Phase Array RF System Design

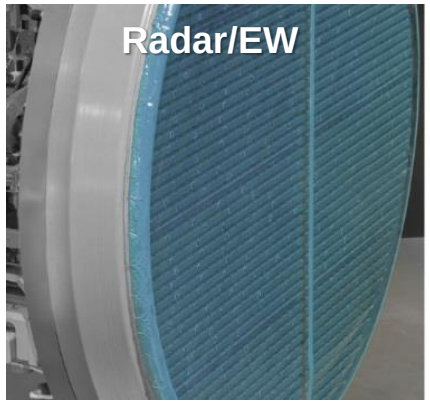
2019.10.22

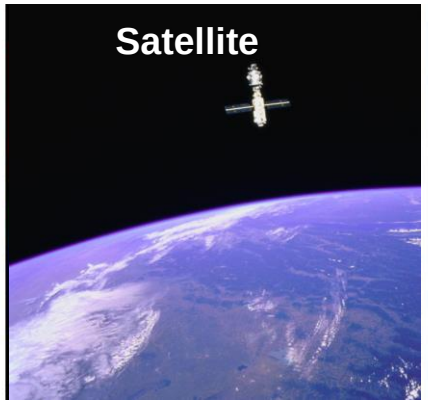
Keysight Technologies

Design Challenges for Phased Array Systems

PHASED ARRAY DESIGN ACROSS MULTIPLE DOMAINS

- Crosses multiple disciplines
- Disjointed tool set
- Design, predict, test, and validate
- Time to market





SYSTEM LEVEL PERFORMANCE
BER, EVM, Throughput
Wireless standard specs
Probability of Detection

BEAMFORMING ARCHITECTURES
RF / Digital / Hybrid

?

ALGORITHM
Multi-function
Nulling interferers
Scanning, tracking
Tapes, Sidelobe mitigation
Error correction, self-calib

OTA MEASUREMENT
OTA chamber, OTA specs

?

RF SYSTEM ARCHITECTURES
Link budget
Component specs, variations
Nonlinearities / intermods
Frequency response
Gain/Phase states
Noise and SFDR
ADC / DAC quantization

?

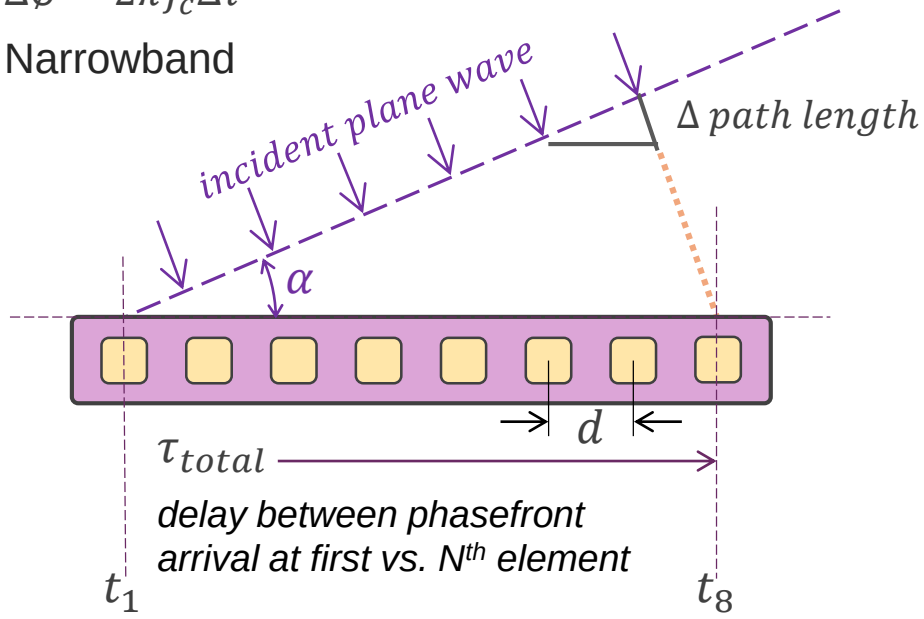
ANTENNA ARRAY
3D configuration
3DEM element patterns
Distribution manifolds

RF / ASIC IMPL
Active/NL performance
Loading, Coupling, Ghosting
DC/PAE efficiency, Thermal

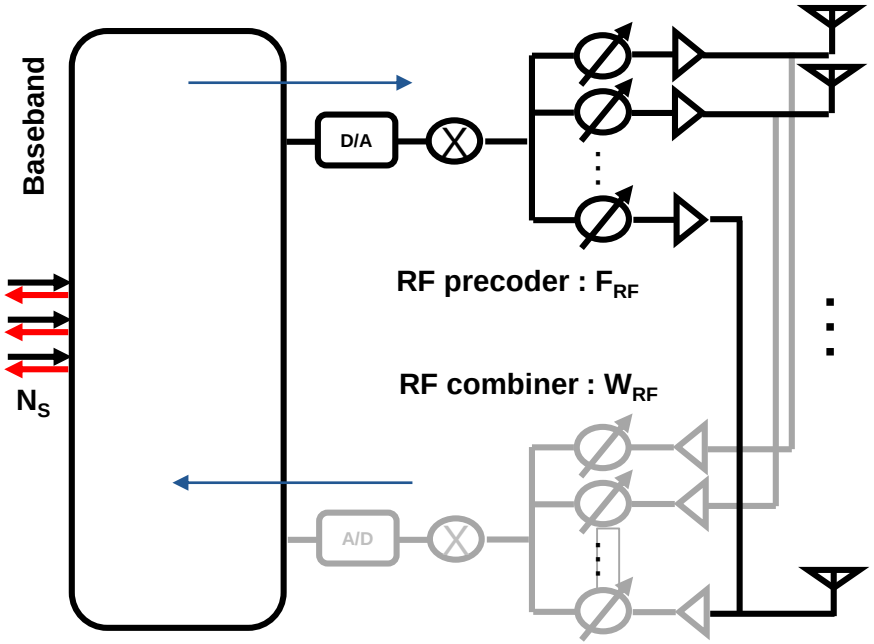
Phased Array Fundamentals & Beamforming Architecture

RECREATING PLANE WAVE PHASE FRONT

- Time delay beamforming: $x(t-\Delta\tau)e^{j2\pi f_c(t-N\Delta\tau)}$
  - Wideband
- Phase shift beamforming: $x(t)e^{j2\pi f_c t}e^{jN\Delta\emptyset}$
  - $\Delta\emptyset = -2\pi f_c \Delta\tau$
  - Narrowband



RF Beamforming



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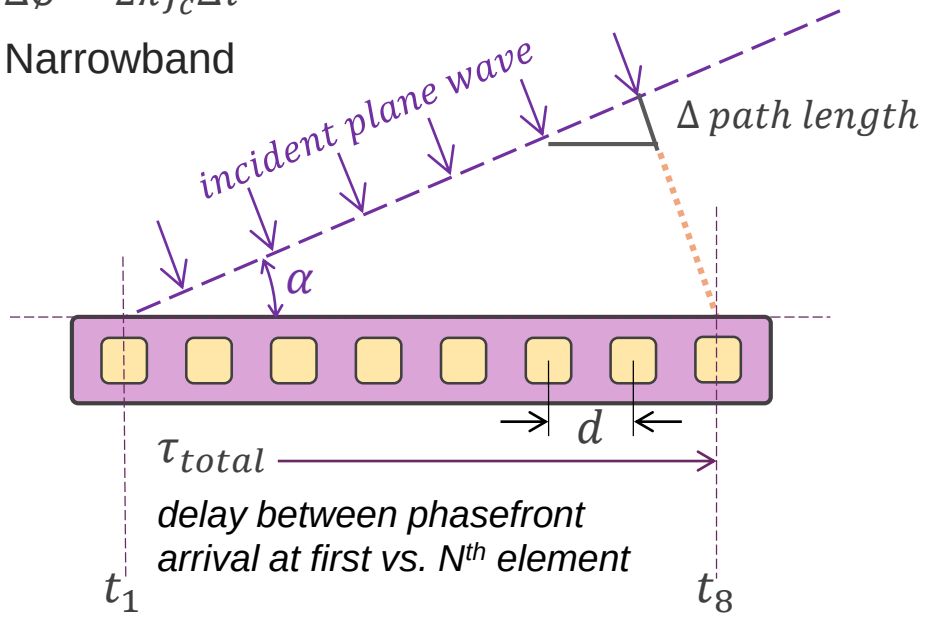
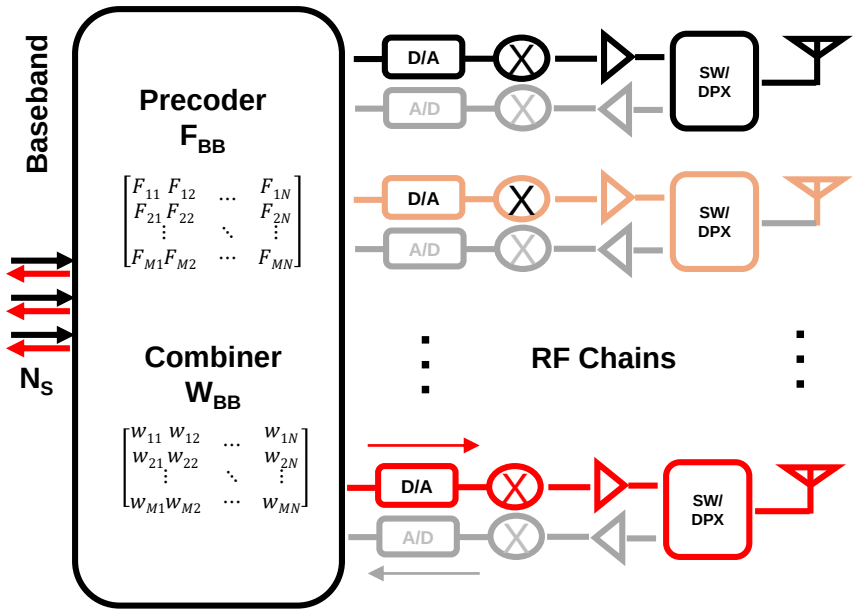


Digital Beamforming



Phased Array Fundamentals & Beamforming Architecture

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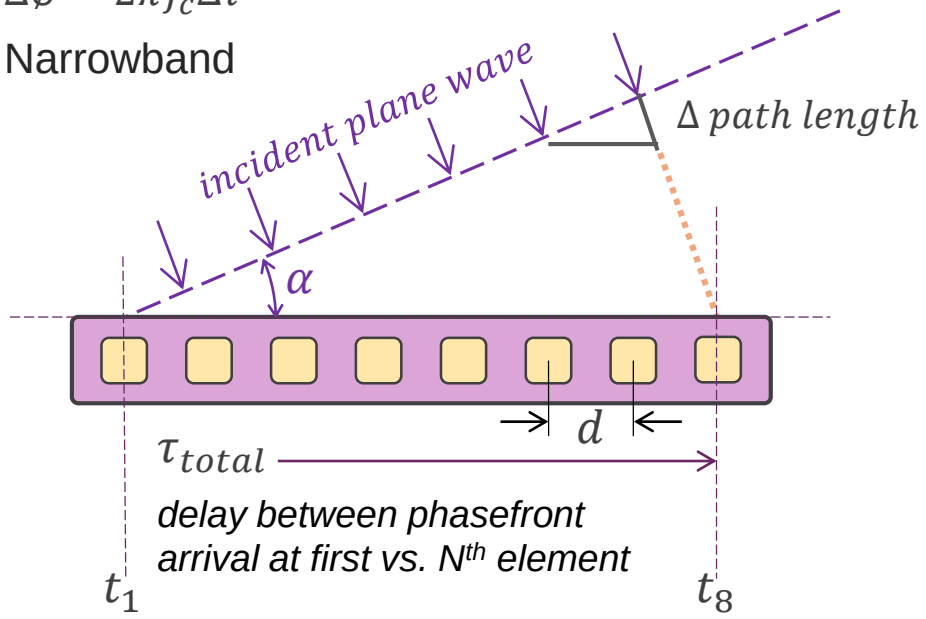
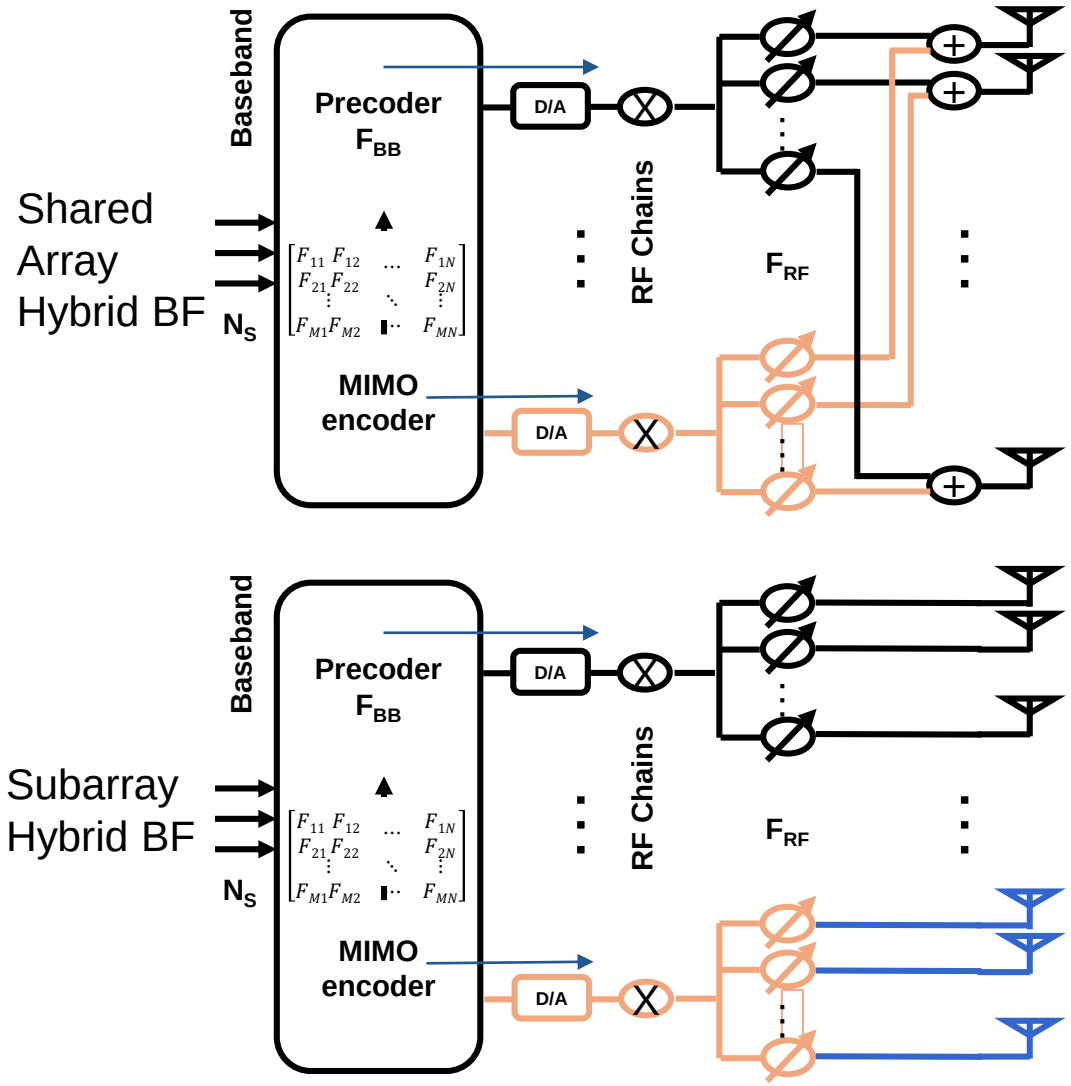




Combined Analysis of RF, BB, and Application Scenarios

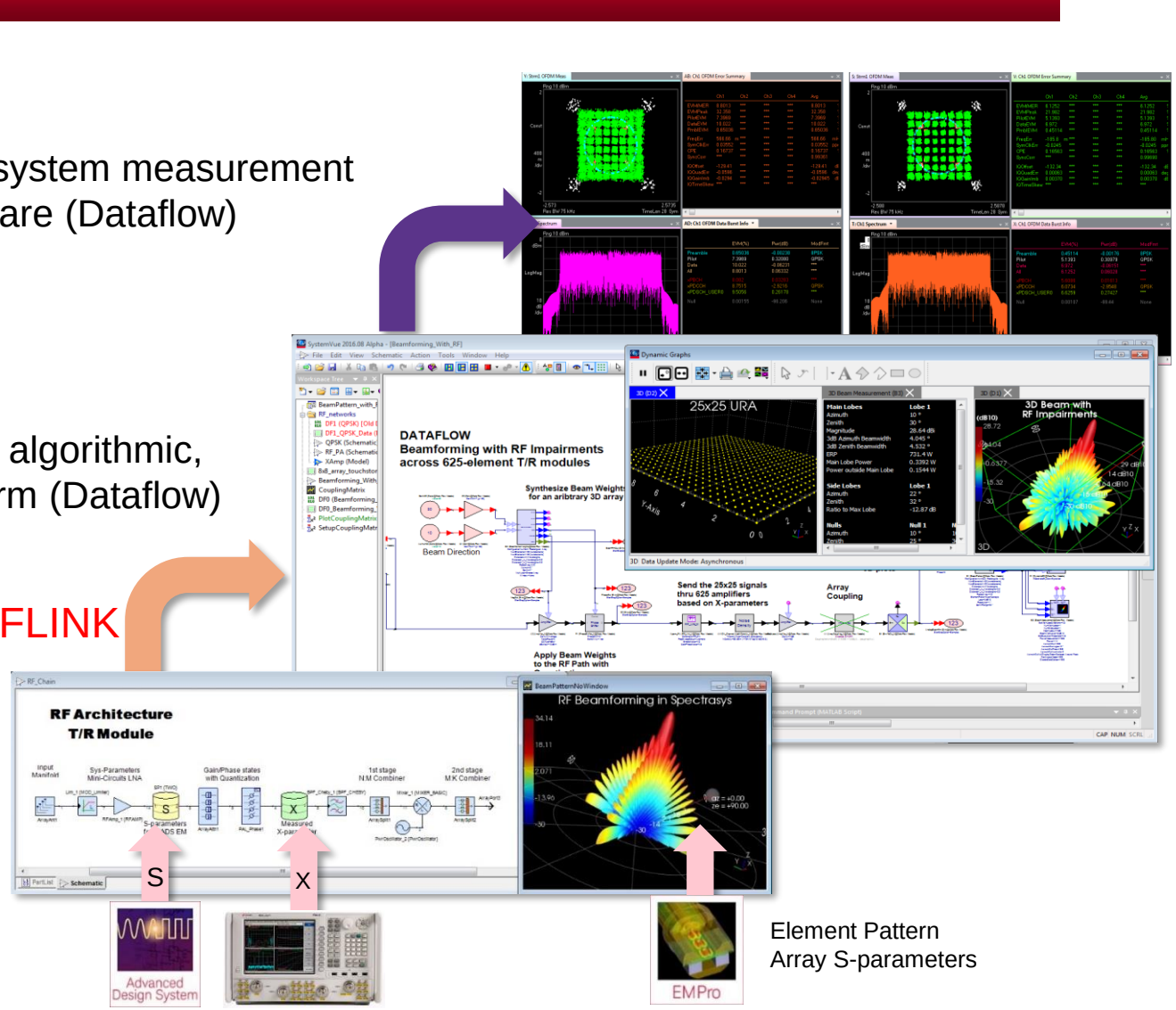
DESIGN & VALIDATE PHASED ARRAY IN SYSTEMVUE

