

# RF/MW Module Design in ADS

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**2019.09.19**

**Keysight EEsof EDA**



# Industry Trends, Challenges, & Solutions

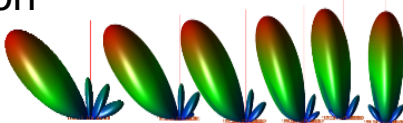
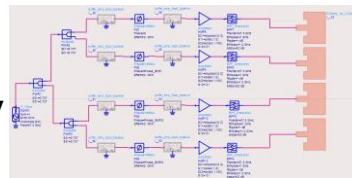
## RF/MW

### RF/MW new applications

- mmWave:  
5G &  
Automotive  
RADAR



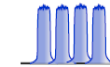
5G/Radar Phased Array  
& Phase Shifter design  
iPDK support & Silicon  
RFIC Interoperability



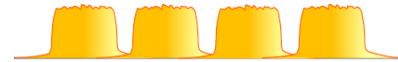
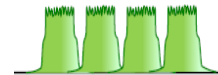
### RF/MW Module Design

- Integration of multiple technologies:
  - RF PCB
  - GaAs, GaN
  - SiGe, SOI, ...
  - Laminate/Package

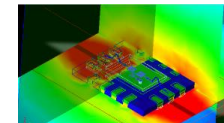
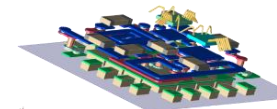
- Transition from PA modules to **multi-band**



**Filter modules:**  
BAW, SAW for  
MIMO, 5G

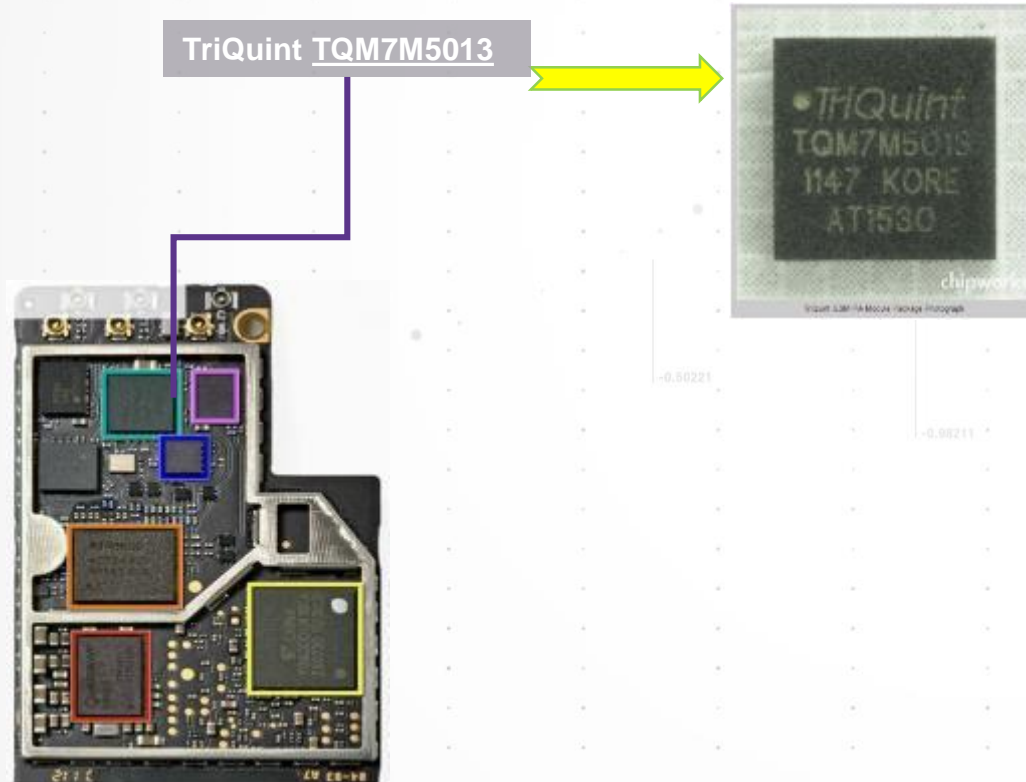


Multi-Technology  
circuit & Integrated  
3DEM Simulation



# Multi Chip RF Modules

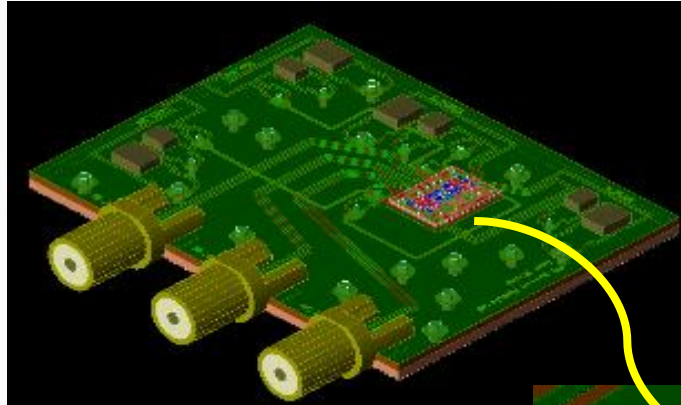
## EXAMPLE – APPLE'S IPAD CELLULAR BOARD



From Chipworks:  
<http://www.chipworks.com/>  
A recognized leader in reverse engineering and patent infringement analysis of semiconductors and electronic systems

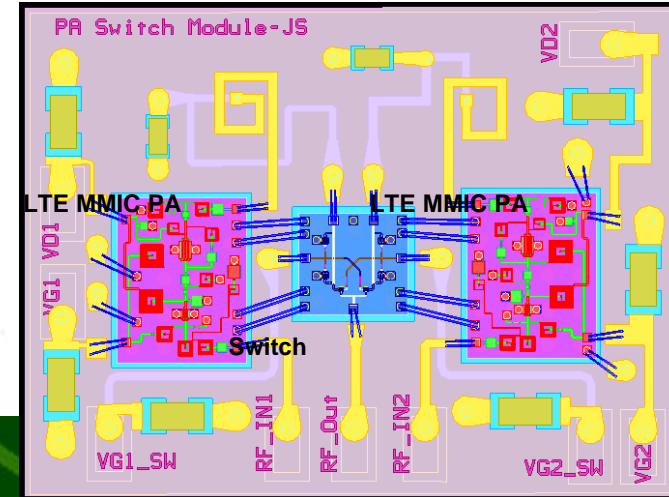
# Multi Chip RF Modules

## PA / SWITCH MODULE



The Complete PA / Switch Multi-Chip Module

- PA / Switch IC's
- Bond wires
- Laminate board
- Solder bumps
- PCB test board
- Connectors



Laminate Board with PA / Switch IC's

# 5G is A Game Changer For Packages

## HIGH FREQUENCIES AND HIGH BANDWIDTH



Frequency Range 1: 400 MHz to 6 GHz	Frequency Range 2: 24.25 to 52.6 GHz	Frequencies up to 90 GHz are currently being investigated for future releases.
Adds 1.5 GHz of new spectrum in frequency bands	Adds 8.25 GHz of new spectrum in frequency bands	
n77: 3.3–4.2 GHz n78: 3.3–3.8 GHz n79: 4.4–5 GHz	n257: 26.5–29.5 GHz n258: 24.25–27.5 GHz n260: 37–40 GHz	

mmWave spectrum will be needed to meet 5G peak data rate goals of 20 Gbps in downlink (DL) and 10 Gbps in uplink (UL).

Source : Keysight ([Top considerations for 5G NR device designers](#))

Modulation scheme for PDSCH	Required EVM
QPSK	17.5 %
16QAM	12.5 %
64QAM	8 %
256QAM	3.5 %

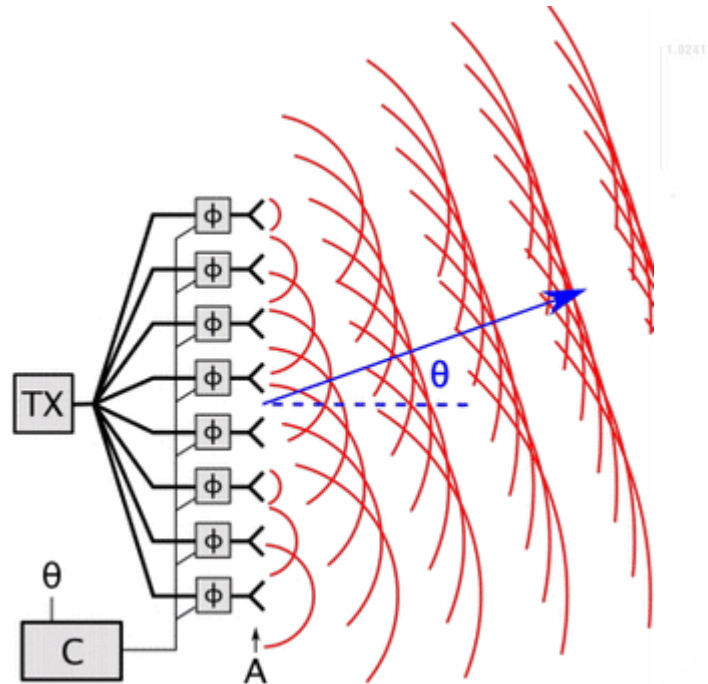
Figure 5: 3GPP TS 38.101-1 EVM requirements for different 5G modulation schemes

- Maintaining these high bandwidths at high frequencies have a direct impact on the design on every interconnection and then packages

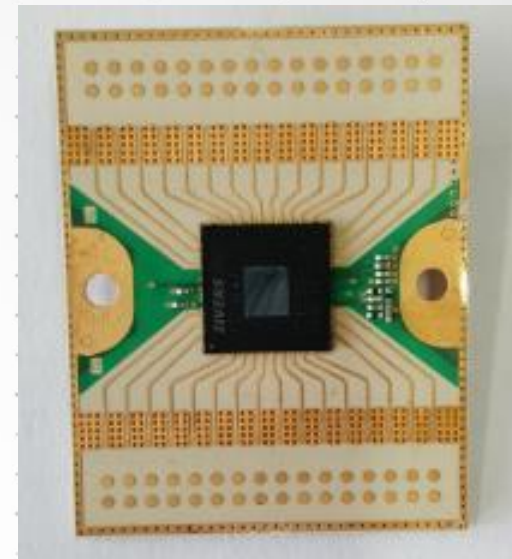


# One Slide Overview Of Phased Array

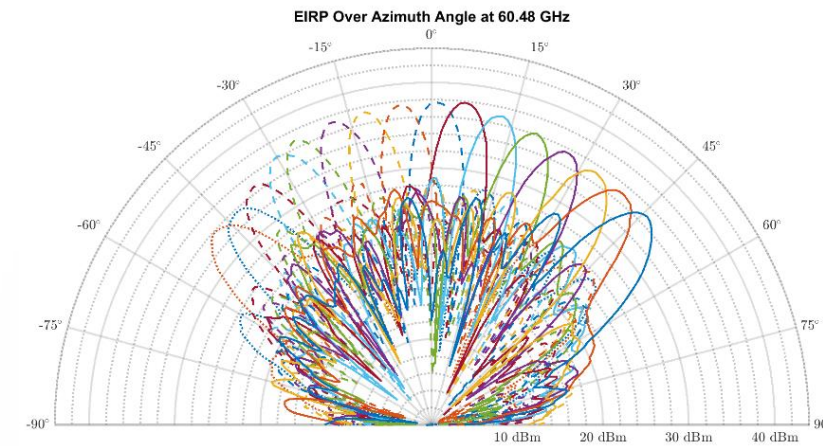
- Just basic physics of wave propagation
- Adjusting the time delay or phase difference between adjacent antennas results in maximum radiation in a specific direction



Source : [Wikipedia](#)

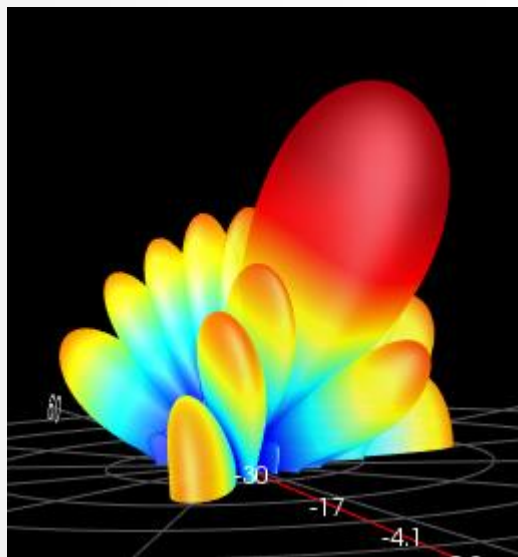


WLAN 802.11ad transceiver  
(courtesy of [Sivers IMA](#))

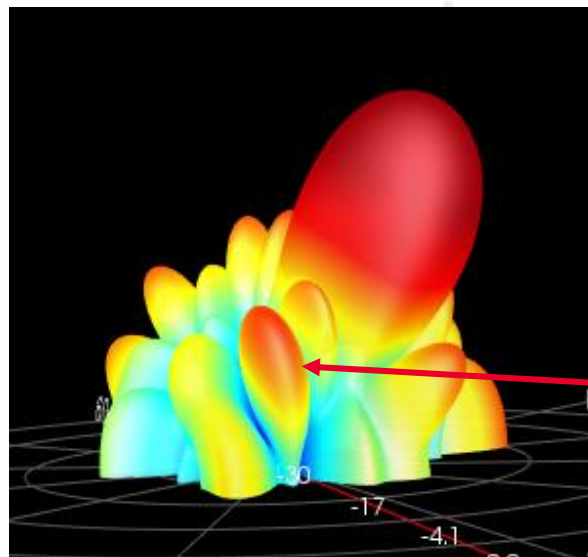


# Phased Array And Packaging

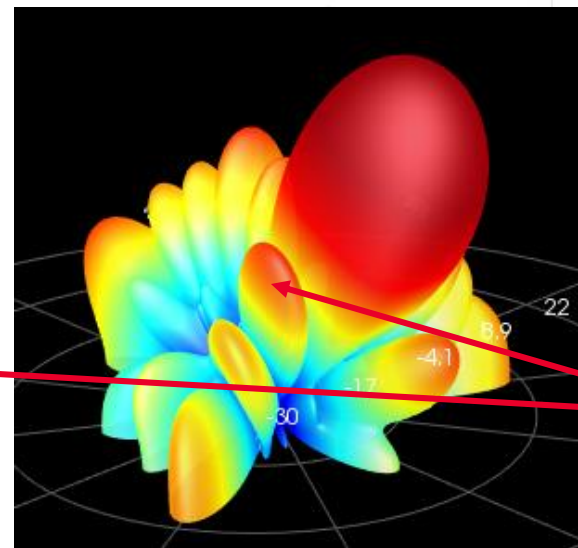
- As this is phase-driven, the group delay or amplitude loss in the package interconnection could be a bottleneck



No error



Phase error

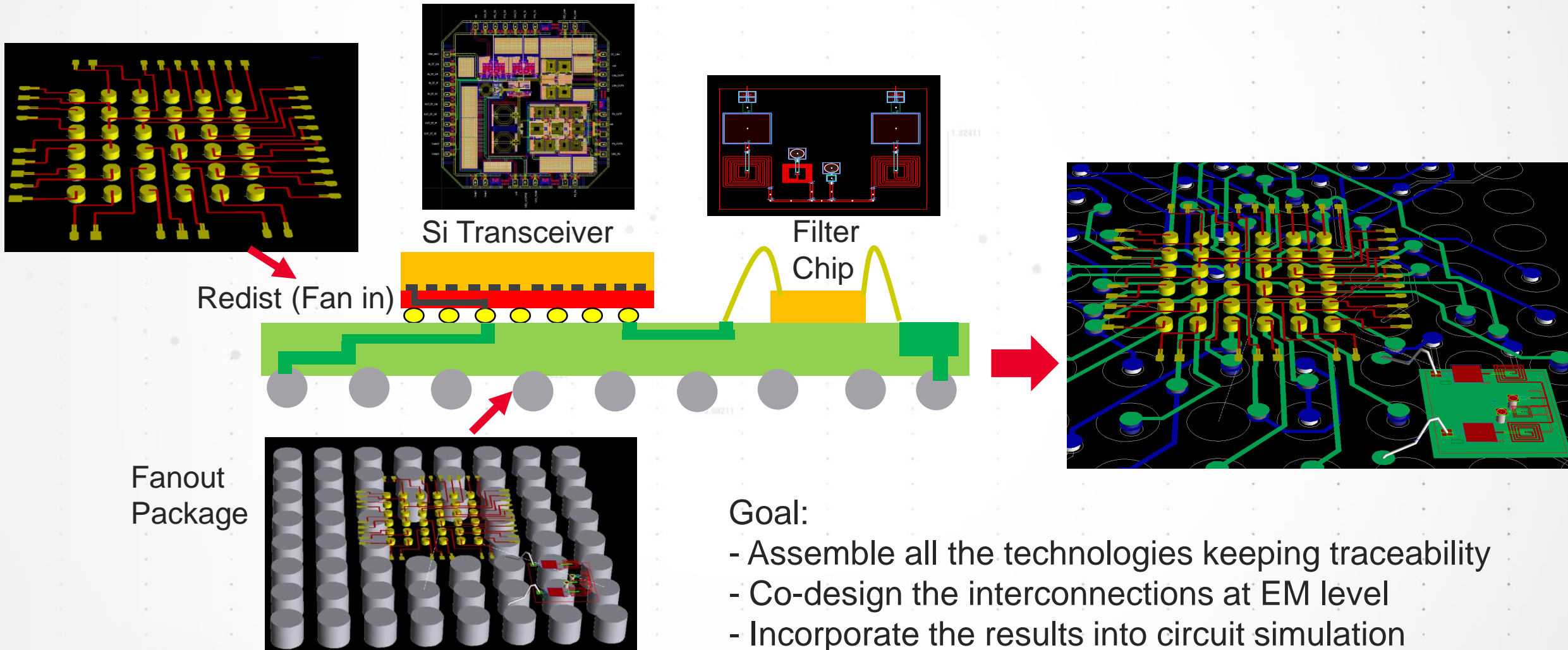


Amplitude error

Not co-designing can lead to several dBs of error in Side Lobes Level and then deteriorate the original antenna performances

