5G 毫米波阵列天线仿真与优化设计

ANSYS HFSS, SBR+, EMIT



2020/06/19

Nicholas Chang, Ph.D

CYBERNET

Cybernet Systems Worldwide



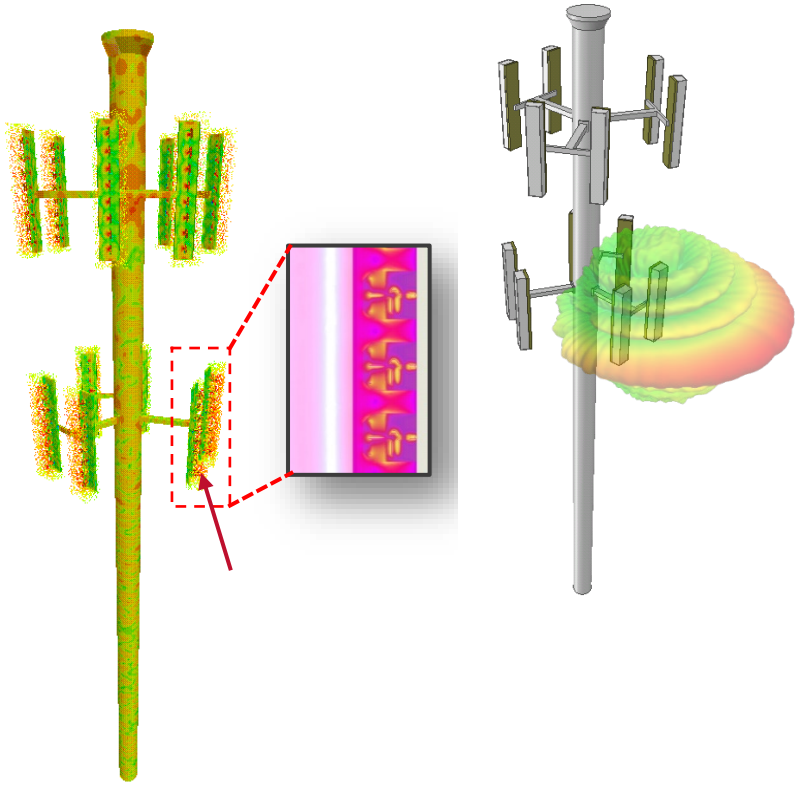
關於 CYBERNET 集團

日本 CYBERNET SYSTEMS 公司自1985年成立至今，為日本一級的成功上市股票公司，旗下有數百位專業的碩、博士專業工程師，提供各種工程分析、顧問服務以及開發相關軟硬體介面、模式以及分析模塊開發與 IT 相關軟體工具。 CYBERNET SYSTEMS 擁有超過30年頂尖工程專業經驗，各行業之領導廠商皆是 CYBERNET 之忠誠客戶。

CYBERNET 集團於2006年始積極拓展版圖，積極於中國、台灣等處成立服務據點，並陸續併購公差分析軟體開發大廠 Sigmetrix、符號運算引擎開發大廠 Maplesoft，以及程序整合暨設計最佳化開發大廠 Noesis Solutions，期能提供更完整、更即時之工程服務予全球客戶。

Agenda

- Introduction
  - What is 5G?
  - ANSYS Electronic Product for 5G
- 5G Array Design
  - Element Design
  - Array Synthesis
  - Installed Performance
  - Link Margin and Interference Analysis
  - Multi-Physics
- Automation
  - Antenna Work Flow Automation



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Introduction

5G网络能源支出将增长数倍

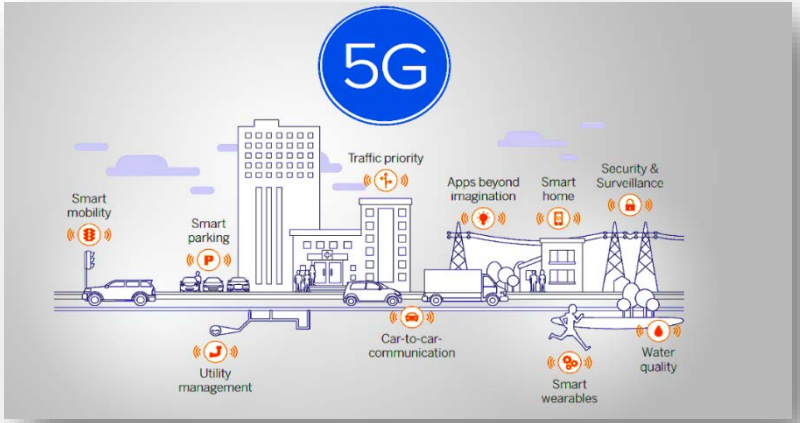
1G 语音

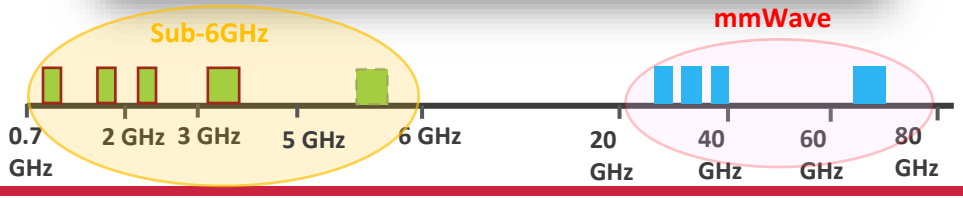
2G 语音与文字讯息

3G 语音、文字讯息与行动网路

4G 语音、文字讯息、行动网路与多媒体

5G 自动驾驶、物联网、智能环境与传统 4G...等





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5G将推动各行各业的新应用



5G供应商面临巨大的部署和运营成本

DEVICES

Mobile IoT Automotive



NETWORKS

Wireless



EDGE DEVICES & COMPUTE

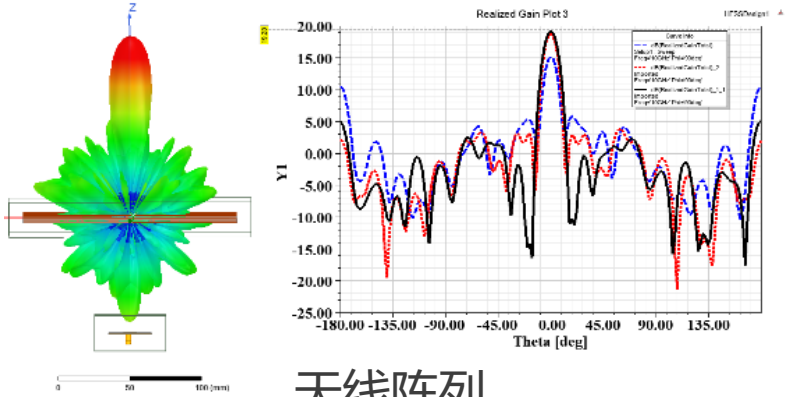
DATA CENTERS

Compute / Cloud

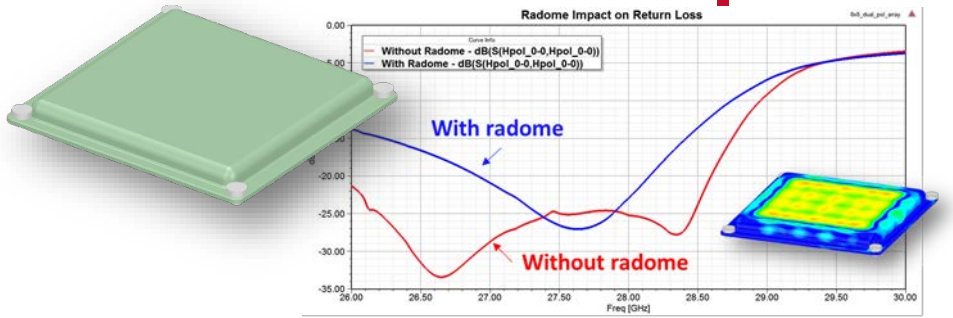


频段更新，设备跟更新甚至研发

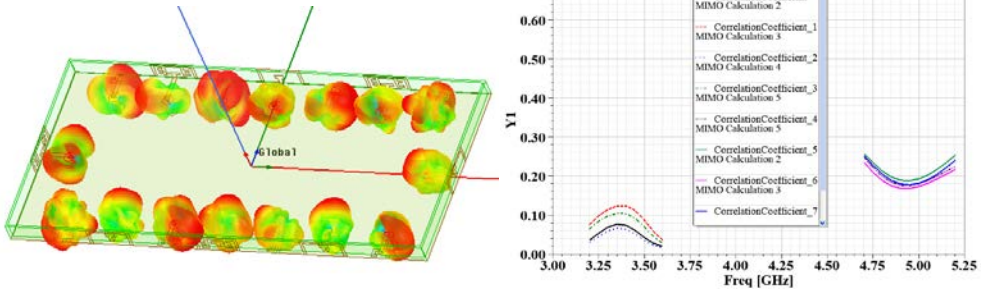
5G毫米波频段对天线与微波产业的冲击



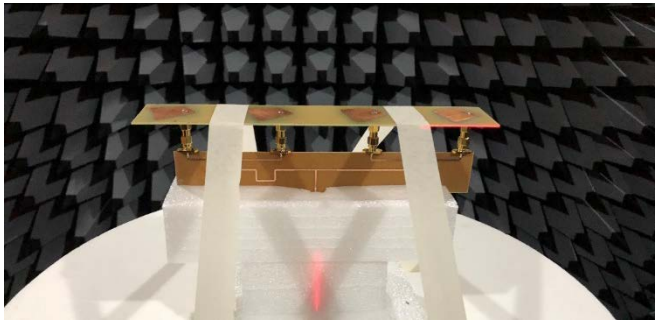
天线阵列



多重物理天线仿真



更多天线的 MIMO 效应



更精确量测技术

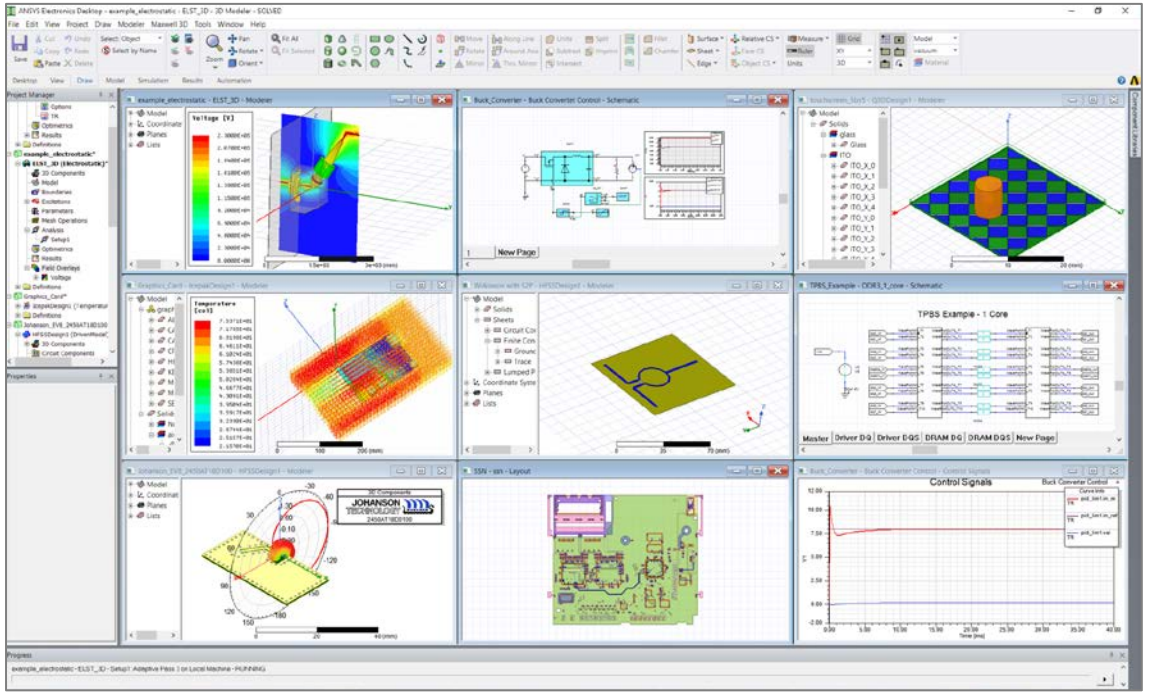
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5G Array Design

ANSYS Electronics Desktop (AEDT)

- ANSYS Electronics Desktop – Electromagnetics Suite
- Single Unified Desktop for Electronics Tools
  - HFSS Design Types
  - Q3D Extractor Design Types
  - Circuit Design Types
  - ICEpak Designs
  - Maxwell Design Types
  - Simplorer
  - SBR+

