Smart Antenna Design

Antenna Diversity: Agenda

- Overview
- Diversity Systems
- Mobile Wireless Environment
- Quantifying Diversity Antenna Performance
- PCS Antenna Design
- Diversity Antenna Analysis
- Summary
- References

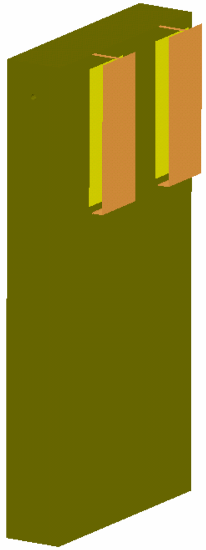
Antenna Diversity: Overview

- Major Challenges facing wireless communication industry
  - Signal Reliability
    - Minimize signal loss
    - Combat multipath fading effects
  - Power requirements
    - Miniaturization
  - Data rates
  - Frequency utilization

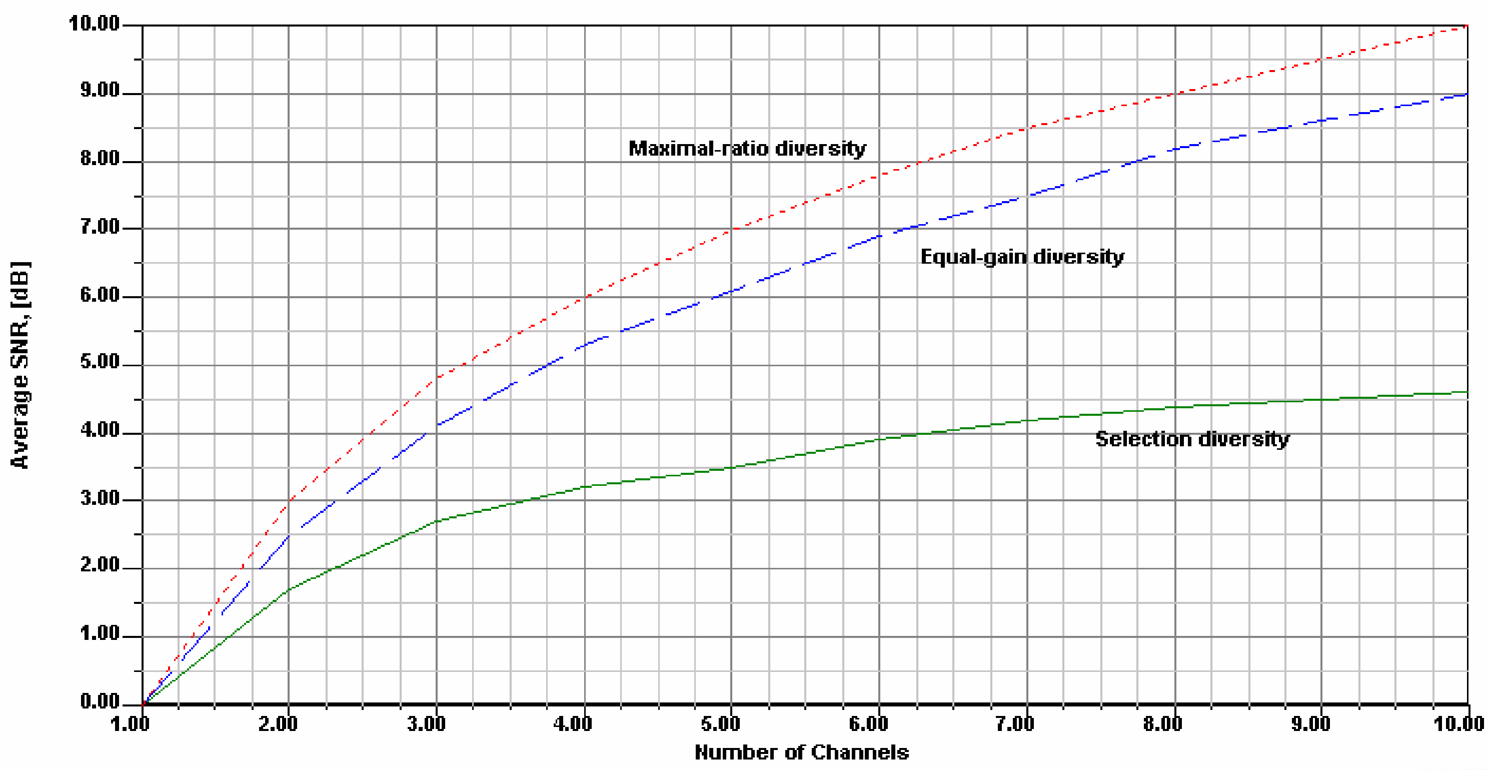
- Solving these problems
  - Of the challenges listed, *Signal Reliability* is the most important challenge to address.
    - Customers will demand it
      - Direct measure of Quality of Service
    - Improves the overall system performance
      - Reduces power requirements
      - Reduces dropped calls and lost data
      - Increases system efficiency