Test system measurement software (Dataflow)

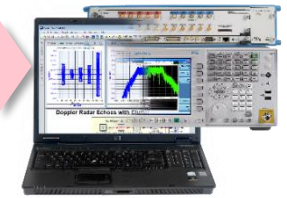
Dynamic behavior, algorithmic, modulated waveform (Dataflow)

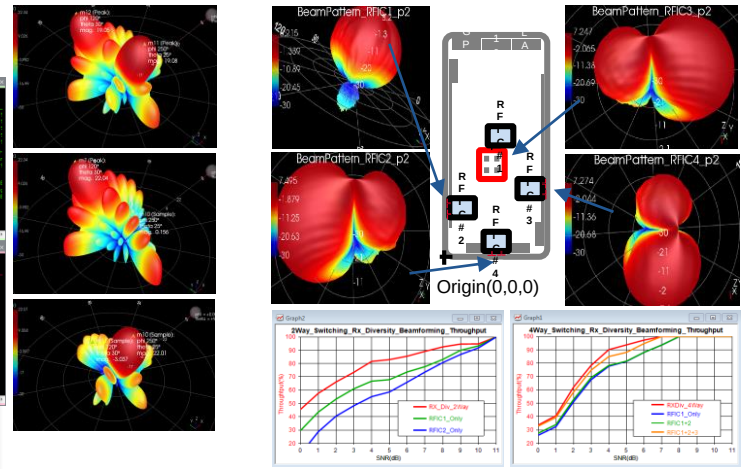
RFLINK

RF phased array system architecture



T&M



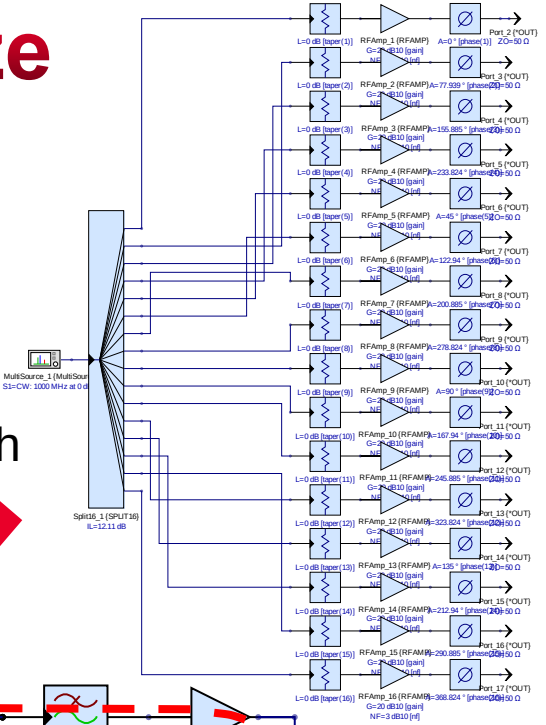


Element Pattern
Array S-parameters

Designing Phased Array Systems with Any Size

NXN URA RF-BF RF-IF T/R MODULE

Traditioanl
v.s.
New Approach

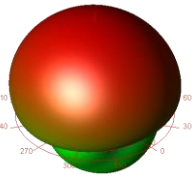


Attenuator array: Window (Taper)

Phase Shifter array: Beam direction

Combiner / Splitter network (multi-stage)

Array configuration &
element patterns



ArrayAnt1 {ArrayAnt}
Configuration=Uniform Rectangular Array
NumElementsX=16 [NumEl]
NumElementsY=16 [NumEl]
DistanceUnit=Meters
DistanceX=0.015 m
DistanceY=0.015 m
ActiveLoading=None
RxTx=Rx [ArrayState]
Freq=10 GHz [FRxTx]
RxPwrDensity=-50 dBm [RxPwrDensity_dBm]

SW1 {SWITCH_Linear1}
IL=0.5 dB

Lim_1 {MOD_Limiter}
IL=0.2 dB10
Pmax=10 dBm

LNA {RFAMP}
G=20 dB10
NF=2.5 dB10

FinalAmp {RFAMP}
G=20 dB10
NF=5 dB10

DriverAmp {RFAMP}
G=15 dB10
NF=3 dB10

SW2 {SWITCH_Linear2}
IL=0.5 dB

ArrayAttn2 {ArrayAttn}
Window=Taylor
SideLobeLevel=-20 dB10
NumBars=2
InsertionLoss=1 dB

ArrayPhase1 {ArrayPhase}
CalcMode=Auto
Theta=20 ° [beamTheta]
Phi=0 ° [beamPhi]
InsertionLoss=1 dB

ArraySplit1 {ArraySplit}
InsertionLoss=1 dB
Mode=SubArray
NumRows=4 [NumEl/4]
NumCols=4 [NumEl/4]

ArraySplit2 {ArraySplit}
InsertionLoss=1 dB
Mode=SubArray
NumRows=4
NumCols=4

SW3 {SWITCH_Linear2}
IL=0.5 dB

RF_BPF_Rx {BPF_BUTTER}

Mixer_1
ConvGain=-8 dB
SUM=Difference

F=5 GHz [LOFreq_GHz]
Pwr=9 dBm

IF_BPF_Rx {BPF_BUTTER}

IFAmpRx
G=15 dB10
NF=3 dB10

RF ←→ IF

RF_BPF_Tx {BPF_BUTTER}

Mixer_2
ConvGain=-8 dB
SUM=Sum

IF_BPF_Tx {BPF_BUTTER}

IFAmpTx
G=15 dB10
NF=3 dB10

SW4 {SWITCH_Linear2}
IL=0.5 dB

ArrayPort2 {ArrayPort}
RxTx=Rx [ArrayState]

FRxTx = 10
5 15
Center Freq

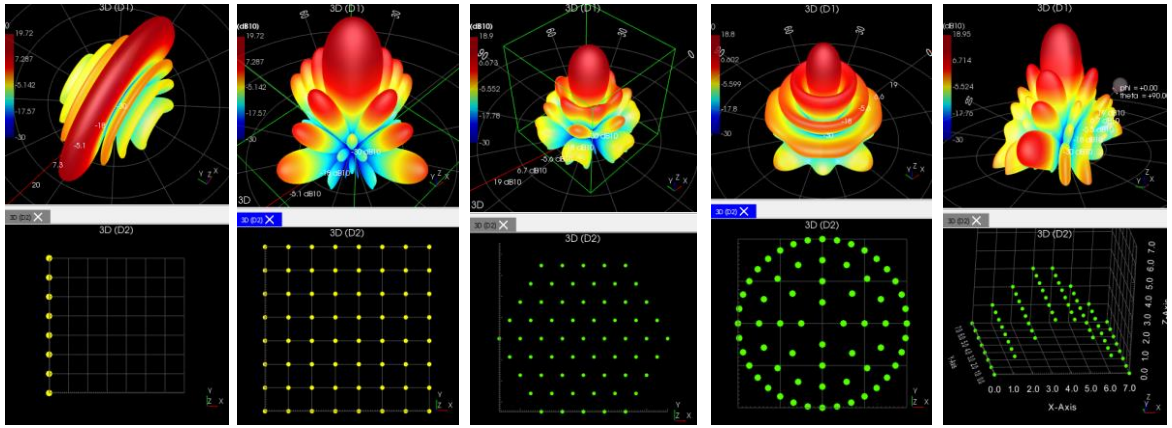
NumEl = 16
4 36
Number of Elements (NxN)

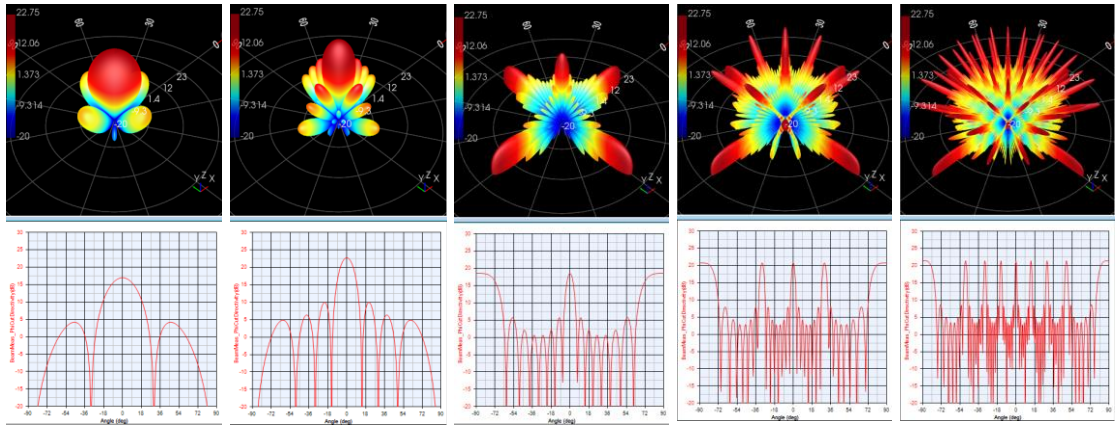
ArrayState
1
2
1

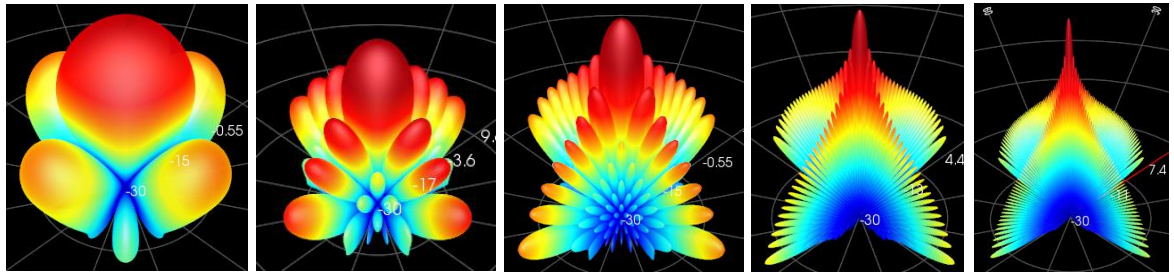
MODE:
TX=2
RX=1

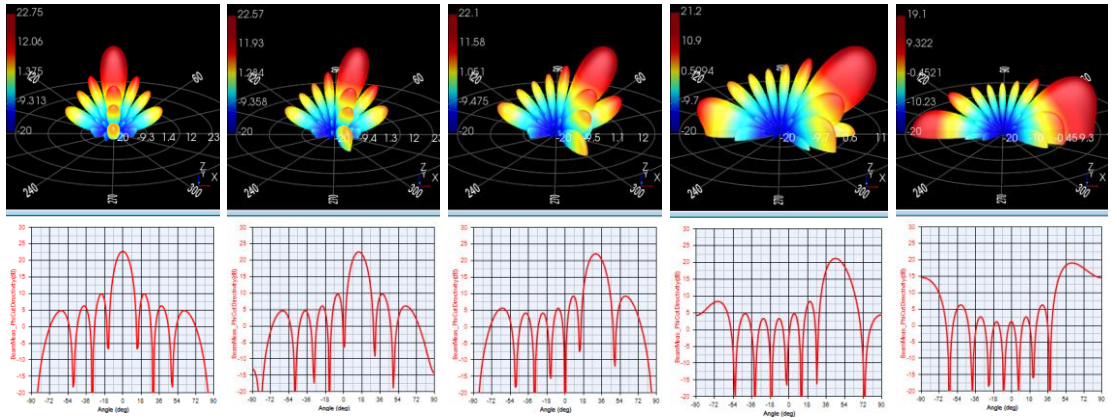
Explore Phased Array Design Space

CONFIGURATION, SIZE, SPACING, SCAN ANGLE



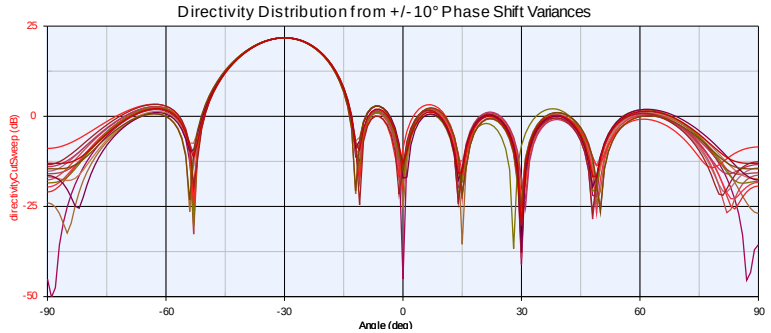


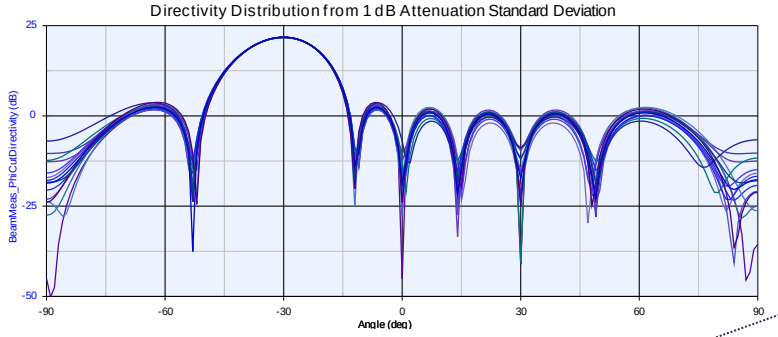


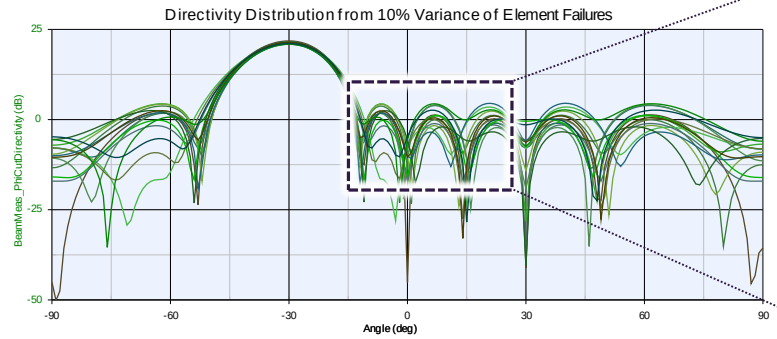


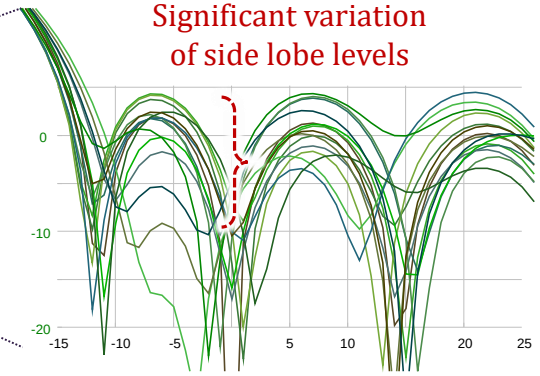
Monte Carlo Analysis of Multi-Channel Variations

