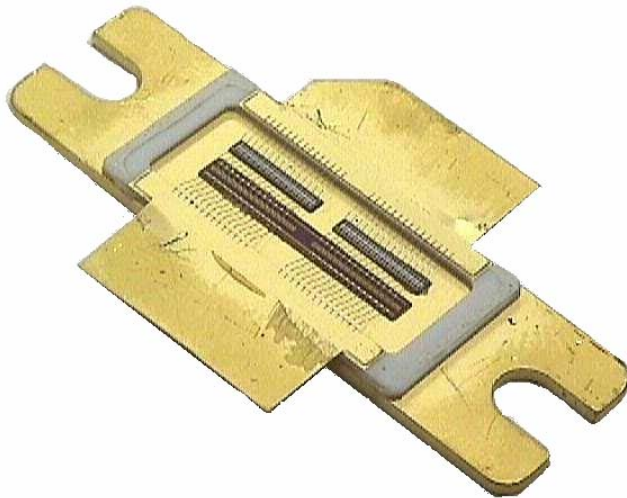


Integrating HFSS into a Computer-Aided Design Environment for RF Power Transistors



by

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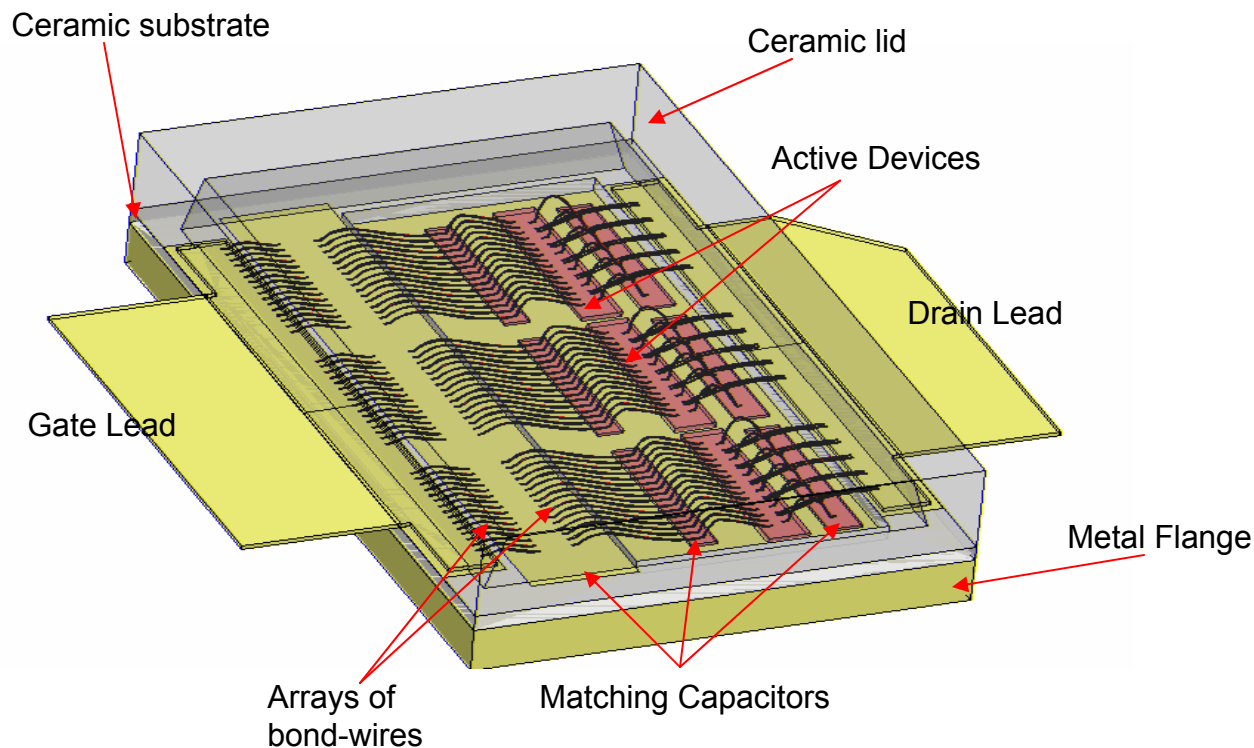
<http://www.motorola.com/sps/rf>

P. H. Aaen, HFSS Users Workshop , 2004 02 20

Outline

- Motivation
- HFSS™ Simulation Strategies
- Integrating HFSS into the design process
- Developing a Matlab® toolbox
- Ensuring accurate simulation results
- Case Studies
- Conclusions

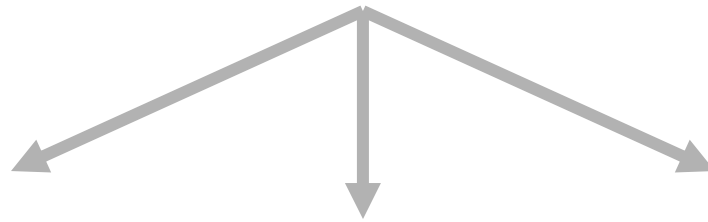
Motivation – RF Power Transistor Design



- The design and manufacture of high-power RF transistors for wireless infrastructure
- Transistor performance is very sensitive to matching network design
- A computer-aided design (CAD) process is very desirable

HFSS Simulation Strategies

- An Electromagnetic Simulation Framework -



Parameterized simulation

Solver on demand™

- Parameterized interface to Ansoft's Designer
- Simulator is invoked from the circuit/system simulator

Graphical User Interface

- Standard HFSS interface
- Very flexible
- Limited parameterization ability

Back-end access

- HFSS macro language
- Programming macros can be a complex process

Our design environment requires a system which is easy to use yet it retains its flexibility.



