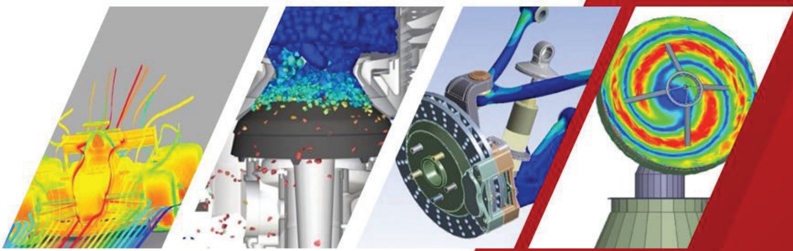
www.esss.com.br

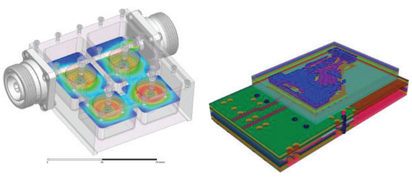


Designing a Full IEEE 802.11 Communication System Using ANSYS HFSS

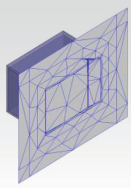
SIMULATING THE FUTURE

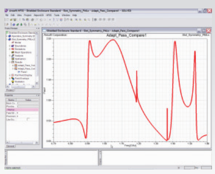
Introducing HFSS

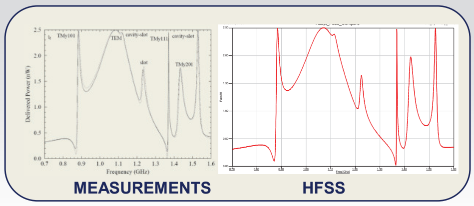
Networking



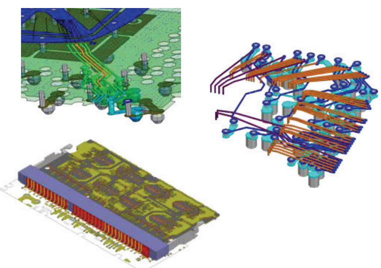
HFSS is the industry standard for 3D full wave electromagnetics simulation



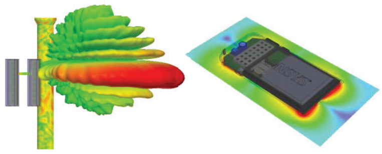




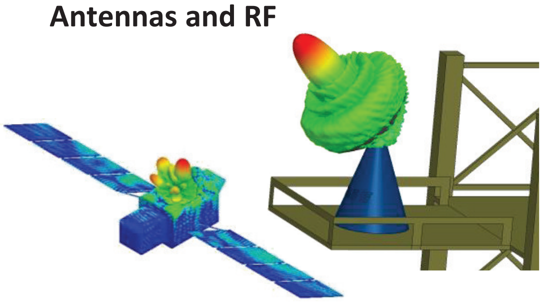
Semiconductor



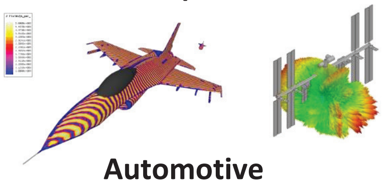
Wireless



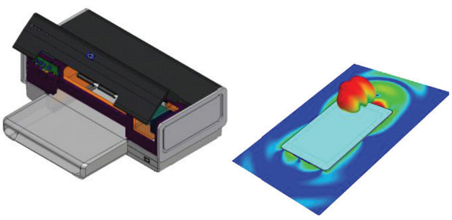
Antennas and RF



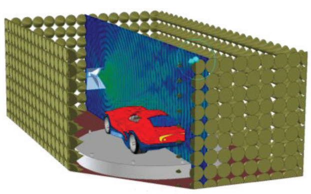
Aerospace / Defense



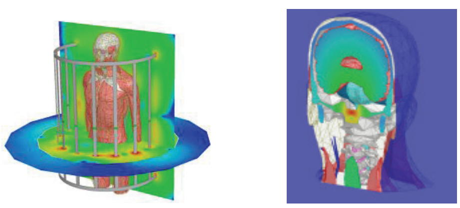
Computing Devices



Automotive

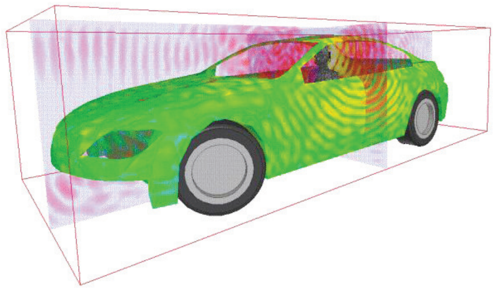


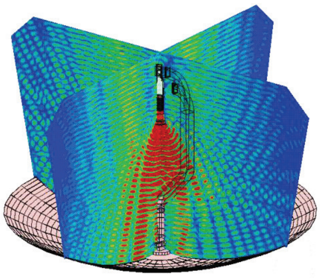
Bio-Medical

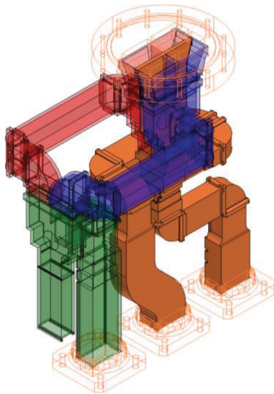


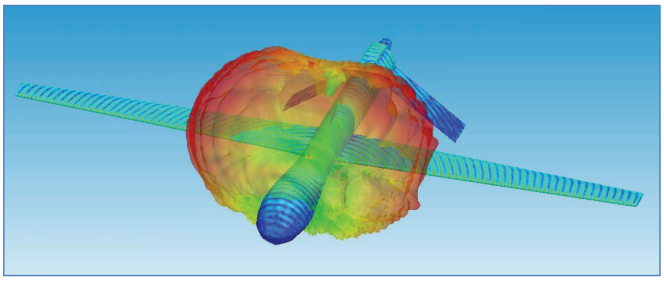
ANSYS HFSS: High Frequency Structure Simulator

- **Full-wave 3D electromagnetic field solver**
  - Computes electromagnetic behavior of high-frequency and high-speed components and systems
  - Extracts S-, Y-, and Z-parameters
  - Provides 3D electromagnetic fields
- **Industry leading EM simulation tool**
  - Simulation driven product development
  - Shorten design cycle
  - First-pass design success

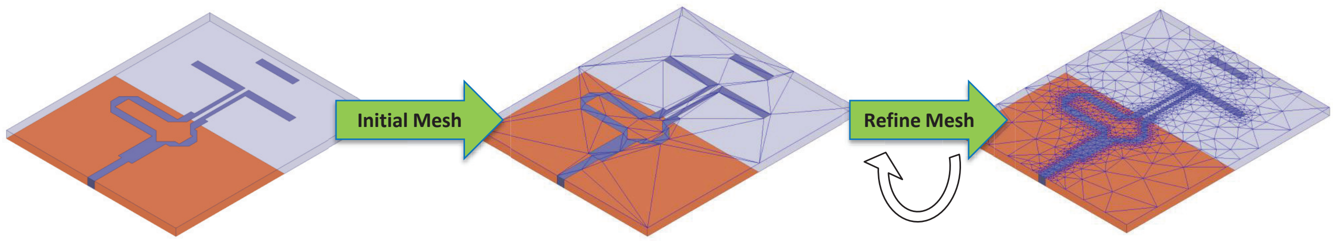








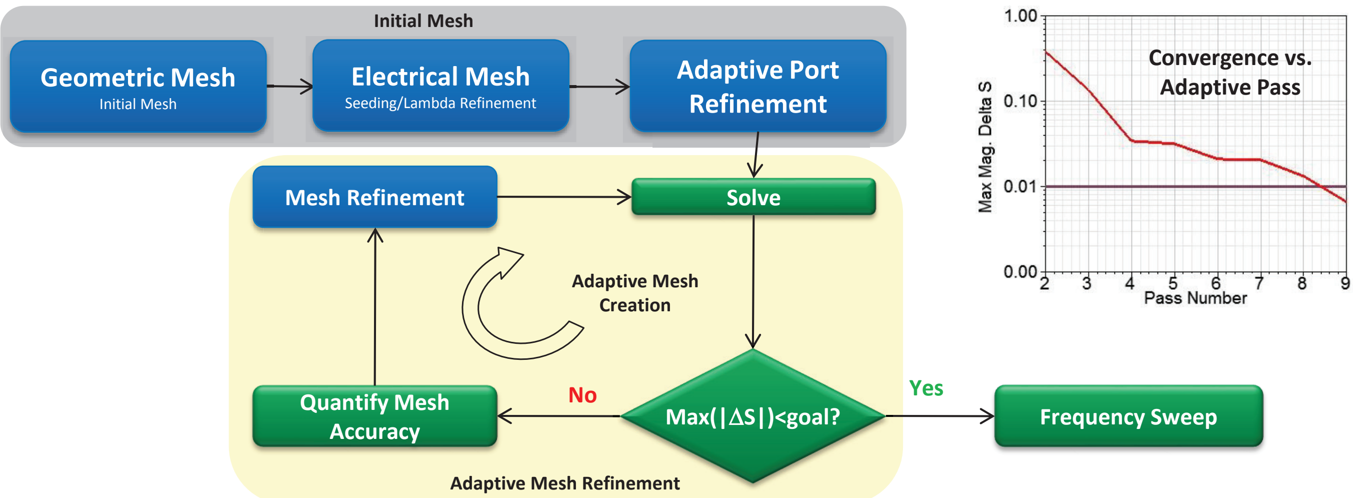
HFSS: Automated solution process



Geometry

Initial Mesh

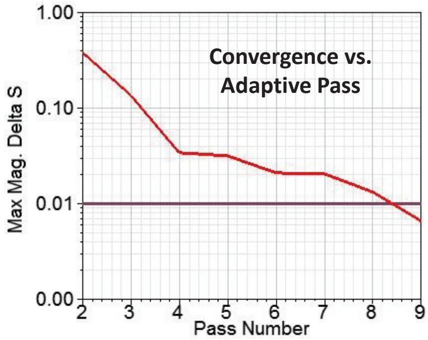
Converged Mesh



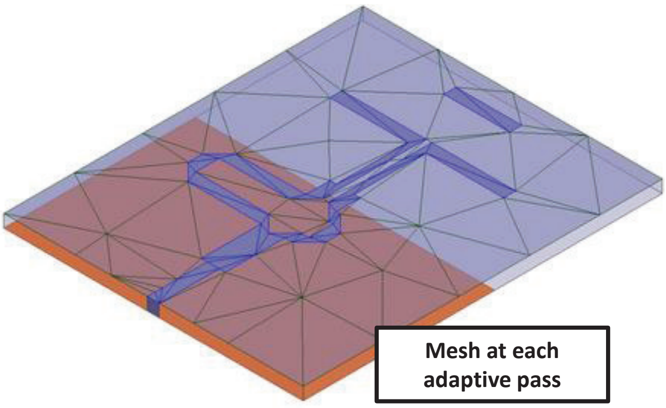
Example: Adaptive Meshing

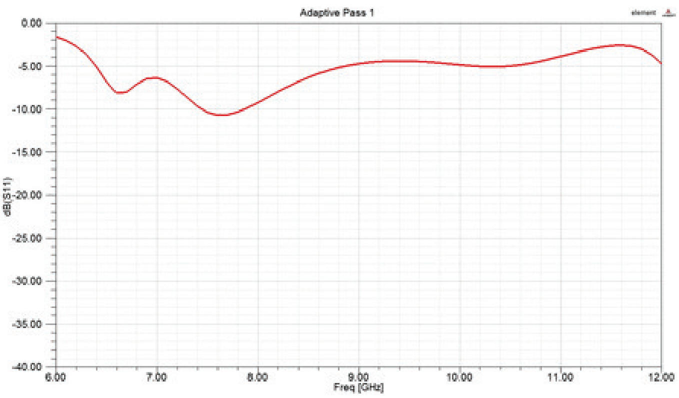
ESSS

- Automatic Adaptive Meshing
  - Provides an Automatic, Accurate and Efficient solution
  - Removes requirement for manual meshing expertise



- Meshing Algorithm
  - Meshing algorithm adaptively refines mesh throughout geometry
  - Iteratively adds mesh elements in areas where a finer mesh is needed to accurately represent field behavior
    - Resulting in an accurate and efficient mesh

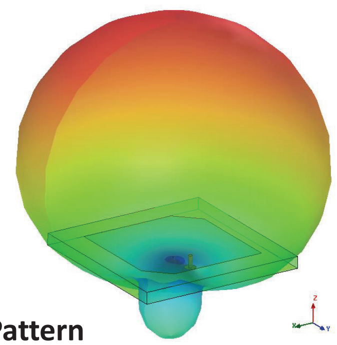




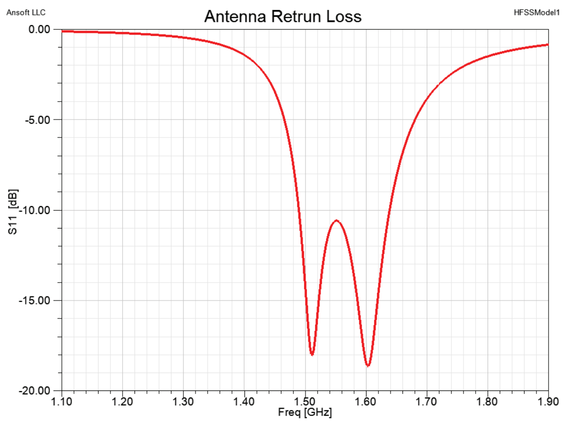
Insights Provided By Simulation

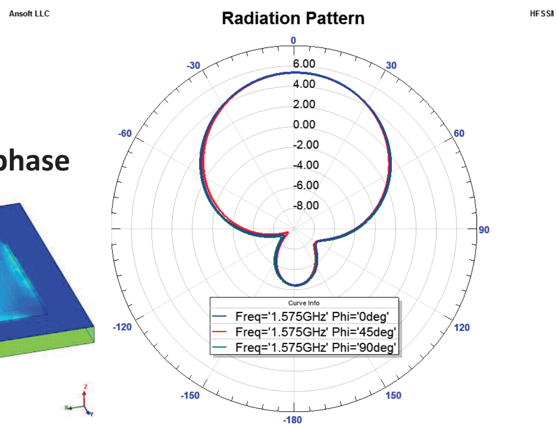
ESSS

- **Basic Performance Characterization**
  - Return Loss
  - Gain
  - Polarization
  - Efficiency

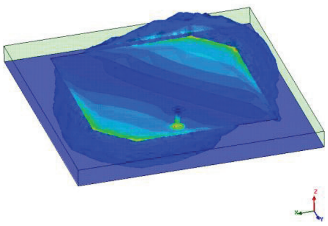


Radiation Pattern

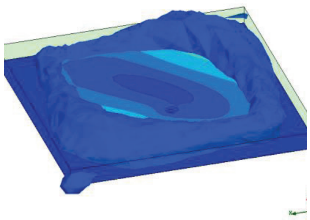




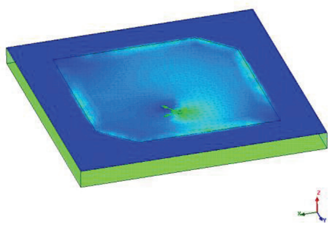
E-Field over phase



Complex E-Field

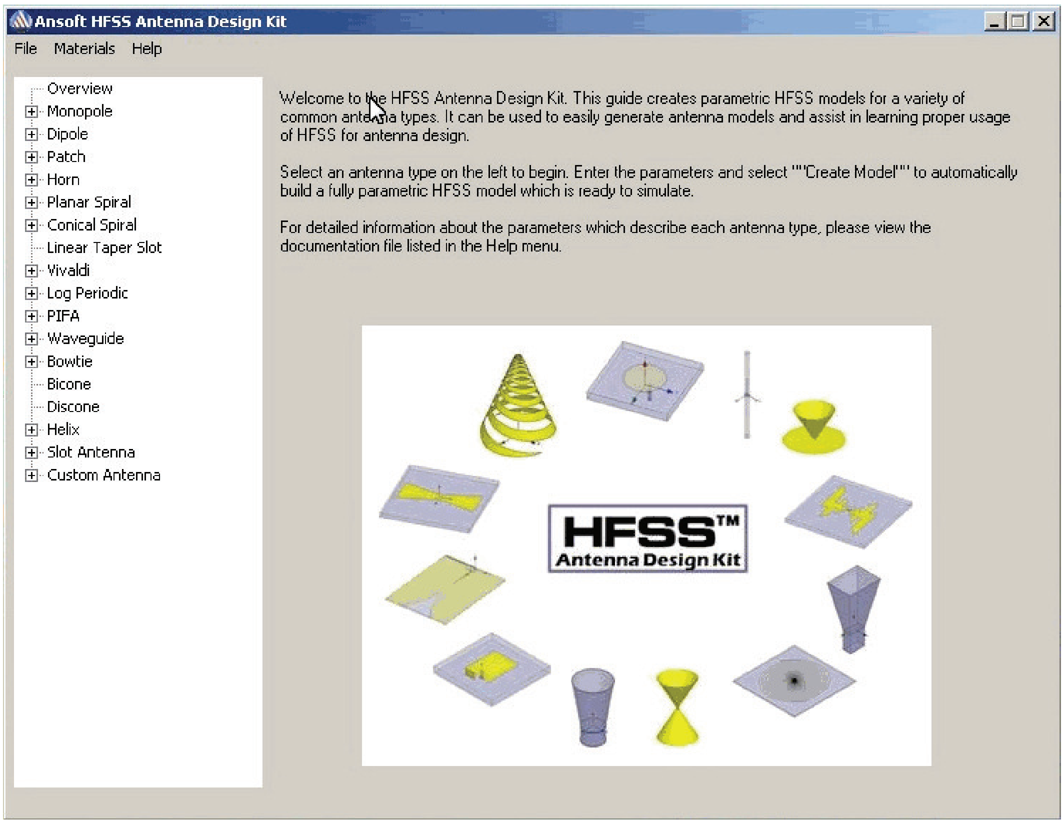


Current over phase

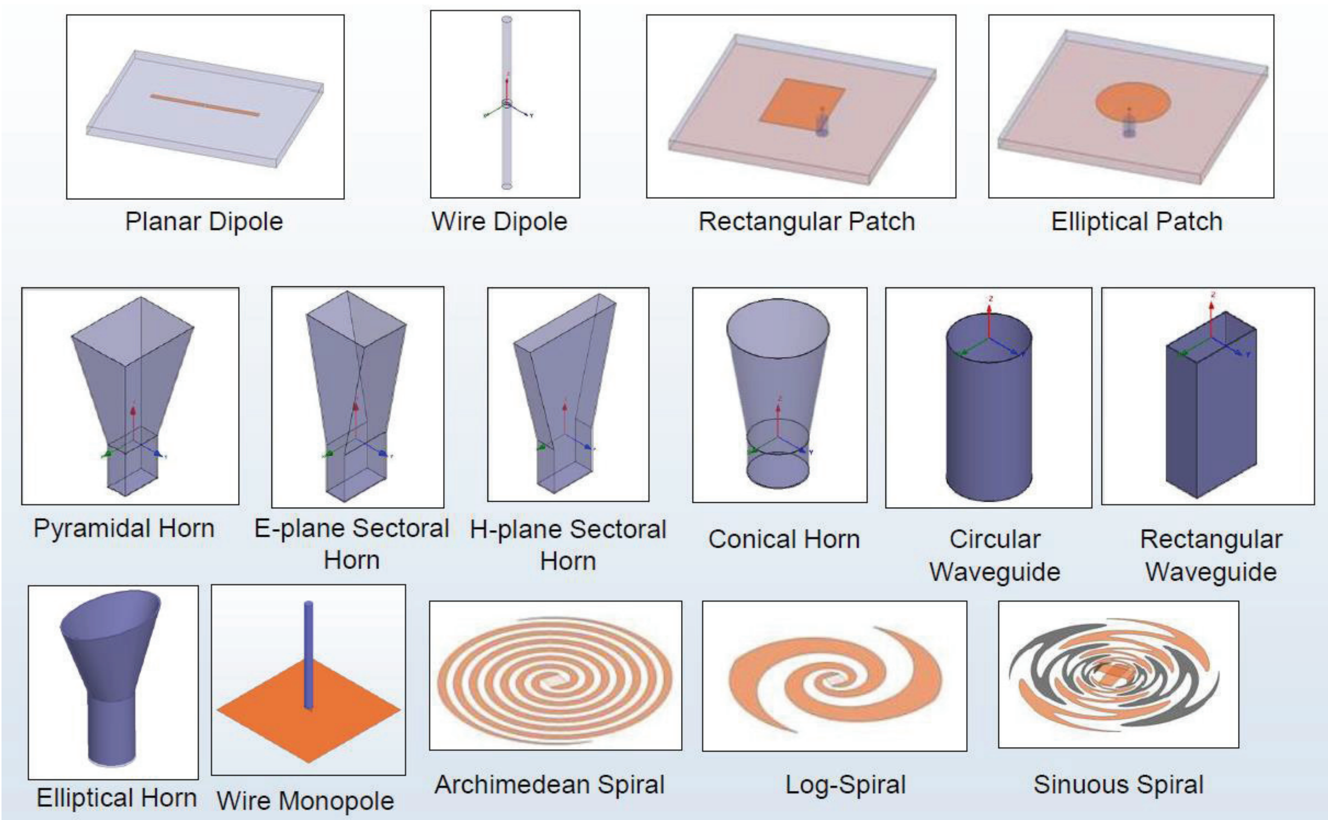


Antenna Design kit

- Parameterized model for different antenna types:

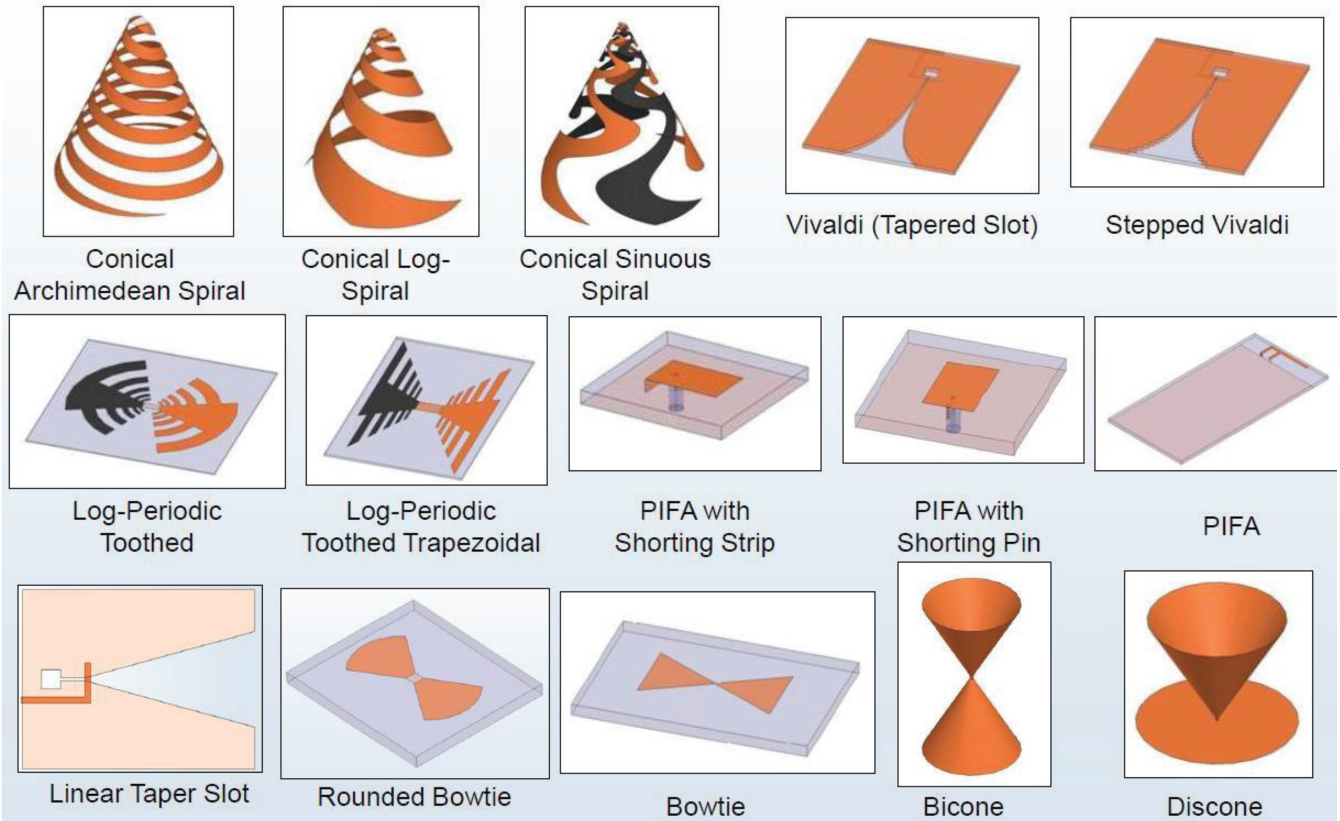


ADK: Available Antenna Types



ADK: Available Antenna Types

ESSS



Example HFSS Model Created by Antenna Design Kit

ESSS

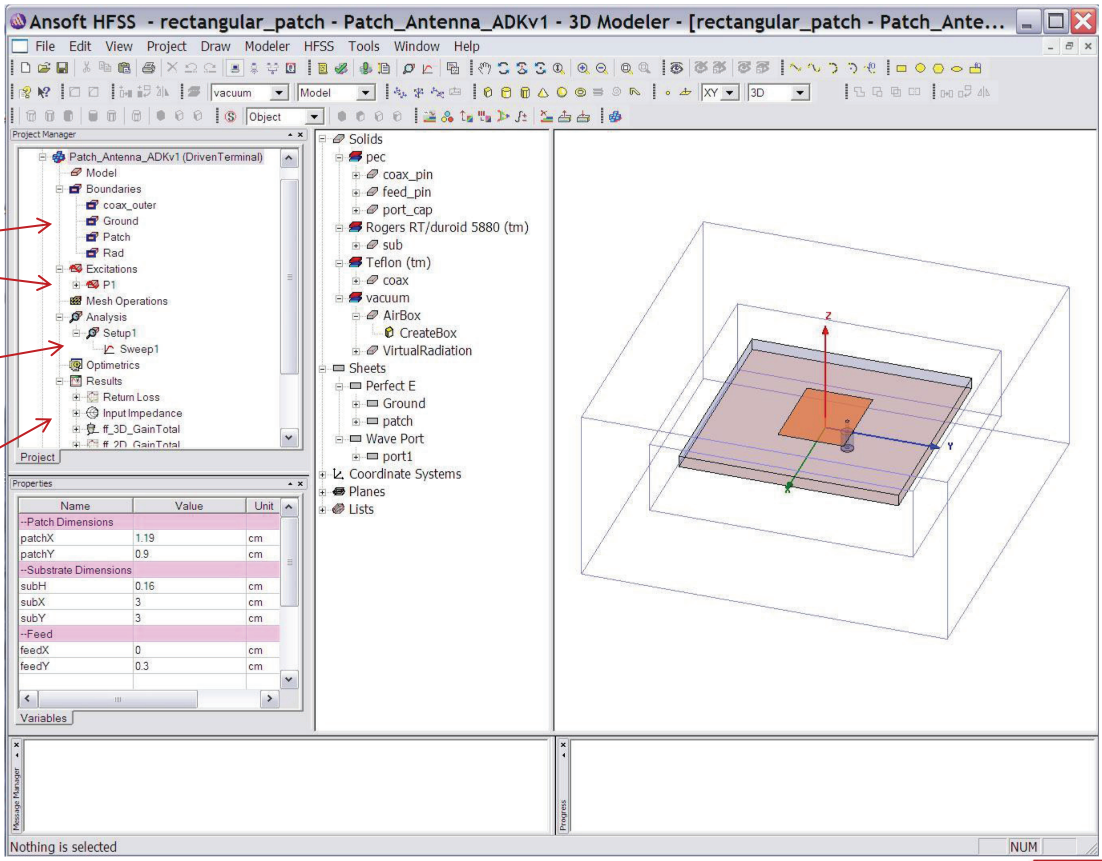
- Model ready to solve

Ports and Boundary Conditions

Solution Setup and Frequency Sweep

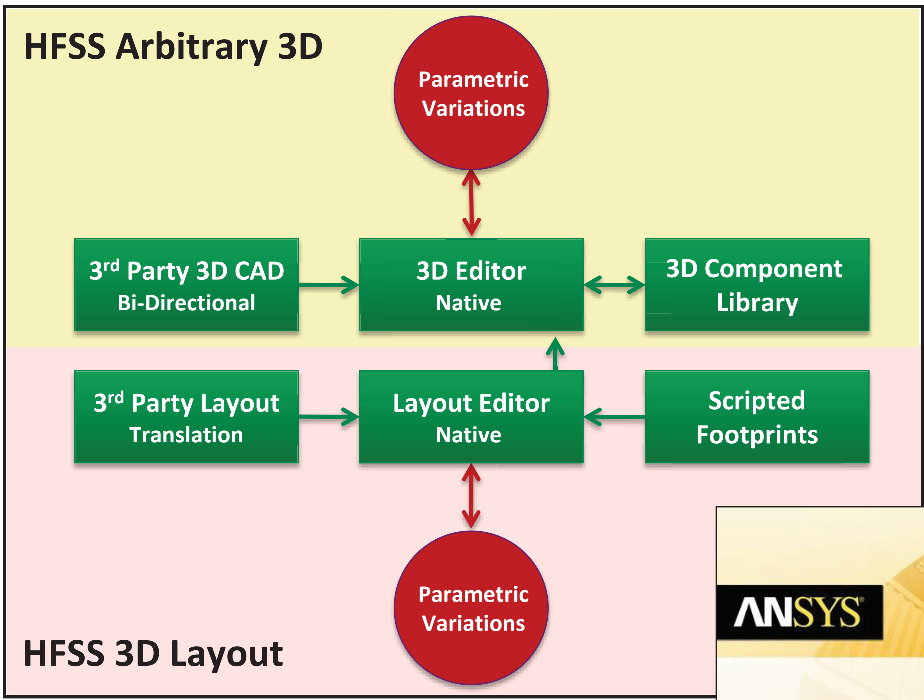
Reports for Input Impedance and Radiation Patterns

