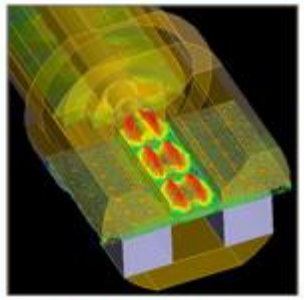


Export 3D Far Field of Antenna Element to UAN

Examine Array Performance in SV

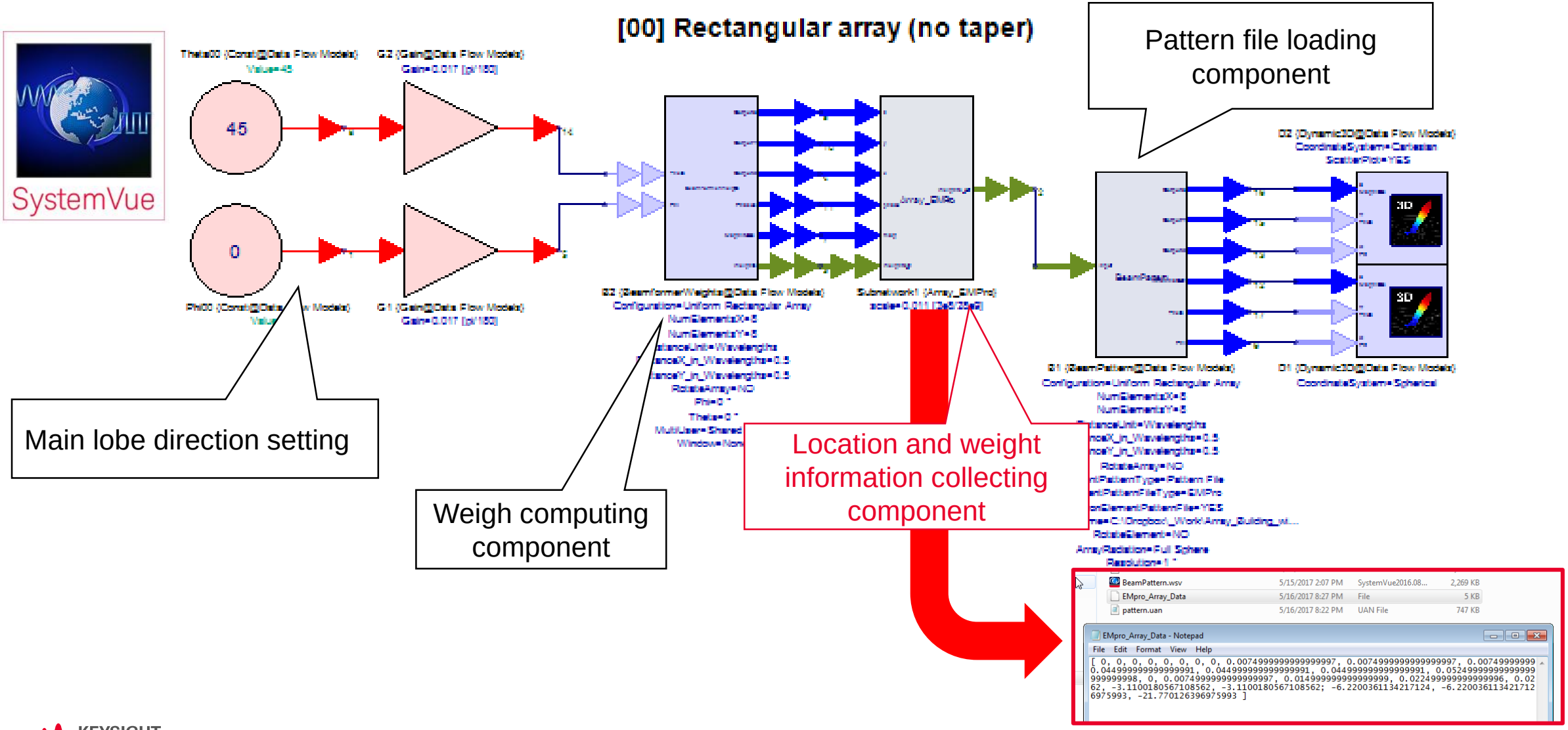
SystemVue



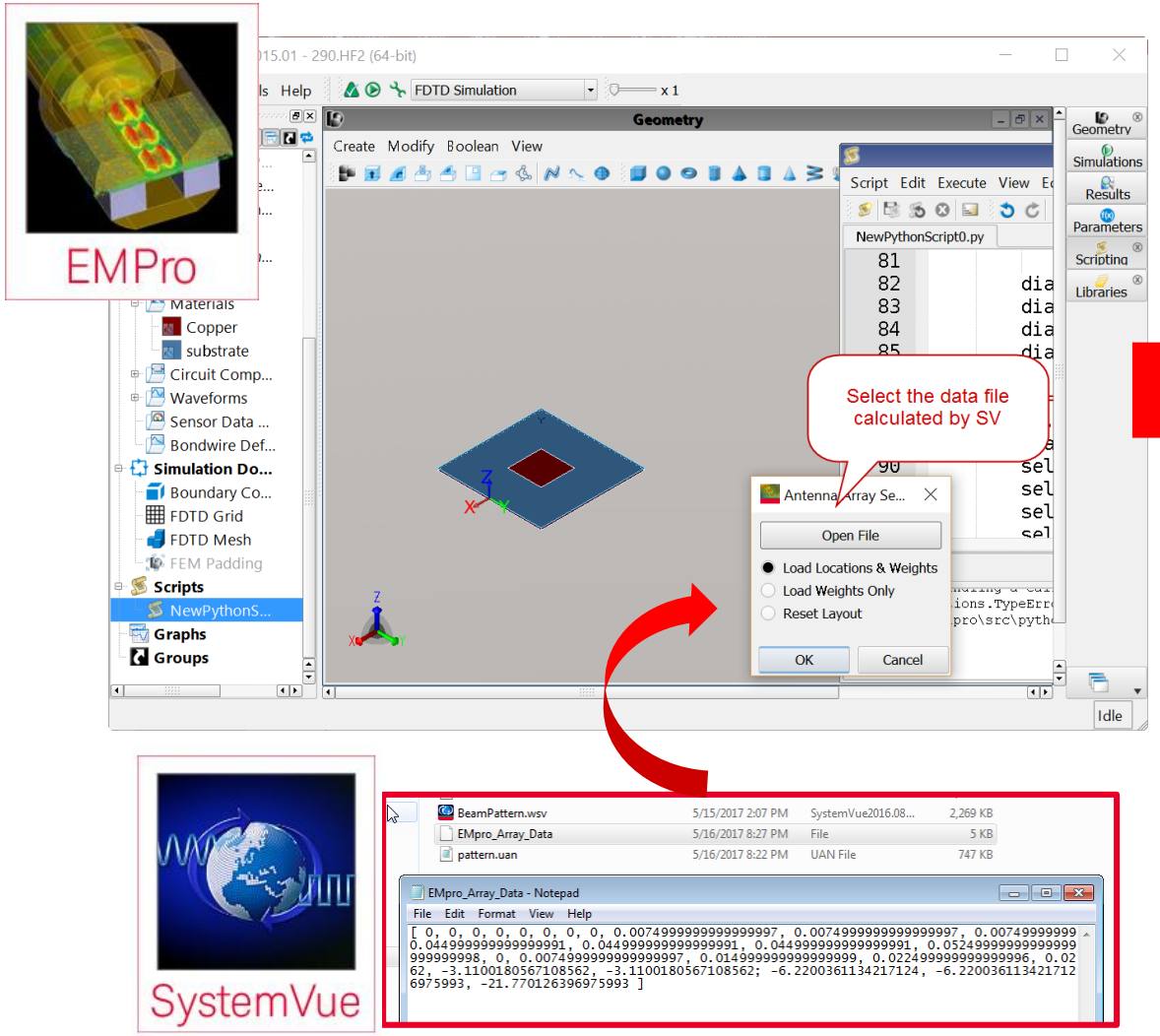


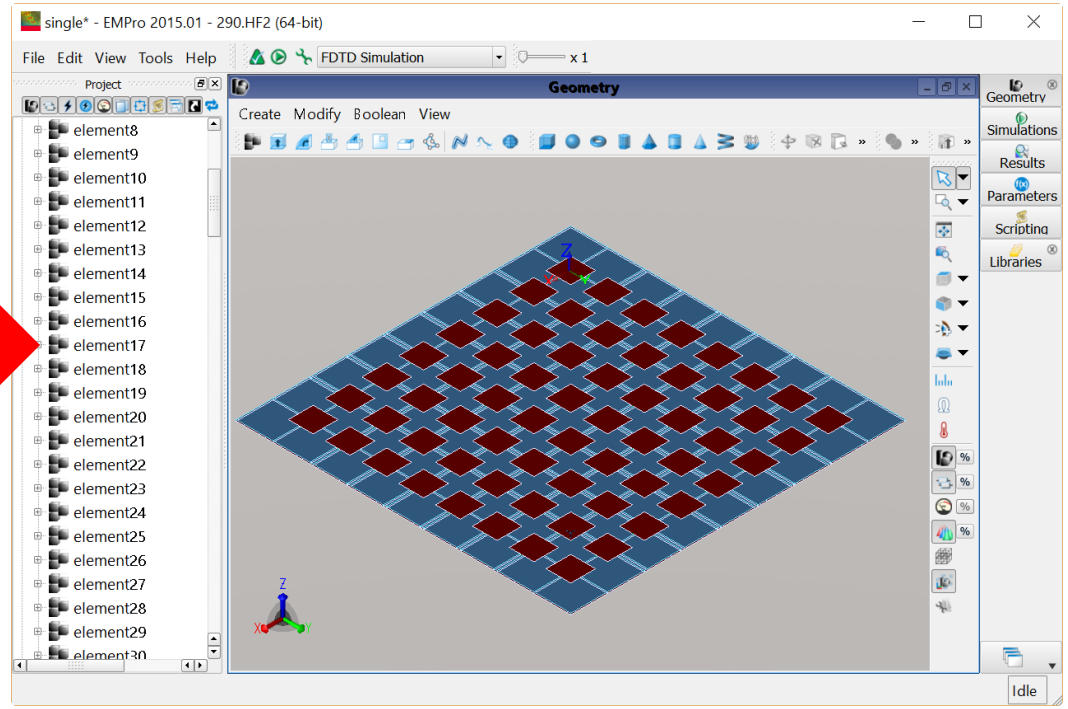
EMPro