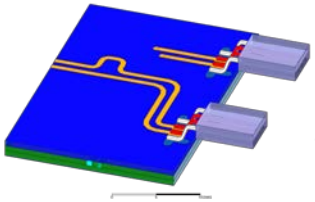


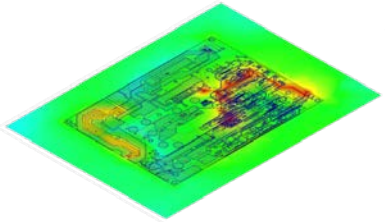
ANSYS HFSS™

- **3D full-wave frequency domain electromagnetic field solver**
- **Gold standard for extraction of parameters (S, Y, Z) since 1990**
- **Visualize 3D electromagnetic fields (near- and far-field)**
- **Automatic and adaptive mesh that provide best-in-class solutions.**

Versatile Modeling

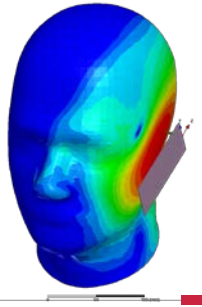
Efficient design-entry environment





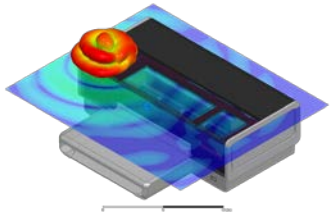
Rigorous Validation

Sign-off quality high-frequency EM results



Rapid Iteration

Parametrized design space exploration, multi-team convergence

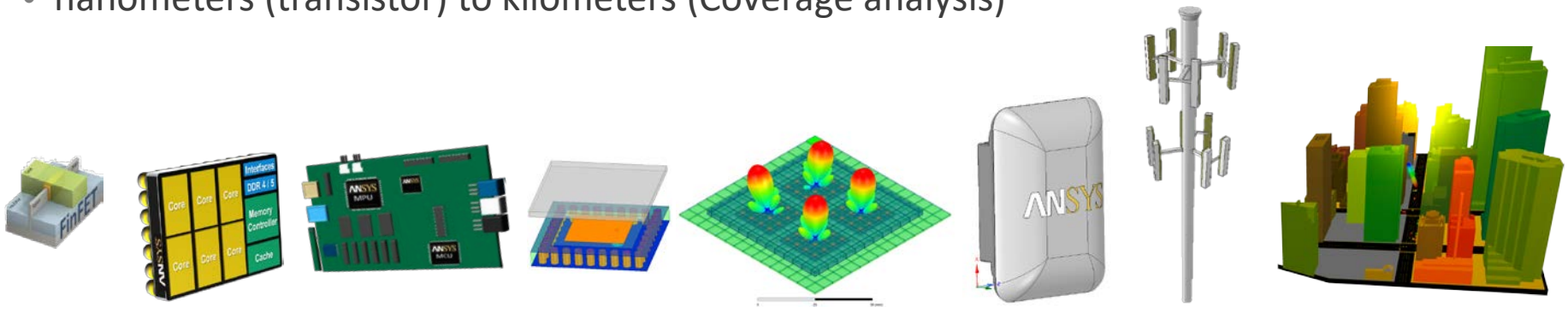


Applications

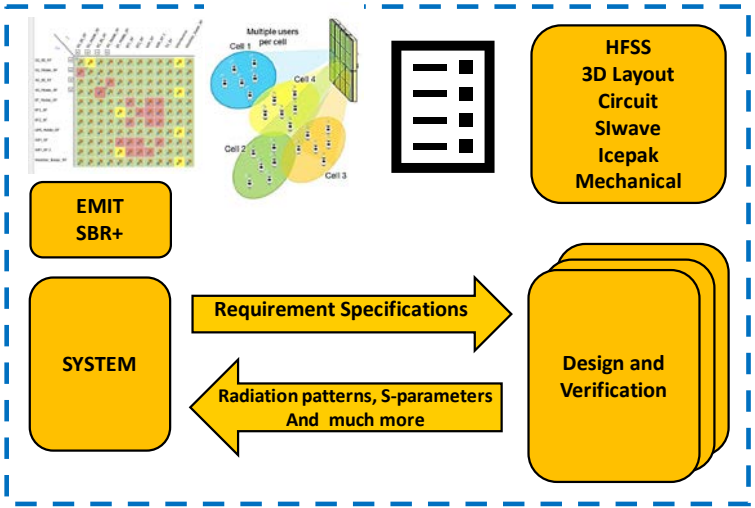
- Antennas
- Waveguides
- Filters
- Integrated circuit (IC) packages
- Connectors
- Vias
- Transitions
- LTCC devices
- MMIC devices
- Radar equipment
- Cell phones
- Satellite equipment
- Bio-Medical equipment
- Wireless components
- EMI/EMC

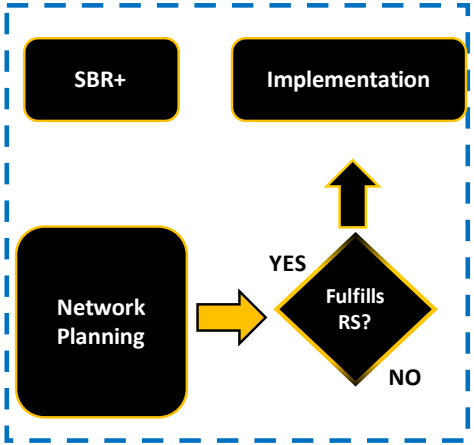
Simulation Across All Major Physics

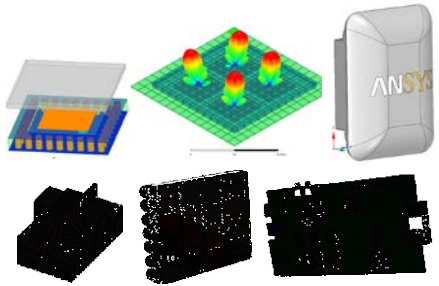
- Electromagnetics, Optics, Semiconductor, Structures, Fluids, Embedded Software
- Multiscale Modeling
- nanometers (transistor) to kilometers (Coverage analysis)

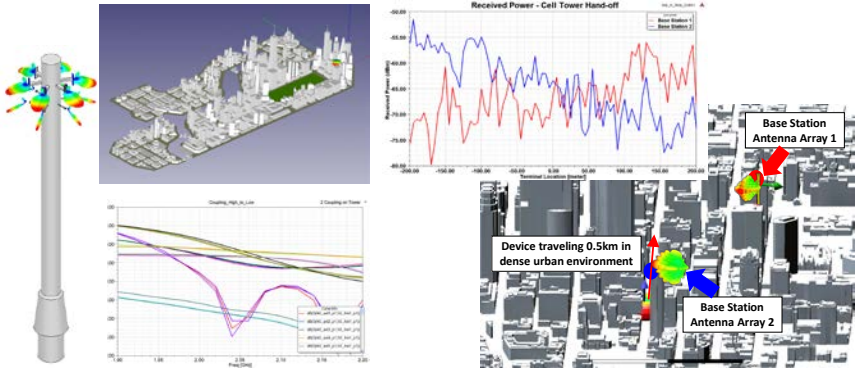


Product Development Work-Flow







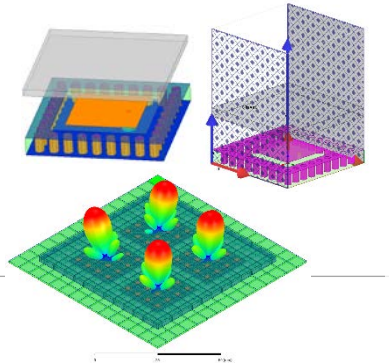


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5G 阵列设计流程 1

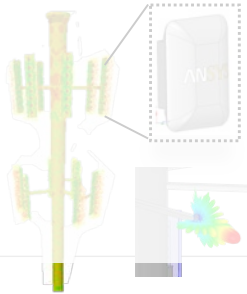
Antenna Element & Array Design

HFSS
Unit cell analysis,
Design of Experiment (DOE)
Analysis/optimization
Infinite array,
3D Component Array,
Explicit array



Installed Antenna Performance

SBR+
Antenna Housing
Installed phase array antenna including housing on Mast



SYSTEM

SBR+ & EMIT
Link margin, Interference,
Coupling models
Beam forming and
Coverage estimates
Develop specifications

Network Planning & Coverage studies

SBR+
Network planning
BS – UE coupling
Handoff
Multi-User Massive-MIMO
Evaluate Channel-performance

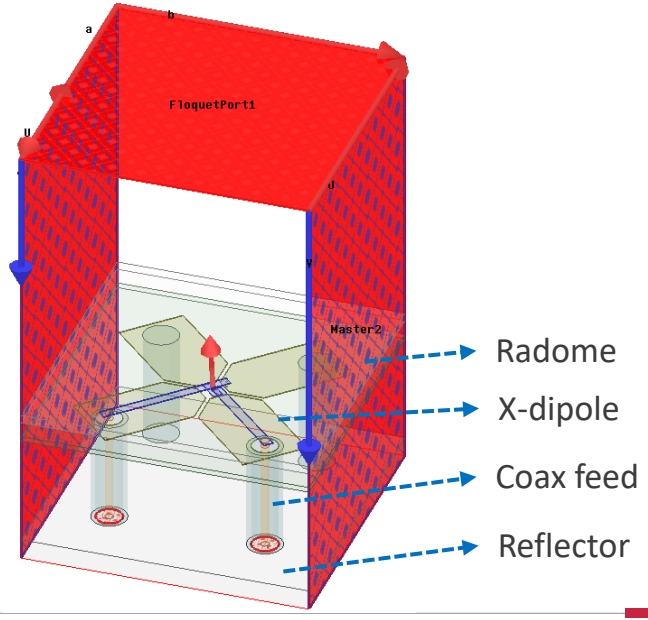
Multi-physics Analysis

AEDT/WB
Temperature,
Structural,
Two-way coupling

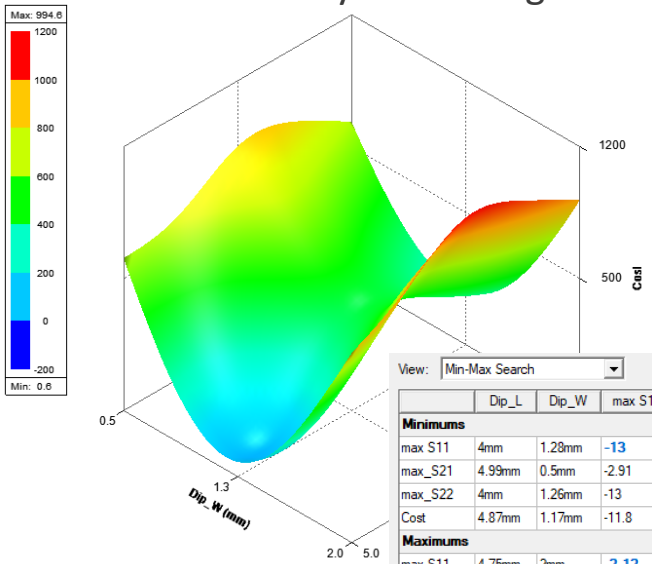
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Array Element Design

- Dual-slanted-polarized cross-dipole antenna element
- Periodic BC is applied



- Design of Experiment in AEDT
  - To obtain response surface
  - To optimize the design parameters
  - Tolerance Analysis of Design Parameters



View: Min-Max Search | Update | Refinement Converged

	Dip_L	Dip_W	max S11 (P)	max_S21 (P)	max_S22 (P)	Cost (P)
Minimums						
max S11	4mm	1.28mm	**-13**	-10.7	-16.7	197
max_S21	4.99mm	0.5mm	-2.91	**-27.8**	-3.21	577
max_S22	4mm	1.26mm	-13	-10.9	**-16.8**	192
Cost	4.87mm	1.17mm	-11.8	-21.3	-13.9	**0.342**
Maximums						
max S11	4.75mm	2mm	**-2.12**	-13	-2.76	854
max_S21	4.25mm	2mm	-3.92	**-2.67**	-4.02	928
max_S22	4.72mm	0.5mm	-3.1	-23	**-2.73**	641
Cost	4.46mm	2mm	-3.04	-4.23	-3.17	**995**