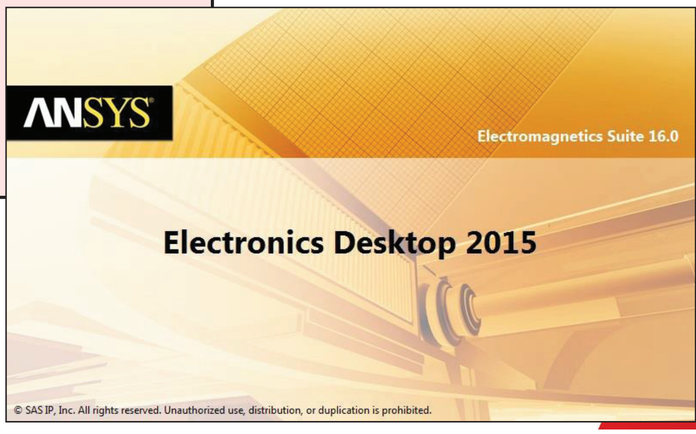
Parameters for Antenna Geometry



HFSS: Has Two Design Entry Interfaces

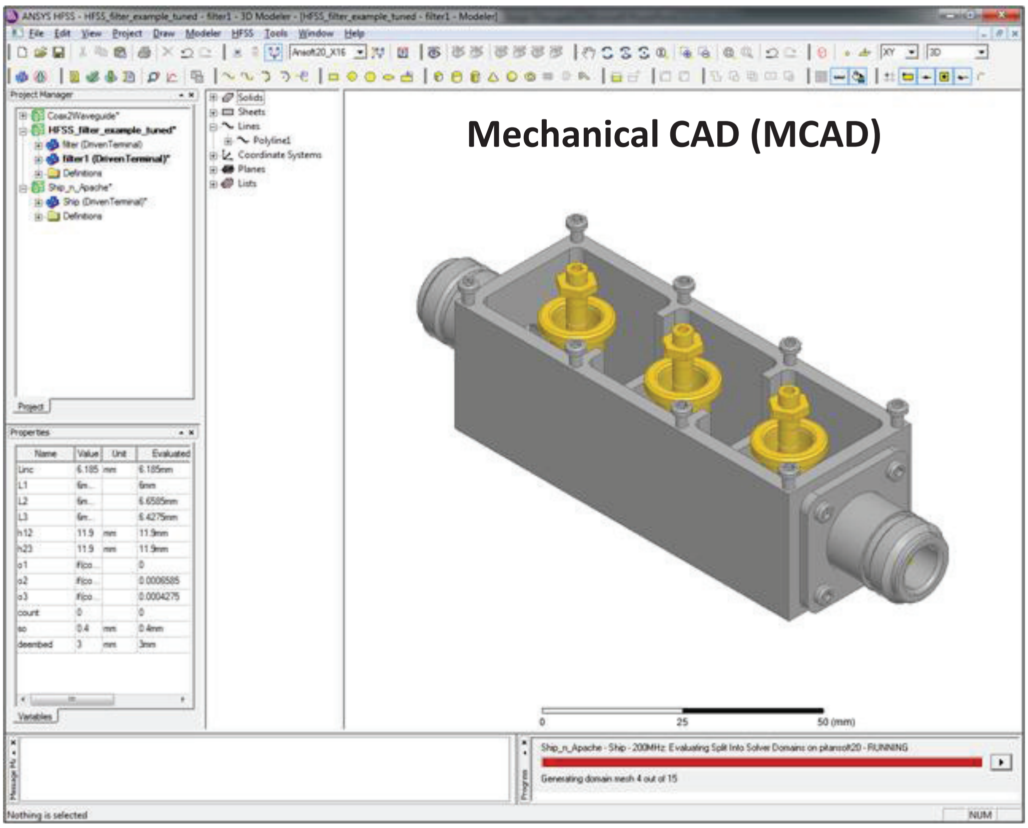
ESSS





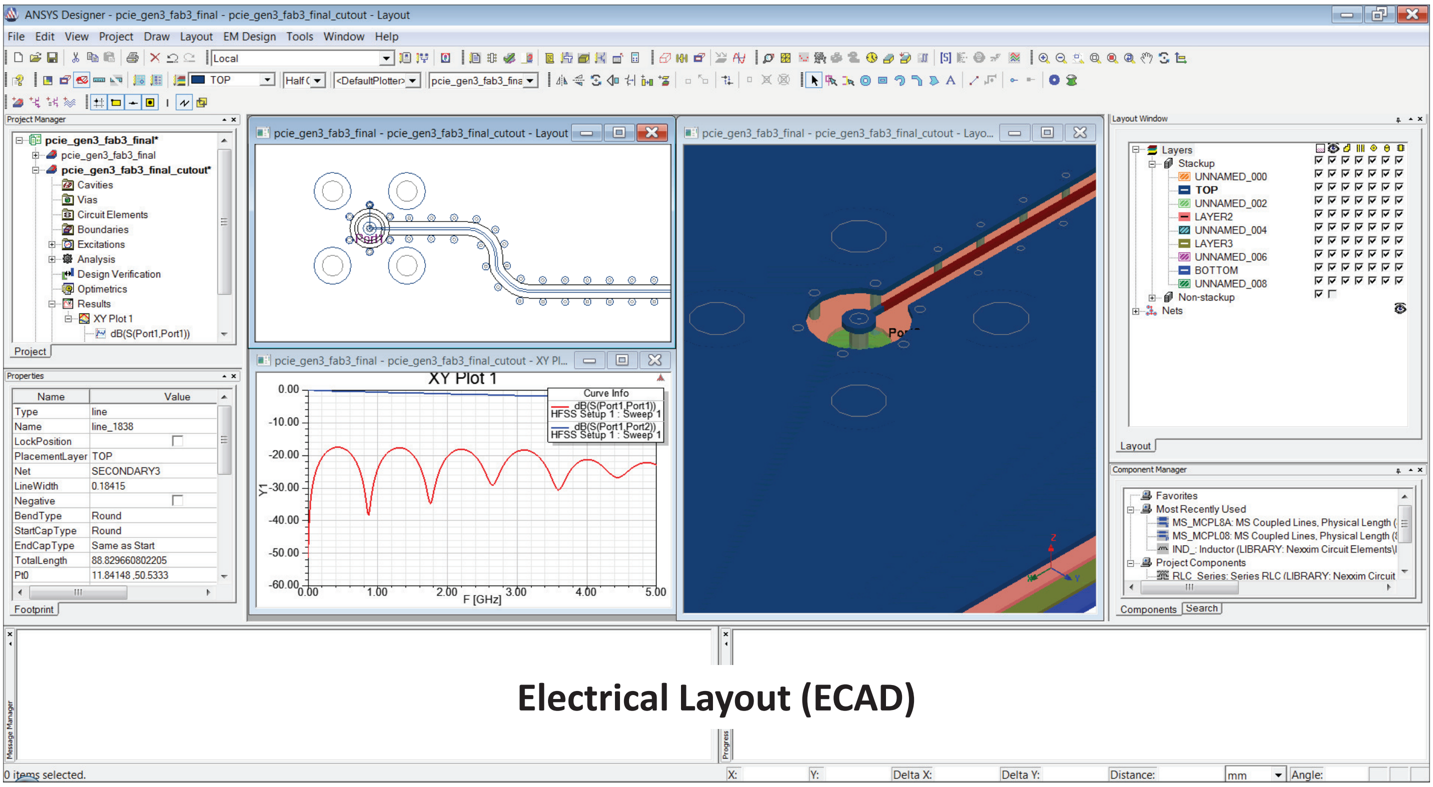
HFSS: Arbitrary 3D Geometry Editor

ESSS



HFSS: 3D Layout Editor

ESSS

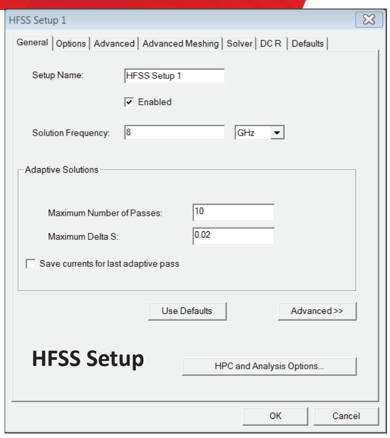


Electrical Layout (ECAD)

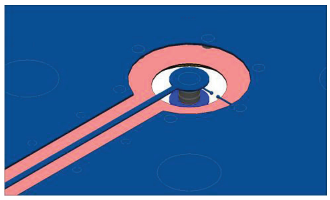
HFSS 3D Layout Editor

ESSS

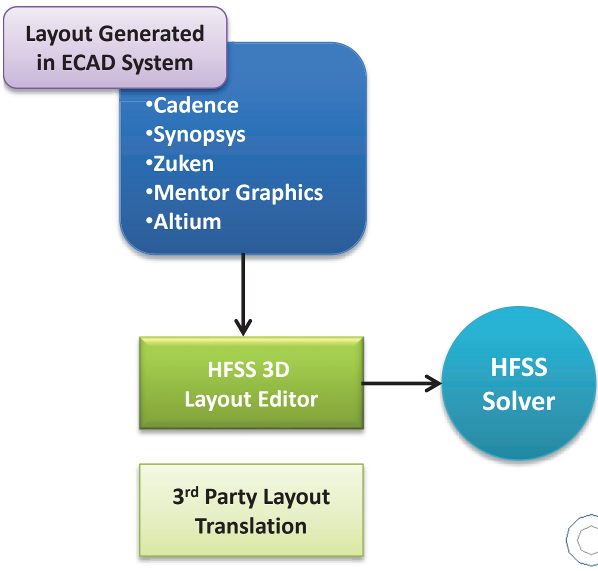
- **HFSS 3D Layout Integration**
  - Native Layout Editor for 3D HFSS simulations
    - Cadence, Mentor, Zuken, Altium, DXF, GDSII



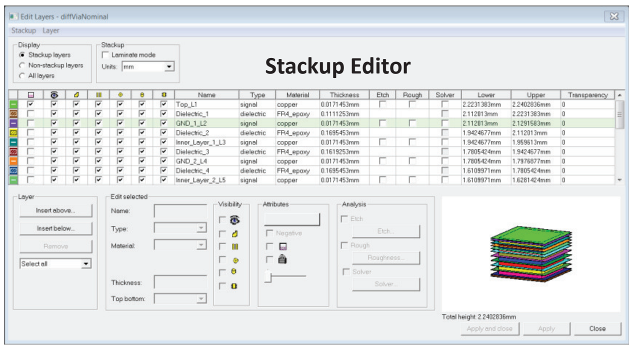
HFSS Setup



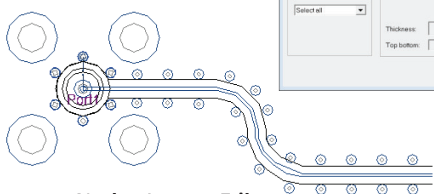
HFSS Circuit Port



Alinks for EDA



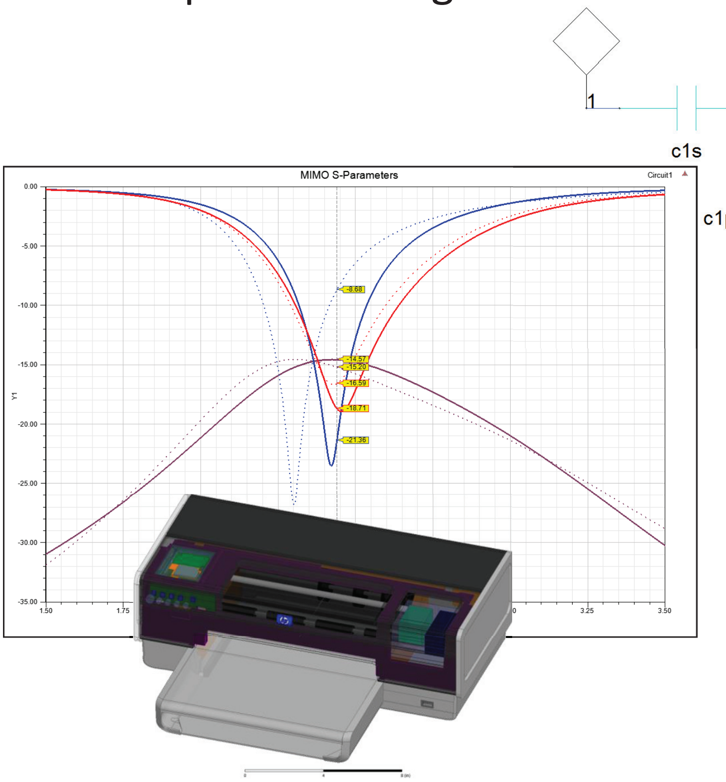
Stackup Editor

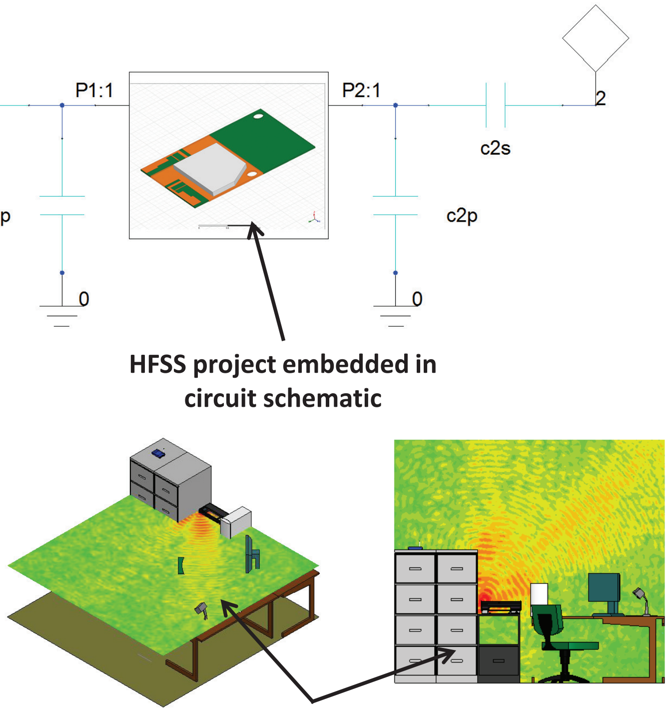


Native Layout Editor

Linear Circuit Simulation

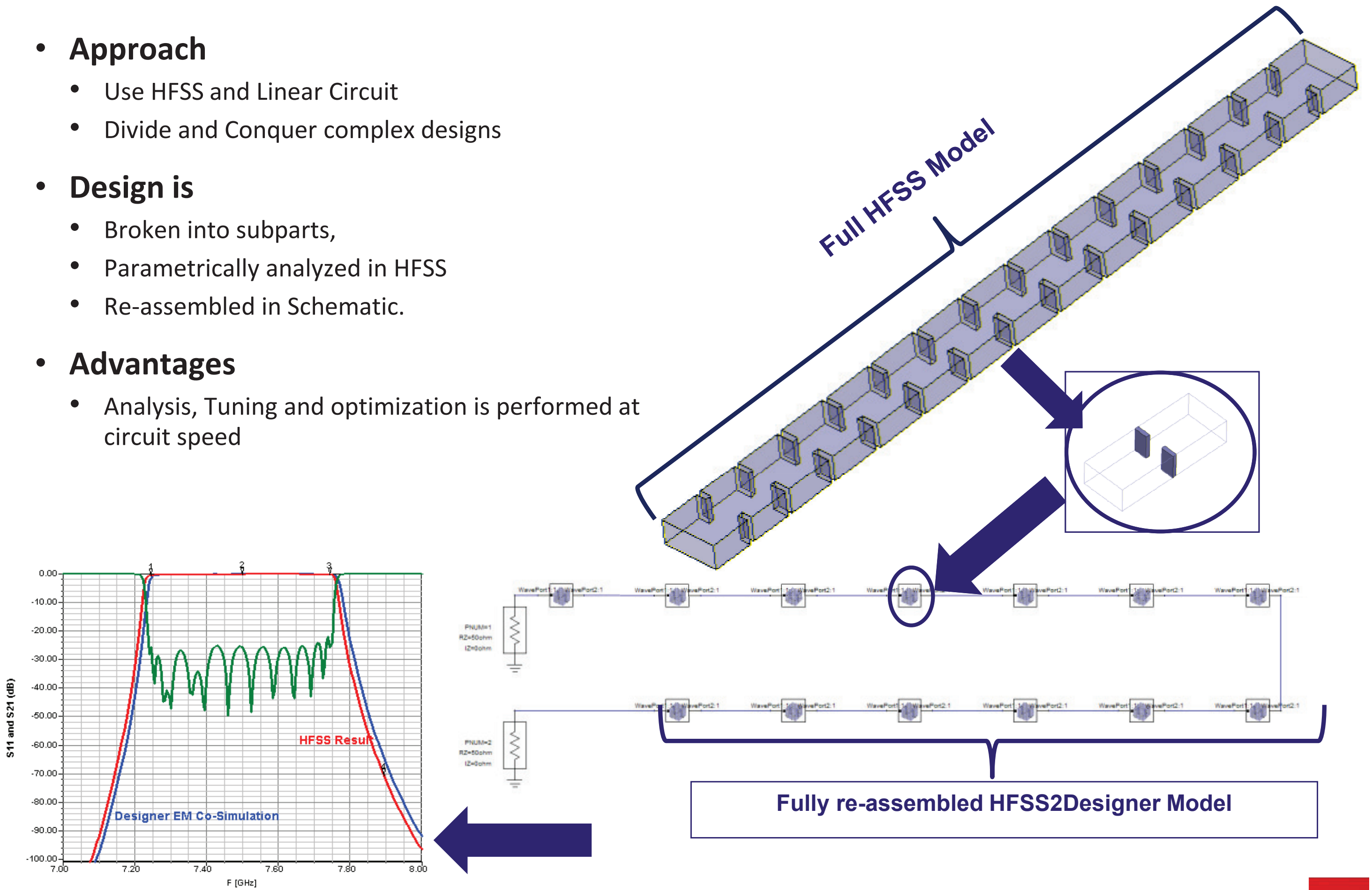
- The HFSS core license enables linear circuit simulation
- Example: Matching network for MIMO Bluetooth antenna feed





Divide and Conquer

- **Approach**
  - Use HFSS and Linear Circuit
  - Divide and Conquer complex designs
- **Design is**
  - Broken into subparts,
  - Parametrically analyzed in HFSS
  - Re-assembled in Schematic.
- **Advantages**
  - Analysis, Tuning and optimization is performed at circuit speed



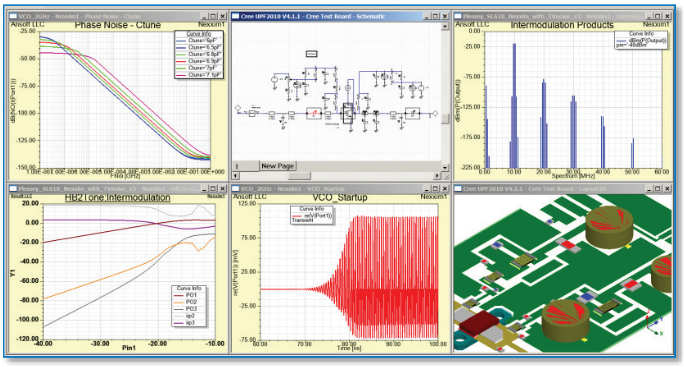
Enhanced circuit capabilities

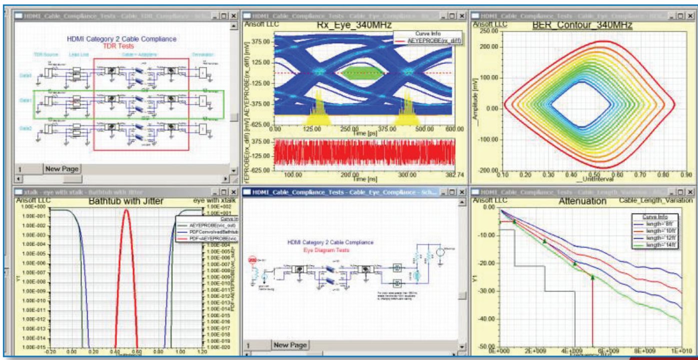
- **Expand the Linear Circuit capabilities**
  - Add-on the RF Option to enable: Harmonic Balance, Oscillator Analysis, Load-Pull, DC, Transient Circuit Simulation
  - Add-on the SI Option to enable: DC, Transient Circuit, 3D HFSS-TR, HSPICE Co-Simulation, QuickEye/VerifEye, IBIS-AMI

HFSS with Linear Circuit

ANSYS RF Option

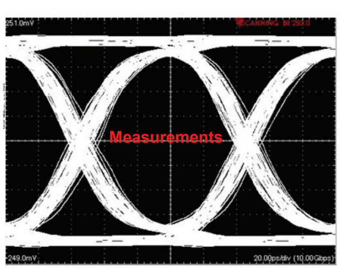
ANSYS SI Option

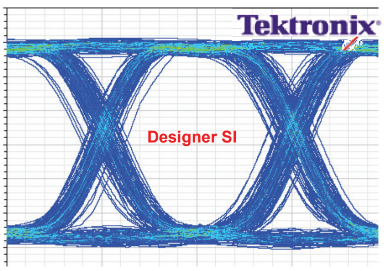


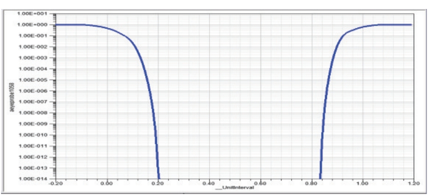


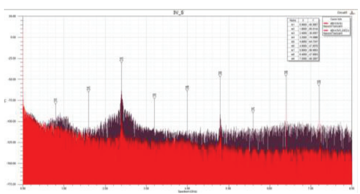
SI Option

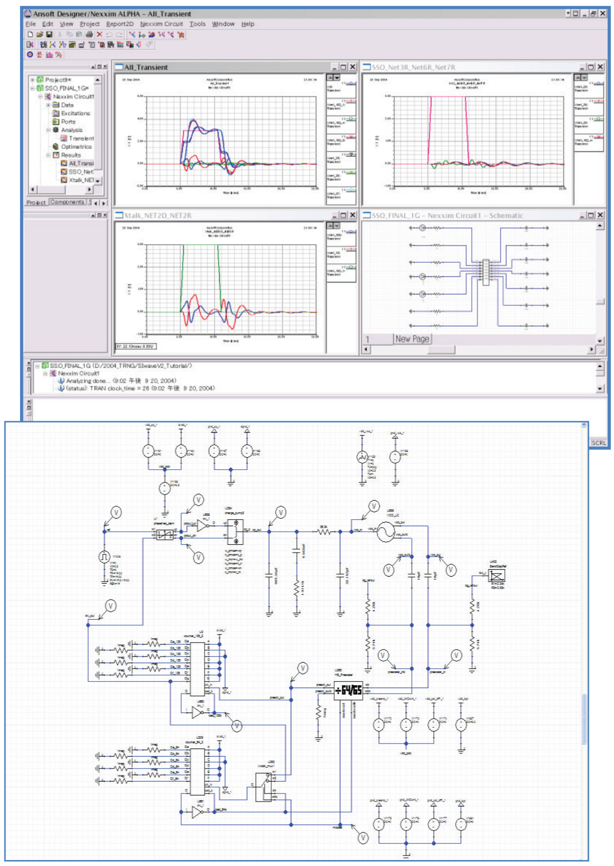
- Design Environment for System-Level Electronics
  - Design framework with schematic, layout, and post-processing
  - Links to EM field solvers and Circuit Simulation
- Advanced Circuit Simulator
  - Transient, Harmonic Balance, BER and Statistical Eye Simulation