Ease of Use

Flexibility

Integrating HFSS into a Design Environment

In order to integrate HFSS into our CAD environment two major tasks needed to be completed:

1. Reducing the steep learning curve associated with:

- Difficultly drawing complex packaging structures
- Understanding the simulation process
 - Which boundary conditions should be used?
 - What are the convergence criteria settings?
 - What are the material parameters?

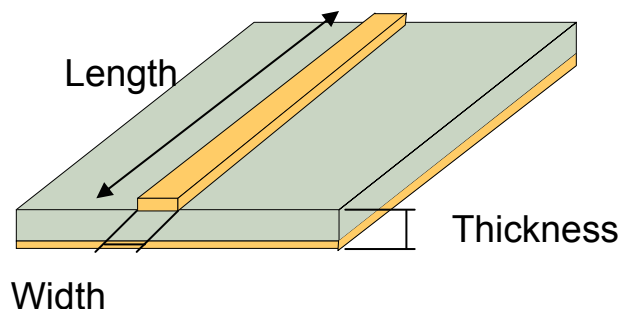
2. Ensuring simulations are accurate

Once these tasks have been completed:

- The macro language can be used to create a 'sandbox' for which typical structures are easily drawn and accurately simulated

Creation of a Matlab Toolbox

Creating Objects for Use Within HFSS

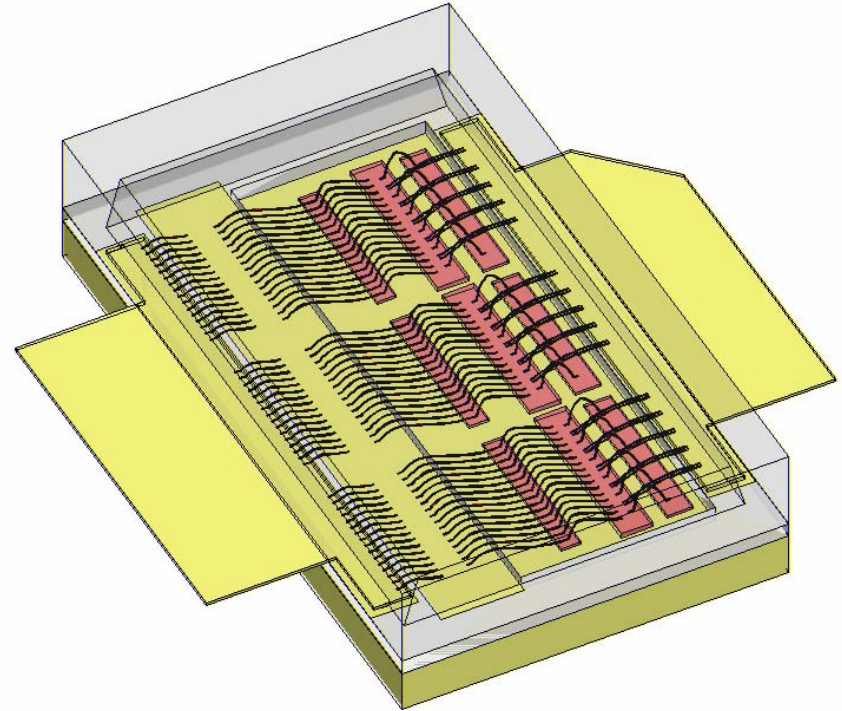


- The concept of the macro language can be extended to include higher level objects (selections of parameterized macro code).
- The object can be easily implemented as a Matlab function which generates HFSS macro code.
- Each object has material, geometrical and location information associated with it.