PHASE ERROR, MAG. ERROR, & ELEMENT FAILURE

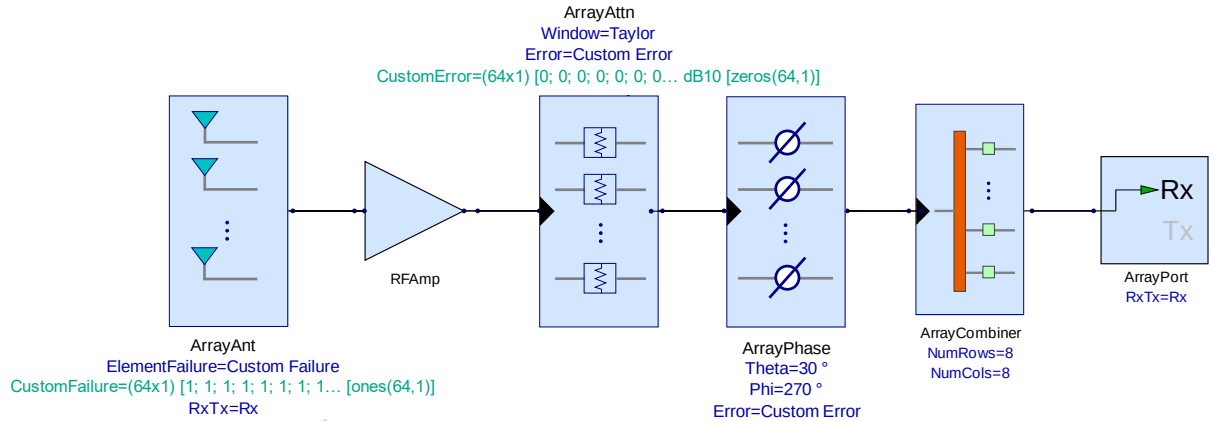


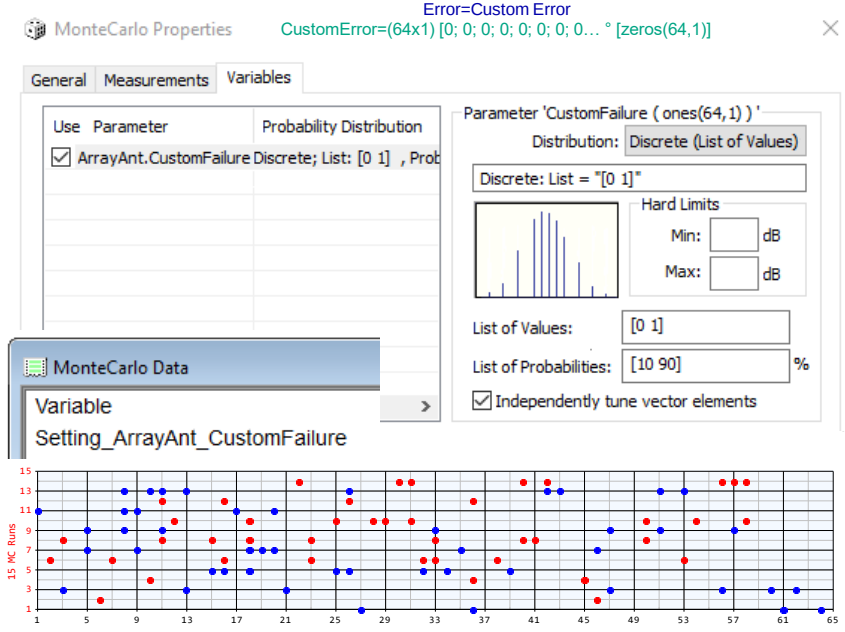






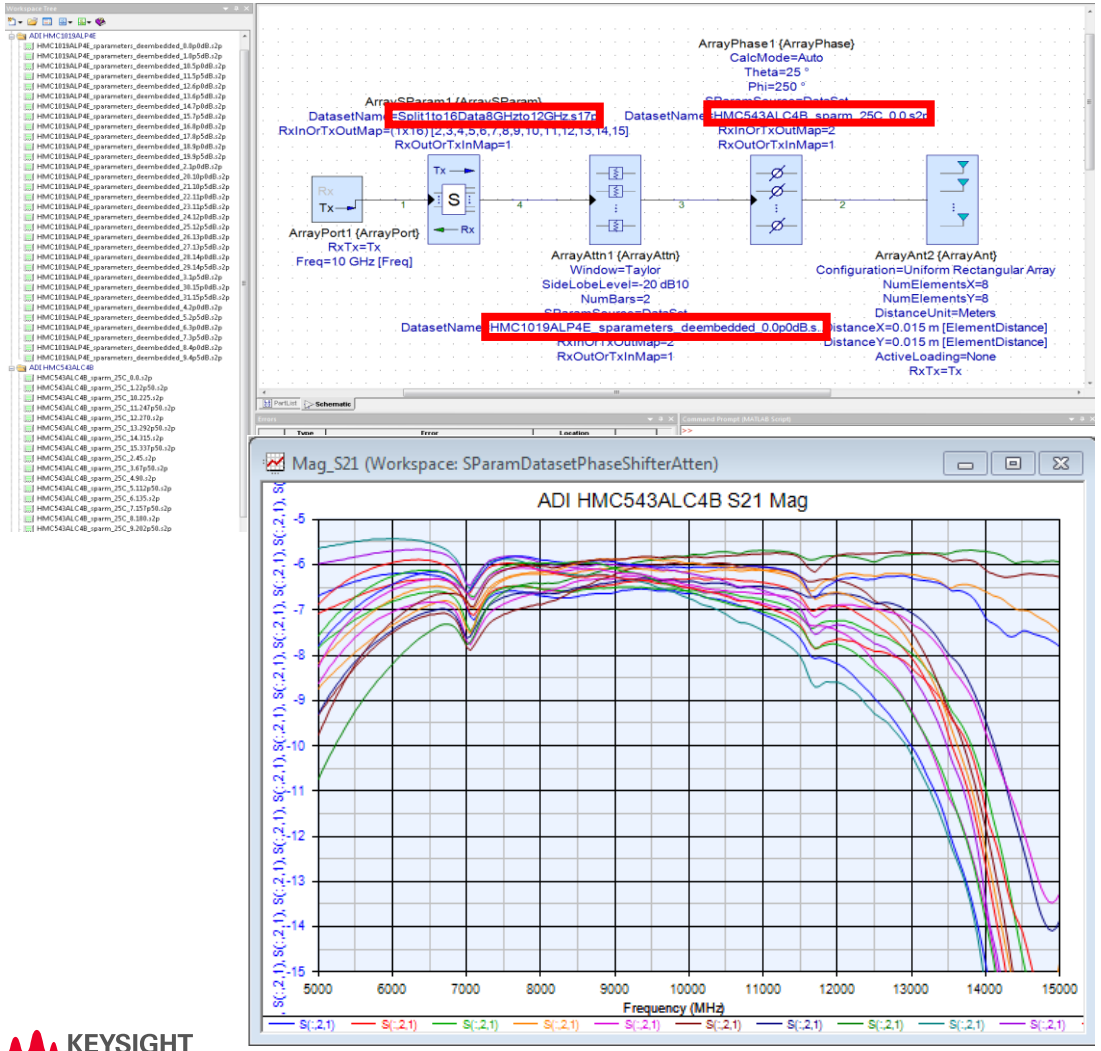
Significant variation of side lobe levels

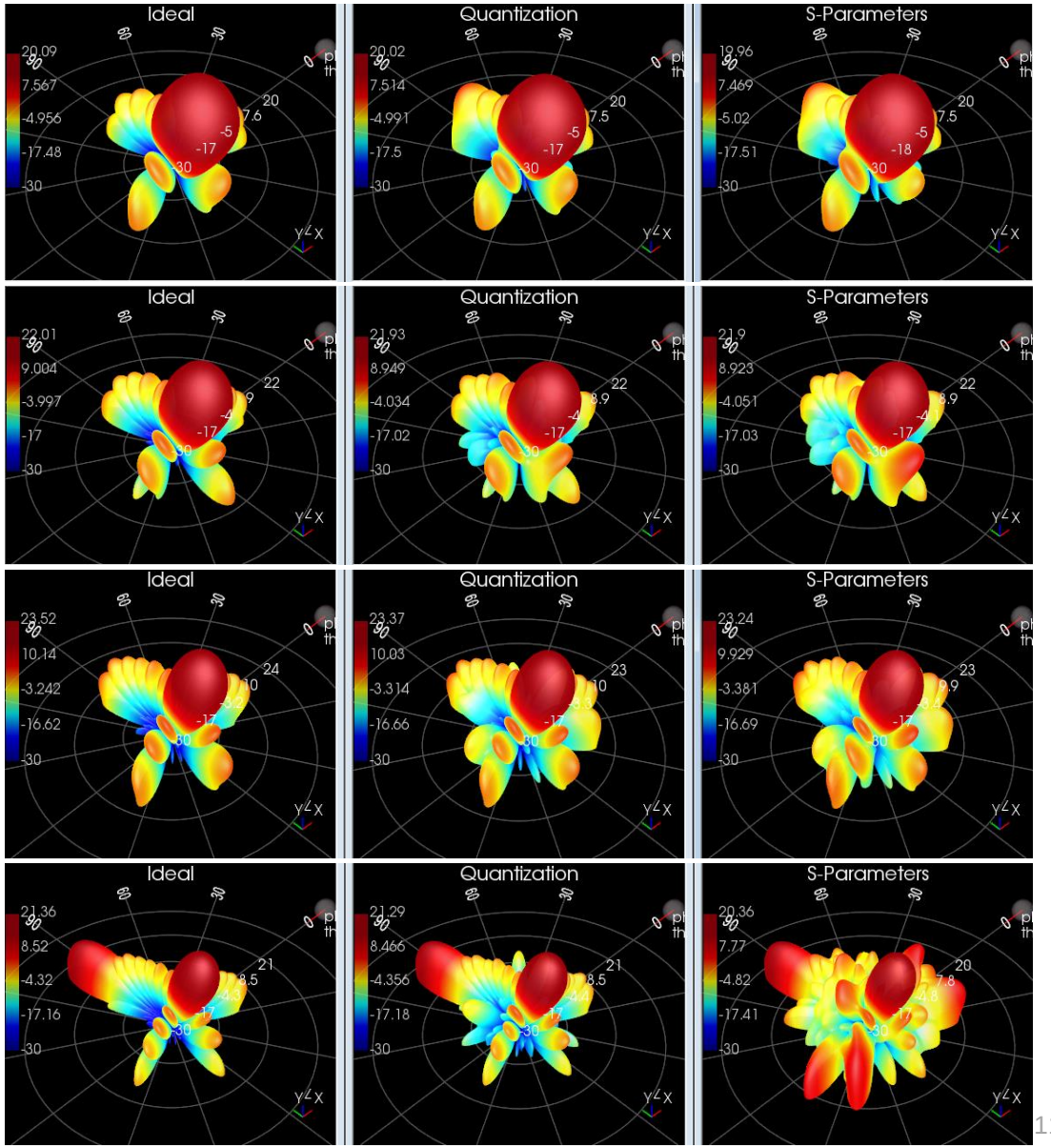




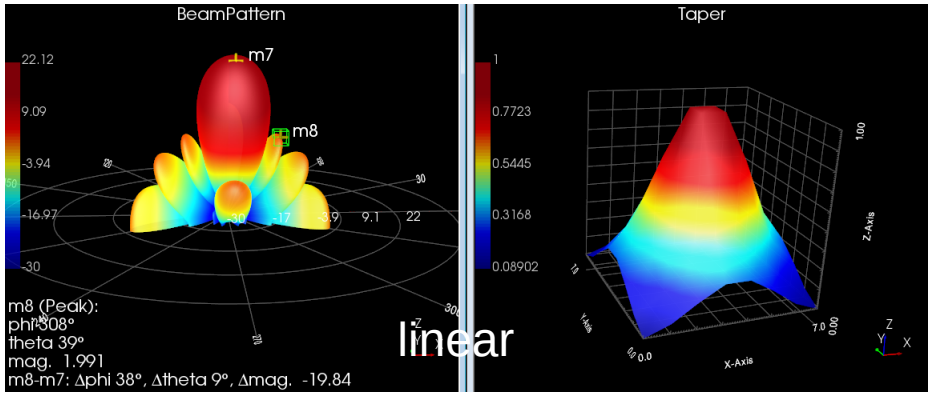
Impact of Non-ideal Linear Devices on Beam Patterns

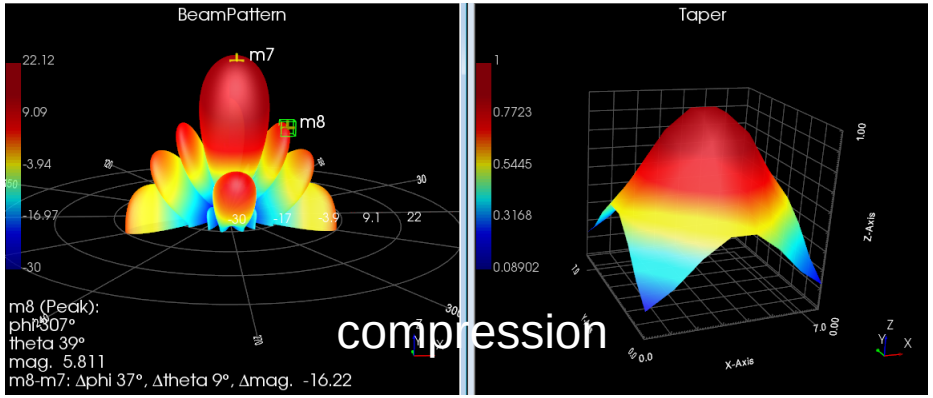
QUANTIZATION & S-PARAMETERS

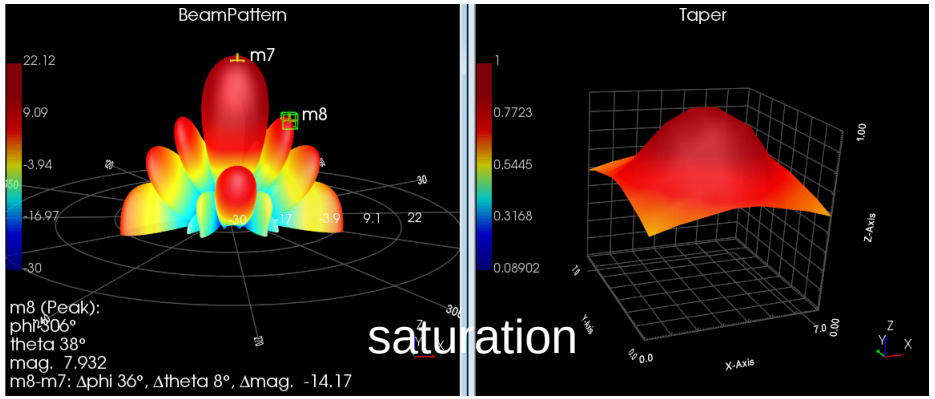


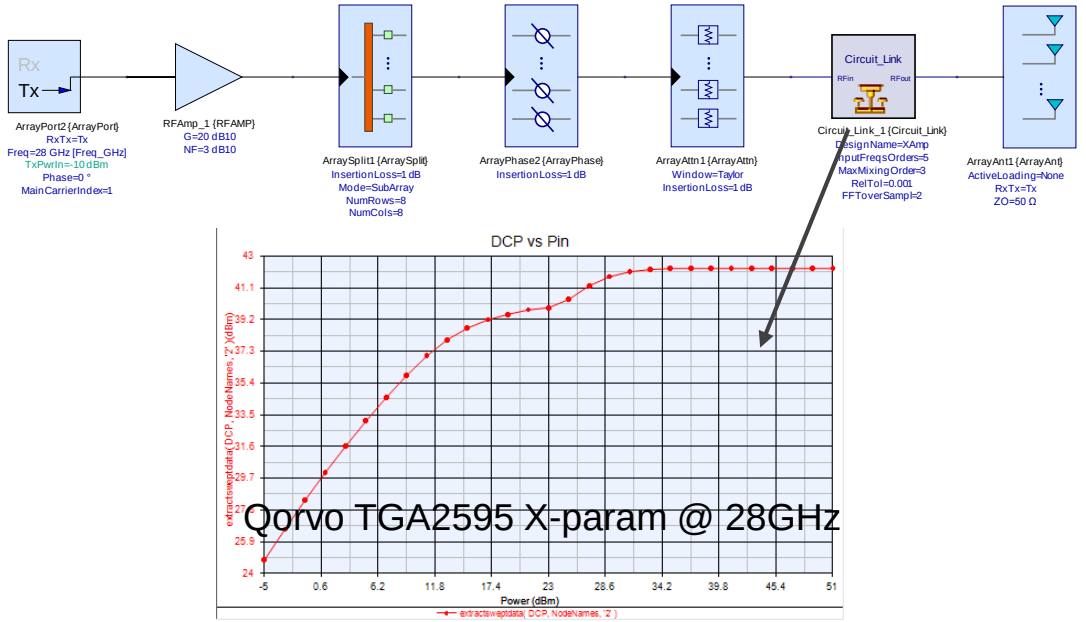


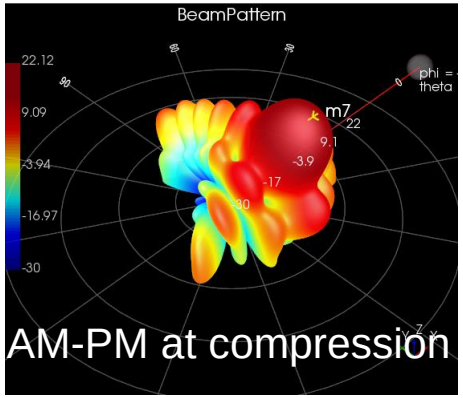
Impact of Nonlinear Devices on Beam Patterns