Design Antenna Array in SystemVue



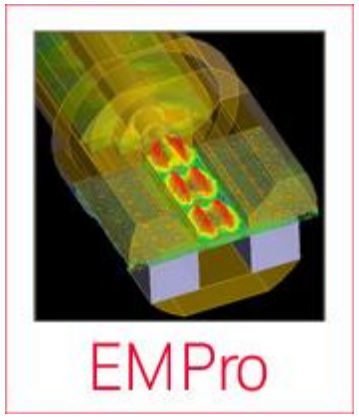
Build Array with Data provided by SV

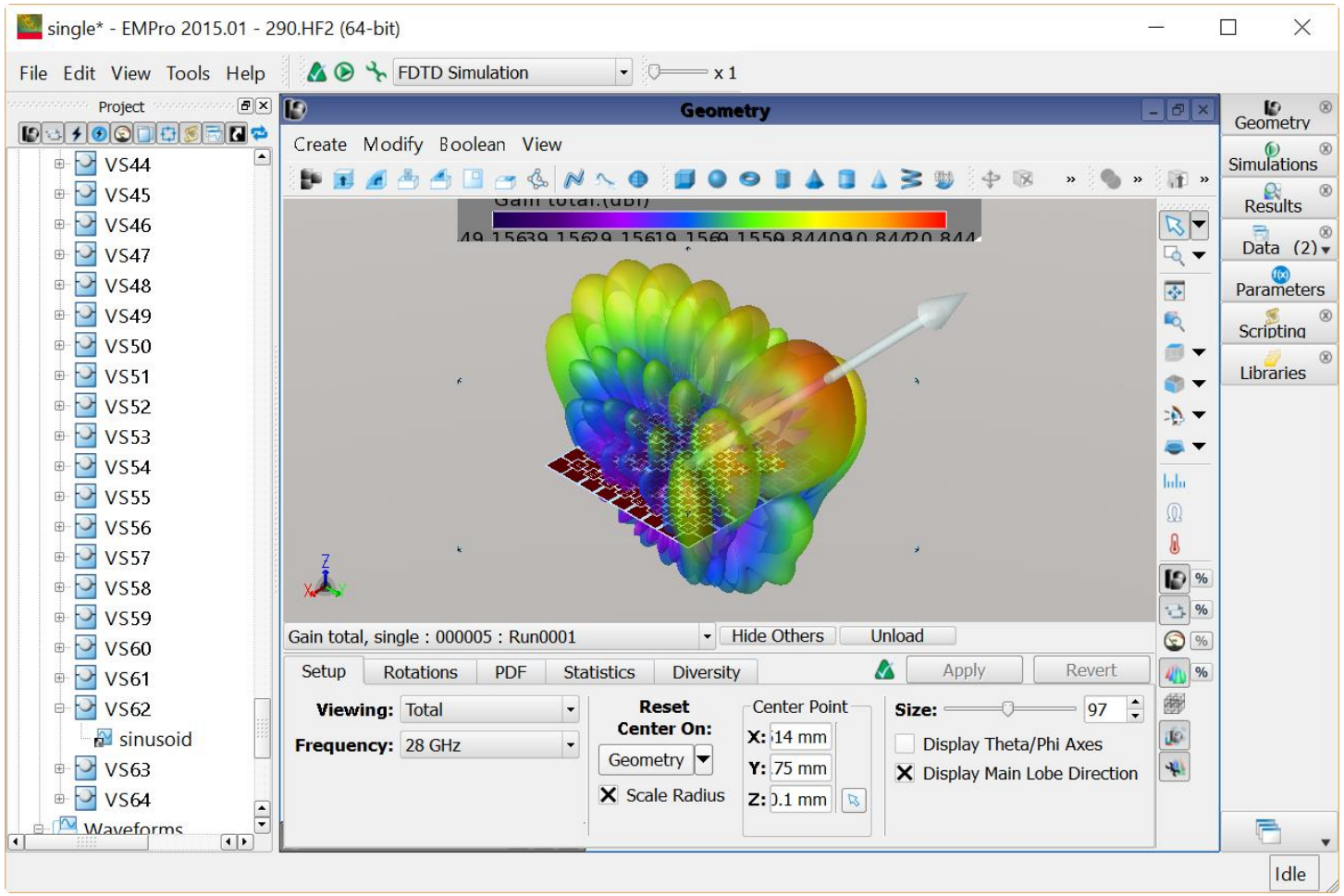




