5G mmWave Device Design and Simulation with Thermal Analysis

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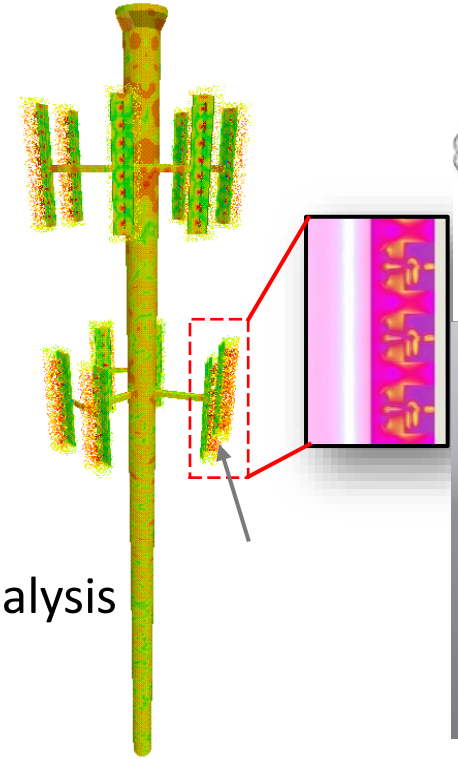
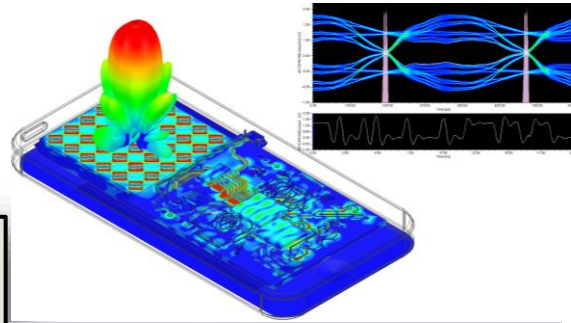
Ansys 2021 R1
Engineering What's Ahead.

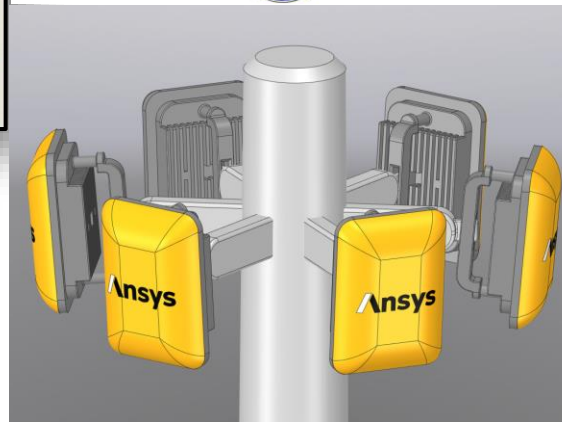
Solve it, with CYBERNET

Agenda

- Introduction
  - 5G mmWave
  - Thermal Case Study
- 5G Simulation
  - Element Design
  - Array Synthesis
  - Installed Performance
  - Link Margin and Interference Analysis
  - Multi-Physics
- Summary







Cybernet System Co., Ltd.: Solutions

CAE solution

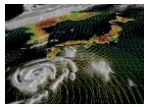
Total support of CAE utilization in various fields

Main application areas

- Mechanical systems: structure stress, heat, vibration, noise, fluid
- Control system: Development of control devices for automobiles and electronic devices
- Optical system / measurement system: development of optical lenses, displays, lighting equipment, etc.
- Electrical: Design of printed circuit boards and high-speed signal transmission

AR/VR・Visualization solution

"People to People" and "People and Data" Connected by Advanced Visualization Technology



Main application areas

- General-purpose visualization: simulation, R&D, experimental measurement, data visualization, visualization,
- AR (augmented reality) / VR (virtual reality): artificial reality, mixed reality, telemetry, stereoscopic vision, HMD, simulator
- Medical: Medical imaging, CT, MRI, PET, DICOM, Ultrasonography, Radiology, Endoscope

Bigdata solution

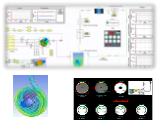
Supporting the effective use of the growing big data

Main application areas

- Mapping (data density, outliers, overall shape), similarity determination between data, abnormality detection / monitoring, etc.

IoT・Digital Twin・AI service

Realize manufacturing equipment maintenance and service by utilizing IoT



Main application areas

- Improved accuracy of failure prediction
- Labor saving and efficiency improvement of equipment maintenance
- Collaboration between experiment and CAE

IT solution

Proposal to improve security of IT environment becoming complicated and cloud

Main application areas

- Cloud security
- Endpoint security
- Email / web security
- IT asset management
- IT infrastructure
- Manufacturing support

Engineering service

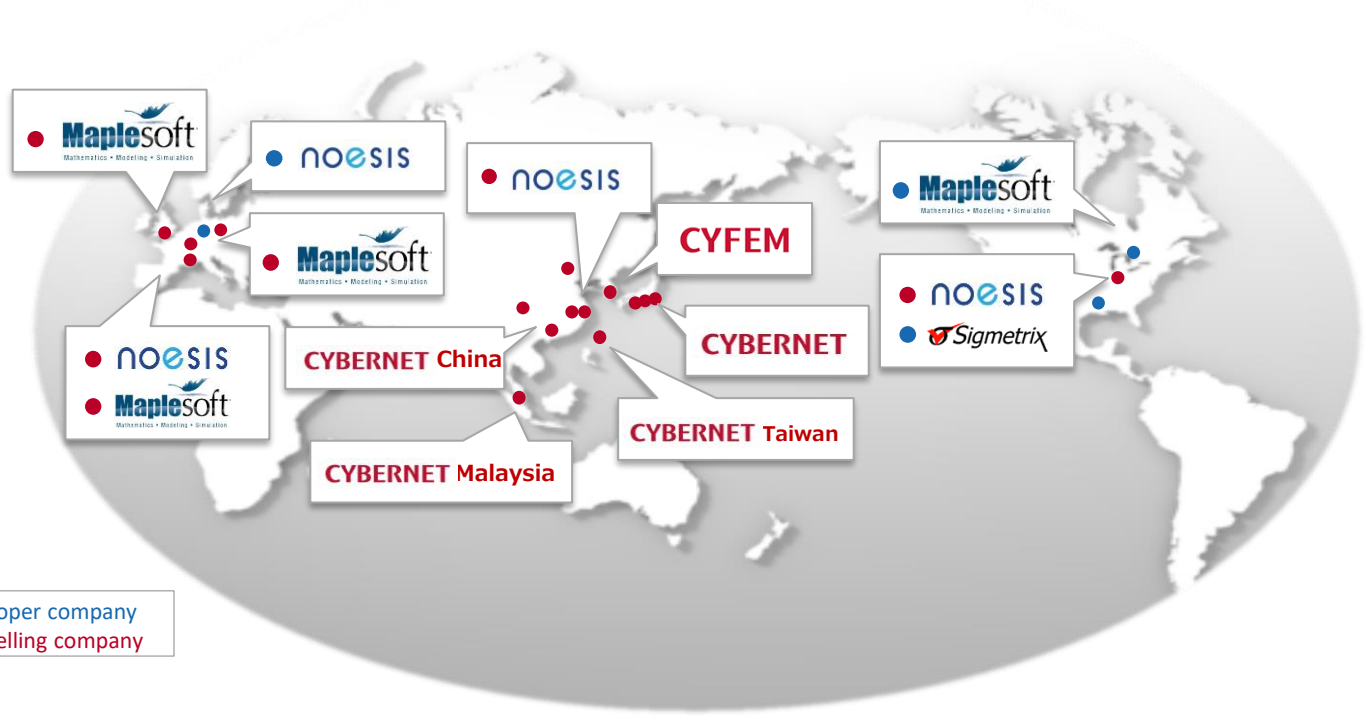
Expert group helps engineers solve issues

Main application areas

- Consultation
- MBSE / MBD Professional Services: Optimization of upstream design, modeling, development environment construction, verification environment construction
- Contract development / analysis: Structural analysis, fluid, electromagnetic field, resin flow, acoustics, coupling of multiple domains, optical design, macro program development

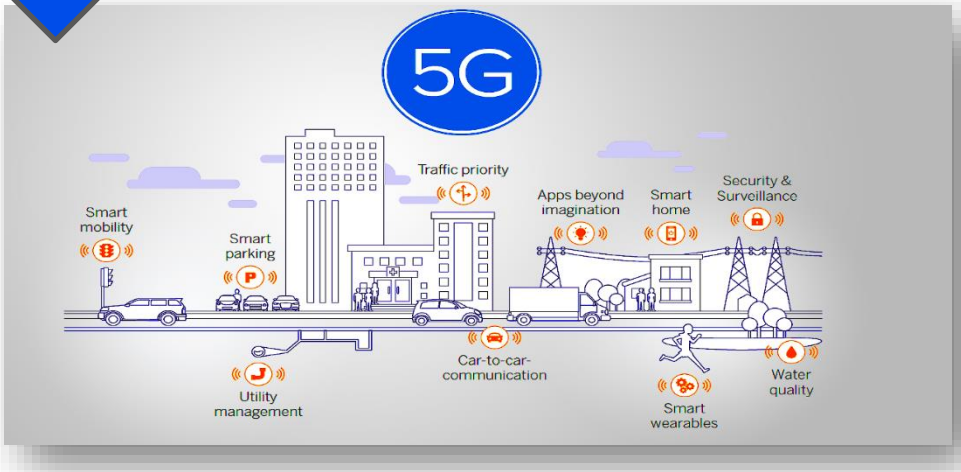
Cybernet System Co., Ltd.: Global Network

Cybernet is working with overseas group companies to develop software that will help customers not only in Japan but also around the world, and to develop our Group products and solutions overseas.