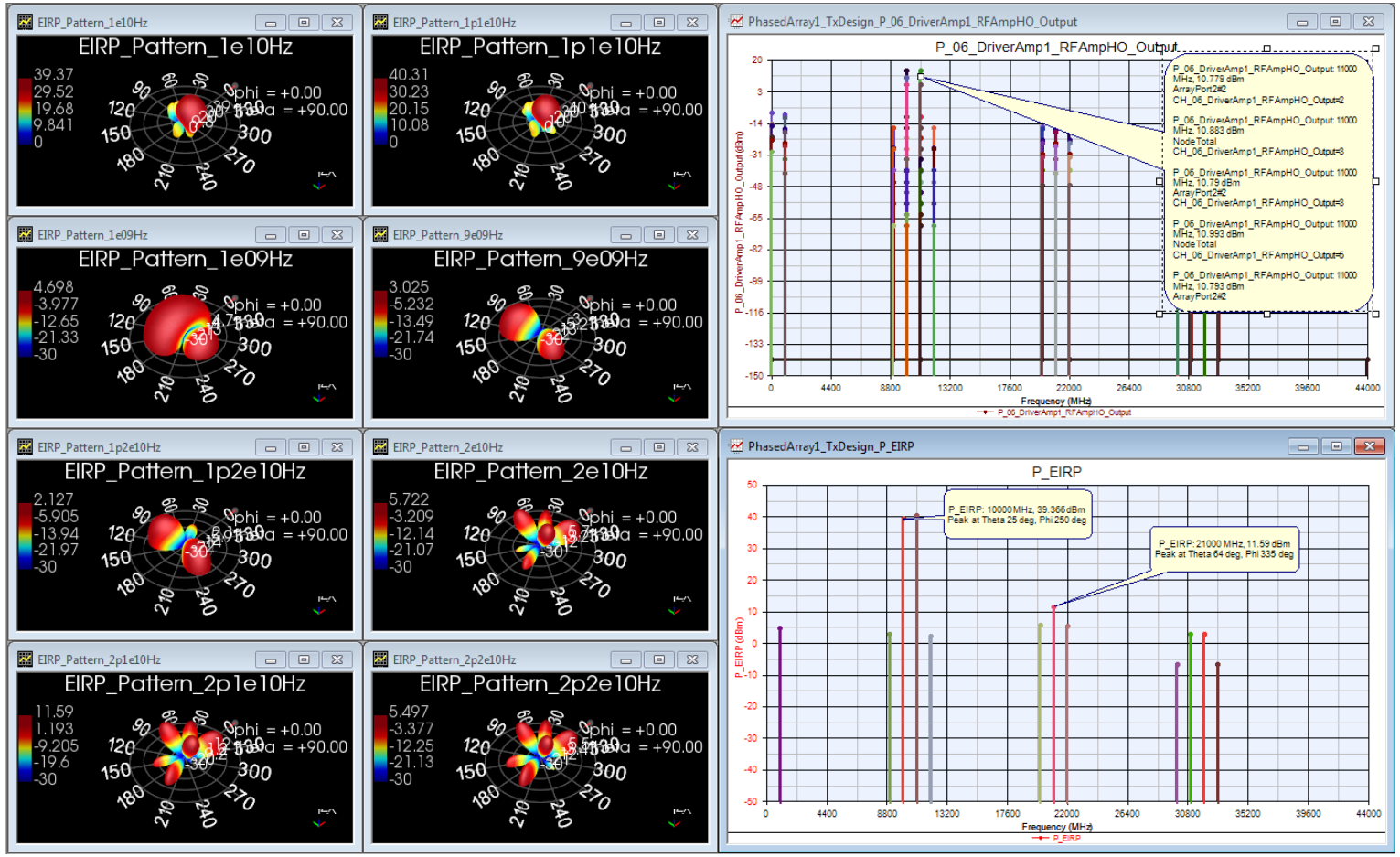


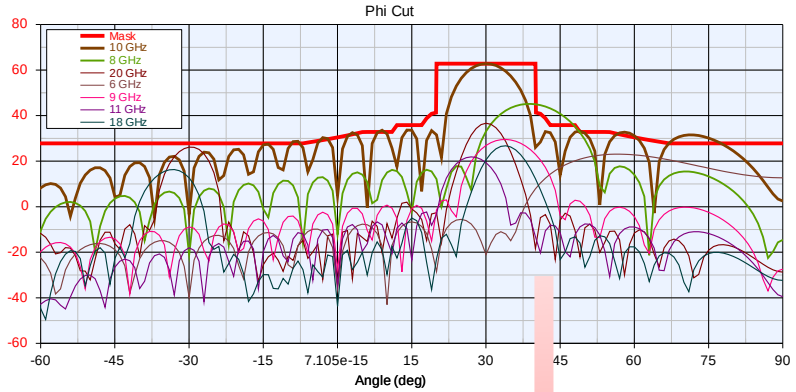




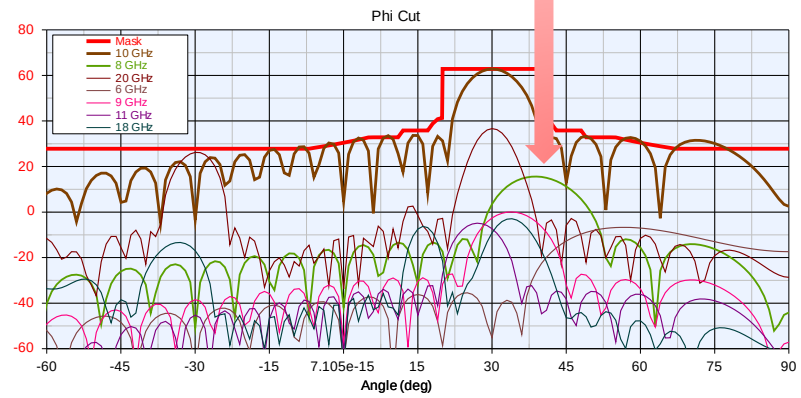
Analyzing Spectrum & Patterns at Spurious Frequencies

SPECTRAL & SPATIAL MASK ON EIRP PATTERNS

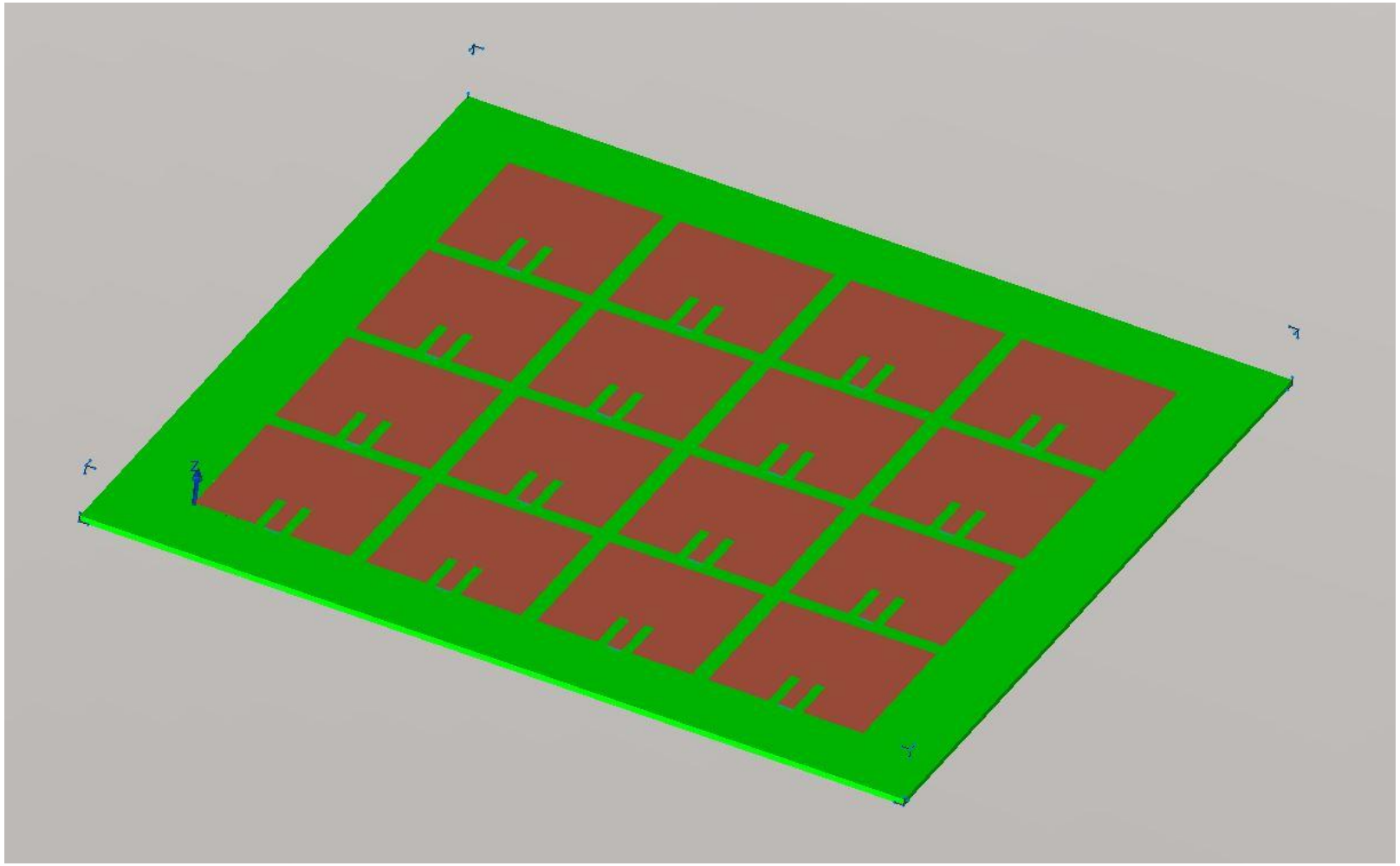




filter after nonlinear PA to pass mask



EMPro Patch Array Antenna Design (4X4)



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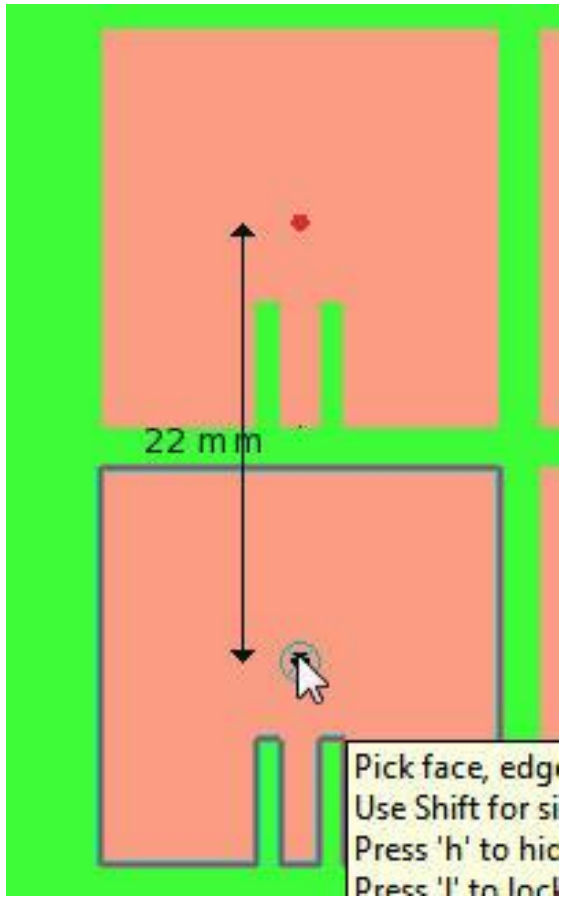
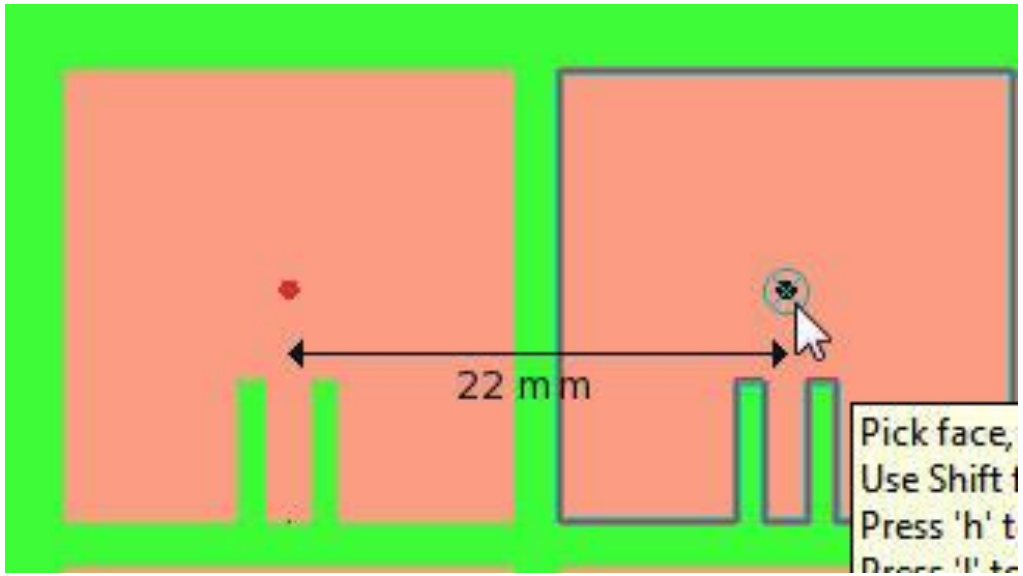
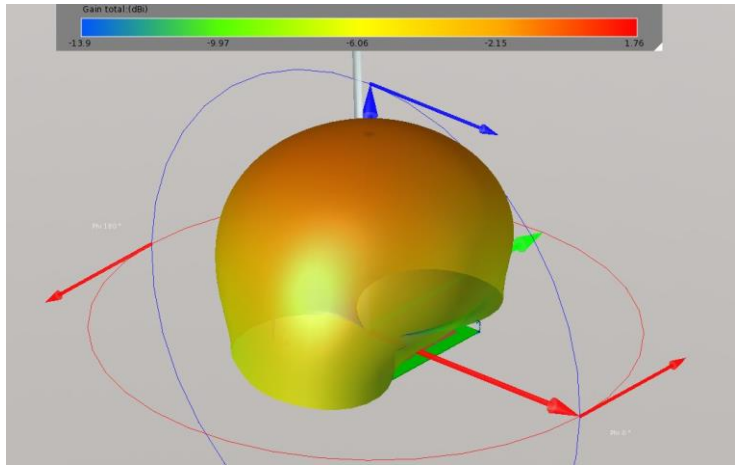


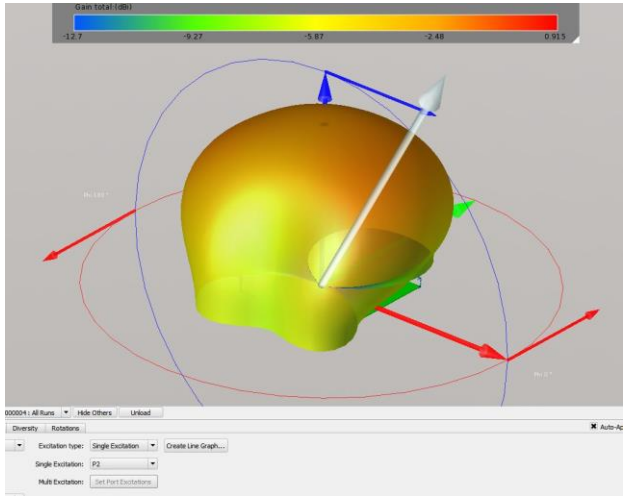


EMPro Patch Array Antenna Design (4X4)

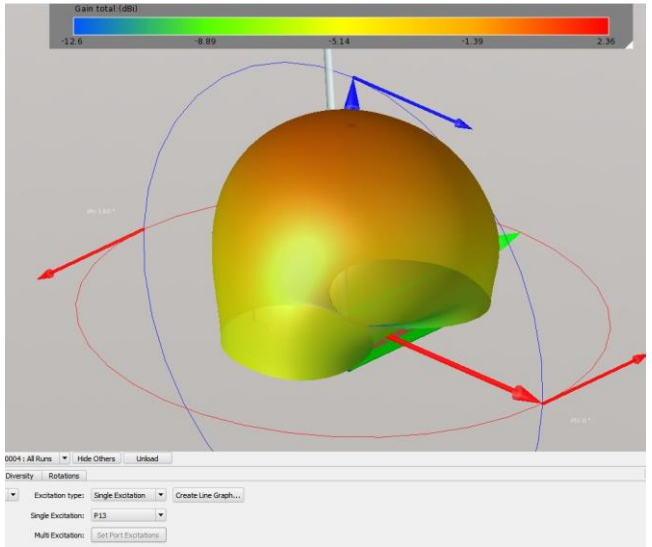
Radiation Pattern for individual elements. Notice they are not same and properties will vary depending on Radiator's position in the Antenna Array