Array and Weights are Created Automatically

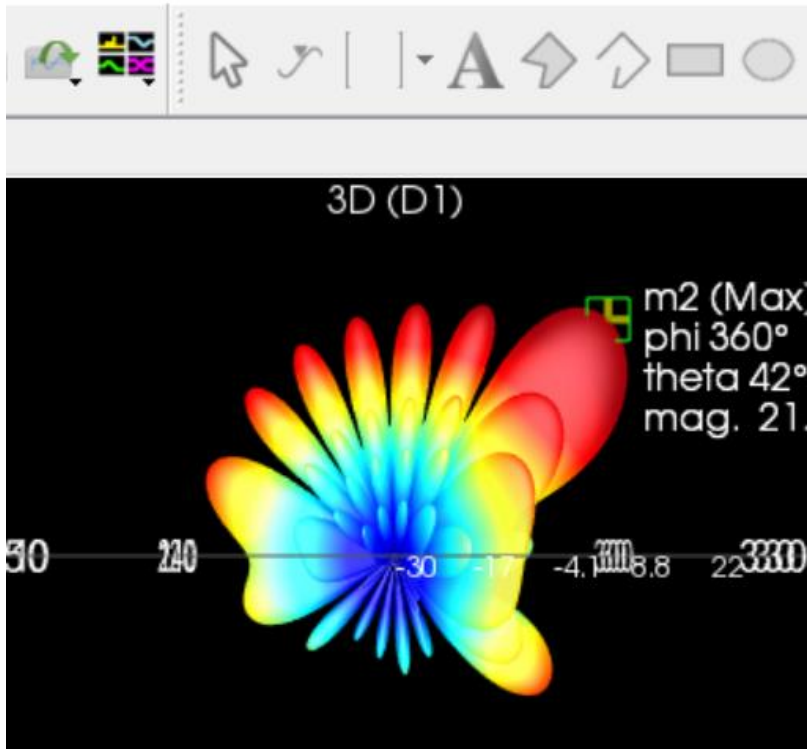
Run EMPro FDTD to check Final Performance of Array