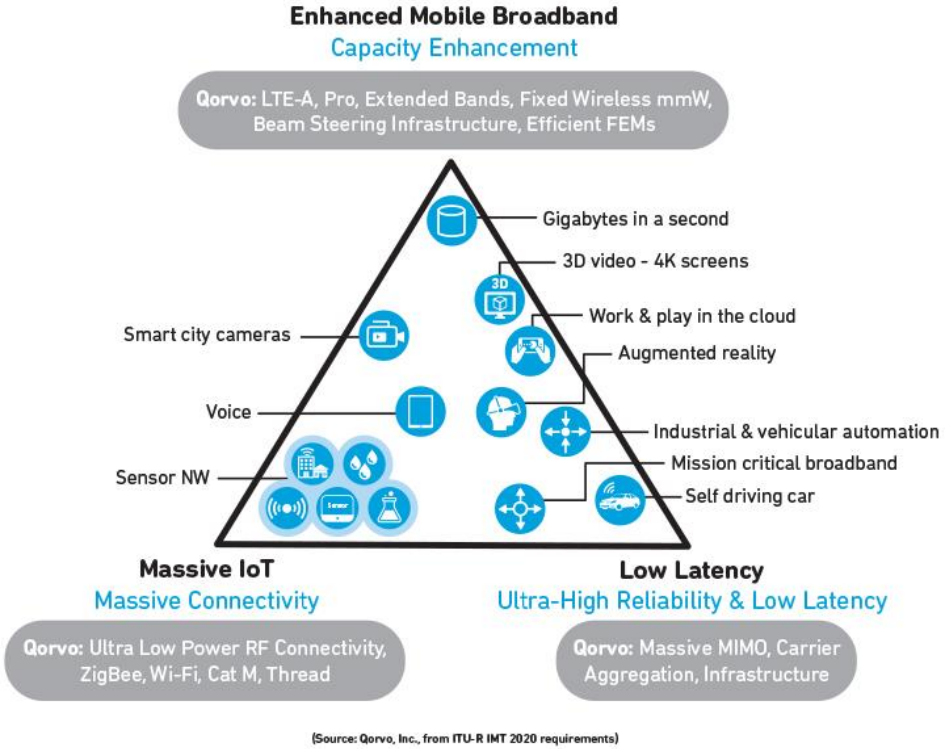


The 5G Paradigm Change

1G	Voice
2G	Voice & Text
3G	Voice & Text & Internet
4G	Voice & Text & Internet & Multi-Media
5G	Smart Environment, IoT, Self-Driving Cars, …



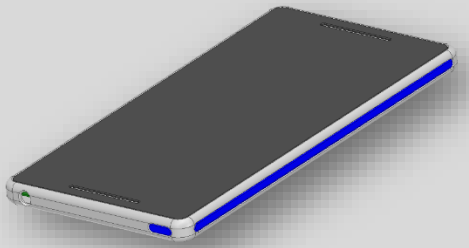
Three dimensions of 5G



- Enhanced Mobile Broadband
  - 4K Video, AR/VR streaming in office, industrial parks, malls, sports venues.
  - High volumes in localized areas with lower cost
- Massive Internet of Things
  - Economy of scale for IoT and M2M
  - Low power
- Mission Critical Services
  - New market for high reliability, ultra-low latency, security, availability
  - Supports autonomous vehicles and remote operation of equipment

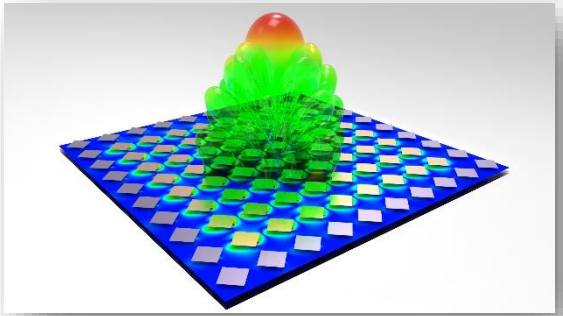
*The 5G Economy, IHS.com

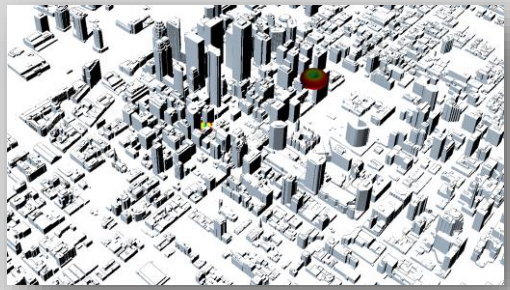
5G: A Simulation Vision



- **User Equipment**
  - Antenna Design, Integration, and Optimization
  - Antenna Matching
  - Statistical and Sensitivity Analysis
  - Cumulative Distribution Function
  - Human interaction and sensing
    - Power Density and SAR

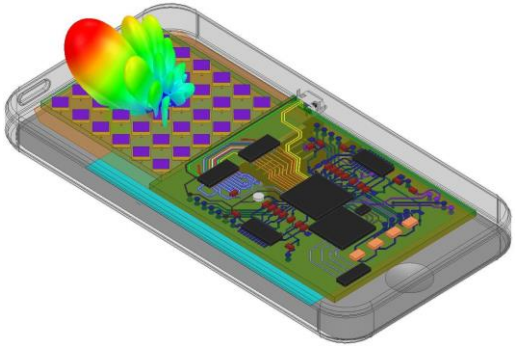
- **Base Station**
  - Phased Array Antenna Analysis
  - Statistical Analysis of Antenna Elements
  - Radome Interaction and Placement
  - Beamforming and Pattern Synthesis

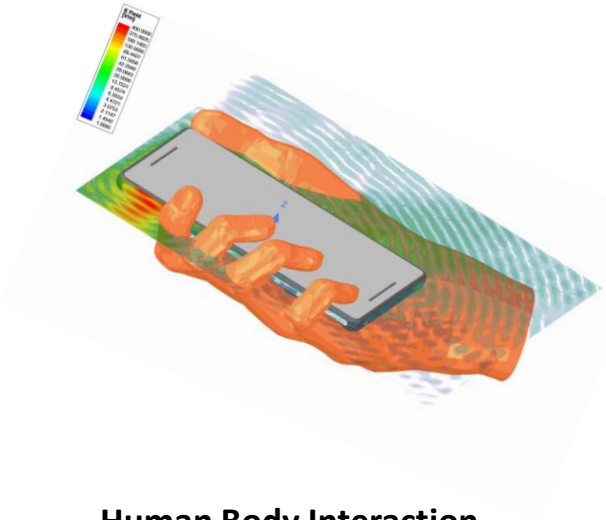


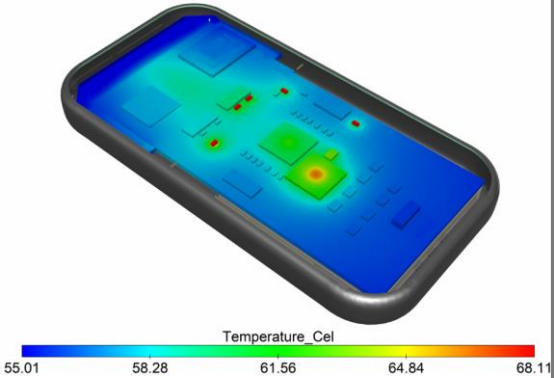


- **Channel Characterization**
  - Environmental Modeling
    - ➢ Channel State Information (CSI) between Base Station and Multiple Users
  - Multi-User Massive MIMO
  - Coupling and Interference
    - ➢ Signal processing
  - Coverage Zones

5G Antenna Simulation







Antenna Design and Modeling

Antenna and Array design
Optimization and Beamforming
Installed antenna pattern, Coupling

Human Body Interaction

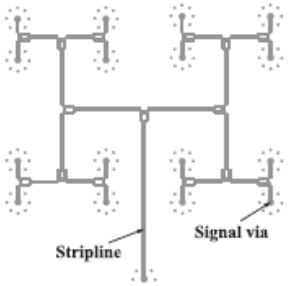
Power density
Far field and impedance detuning