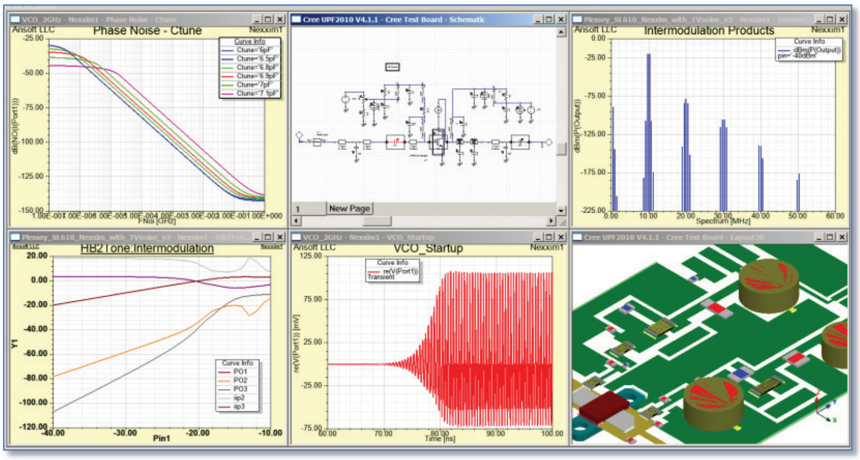






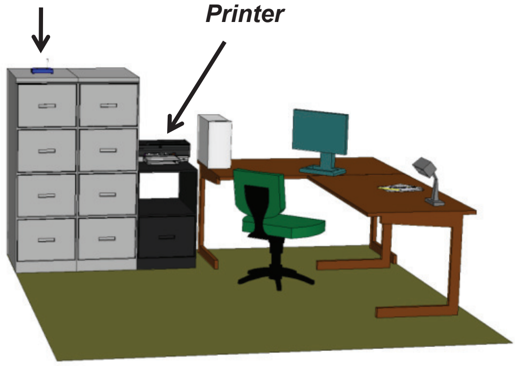
RF Option

- Designer RF
  - RF and µwave frequency domain
  - Analysis types
    - Linear
    - Harmonic Balance
    - Loadpull
    - Envelope
    - PXF Analyses
    - Oscillator
    - TV Noise
    - Phase Noise

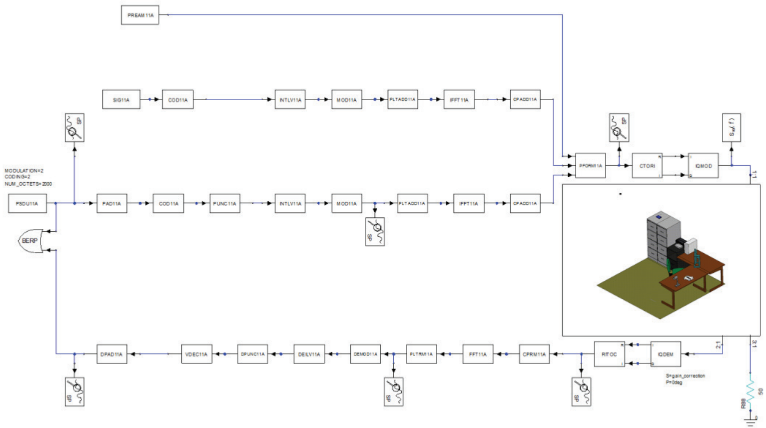


Possibility to expand RF Capabilities

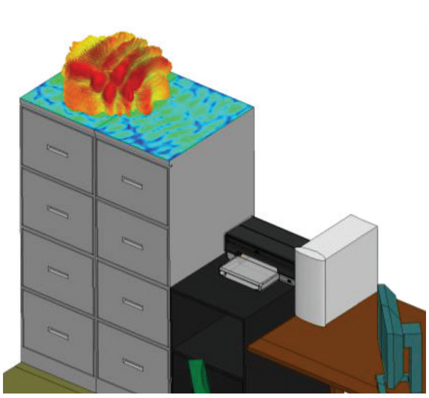
Wireless Printer



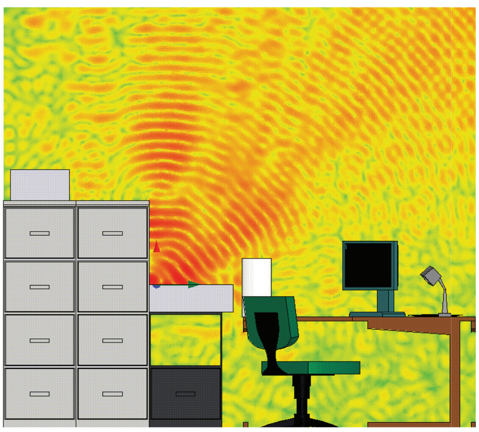
Full WiFi IEEE802.11g Schematic in Designer with HFSS Model

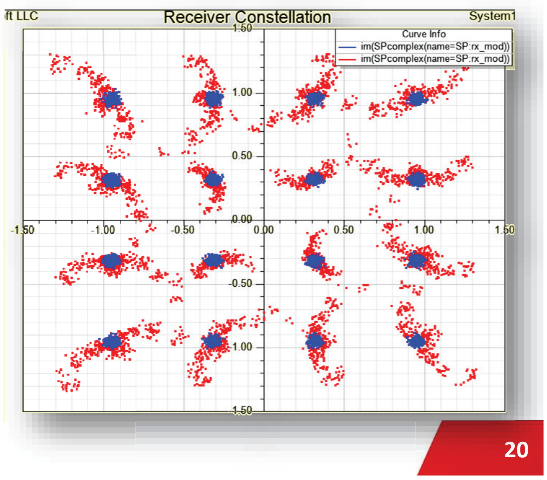


Real Far Field Pattern due to Designer circuitry excitation



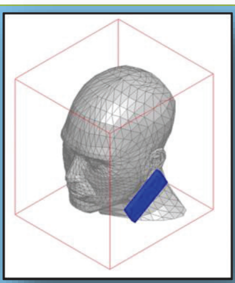
Efield produced by printer



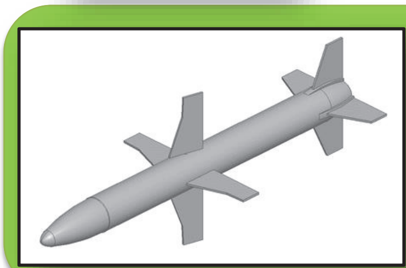


HFSS: Simulation Technologies

ESSS

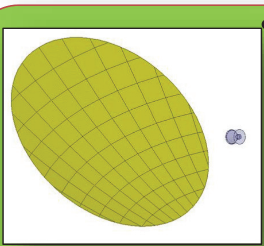


- **Finite Element Method**
  - Enabled with HFSS
  - Efficiently handles complex material and geometries
  - Volume based mesh and field solutions
  - Fields are explicitly solved throughout entire volume
  - Frequency and Transient solutions

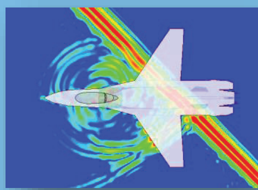


- **Integral Equations**
  - Enabled with HFSS-IE
  - Efficient solution technique for open radiation and scattering
  - Currents solved only on surface mesh
  - Efficiency is achieved when structure is primarily metal

Hybrid Solutions



- **Physical Optics**
  - **Enabled with HFSS-IE**
  - **High frequency approximation**
  - **Ideal for electrically large, smooth objects**
  - **1st order interactions**

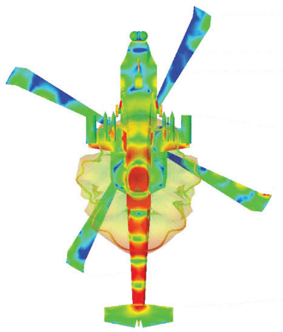


- **FEM Transient**
  - **Enabled with HFSS**
  - **Ideal for fields that change versus space and time; scattering locations**

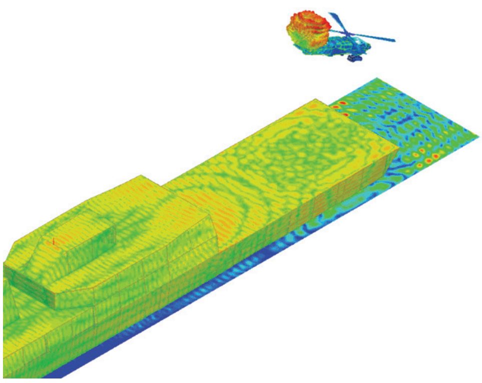
HFSS-IE (Integral Equation Solver)

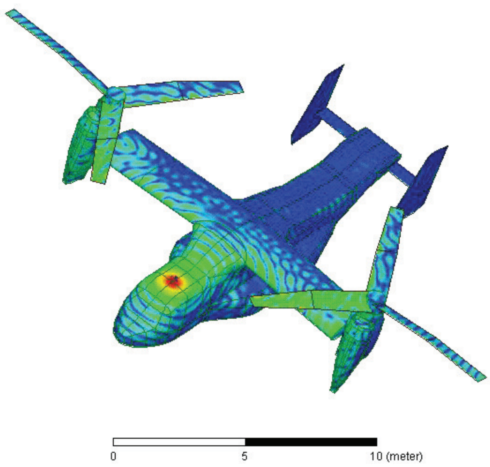
ESSS

- **Technology**
  - An Integral Equation solver technology in the HFSS desktop
    - A 3D Method of Moments (MoM) Integral Equation technique
    - Only surfaces are meshed. Uses equivalence principle to solve only on surfaces
    - Physical optics, high frequency solver also included within HFSS-IE design type
- **Applications**
  - Efficient solution technique for large, open, radiating or scattering analyses
    - Antenna placement, Radar cross section (RCS), and S-Parameters



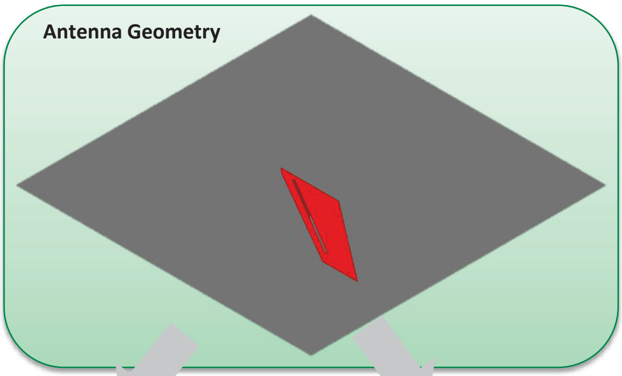
$$E(r) = j\frac{\eta}{k_0}\left(\nabla\nabla\bullet + k_0^2\right)\iint_S J(r')\,G(r-r')\,dS'$$





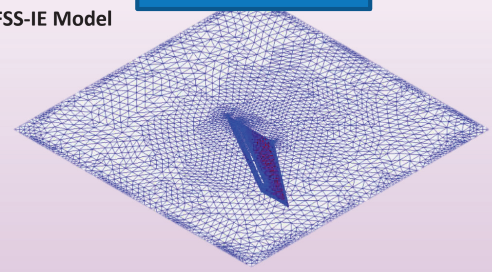
Choice of Solution Methods

- **Solution to geometry using either FEM or IE**
- **Both solution yield the same results**
  - FEM solution requires an air volume surrounding antenna, IE solution does not
  - Integral equation solution would be most efficient when geometry is primarily metal



Integral Equation

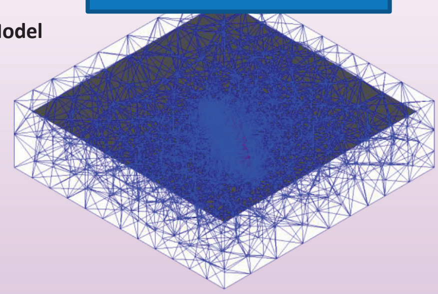
HFSS-IE Model



- Efficient solution technique for open radiation and scattering
- Currents solved only on surface mesh
- Efficiency is achieved when structure is primarily metal

Finite Element Method

HFSS Model

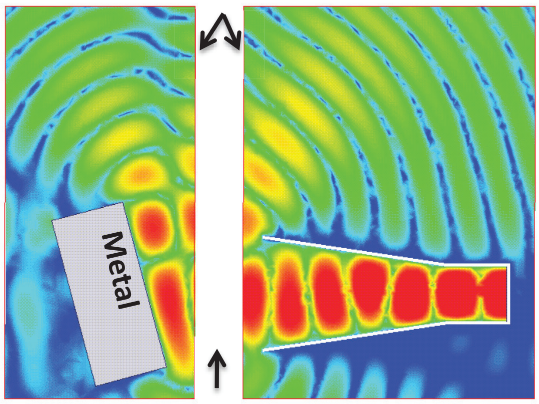


- Efficiently handles complex material and geometries
- Volume based mesh and field solutions
- Fields are explicitly solved throughout entire volume

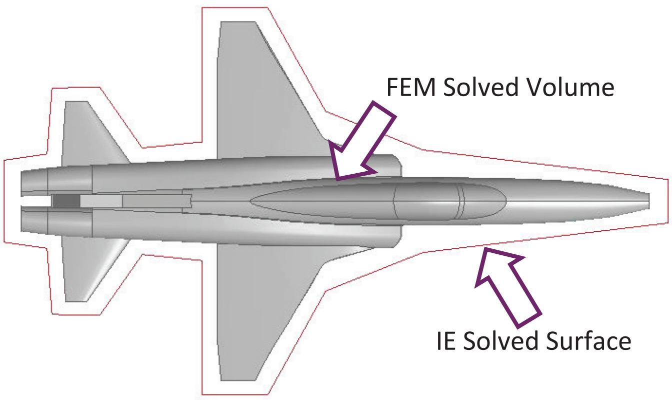
Finite Element – Boundary Integral

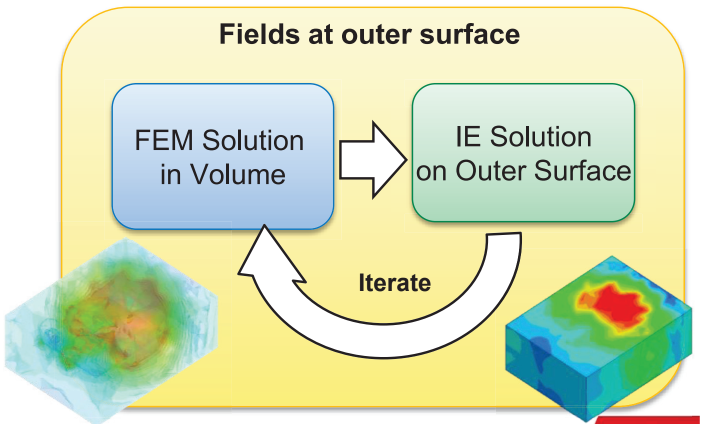
- **FEBI**
  - Mesh truncation of infinite free space into a finite computational domain
  - Alternative to Radiation or PML
  - Hybrid solution of FEM and IE
    - IE solution on outer faces, FEM solution inside of volume
    - Separate volumes will be fully coupled with FE-BI
  - FE-BI Advantages
    - Arbitrary shaped boundary: Conformal to minimize solution volume
    - Reflection-less boundary condition: High accuracy for radiating and scattering problems
    - IE solution solve for field propagation through free space and conductors outside of FEM volume, no volume mesh required
    - **No theoretical minimum distance from radiator**
      - Reduce simulation volume and simplify problem setup

FE-BI



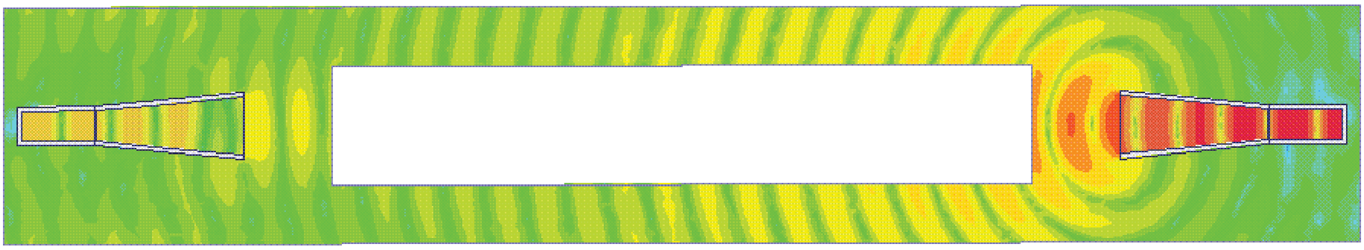
Free space
(No Solution Volume)





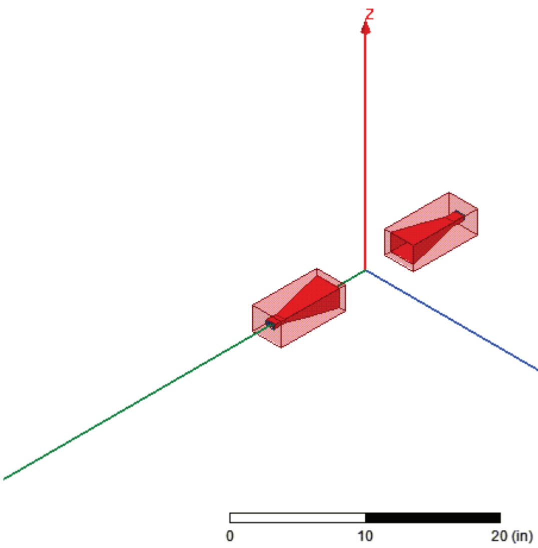
Internal Boundary

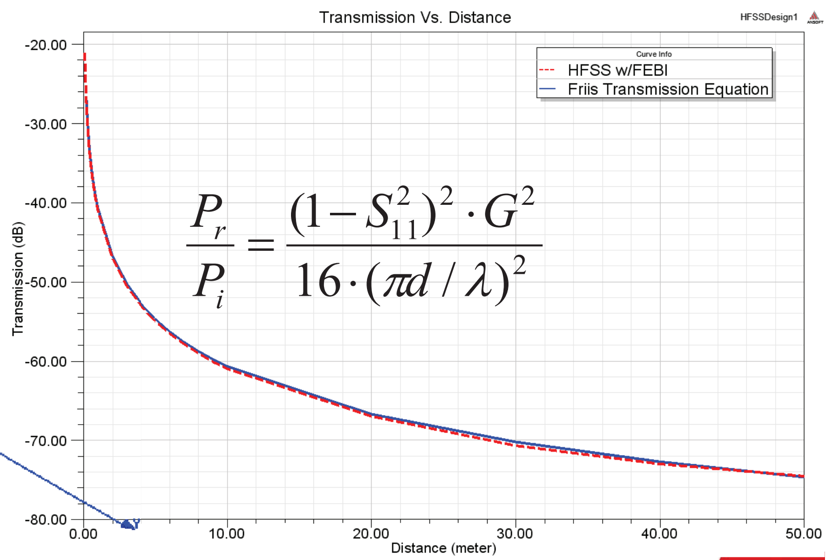
- Internal air volume can be handled analytically.



Friis Transmission Equation and FE-BI Comparison

- Open Ended waveguides
  - Each waveguide surrounded by a separate FE-BI surface
  - Free space modeled with IE method
- Comparison between **Friis Transmission Equation** and HFSS with FE-BI
- Excellent agreement to 50 meter separation at 10 GHz



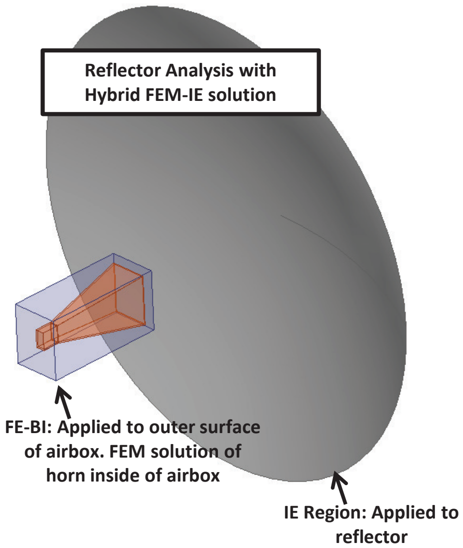


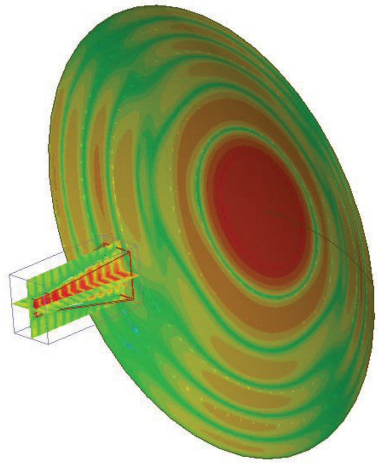
$$\frac{P_r}{P_i} = \frac{(1 - S_{11}^2)^2 \cdot G^2}{16 \cdot (\pi d / \lambda)^2}$$

Hybrid IE-Regions

ESSS

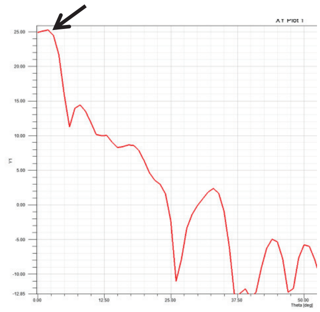
- **Metal objects that are outside of the FEM solution volume can be directly solved using the integral equation solution**
  - Removes the need for air box to surround metal objects
  - Fully coupled FEM and IE domains





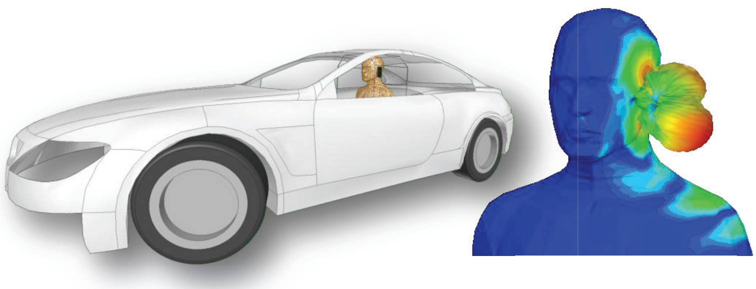
Hybrid solution of reflector fully couples the solutions of the FEM and IE Domain

Blockage due to feed

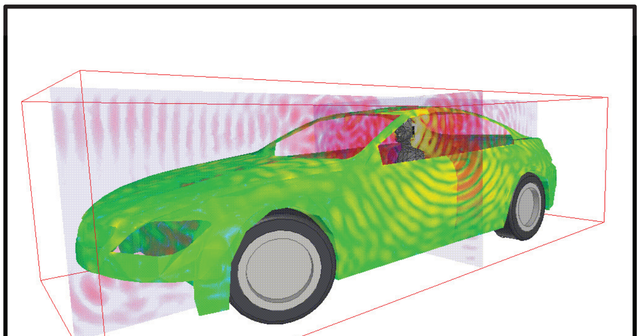


IE Region: Head and Phone inside a Car

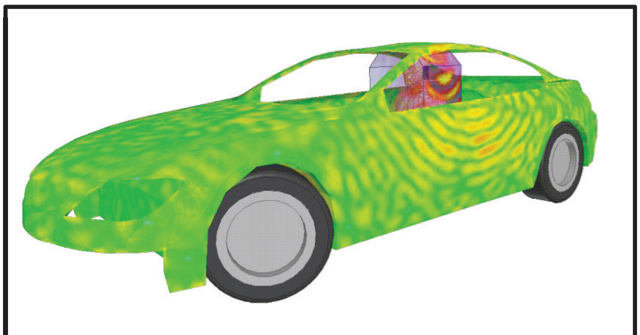
ESSS



1. **FEM**: around body and cell phone
2. **IE Region (dielectric)**: human body
3. **IE Region (MoM)**: metallic car body



Full FEM Solution

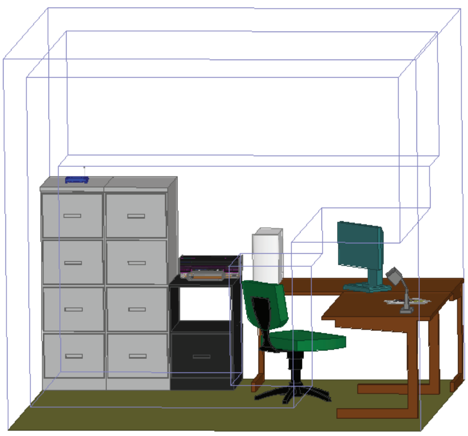


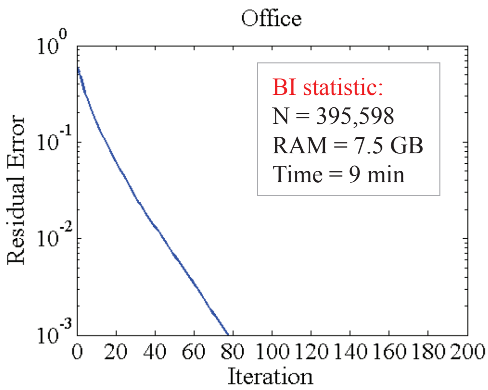
Hybrid FEM-IE Solution

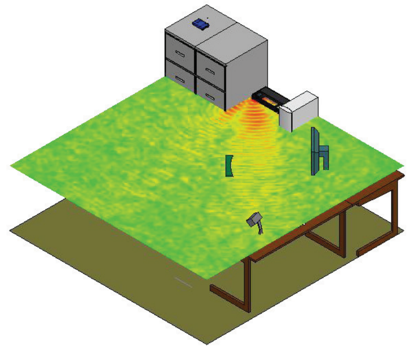
Solution Type	Total RAM	Time
FEM w/ DDM	160 GB	8 hours
Hybrid Solution	**11 GB**	**2.7 hours**