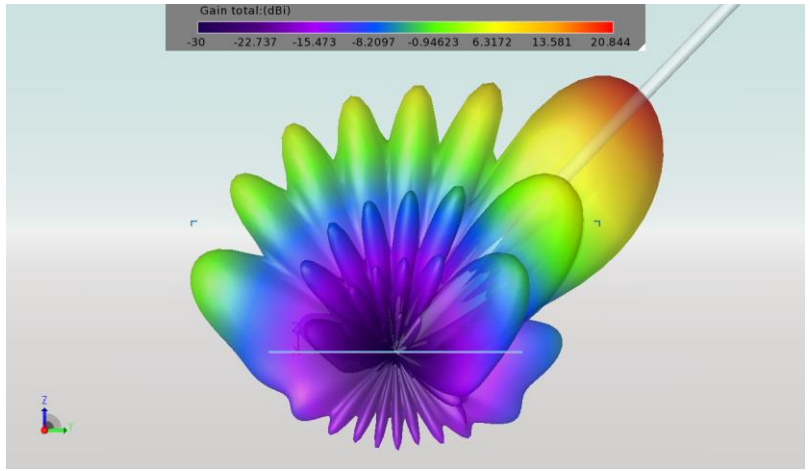


Compare Side View between SV and EMPro

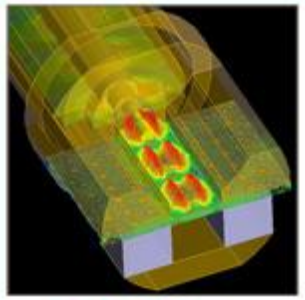
SystemVue



Initial design

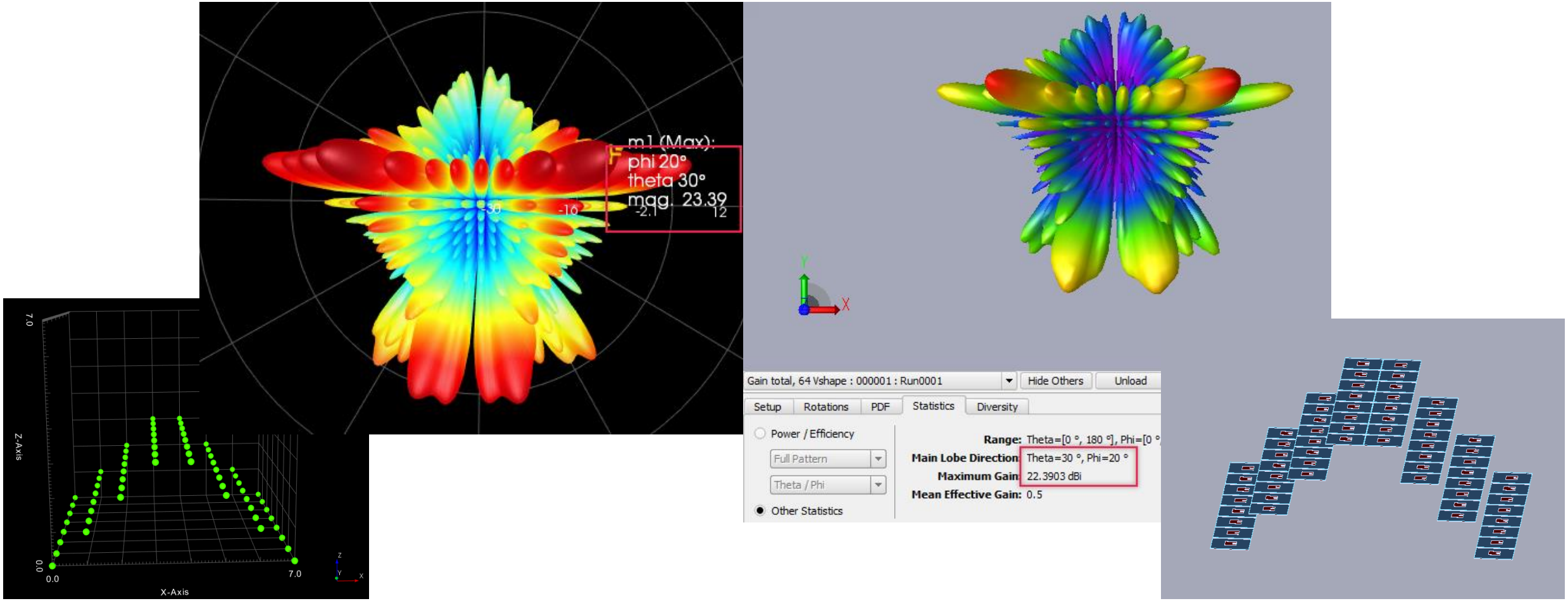


Final verification



EMPro

64 Elements V-shape Array



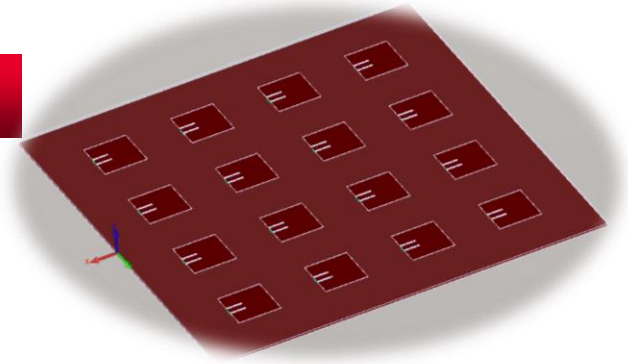
- Nice agreement between pre and post simulation