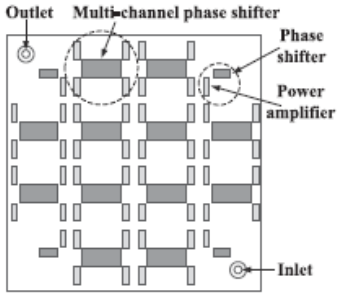
Thermal Coupled Analysis

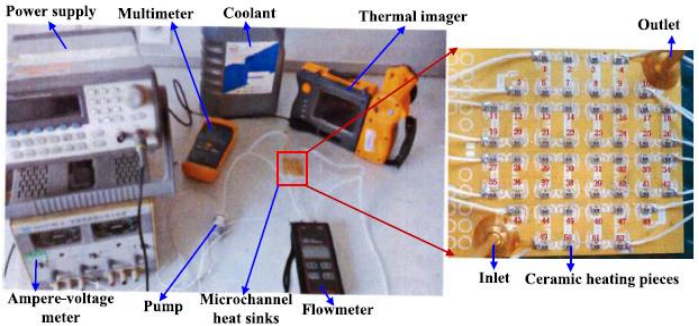
Drop in antenna efficiency due to temperature

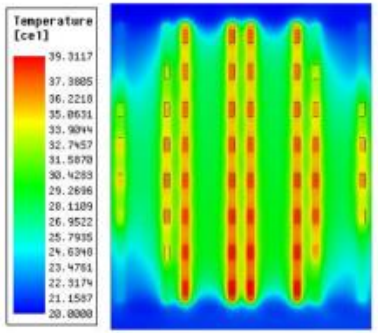
Important

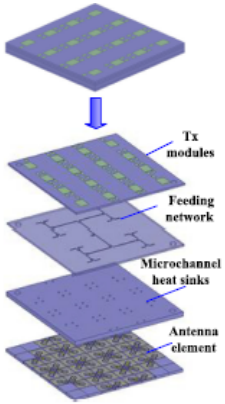
Case Study 1: Embedded Cooling

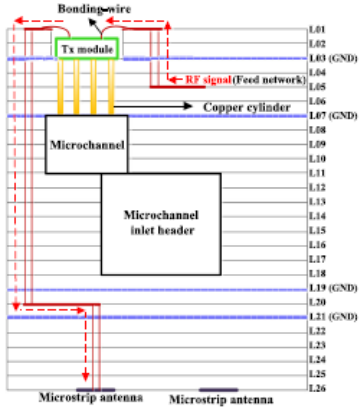


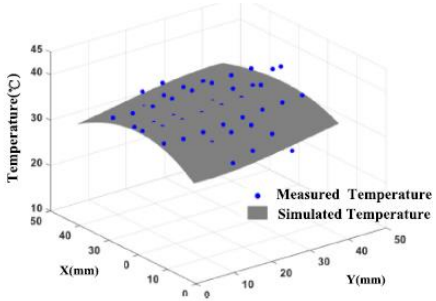


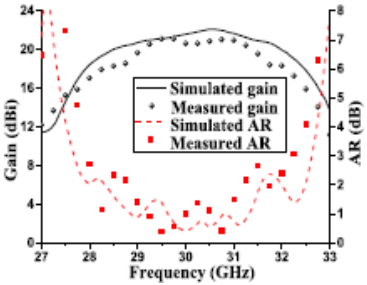


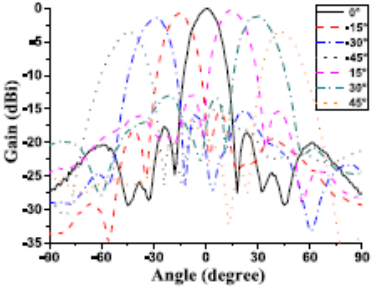








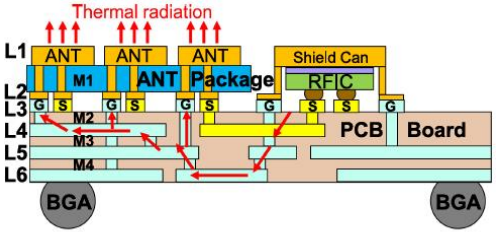


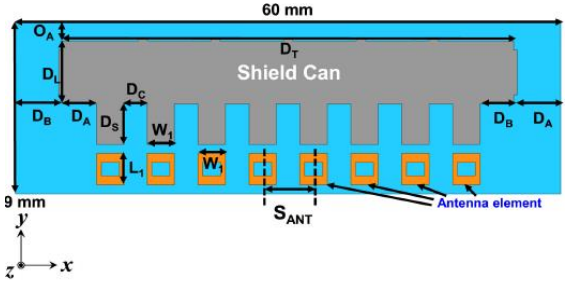


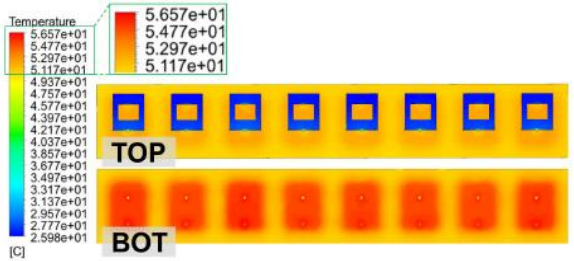
Simulation with Ansys HFSS and Icepak

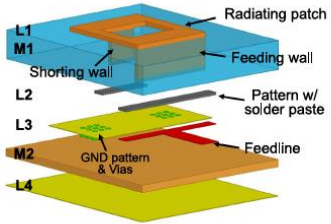
J.Z. Zhou , L. Yin, L. Kang , M.Wang, and J. Huang, “Joint Design and Experimental Tests of Highly Integrated Phased-Array Antenna With Microchannel Heat Sinks,” IEEE Antennas Wireless Propag. Lett., vol. 18, pp. 2370–2374, 2019.

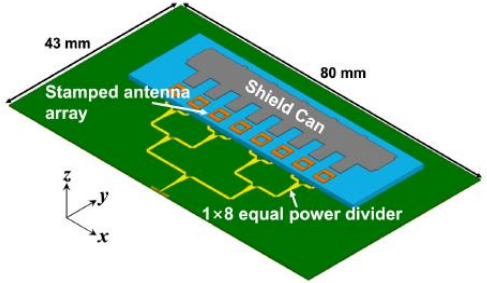
Case Study 2: Antenna in Package

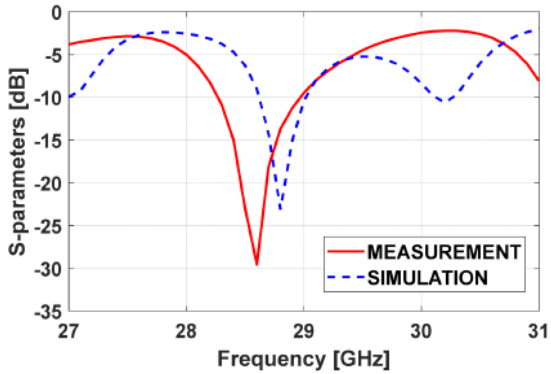


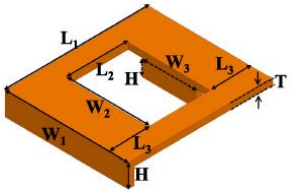












Simulation with Ansys HFSS and CFD (Fluent)

J. Park, D. Choi, and W. Hong, "Millimeter-Wave Phased-Array Antenna-in-Package (AiP) Using Stamped Metal Process for Enhanced Heat Dissipation," IEEE Antennas Wireless Propag. Lett., vol. 18, pp. 2355–2359, 2019.

5G Simulation

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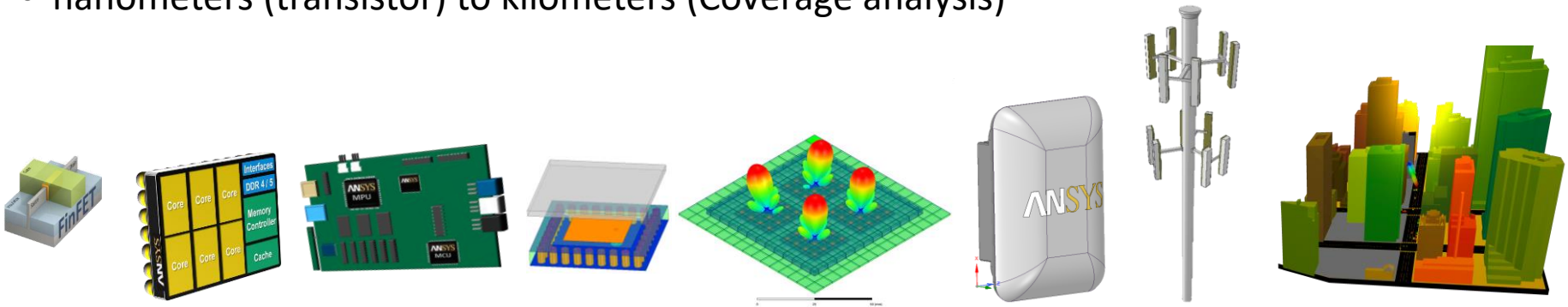
Simulation Across All Major Physics