15X Less **3X Faster**

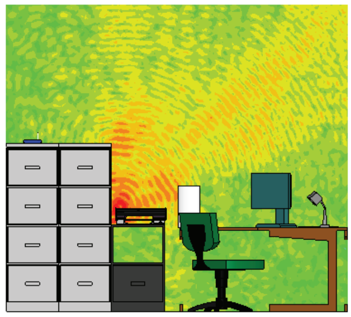
Internal FEBI: Office Simulation



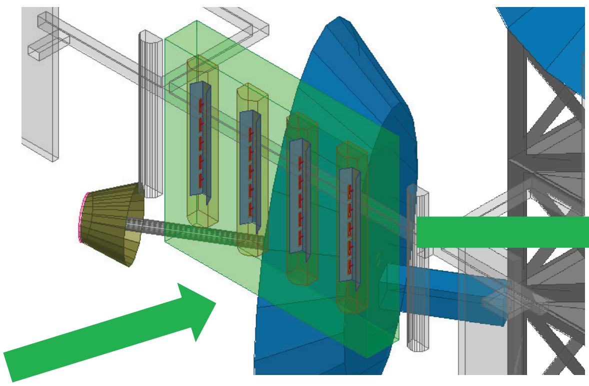


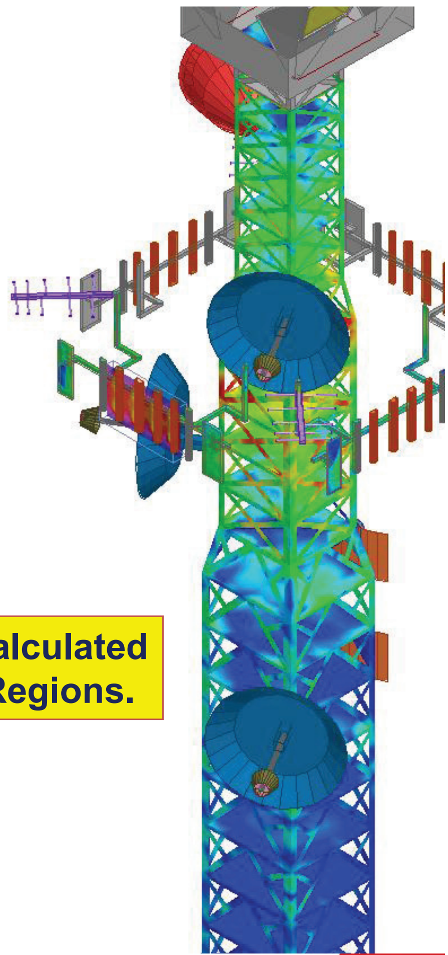


Boundary Type	#Tetra	Unknown	Total RAM	Elapsed Time
ABC	412,642	5,861,283	44 GB	11.5 hours
FE-BI	**277,972**	**3,594,473**	**30 GB**	**3 hours**



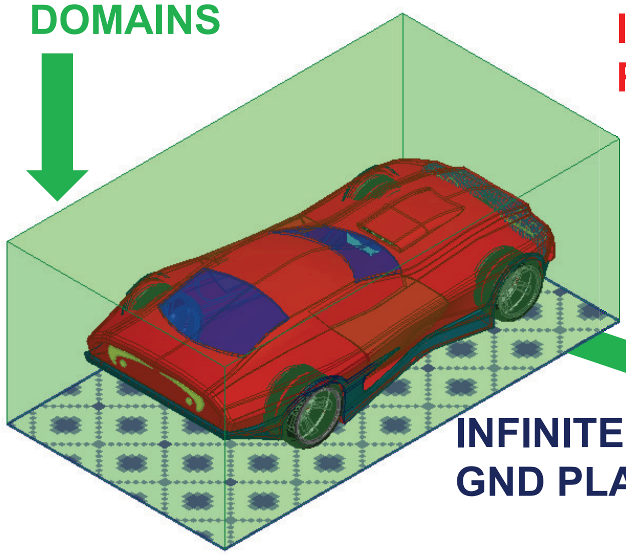
GSM Communication Using FEBI and IE Regions



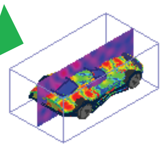


FEBI DOMAINS

IE REGION

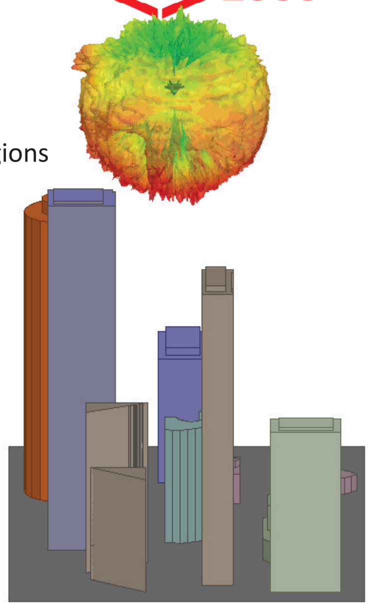


INFINITE GND PLANE

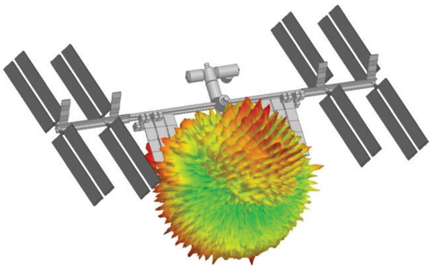


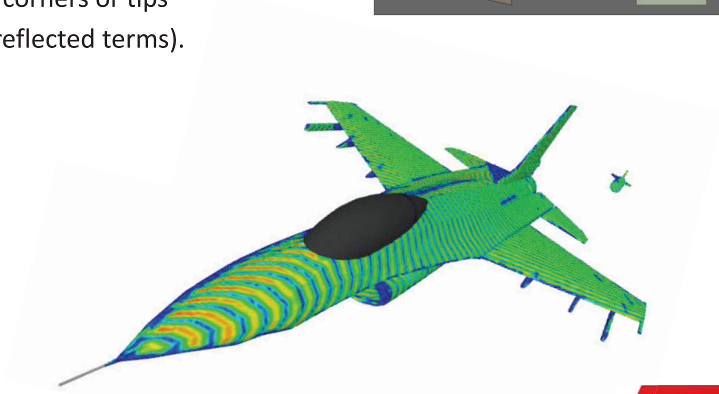
S-Matrix can be calculated using FEBI and IE Regions.

HFSS-IE: Physical Optics (PO) Solver

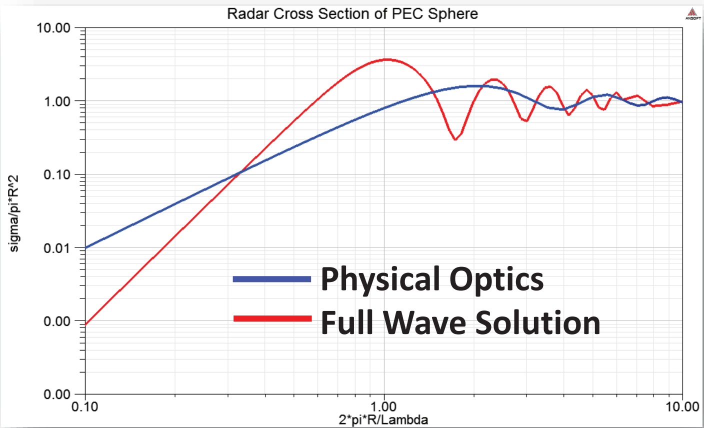


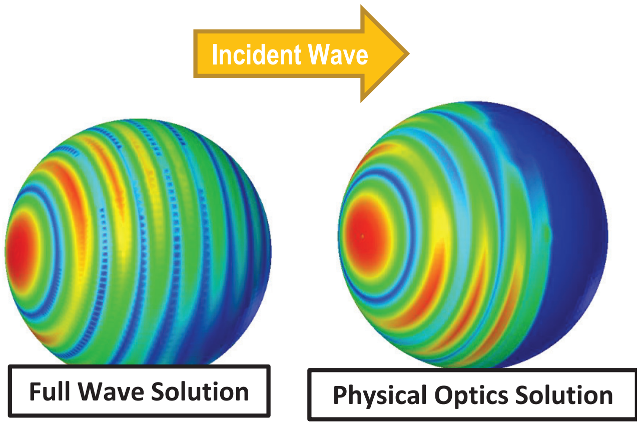
- **Technology**
  - Currents are approximated in illuminated regions and set to zero in shadow regions
  - First order interaction only (Single bounce)
  - Source excitation from HFSS Far Field Data-Link as incident plane wave
  - Incredibly efficient in both time and memory
- **Applications**
  - Efficient solution technique for large, open, radiating or scattering analyses
    - Antenna placement, Radar cross section (RCS), and S-Parameters
  - Quickly estimates performance of electrically large problems
  - Ideal for electrically large, conducting and smooth objects
- **However**
  - No diffraction (edge, corner, tip,…) from edges, corners or tips
  - No higher order interaction (e.g. the reflected-reflected terms).
  - Only good conductors – no dielectrics.





Physical Optics





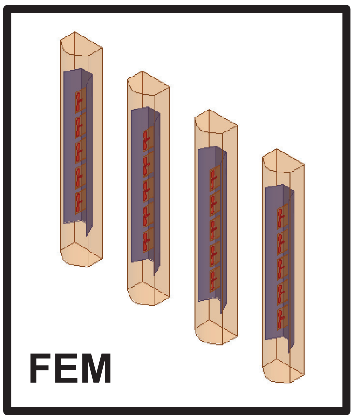
Solution @ High Freq.	Total RAM (GB)	Elapsed Time (sec)
Full Wave (HFSS-IE)	1.4	87
Physical Optics	0.1	14

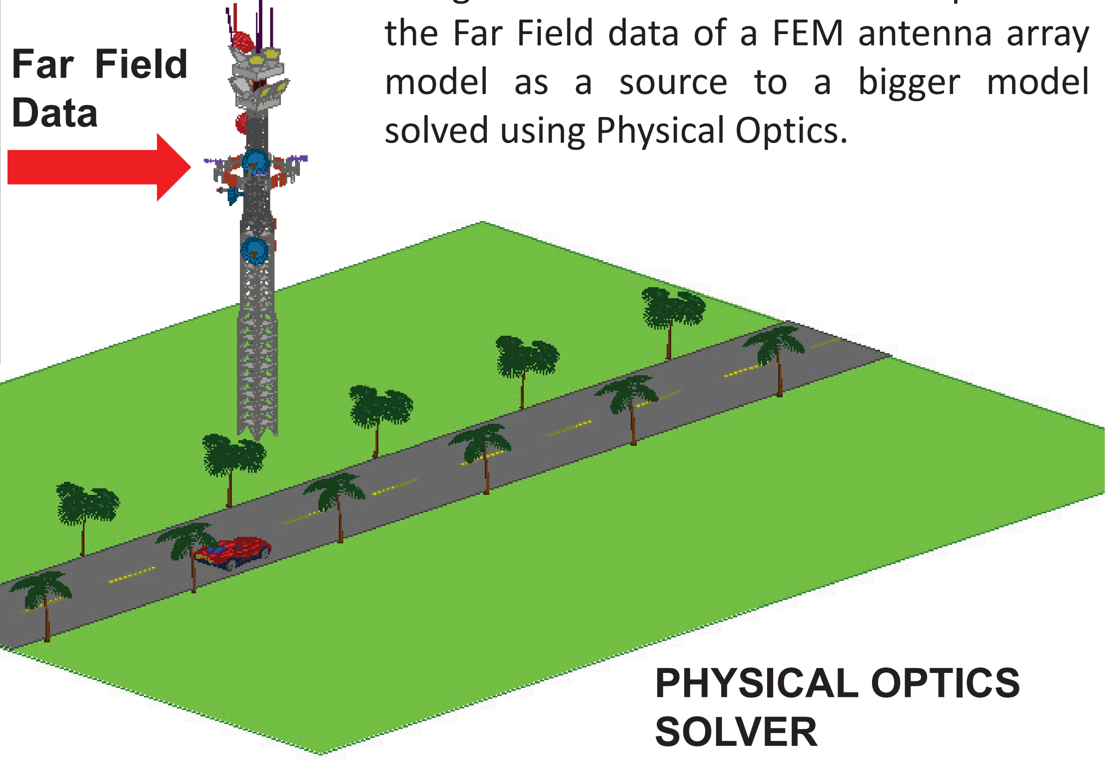
RCS of PEC Sphere

- Highlights capabilities and limitation of physical optics
- Creeping wave effects not accounted for by PO
- When electrical size of sphere becomes large, full wave solution converges with physical optics solution

Physical Optics Solver

Bigger environments can be simulated using different solvers. This example uses the Far Field data of a FEM antenna array model as a source to a bigger model solved using Physical Optics.

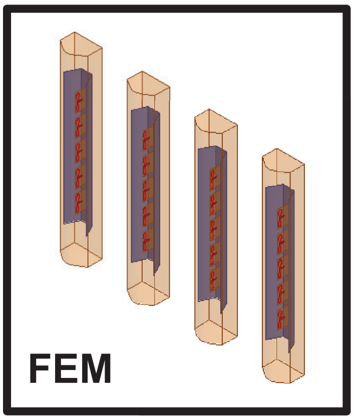


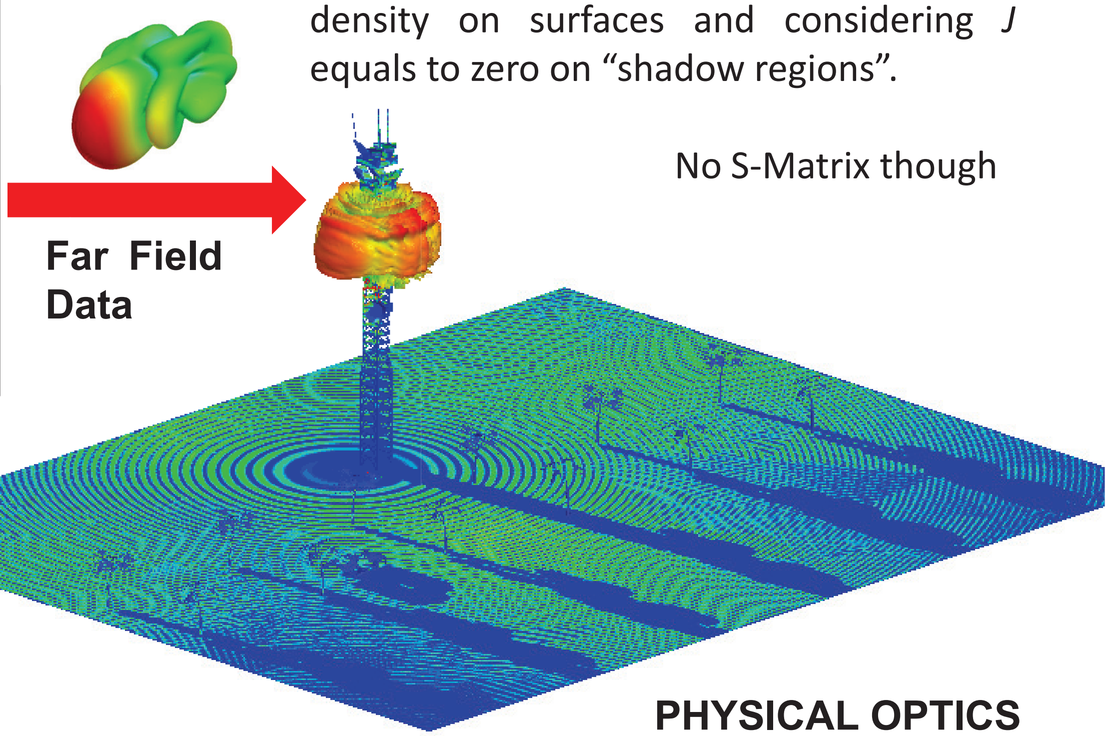


Physical Optics Solver

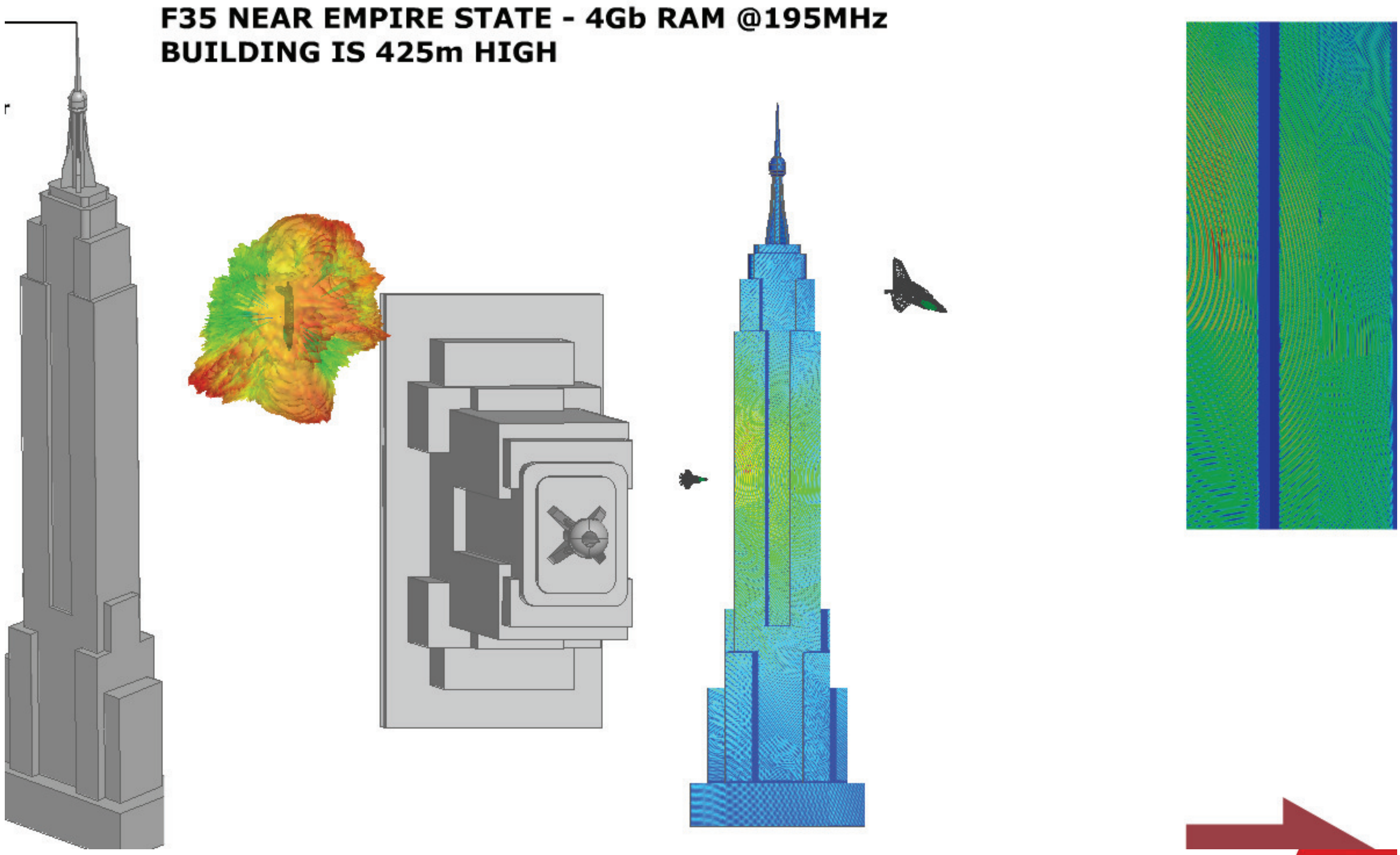
Physical Optics solver gives fast results of Far Fields by approximating the current density on surfaces and considering *J* equals to zero on “shadow regions”.

No S-Matrix though





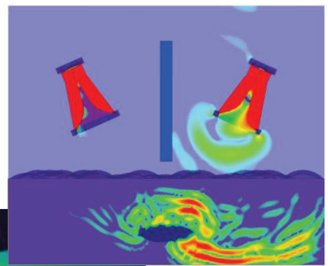
PO Example

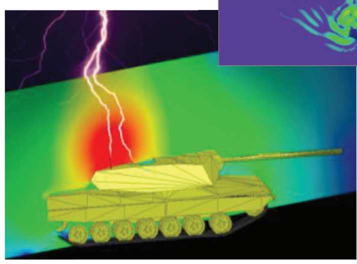


HFSS-Transient

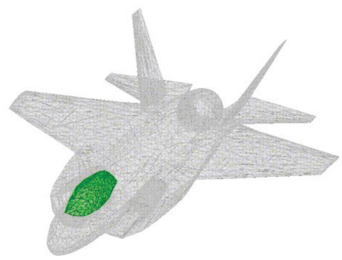
- **Technology**
  - Finite Element Transient Solver
    - Hybrid Implicit/Explicit transient solver coupled with local time stepping
    - Unstructured finite element tetrahedral mesh
- **Applications**
  - Pulsed Ground Penetrating Radar (GPR)
  - Electrostatic discharge (ESD)
  - Time Domain Reflectometry (TDR)
  - Transient field visualization
  - Pulsed radar cross section (RCS)

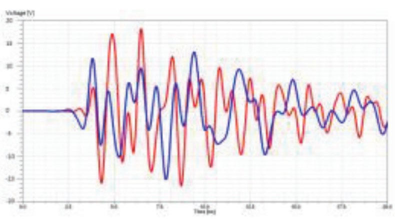
GPR



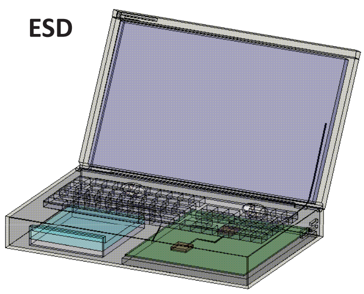


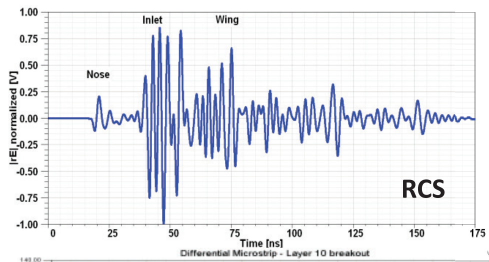
ESD

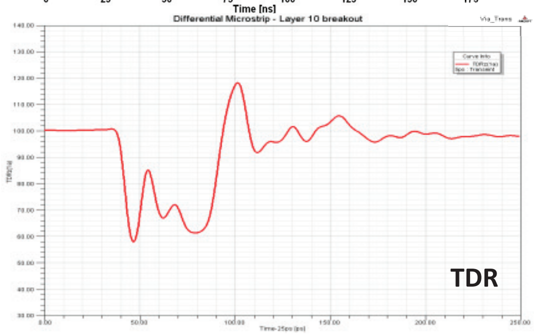


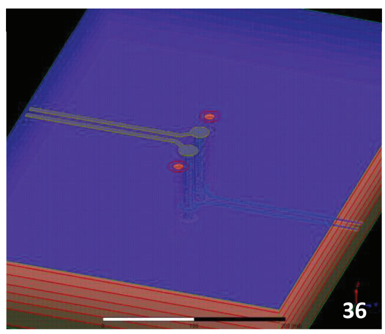


ESD



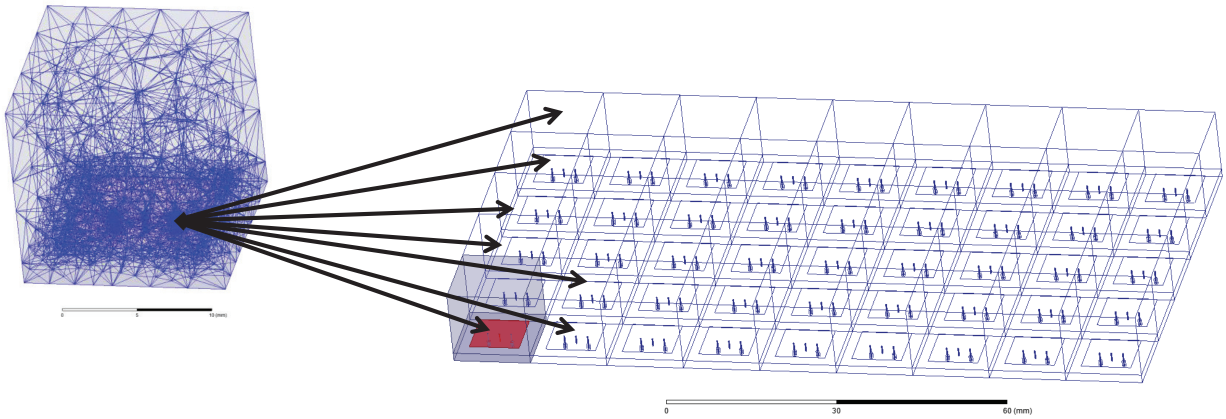






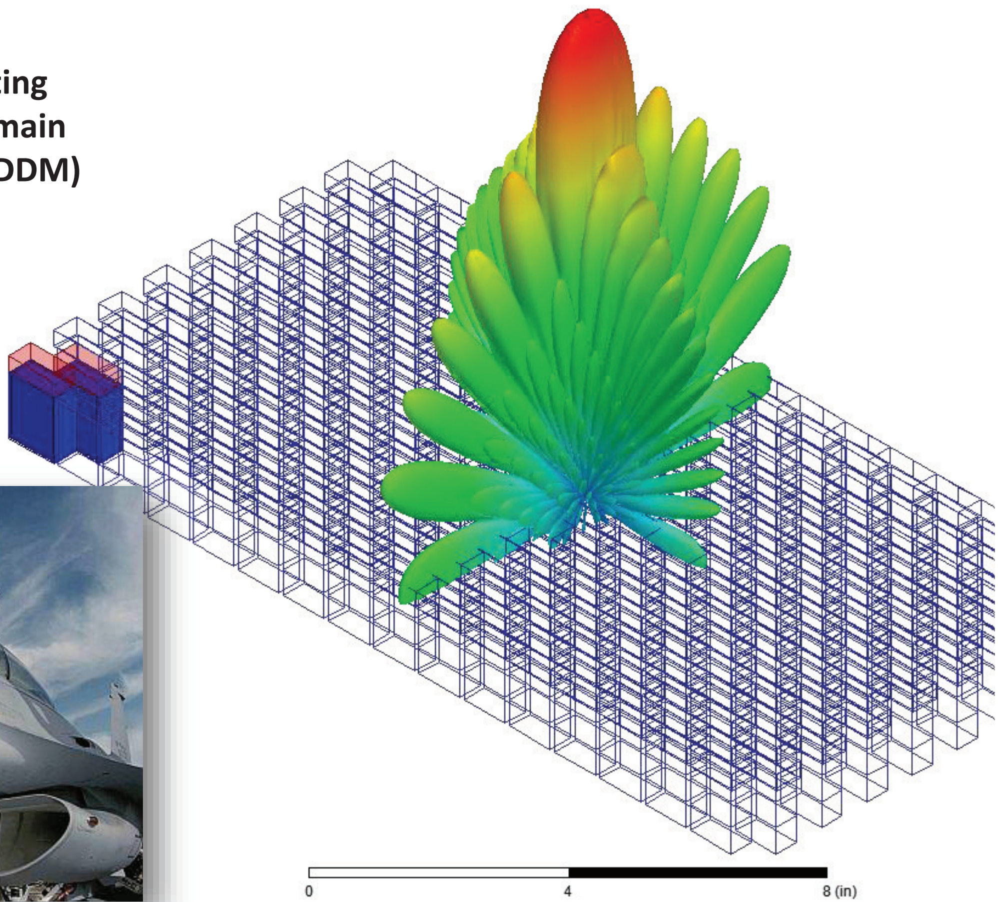
Finite Array Domain Decomposition

- Utilizes Replicated DDM Unit Cell to Address Array Concerns
- Geometry and Mesh copied directly from Unit Cell Model
  - Unit Cell geometry expanded to finite array through a simple GUI
  - Adaptive Meshing Process imported from Unit Cell Simulation
    - Dramatically reduces the meshing time associated with finite array analyses.
    - Mesh periodicity reinforces array's periodicity.