Required Objects for Our Designs

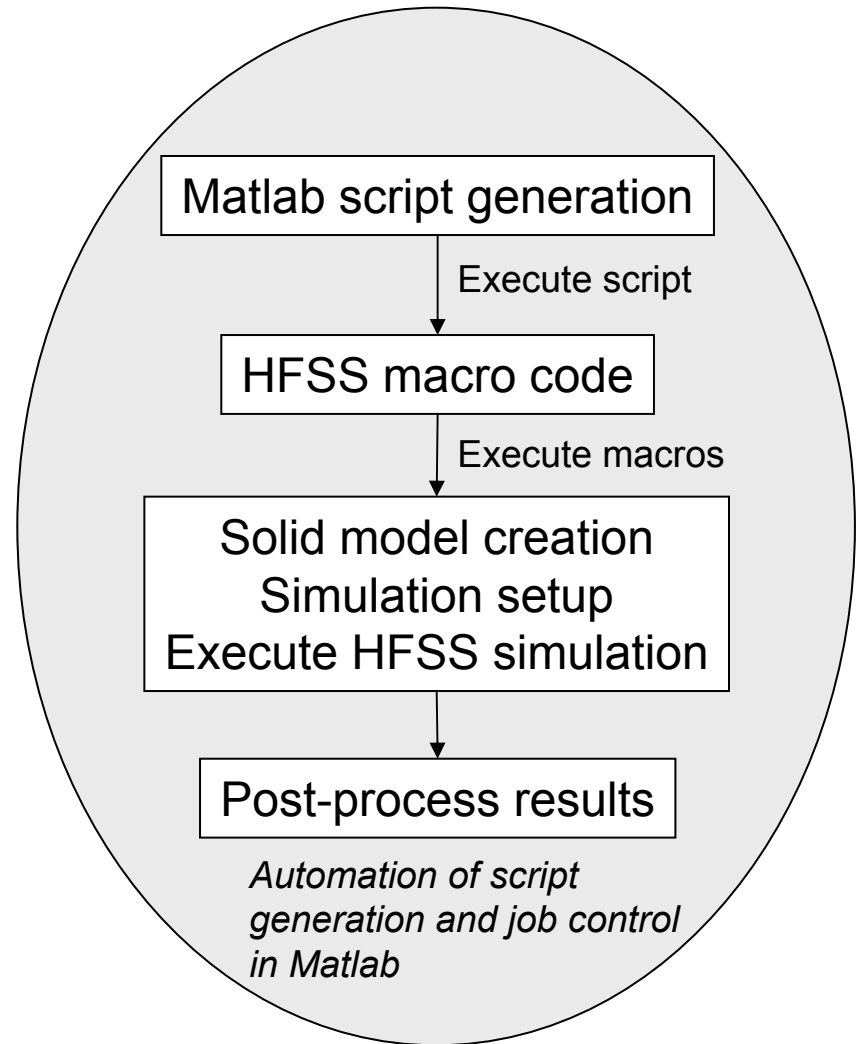
- For transistor simulation we require Matlab functions to generate HFSS macro code for:
 - Microstrips
 - Bond-wire arrays
 - Capacitors
 - Die
 - Package styles
 - Set of functions to setup materials, boundary conditions, simulator setup and post-processing

- A Matlab toolbox was created for use with HFSS v8.5.
 - We are evaluating adapting it to v9.1



Simulation Flow

- Object functions are called by Matlab scripts to create drawings, setup materials, boundary conditions, invoke the simulator and post-process results.
- It is possible to automate the entire simulation process.



Illustrating the Toolbox Usage

- A Matlab script controls the execution of all functions

```
fid = fopen('example1.mac','w+');

% Load wire profile data from disk
pflFileName = 'example1.pfl.txt';
profile_data=eval('load(pflFileName)');
Wire.profile = [profile_data(:,1),profile_data(:,2)];

% setup wire parameters
Wire.radius      = 0.75;
Wire.shroudRadius = 1.5;
Wire.num         = 3;
Wire.spacing     = 20;
Wire.offset      = [147-4.60 0 20];
Wire.symm        = 'on';
Wire.units       = 'mils'

% setup package parameters
Pkg.offset = [0 0 0];
Pkg.mirror = 'off';
Pkg.type   = 'M3carrier';
Pkg.sep    = 64.65;
Pkg.units  = 'mils'
```

Create text file

Load bond-wire profile from disk

Wire geometry parameters

Package geometry parameters

Illustrating the Toolbox Usage *(continued)*

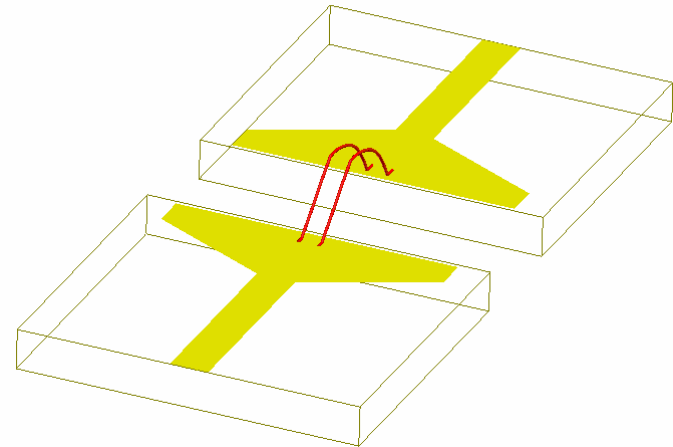
```
% start drawing objects
[Pkg_length1] = createHFSSPkg(Pkg, fid);
  Pkg.offset    = [Pkg_length1+Pkg.sep 0 0 ];
Pkg.mirror     = 'on';
[Pkg_length2] = createHFSSPkg(Pkg, fid);

createHFSSBondWire(Wire, fid);
fclose(fid);
```