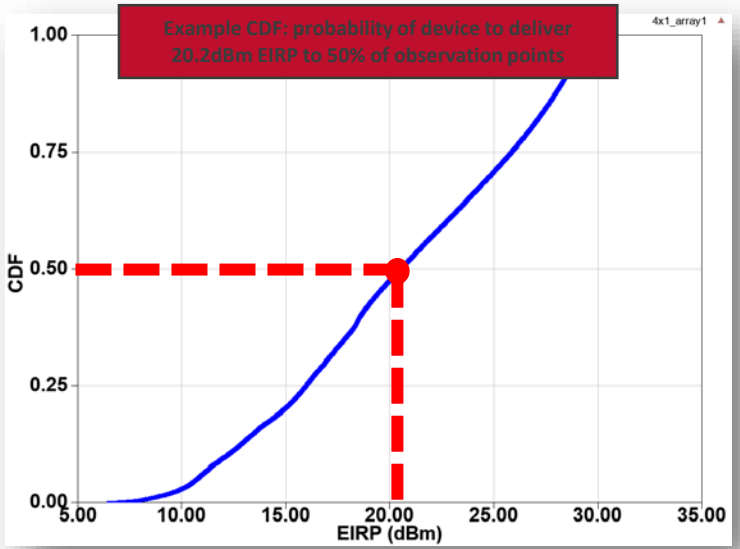
5G Array Post Processing: CDF

Cumulative Distribution Function (CDF) for Antenna Arrays

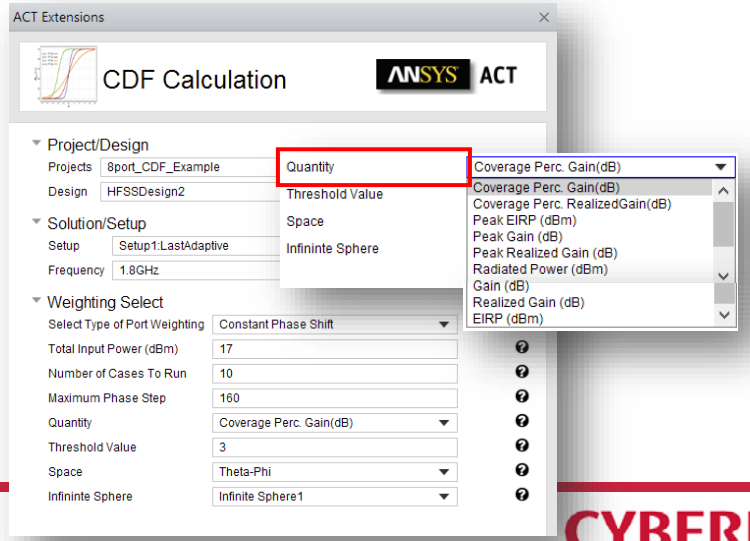
Statistical analysis of far field quantities that results in the probability that a quantity will be less than or equal to a certain percentage over the entire infinite far field sphere

Post processing CDF in ANSYS Electronics Desktop (AEDT)

ACT Extension developed to automatically extract CDF curve for antenna arrays with multiple weightings



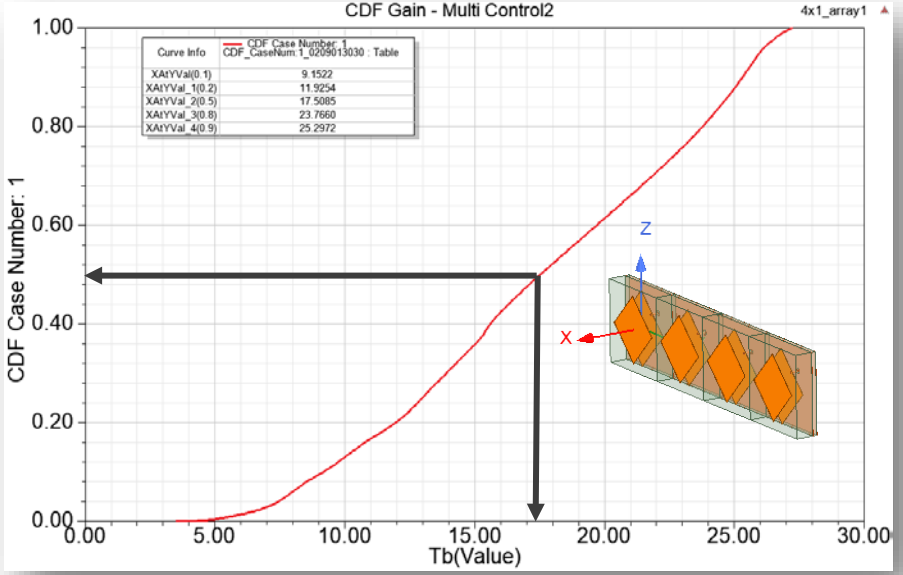
CDF ACT Extension



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CDF: mmWave Antenna Module Results

- CDF ACT Extension
  - Quantify array performance for various beam configurations
  - 5 beam definitions used to compile CDF across each beam
- Requirement of 50 percentile CDF of 11.5dBm EIRP
  - mmWave antenna module demonstrated here shows 17dBm at 50% CDF is achieved, meeting minimum requirements
  - ANSYS Customization Toolkit (ACT) allows max EIRP normalization



Probability of device to deliver EIRP of 17 dBm to 50% of observation points

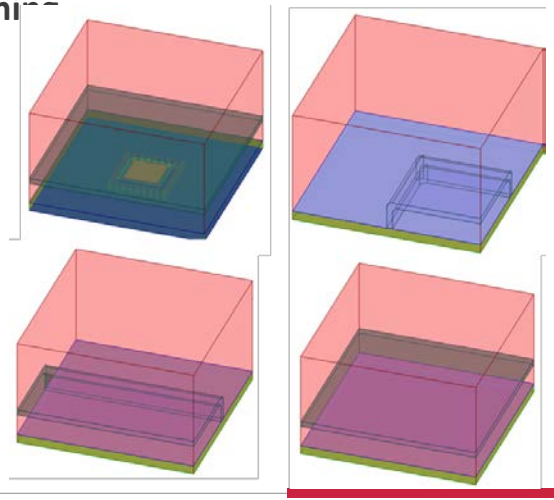
Table 6.2.1.3-3: UE spherical coverage for power class 3

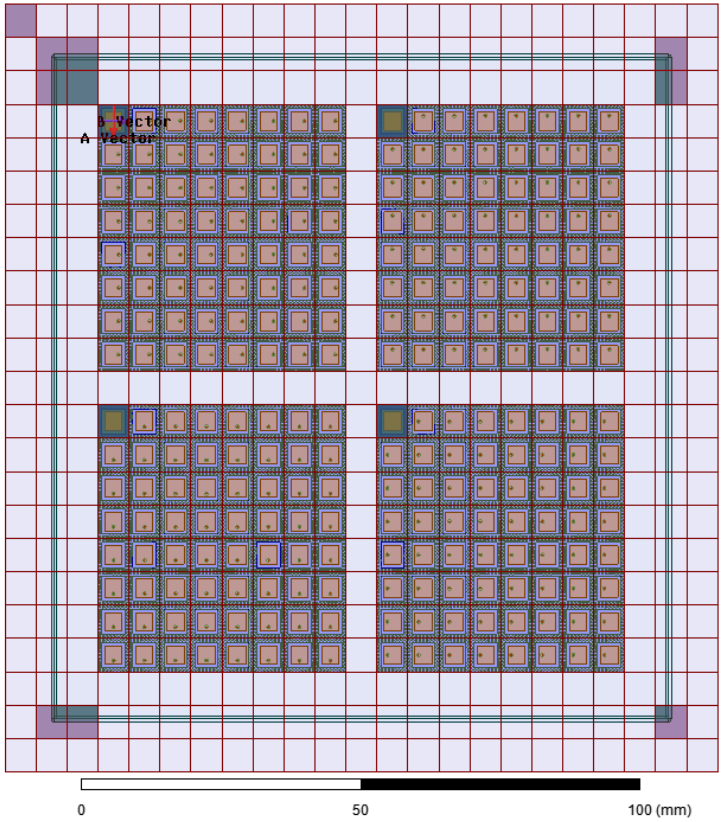
Operating band	Min EIRP at 50%-tile CDF (dBm)
n257	11.5
n258	11.5
n260	8
n261	11.5

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Phase Array Synthesis – 3D Component Antenna Array

- **Phased array example using Novel HFSS 3D component finite array simulation technique**
- **Makes use of:**
  - **3D components**
  - **Non-conformal mesh**
  - **Ability to adapt component mesh Independently**
  - **Dynamic surface meshi**

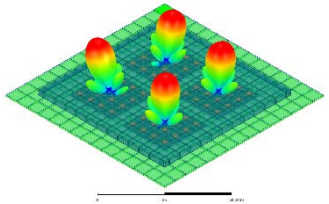


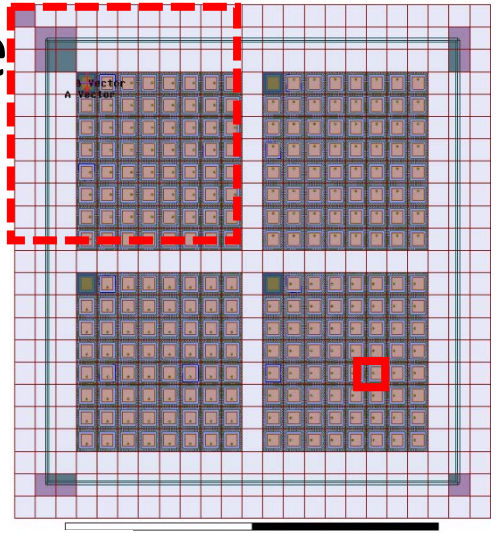


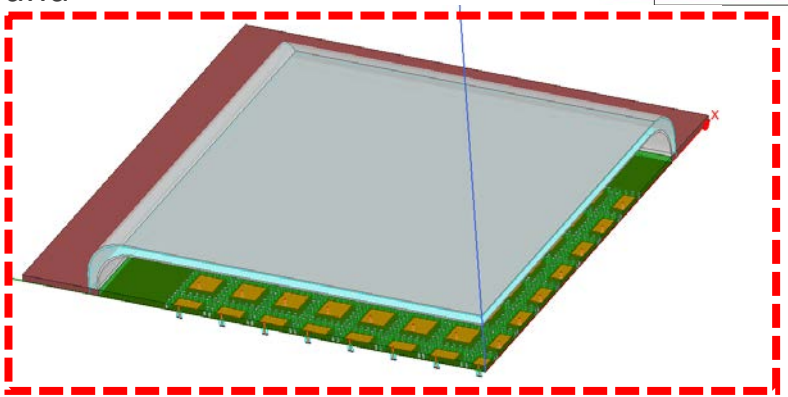
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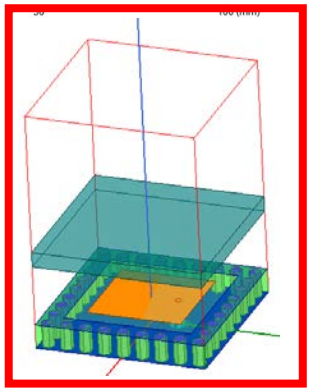
New Feature AEDT 2019R3 – Example

- **256 Element Example**
  - Four times 8x8 array for 5G (28 GHz)
  - Radome covering all panels
  - Radome is bended to touch the ground plane
  - Each Array panel is separated with an antenna element size ground plane
  - Includes finite ground size (size of ground plane extension from antenna edge)
- **Full wave (FEM) Simulation time**
  - **Adaptive Mesh included**
  - **32 Cores: 3 hours**
  - **128 Cores: Approximately 1 hour**