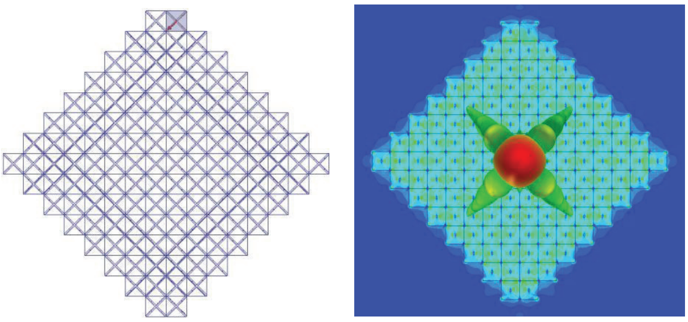
Finite Array Domain Decomposition

Efficient solution for repeating geometries (array) with domain decomposition technique (DDM)

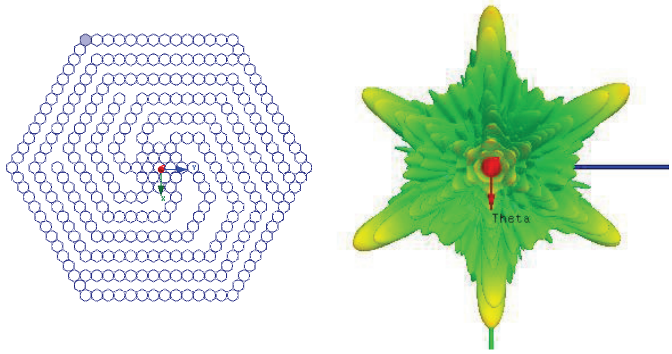


Flexibility – Shaped and Sparse Arrays

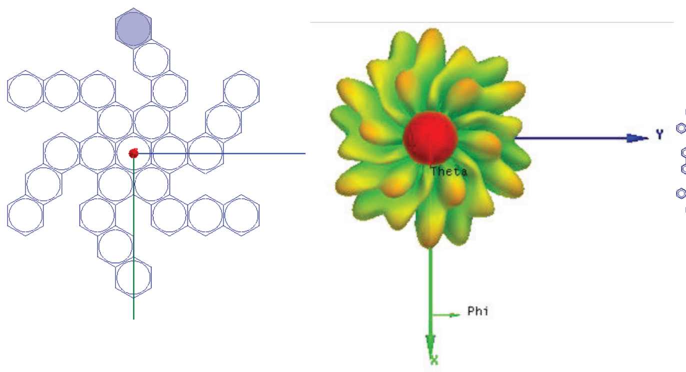
Diamond



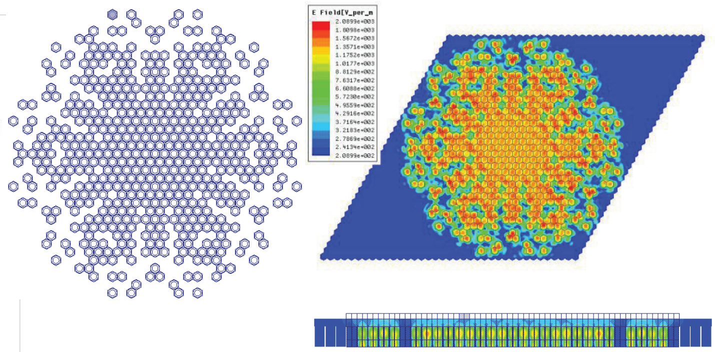
Asymmetric Spiral/Hex



Small Spiral

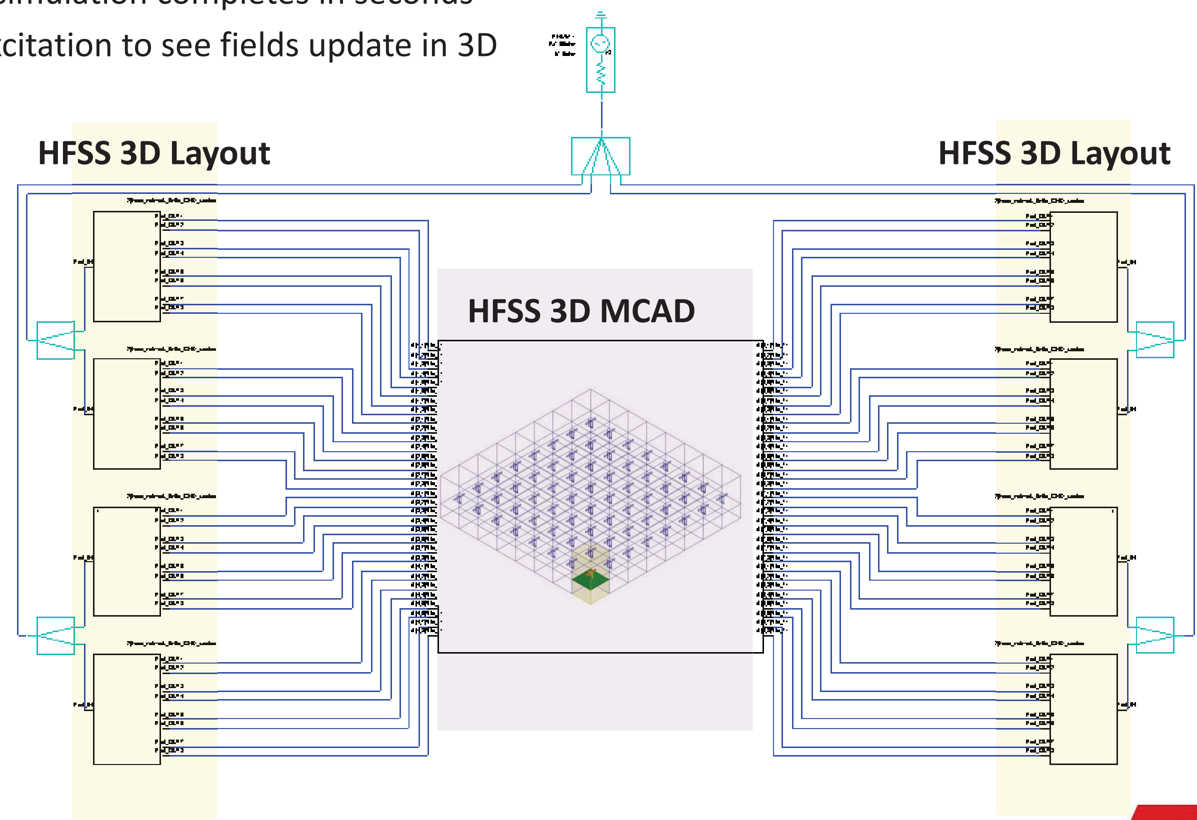


Snowflake



Individual Excitation Control

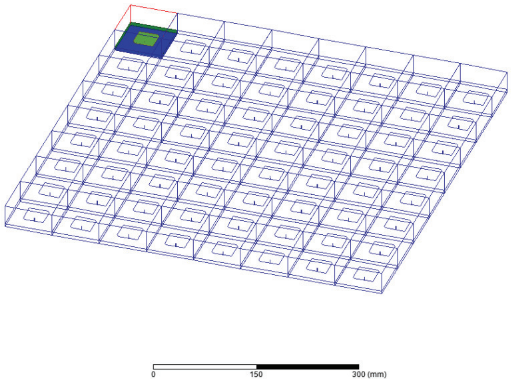
- Modular workflow
- Circuit simulation completes in seconds
- Push Excitation to see fields update in 3D

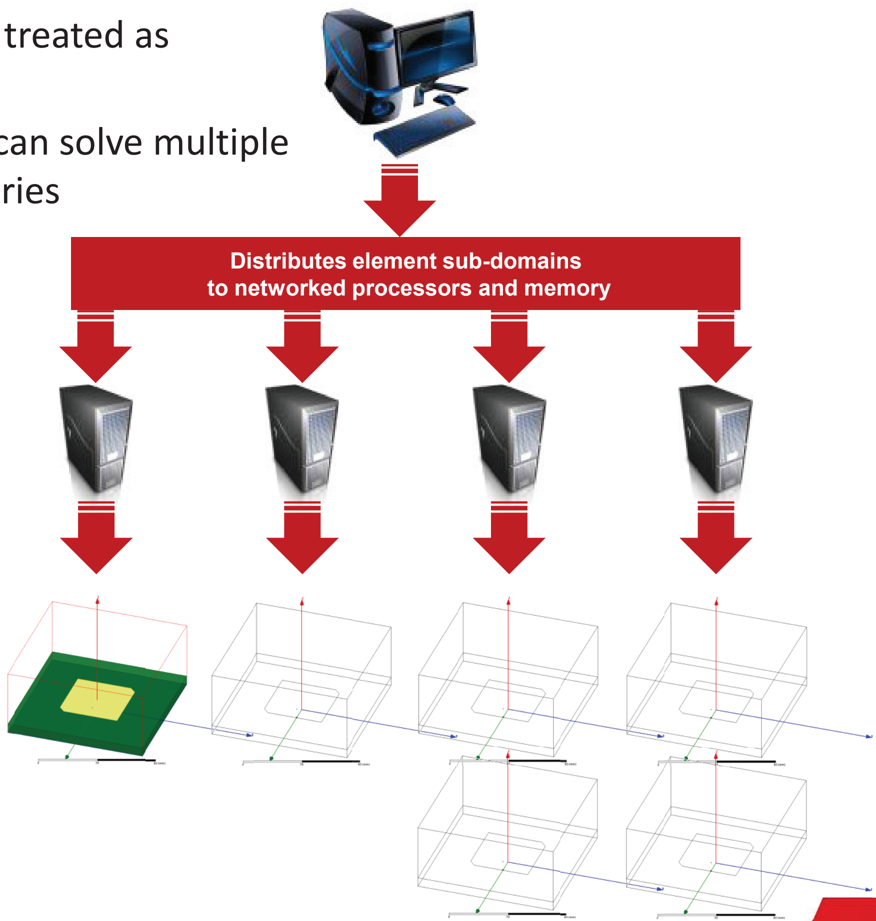


Finite Arrays Domain Decomposition

ESSS

– Each element in array treated as solution domain
– One compute engine can solve multiple element/domain in series

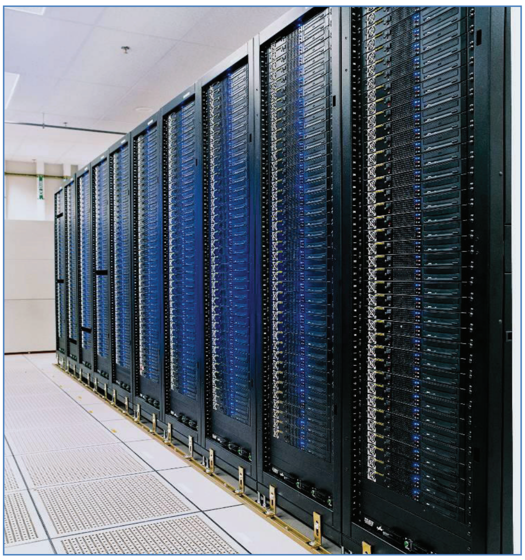


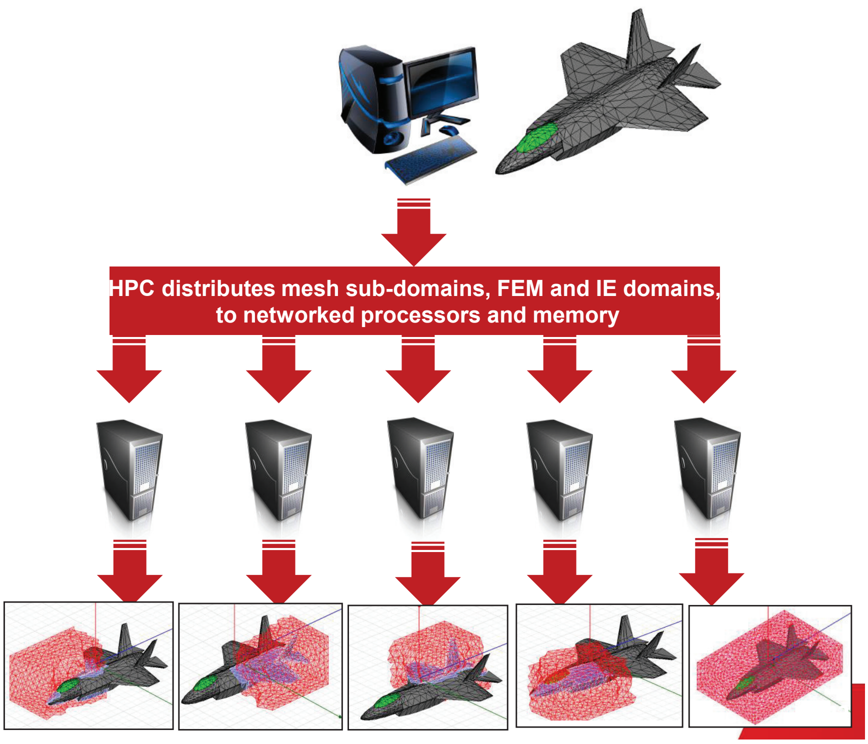


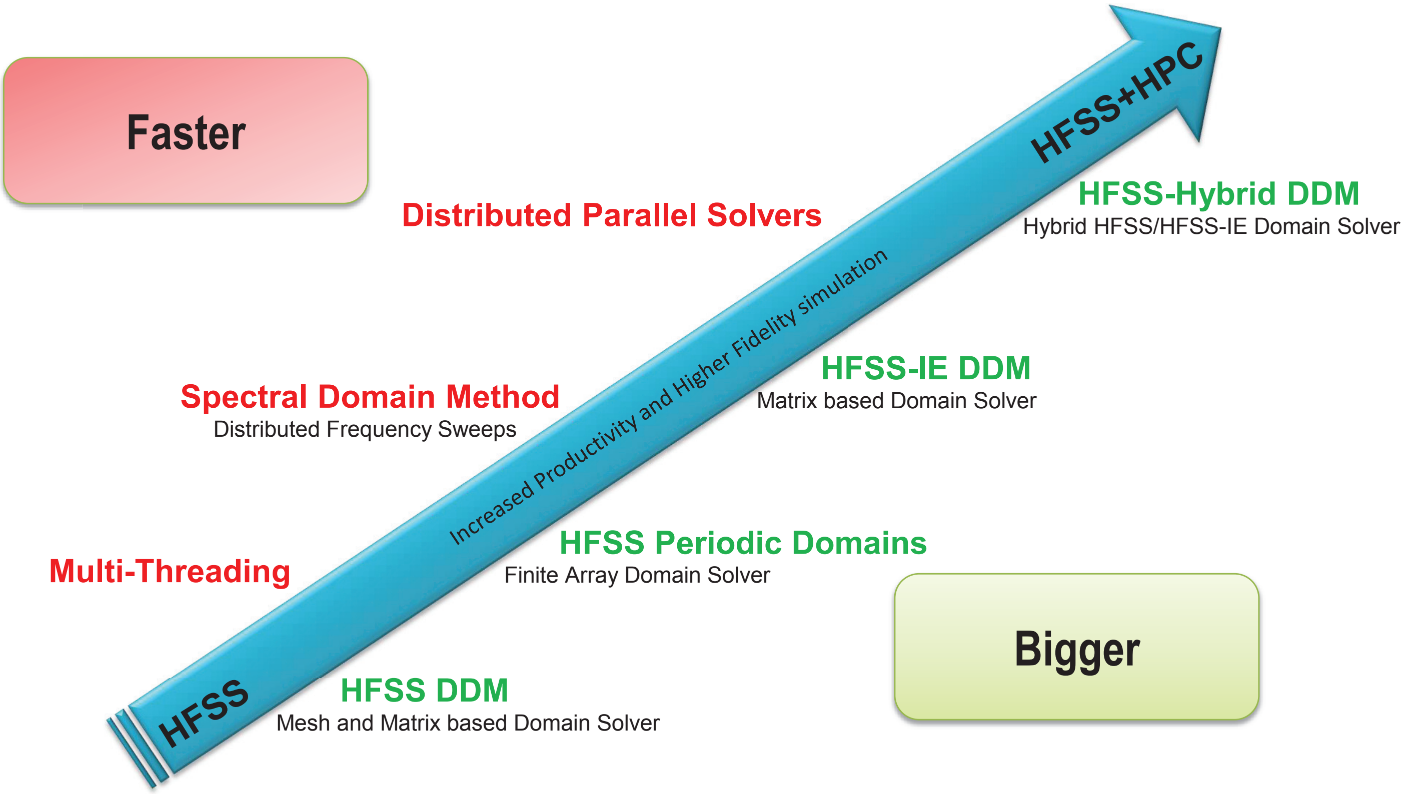
HPC Productivity Enhancements

ESSS

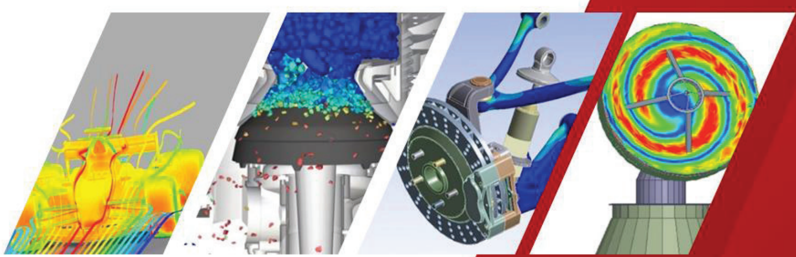
- High Performance Computing (HPC)
  – HPC enables increased productivity and higher fidelity simulation - including more geometric detail and larger systems.
  – Using HPC you can make your engineering staff, and your product development process, more productive and efficient. Faster turnaround and larger models all mean better designs in less time.







www.esss.com.br



Platform Integration

SIMULATING THE FUTURE

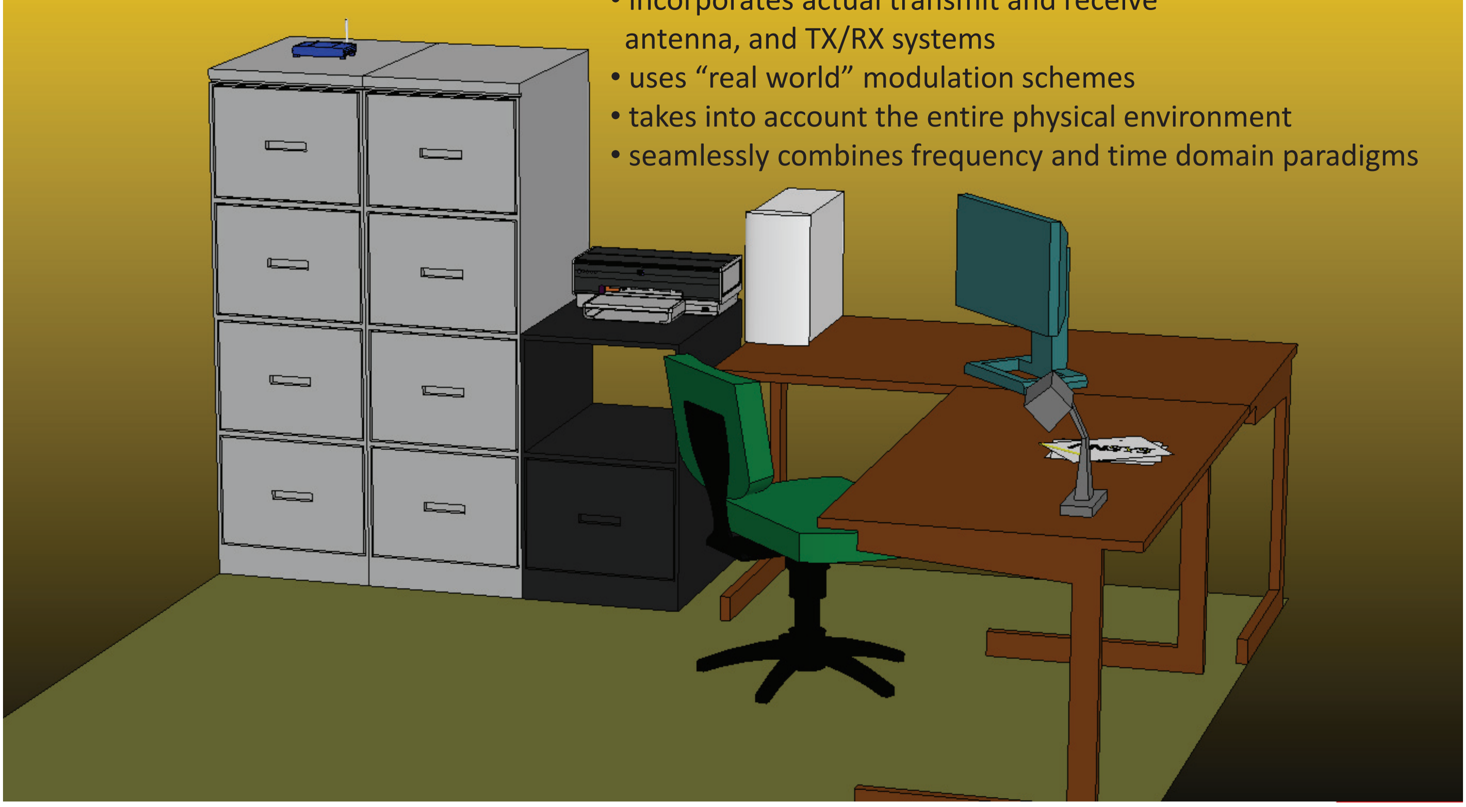
Definitions

- For the purposes of this presentation, a short-range wireless communication channel is defined as a:
  - Local area network
    - » WiFi
  - Personal area network
    - » Bluetooth, Zigbee
  - Body area network
    - » Pacemaker, other implantable medical device
- The concepts shown in this presentation can be applied to any of the above wireless network types

SR Wireless Communication Channel Methodology

State of the art simulation method that

- utilizes the best in class tools
- incorporates actual transmit and receive antenna, and TX/RX systems
- uses “real world” modulation schemes
- takes into account the entire physical environment
- seamlessly combines frequency and time domain paradigms

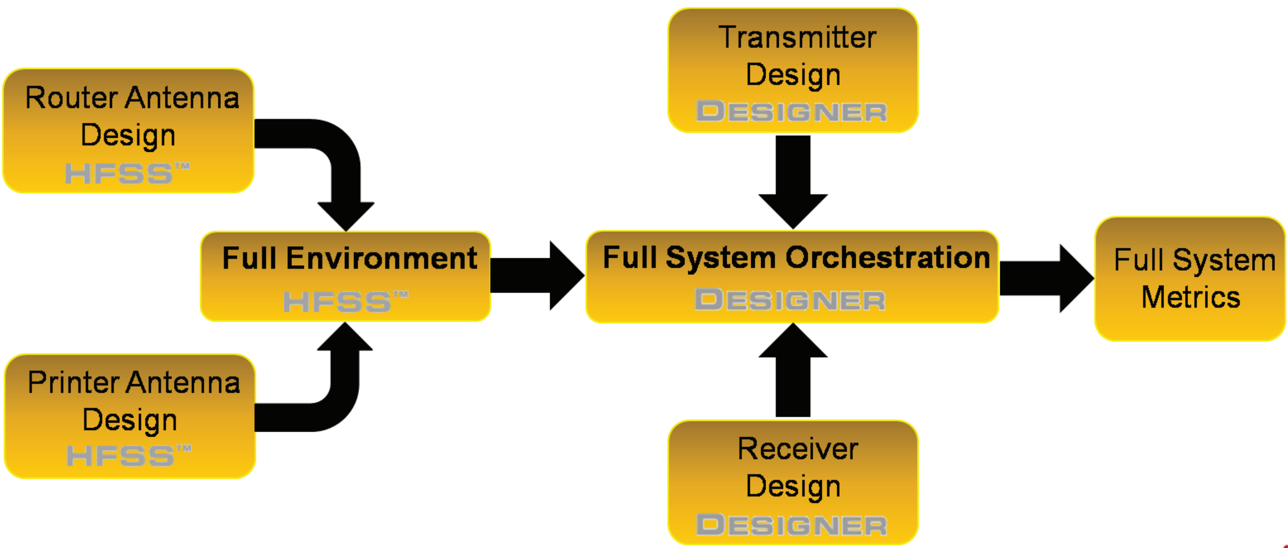


What are the tools needed

- Transmit and Receiver Antenna Modeling
  - HFSS
- Full 3D Environment Simulation
  - HFSS
- "Real World" Transmit and Receiver blocks
  - Designer
- Realistic Modulation Scheme
  - Designer
- Methodology Enablers
  - HPC

What are the steps

1. Use Designer to design / optimize transmitter and receiver system designs
2. Use HFSS to design / optimize printer and router antennas
3. Create 3D model of entire short-range environment
4. Dynamically link all above models together in Designer Schematic Desktop
5. Obtain Full Systems performance data / metrics



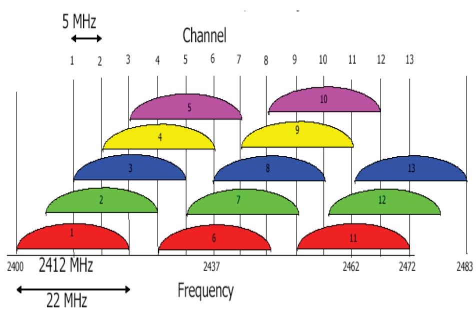
IDEAL WIRELESS SYSTEM DESIGN

WiFi Review

- Wireless Fidelity
  - Based on IEEE802.11 standard
  - Wireless network link
  - Device applications
    - Laptops, Video Games, Smart phones, Printers, etc.