Element-1



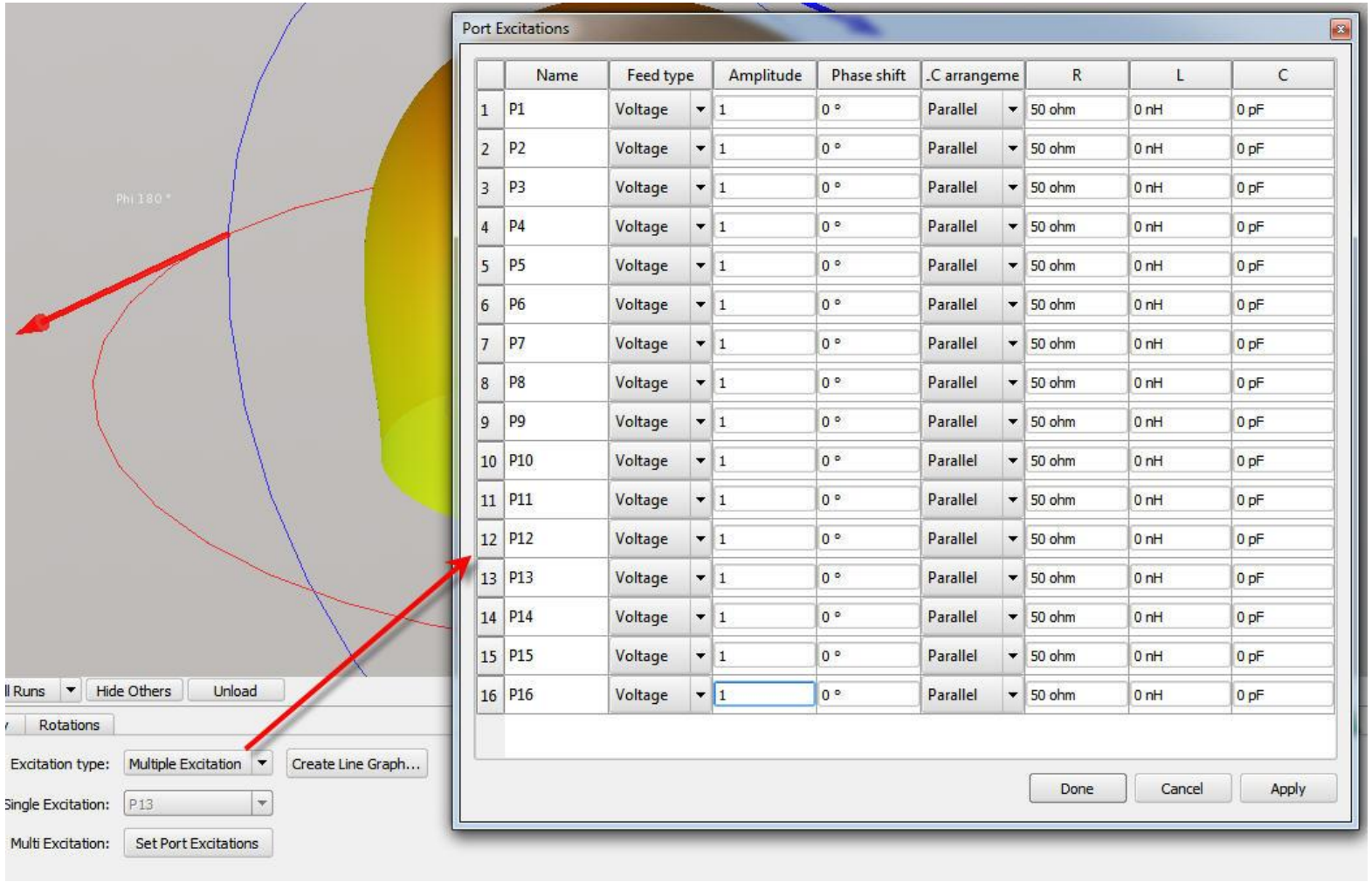
Element-2



Element-13

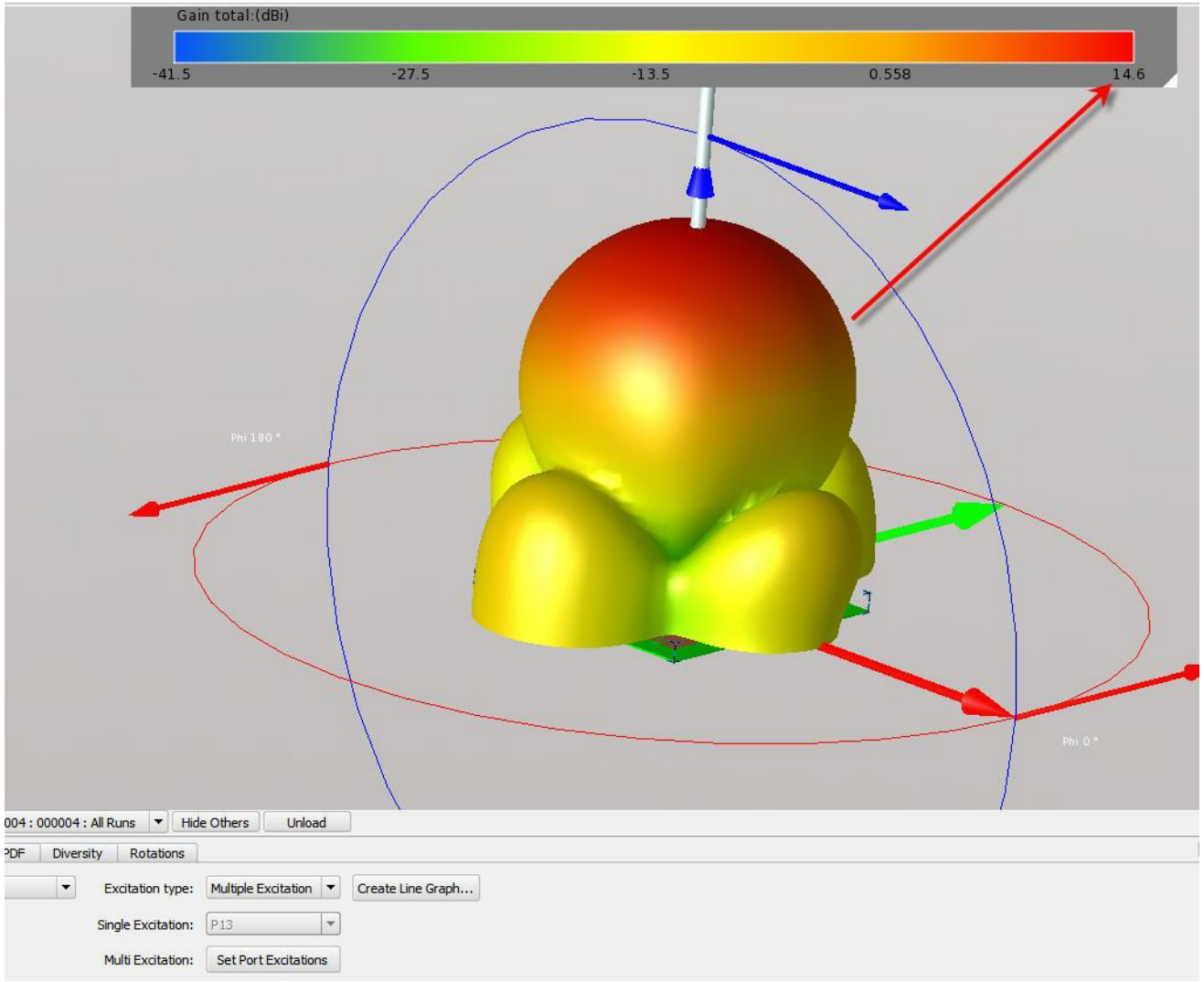
EMPro Patch Array Antenna Design (4X4)

Setup Multi-Excitation in EMPro to activate all radiators, here we are using phase of 0º for all radiators



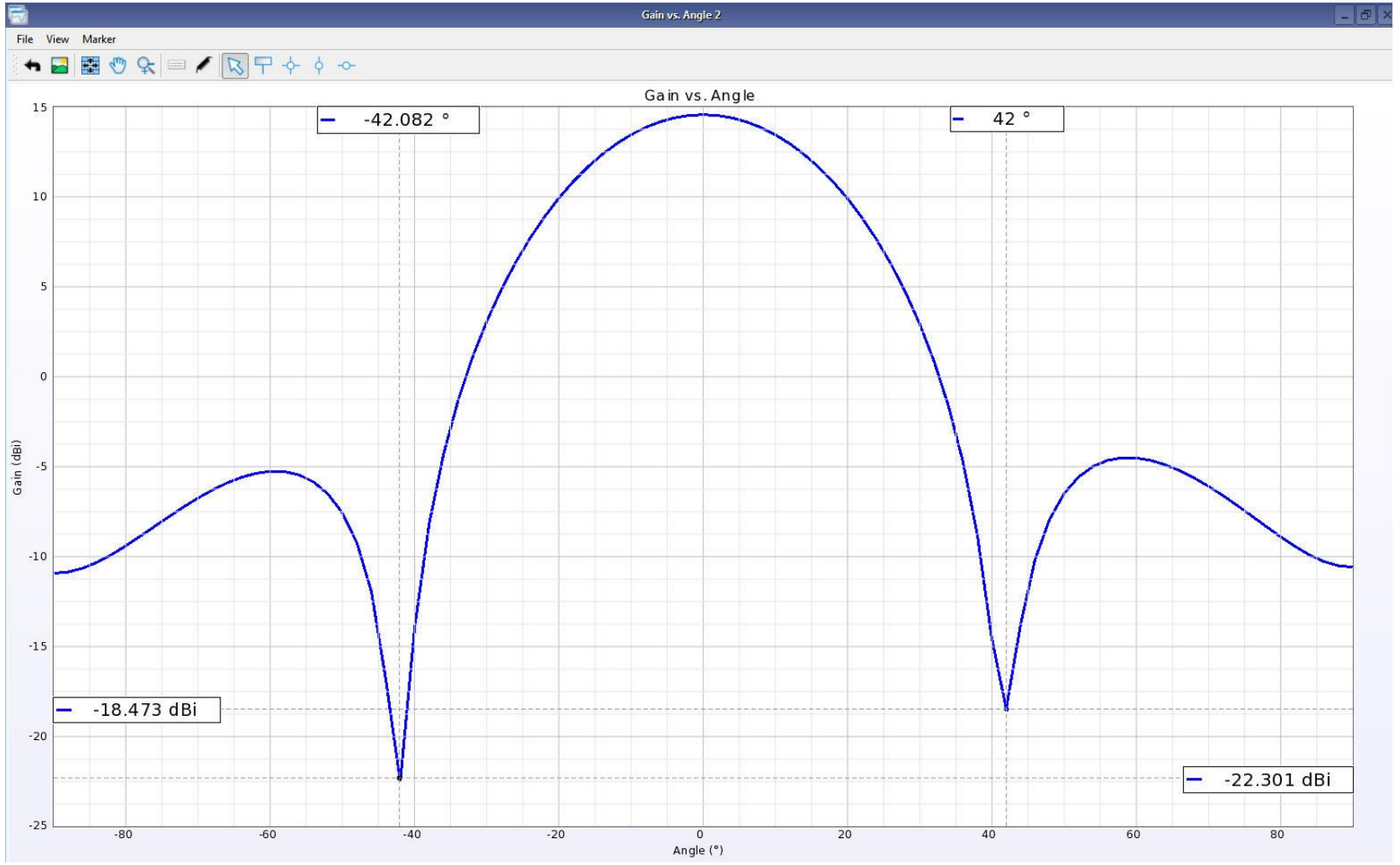
EMPro Patch Array Antenna Design (4X4)

Resulting Far Field pattern showing array gain of ~14.6dBi



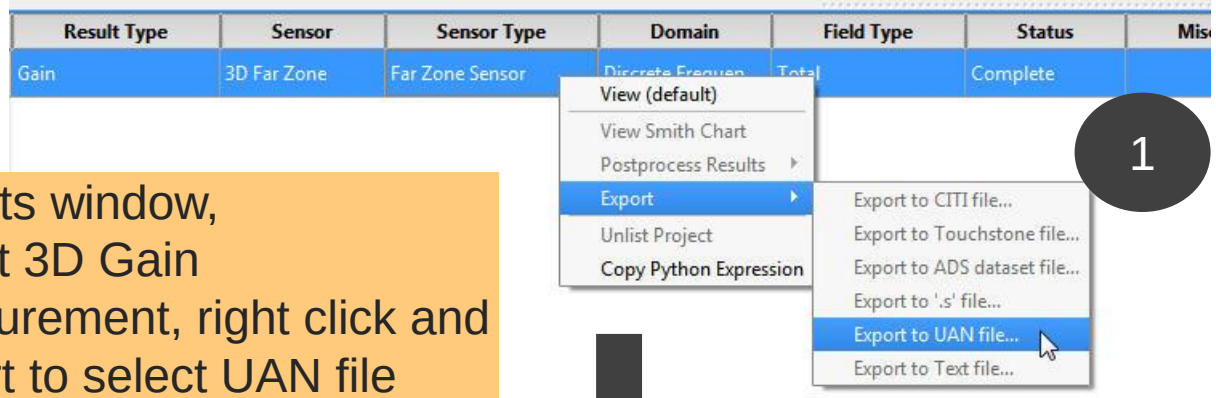
EMPro Patch Array Antenna Design (4X4)

2D cut pattern at Phi=0, Nulls @42º



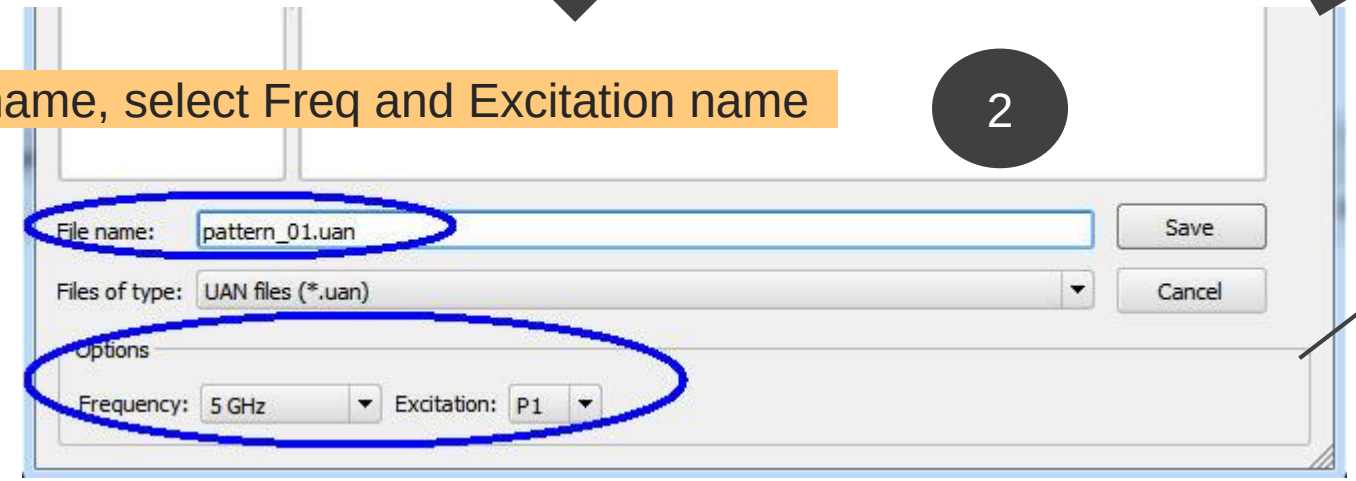
EMPro Patch Array Antenna Design (4X4)

Export far field pattern files (.uan files) for individual radiators.

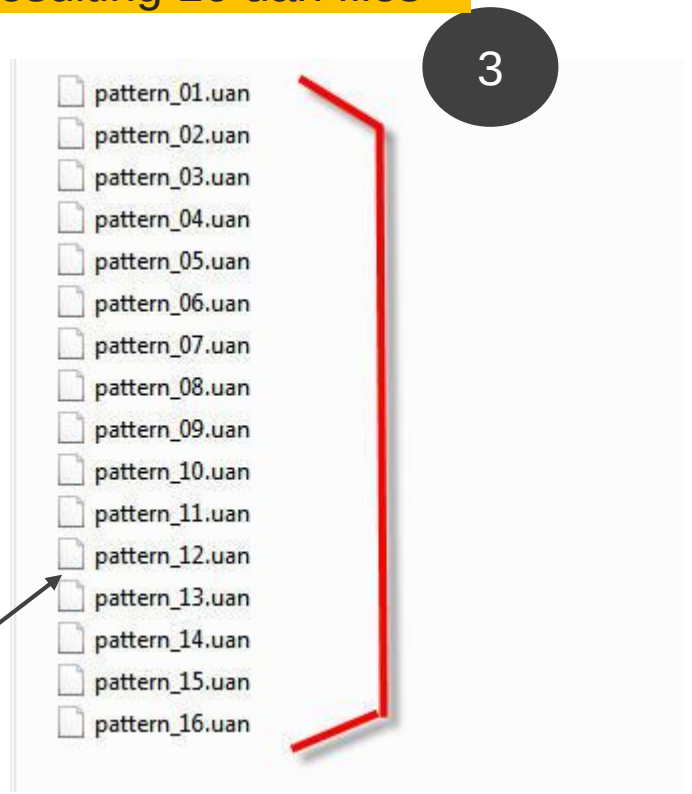


Results window,
Select 3D Gain measurement, right click and Export to select UAN file