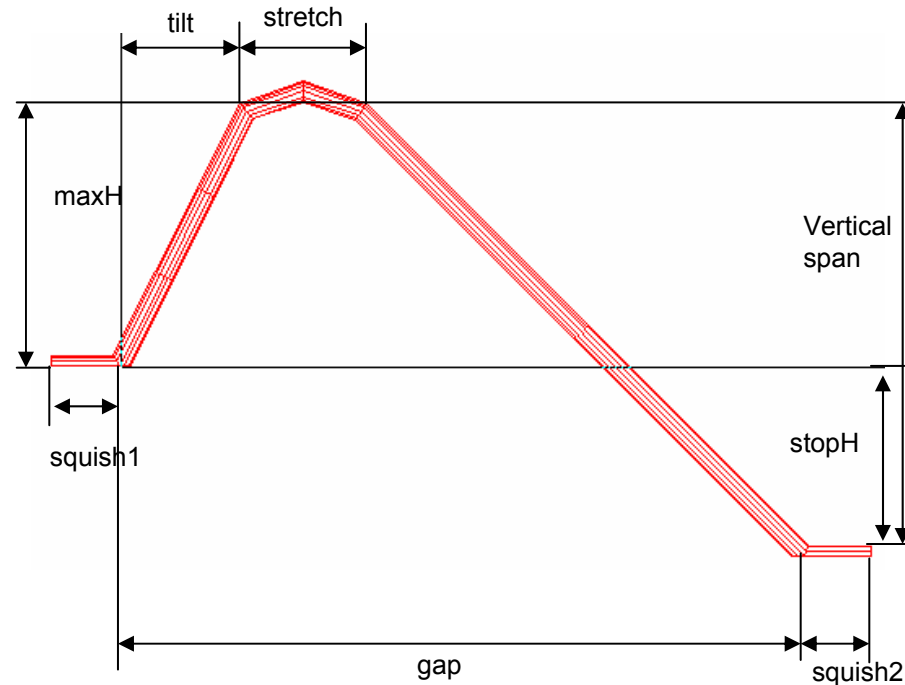
- | Draw one-side of package
- | Position of second-side of package
- | Mirror image on for second-side of package
- | Draw second-side of package

- | Draw wire array
- | Close file

- After executing the Matlab script an HFSS macro file is generated.
- Execute the macro file and the geometry is ready for simulation.



Example Matlab Functions – Wire Profile Generation



```
createWireProfile(Profile)
```

- Function creates a fully parameterized shape for bond-wires
- A structure containing the geometrical information is passed to the function

Example Matlab Functions – Box Drawing

- Boxes are basic building blocks and are frequently employed in the solid model
- This function generates the macro code for a box and positions it at specified co-ordinates in 3-D space.
- A structure containing the geometrical information is passed to the function

```
function [] = createHFSSBox(Box, fid)

% create unique box name
[token,rem] = strtok(num2str(rand),'.');
uniqueID = rem(2:end);
Box.name    = ['free_' uniqueID '_space' ];

fprintf(fid,'# --- start drawing box ---\n');
fprintf(fid,'setunits "%s" "y"\n',Box.units);
fprintf(fid,'NewObjColor 0 0 254\n');

% Draw the box
fprintf(fid,'Box [0, 0, 0] %d %d %d "%s"\n', ...
        Box.size(1), Box.size(2), Box.size(3),...
        Box.name);

% move box to offset position if necessary
if sum(Box.offset) ~= 0
    selectedObjects = ['+' Box.name ' '];
    selectCmd = ['Select {' selectedObjects '}\n'];
    fprintf(fid,selectCmd);
    fprintf(fid,'Move <%d, %d,%d>\n', ...

            Box.offset(1),Box.offset(2),Box.offset(3));
    fprintf(fid,'DeSelect '*' '\n');
end
```

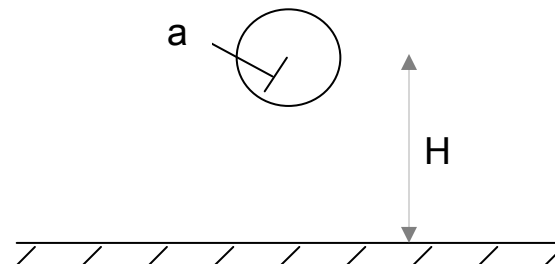
Ensuring Accurate Simulation Results

Simulation of sample structures

- In order to have confidence when simulating a new class of structures, there are three basic tests which must be performed.
 1. Compare electromagnetic simulation results with exact results (if possible)
 2. Convergence test
 3. Examine the solution dependence on boundary conditions
- These tests are designed to increase confidence in simulation results

Simulation of an Ideal Geometry

- Maxwell's equations can only be used to solve the fields for a few select geometries
- Simulation results can be compared with these exact results to check simulation accuracy
- Simulation of a cylinder above a ground plane can be compared with the per-unit-length quantities obtained from the solution to Maxwell's equations.