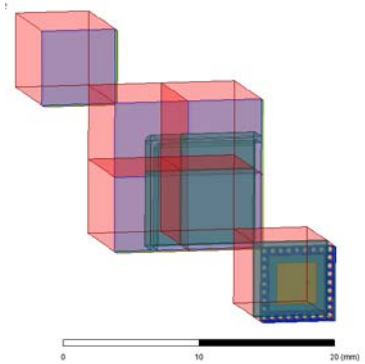








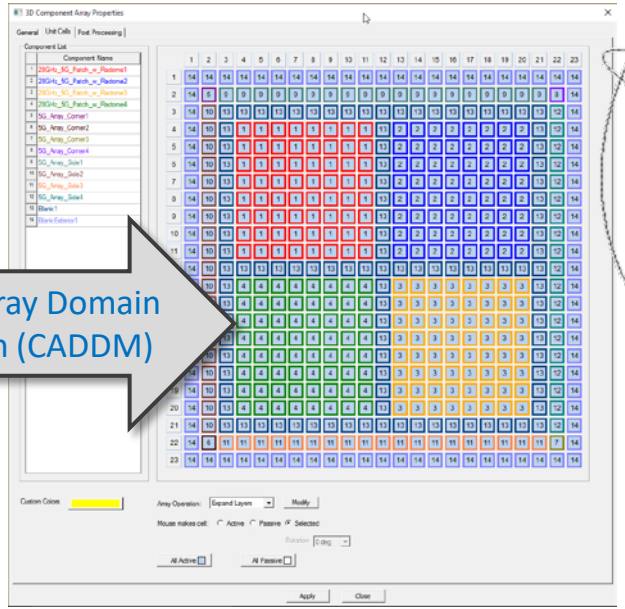
Array Antenna Analysis in HFSS

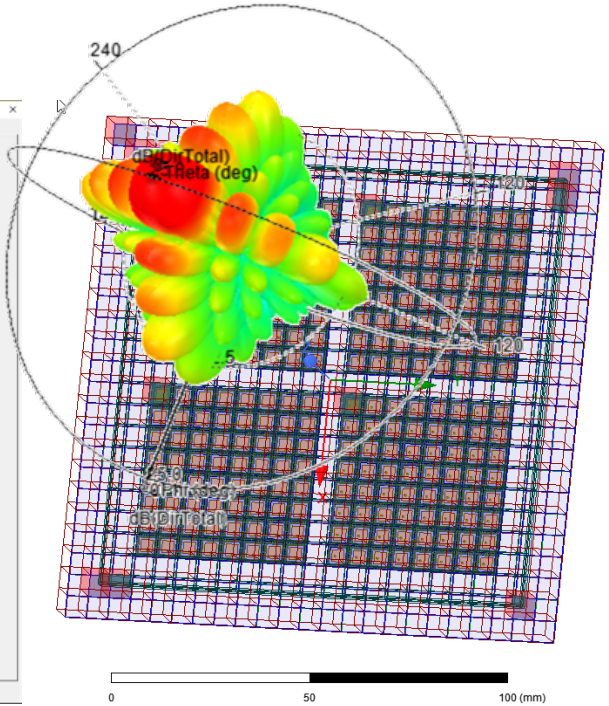


Unit Cells

- Models a single, repeated buildi for a large array
- Low computational resources
- Can model finite edge effects, multiple element types on lattice, dummy elements and element failure effects

Component Array Domain Decomposition (CADDM)



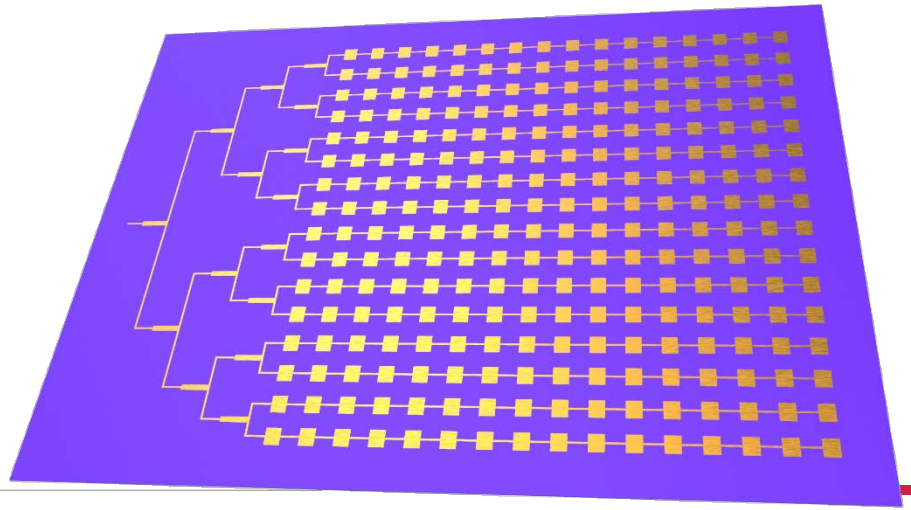


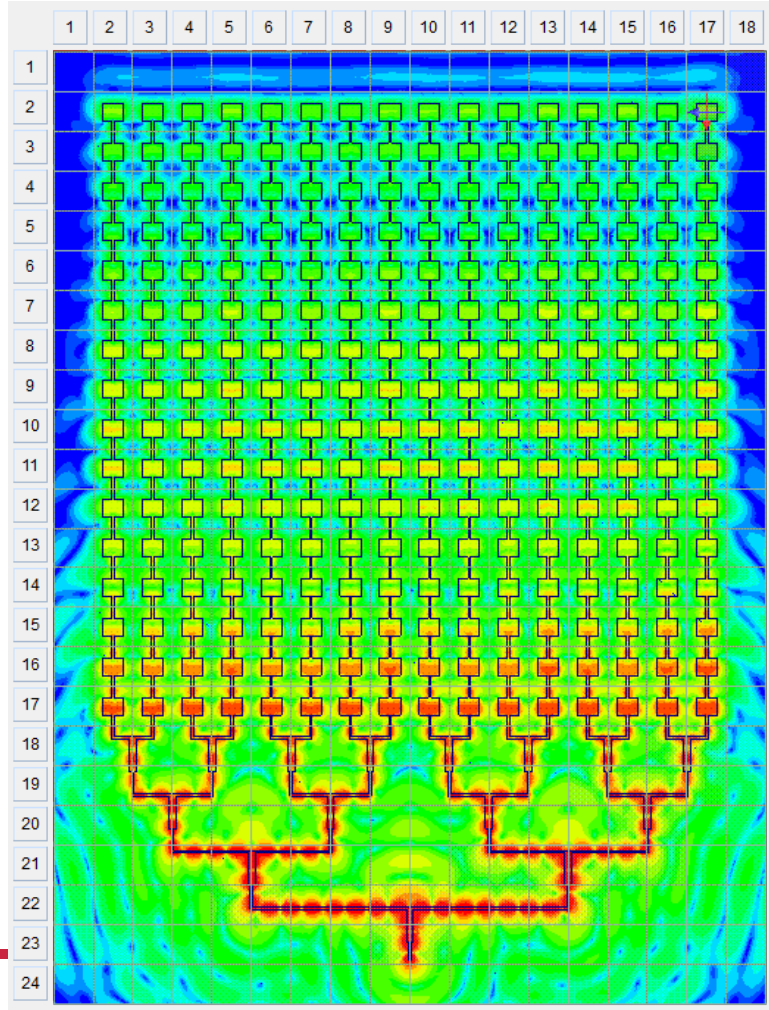
Compute scanned beam/directivity

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16 x 16 Array with Feed network

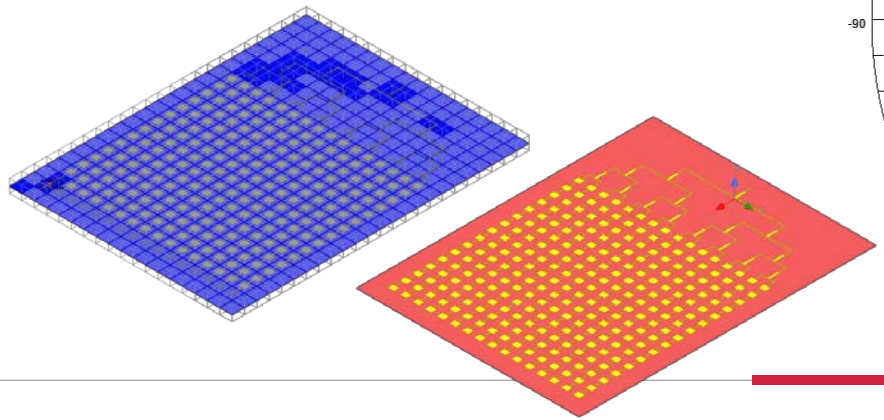
- Array Mask with 432 Elements
- 26 Individual Components
- Full Array
- Fields propagating through the domains

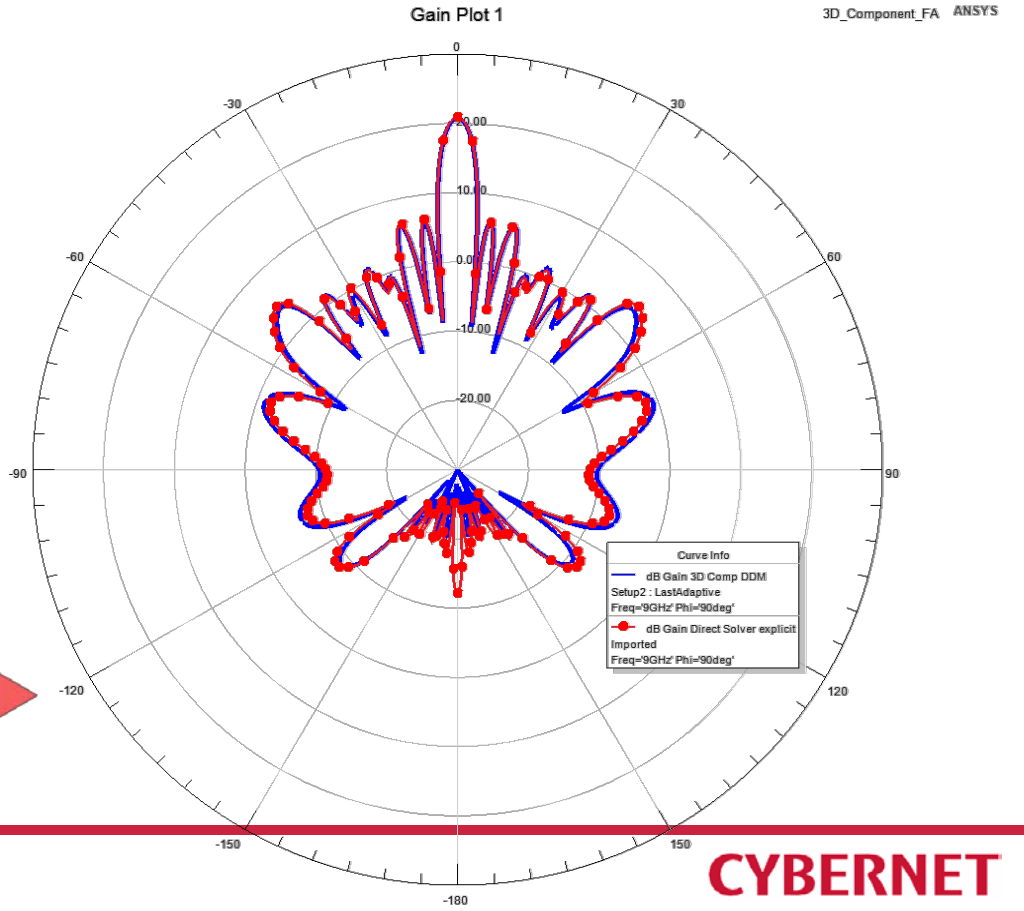




Results Comparison for 16 x 16 Array

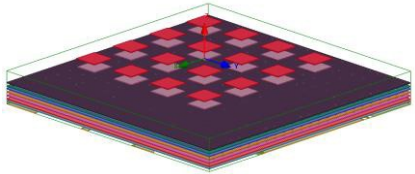
- Compare explicit, direct matrix solve with 3D Comp DDM
- Excellent agreement in far field
- 3D Comp DDM
  - 67% savings in memory
  - 37% savings in simulation time