- Wireless Local Area Networks
  - Wireless access to Internet
  - Access points serve homes and businesses
    - Typical range of up to 50 meters

- IEEE802.11g Data Rates & Spectrum
  - ISM Band with 22MHz channels
  - Data Rates from 6-54Mbps

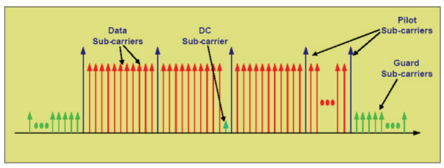


WiFi 802.11g Transmitter Model

- IEEE802.11g Specification
  - Fixed 22MHz channels from 2.4 to 2.4835GHz
  - Data rates from 6-54 Mbps
  - **Built in bit and frame accurate waveforms**
- OFDM Description
  - Orthogonal Frequency Division Multiplexing
  - Advantages
    - Relative multi-path immunity
    - Multiplexing scheme easy to implement (IFFT)
    - Ideal sub-carrier packing
    - Low sensitivity to time synchronization errors
  - 64 sub-carriers for IEEE802.11g
- Modulation & Encoding
  - BPSK, QPSK, QAM-16 or QAM-64
  - Coding rates of 1/2, 2/3 or 3/4
  - Data Rate = bit_rate*bits/symbol*coding_rate*overhead

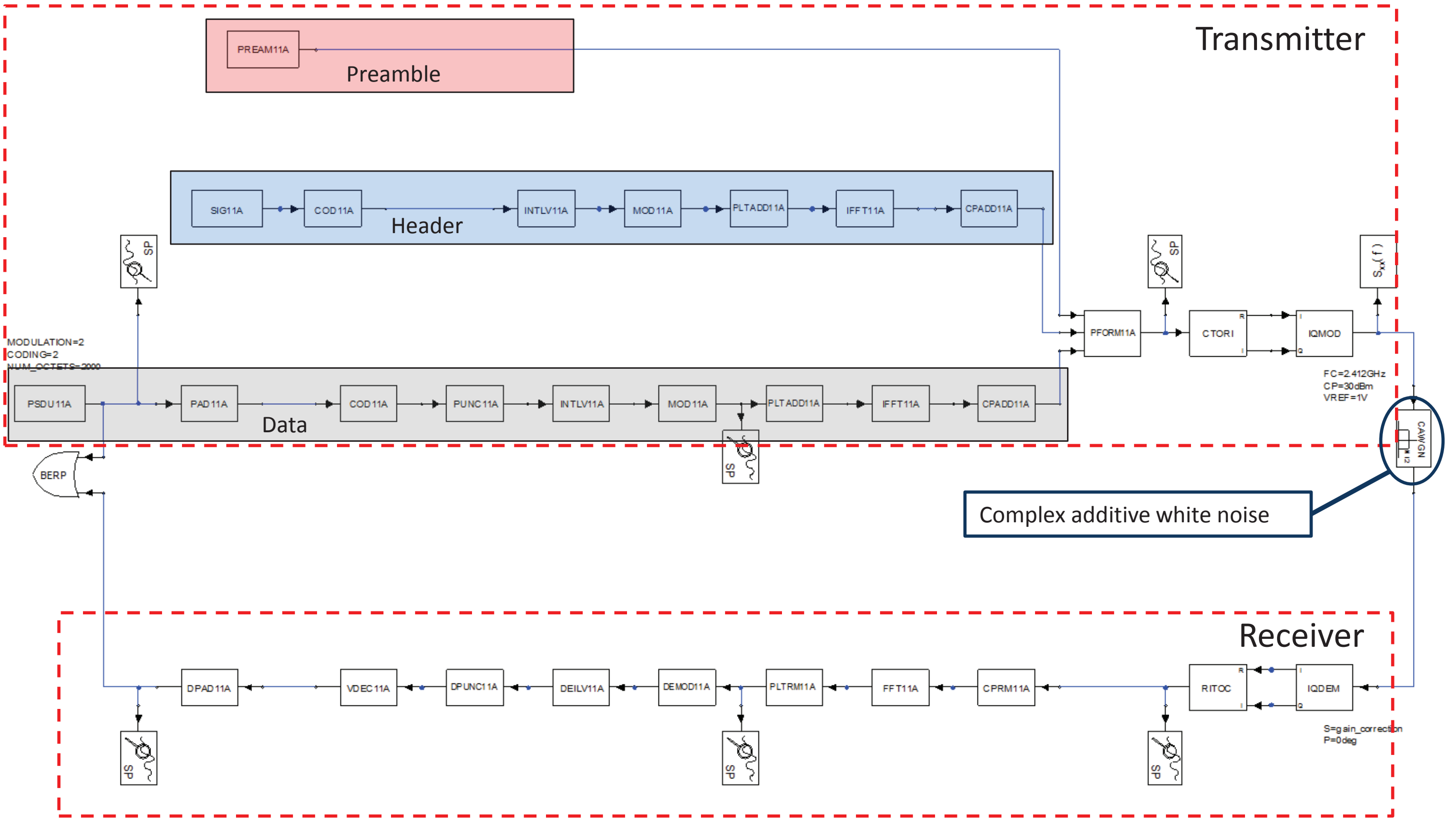
WiFi 802.11g Receiver Model

- Channel Correction
  - Use pilot channels for mag/phase

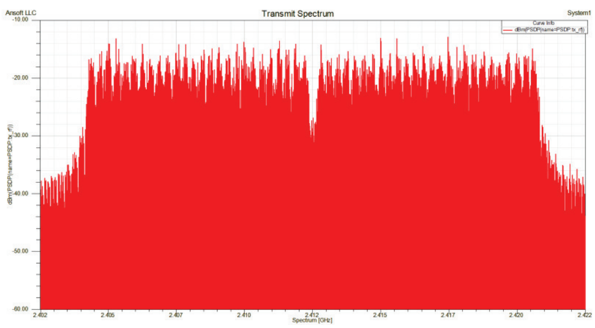


- OFDM Receiver
  - Cyclic prefix mitigates synchronization and multi-path
  - FFT integrates OFDM signal to extract modulated data
- Data Extraction
  - Framed data removed after demodulation, deinterleaving, decoding and descrambling

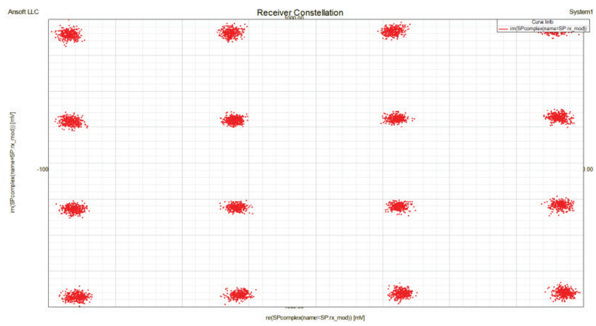
Full 802.11g Tx/Rx System Model (Ideal)



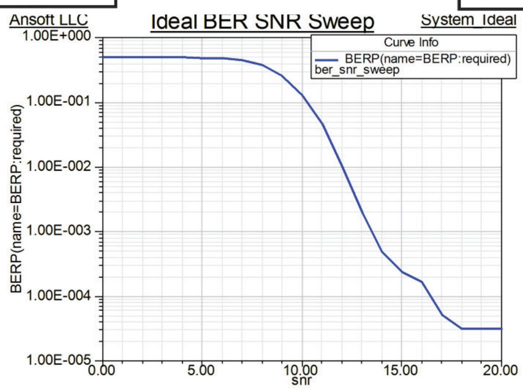
802.11g Ideal System Results



OFDM Spectrum



Rate = 36Mbps (QAM16)

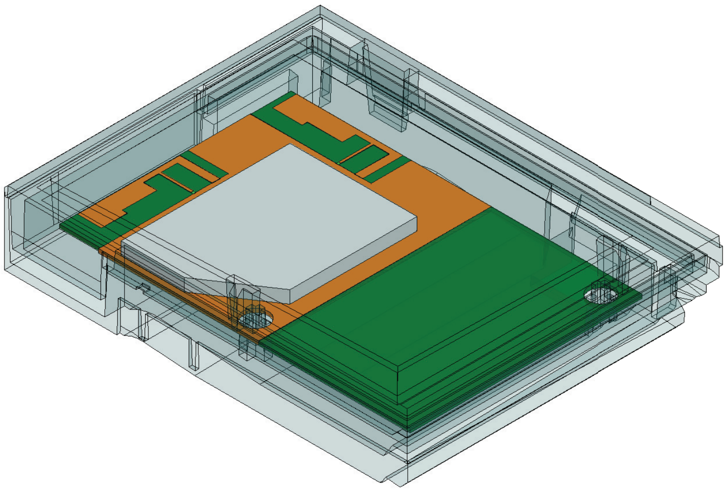


Ideal System Floor

Printer Antenna Design in HFSS

ESSS

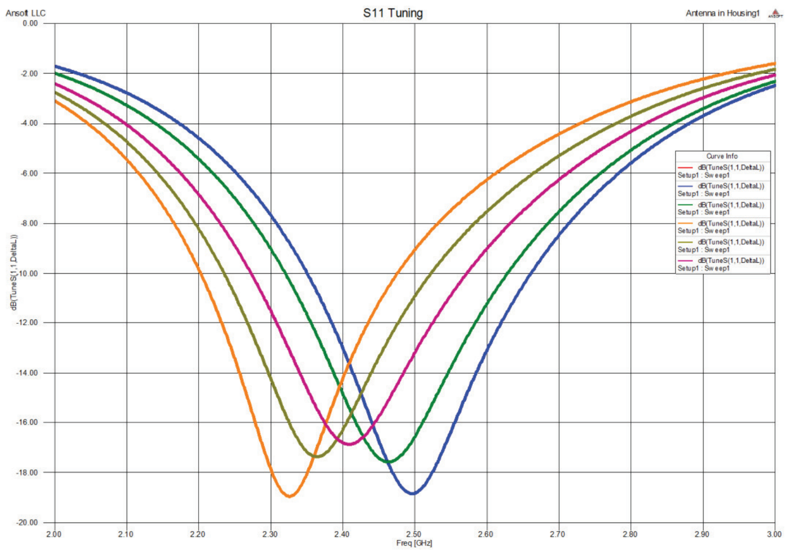
- Antenna Specifications
  - Operating Frequency of 2.44 GHz
  - Planar inverted-F (PIFA) elements used in spatial diversity combiner mode
  - Return Loss <= -10 dB
  - Antenna impedance matched to 50 ohms



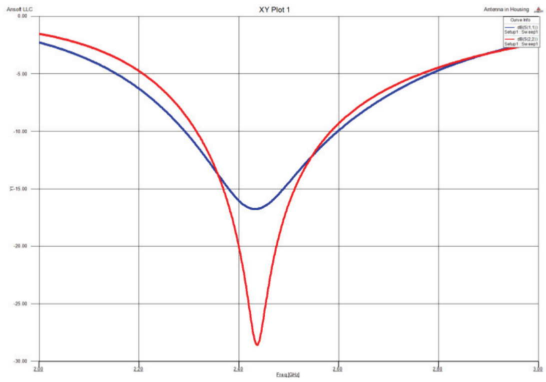
Antenna Tuning using Adjoint Derivatives

ESSS

- New Capability for sensitivity, tuning, and optimization
- Compute the derivatives of SYZ parameters with respect to project and design variables
- Eliminates need to solve multiple variations with small differences and numerical noise
  - More efficient and more accurate
- Provides real-time tuning of reports to explore effects of small design changes
- Improves derivative-based optimization methods

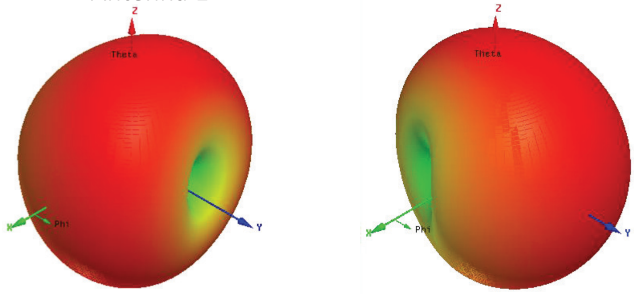


PIFA Antenna Results

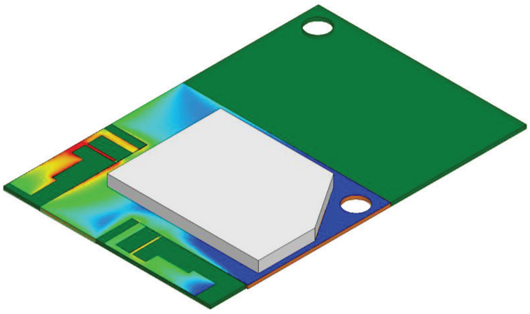


Return Loss

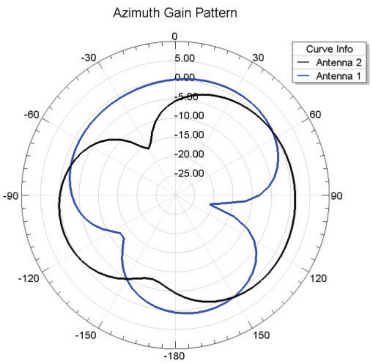
Antenna 1 Antenna 2



3D Antenna patterns

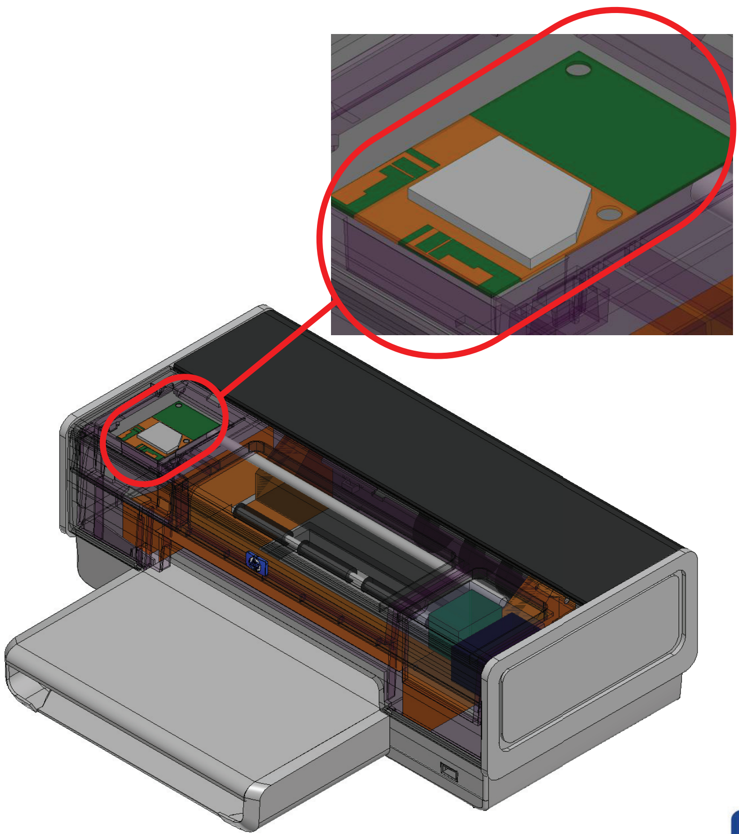


Surface current magnitude

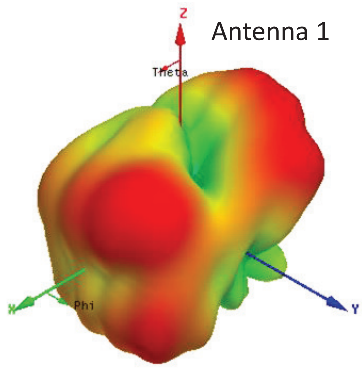


2D Antenna pattern

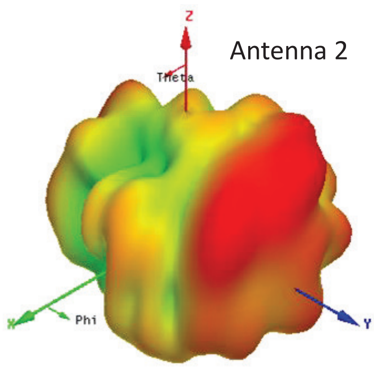
Installed Antenna Results



Antenna 1



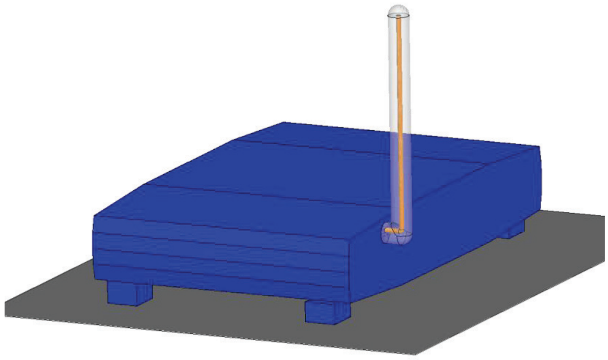
Antenna 2



Printer Model courtesy of

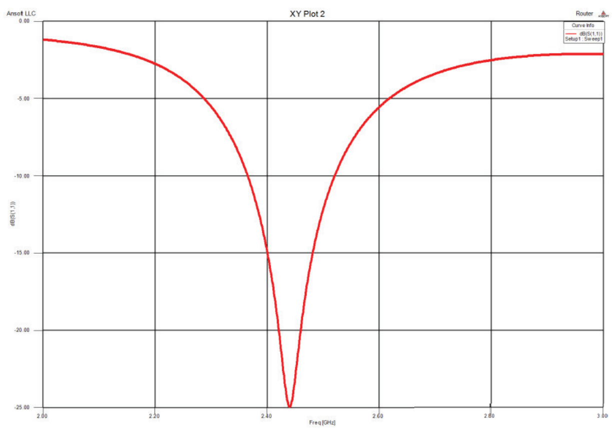
Transmit Antenna Design in HFSS

- Transmit Antenna Specifications (Router)
  - Simple Monopole
  - Operating Frequency of 2.44 GHz
  - 50 ohm input impedance
  - Linearly polarized
  - Return loss of -15 dB or better

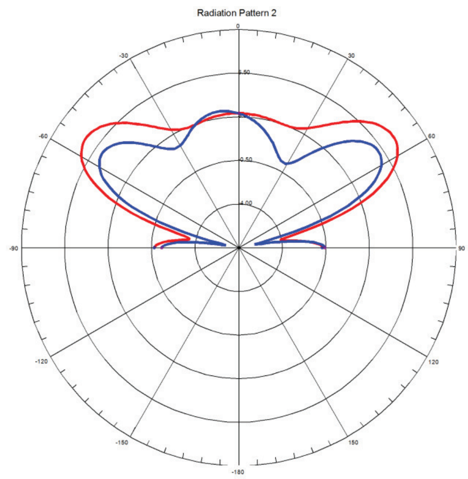


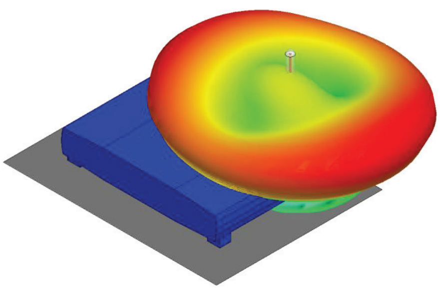
Full 3D model of Antenna
Antenna Sleeve shown as transparent for clarity

Final Transmit Antenna Results



Return Loss





Far Field pattern
Phi = 0
and 90 degrees

3D Far field Pattern (superimposed on router)

WIRELESS SYSTEM WITH REALISTIC ENVIRONMENT

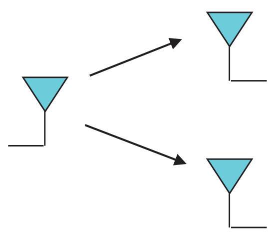
Channel Modeling

- Approximate Channel Modeling
  - Simple path loss for line of sight
  - Multi-path Rayleigh Fading for outdoors
  - Exponential statistical indoor channel models

$$\frac{\mathrm{Pr}}{Pt} = GtGr\left(\frac{\lambda}{4\pi R}\right)^2$$

$$\frac{\mathrm{Pr}}{Pt} = G_t(\theta_t, \phi_r)G_r(\theta_t, \phi_r)\left(\frac{\lambda}{4\pi R}\right)^2 (1-|\Gamma_t|^2)(1-|\Gamma_r|^2)\left|a_t \cdot a_r^*\right|^2 e^{-\alpha R}$$

- Exact Channel Modeling
  - Component coupling, mismatch, orientation
  - Physical surroundings, obstacles, etc.
  - **HFSS**: Exact, full wave, channel models



Realistic Wireless LAN Environment HFSS

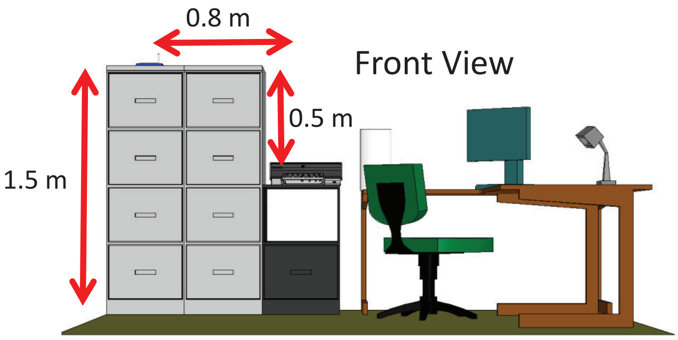
3D View

Router Antenna
Printer Antennas
Steel filing cabinets
Wood and steel desk
Various office equipment
3.3 m by 3.3 m office space

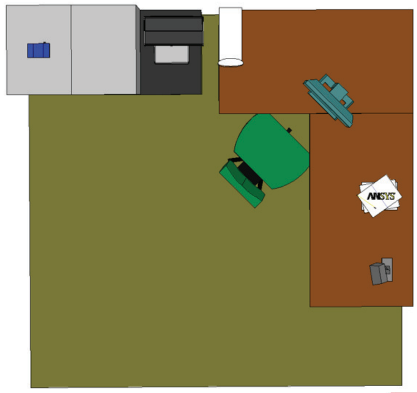
Side View

Note: No direct "Line-of-Sight" between router and printer antennas!

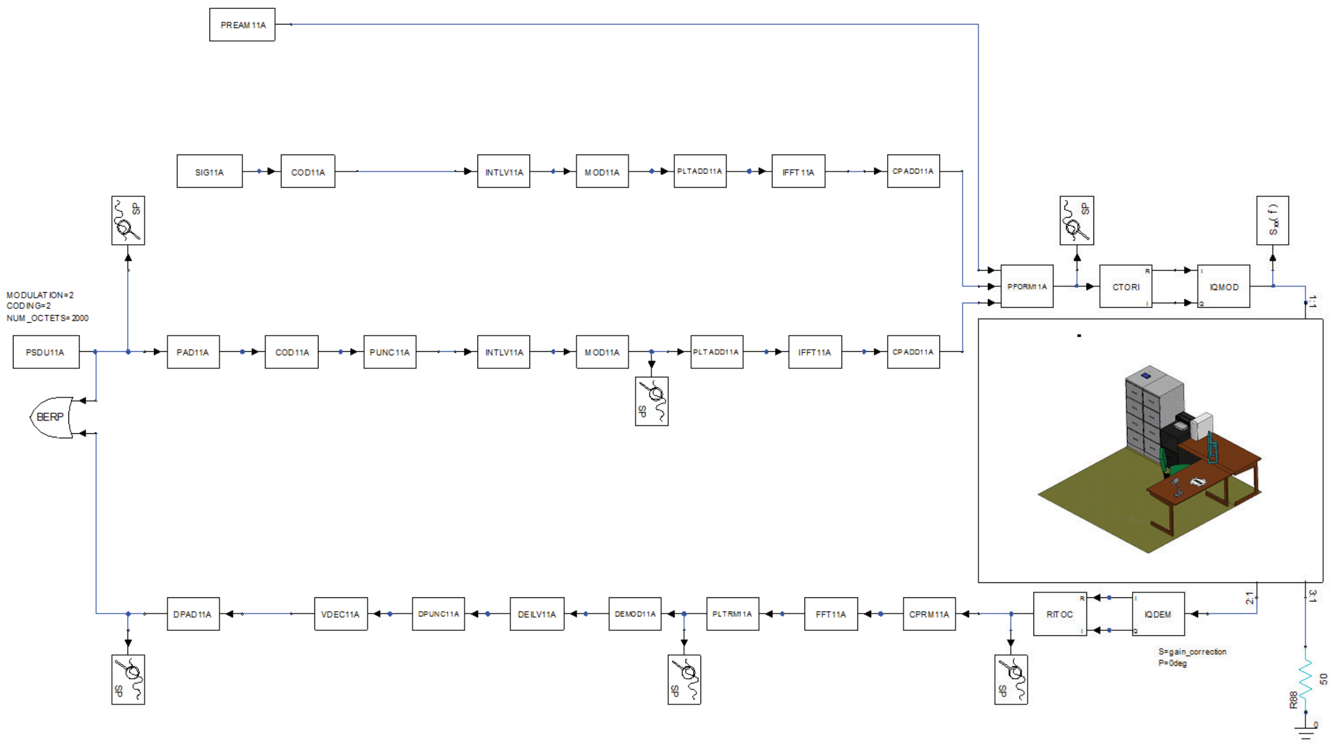
Front View



Top View

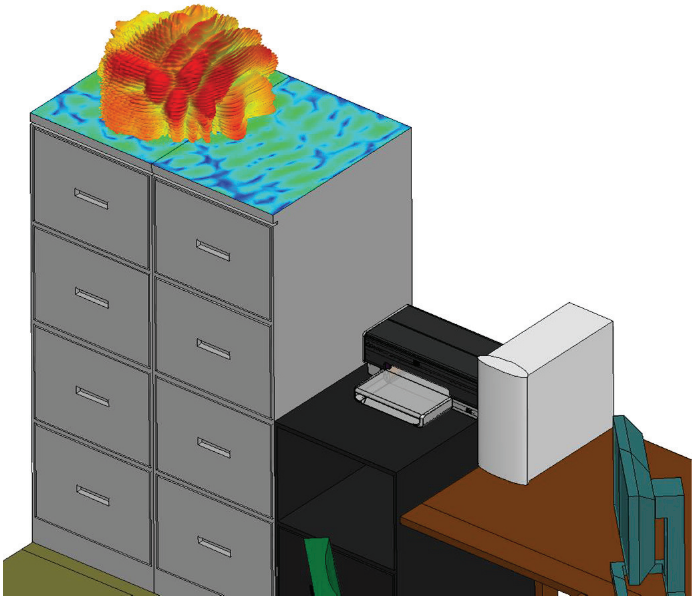


End to END Realistic Accurate Channel

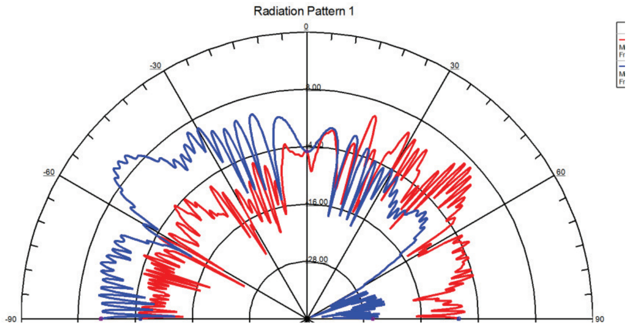


Full System Field Results

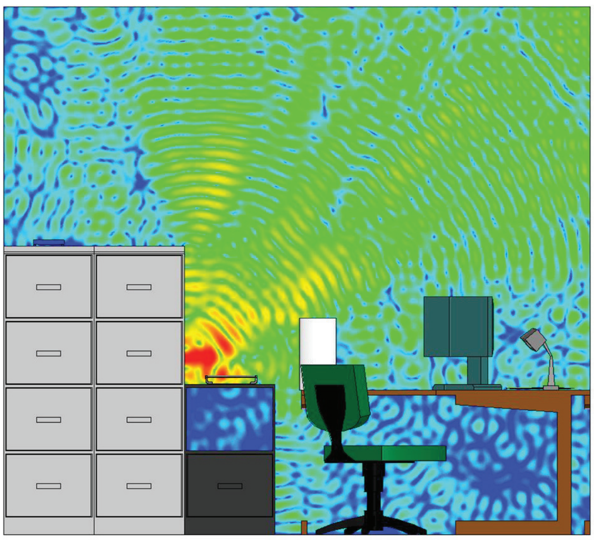
Full System Router Antenna patterns



Full System Router Antenna patterns



Full System Field Results



E Field Produced by Printer Antenna 1

Far Field Produced by Printer Antenna 1

End-to-End System Performance

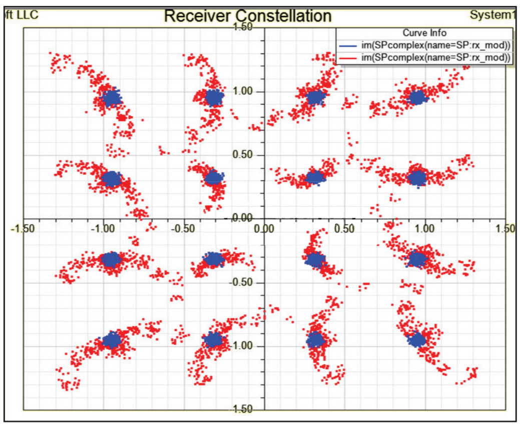
ESSS

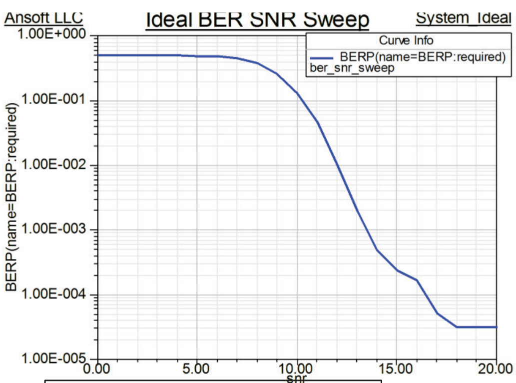
- Receiver Sensitivity
  - Ability to extract information at receiver
  - Path and signal corrections are critical
  - Signal/Noise dictates receiver sensitivity
- Bit Error Rate Analysis
  - System verification
  - Performance degradation
    - Comparisons of ideal channel versus realistic room model
    - Full wave EM simulation identifies true system performance limit