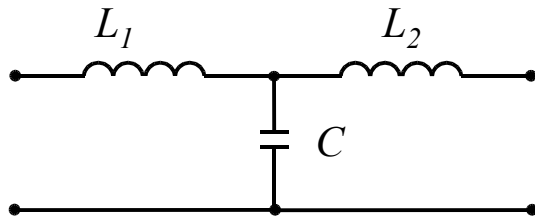


$$L = \frac{\mu_o}{2\pi} \operatorname{arccosh}(H/a)$$

$$C = \frac{2\pi\epsilon_o}{\operatorname{arccosh}(H/a)}$$

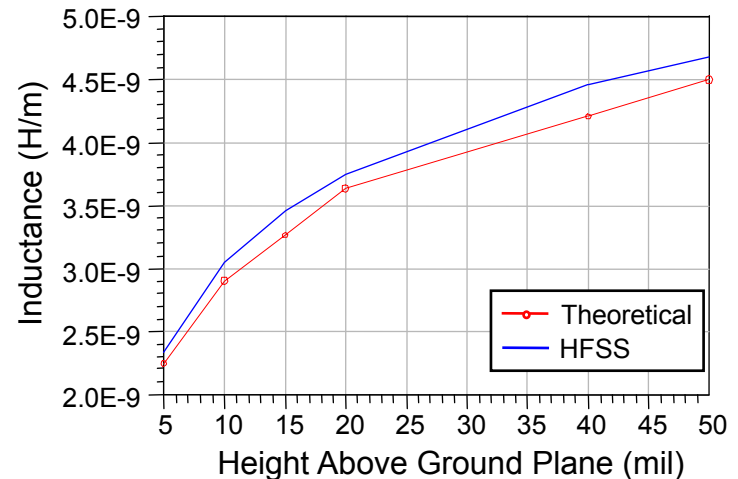
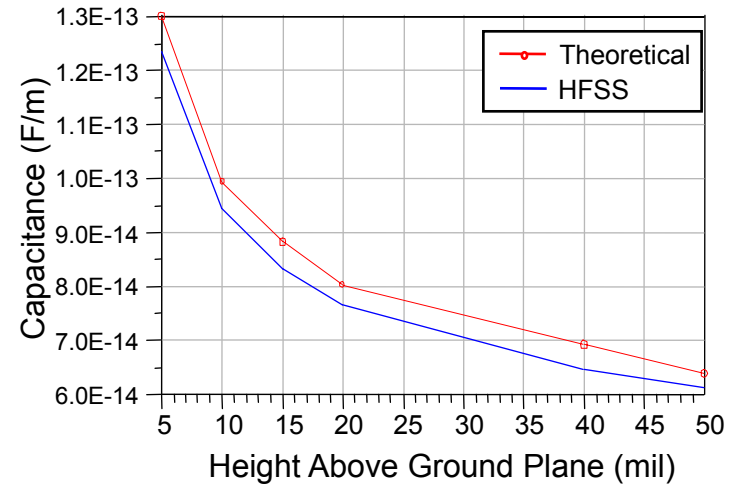
Simulation of an Ideal Geometry *(continued)*

- Per-unit-length inductance and capacitance are extracted by an equivalent circuit.

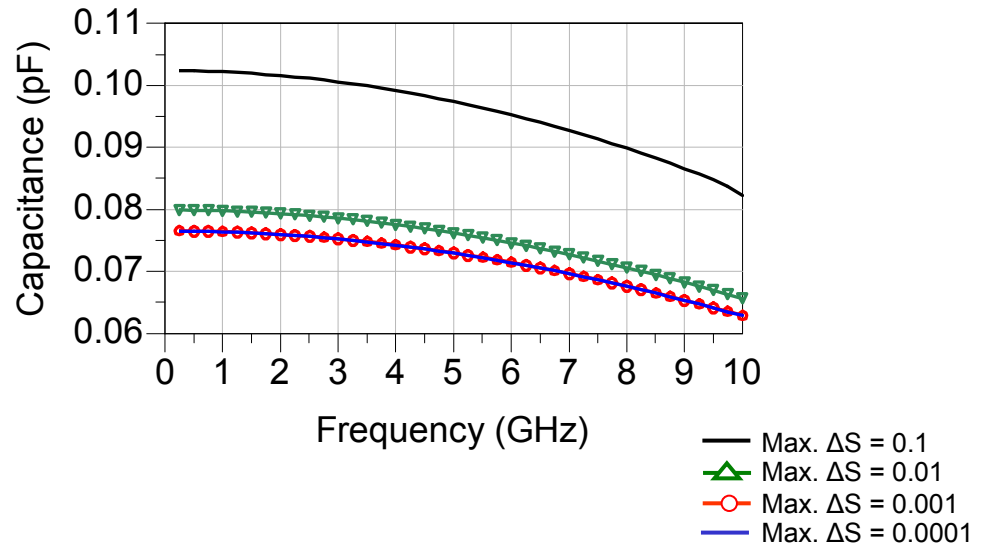
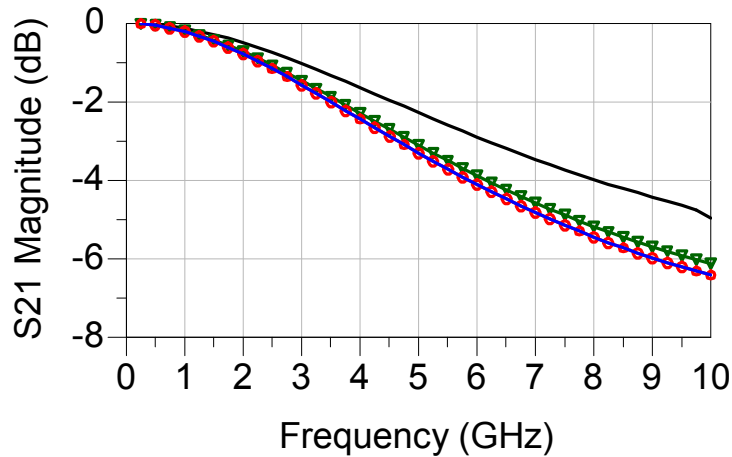