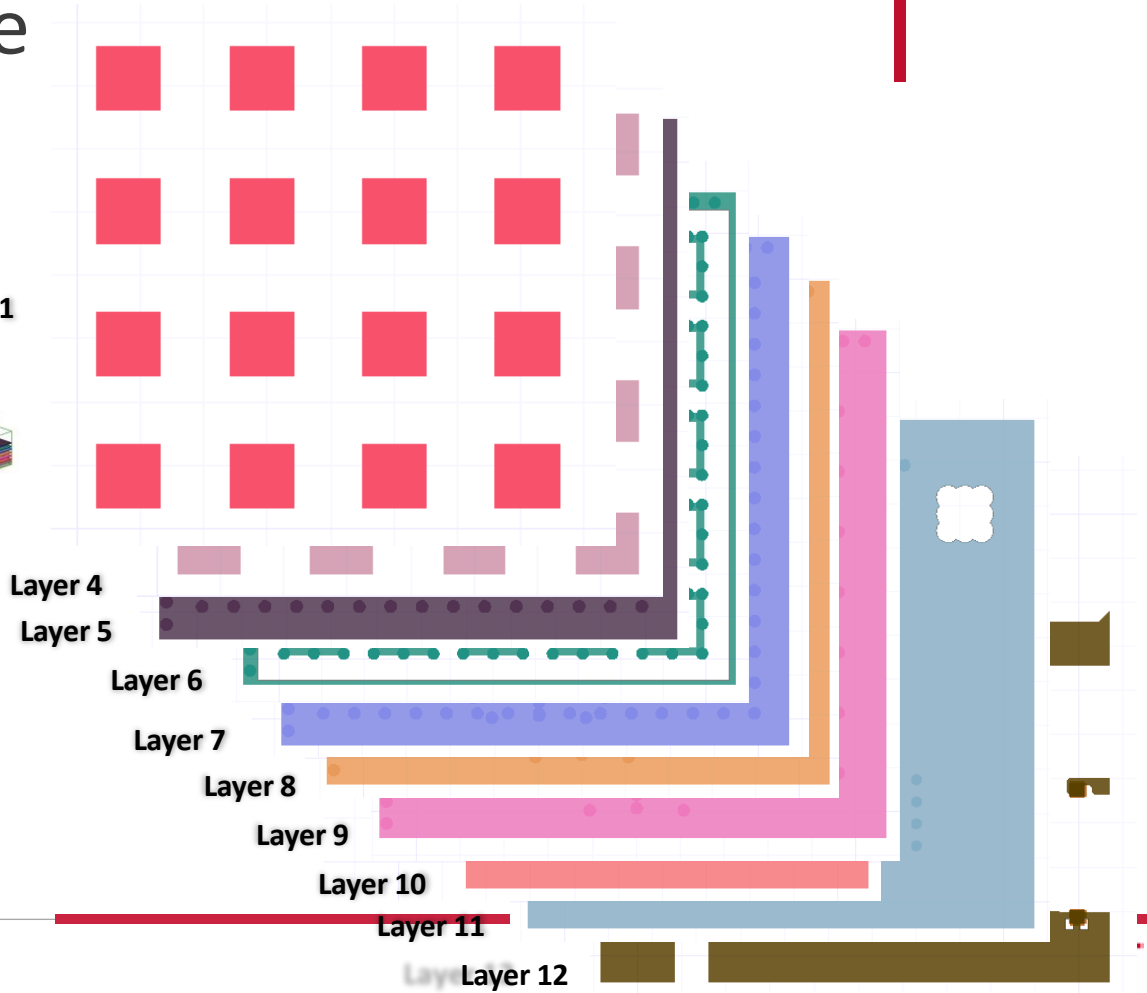


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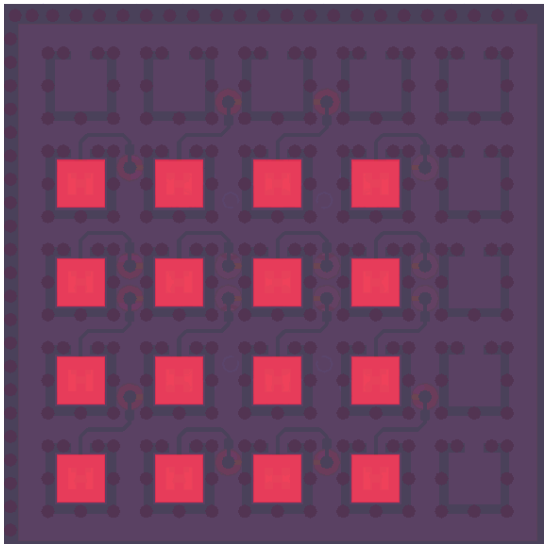
Antenna in Package



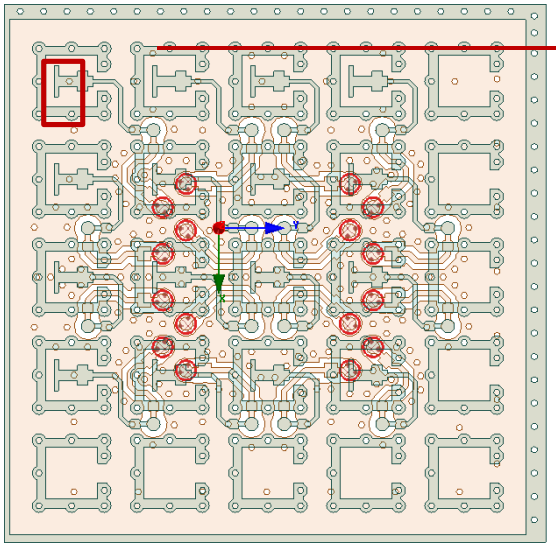
overview



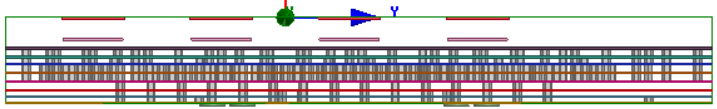
Antenna with Feed lines



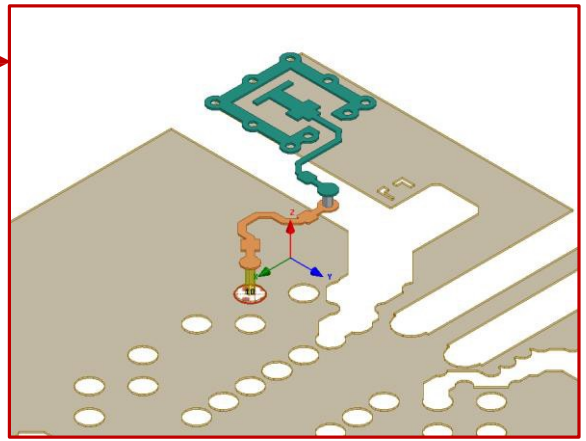
Top view



Sketch view

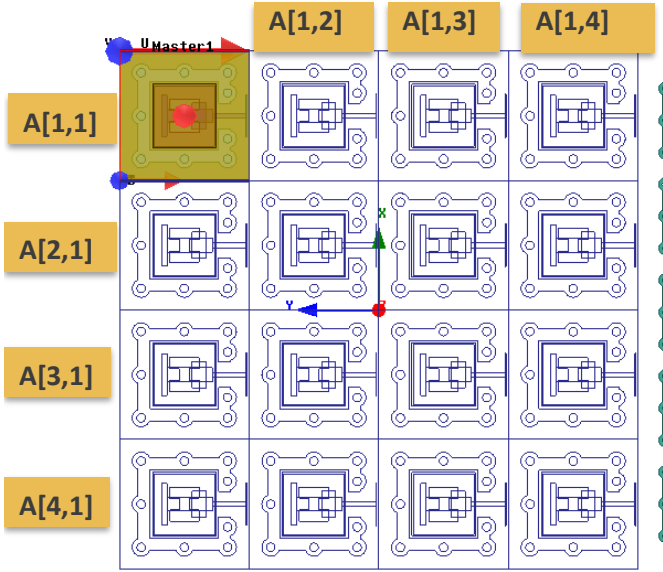


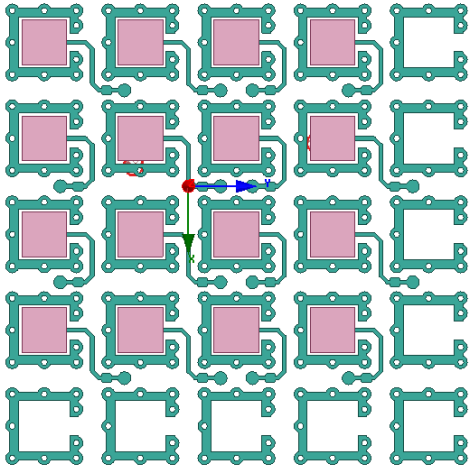
Side view

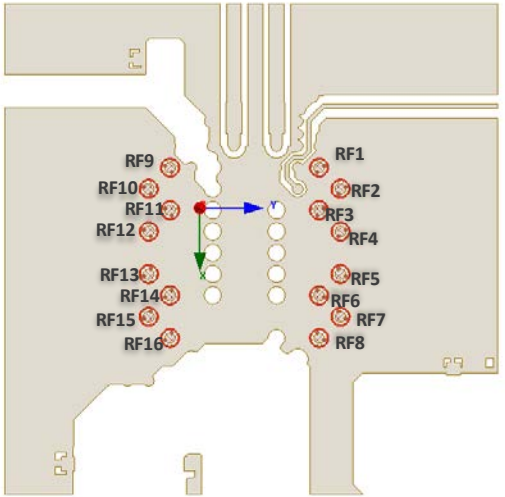


Antenna to PCB to BGA transition

Antenna to PCB mapping

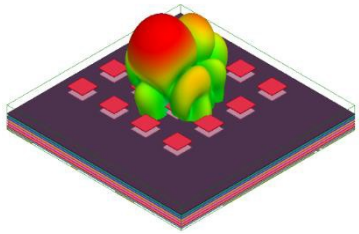


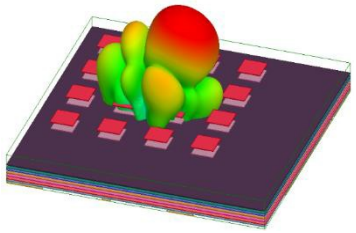


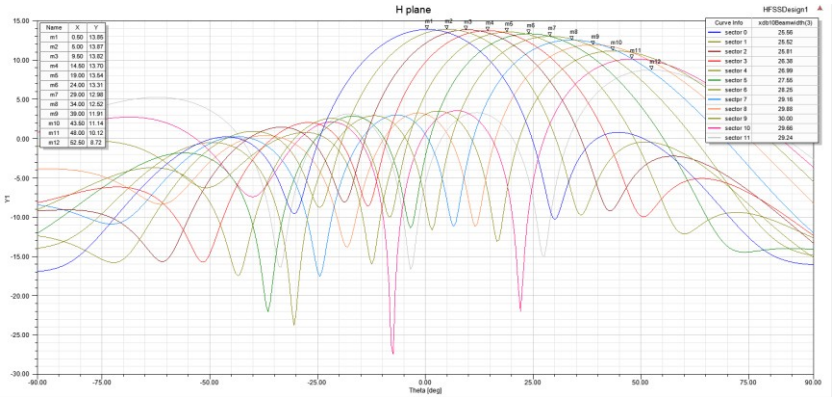


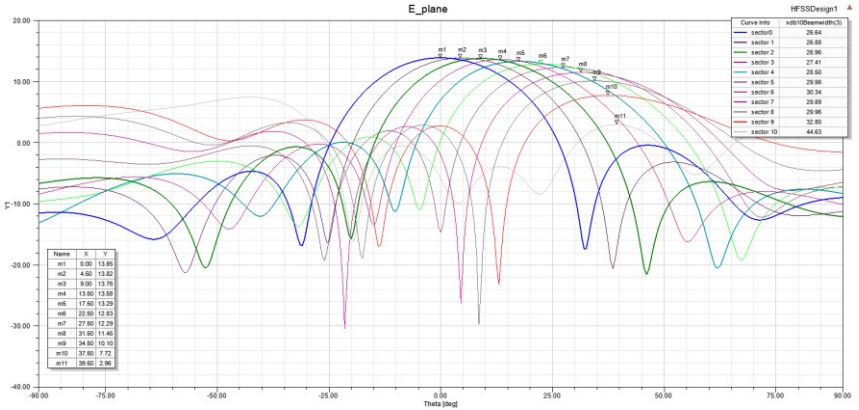
ANT	RF port
A[1,1]	RF10
A[1,2]	RF9
A[1,3]	RF1
A[1,4]	RF2
A[2,1]	RF12
A[2,2]	RF11
A[2,3]	RF3
A[2,4]	RF4
A[3,1]	RF13
A[3,2]	RF14
A[3,3]	RF6
A[3,4]	RF5
A[4,1]	RF15
A[4,2]	RF16
A[4,3]	RF8
A[4,4]	RF7

Beam Steer Performance in BGA







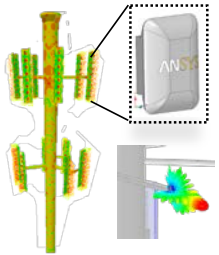


H plane beam steer performance

E plane beam steer performance

5G 阵列设计流程 2

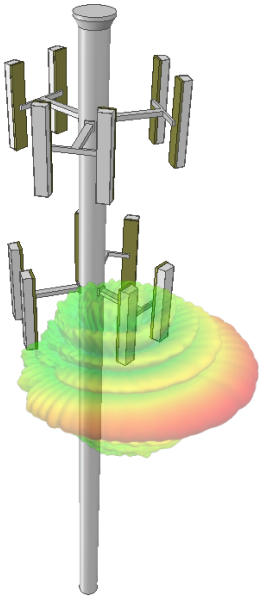
Antenna Element & Array Design	Installed Antenna Performance	SYSTEM	Network Planning & Coverage studies	
HFSS Unit cell analysis, Design of Experiment (DOE) Analysis/optimization Infinite array, 3D Component Array, Explicit array	***SBR+*** Antenna Housing Installed phase array antenna including housing on Mast	***EMIT*** Link margin, Interference, Coupling models Develop specifications SBR+ Beam forming and Coverage estimates	***SBR+*** Network planning BS – UE coupling Handoff Multi-User Massive-MIMO Evaluate Channel-performance	