Give filename, select Freq and Excitation name

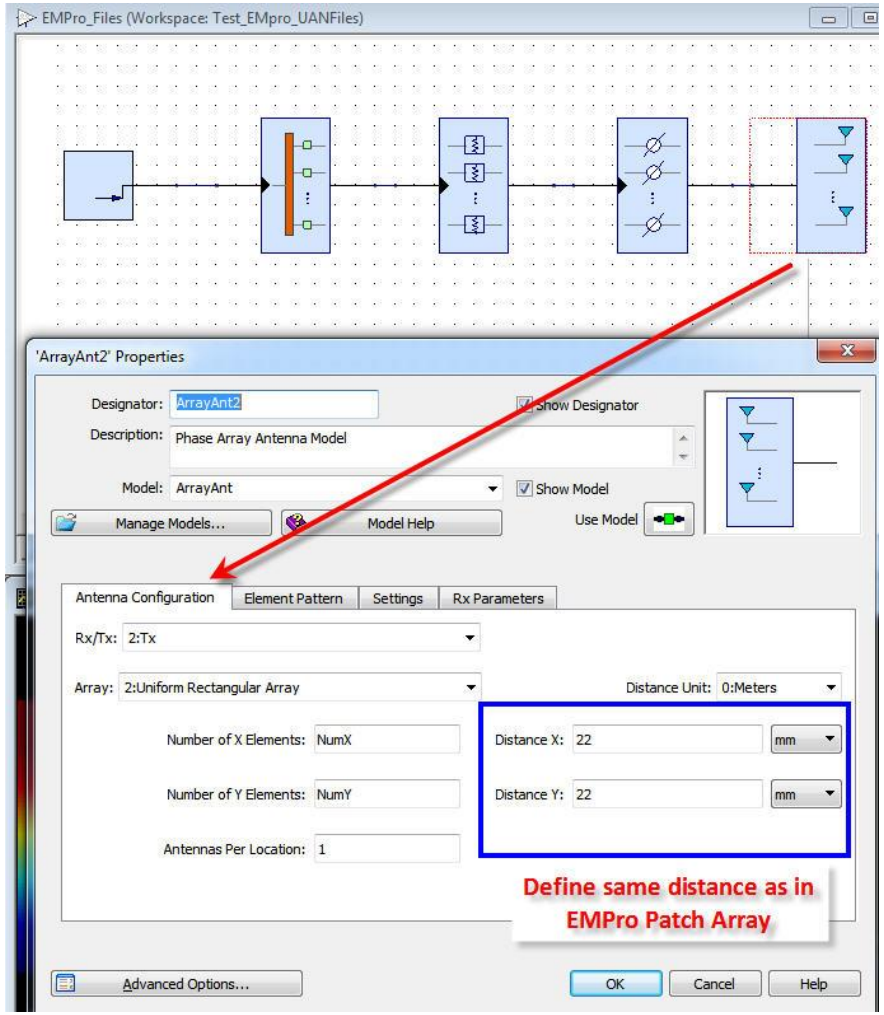


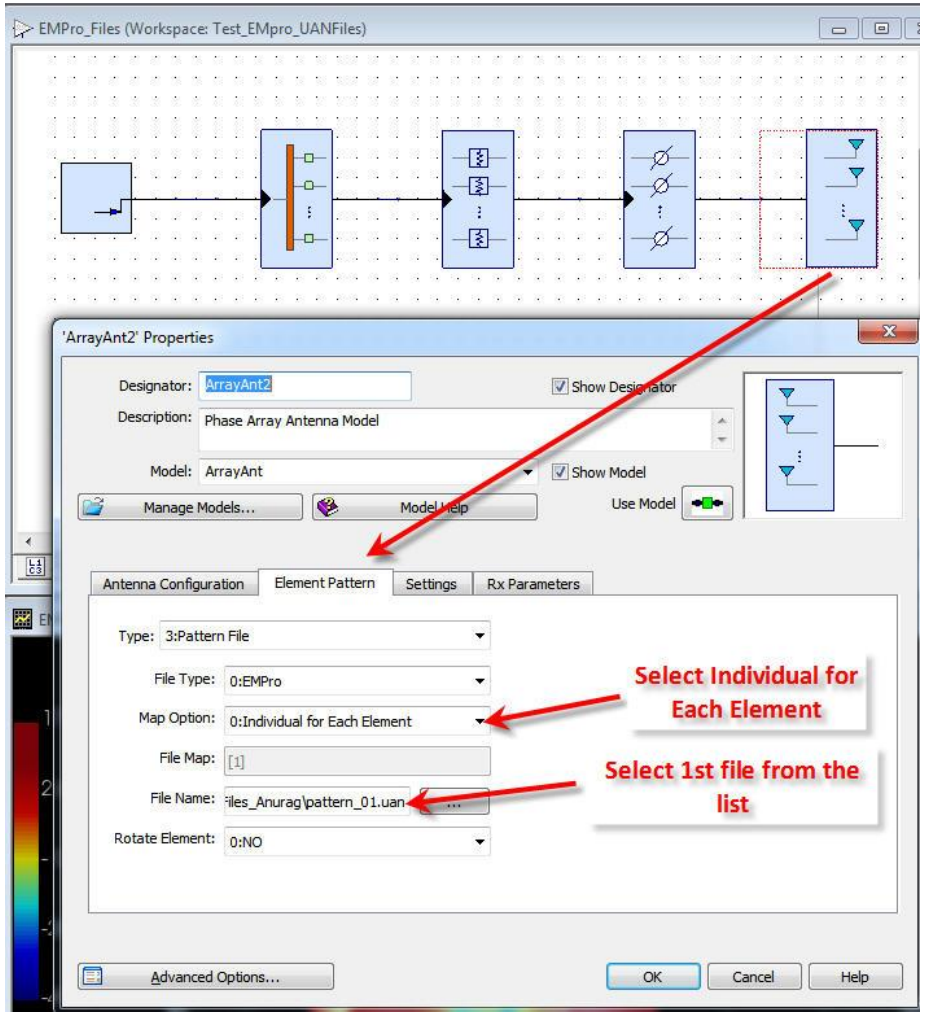
Resulting 16 uan files



SystemVue Phased Array System Design

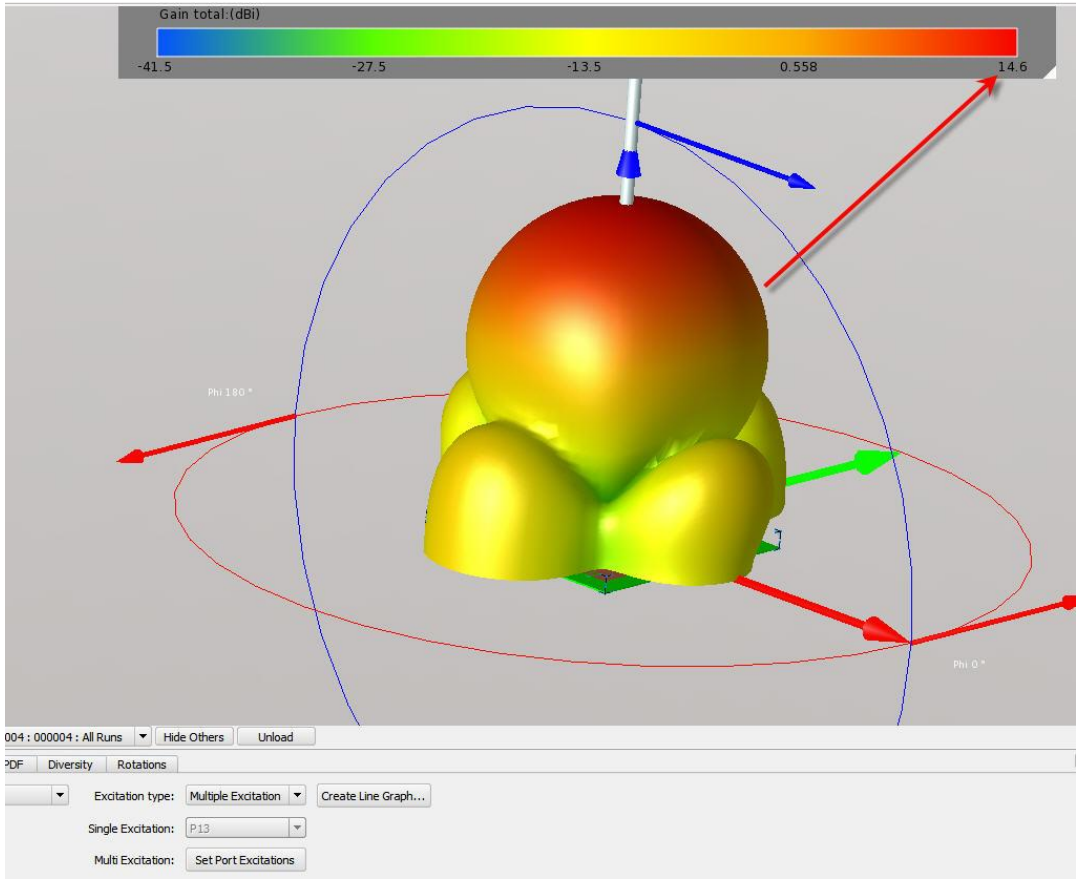
Setup equivalent Antenna configuration in SystemVue

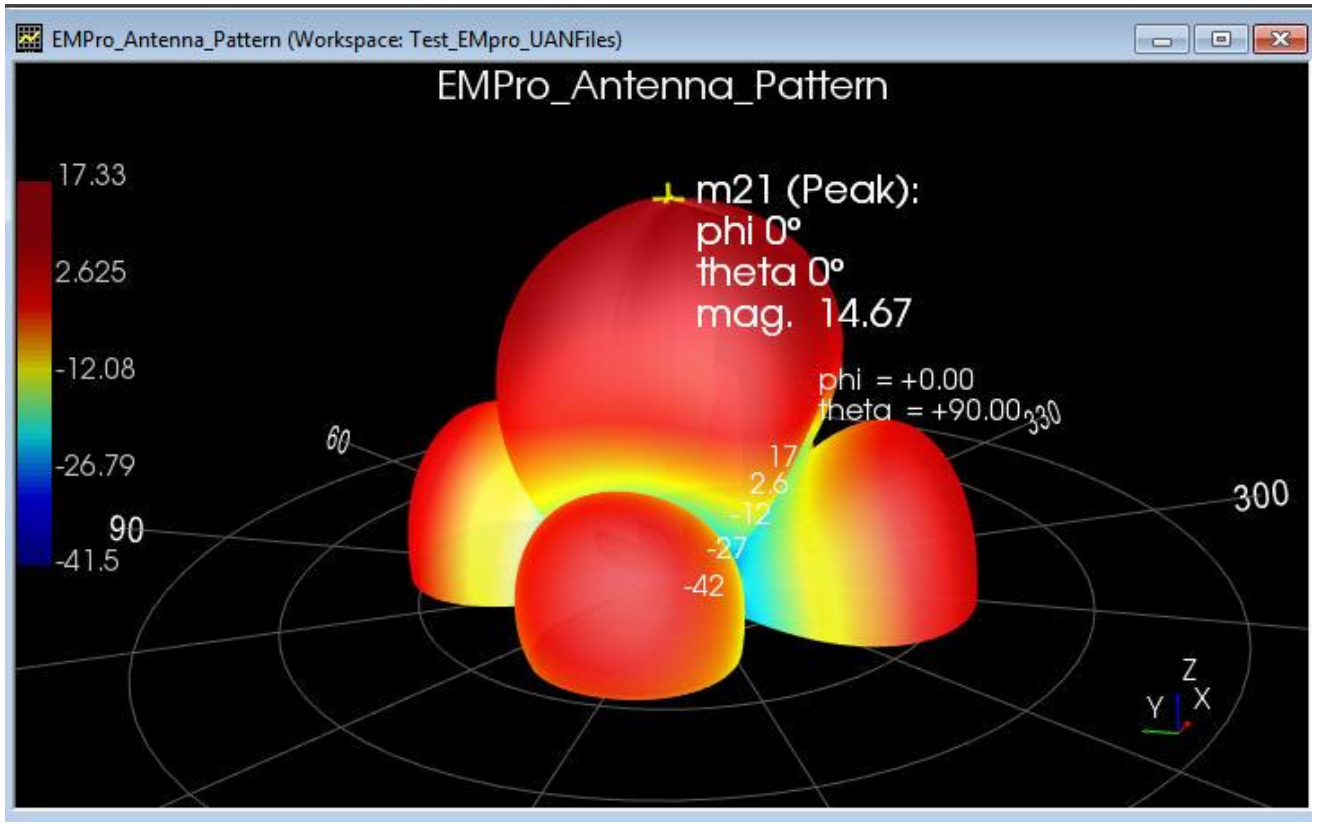




SystemVue Phased Array System Design

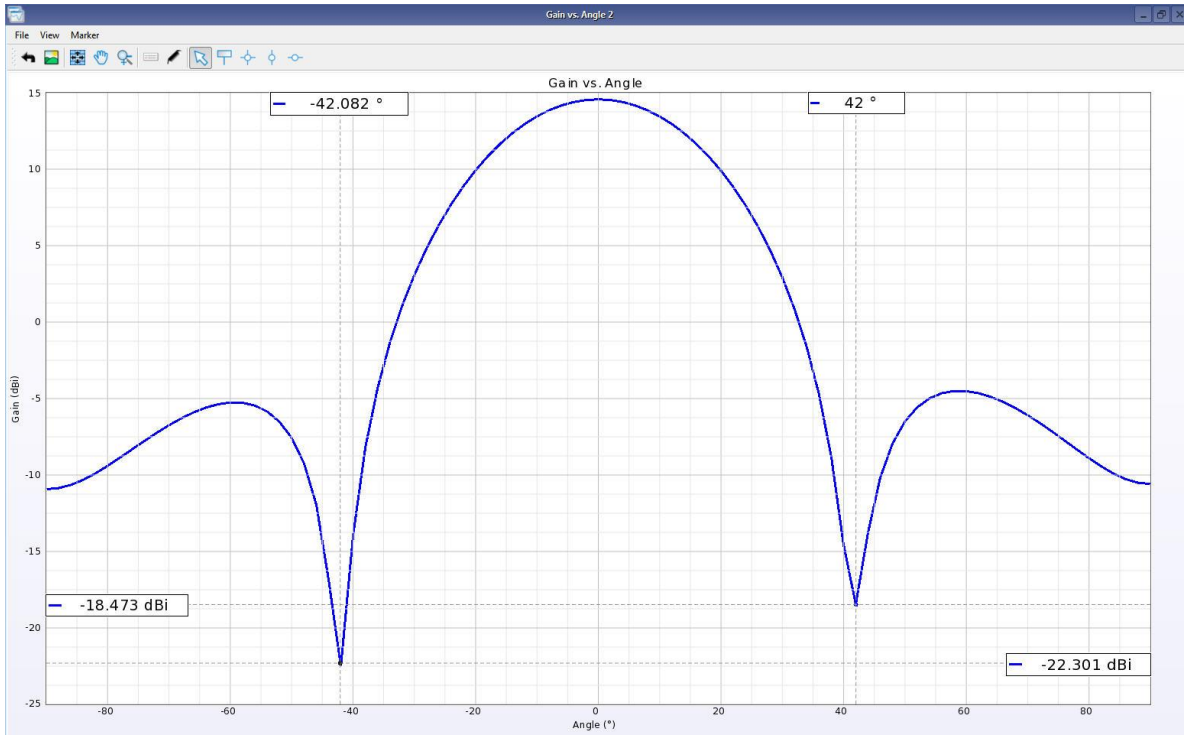
Comparison of EMPro and SystemVue Farfield patterns…..***Excellent Correlation…!!!***

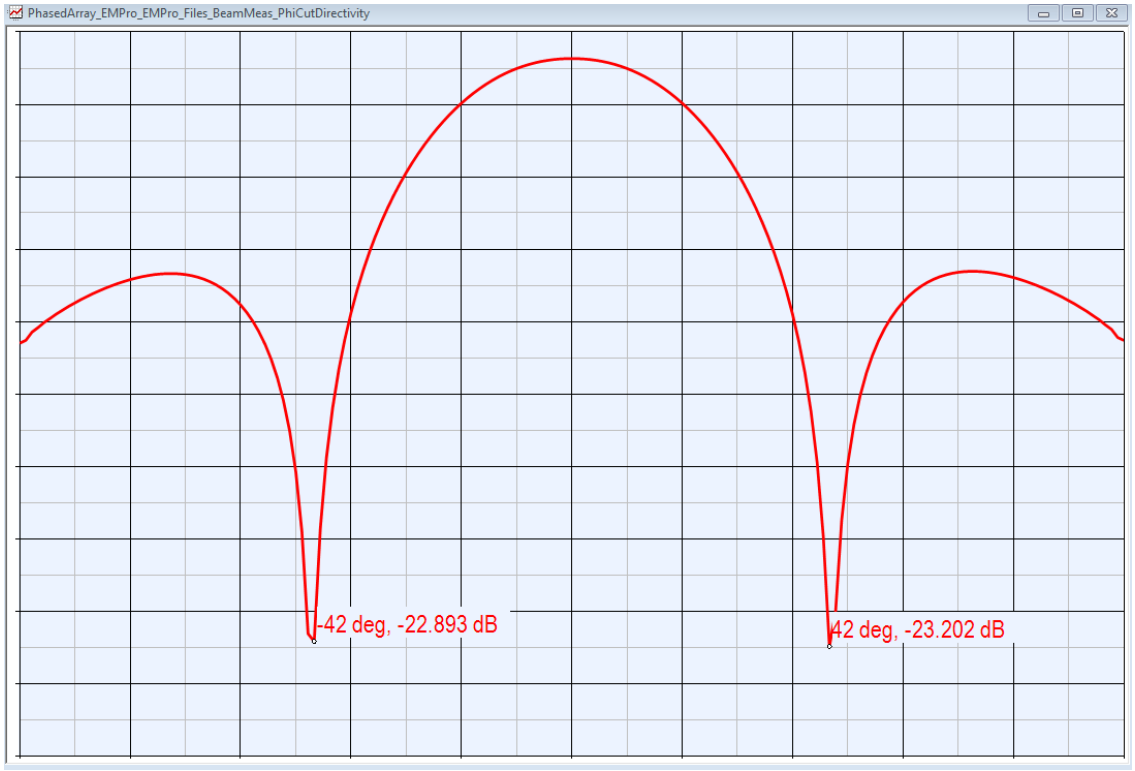




SystemVue Phased Array System Design

Comparison of EMPro and SystemVue 2D Cut pattern

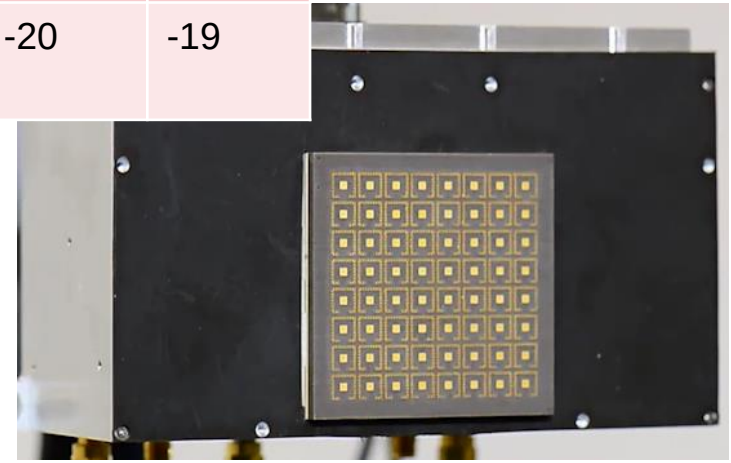




Simulation vs. Measurement Results

8X8 28GHZ URA RF BEAMFORMER RF-IF CONVERTER

Beam Direction	3dB Beamwidth (deg)		First Null Left (deg)		First Null Right (deg)		First Sidelobe Left (dB)		First Sidelobe Right (dB)	
	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas
0 degree	12.2	12.0	-15	-15	15	14	-20	-19	-20	-18
30 degree	14.5	14.0	14	13	50	50	-20	-21	-20	-20
-30 degree	14.5	14.5	-50	-50	-14	-13	-20	-22	-20	-19