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



Transistors *3D-RFIC* *PCB* *Antenna Element* *5G Phase Array* *Base station Radio* *Mast with BS* *Network Planning, Base Station Coverage*

nm *km*

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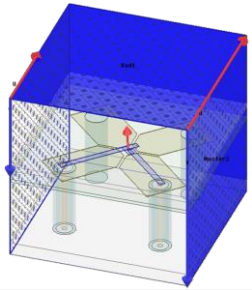
Workflow for Design of 5G Array Antenna

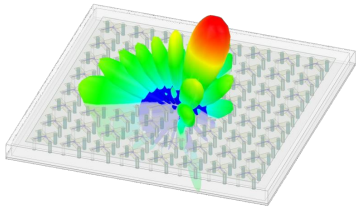
Element Design

HFSS FEM
Unit cell analysis, Optimetrics



Phased Array Synthesis

HFSS FEM
Infinite array, FADDM, Explicit array

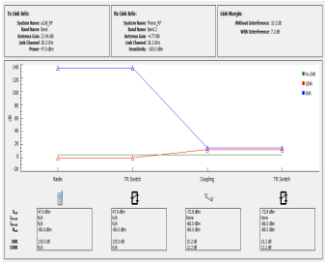


Installed Antenna Performance

HFSS SBR+
Installed antenna pattern, Coupling

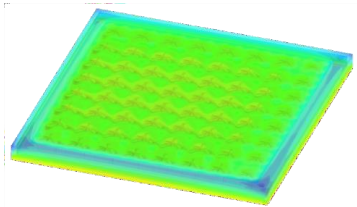
Link Margin & Interference Analysis

EMIT
Link margin, Interference, Coupling models



Multiphysics Analysis

Icepak/ Mehchanical
Temperature, Structural Deformation



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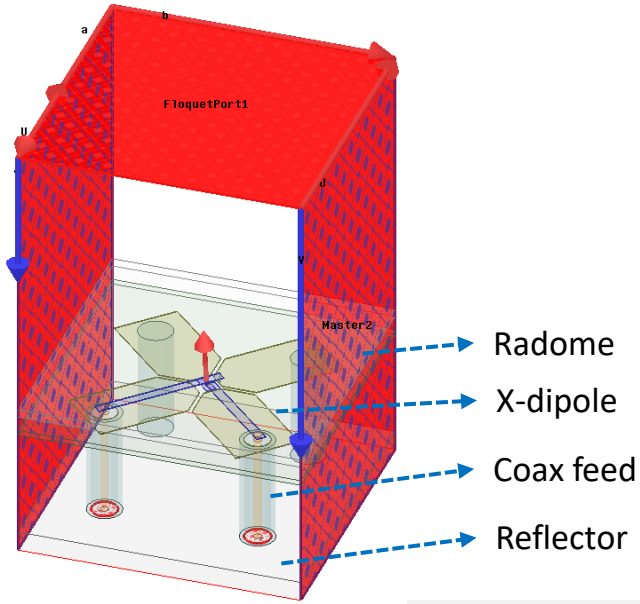
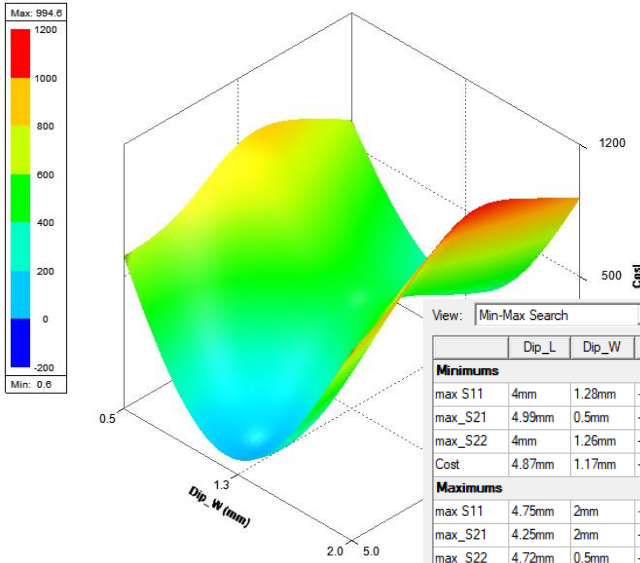
Array Element Design

- 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**

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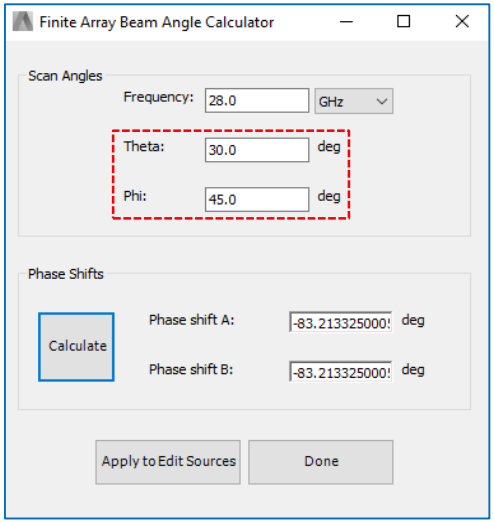
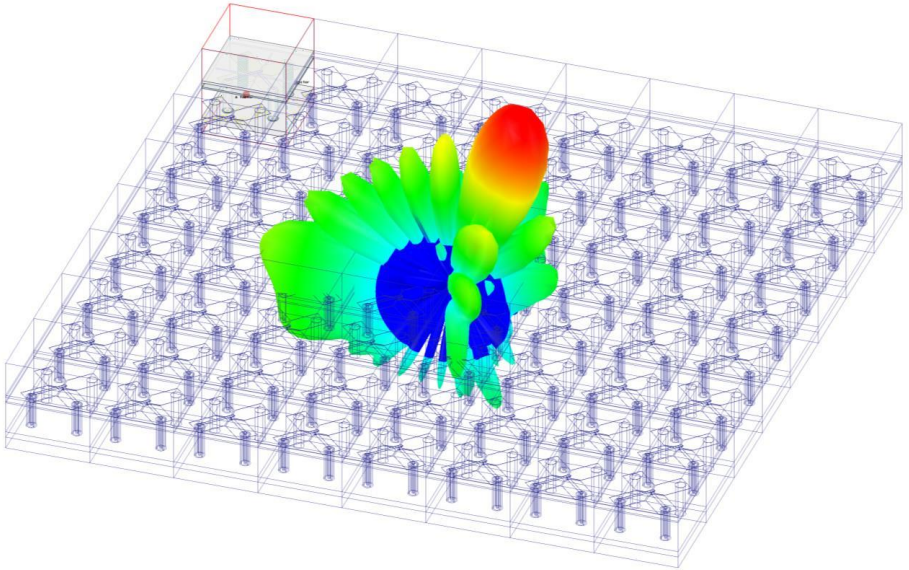
Array Synthesis: FA-DDM

- FA-DDM (Finite Array DomainDecomposition)
  - Converged mesh from unit cell simulation is duplicated to the entire array
  - Meshing process is very fast and RAM-efficient compared to the equivalent explicit array
- Finite Array Beam Angle Calculator Toolkit: Phase shift for scanning is calculated and applied (no need to re-simulate)