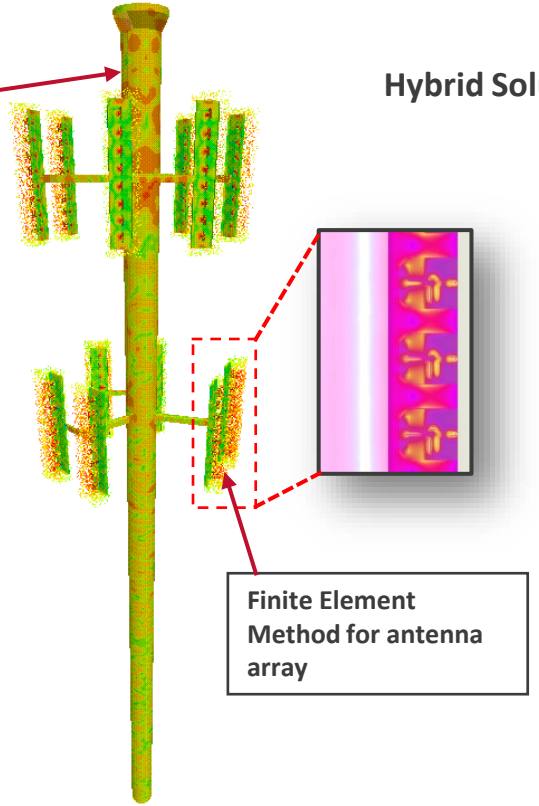


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Advanced Electromagnetic Solution for Electrically Large Geometry: Fully Coupled Hybrid Solution

Integral Equation, Physical Optics or Shooting Bouncing Ray –Tower Geometry



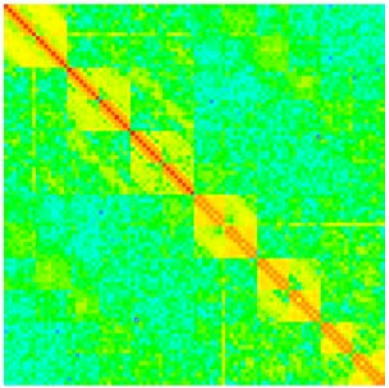


Finite Element Method for antenna array

Hybrid Solution

Combining multiple numerical techniques in a hybrid solution allows for most efficient solution to this electrically large complex problem

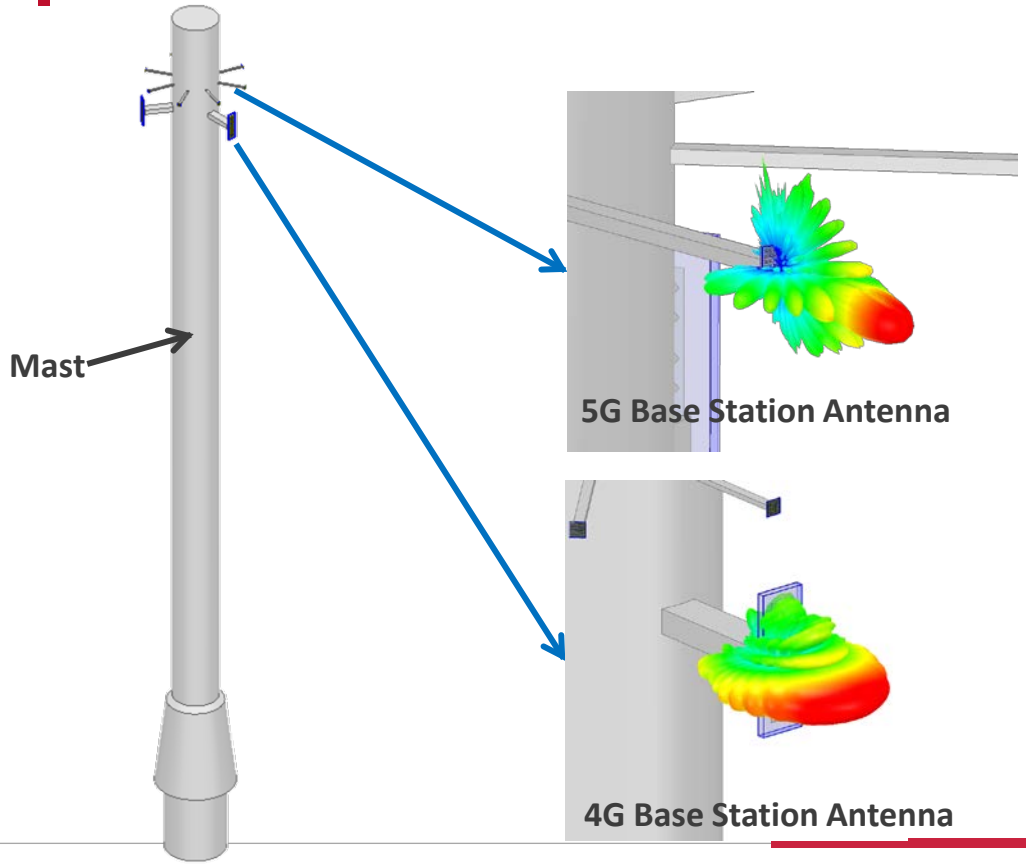
Fully coupled solutions



Coupling Matrix

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Installed Antenna Performance (SBR+)

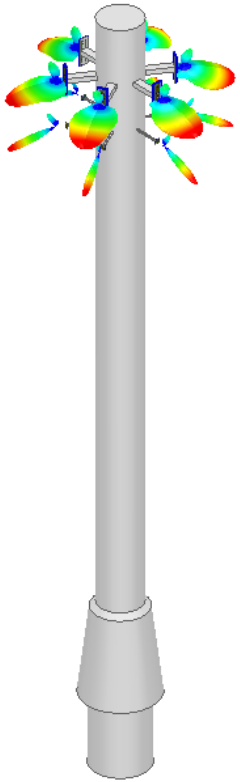


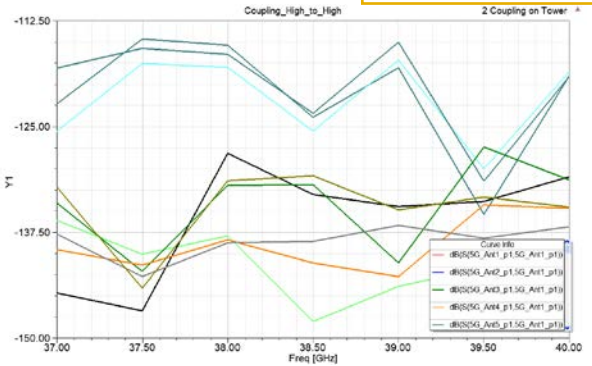
HFSS SBR+ simulation to calculate antenna pattern installed on a communication tower

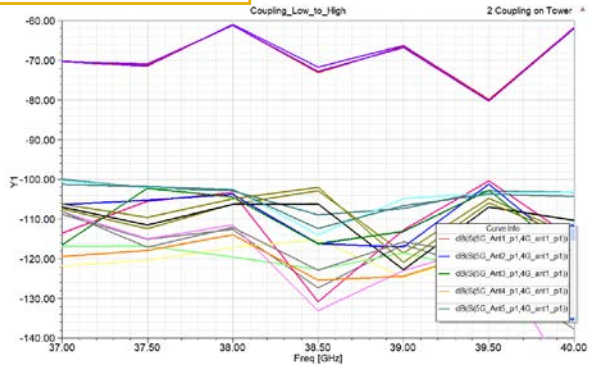
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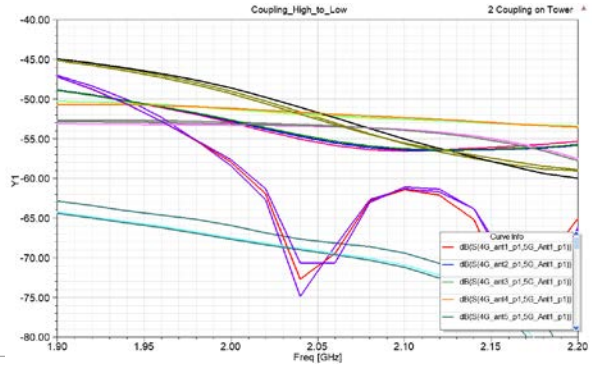
Installed Antenna Performance

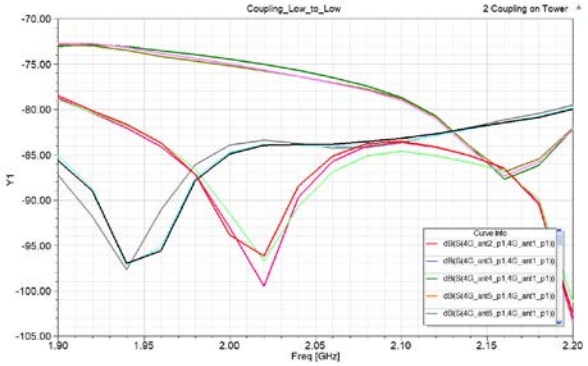
Coupling between 12 BS antennas





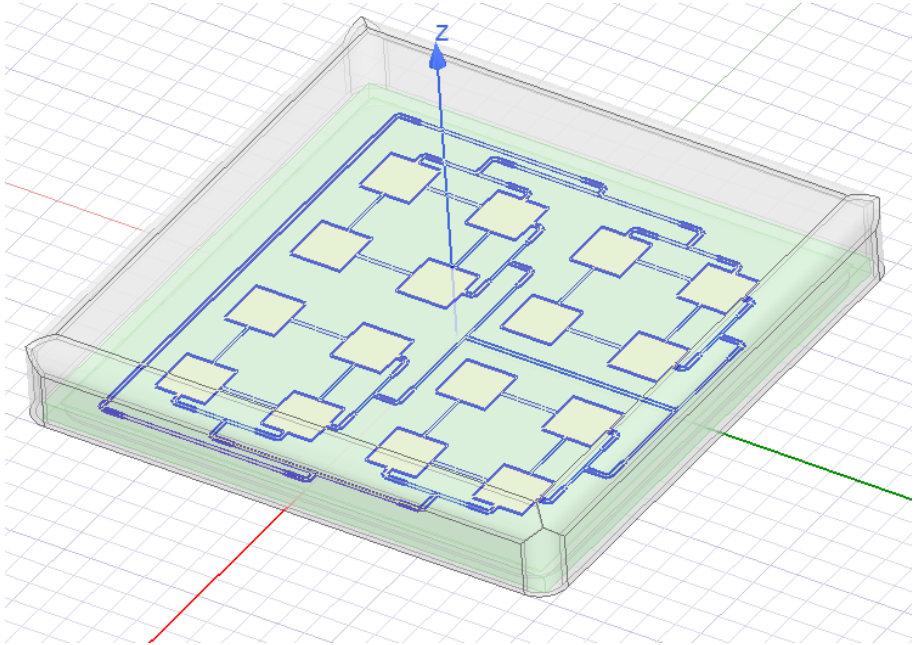






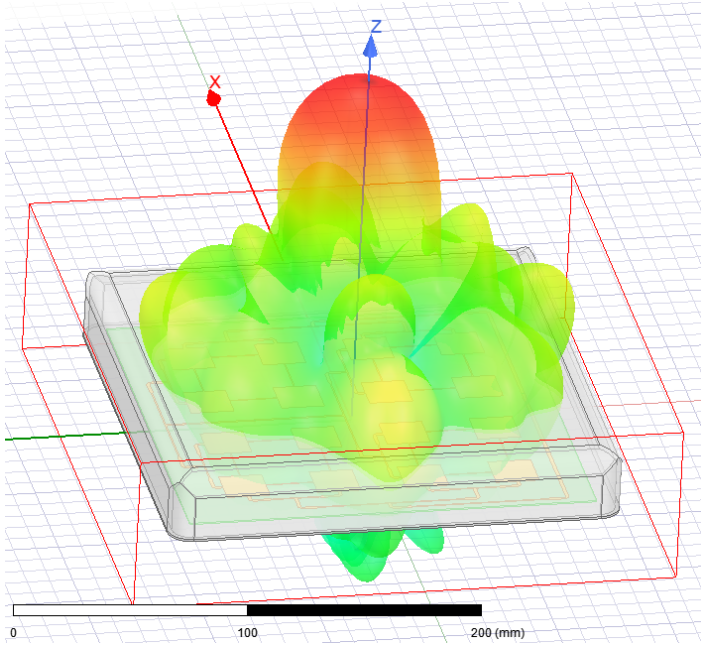
CYBERNET

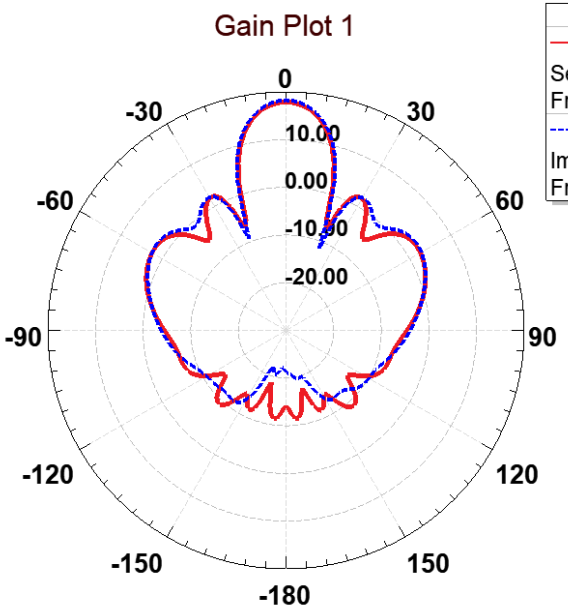
Hybrid Region Case



Hybrid Region Case Results

CYBERNET Taiwan

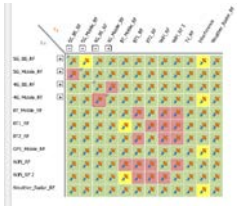


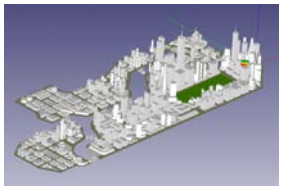


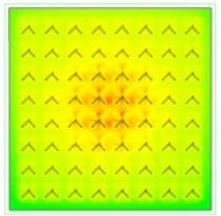
求解器	Ram	迭代次数	模拟时间
FEM	21.9 GB	12	48 min
Hybrid Region	6.7 GB	12	17 min