# Higher Integration Needs Efficient Co-Design

DATABASES COME FROM DIFFERENT SOURCES

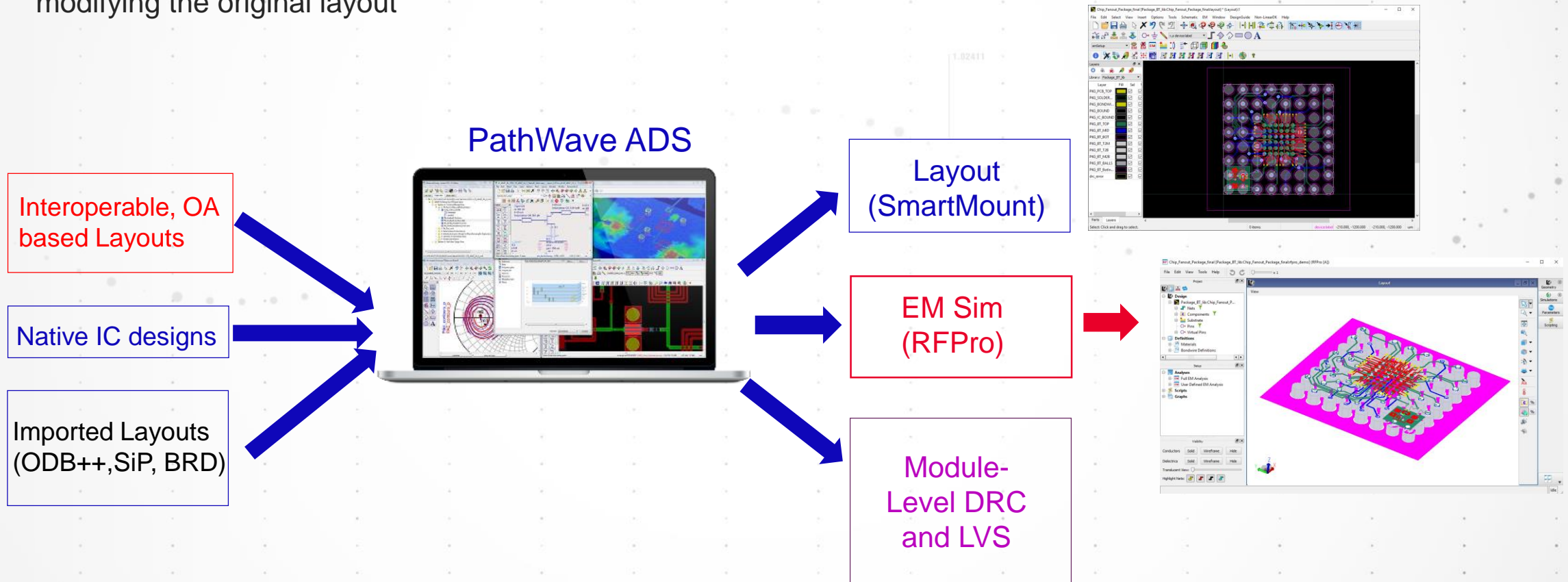




# Using PathWave ADS As An Assembly Platform

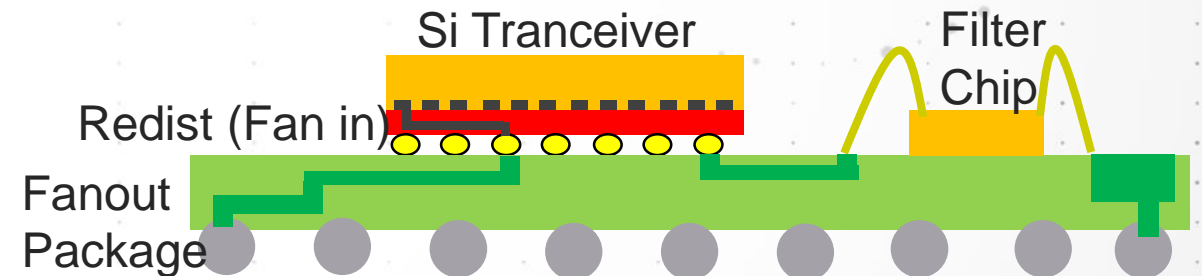
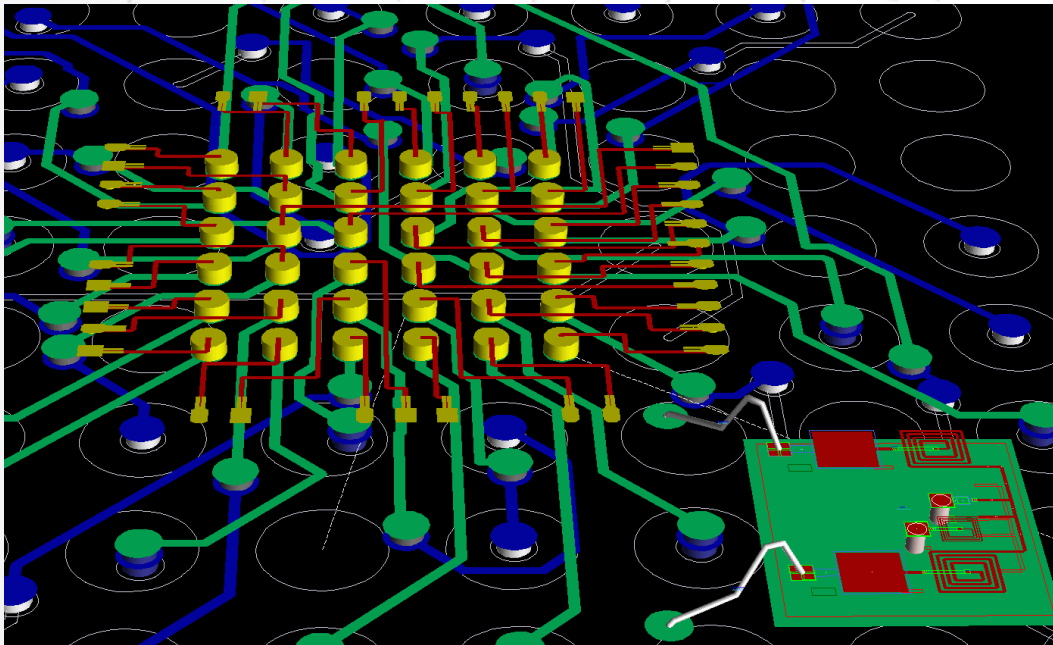
- **Goals:**

- Build a multi-technology assembly and simulation flow which scales with the complexity of the products.
- Build a user friendly capability to EM simulate pieces of this complex multi-technology design without cutting or modifying the original layout



# Smart Mount Enables Complex Technology Assembly

- A new, unique, innovative way to assemble Multi-technology designs.
  - **Simple:** does not need layer mapping, does not require substrate modification
  - **Powerful:** user can write macros to do all sorts of custom mount configurations
  - **Versatile:** Supports read only and interoperable libraries, and scaled technologies (nm Si)
  - **Scalable:** works well for large scale assemblies and stacked technology



# RFPro Vision: EM For Every RF Circuit Designer

ALLOWS USERS TO FOCUS ON DESIGN RATHER THAN SETTING UP EM

- Main customer requests for the EM flow

- Integration

- ✓ 3D view
- ✓ Solution for RF PCB, RFIC, MMIC and RF Modules
- ✓ Same user interface for ADS and Cadence Virtuoso
- ✓ Same environment for FEM and Momentum

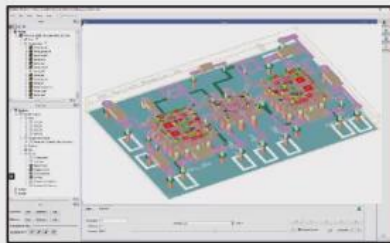
- Solver

- ✓ No expert setup
- ✓ Be confident in the setup of the simulation and accuracy of the results
- ✓ Better automated defeaturing (via merging/dummy removal/hatched planes...)

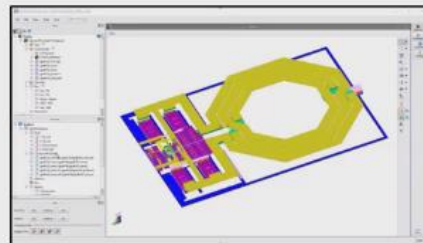
- Layout

- ✓ No Cookie cutting
- ✓ No exporting
- ✓ No removing active devices and placing pins & ports
- ✓ No reconnecting schematics to s-parameter files

## RFPro



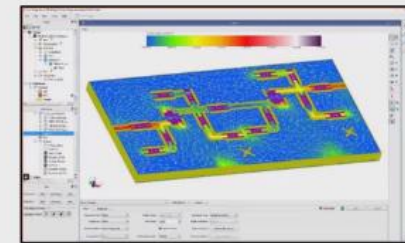
RF Module



RFIC

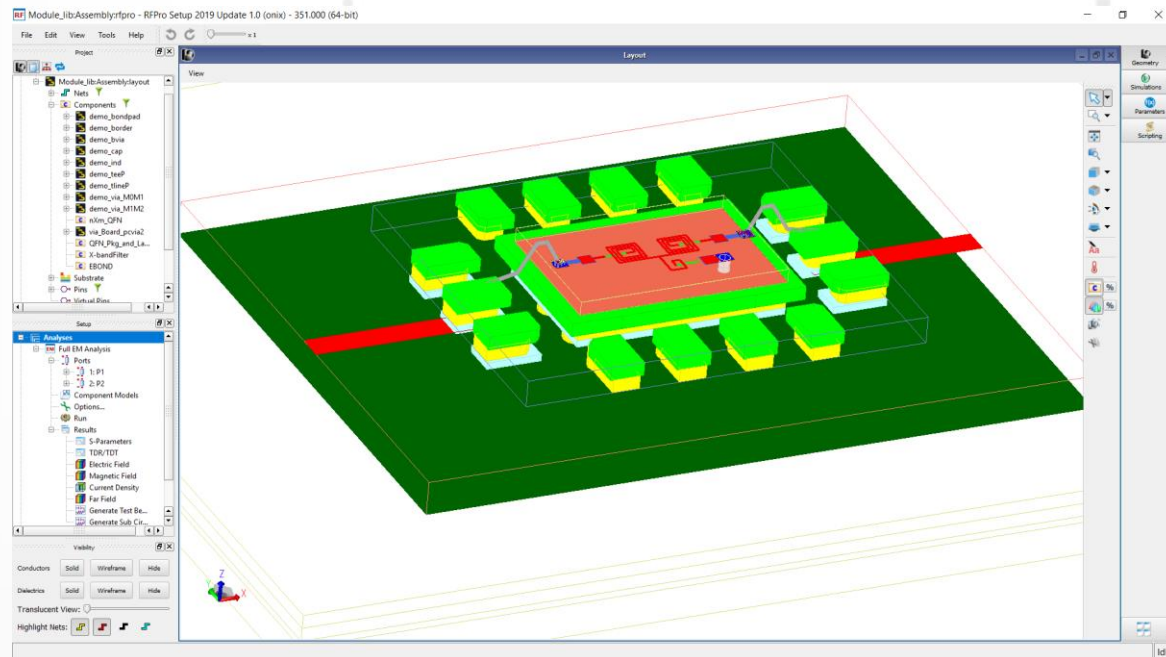


MMIC



RF Board

# X-Band Filter IC in QFN Package Using Smart Mount (ADS 2019U1)





# Steps using Smart Mount

- Smart Mount Setup
- Building the Module Assembly
- Placing and Configuring the Bond Wires

# Smart Mount Technology Setup

Nested Technology

View Technology for this Library:

Layer Display Properties | Layers | Purposes | Display Order | **Nested Technology**

Nested Technology Scale Factor:

Default Smart Mount

Smart Mount Subtype:

Automatically use smart mount proxy pcell for all designs in library

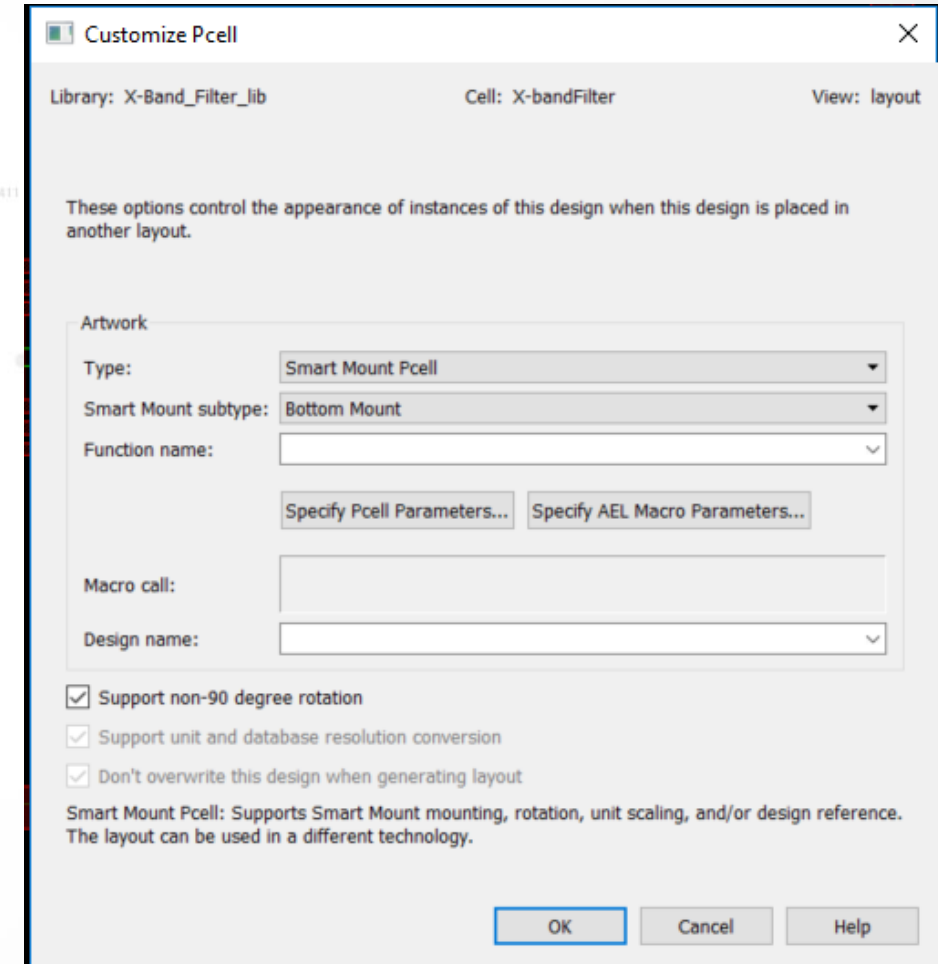
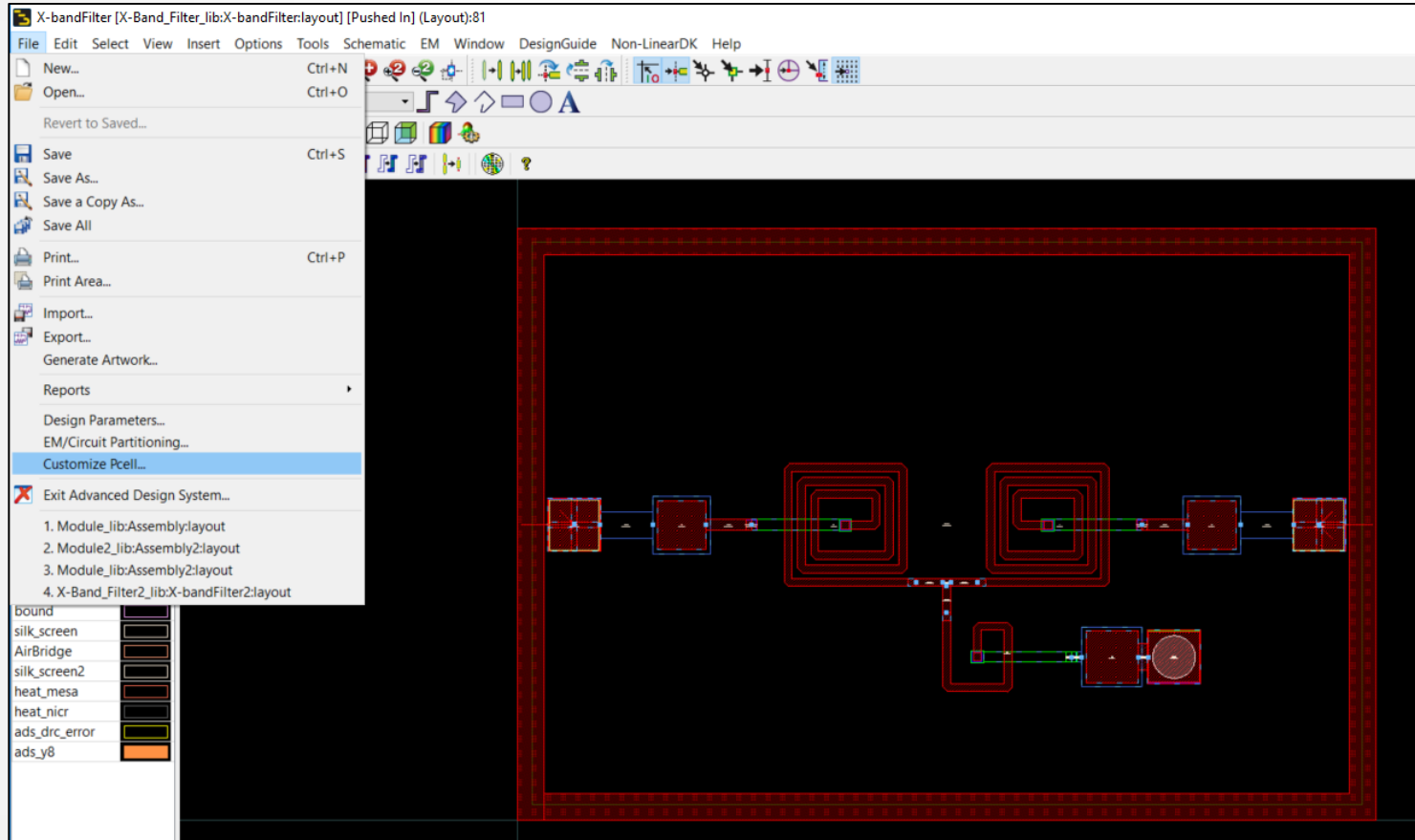
AEL Function Name (optional):