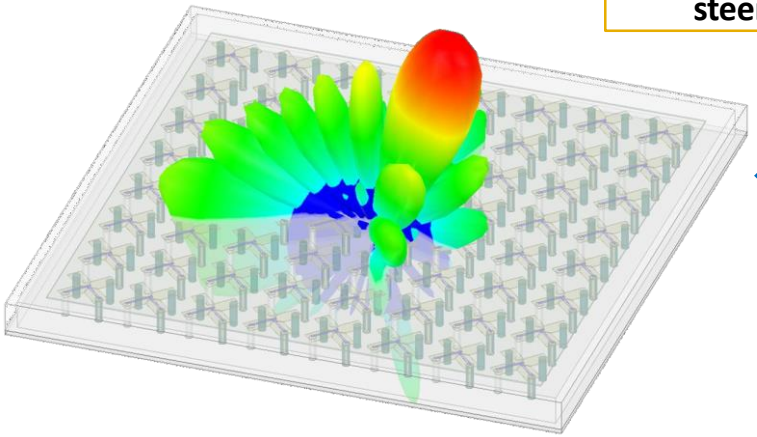


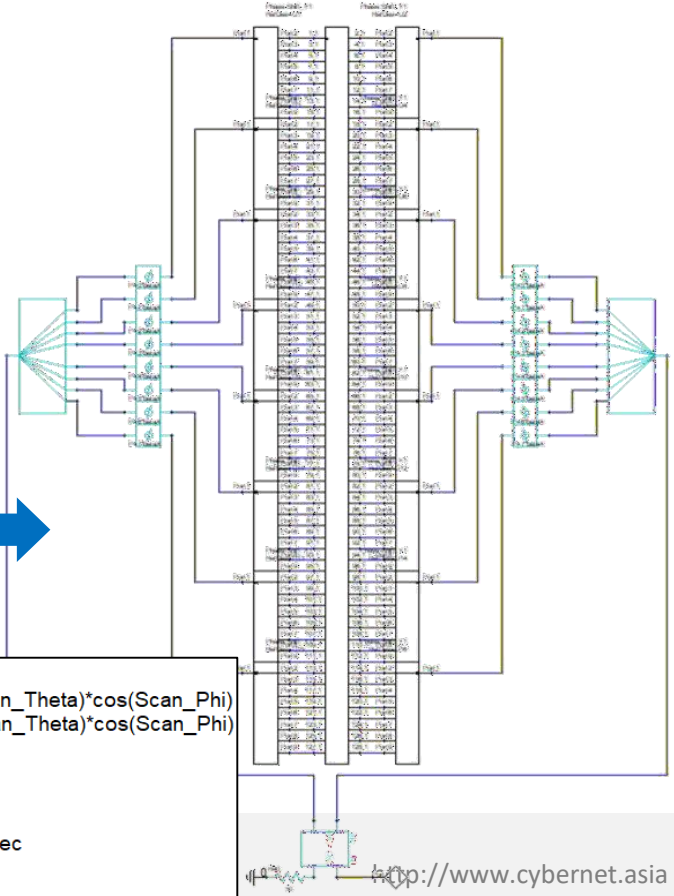


Phased Array Synthesis: Explicit Array

- Explicit modeling of array is necessary for multiphysics analysis
- Dynamic link to beamforming network in Circuit
- Push excitation from Circuit steers the beam in HFSS

Dynamic link/Push Excitation steers beam in HFSS

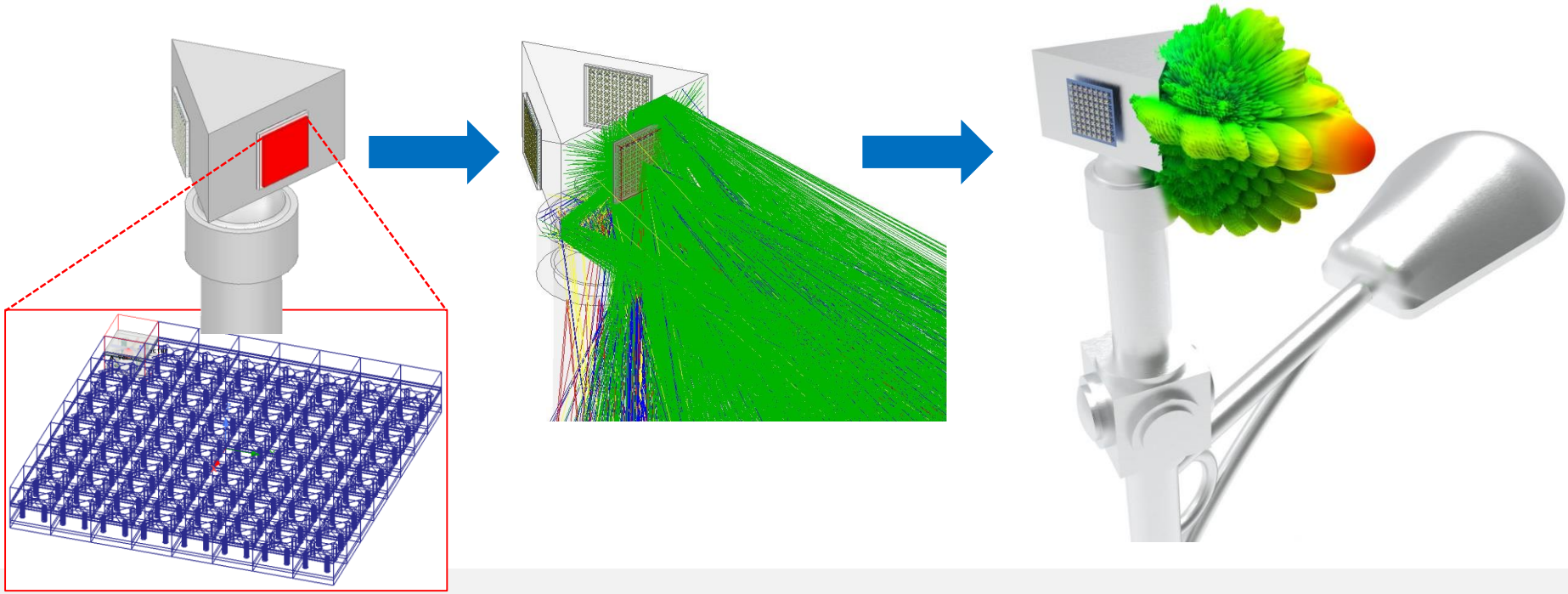




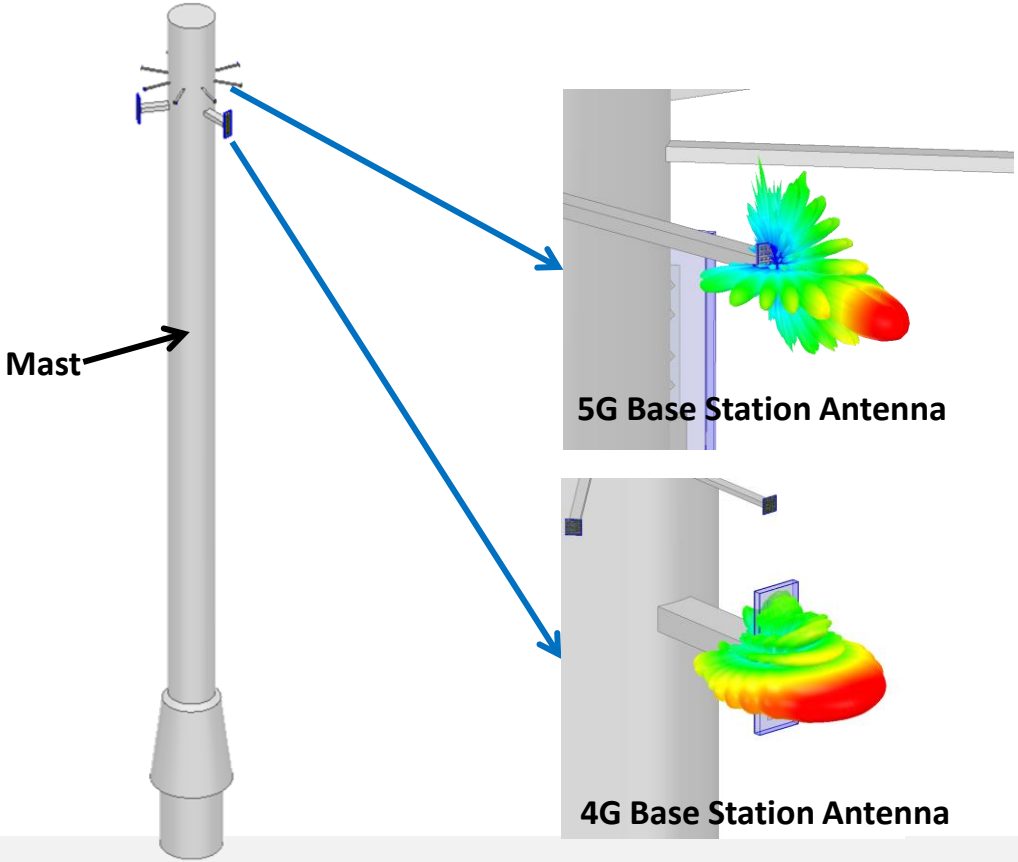
Design Properties
betaY = k_c*dist*sin(Scan_Theta)*cos(Scan_Phi)
betaX = k_c*dist*sin(Scan_Theta)*cos(Scan_Phi)
Scan_Phi = 45deg
Scan_Theta = 30deg
dist = 7mm
k_c = 2*pi*f_c/c
c = 300000000m_per_sec
f_c = 28GHz
Pin = 40

Installed Antenna Performance on a uCell

- FA-DDM simulation of phased array can be mapped onto uCell design in SBR+ as a near-field source
- SBR+ calculates the installed antenna pattern on the uCell

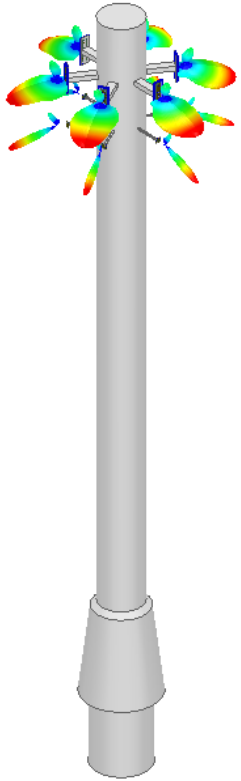


Installed Antenna Performance (SBR+)