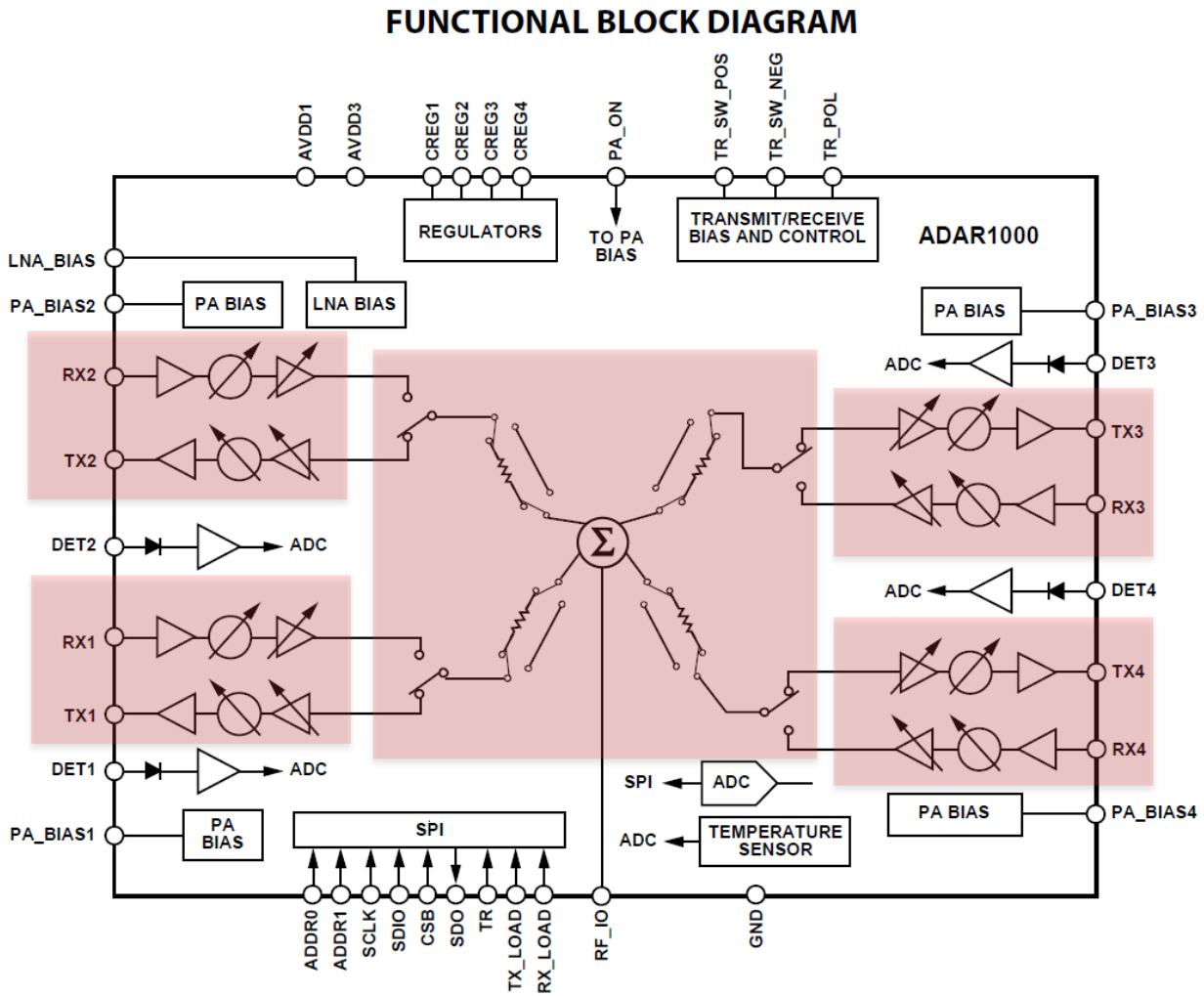


Phased Array Radar Design Case Study

ANALOG DEVICES ADAR 1000

Analog Devices – ADAR1000 Block Diagram

8 GHZ TO 16 GHZ, 4-CHANNEL, X BAND AND KU BAND BEAMFORMER



Highlighted portions is what we are modeling

Data Based Model

ADAR1000 MODEL USES NOMINAL TEMPERATURE AND BIAS DATA

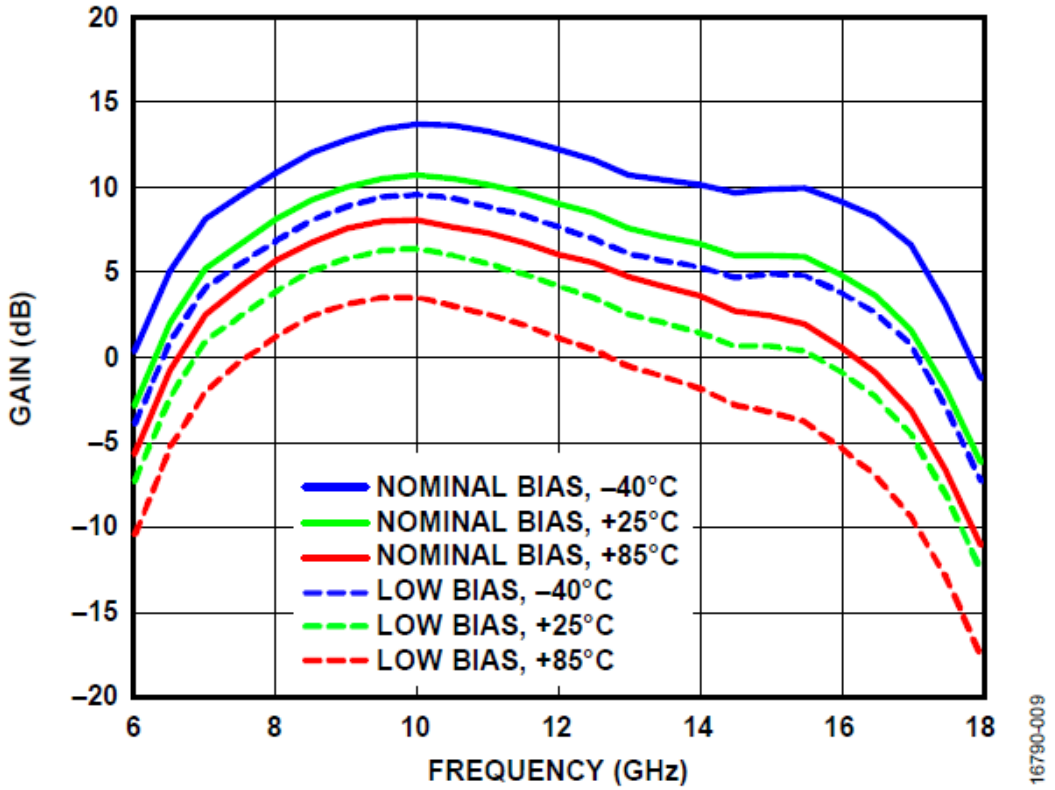


Figure 9. Receive Channel Measured Gain vs. Frequency for Various Bias Settings and Temperatures

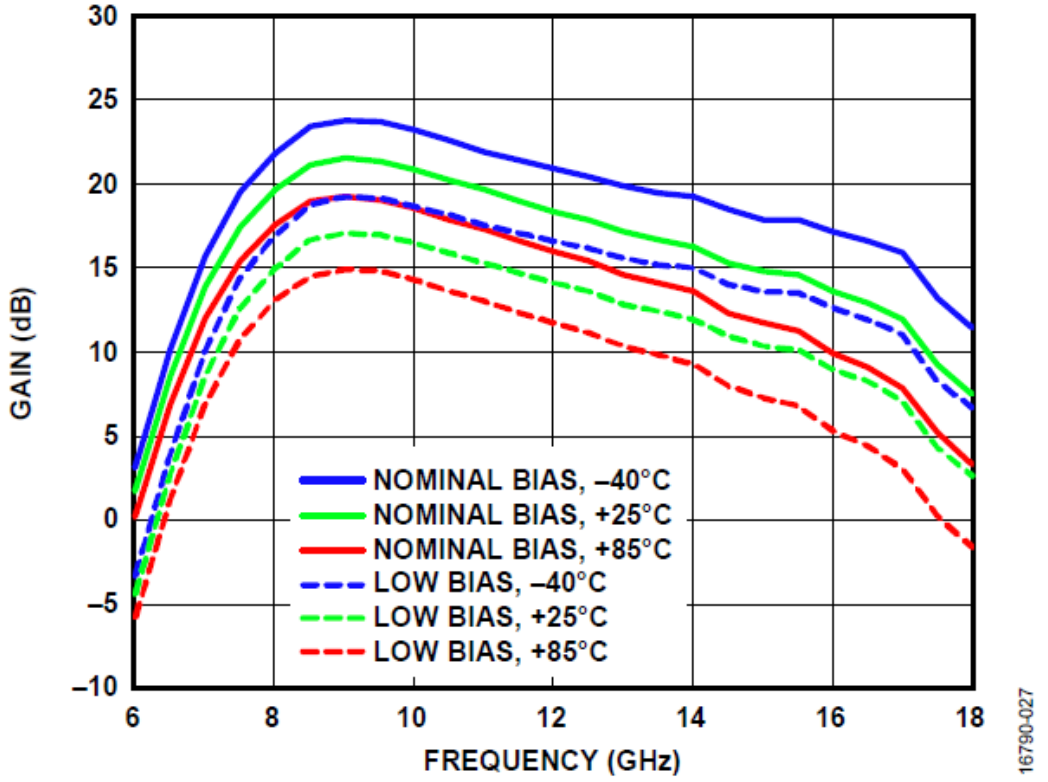
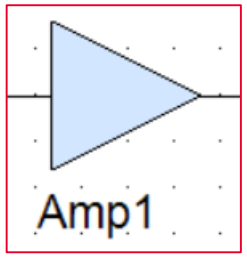


Figure 27. Single Transmit Channel Gain vs. Frequency for Various Bias Settings and Temperature

- Only nominal bias and nominal temperature are part of this version of the ADAR1000 model.

SystemVue Frequency Dependent Data Based Model

PERFORMANCE CAPTURED WITH FREQUENCY DEPENDENT SYSTEMVUE MODEL



ADAR1000 Frequency Dependent Data

'Amp1' Properties

Designator: Amp1 — Show Designator

Description: RF Amplifier

Model: RFAMP — Show Model

Manage Models... | Model Help | Use Model

Parameters | Frequency

Import Sys-Parameters... | Export Sys-Parameters... | Clear Data...

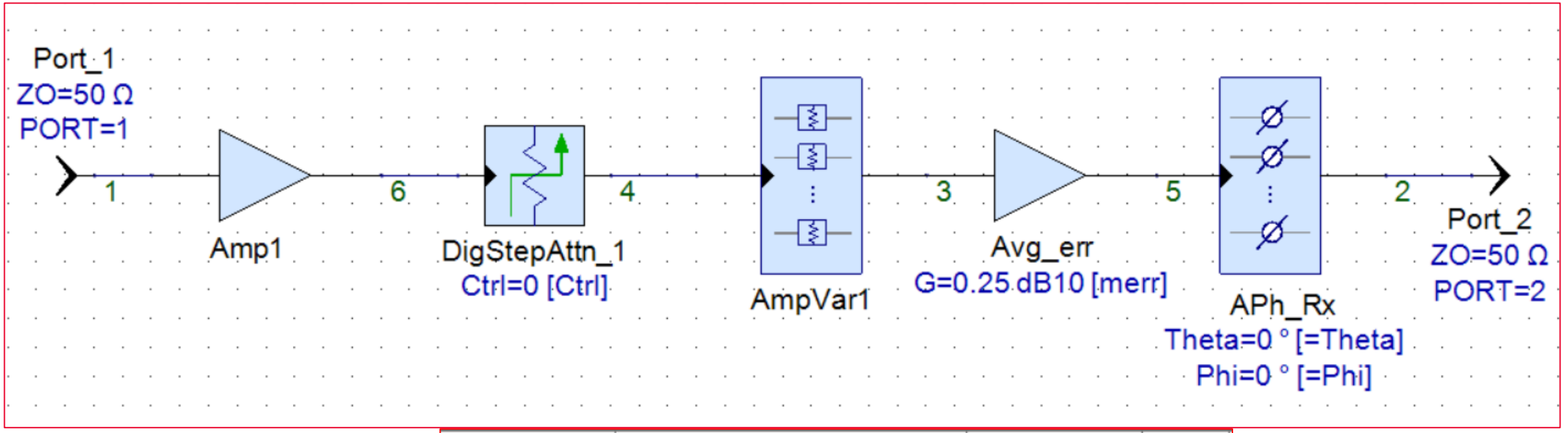
		Freq (GHz)	Gain (dB)	NF (dB)	OP1dB (dBm)	OPSAT (dBm)	OIP3 (dBm)	OIP2 (dBm)	Zin (Ohm)	Zout (Ohm)	Riso (dB)
Add	Remove	8	8.024	8.171	-6.276	-3.276	2.936	12.936			
Add	Remove	8.1	8.269	8.149	-6.089	-3.089	3.055	13.055			
Add	Remove	8.2	8.509	8.109	-5.937	-2.937	3.134	13.134			
Add	Remove	8.3	8.755	8.061	-5.748	-2.748	3.172	13.172			
Add	Remove	8.4	8.998	8.011	-5.63	-2.63	3.244	13.244			
Add	Remove	8.5	9.177	7.947	-5.549	-2.549	3.288	13.288			
Add	Remove	8.6	9.324	7.928	-5.492	-2.492	3.207	13.207			
Add	Remove	8.7	9.501	7.918	-5.41	-2.41	3.142	13.142			
Add	Remove	8.8	9.572	7.899	-5.47	-2.47	3.033	13.033			
Add	Remove	8.9	9.831	7.887	-5.308	-2.308	3.101	13.101			
Add	Remove	9	9.962	7.876	-5.284	-2.284	3.084	13.084			

Parameter Options | Browse...

Advanced Options... | OK | Cancel | Help

Complete Rx or Tx Model

MODEL ALLOWS FOR PROGRAMMABLE GAIN AND PHASE

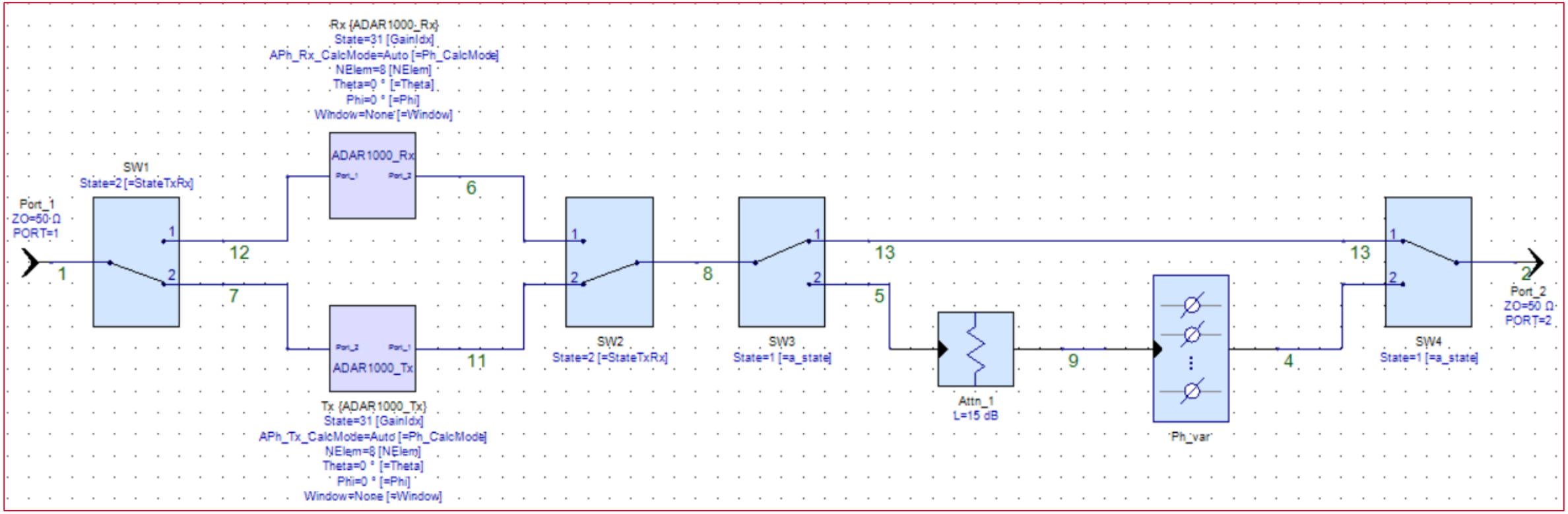


Name	Description	Default Value	Units
State	State 0 thru 31	31	( )
APh_Rx_CalcMode	Calculation mode	0:Auto	( )
BeamPhase	Phase values for Beamforming	[0:45:315]	(deg)
NElem	Element Quantity	8	( )
Theta	Theta angle	0	(deg)
Phi	Phi angle	0	(deg)
Window	Window (taper) type	0:None	( )
WindowParameter	Window parameter for GeneralizedCosine and Rea	1	( )
SideLobeLevel	Side lobe level in dB for Taylor window	-40	dB
NumBars	Number of bars for Taylor window	2	( )
Alpha	Alpha parameter for Gaussian Window	2.5	( )