Function Parameters (optional):

Layer Mapping

**In Smart Mount we did not map the Layers of the IC to be in the Module Layers list**

# Smart Mount Technology Setup - Setup IC Pcell attribution



# Check Layers

**Nested Technology** [Close]

View Technology for this Library:

Layer Display Properties | **Layers** | Purposes | Display Order | Nested Technology

Layer Name	Number	Library	Process Role	Binding	Derived Layer Operation	Manufacturing Grid
ads_text	230	ads_schematic_...	Not defined			default
ads_device	231	ads_schematic_...	Not defined			default
ads_border	232	ads_schematic_...	Not defined			default
ads_snap	233	ads_schematic_...	Not defined			default
ads_align	234	ads_schematic_...	Not defined			default
ads_prBoundary	235	ads_schematic_...	Not defined			default
ads_instance	236	ads_schematic_...	Not defined			default
ads_annotate	237	ads_schematic_...	Not defined			default
ads_marker	238	ads_schematic_...	Not defined			default
ads_select	239	ads_schematic_...	Not defined			default
ads_substrate	240	ads_schematic_...	Not defined			default
ads_grid	251	ads_schematic_...	Not defined			default
ads_axis	252	ads_schematic_...	Not defined			default
ads_hilite	253	ads_schematic_...	Not defined			default
ads_background	254	ads_schematic_...	Not defined			default
ads_drc_error	255	ads_schematic_...	DRC			default

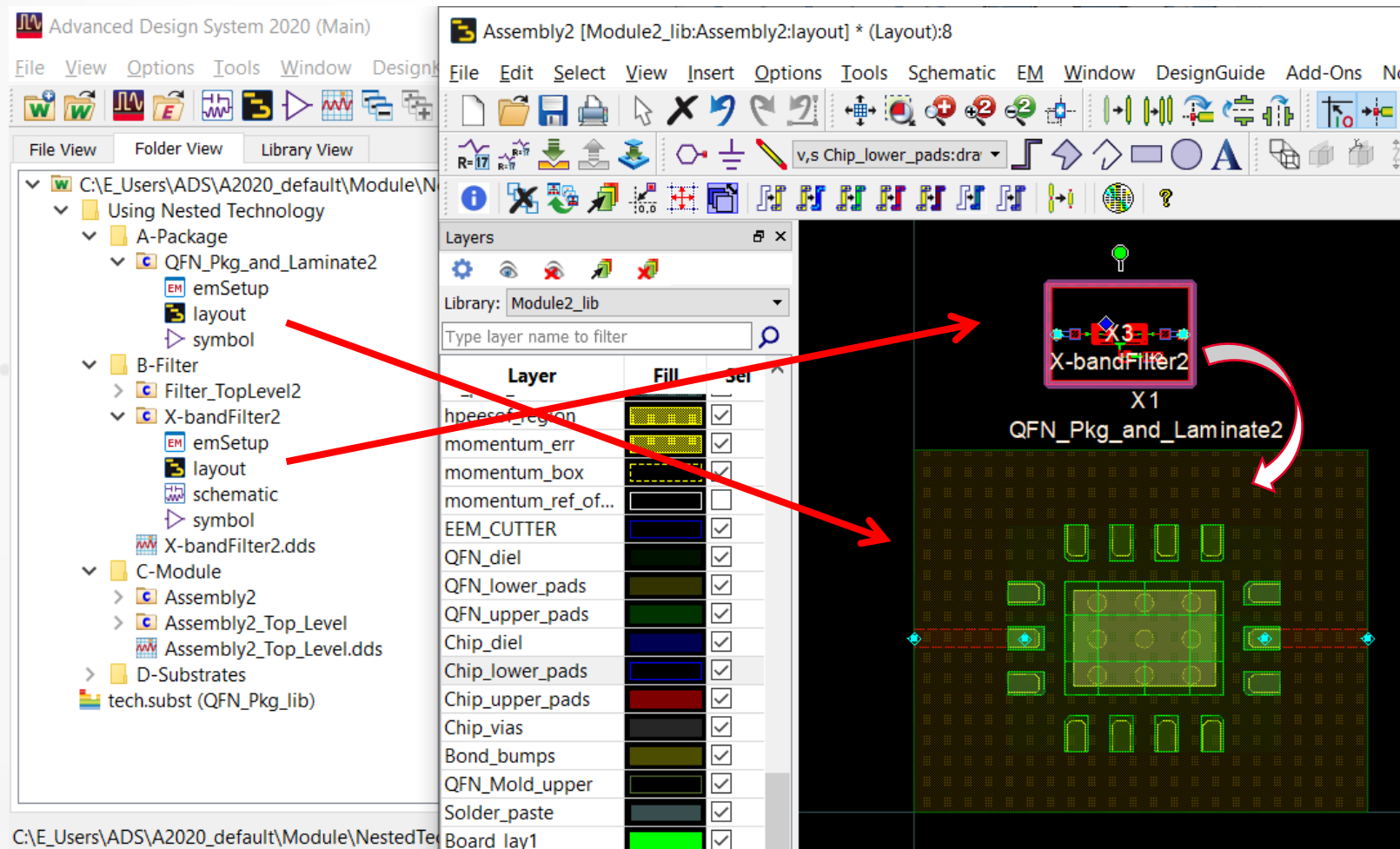
Layer numbers between 200 and 255 are reserved for use with schematics and symbols. Avoid defining layers with these numbers.



# Building the Module Assembly

Drag and drop the package and the IC into the module layout page. The designs will be easily read along with their correspondent technologies (Layers and units)

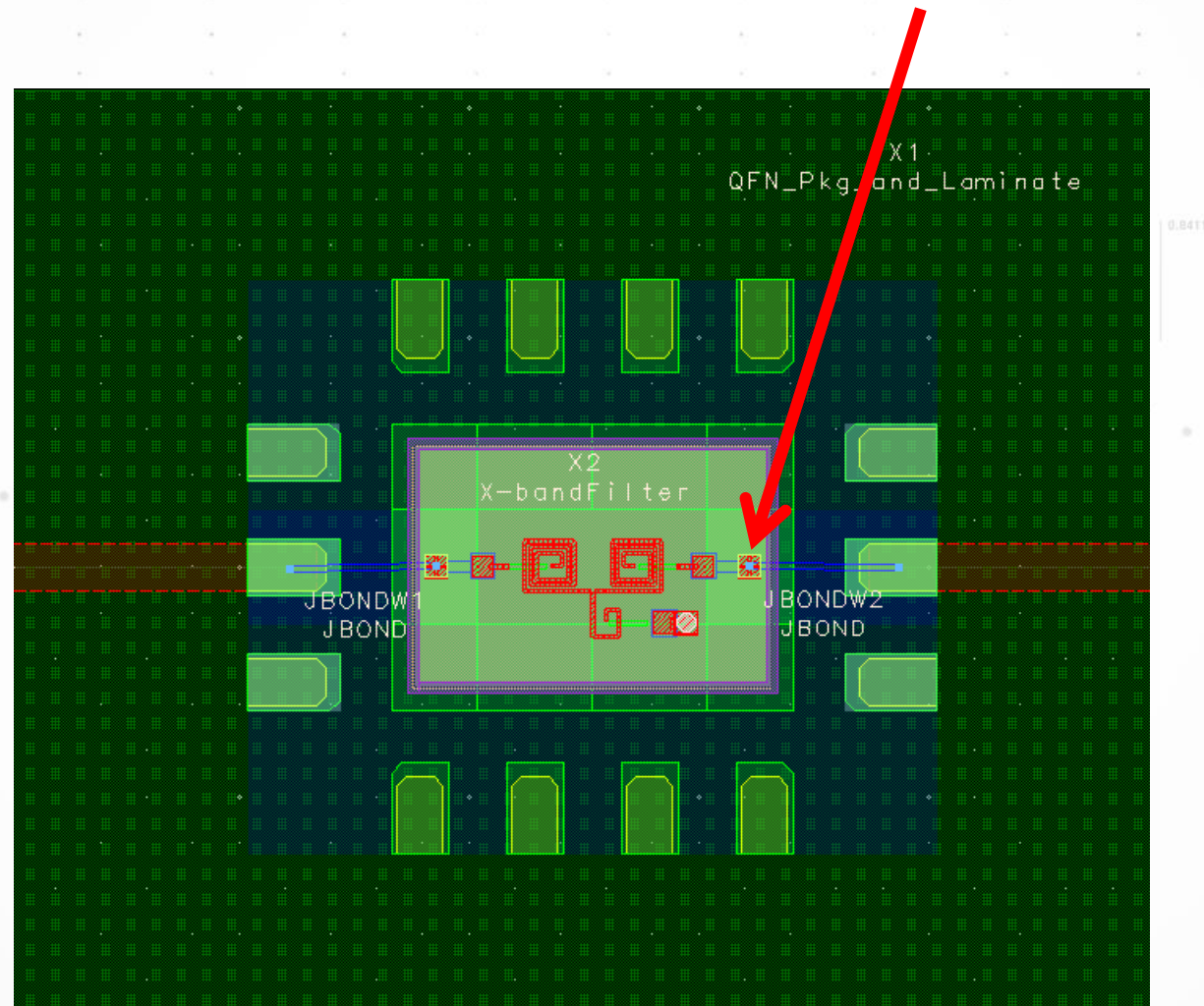
Insert QFN\_Pkg\_and\_Laminate layout, followed by the X-bandFilter layout



Next, drag and align the MMIC onto the package

# Placing and Configuring the Bond Wires

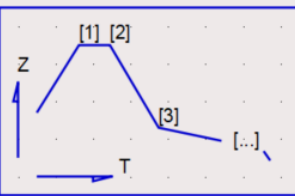
Place bondwire starting on the MMIC pad and ending at the QFN upper pad.



# Configuring Bond Wires parameter and layers in Schematic

Assembly [Module\_lib:Assembly:schematic] (Schematic):17

File Edit Select View Insert Options Tools Layout Simulate Window DynamicLink DesignGuide EM Help



Parts

Search all libr...

DemoKit\_Non\_Linear

EBOND\_Shape  
Shape1  
Rw=12.5 um  
Material=  
Cond=4.1e+07  
Er=1.0  
Subst=""  
Height1=200 um  
Height2=100 um  
Length=500 um  
Ground\_Height=0 um  
Layer1="X3:M2:drawing"  
Layer2="QFN\_upper\_pads:drawing"  
Draw\_Layer="bond:drawing"  
View=top (drc)  
Number\_Of\_Sides=0  
Metal\_Model\_Type=Use modeling default

rT[1]=Previous  
rT[2]=Previous  
rT[3]=End  
rT[4]=End  
tT[1]=Angle  
tT[2]=Proportional  
tT[3]=Proportional  
tT[4]=Length  
vT[1]=60  
vT[2]=0.125  
vT[3]=0.5  
vT[4]=20 um  
rZ[1]=Previous  
rZ[2]=Previous  
rZ[3]=End

rZ[4]=End  
tZ[1]=Proportional  
tZ[2]=Proportional  
tZ[3]=Angle  
tZ[4]=Length  
vZ[1]=0.3  
vZ[2]=0.0  
vZ[3]=15  
vZ[4]=20 um

In Smart Mount we did not map the Layers of the IC to be in the Module Layers list

We must manually type it in:  
"X3:M2:drawing"

Edit Instance Parameters:17

ads\_bondwires:EBOND\_Shape Instance Name

Shape1

Setup Display

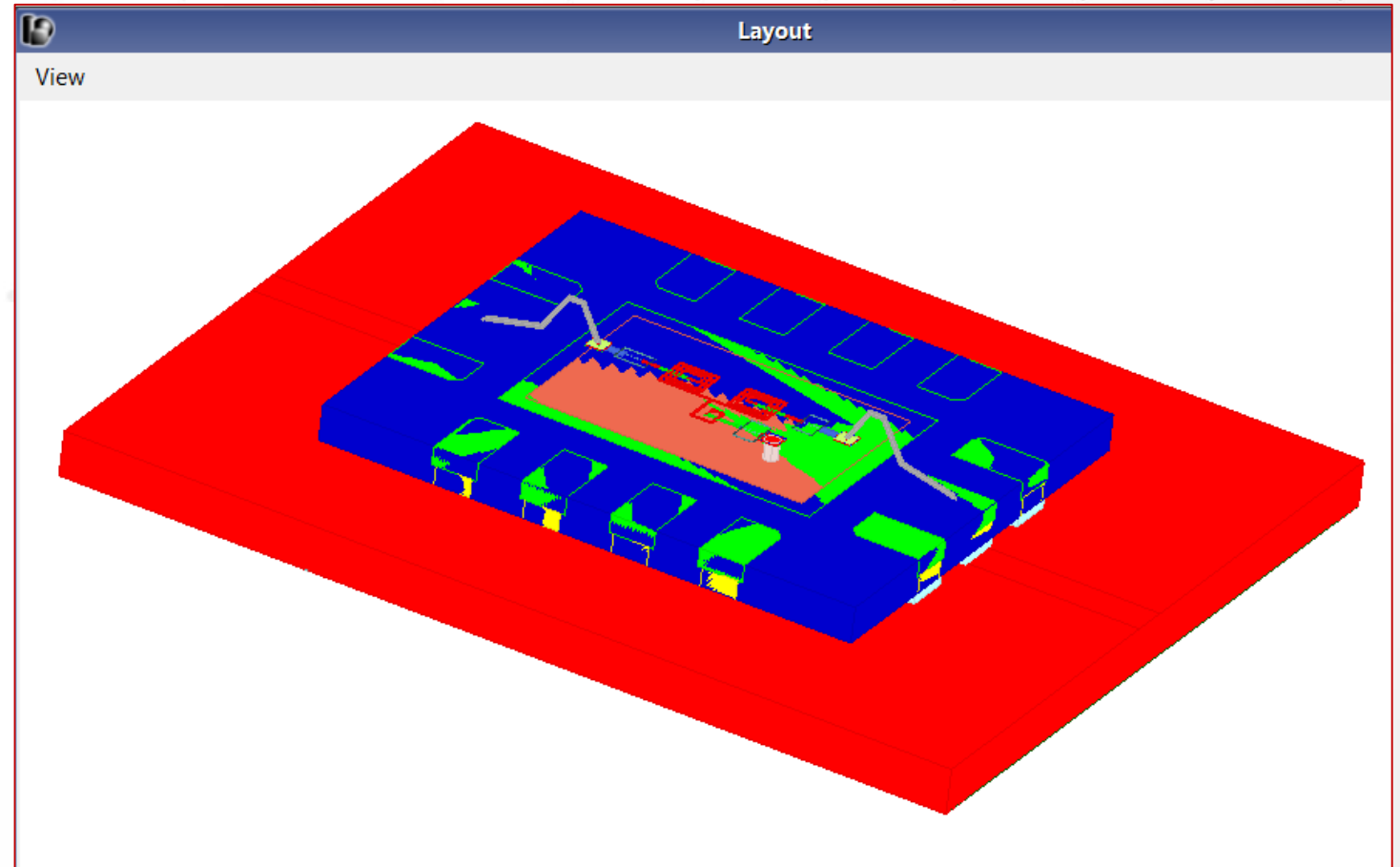
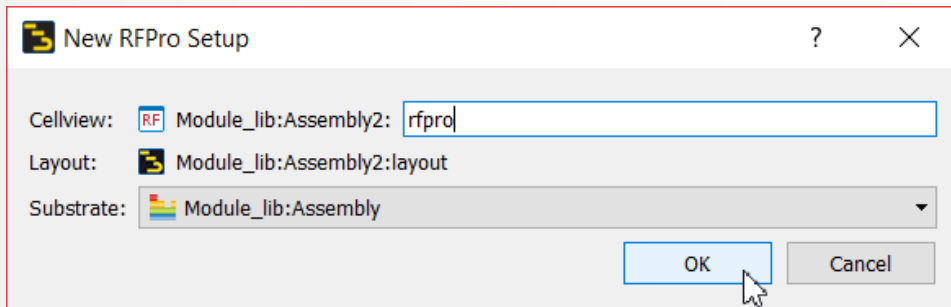
Radius	12.5 um	Substrate	""
Conductivity (Siemens/m)	4.1e+07	Material	
Er	1.0	Use C Model	0
Height1	200 um	Layer1	"X3:M2:drawing"
Height2	100 um	Layer2	"Board_Via:drawing"
Ground Height	0 um	Ground Layer	"Board_sub:drawing"
Length	500 um	Draw Layer	"default:drawing"
Annotate Text Height	0.01	Annotate Layer	"cond:drawing"
Layout View	top view (drc)	Mesh Interior	"cond2:drawing"
Number Of Sides	0		"resi:drawing"
			"diel:drawing"
			"diel2:drawing"
			"hole:drawing"
			"bond:drawing"

Horizontal	Hor. Type	Hor. Ref	Vertical	Ver. Type	Ver. Ref
60	Angle	Previous	0.3	Proportional	Previous
0.125	Proportional	Previous	0.0	Proportional	Previous