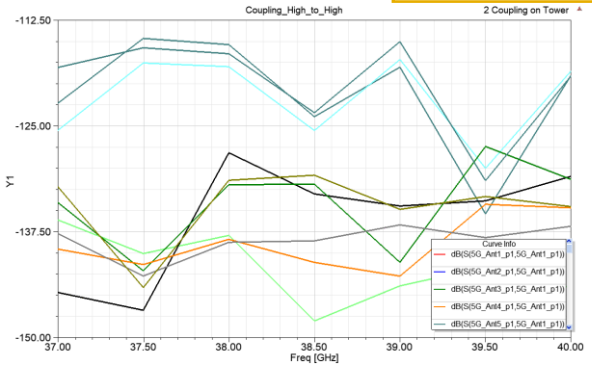


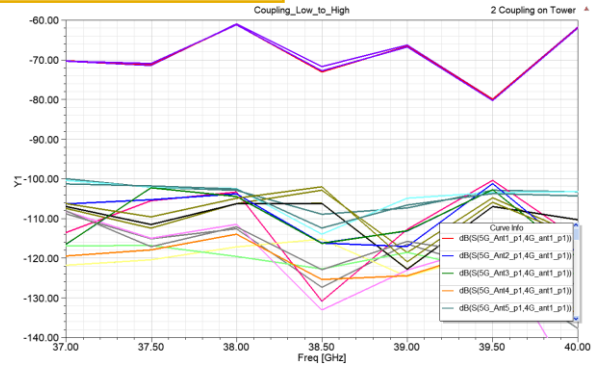
HFSS SBR+ simulation to calculate antenna pattern installed on a communication tower

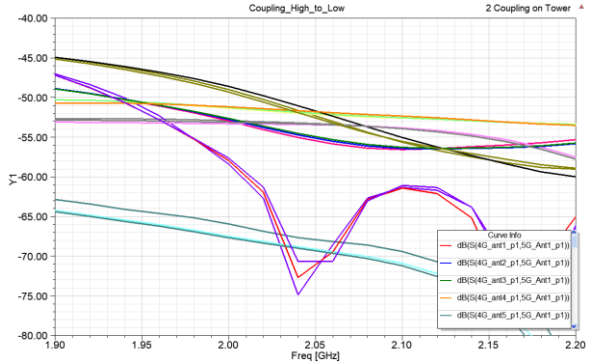
Installed Antenna Performance

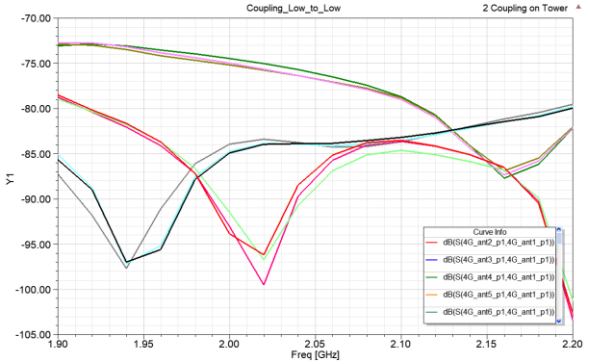


Coupling between 12 BS antennas

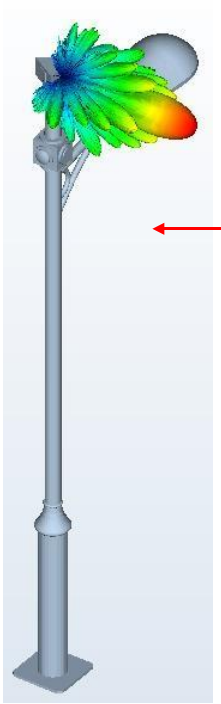






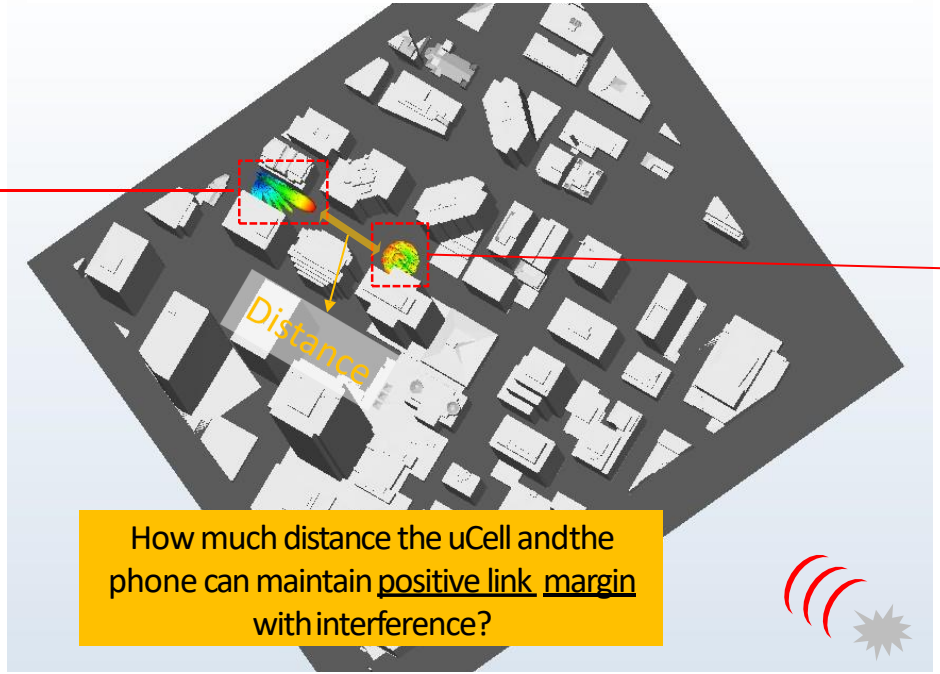


Link Margin Analysis in EMIT

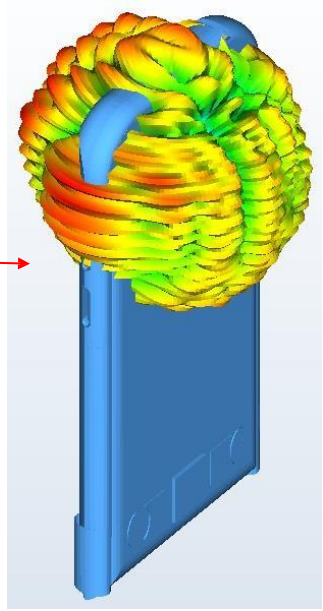


5G mmW uCell on a light pole

5G mmW uCell and mobile device in urban environment



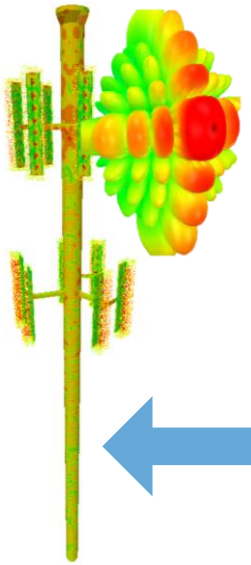
Broadband noisesource



Mobile phone

Link Margin & Interference Analysis Scenario

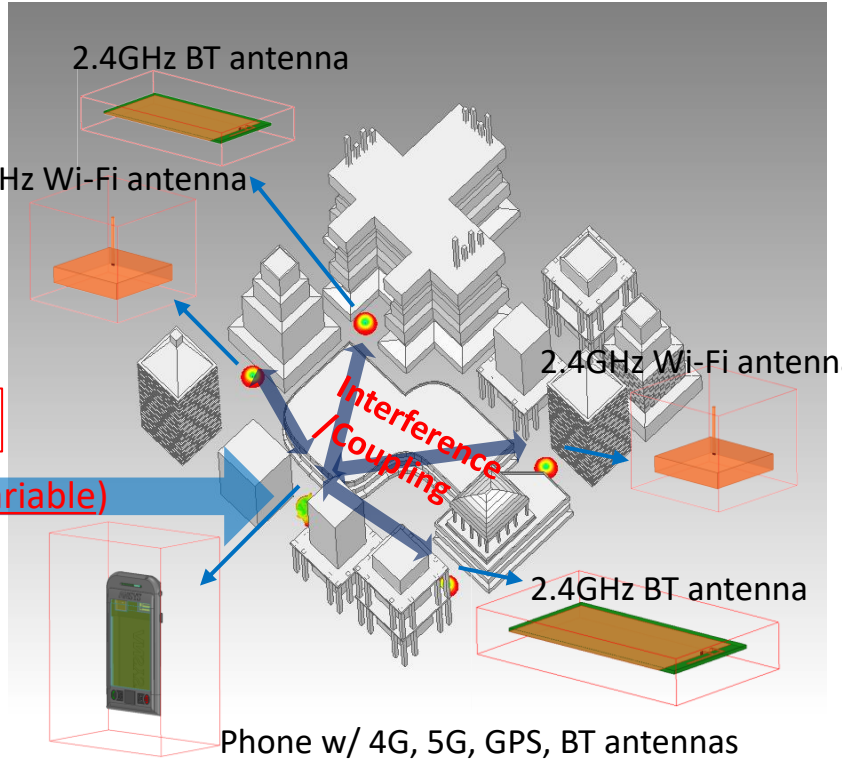
5G BS Antenna



Base Station Tower

Installed Pattern (SBR+)