Simulation Capacity
EMPro FEM vs FDTD

APPENDIX

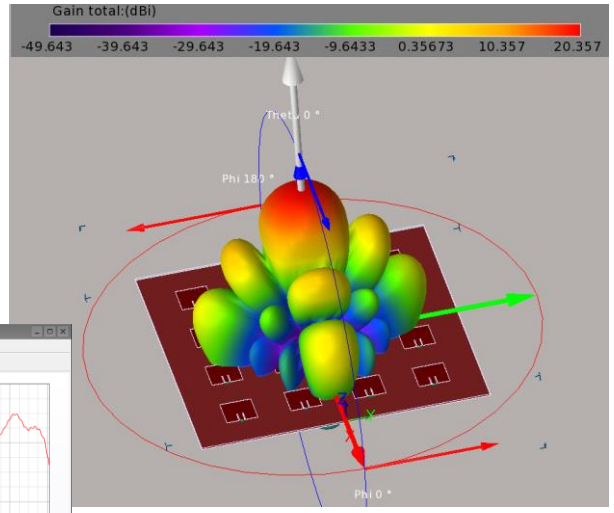
4x4 (16 Elements) 28GHz Patch Array

FEM vs. FDTD Simulation

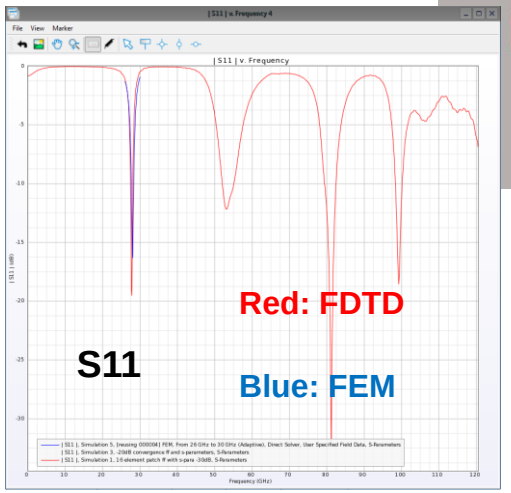


- Inset feed, no feeder network: ~20dBi @28GHz
  - FDTD simulation for antenna gain:
    - 1m31s, 4GPUs

```
  2.73%    13650 / 500000    -29.46 / -30.00        1m, 30s / 53m, 26s
  2.73%    13675 / 500000    -29.46 / -30.00        1m, 30s / 53m, 20s
  2.74%    13700 / 500000    -29.46 / -30.00        1m, 31s / 53m, 50s
  Saving steady state fields for far zone computations.
Time step 13700, -30.01 dB convergence reached.  Computing last time step.
Executing simulation with 8 threads (for supported features).
time step 13700, -30.01 dB convergence reached.  Performing post processing.
Calculating radiated and dissipated power...
finished radiated and dissipated power calculation.
```



- FEM simulation
  - 6.4GB, ~1hr (depending on freq band)