OK Apply Cancel Help

# Start RFPro for RF Module Simulation

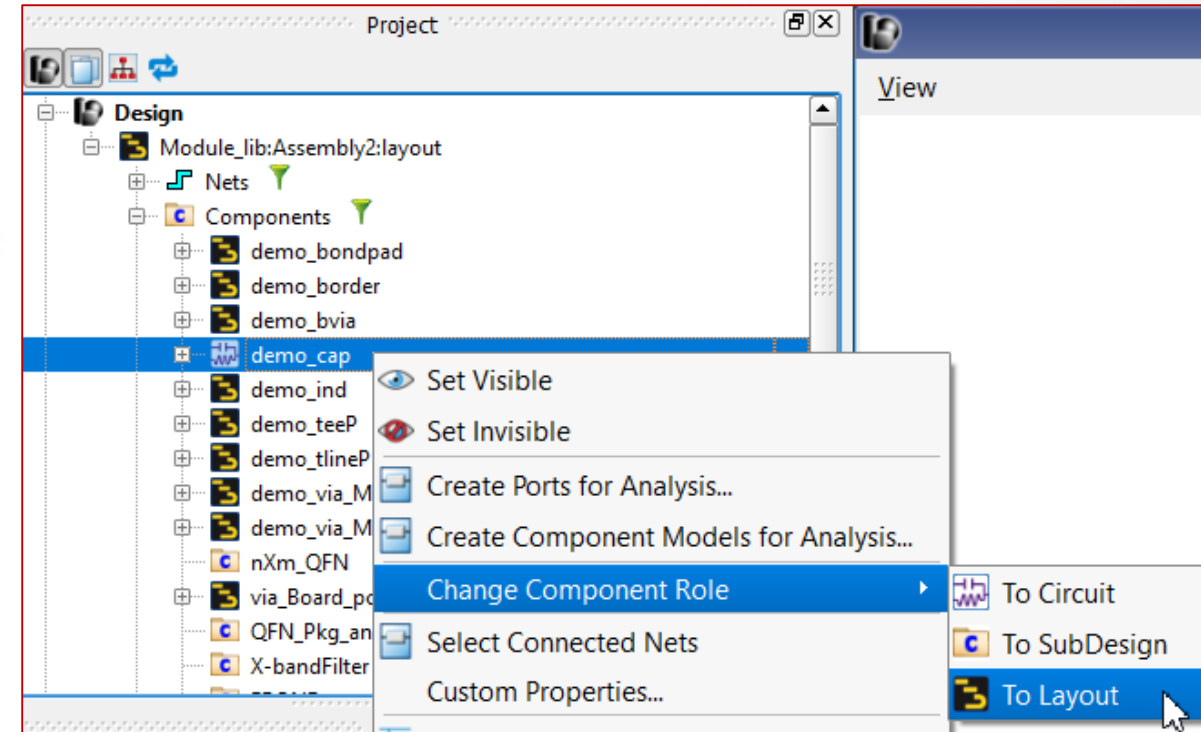
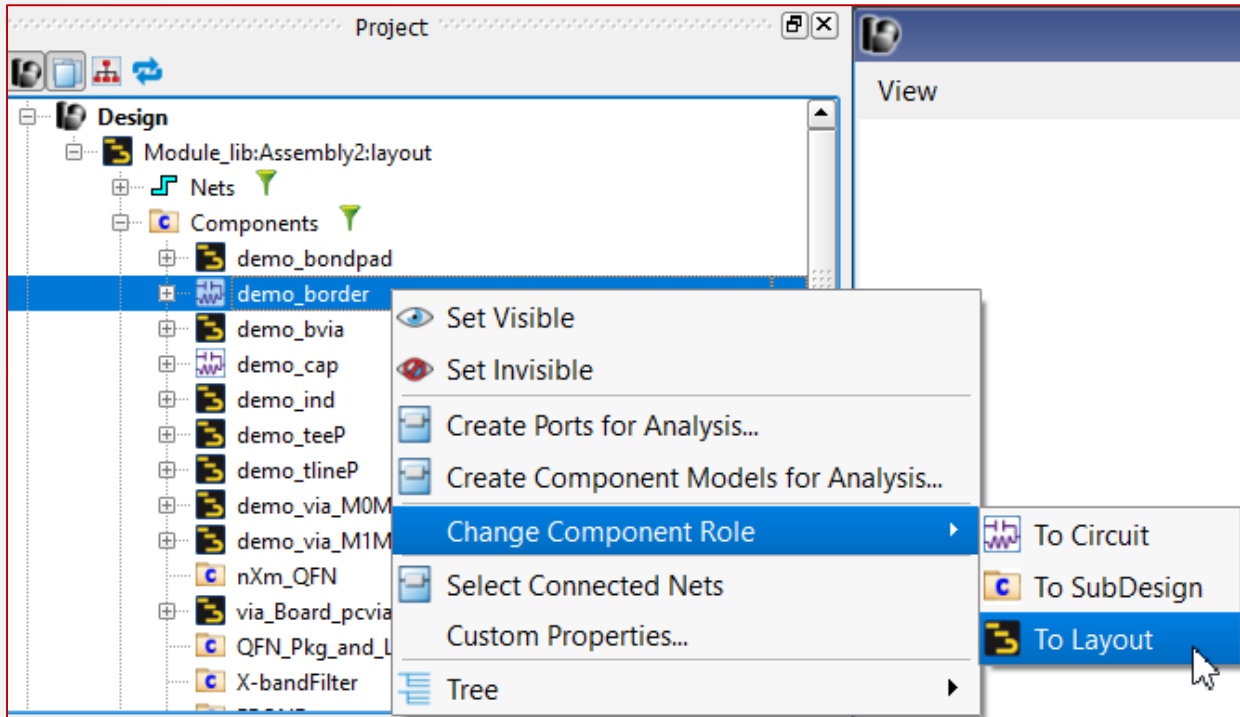
Launch RFPro from Layout window **Tools -> RFPro -> New...**



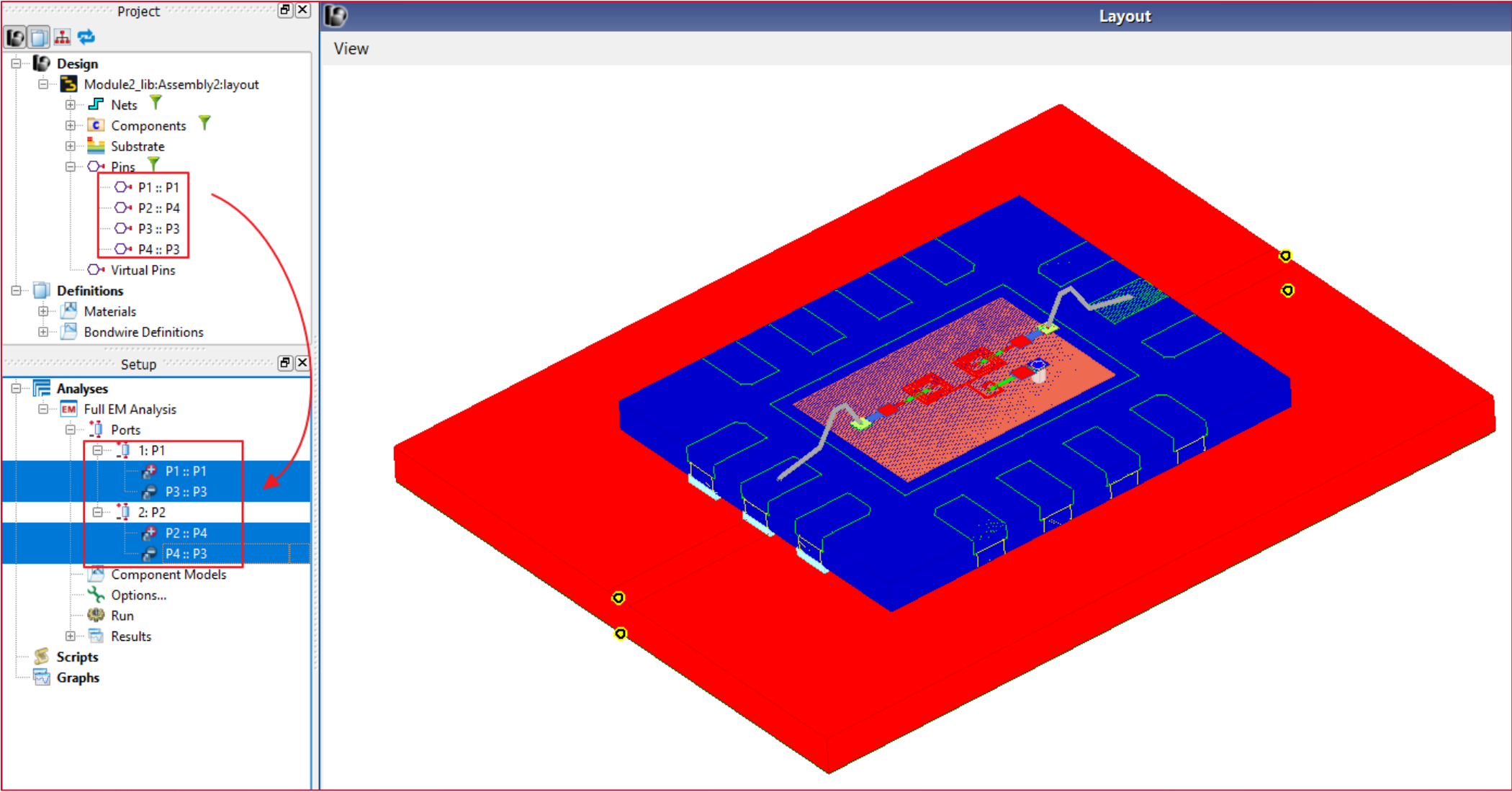


# RFP Pro setup

## Change Component's Role



# RFP Pro Ports Setup



# RFPro Simulation Setup

Double click **Options** , and select Simulator, change to FEM simulator:

The image displays two screenshots of the RFPro Setup dialog box, illustrating the process of selecting the FEM simulator.

**Left Screenshot:** The 'Analyses' tree on the left shows 'Options...' selected. The main dialog box is titled 'RFPro Setup - Setup Full EM Extraction'. The 'Frequency Plans' section shows a table with one entry:

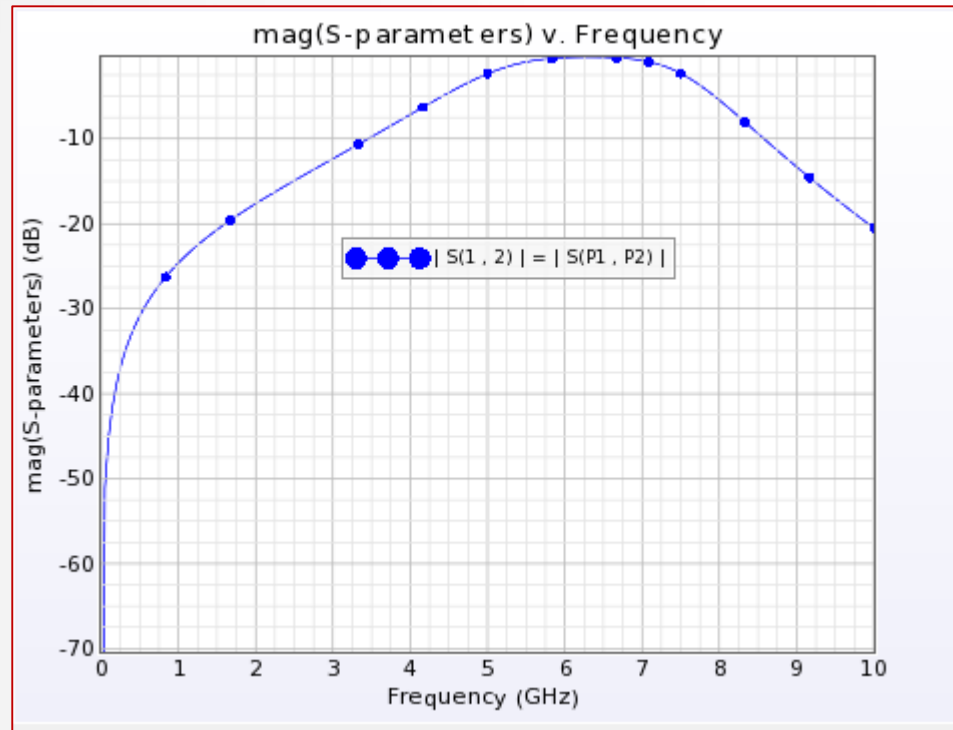
	Type	Start	Stop	Points
<input checked="" type="checkbox"/>	Adaptive	0 Hz	10 GHz	300 (max)

The 'Simulator' section is highlighted with a red box.

**Right Screenshot:** The 'Simulator' dropdown menu is open, showing the following options: FEM, Momentum RF, Momentum Microwave, and FEM. The 'FEM' option is selected.

# RFP Pro Simulation Results

Check result



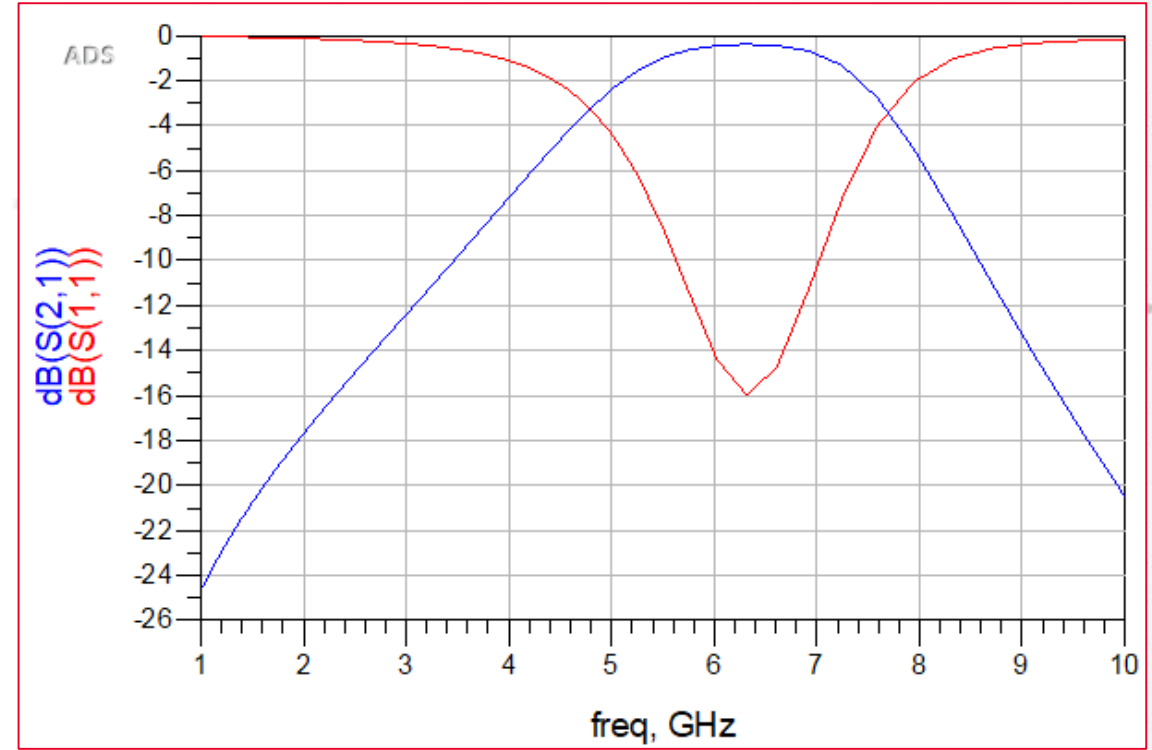
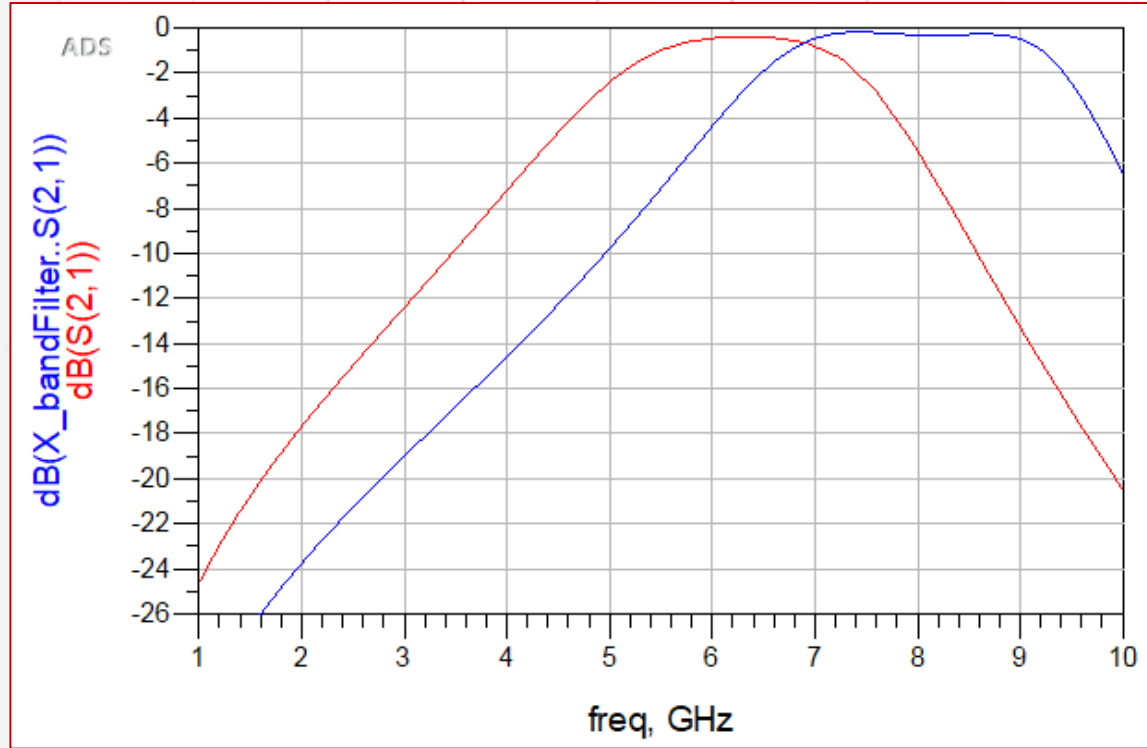
Generate Test bench and simulate in ADS

The screenshot displays the ADS software interface. The 'Analyses' tree on the left shows 'Full EM Analysis' selected, with 'Generate Test Bench...' highlighted. The main workspace shows a circuit diagram with two ports, P1 and P2, and a component labeled 'S-PARAMETERS'. The 'S-PARAMETERS' block is configured with 'Start=1 kHz', 'Stop=10.0 GHz', and 'Dec=50'. The 'NETLIST INCLUDE' block is also visible, with 'OutputPin' selected. The 'Parts' pane on the right shows a list of components, including 'TECH\_LINC', 'DEMO\_CAP', 'DEMO\_IND', 'DEMO\_RES', 'DEMO\_FET\_1', 'DEMO\_FET\_2', 'DEMO\_PAD', 'DEMO\_BVIA', 'DEMO\_FET\_VIA', 'DEMO\_M0-M1', 'DEMO\_M1-M2', and 'DEMO\_M0-M2'.