$$L_1 = \frac{\text{Im}(Z_{11} - Z_{12})}{\omega \cdot \text{length}} \quad L_2 = \frac{\text{Im}(Z_{22} - Z_{12})}{\omega \cdot \text{length}}$$

$$C = \frac{-1}{\omega \cdot \text{length} \cdot \text{Im}(Z_{12})}$$

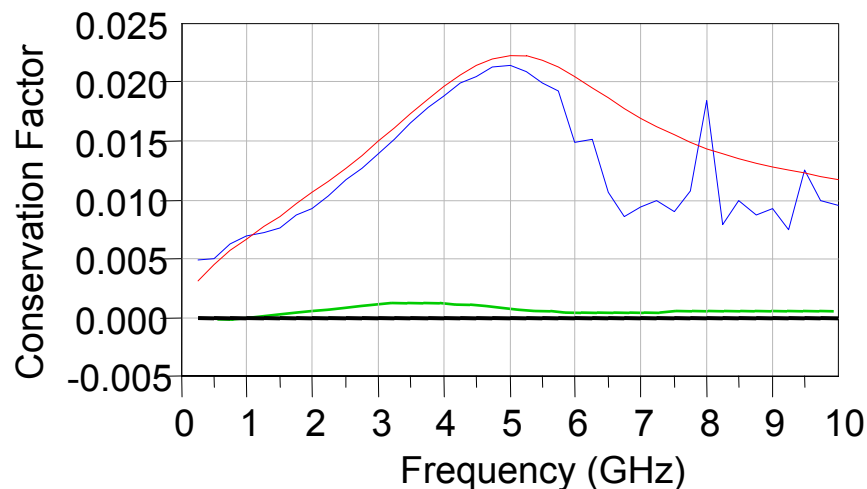
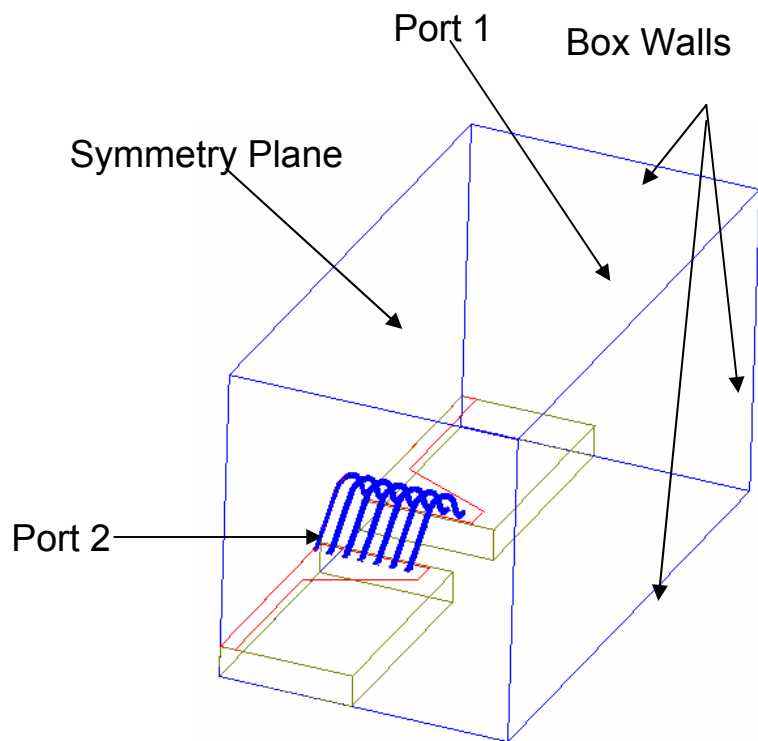


Selecting the Convergence Criteria



- What should be the value for maximum delta S?
- Perform simulations of the same geometry with different settings.
- Results of a 200 mil long cylinder, 1 mil radius, 20 mil above a ground plane
- Different settings can be required for the same problem when examining a different domain, e.g. Equivalent circuit parameters, Z-parameters, ABCD-parameters, etc.