5G 阵列设计流程 3

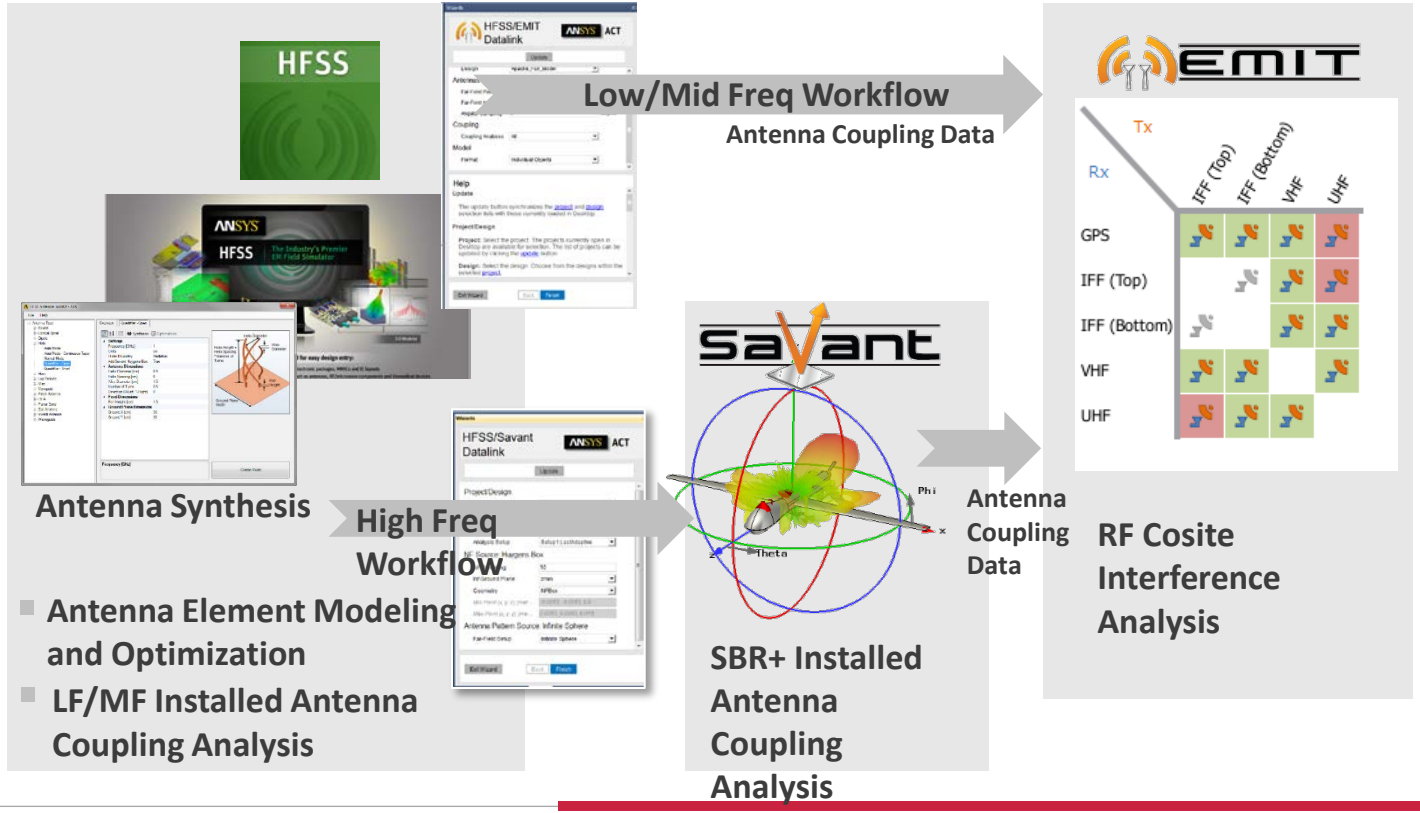
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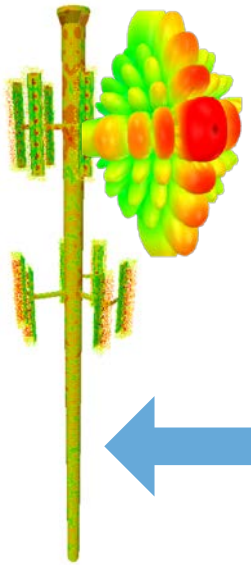


RF Cosite Analysis: An Integrated Workflow



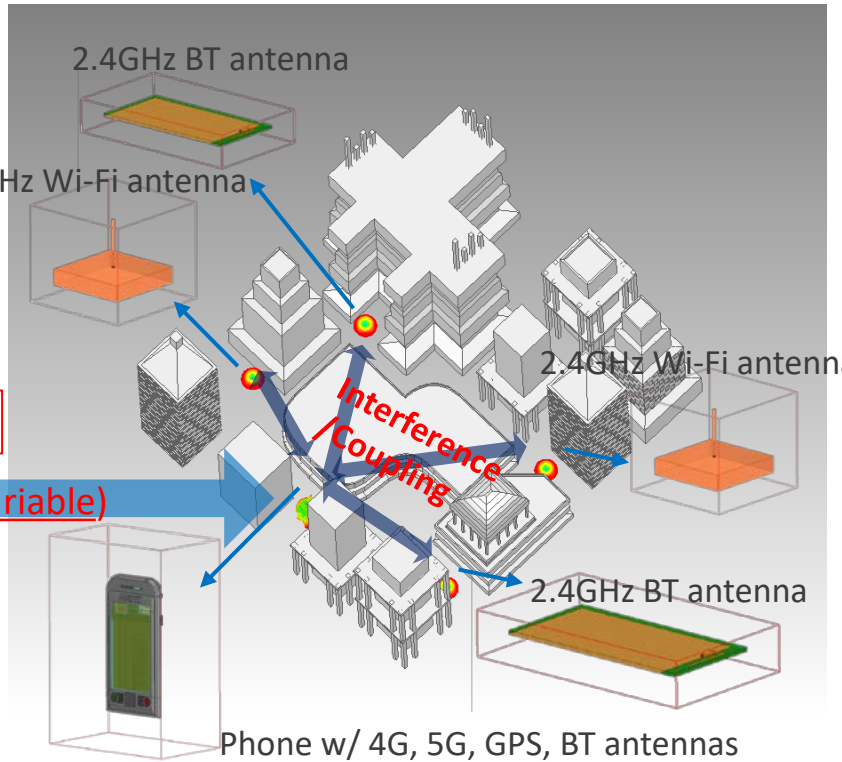
Link Margin & Interference Analysis Scenario

5G BS Antenna



Installed Pattern (SBR+)

EMIT Coupling Model/**SBR+ Simulation**



EMIT Coupling Model/SBR+ Simulation

5G Link over distance **R** (sweep variable)

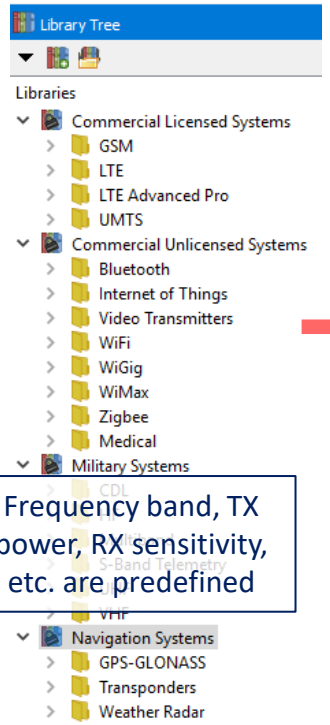
How much distance the base station and the phone can maintain positive link margin with interference?

Base Station Tower

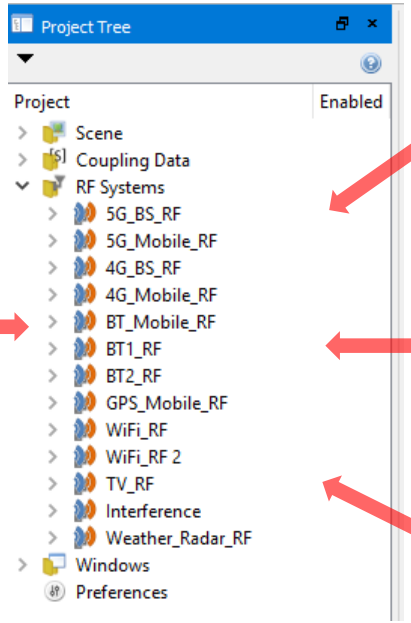
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RF Systems Definition

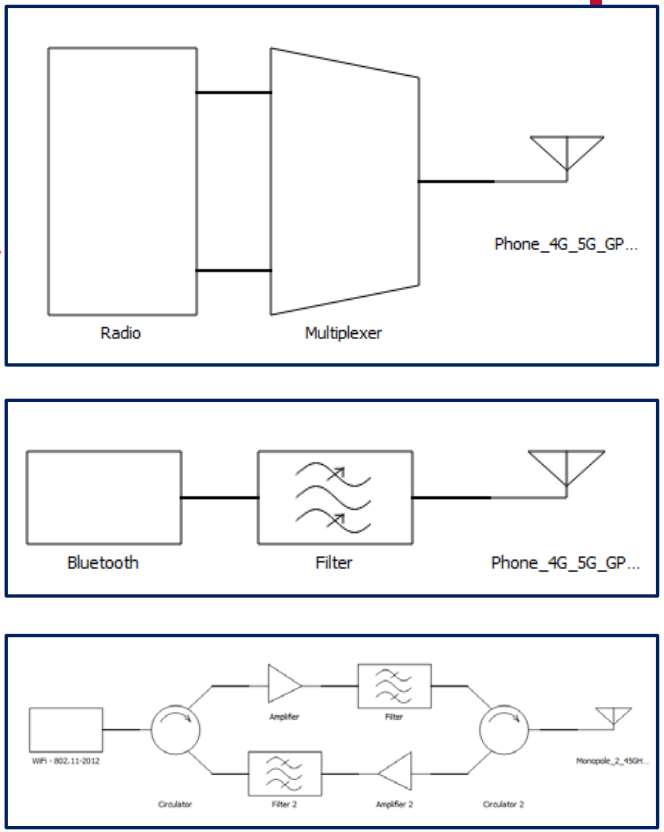
EMIT's built-in RF systems library



Frequency band, TX power, RX sensitivity, etc. are predefined



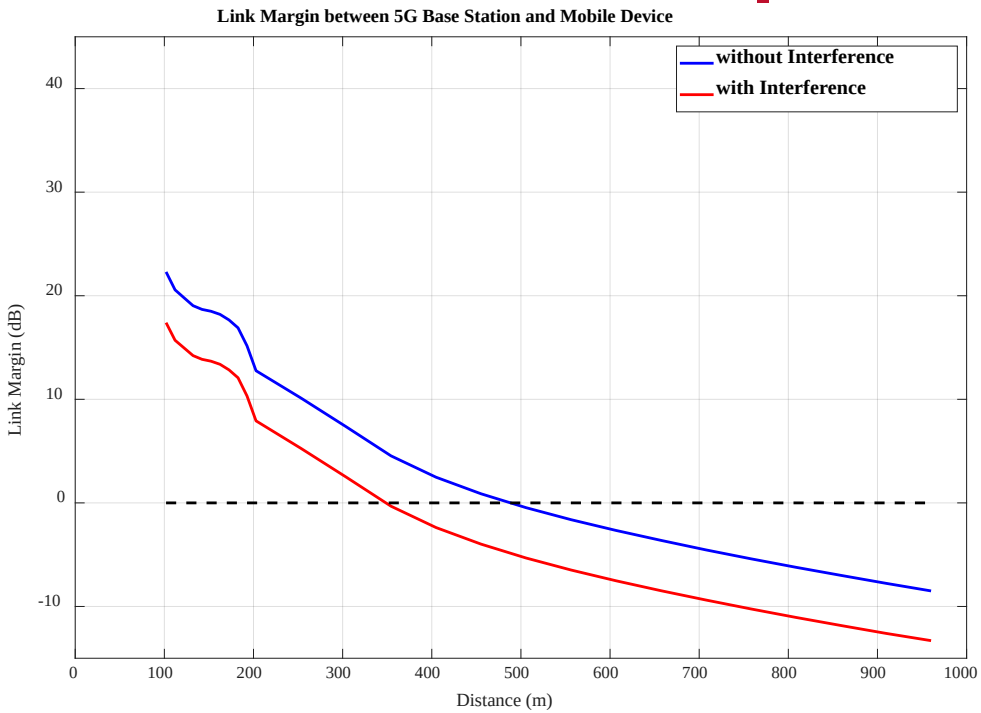
RF System Configuration



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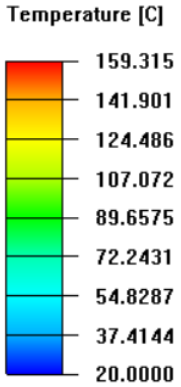
Link Margin vs. Distance