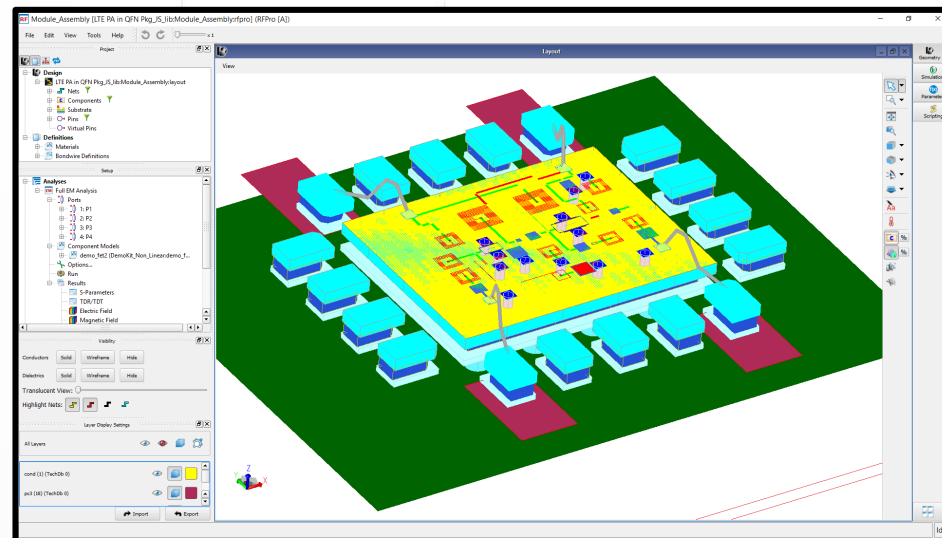
# Smart Mount in ADS 2019\_U1

Compare results with X\_bandFilter

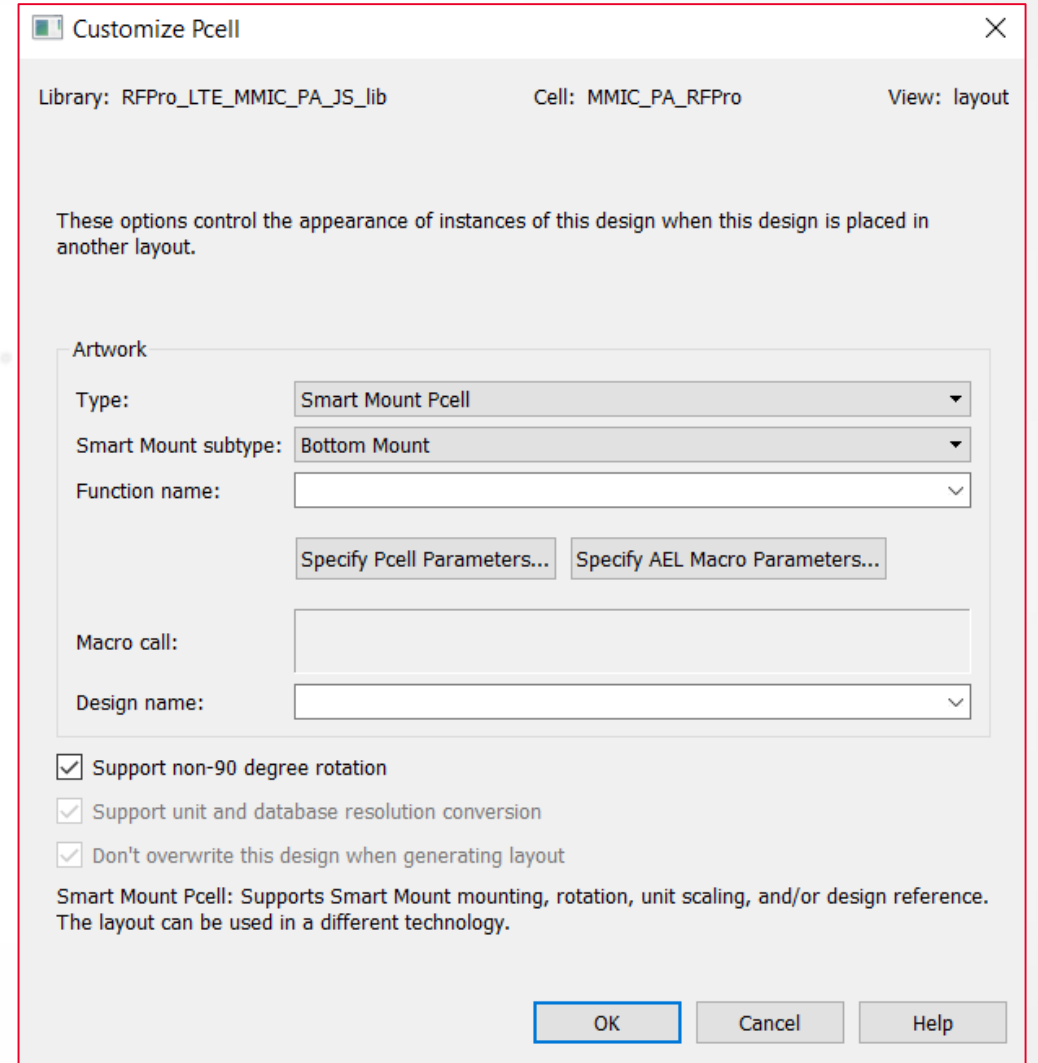
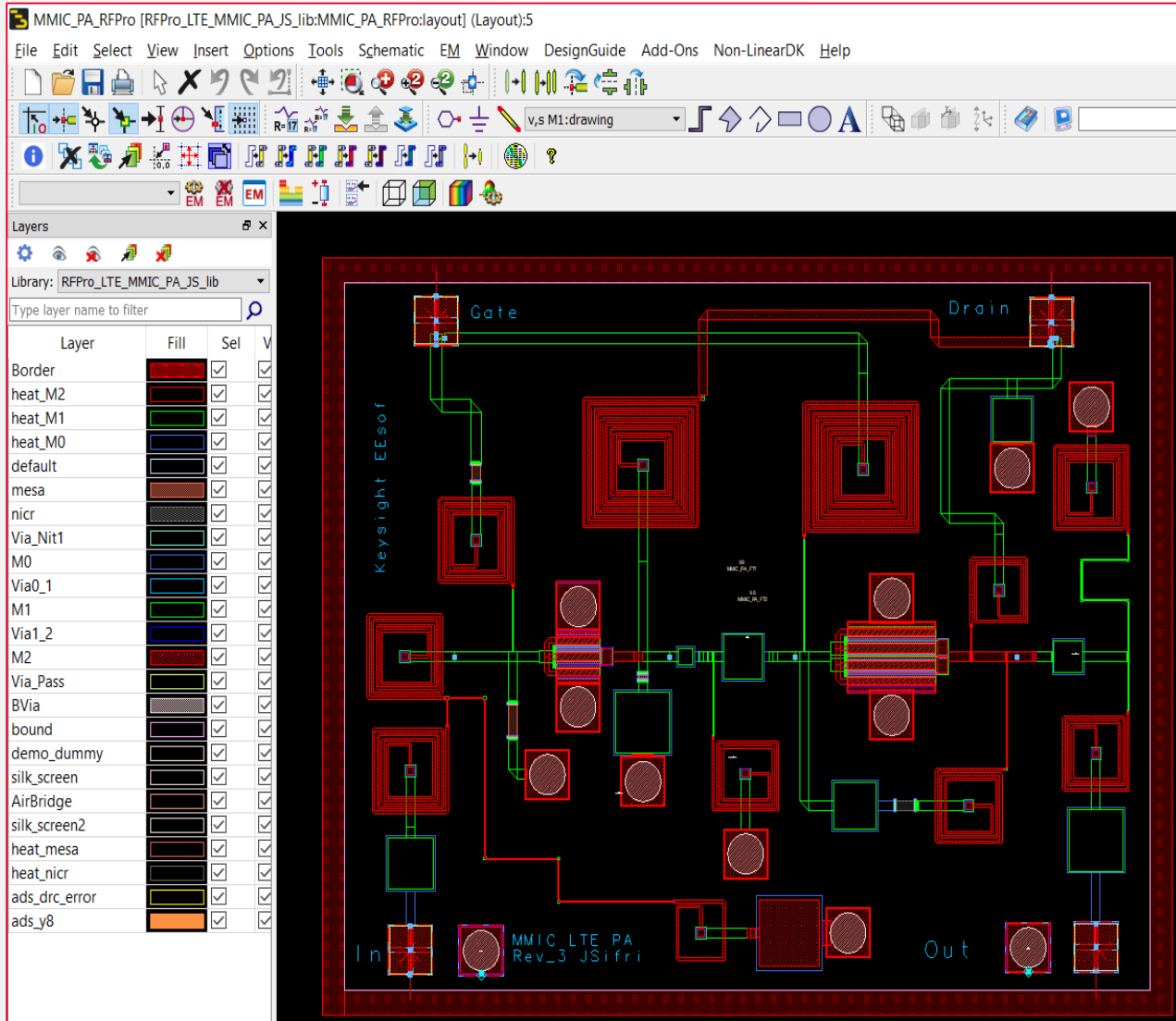


# LTE PA in QFN Package / Laminate

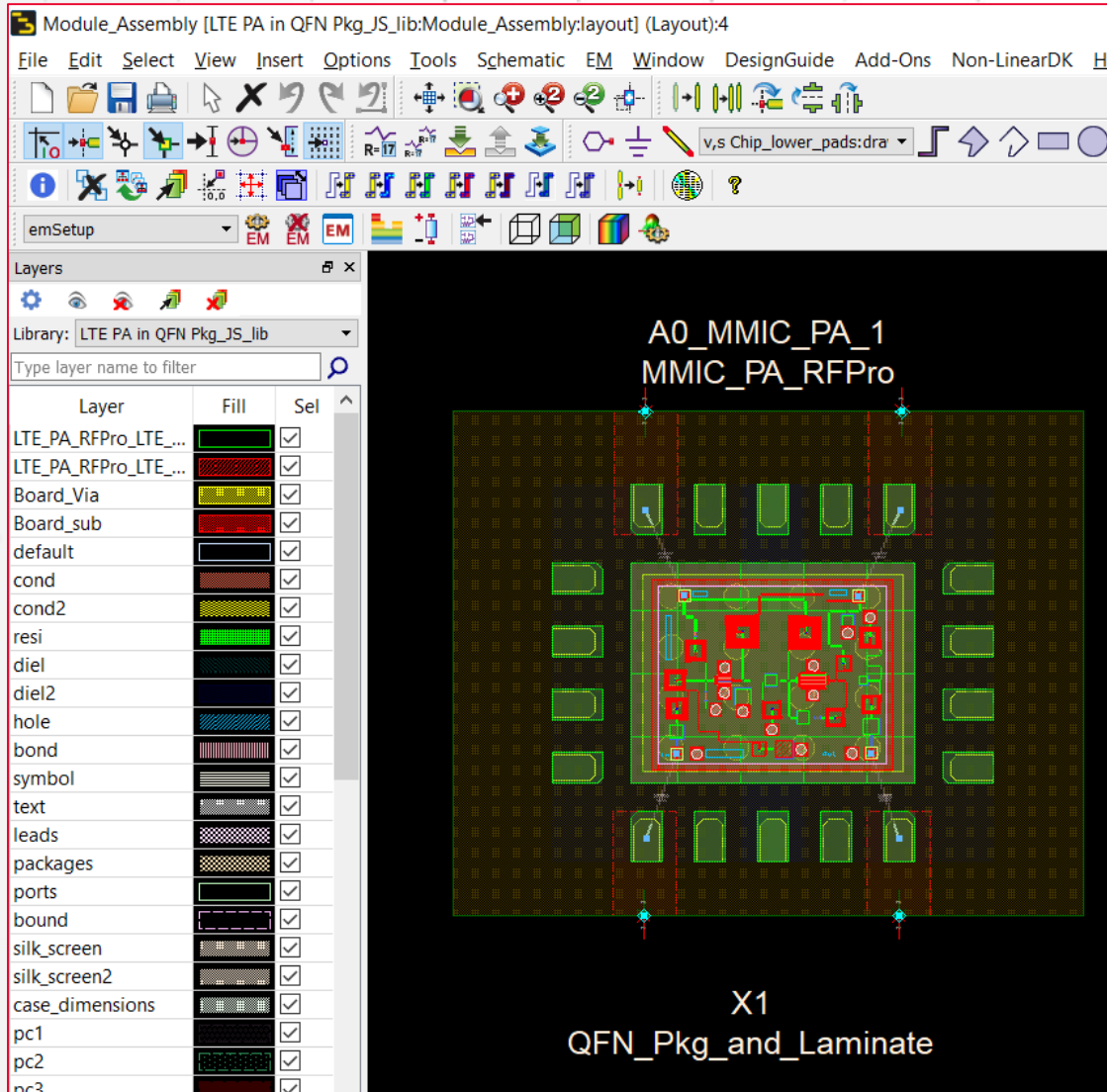
## Using Smart Mount Technology



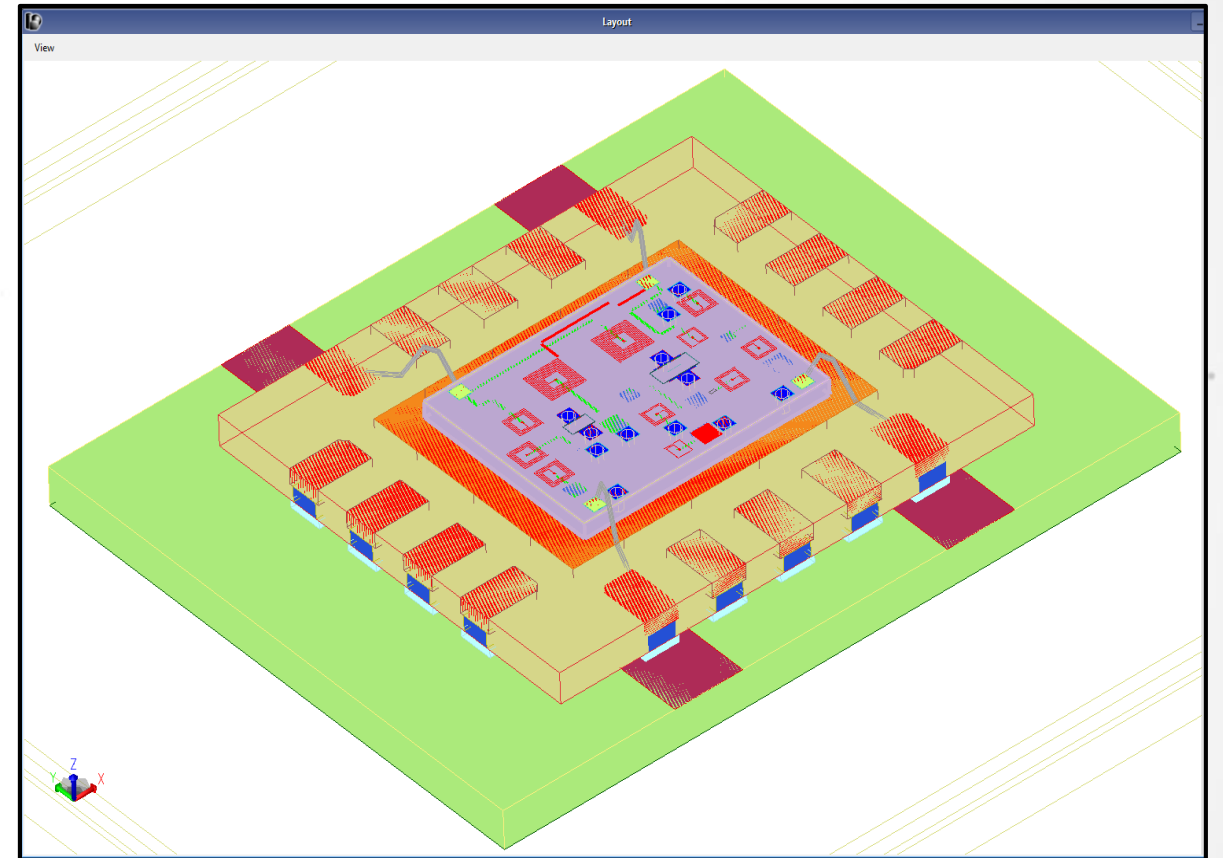
# Smart Mount Technology Setup - Setup IC Pcell attribution