Selecting the proper boundary conditions



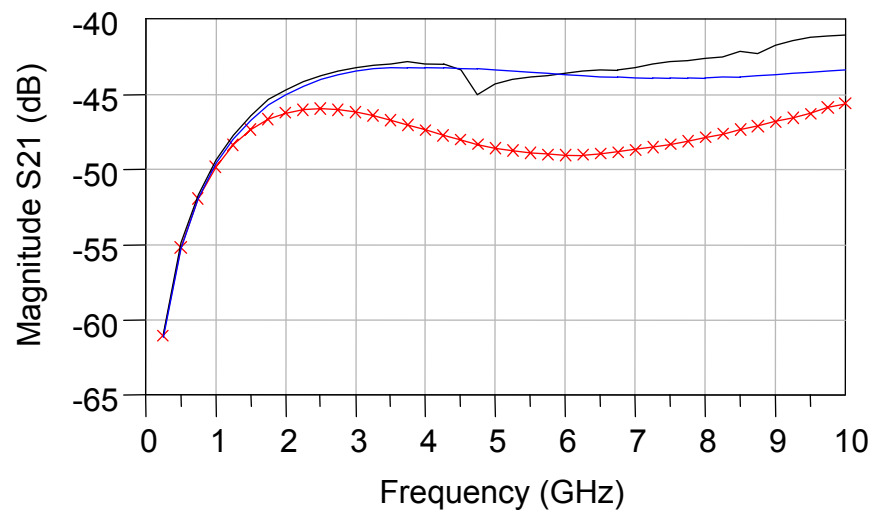
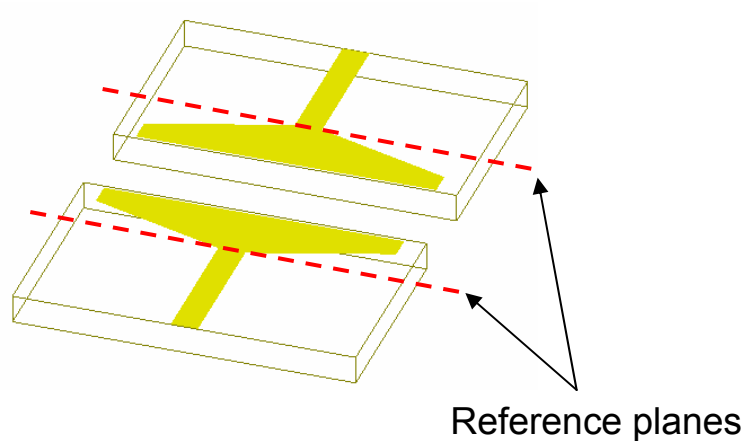
— Radiation Boundaries
— Measurement
— Finite conductivity metal
— PEC Boundaries

- Examine the affect of radiation vs. PEC boundaries on simulation results
- To examine the effects of the loss the conservation factor can be computed from the simulated S-parameters:

$$CF = 1 - |S_{11}|^2 - |S_{12}|^2$$

Case Studies – Examples comparing simulated and measured results

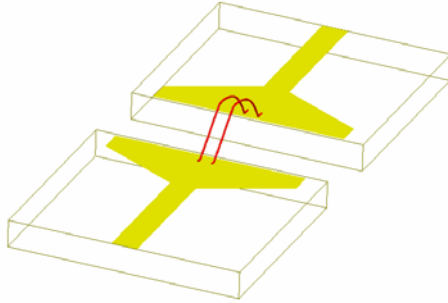
Case Study I: Package Isolation



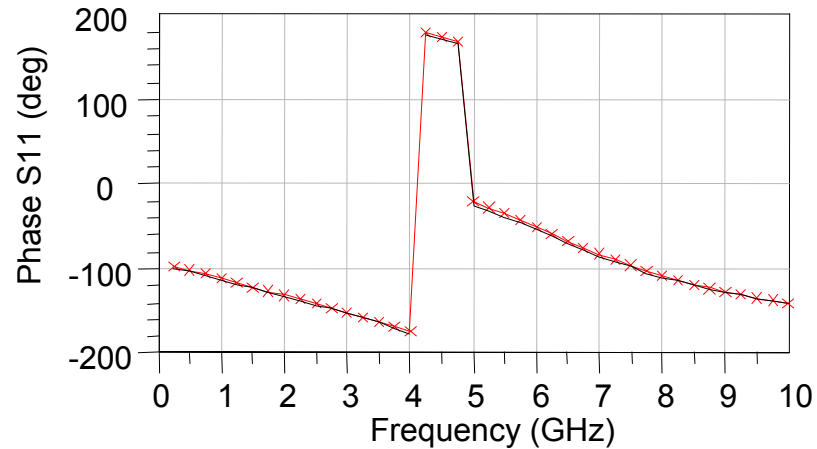
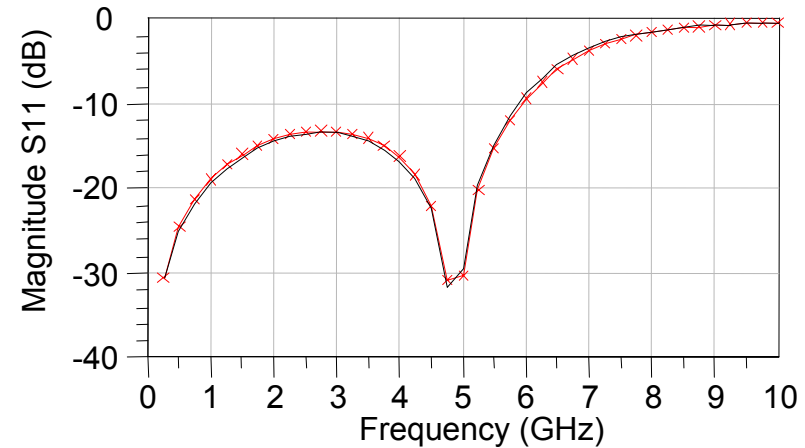
- +— HFSS PEC Boundaries
- Measurement
- HFSS Radiation Boundaries

- S-parameter reference planes are located at the start of the microstrip taper.
- The selection of boundary conditions is critical to the proper simulation of isolation between ports.