802.11g Ideal vs. Realistic System Results

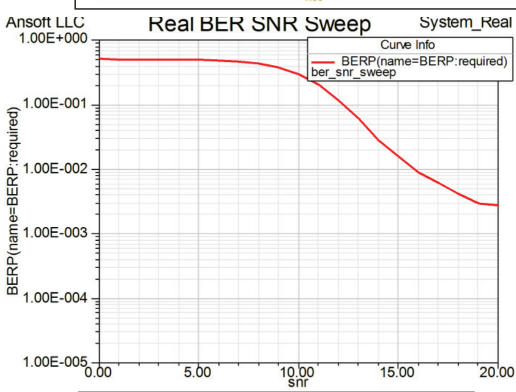
ESSS

- Results show that
  - Phase and magnitude errors are significant even with correction
  - System noise floor is impacted by environment and is quantifiable





Ideal System Floor



Realistic System Floor

FIRST-PASS SYSTEM SUCCESS
APPLICATION WORKSHOPS FOR HIGH-PERFORMANCE ELECTRONIC DESIGN

WiMax MIMO Circuit and System Design

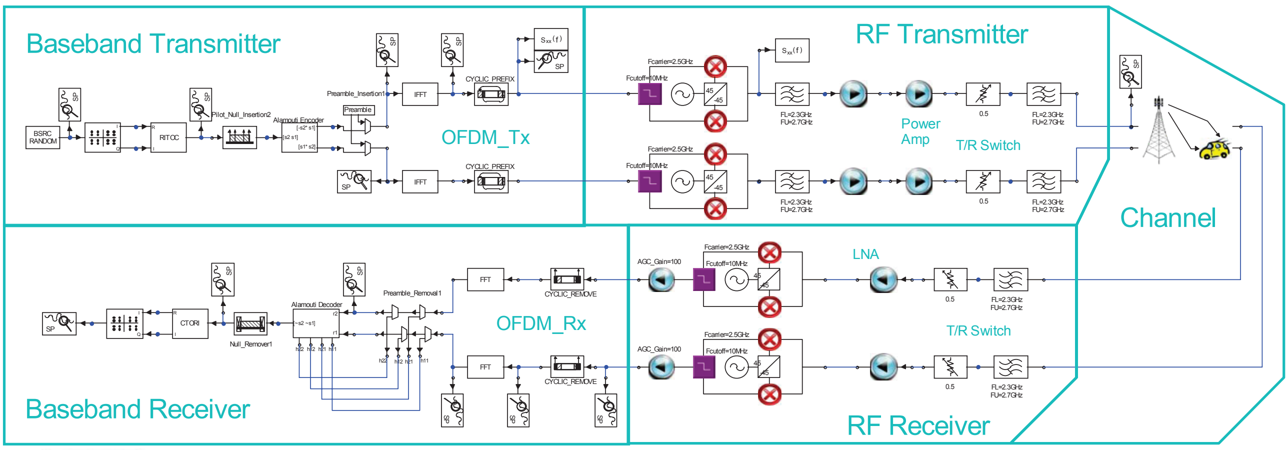
Presenter: **Eldon Staggs**

Authors: **Jim DeLap, John Borelli, Tony Donisi, Eldon Staggs**

Ansoft Corporation

Mobile WiMax System

- WiMax System Modeling
  - Behavioral, Circuit and Physical



Agenda

WiMAX FORUM

Introduction to Mobile WiMax

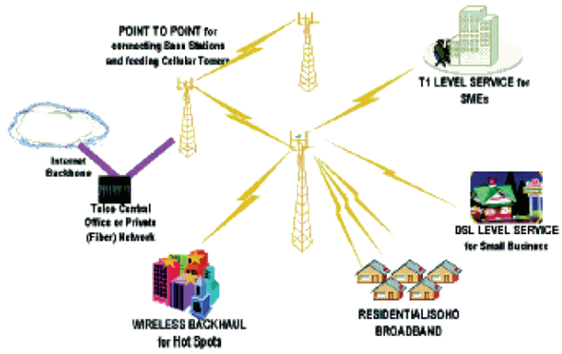
System Architecture

MIMO Antennas

Receiver Circuit

Integration

Conclusion



WiMAX - Mid Range IEEE Communication Standard

Range	Standard
> 10 Km	Wide Area Networks
< 10 Km	Metro Area Networks
< 100 m	Local Area Networks
< 10 m	Personal Area Networks
< 1 m	Body Area Networks

802.16
- Last mile broadband wireless access
- 40Mbps capacity up to 10km
- OFDM with QPSK/QAM16/QAM64
- Fixed, Portable (walking) and **Mobile** (in car) options

today

802.16e
- 63Mbps peak capacity up to 3km at 2.3,2.5 or 3.5GHz
- No line-of-sight required

Our focus today is Mobile WiMAX, a standard designed to enable high data rate applications such as the wireless Internet.

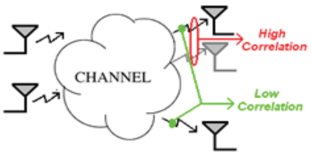
ANSOFT
FIRST-PASS SYSTEM SUCCESS
APPLICATION WORKSHOPS FOR HIGH-PERFORMANCE ELECTRONIC DESIGN

WiMAX Architecture Based on 2 Core Features: MIMO & OFDM

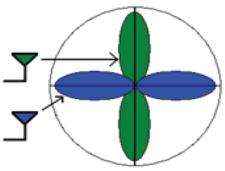
Our examples today will illustrate how MIMO and OFDM can be simulated.

1. MIMO (Multiple Inputs Multiple Output = Many Antennas)
   - **Advantage**: More antennas means more data or reliability. For example, if 2 TX and RX antennas are present, then data rate should double.
     Data rates will scale linearly.
   - **Challenge**: How to design system so that interactions between multiple TX and RX are minimized.

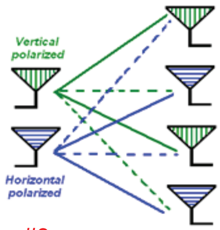
   Solutions, thus far, have emphasized 4 diversity schemes:



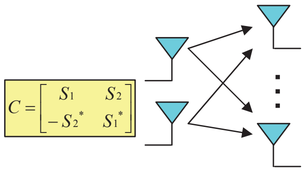
#1: Space Diversity



#2: Pattern Diversity



#3: Polarization Diversity



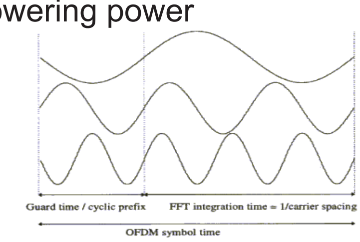
#4: Space Time Coding

APPLICATION WORKSHOPS FOR HIGH-PERFORMANCE ELECTRONIC DESIGN

WiMAX Architecture Based on 2 Core Features: MIMO & OFDM

Our examples today will illustrate how MIMO and OFDM can be simulated.

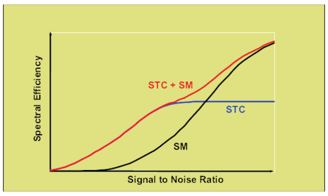
2. OFDM (Orthogonal Frequency Division Multiplexing)
   - **Advantages:**
     → Relative immunity to multi-path effects
     → Multiplexing schemes, using IFFT & FFT, are easily implemented
     → Low sensitivity to time synchronization errors
     → Tuned sub-channel receiver filters are not required (unlike conventional FDM)
   - **Challenges:**
     → Sensitive to Doppler shift
     → Sensitive to frequency synchronization
     → High peak-to-average-power ratio (PAPR), requiring more expensive transmitter circuitry, and possibly lowering power efficiency



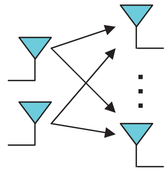
APPLICATION WORKSHOPS FOR HIGH-PERFORMANCE ELECTRONIC DESIGN

Mobile WiMax Details

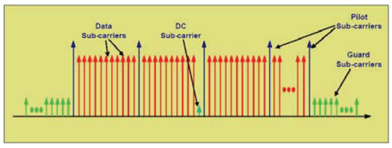
- Flexibility
  - All aspects can change dynamically to suit the channel



- WiMax MIMO 2x2 Configuration
  - Beamforming
  - **Spatial Multiplexing**
    - Complicated algorithms for data rate increase
    - Data rate scales with min(Ntx,Nrx) antennas
  - Space Time Coding
    - Diversity gain with easy implementation

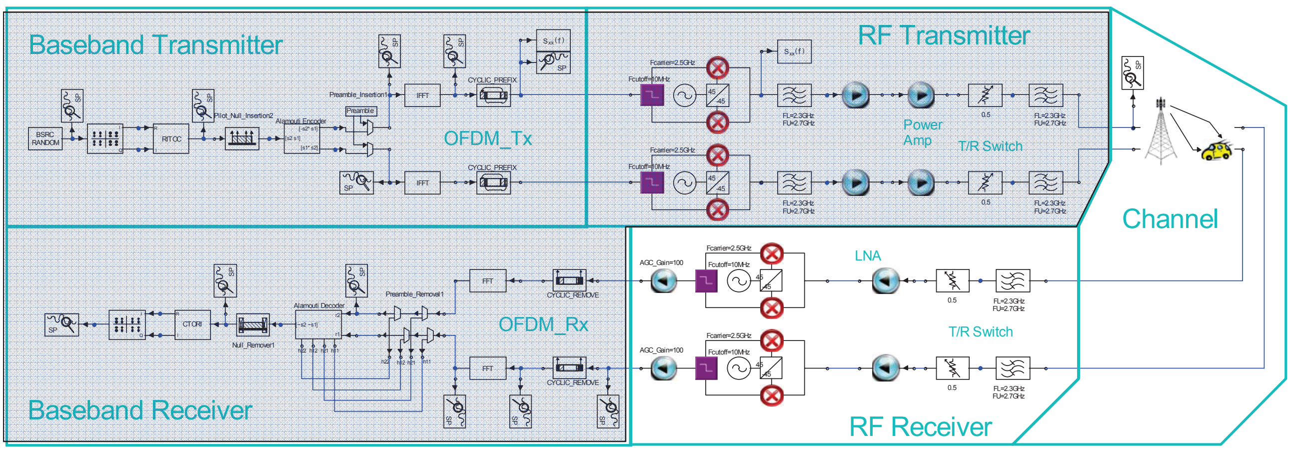


- OFDM Implementation
  - Sub-carrier and Symbol times fixed
  - BW usage dictated by IFFT length
  - Downlink Data Rate



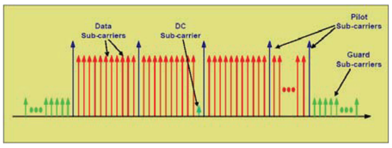
System Architecture

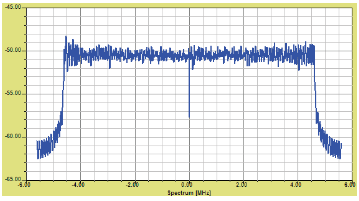
Behavioral

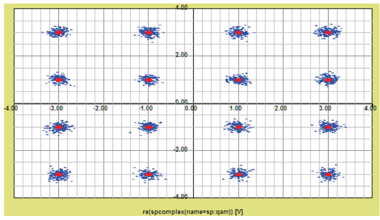


Baseband Modeling

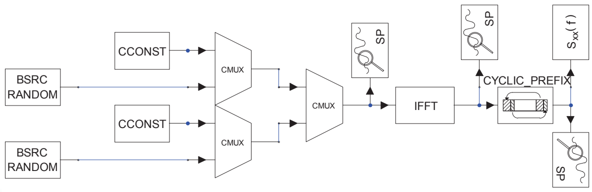
- OFDM Modeling
  - Guard Band
  - Cyclic Prefix
    - Delay Spread & Multipath Immunity







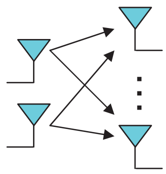
- QAM Modulation
  - 4/16/64 Supported

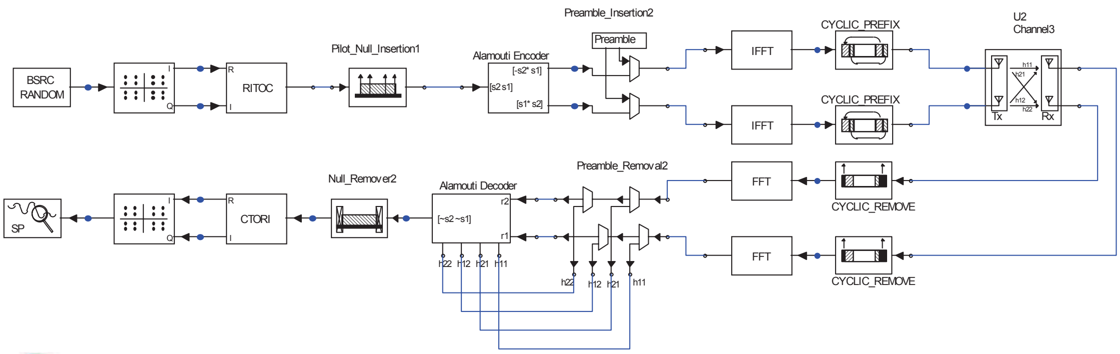


FIRST-PASS SYSTEM SUCCESS
APPLICATION WORKSHOPS FOR HIGH-PERFORMANCE ELECTRONIC DESIGN

Baseband Modeling

- Channel Detection
  - Excite Transmit Antennas separately
    - Initial frequency estimation
  - Pilots
    - Dynamic estimation

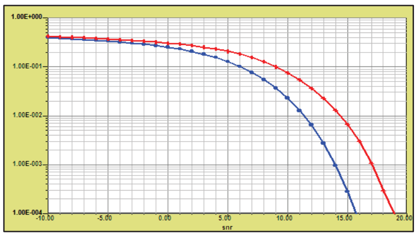




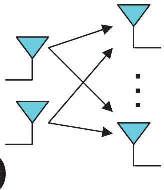
FIRST-PASS SYSTEM SUCCESS
APPLICATION WORKSHOPS FOR HIGH-PERFORMANCE ELECTRONIC DESIGN

Baseband Modeling

- Space Time Coding
  - Orthogonal Alamouti Codes



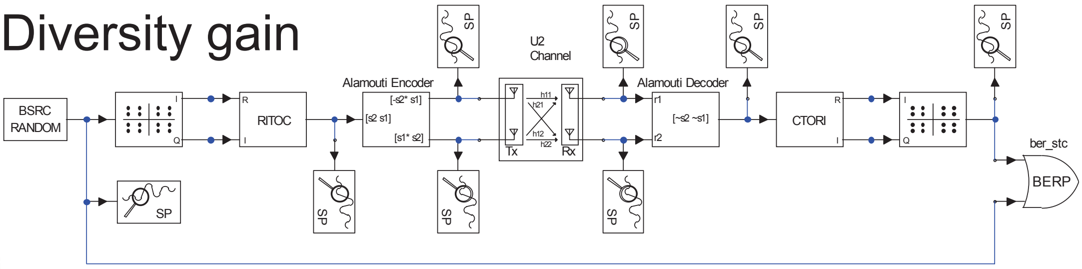
$$C = \begin{bmatrix} S_1 & S_2 \\ -S_2^* & S_1^* \end{bmatrix}$$



$$\tilde{S}_1 = \sum_{j=1}^{Mr} (h_{j1}^* \cdot r_j[0] + h_{j2} \cdot r_j[1]^*)$$

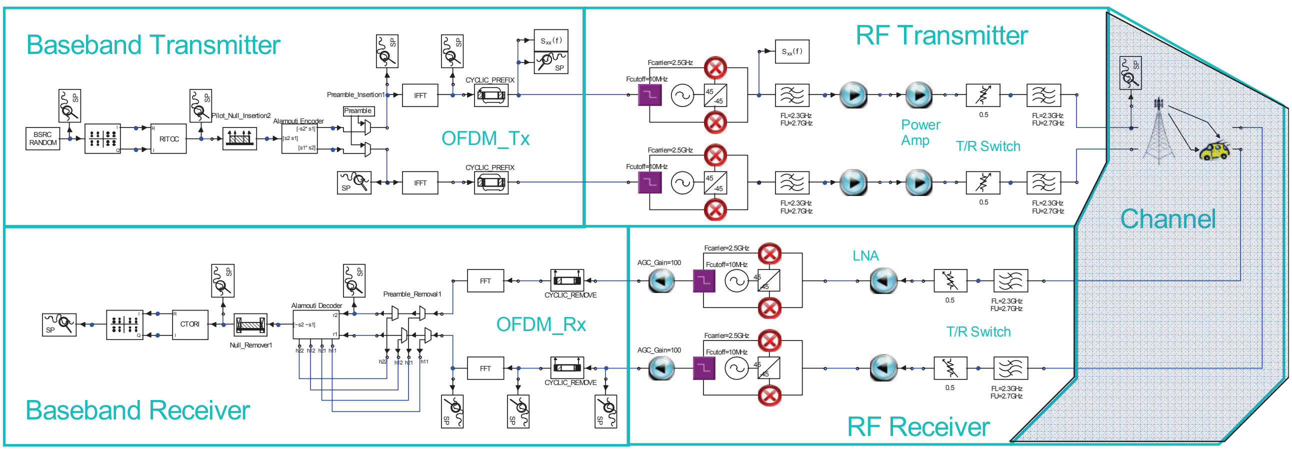
$$\tilde{S}_2 = \sum_{j=1}^{Mr} (h_{j2}^* \cdot r_j[0] + h_{j1} \cdot r_j[1]^*)$$

- SISO vs MIMO
  - Diversity gain



MIMO Antenna Design

Physical



FIRST-PASS SYSTEM SUCCESS
APPLICATION WORKSHOPS FOR HIGH-PERFORMANCE ELECTRONIC DESIGN

WiMax Physical Channel

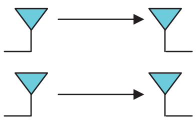
- Simplified Channel Model
  - Path Loss with Friis Transmission equation
  - Non-Ideal effects often ignored
    - Element coupling, Mismatch, Orientation
  - Single value for Antenna gains

$$\frac{Pr}{Pt} = GtGr\left(\frac{\lambda}{4\pi R}\right)^2$$

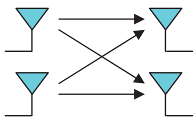
$$\frac{Pr}{Pt} = G_t(\theta_t,\phi_r)G_r(\theta_t,\phi_r)\left(\frac{\lambda}{4\pi R}\right)^2(1-|\Gamma_t|^2)(1-|\Gamma_r|^2)|a_t \cdot a_r^*|^2 e^{-\alpha R}$$

- More Accurate Channel Model
  - Full-wave 3D EM modeling with HFSS
  - System Non-linearities
    - Multi-path, Fading, etc.

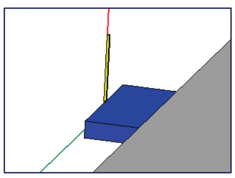
WiMax Physical Channel

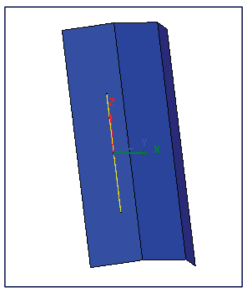


- Antenna Configurations
  - SISO and full 2x2 MIMO
  - Designs centered at 2.5GHz



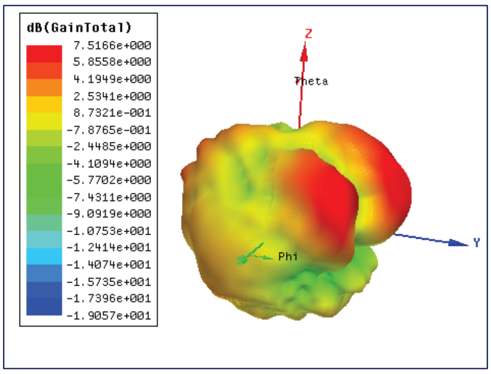
- Mobile Station
  - Laptop with WiMax Modem PC Card
  - Simple Radiating Mononpoles
- Base Station
  - Reflector backed Dipoles

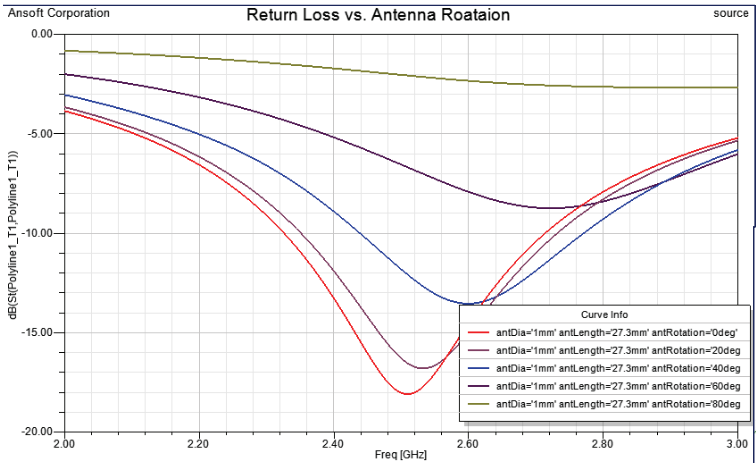


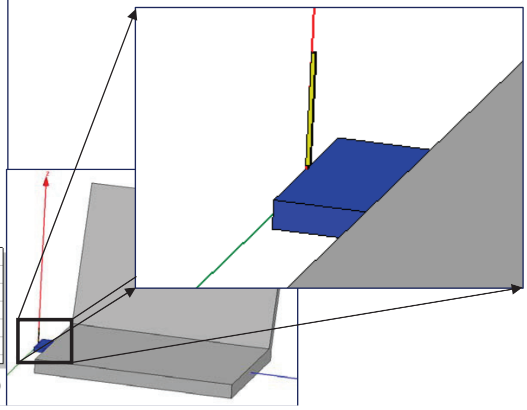


Mobile Station Antenna

- Tuned Monopole
- Monopole Response
  - Far Field
  - Return Loss

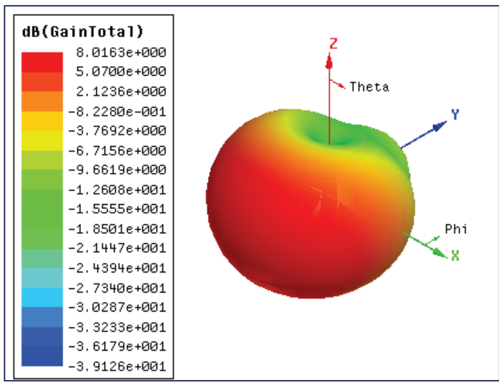


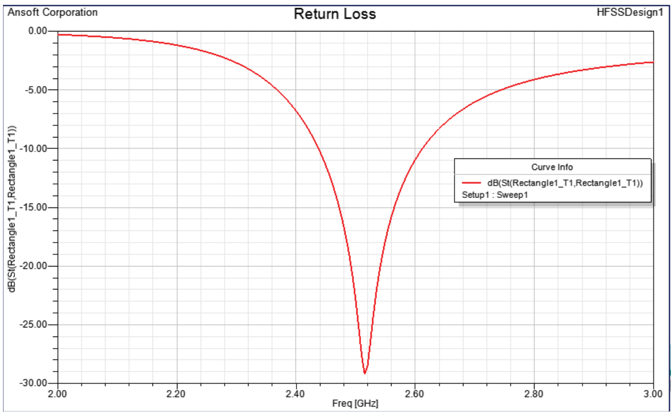


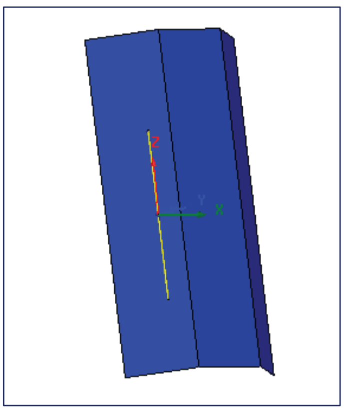


Base Station Antenna

- Reflector Backed Dipole
  - Optimized for Directivity
- Dipole Response
  - Far Field
  - Return Loss