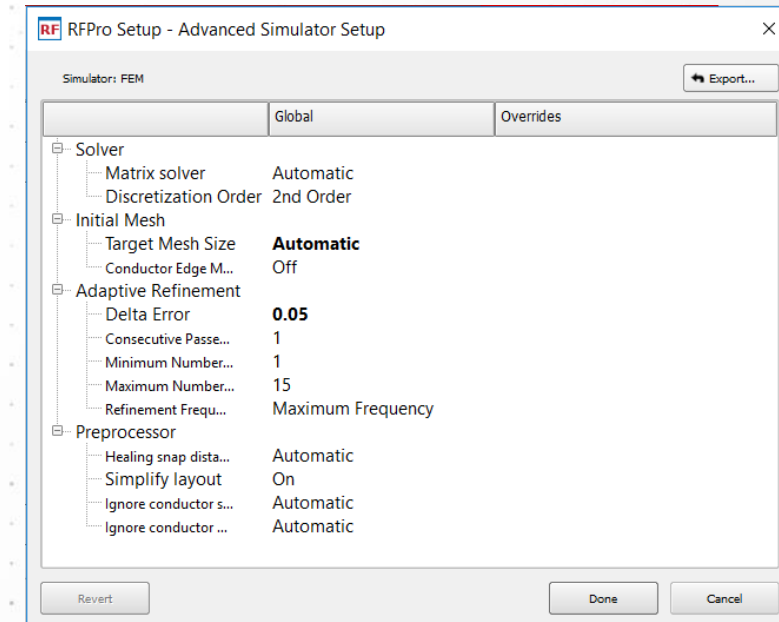
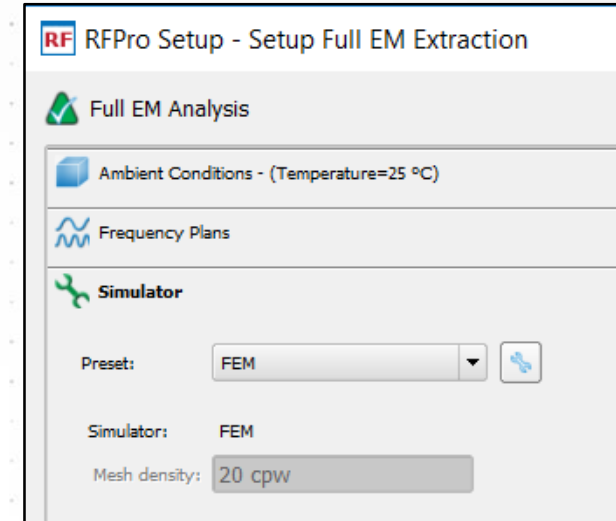
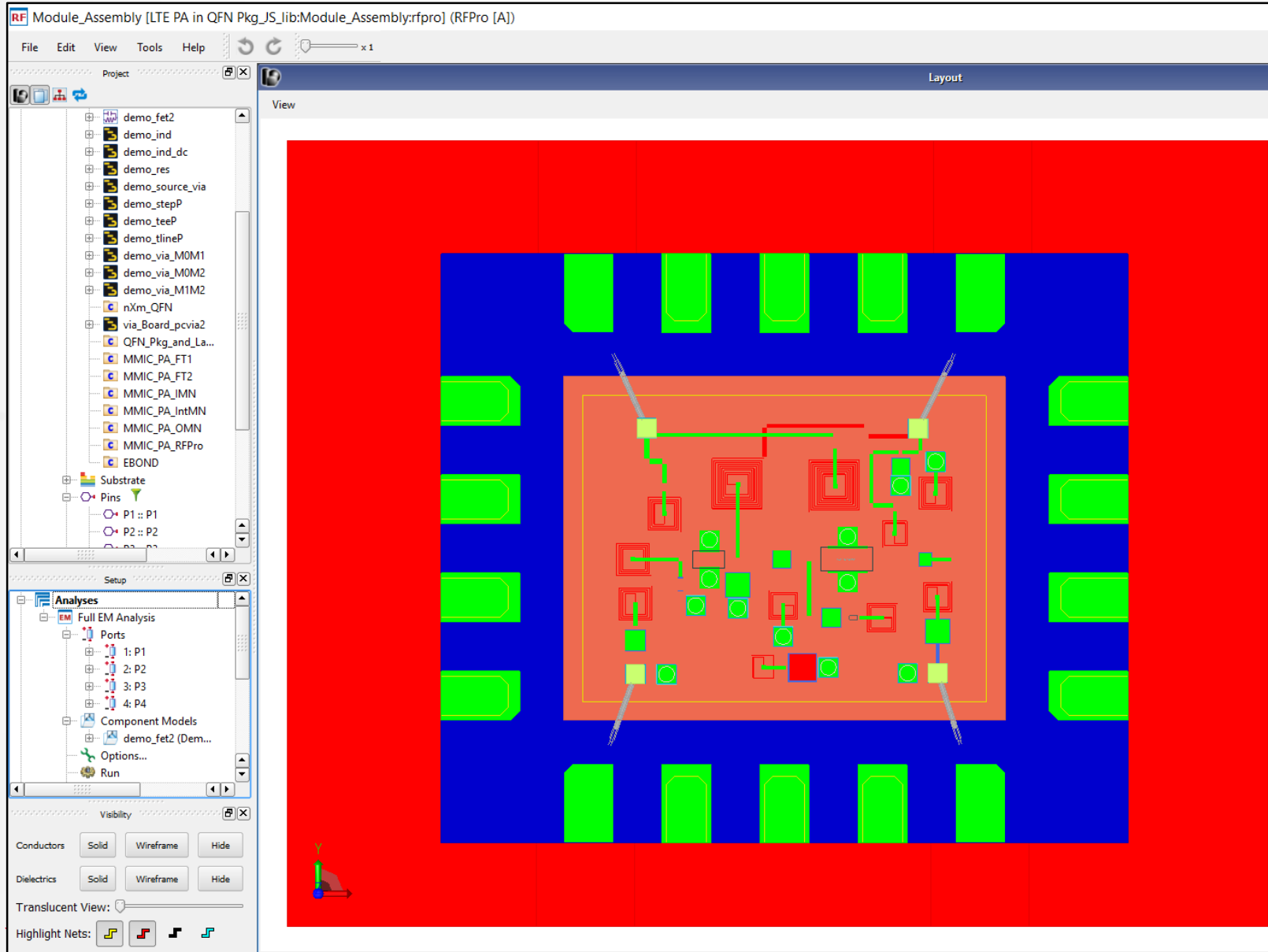
# Building the Module Assembly



Module 3D View

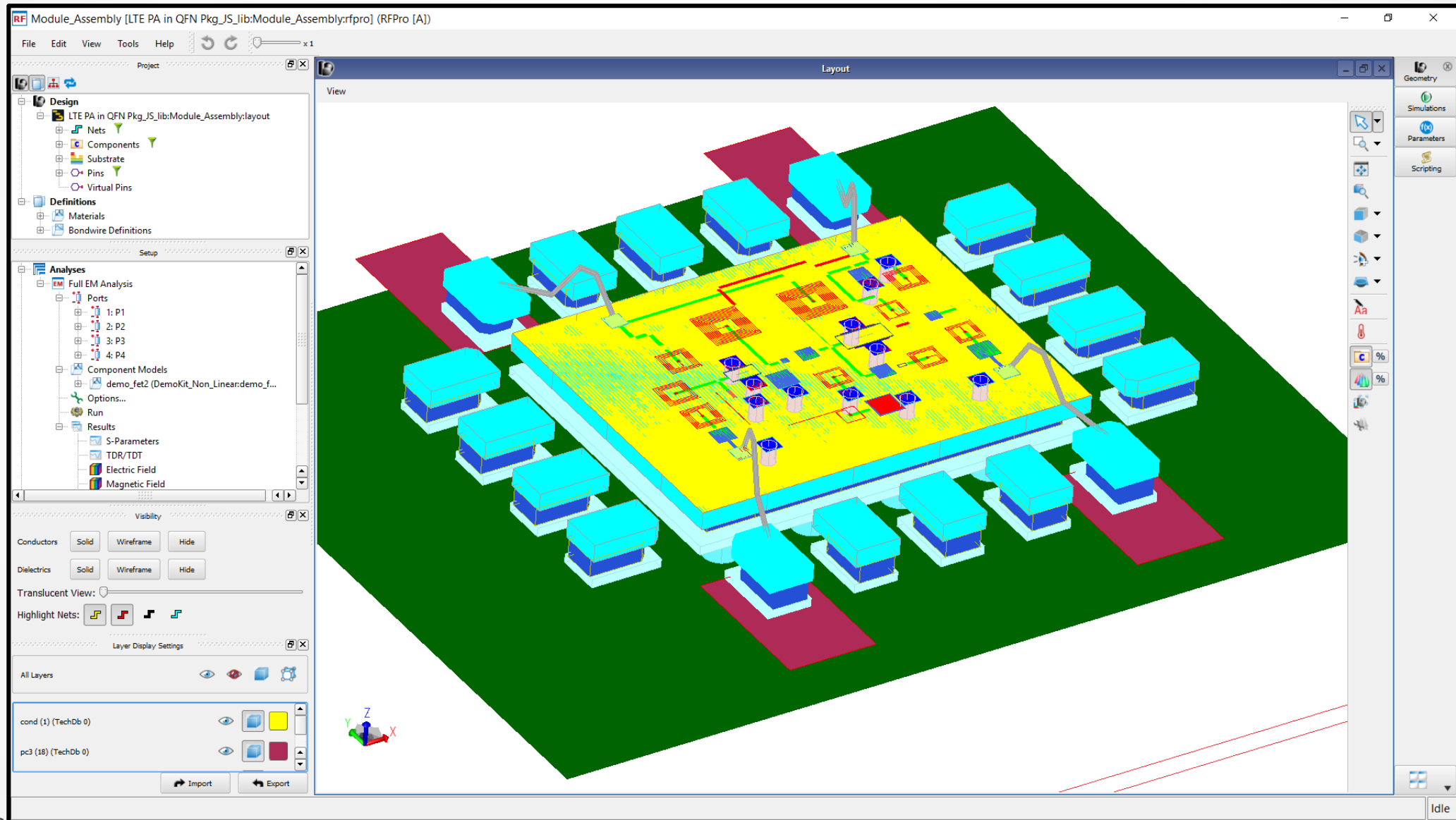


# Module RFPro Simulation Setup





# Module RFP Pro Simulation Setup



# Full EM Analysis Simulation Summary

Module\_Assembly [LTE PA in QFN Pkg\_JS\_lib:Module\_Assembly:rfpro] (RFPro [A])

File Edit View Tools Help

Project

Design

- LTE PA in QFN Pkg\_JS\_lib:Mo...
- Nets
- Components
- Substrate
- Pins
- Virtual Pins

Definitions

- Materials
- Bondwire Definitions

Analyses

- Full EM Analysis
  - Ports
  - Component Models
  - Options...
  - Run
  - Results
    - S-Parameters
    - TDR/TDT
    - Electric Field
    - Magnetic Field
    - Current Density
    - Far Field
    - Generate Test Bench...
    - Generate Sub Circuit...
- Scripts
- Graphs

Setup

Visibility

Conductors: Solid Wireframe Hide

Dielectrics: Solid Wireframe Hide

Translucent View: [Slider]

Highlight Nets: [Icons]

Simulations

Name	Date Created	Engine	Status
Full EM Analysis	Tue Feb 12 14:37:25 2019	FEM	Completed

Summary Log

Design : C:\Users\jsifri\ADS2019\_U1\RFPro\Module\LTE PA in QFN Pkg\_JS\_lib\simulation\LTE PA in QFN Pkg\_JS\_lib\Module\_assembly\rfpro\000001\emds\_dsn\design  
 FEM Mesher: 2.0.1  
 Automatic initial target mesh size: 3.33e+01 mm

INITIAL MESH

nbPoints : 79257  
 nbTetrahedra : 394257

REFINING

level	frequency	nbTetr	Elapsed time	CPU time	nbUnknowns	mem(GB)	Elapsed time	CPU time	Delta(S)	solver	nbIter	normRes	
1	3.000 GHz	394257	00:07:50.7	00:07:24.0	2357194	12.199	00:07:57.9	00:26:34.2	/	Im64	50	1.740e-06	
2	3.000 GHz	496644	00:00:52.3	00:00:51.4	2623958	19.703	00:09:22.0	00:30:42.2	0.1477	[>-0.0500]	Im64	45	4.590e-06
3	3.000 GHz	488440	00:00:51.7	00:00:50.9	2948222	15.865	00:09:17.0	00:30:58.1	0.0790	[>-0.0500]	Im64	45	3.920e-06
4	3.000 GHz	540465	00:00:57.0	00:00:56.1	3275268	17.746	00:10:38.2	00:35:30.1	0.0696	[>-0.0500]	Im64	45	6.190e-06
5	3.000 GHz	600160	00:01:06.9	00:01:06.0	3649468	20.002	00:13:06.9	00:43:43.0	0.0518	[>-0.0500]	Im64	50	4.840e-06
6	3.000 GHz	660946	00:01:07.9	00:01:06.9	4030236	22.702	00:13:43.3	00:45:39.5	0.0238	[>-0.0500]	Im64	45	7.200e-06

COMPUTING SOLUTION

sample	frequency	nbUnknowns	mem(GB)	Elapsed time	CPU time	solver	nbIter	normRes
1	0.000 Hz	3649468	15.477	00:02:16.4	00:06:29.4	LF		
2	1.000 GHz	3649468	20.305	00:09:30.5	00:32:09.8	Im64	35	3.000e-06
3	2.000 GHz	3649468	20.392	00:11:22.0	00:39:04.2	Im64	45	5.160e-06
4	3.000 GHz	3649468	20.392	00:13:06.9	00:43:43.0	reuse		
5	2.500 GHz	3649468	20.393	00:11:44.3	00:40:03.3	Im64	45	3.090e-06
6	1.500 GHz	3649468	20.393	00:09:50.2	00:33:22.5	Im64	35	7.210e-06
7	800.001 MHz	3649468	20.393	00:08:11.6	00:27:42.2	Im64	30	4.330e-06
8	250.001 MHz	3649468	20.393	00:06:55.9	00:23:39.9	Im64	25	5.370e-06
9	1.750 GHz	3649468	20.393	00:11:10.1	00:35:29.0	Im64	45	2.970e-06
10	1.875 GHz	3649468	20.393	00:10:16.6	00:35:02.9	Im64	40	7.260e-06
11	750.001 MHz	3649468	20.393	00:09:06.4	00:31:12.3	Im64	35	7.850e-06
12	125.001 MHz	3649468	20.393	00:08:01.7	00:27:27.4	Im64	30	2.240e-06
13	62.501 MHz	3649468	20.393	00:06:58.1	00:23:50.8	Im64	25	1.350e-06
14	875.001 MHz	3649468	20.393	00:09:24.2	00:31:47.9	Im64	35	3.150e-06
15	1.250 GHz	3649468	20.393	00:10:17.2	00:35:17.9	Im64	40	1.530e-06
16	1.375 GHz	3649468	20.393	00:09:59.7	00:34:09.6	Im64	35	6.450e-06
17	1.438 GHz	3649468	20.393	00:10:12.0	00:34:10.0	Im64	35	7.310e-06

FARFIELDS

Computing far-field pattern at 0 Hz  
 Computing far-field pattern at 3 GHz  
 !! WARNING : Farfields calculations require the field solutions to be available.  
 No fields are stored for 16 simulated frequencies.  
 To obtain farfields for these frequencies, change the option accordingly,  
 enable the reuse option and resimulate.

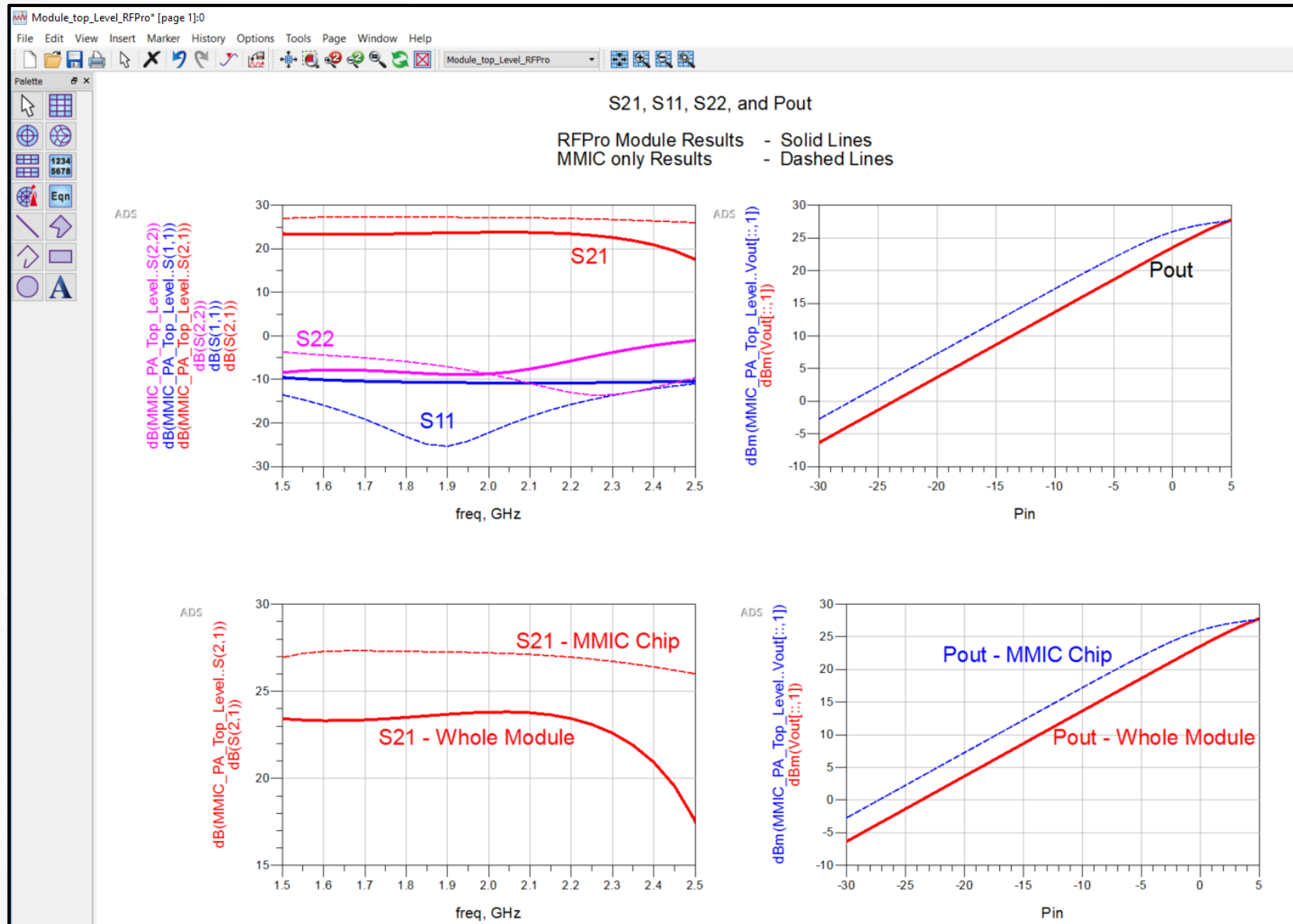
CPU time: 00:00:38.7 Elapsed time: 00:00:34.0 Memory: 1.938 Gbyte  
 Total Elapsed Time = 3:43:23