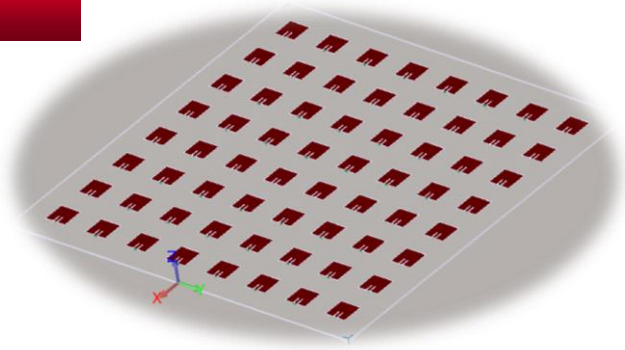
8x8 (64 Elements) 28GHz Patch Array

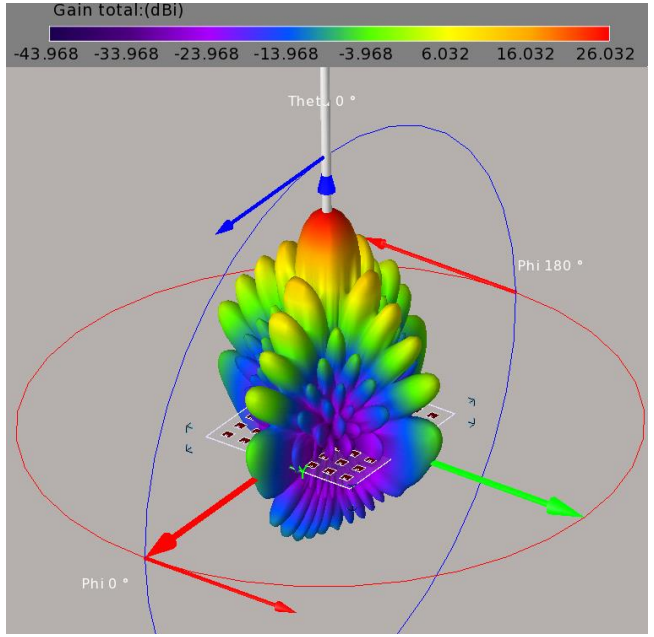
FDTD Simulation

- Inset feed, no feeder network
  - FDTD simulation for antenna gain:
    - 4m51s, 4GPUs

```
28.46%    14230 / 50000    -28.94 / -30.00        4m, 50s / 12m, 8s
28.48%    14240 / 50000    -28.94 / -30.00        4m, 50s / 12m, 8s
28.50%    14250 / 50000    -28.94 / -30.00        4m, 50s / 12m, 7s
28.52%    14260 / 50000    -28.94 / -30.00        4m, 50s / 12m, 6s
28.54%    14270 / 50000    -28.94 / -30.00        4m, 50s / 12m, 6s
28.56%    14280 / 50000    -28.94 / -30.00        4m, 51s / 12m, 7s
28.58%    14290 / 50000    -28.94 / -30.00        4m, 51s / 12m, 7s
28.60%    14300 / 50000    -28.94 / -30.00        4m, 51s / 12m, 6s
  Saving steady state fields for far zone computations.
Time step 14300, -30.02 dB convergence reached.  Computing last time step.
Executing simulation with 8 threads (for supported features).
time step 14300, -30.02 dB convergence reached.  Performing post processing.
Calculating radiated and dissipated power...
```

  - FEM simulation's failed
    - 220GB memory consumption



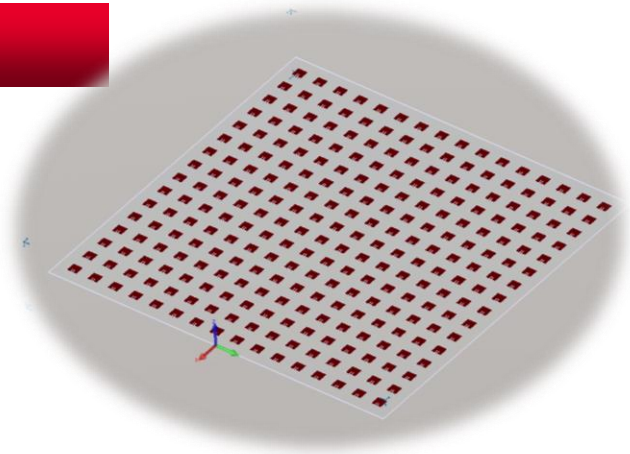


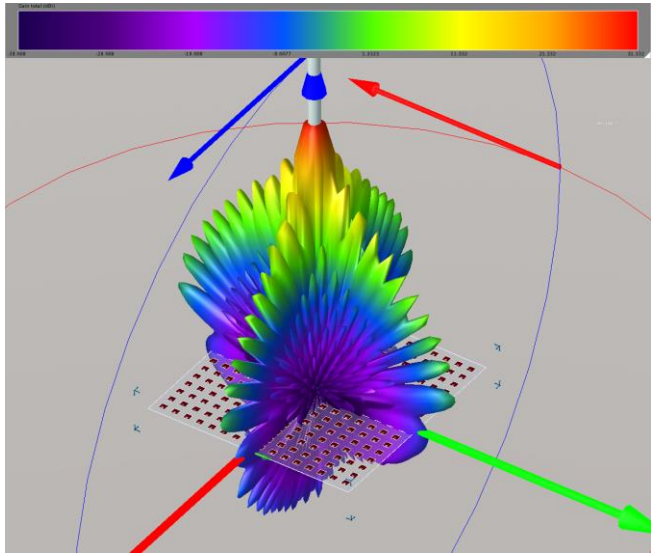
16x16 (256 Elements) 28GHz Patch Array

FDTD Simulation

- Inset feed, no feeder network
  - FDTD simulation for antenna gain:
    - 27m46s, 4GPUs