Case Study 2: Package and Bond-Wires



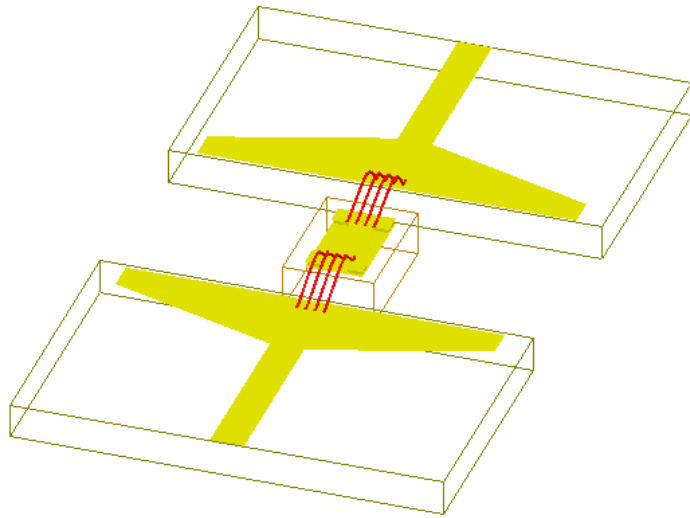
- Bonding-wires were used to connect the two sides of an alumina package
- Device contains 2 gold wires, 1.5 mil diameter, having a centre-to-centre spacing of 20 mil and 50 mil loop height.



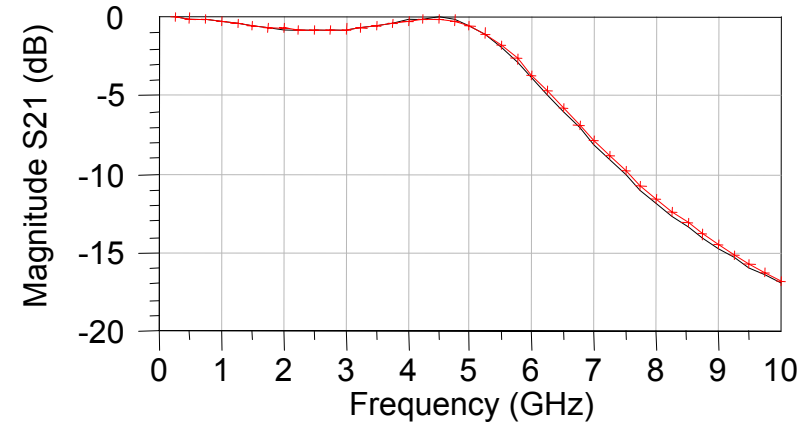
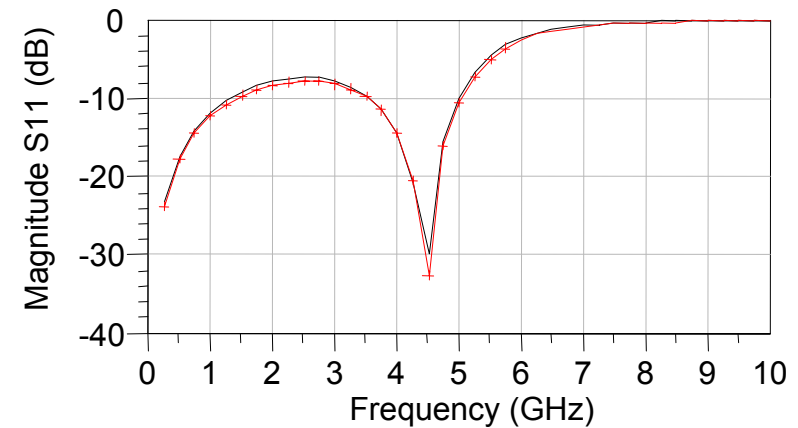
—x— HFSS Simulation

— Measurement

Case Study 3: Packaged LTCC buried Transmission Line



- A buried LTCC transmission line was mounted in a package.
- 4 gold wires having a centre-to-centre spacing of 5 mil, 1.5 mil diameter connected the package to the device.



—+— HFSS Simulation

— Measurement

Conclusions

- An electromagnetic simulation framework for integrating HFSS into a CAD based design flow was presented.
- Examples were provided in which the use of the macro language in combination with a Matlab toolbox vastly automated the generation solid models and the simulation process.
- Guidelines were presented and demonstrated on how to obtain accurate simulation results with respect to convergence, boundary conditions when compared to closed form solutions of Maxwell's equations and measured data.
- The simulation of several case studies and their comparison with measured data demonstrated a satisfactory level of accuracy and usability of the aforementioned electromagnetic simulation framework.