Simulation results can be reusedSimulation Time: 3:44:01.045000  
 Simulation Finished

Geometry  
 Simulations  
 Parameters  
 Scripting

Idle

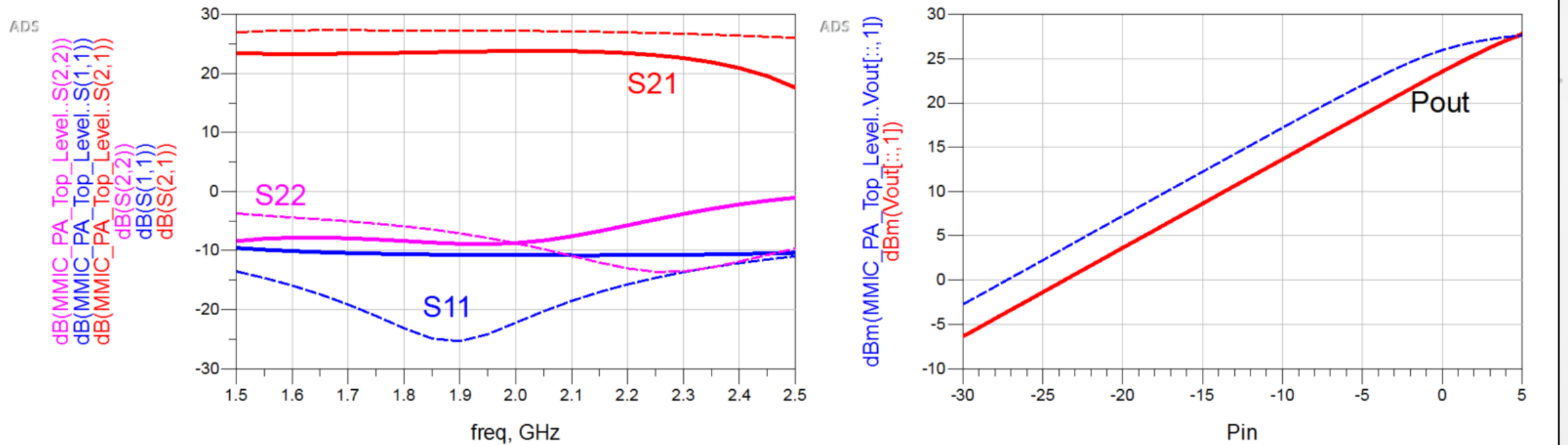
# Simulation Results



# Simulation Results

S21, S11, S22, and Pout

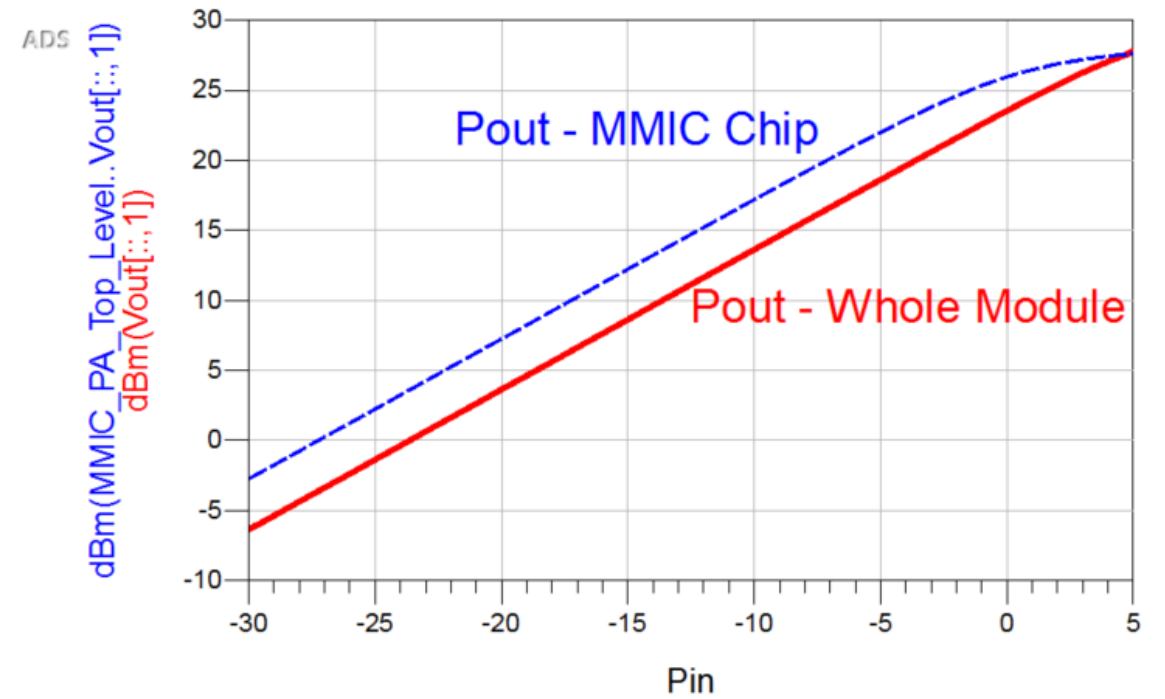
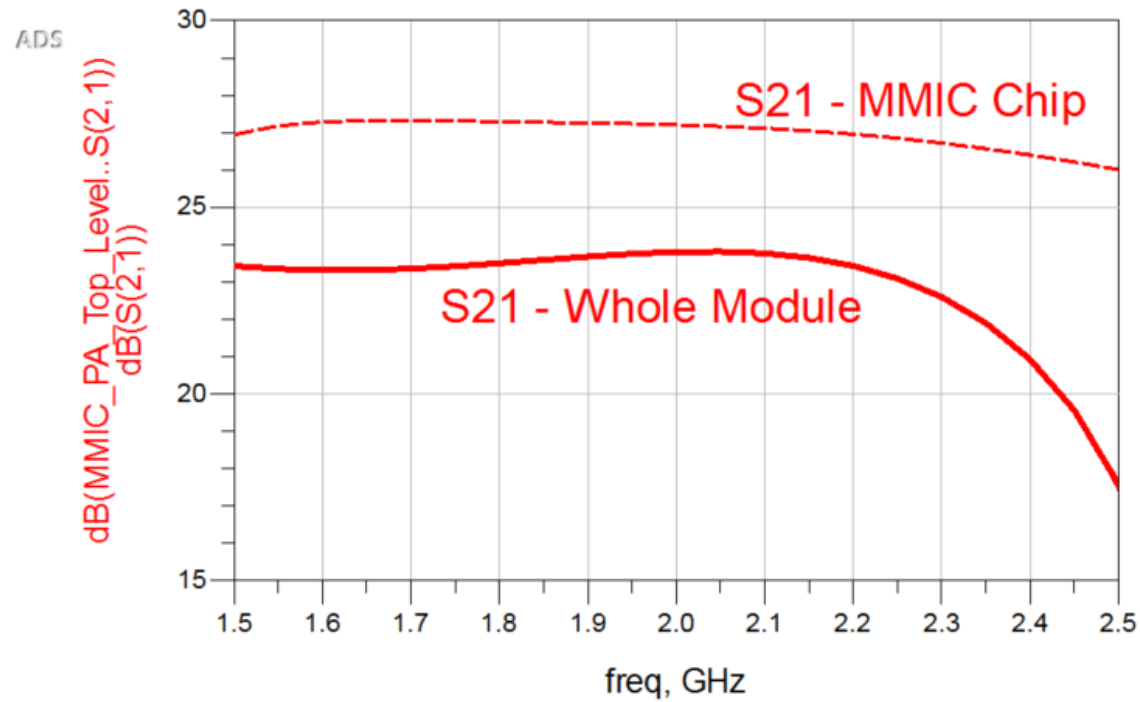
RFPro Module Results - Solid Lines  
MMIC only Results - Dashed Lines



# Simulation Results

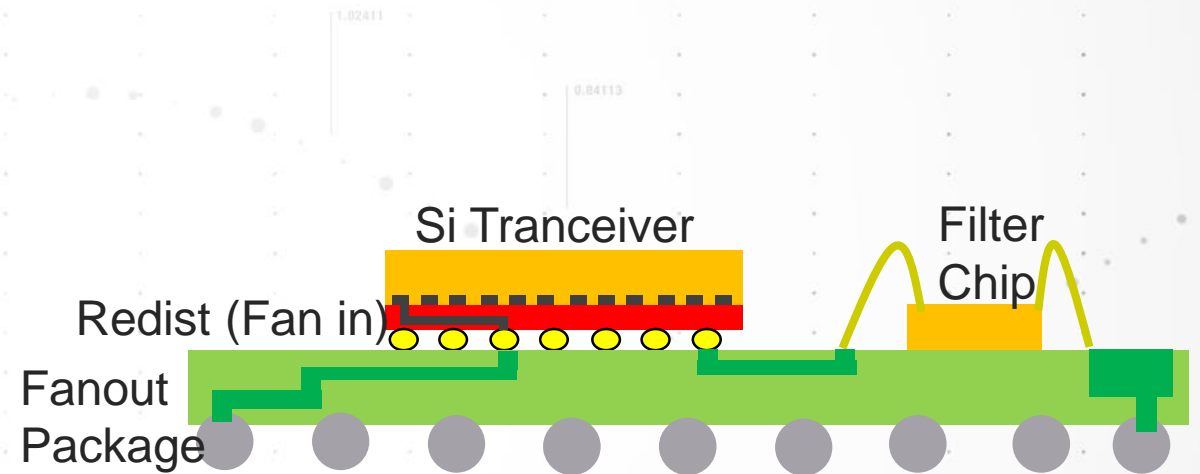
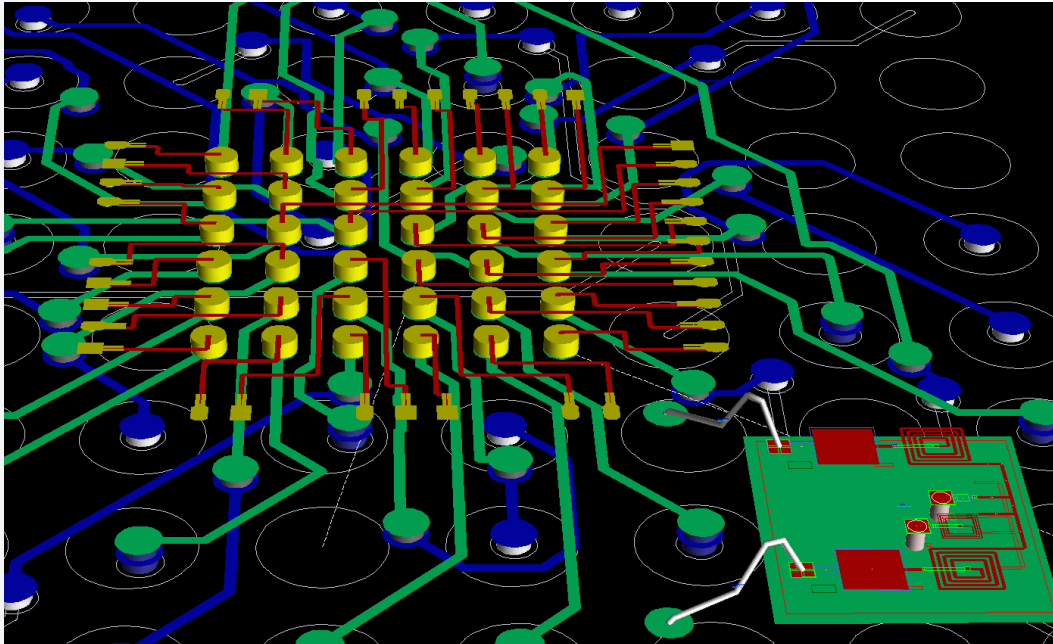
S21 and Pout

RFPPro Module Results - Solid Lines  
MMIC only Results - Dashed Lines



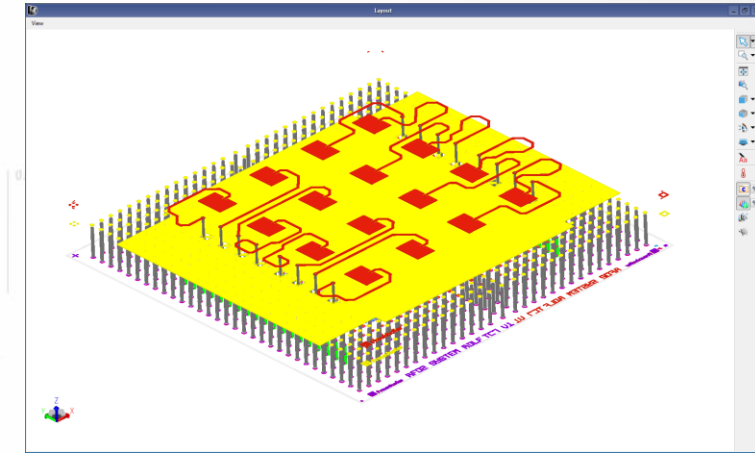
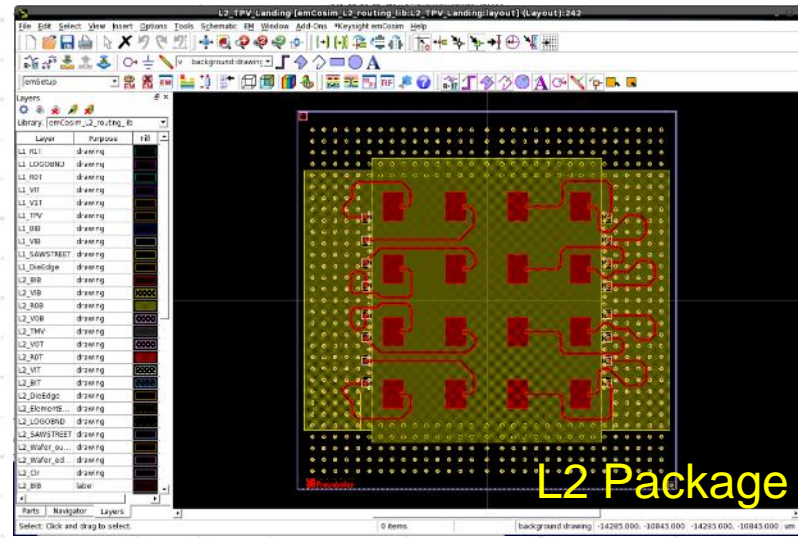
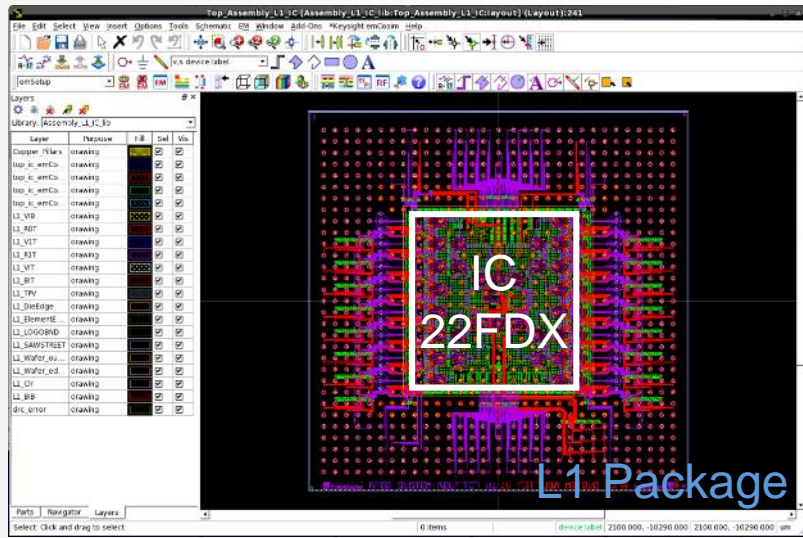