34.32%	17160 / 50000	-29.18 / -30.00	27m, 43s / 53m, 2s
34.34%	17170 / 50000	-29.18 / -30.00	27m, 44s / 53m, 1s
34.36%	17180 / 50000	-29.18 / -30.00	27m, 45s / 53m
34.38%	17190 / 50000	-29.18 / -30.00	27m, 45s / 52m, 57s
34.40%	17200 / 50000	-29.18 / -30.00	27m, 46s / 52m, 57s



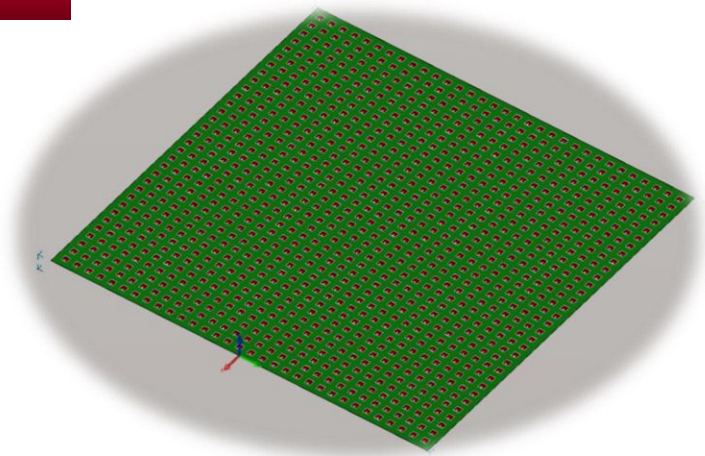


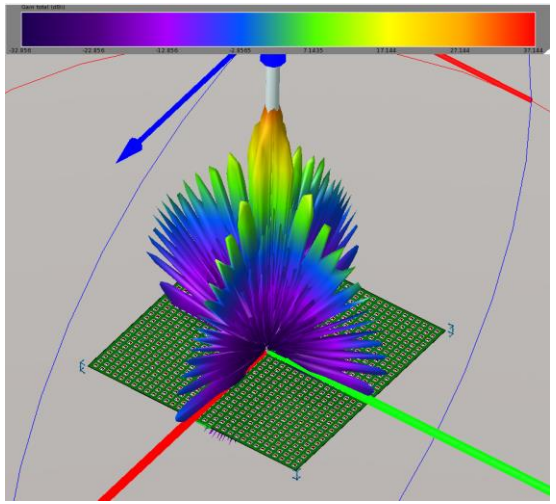
32x32 (1024 Elements) 28GHz Patch Array

FDTD Simulation

- Inset feed, no feeder network
  - FDTD simulation for antenna gain:
    - 2hrs 26 m 1s, 4GPUs

```
 48.06%    24030 / 50000     -29.89 / -30.00   2hrs, 25m, 46s / 2hrs, 37m, 32s
 48.08%    24040 / 50000     -29.89 / -30.00   2hrs, 25m, 48s / 2hrs, 37m, 26s
 48.10%    24050 / 50000     -29.89 / -30.00   2hrs, 25m, 50s / 2hrs, 37m, 21s
 48.12%    24060 / 50000     -29.89 / -30.00   2hrs, 25m, 52s / 2hrs, 37m, 15s
 48.14%    24070 / 50000     -29.89 / -30.00   2hrs, 25m, 55s / 2hrs, 37m, 11s
 48.16%    24080 / 50000     -29.89 / -30.00   2hrs, 25m, 57s / 2hrs, 37m, 6s
 48.18%    24090 / 50000     -29.89 / -30.00     2hrs, 25m, 59s / 2hrs, 37m
 48.20%    24100 / 50000     -29.89 / -30.00   2hrs, 26m, 1s / 2hrs, 36m, 55s
  Saving steady state fields for far zone computations.
Time step 24100, -30.18 dB convergence reached.  Computing last time step.
Executing simulation with 8 threads (for supported features).
time step 24100, -30.18 dB convergence reached.  Performing post processing.
```





KEYSIGHT
TECHNOLOGIES