EMIT Coupling Model/**SBR+ Simulation**



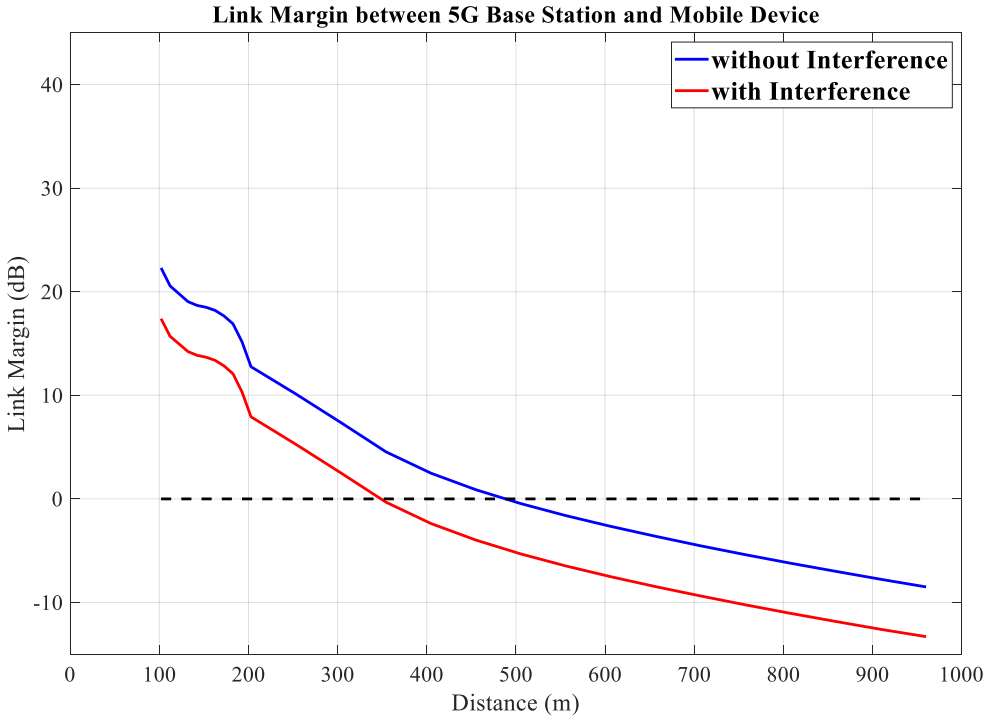
EMIT Coupling Model/SBR+ Simulation

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

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

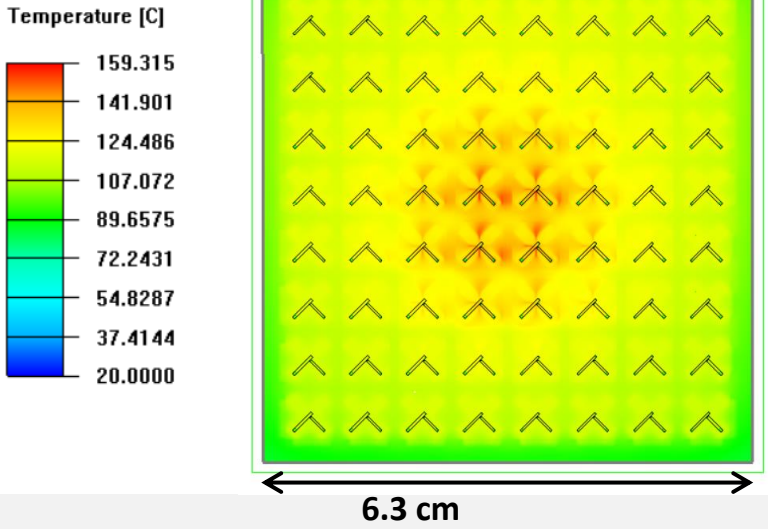
Link Margin vs. Distance

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



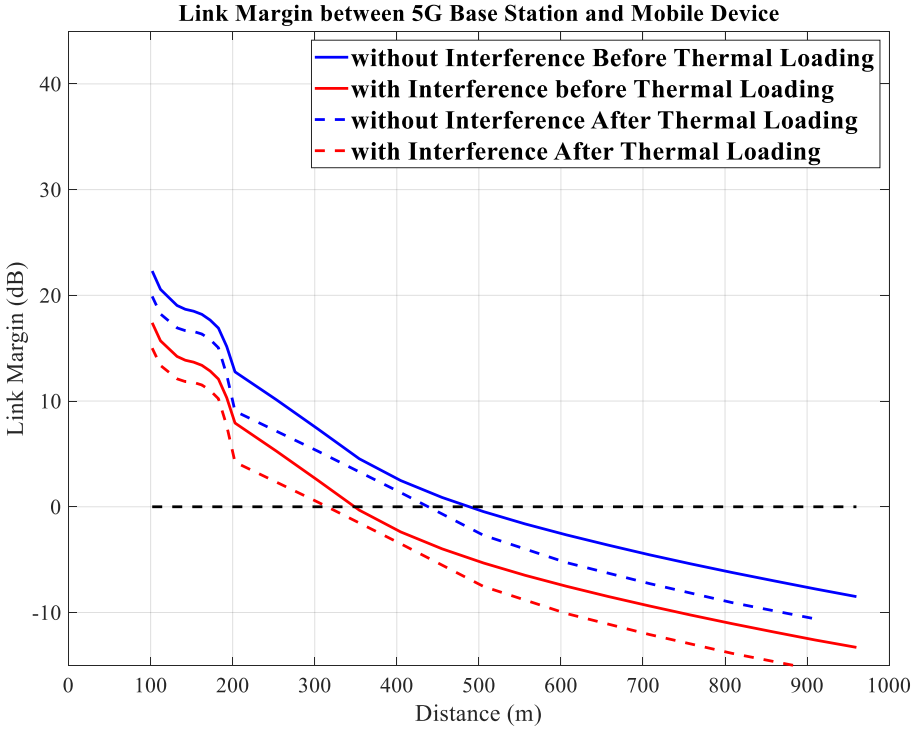
Electro-Thermal Simulation of 5G Base Station Antenna

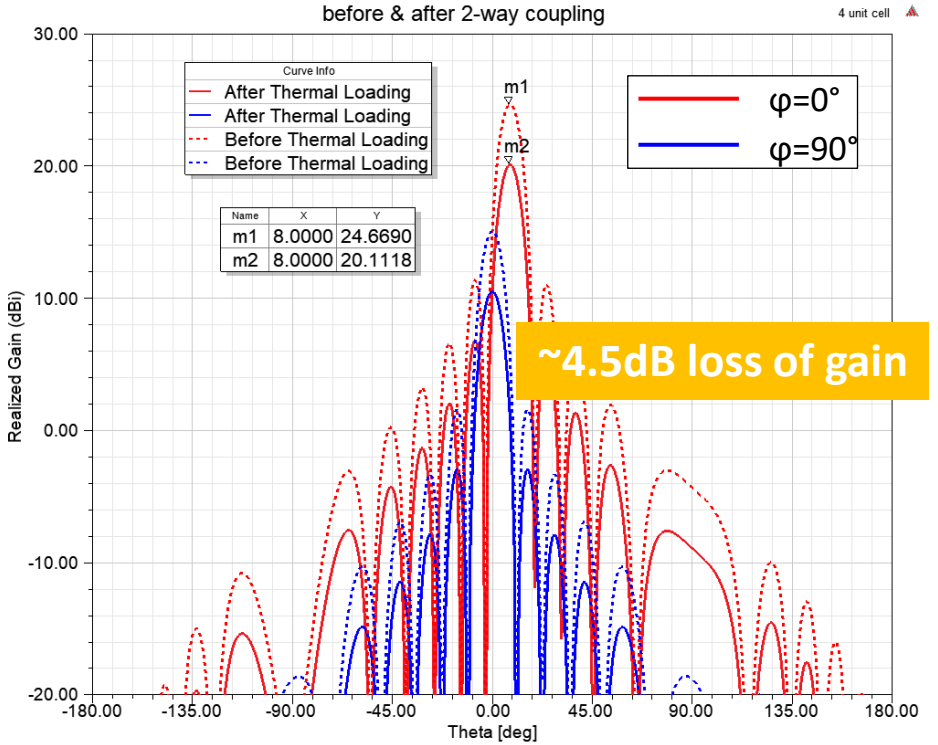
- Temperature of 8x8 dipole array for mmW 5G base station is simulated in Icepak (classic)
- 40W input, ~4W RF loss
  - Input power per unit cell: 0.625W
- Maximum temperature is 159°C ← may exceed the decomposition temperature