Antenna Diversity: Overview

- Utilize Multiple Antennas to Improve Signal Reliability
  - Considerable performance improvements can be obtained
  - Incorporated into most mobile telephone basestations
  - Limited(Almost Non-Existent) use in mobile handsets
- Design Challenges - Integrating Multiple Antennas on a mobile handset
  - Physical size of dual/multiple antennas
    - Conformal Antennas
  - Performance
    - Antenna Isolation
    - Envelope Cross Correlation
    - Performance degradation due to biological tissue
    - Conformal Antennas
      - Size and location on handset
      - Bandwidth
      - Sensitivity to design parameters

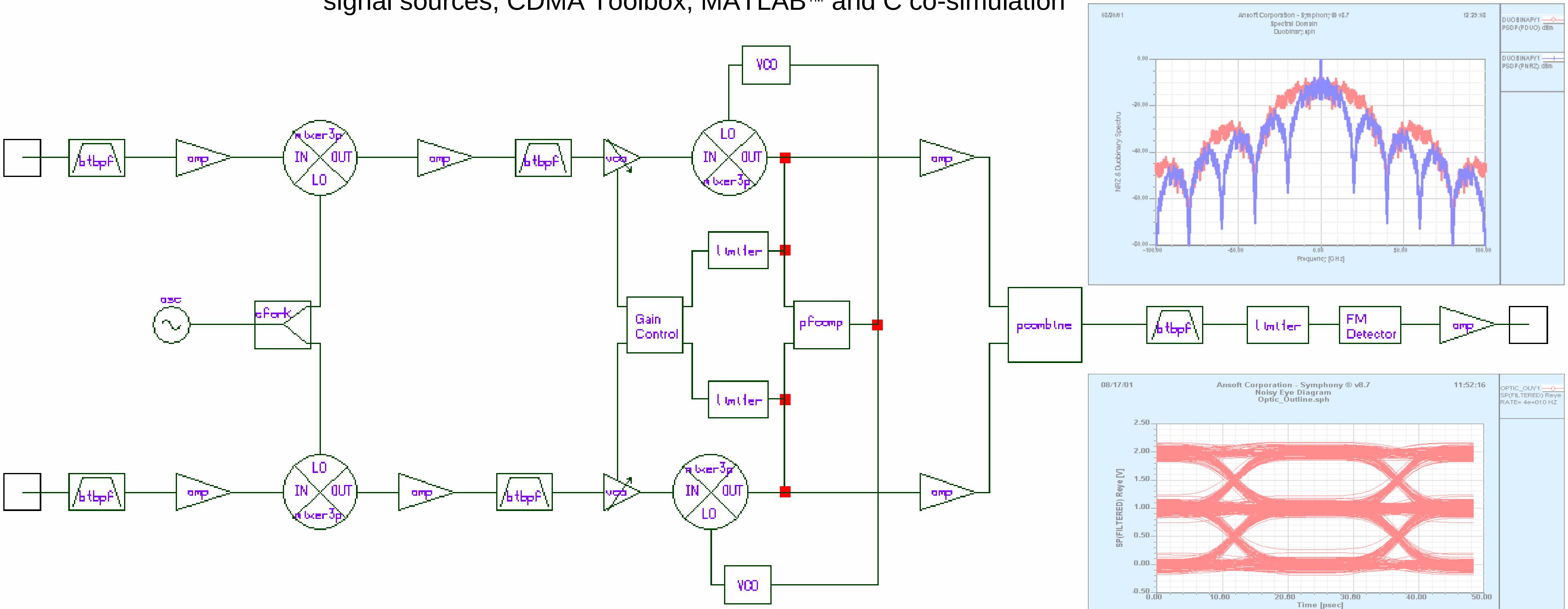


- Types of Diversity Systems
  - Adaptive Processing Techniques
    - Switched/Selection - Selects the input with the best SNR
    - Equal-Gain Combining - Adds the inputs
    - Maximal Ratio Combining - Co-Phases, weights, and adds each input