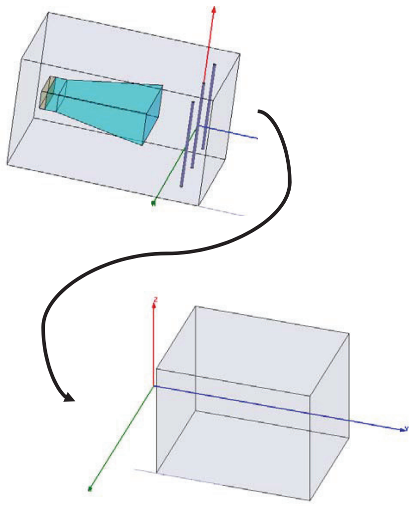






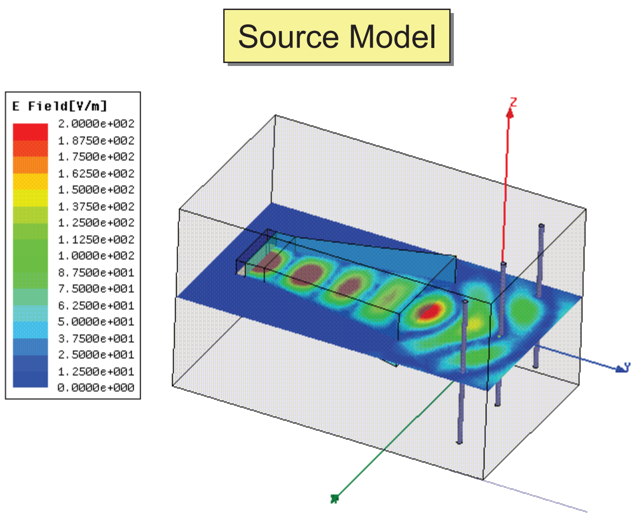
Link Simulation

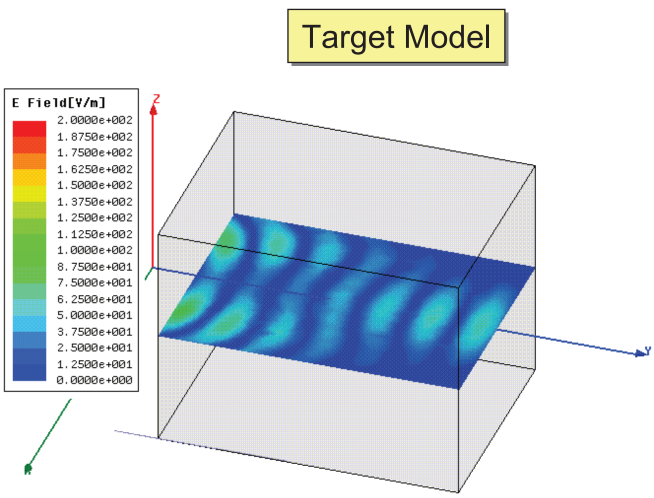
- Physical Channel
  - Antennas modeled
  - How to simulate link between?
- Utilize Ansoft HFSS Datalink
  - Fields from one drive another
  - Large separation *without* modeling air



HFSS Datalink

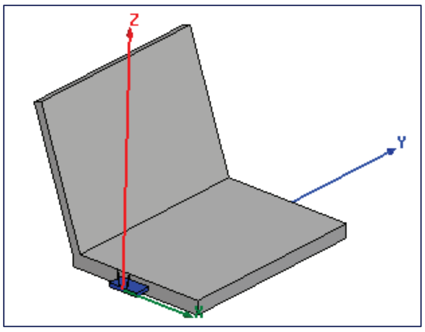
- Source Fields of Radiation Boundary
  - Imposed on target model with loss and phase



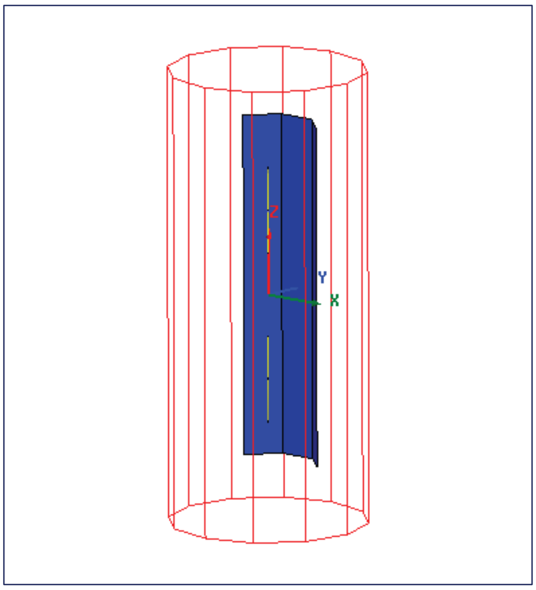


MIMO Datalink

Fields from Source model radiation BC Mapped to target model using a Far Field Incident Wave

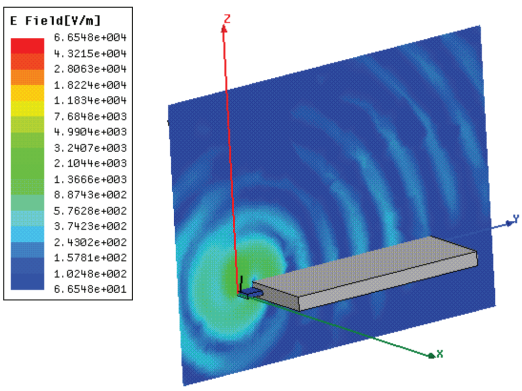


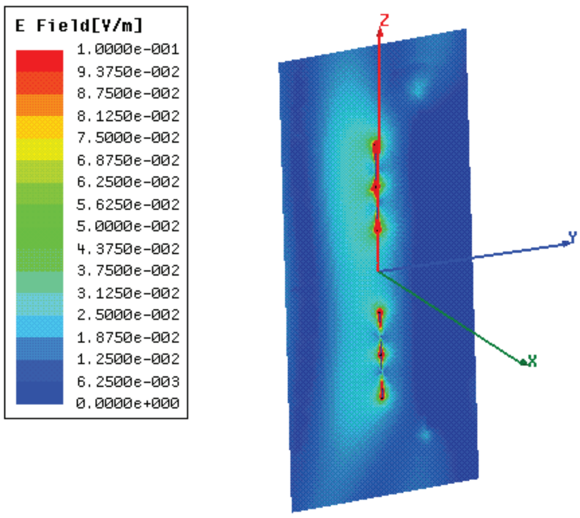
Laptop Model with Dual Monopoles



BS Model with Dual Dipoles and reflector

MIMO Physical Channel Datalink





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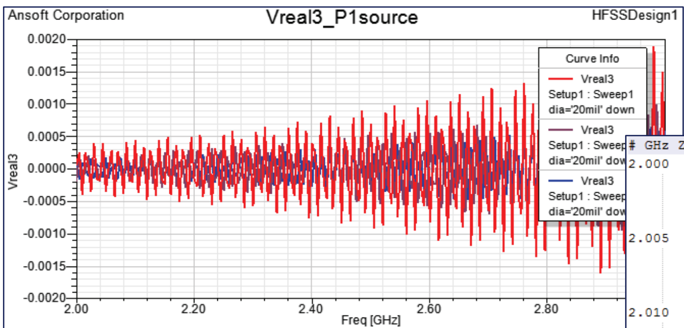
MIMO Physical Channel Circuit Model

- HFSS-HFSS Datalink maps fields from a source volume to the target volume
- Q: How does this translate to a working circuit model ?
- A: Utilize the [Z] matrix in Nexxim
  1. Excite each antenna in system with a 1 A current source
  2. Using Datalink, measure O.C. voltage at all the other antennas
  3. Construct [Z] matrix from Voltages

MIMO Physical Channel Circuit Model

- Voltage values extracted as real/imaginary pairs
- Assembled into [Z] matrix

$$Z_{ij} = \left. \frac{V_i}{I_j} \right|_{I_k=0, k \neq j}$$



# GHz	Z RI			
2.000	4.303477e+001	-5.283275e+001	1.201388e+001	-3.679990e+001
	1.201388e+001	-3.679990e+001	4.303477e+001	-5.283275e+001
	6.063290e-005	3.853089e-004	1.171931e-004	3.914764e-004
	1.491240e-004	3.505291e-004	2.185571e-004	3.652588e-004
2.005	4.320975e+001	-5.219445e+001	1.178980e+001	-3.702757e+001
	1.178980e+001	-3.702757e+001	4.320975e+001	-5.219445e+001
	2.541410e-004	-2.992045e-004	2.215559e-004	-3.465905e-004
	1.694106e-004	-3.437999e-004	1.348097e-004	-4.063301e-004
2.010	4.338952e+001	-5.155145e+001	1.156398e+001	-3.725475e+001
	1.156398e+001	-3.725475e+001	4.338952e+001	-5.155145e+001
	-3.951430e-004	2.533272e-006	-4.099391e-004	5.873764e-005
	-3.734146e-004	9.648559e-005	-3.981625e-004	1.640419e-004
2.015	4.357428e+001	-5.090417e+001	1.133625e+001	-3.748166e+001

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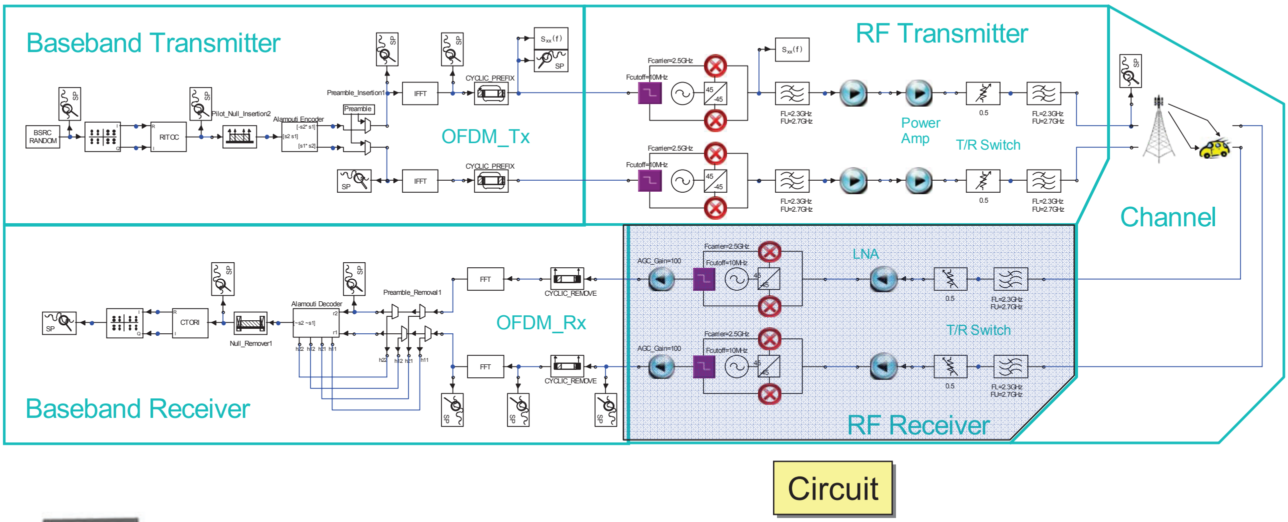
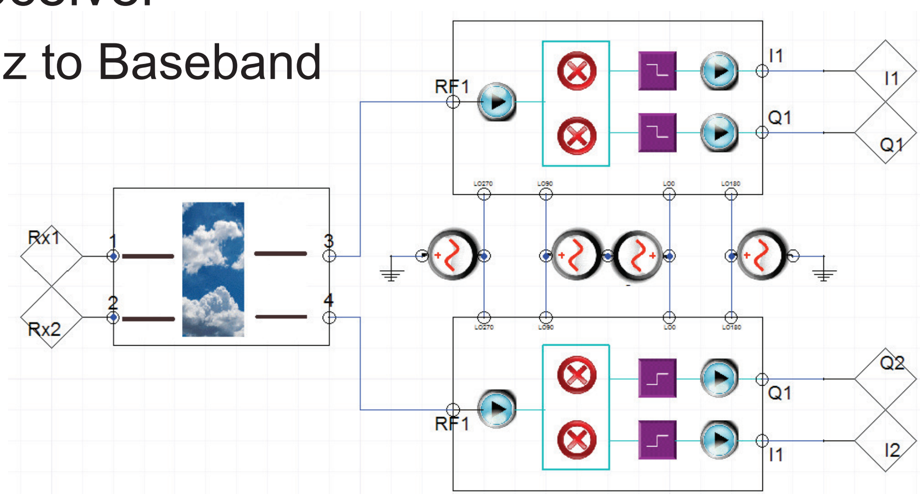
WiMax Circuit Design



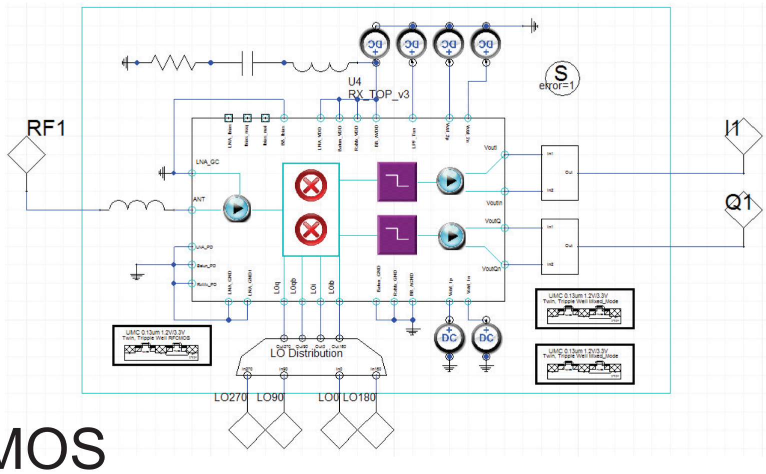
Antenna/Circuit Test Bench

- 2x2 MIMO Channel
- Dual Receiver
  - 2.5GHz to Baseband



WiMax Single RX Block Diagram

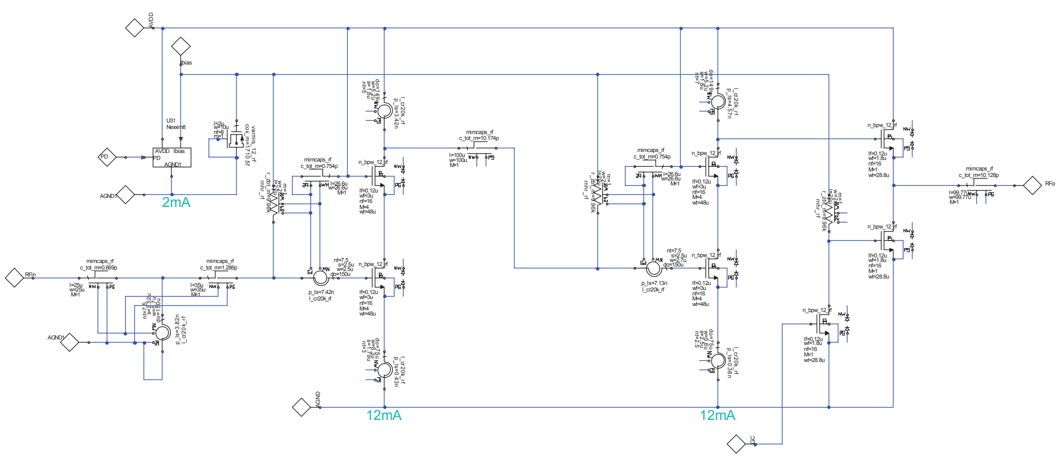
- Receiver per Antenna
  - Variable Gain LNA
  - Active Balun
  - IQ Mixer
  - Baseband Filter
  - AGC



- UMC 0.13um CMOS

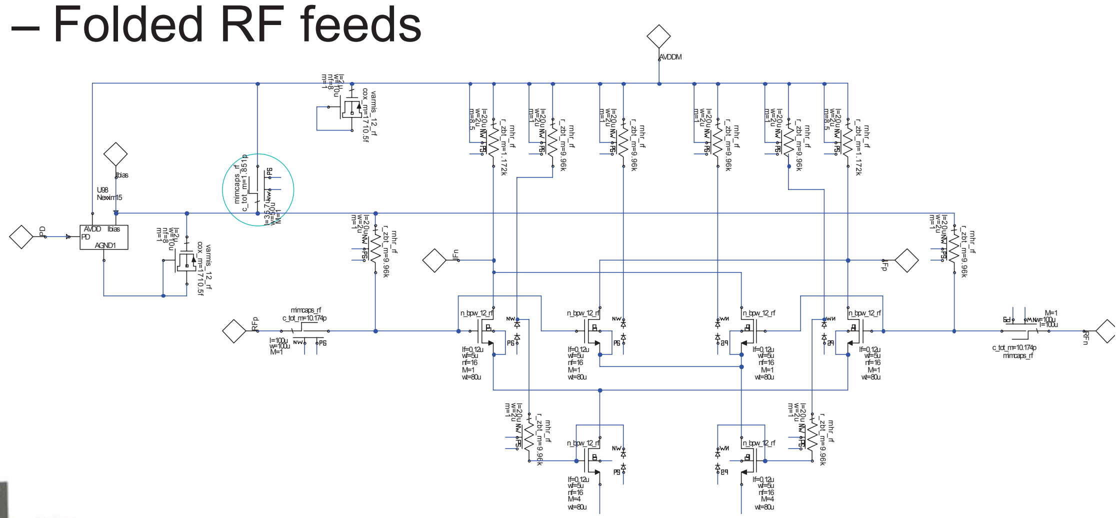
WiMax Receiver

- Variable-Gain LNA
  - 2-stage, inductively-loaded cascode topology
  - output follower stage gain control.



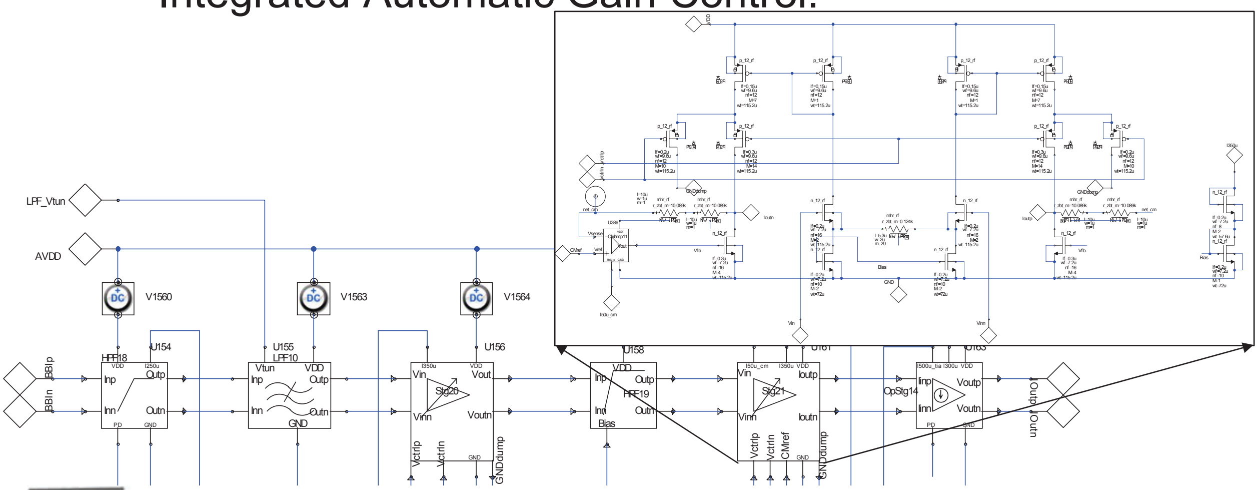
WiMax Receiver

- I-Q Mixer
  - Dual, resistively-loaded Gilbert Cell cores
  - Folded RF feeds



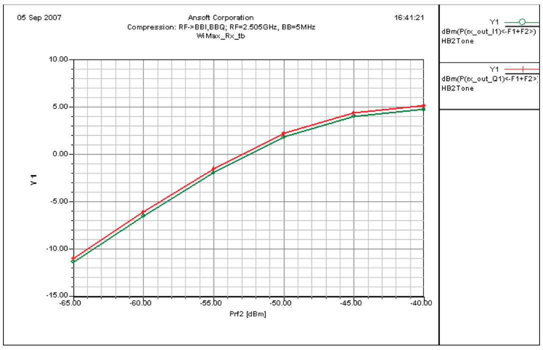
WiMax Receiver

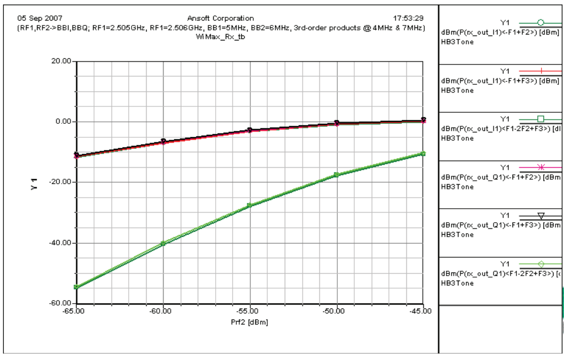
- Baseband Filter & AGC
  - Buffered active (gm-C)/passive bandpass
  - Integrated Automatic Gain Control.

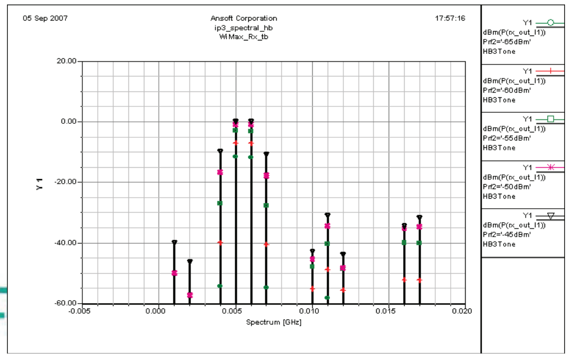


WiMax RX Linearity Metrics

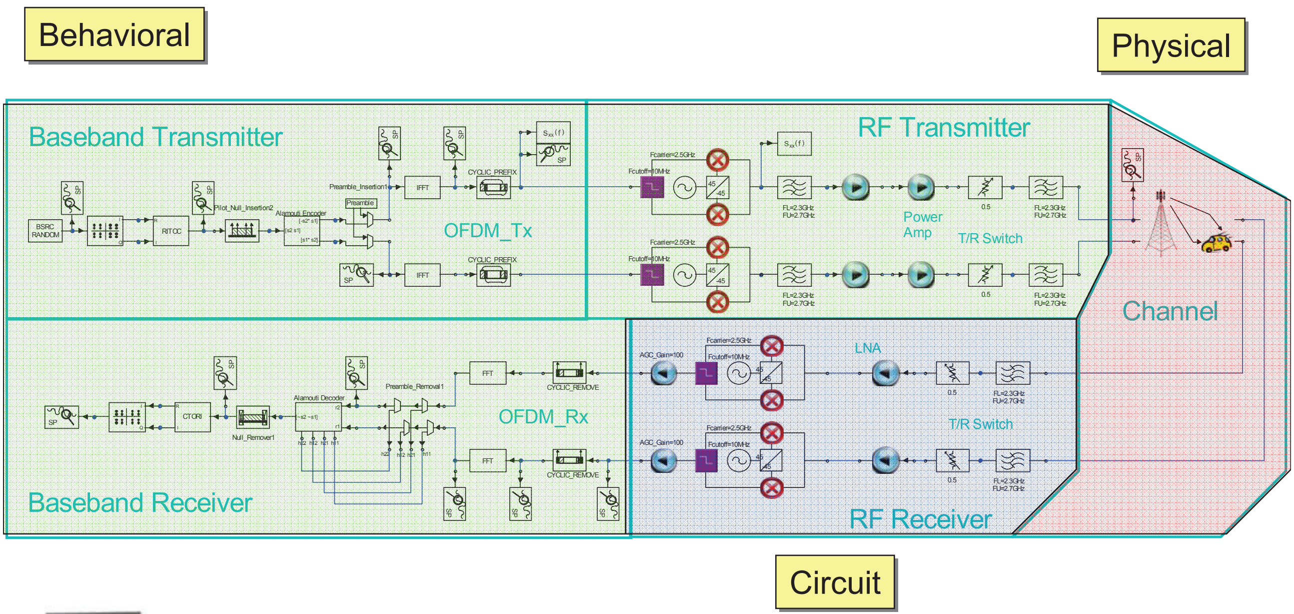
- Compression
  - Single RF & LO to baseband
- Third Order Intercept
  - Two RF & Single LO
  - Swept & Spectral Response







Integration



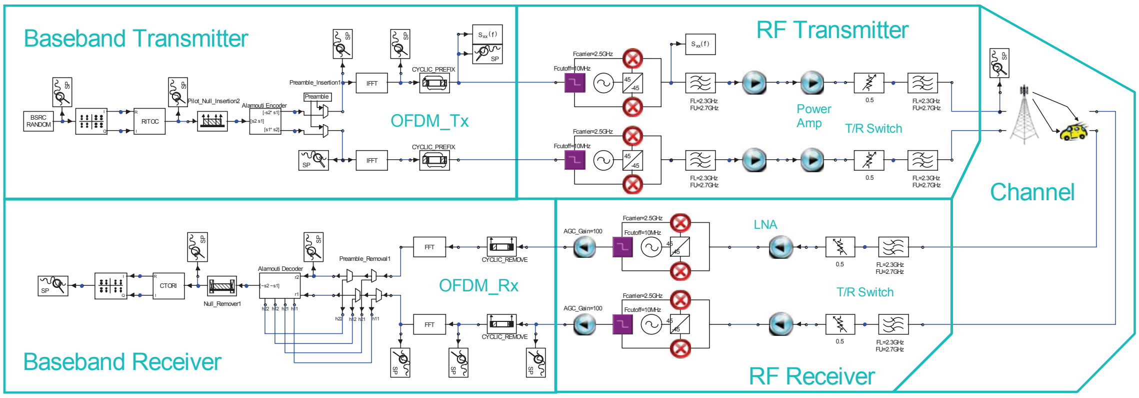
Complete WiMax System

- Baseband Tx/Rx
  - QAM, STC Encoder/Decoder, OFDM
- RF Tx/Rx
  - Quadrature Mixing, Amplification, Filtering
- Channel
  - SISO & MIMO, Link, Noise

Behavioral

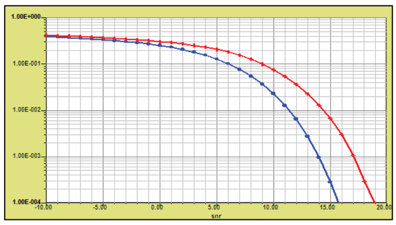
Circuit + Behavioral

Physical

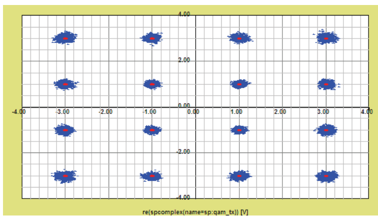


Complete WiMax System

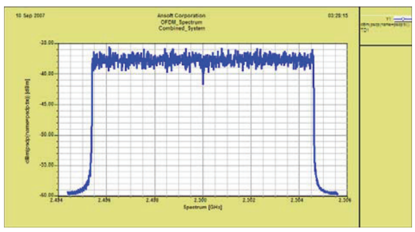
- Behavioral and Physical
  - SISO vs MIMO (Diversity gain)
  - EVM Distortion



- Circuit and Physical
  - Nonlinear interactions
  - Loading effects



- Behavioral, Physical and Circuit
  - BER distortion
  - Multipath degradation



Conclusion

- WiMax System Modeling
  - HFSS dynamic link for Channel
  - Nexxim for NL circuit impact
  - ***Unique Integration*** of Physical, Circuit & Behavioral
- HFSS, Nexxim & Designer together help you pave the way for:

First Pass System Success

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Thank You!

Questions?

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