SystemVue

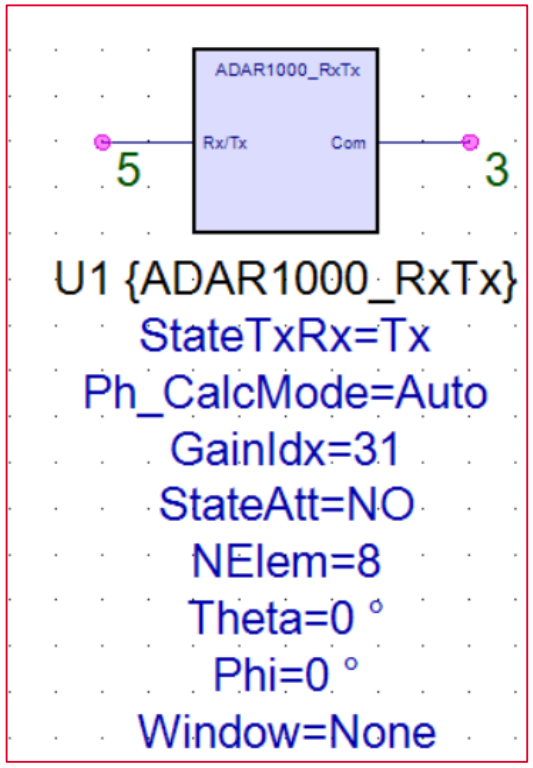
Complete ADAR1000 Model

RX OR TX MODEL AND ATTENUATOR SELECTABLE



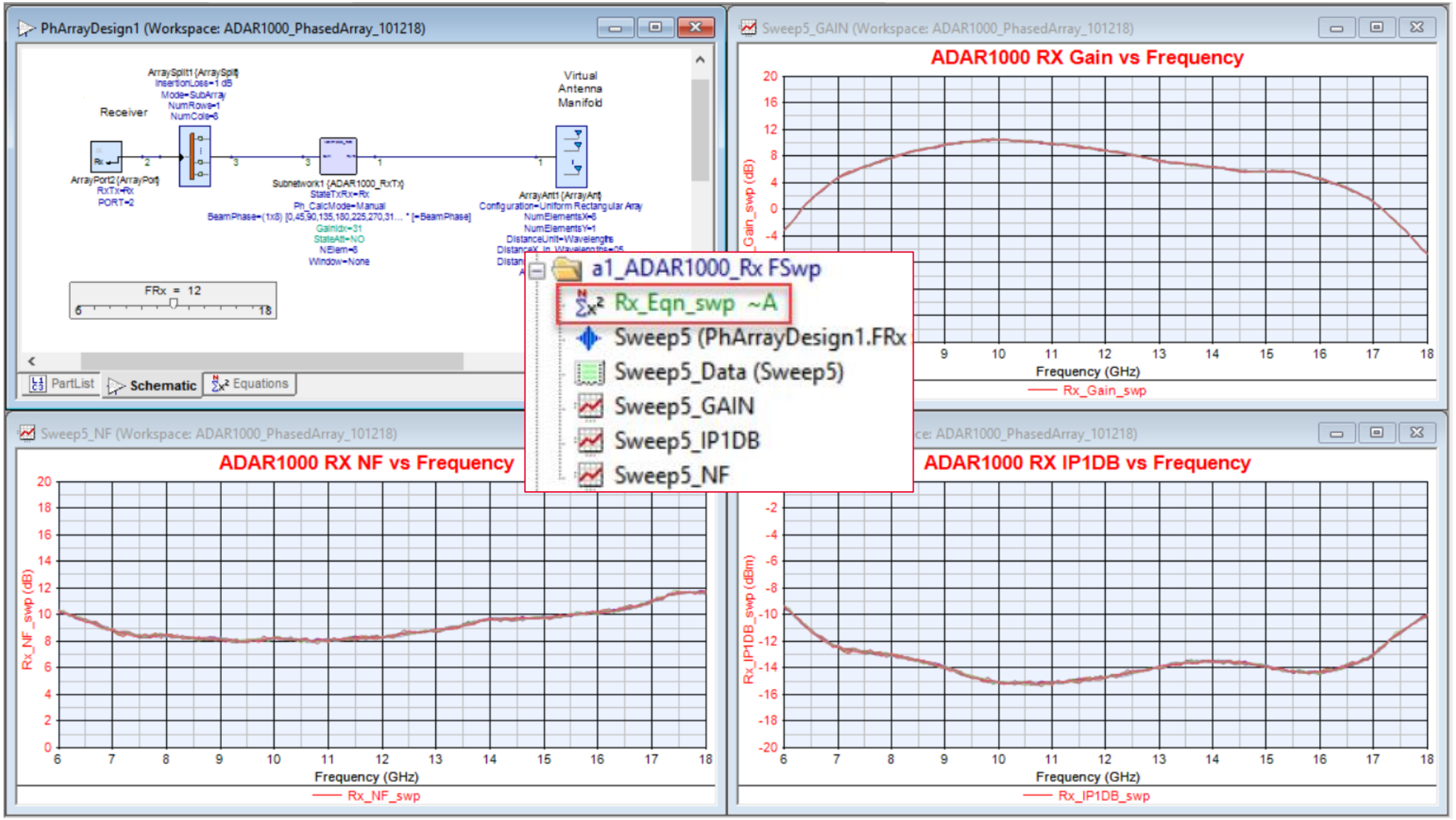
ADAR1000 Model Parameters

READY FOR PHASED ARRAY ANALYSES AND DESIGN



Name	Description	Default Value	Units
StateTxRx	Rx / Tx	2:Tx	( )
Ph_CalcMode	Calculation mode	0:Auto	( )
BeamPhase	Phase values for Beamforming	[0:45:315]	(deg)
GainIdx	Gain Index (0 -> 31)	31	( )
StateAtt	Attenuator Off =1, On =2	0:NO	( )
NElem	Element Quantity	8	( )
Theta	Theta angle	0	(deg)
Phi	Phi angle	0	(deg)
Window	Window (taper) type	0:None	( )
WindowParameter	Window parameter for GeneralizedCosine and Rea	1	( )
SideLobeLevel	Side lobe level in dB for Taylor window	-40	dB
NumBars	Number of bars for Taylor window	2	( )
Alpha	Alpha parameter for Gaussian Window	2.5	( )

Frequency Sweep Analysis

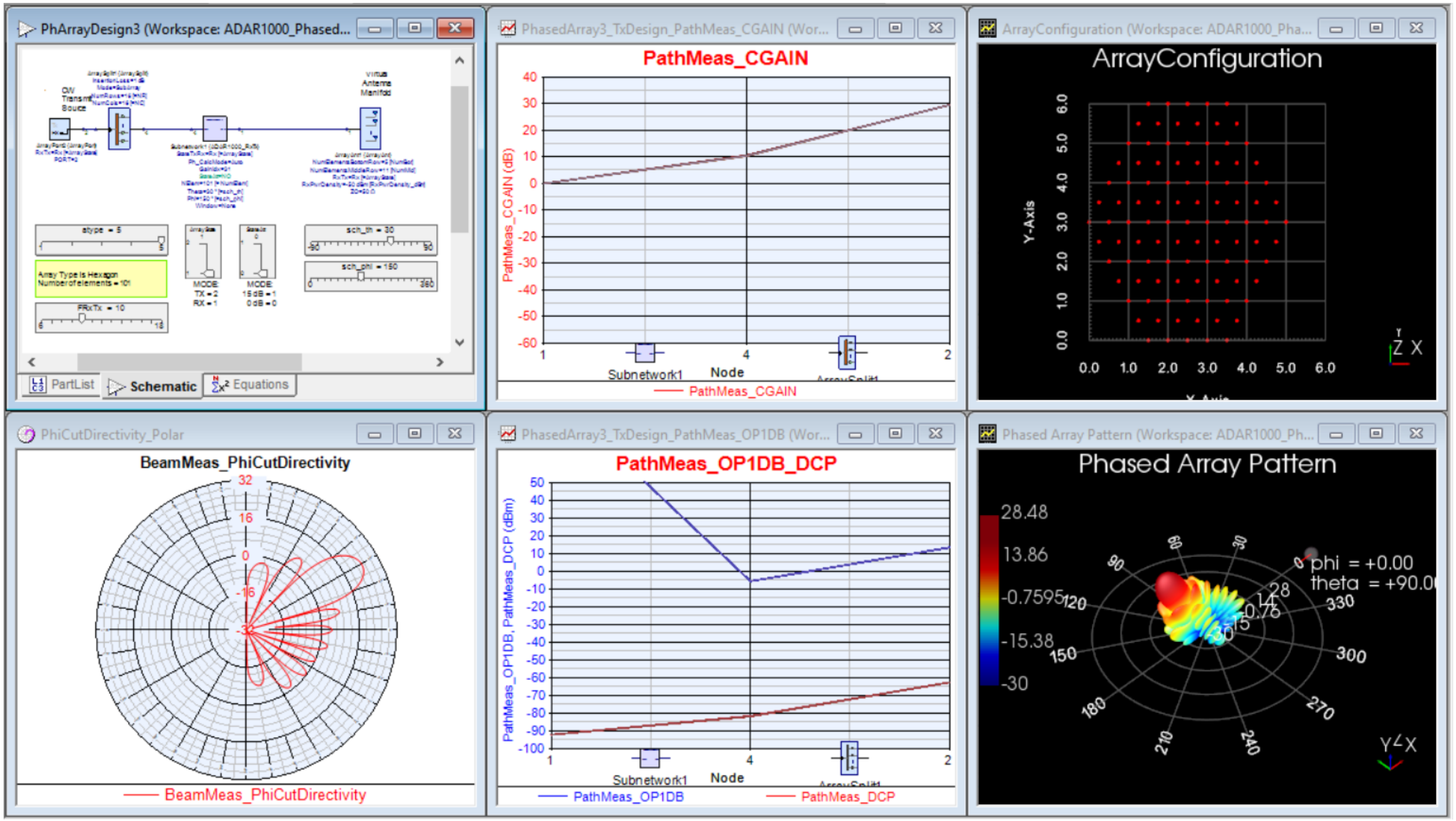


12 GHz Gain values

1) 12
   a) 9.173 dB
   b) 9.269 dB
   c) 9.04 dB
   d) 9.153 dB
   e) 9.015 dB
   f) 8.979 dB
   g) 9.026 dB
   h) 9.077 dB

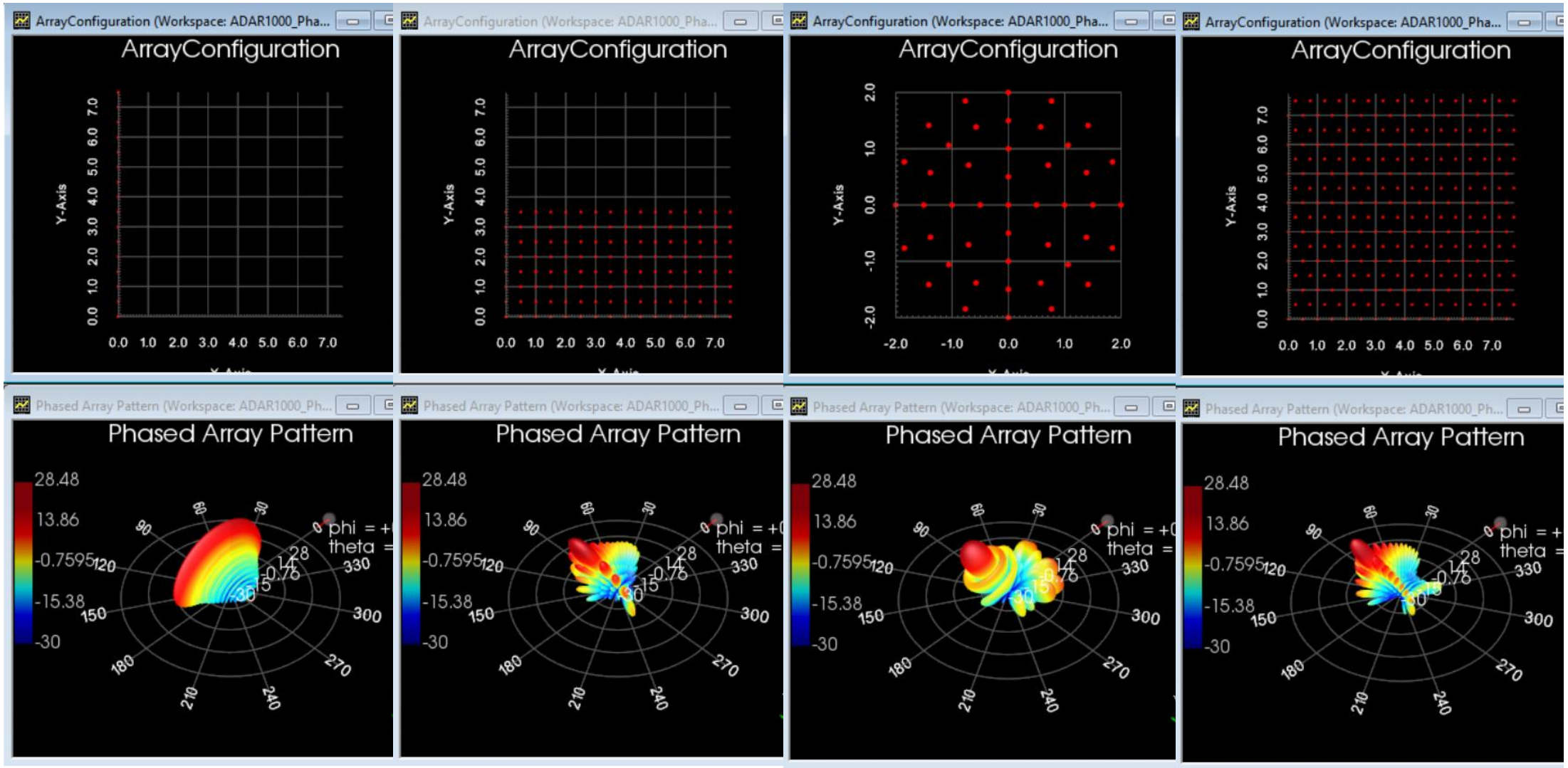
SystemVue

Phased Array Hexagon Configuration - Rx

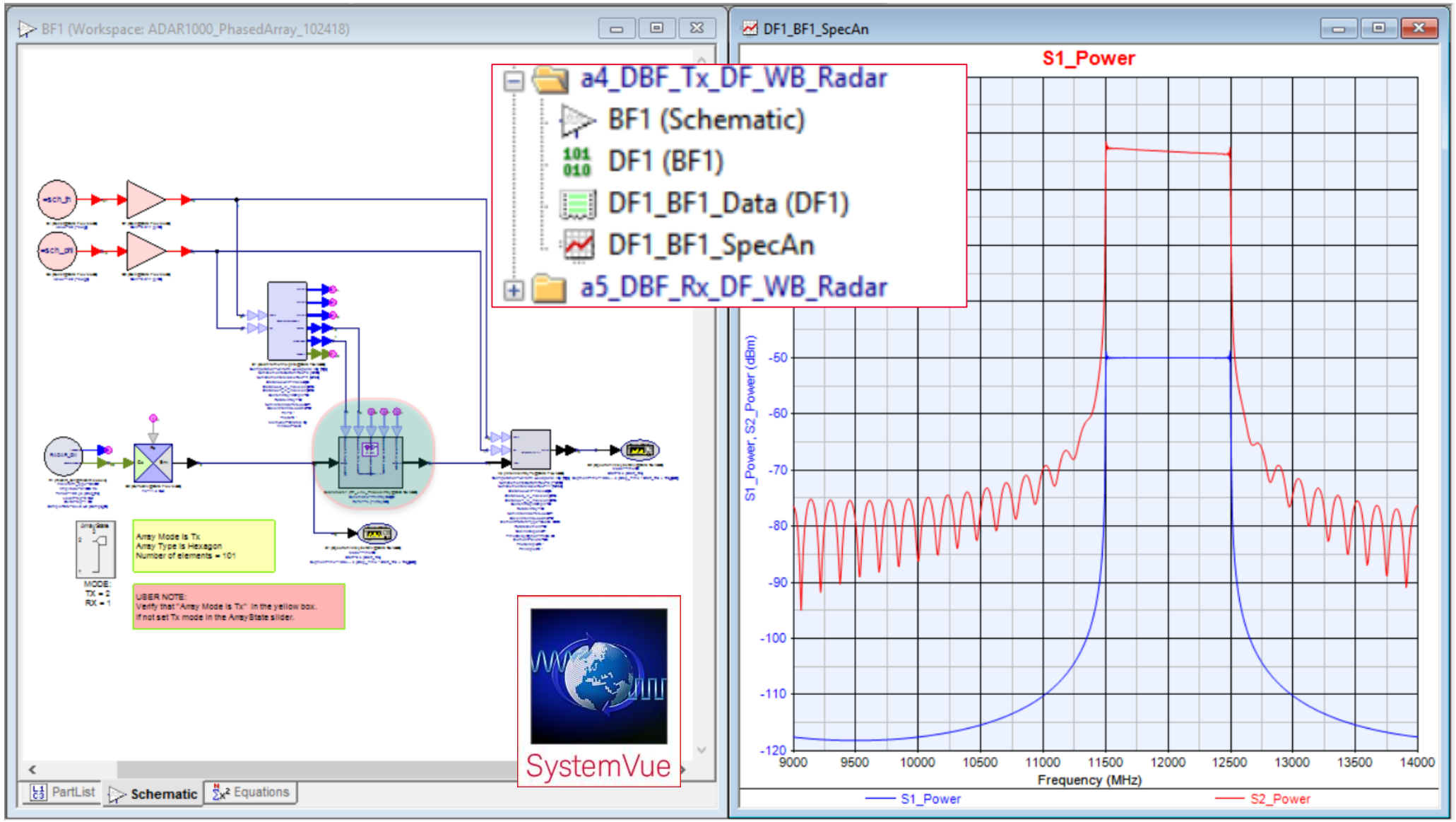


SystemVue

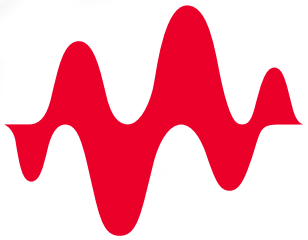
Array Configurations Supported



ADAR1000 TX Phased Array Design with real Radar Signal



Thank You for Attending!



KEYSIGHT
TECHNOLOGIES