Antenna Diversity: Overview

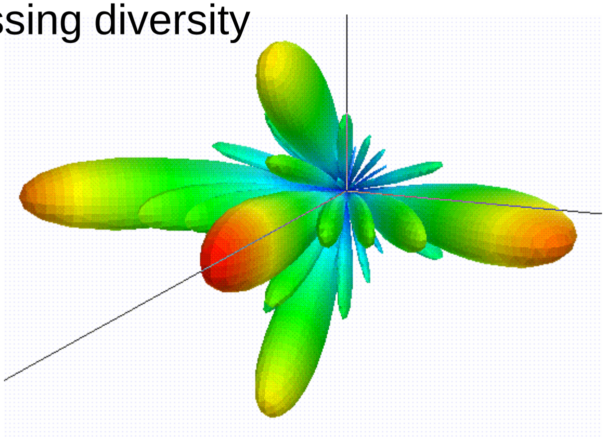
- System Analysis with Ansoft Symphony
  - Adaptive Processing is intended to modify receiver characteristics with a changing signal environment to improve performance
    - At the system level, Ansoft Symphony can be used to investigate receiver improvements
      - **Mixed mode simulator** - Time/Frequency Domain
        - **Time Domain**: inter-symbol interference (ISI - delay and signal spreading between signals), multi-path reflection interference, amplitude/phase distortion, SNR and BER degradation due to noise (Gaussian, shot and thermal), etc.
        - **Frequency Domain**: inter-modulation and harmonic distortion, spectral regrowth, Doppler effects, spurious signal generation, small carrier suppression due to large interferer, etc.
      - **Powerful models**: Channel Equalization, Raleigh Fading, Rohde and Schwarz 3G I and Q baseband signal sources, CDMA Toolbox, MATLAB™ and C co-simulation