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

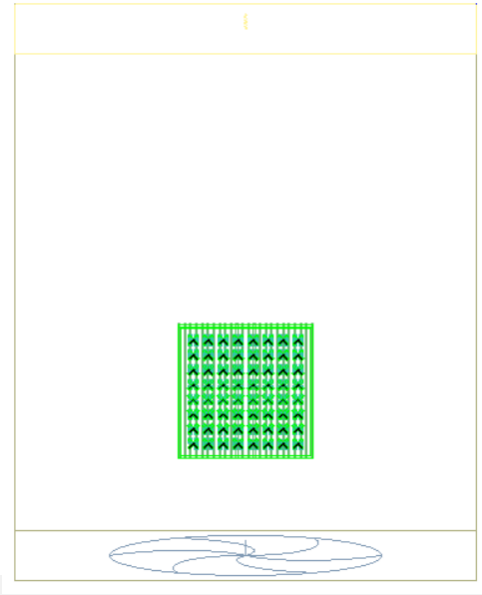
Array Performance After Thermal Loading (2-way Coupling)

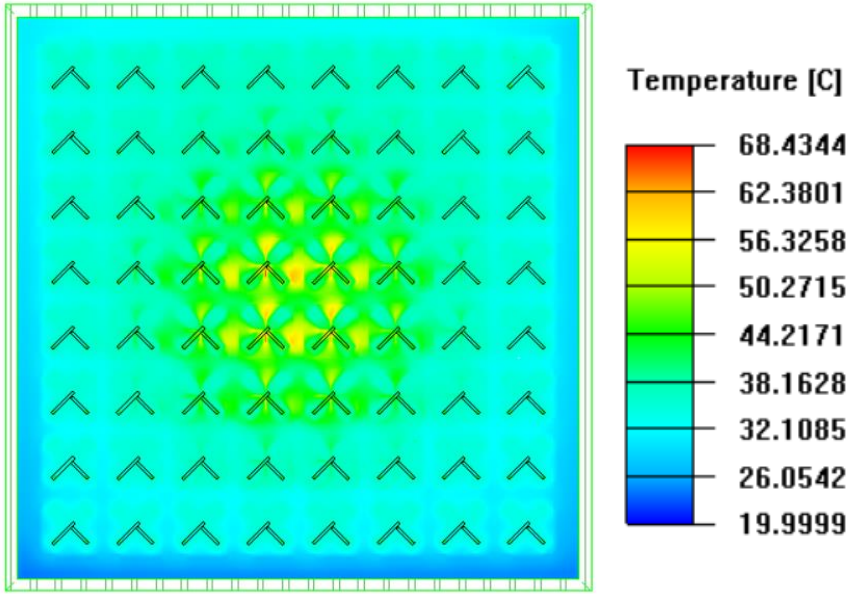




Thermal Management in Icepak

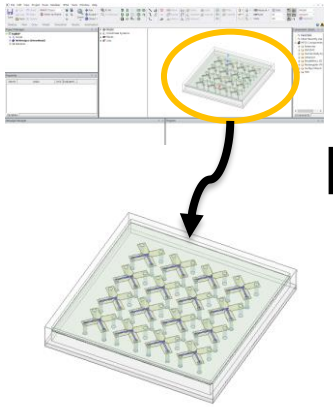
- To reduce overall temperature, a 50mm fan is added on the bottom
- Temperature is decreased to 68°C
- Thermal issue is much mitigated



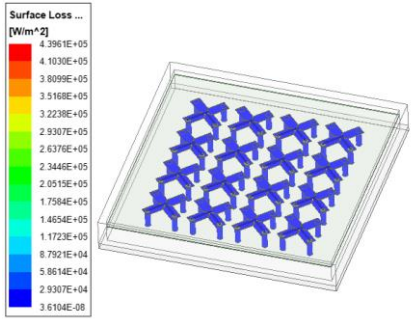


HFSS & Icepak Co-Simulation Flow In AEDT

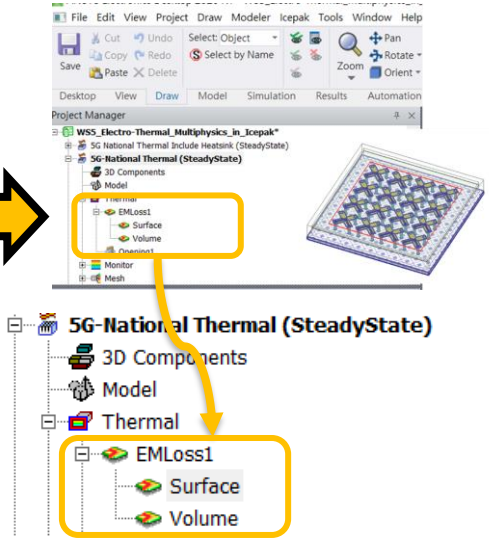
Create 3D model → **Calculate EM Loss in HFSS** → **Import EM loss to Icepak** → **Icepak Result**



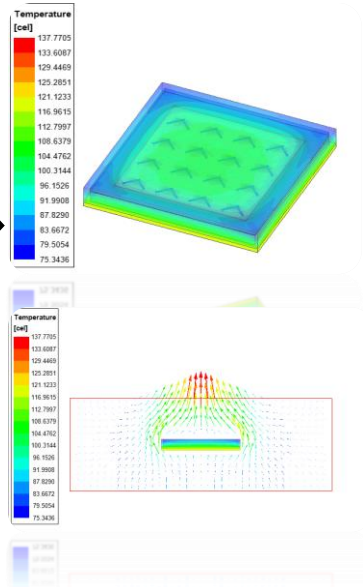
Create Model
(SpaceClaim or HFSS)



Calculate EM Loss
(HFSS)



Import EM Loss
(Icepak)



Calculate Temperature
(Icepak)

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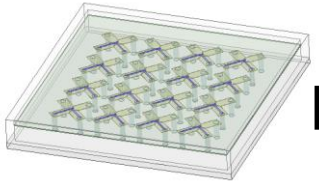
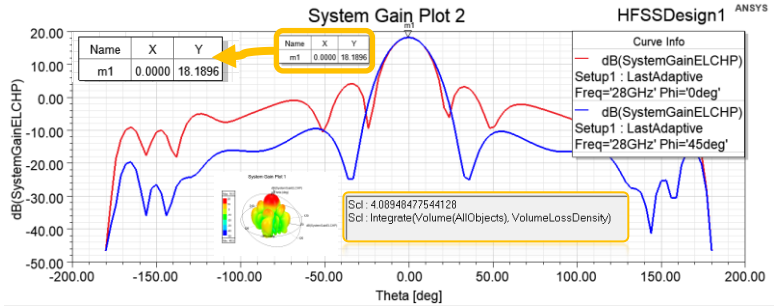
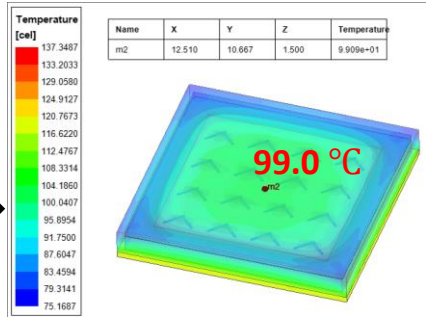
HFSS & Icepak Co-Simulation Flow In AEDT



Model 1



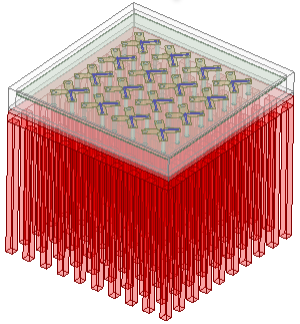


Add Cooling design

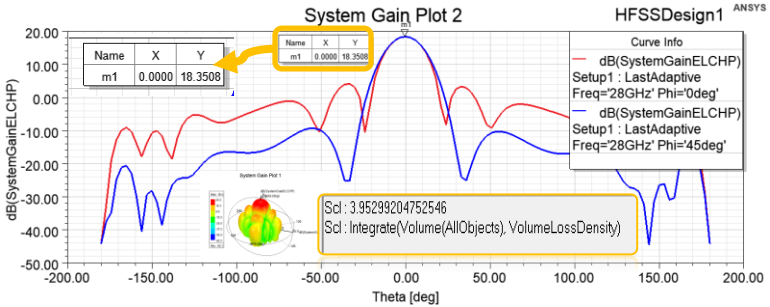
Gain value 18.18 dB improve to 18.35 dB

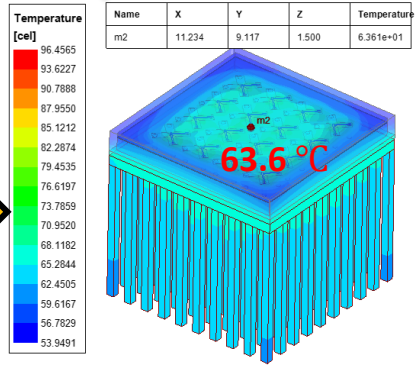
EM Loss 4.08 W improve to 3.95W

Temperature from 99 ℃ improve to 63.6 ℃



Model 2





Summary

- Workflow of 5G phased array antenna design from element-level to system-level in multiphysics domain
- ANSYS simulation tools can be used to analyze every level of design process in every physics
  - HFSS: Optimized antenna element and phased array design
  - SBR+: Installed antenna performance and coupling
  - EMIT: Interference and link margin analysis
  - Icepak/WB Thermal solver: Multiphysics
- Thermal effect can be more critical for mmW systems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