# Connecting Different ICs In A FCBGA



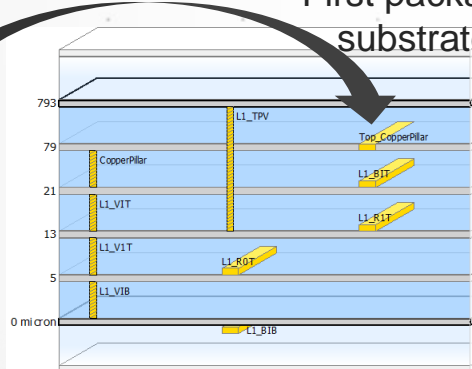
# Application To a mmWave Example

Presented at EuMW 2018

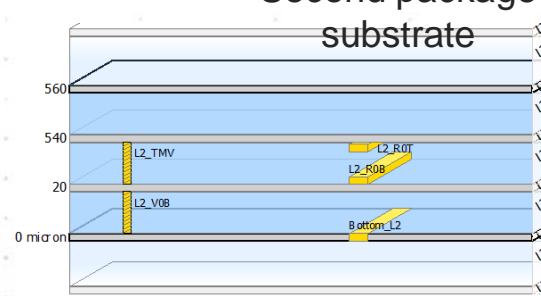


22FDX substrate

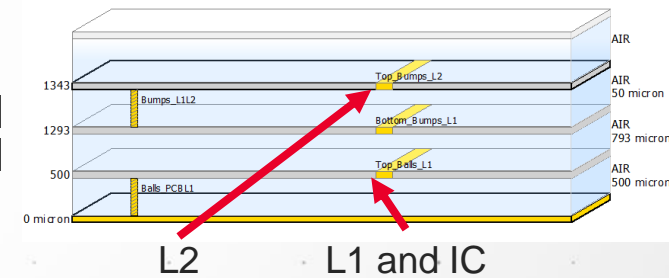
First package substrate



Second package substrate



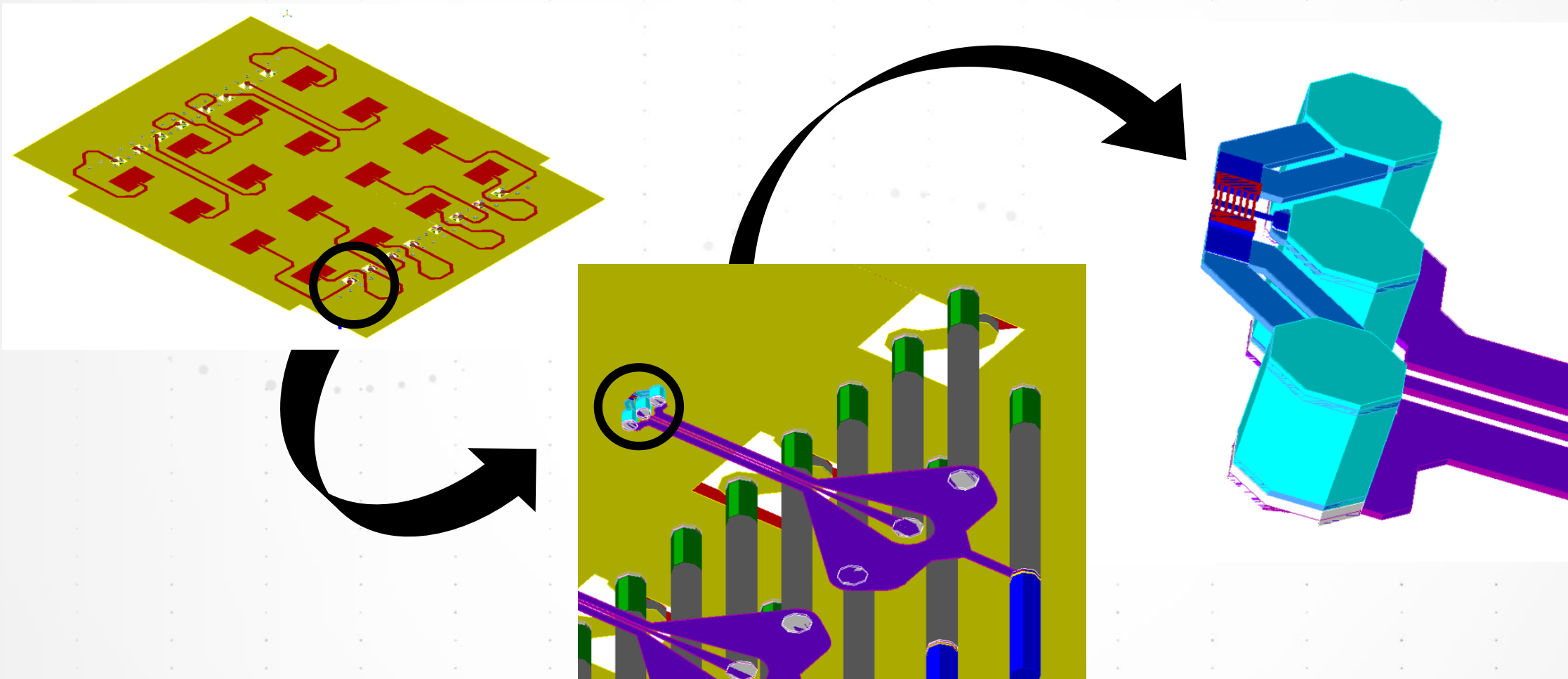
Overall substrate



# Application To a mmWave Example

MMW PATH FROM IC TO PATCH ANTENNA

Presented at EuMW 2018

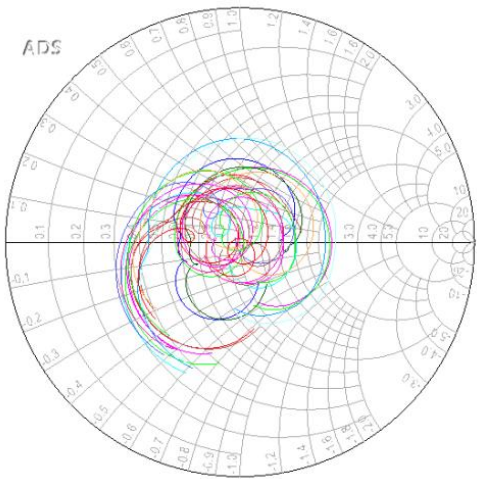
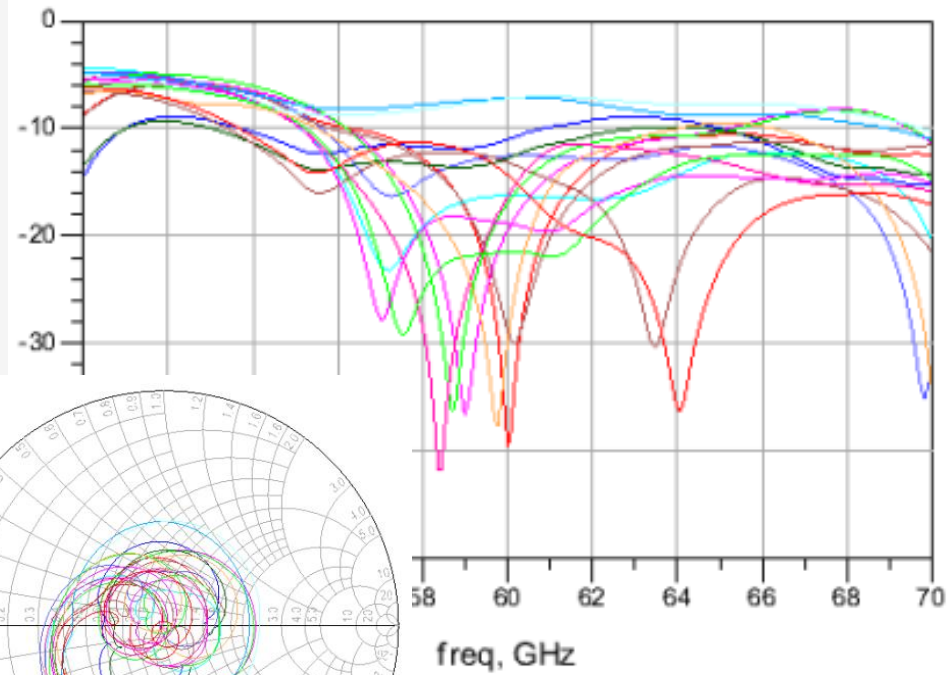


# Application To a mmWave Example

## FEED-CIRCUIT-INTEGRATED PATCH ARRAY ANTENNA

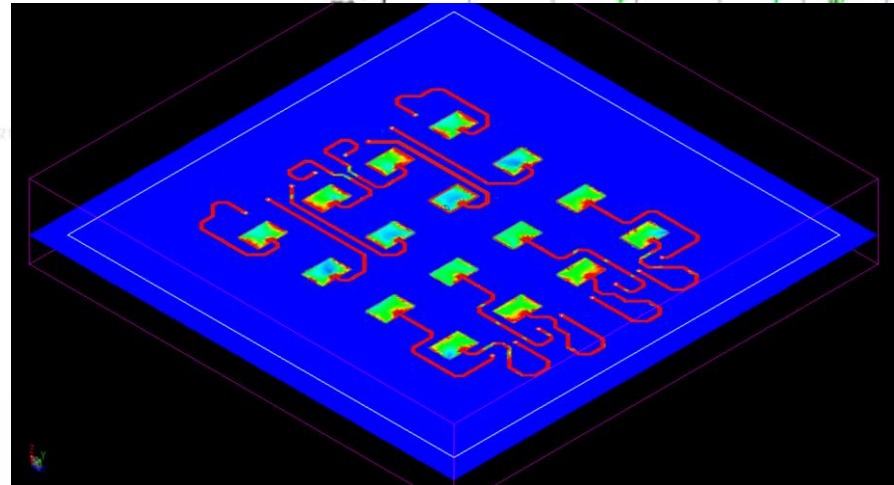
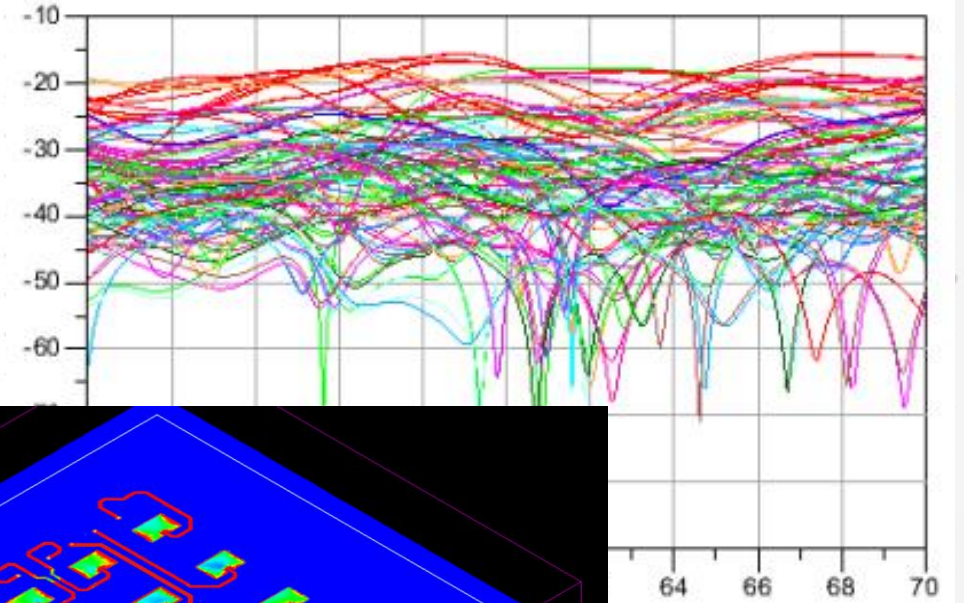
Presented at EuMW 2018

Return losses at antennas input



freq (50.00GHz to 70.00GHz)

Coupling between antennas



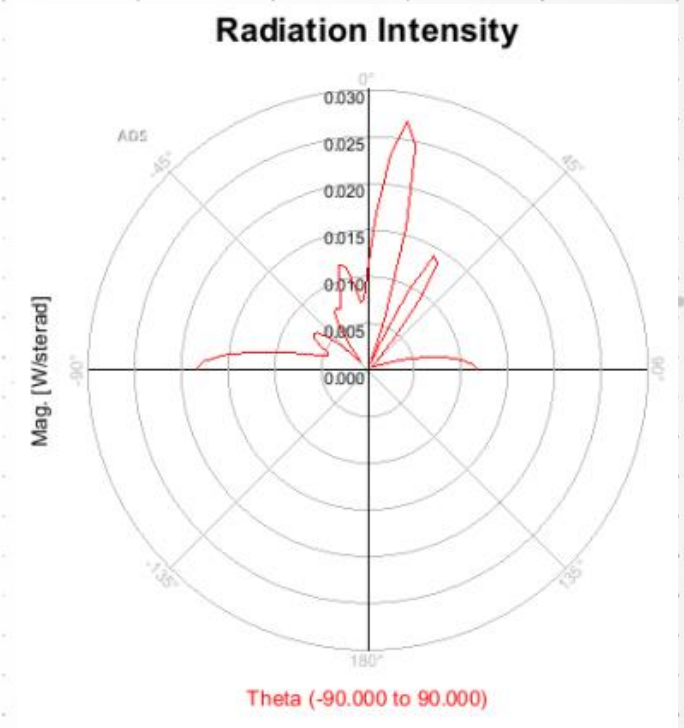
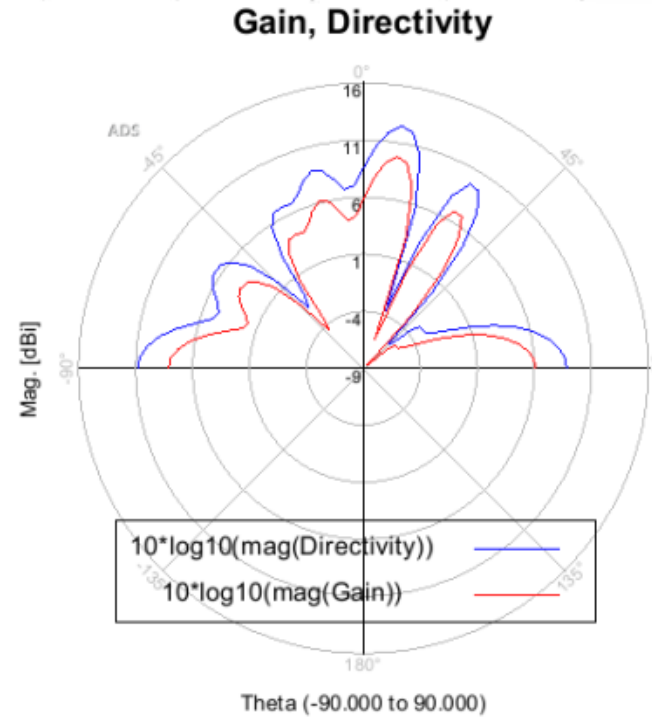
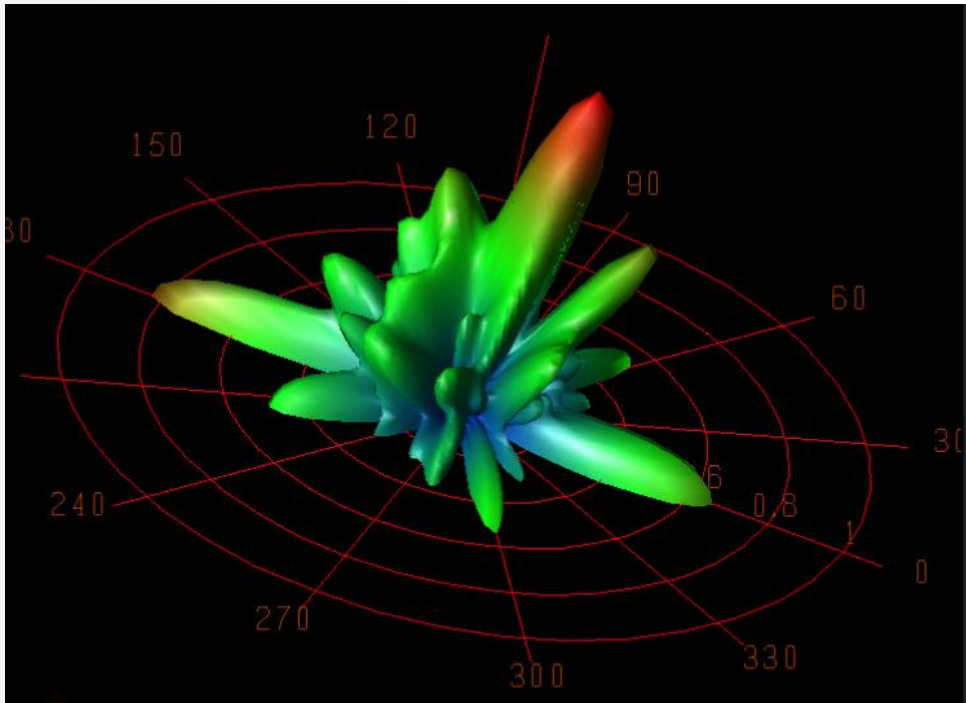


# Application To a mmWave Example

## RADIATION PATTERN OF 4x4 PATCH ANTENNA ARRAY

Presented at EuMW 2018

0° phase at all inputs

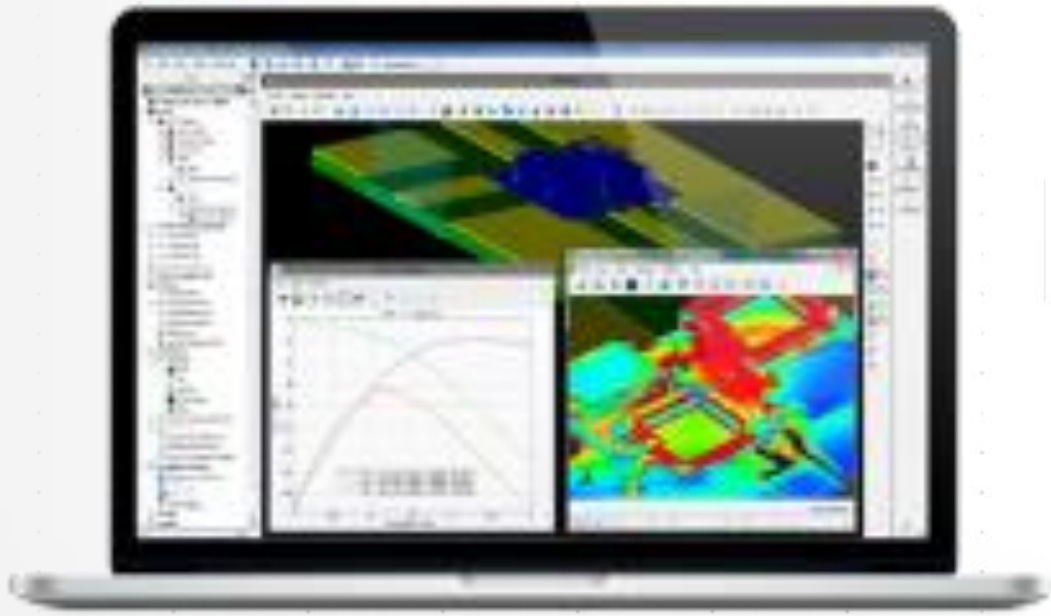


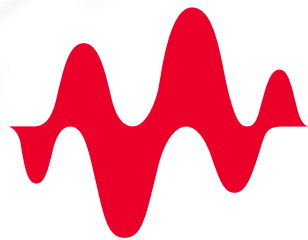
Gain : 9.7 dBi  
 Directivity : 12.4 dBi  
 Radiation Efficiency : 54%



# Summary

- PathWave ADS allows to read databases coming from different tools
- The focus is made to swiftly assemble all the pieces
- The EM tools have been simplified to enable circuit, antenna and package designers to perform simulations seamlessly





**KEYSIGHT**  
TECHNOLOGIES

4.50221