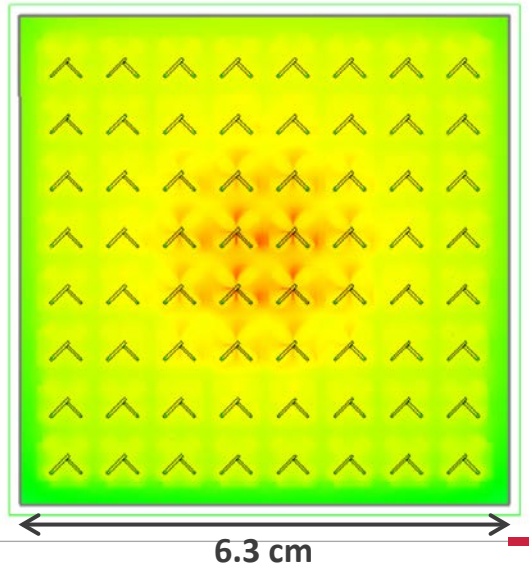
- For 5G, link margin ≥ 0 dB
  - Up to 490m without interference
  - 350m with interference



Electro-Thermal Simulation of 5G Base Station Antenna

- Temperature of 8x8 dipole array for mmW 5G base station is simulated in Icepak (classic)
- 40W input, ~4W RF loss
  - Input power per unit cell: 0.625W
- Maximum temperature is 159°C ← may exceed the decomposition temperature

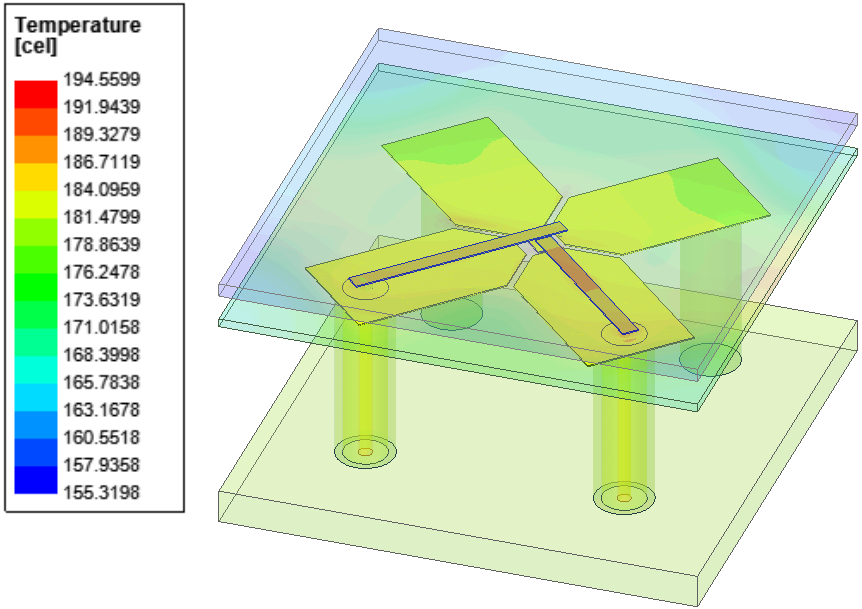


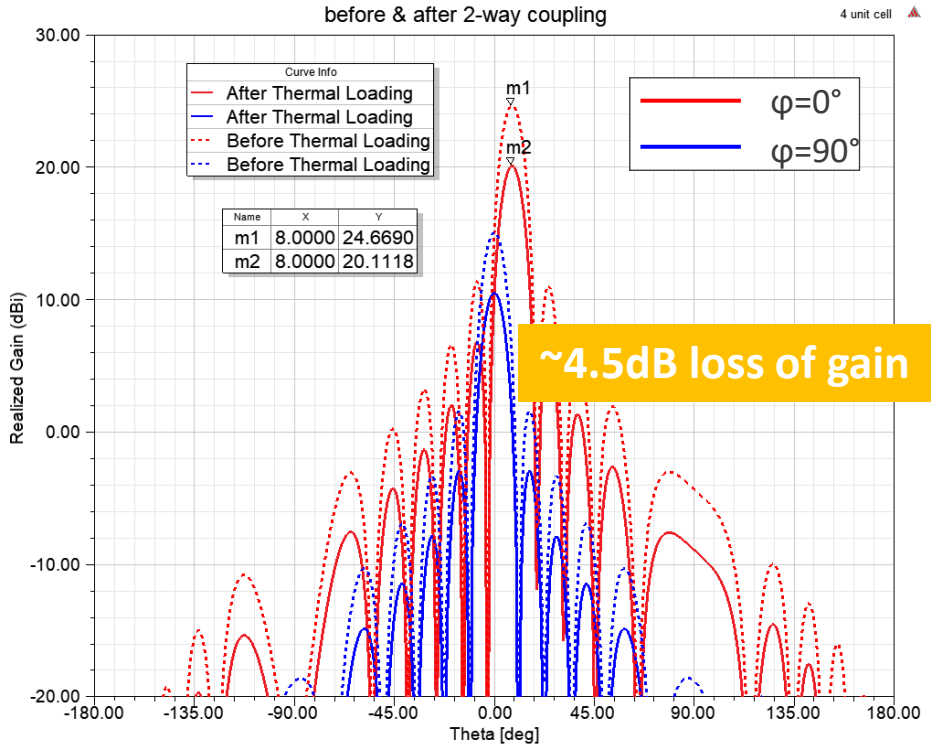


ID	Material	EM Loss Type	Maximum Temperature
Dipole	Copper	Surface	146.83 °C
Coax_Inner	Copper	Surface	135.14 °C
Coax_Outer	Copper	Surface	134.535 °C
uStrip_Line	Copper	Surface	146.634 °C
uStrip_Via	Copper	Surface	137.723 °C
Reflector	Aluminum	Surface	129.51 °C
Coax_Middle	Teflon	Volume	140.263 °C
Radome	Teflon	Volume	126.911 °C
Subst	FR4	Volume	159.315 °C

Array Performance After Thermal Loading (2-way Coupling)

Temperature under 0.625W input
(corresponds to 40W to 8x8 array)



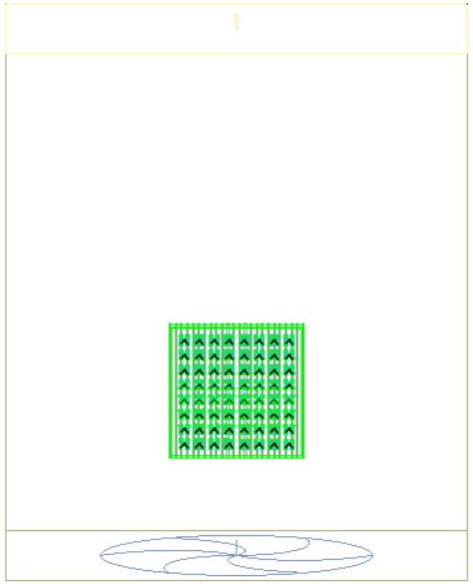


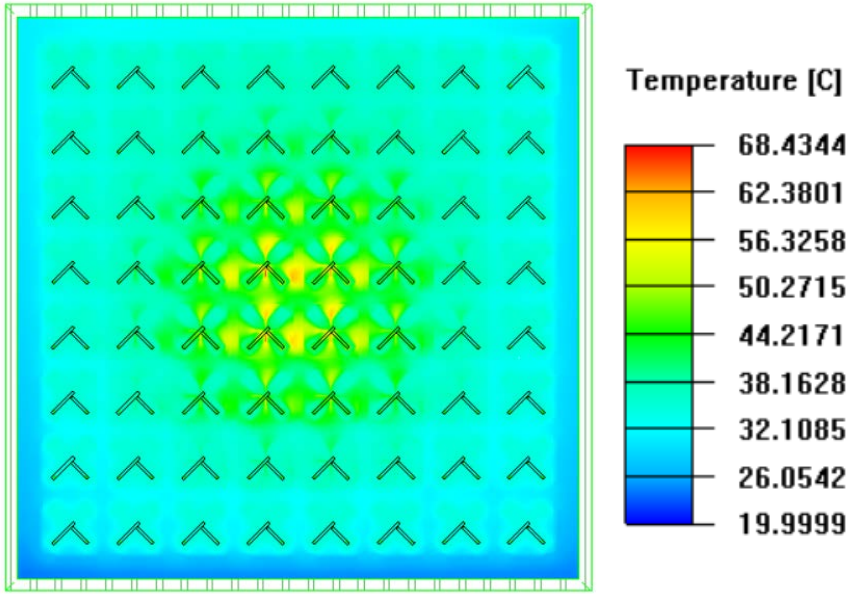
2-way coupling further increased temperature

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Thermal Management in Icepak

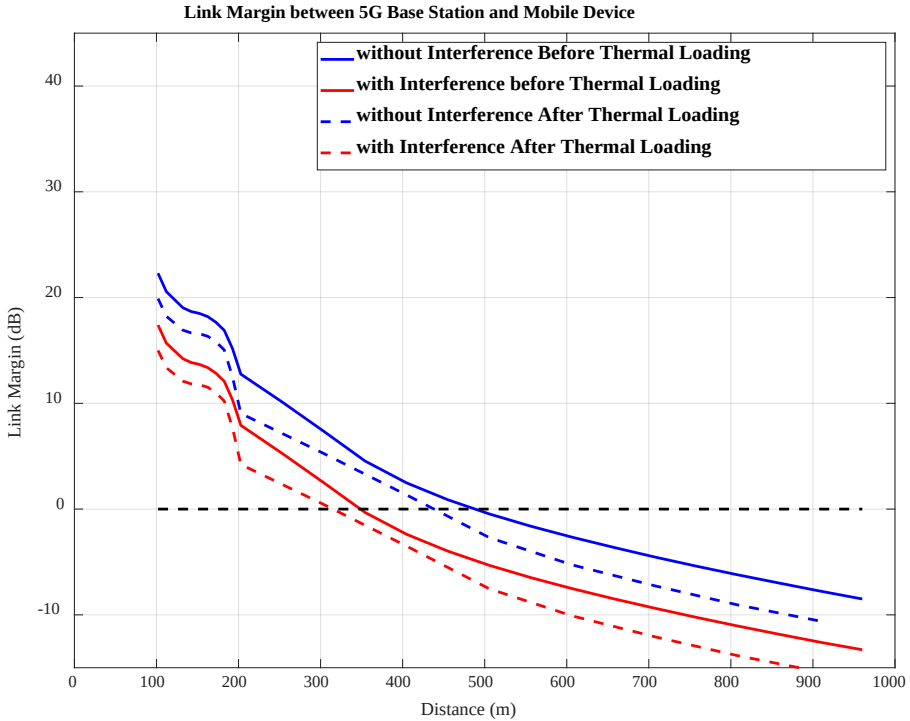
- To reduce overall temperature, a 50mm fan is added on the bottom
- Temperature is decreased to 68°C
- Thermal issue is much mitigated





Link Margin Simulation After Multiphysics Simulation

- Link margin vs. distance is re-calculated in EMIT
  - Link margin of 5G channel is reduced



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