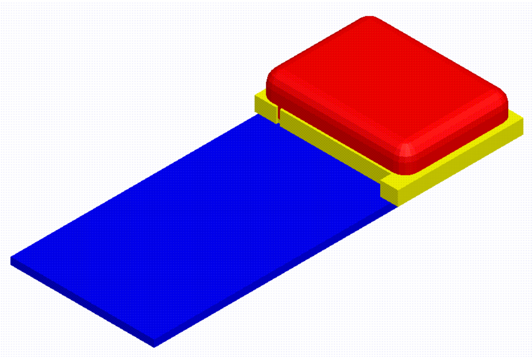


Equal-Gain Predetection Combiner

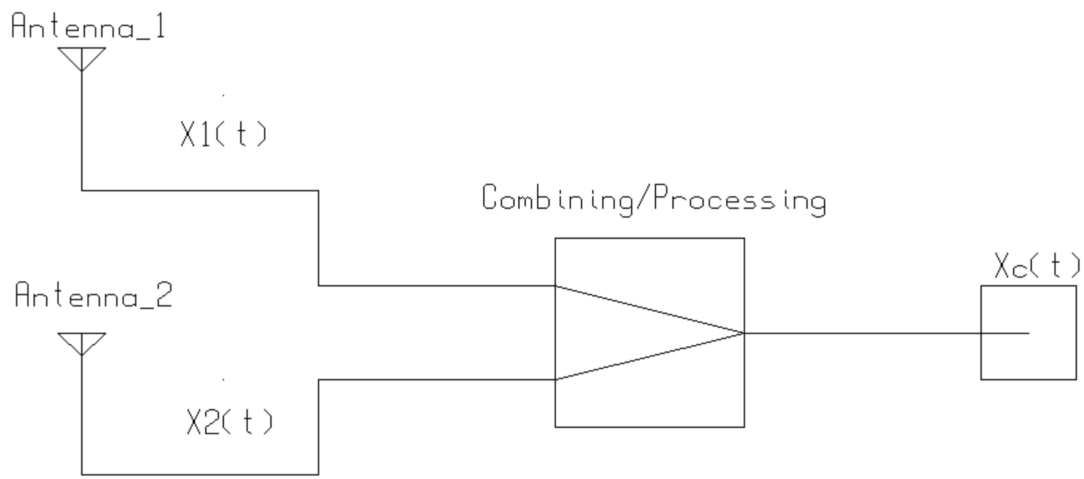
Antenna Diversity: Overview

- Antenna Techniques - Used in conjunction with processing diversity
  - Spatial Diversity - Uses multiple antennas.
    - Each antenna is physically separated.(Arrays)
    - Too large for compact handsets
  - Pattern Diversity - Uses Co-located antennas.
    - Each antenna has a different field pattern
  - Polarization Diversity - Uses a dual antenna system.
    - Each antenna pair uses orthogonal polarizations.
      - Polarization Pairs: Horizontal/Vertical, ±45° slant, LHCP/RHCP
  - Transmit/Receive Diversity - Uses separate antennas for transmit and receive
    - Can be co-located
    - Eliminates the duplexer (Or relaxes the design specifications)





Antenna Diversity: Overview



- The Diversity System
  - To reduce fading and cochannel interference, a dual diversity system processes two input signals(x1(t) & x2(t)) to create an improved signal $x_c(t)$
  - The signal improvement is dependent on the cross correlation and relative signal strength levels between the two received signals
    - The average signal strength at each antennas is:

$$P_1 = E\left(\left|x_1(t)\right|^2\right) \qquad P_2 = E\left(\left|x_2(t)\right|^2\right)$$

    - The complex cross correlation is:

E denotes the Expectation

Statistical value that indicates the similarity of the received voltages at the antennas

$$\rho_c = \frac{E\left[\left(x_1(t)-\bar{x}_1\right)\left(x_2(t)-\bar{x}_2\right)^*\right]}{\sqrt{E\left[\left|x_1(t)-\bar{x}_1\right|^2\right]E\left[\left|x_2(t)-\bar{x}_2\right|^2\right]}}$$

- The *Mobile Wireless Environment*
  - The complex cross correlation coefficient(ρ_c) is a common performance evaluator
    - Statistical value that indicates the similarity of the received voltages at the antennas

  - The envelope cross correlation coefficient(ρ_e) is a measurable quantity of performance
    - $\rho_e \approx |\rho_c|^2$
    - Good diversity gain is possible when $\rho_e < 0.5$

  - Incoming multipath field assumptions
    - The fading signal envelope is Rayleigh distributed
    - Orthogonal polarizations are uncorrelated
    - The incoming field only arrives in the horizontal($\theta=\pi/2$) plane
    - The time-averaged power density per steradian is constant

  - Using these assumptions, the performance of diversity antennas can be determined from the radiation patterns:

Complex cross correlation coefficient for two antennas

$$\rho_c = \frac{\int_0^{2\pi} A_{12}(\phi)d\phi}{\left\{\int_0^{2\pi} A_{11}(\phi)d\phi \int_0^{2\pi} A_{22}(\phi)d\phi\right\}^{1/2}} \quad (1)$$

$$A_{mn}(\phi) = \Gamma E_{\theta m}(\pi/2,\phi)E_{\theta n}^*(\pi/2,\phi) + E_{\varphi m}(\pi/2,\phi)E_{\varphi n}^*(\pi/2,\phi)$$

$$\vec{E}_m(\theta,\phi) = E_{\theta m}(\theta,\phi)\hat{\theta} + E_{\phi m}(\theta,\phi)\hat{\phi}$$ — Electric field pattern of antenna $m = 1,2$

$$\Gamma = \frac{S_\theta^o}{S_\phi^o}$$

- Γ = Cross-polarization discrimination(XPD) - ratio of vertical to horizontal electric field strength of the incident field
- Γ = 0 dB - Equal likely hood of either polarization
- Γ = 6 dB - Vertical polarization
- Instantaneous XPD = -6 to 18 dB

Antenna Port Cross Correlation

$$r_{ij} = \frac{\mathrm{Re}\left(Z_{ij}\right)}{\mathrm{Re}\left(Z_{ii}\right)} \qquad (2)$$

$$\rho_c \cong r_{ij}$$

•Normalized Mutual Resistance – ratio of the standard two port impedances

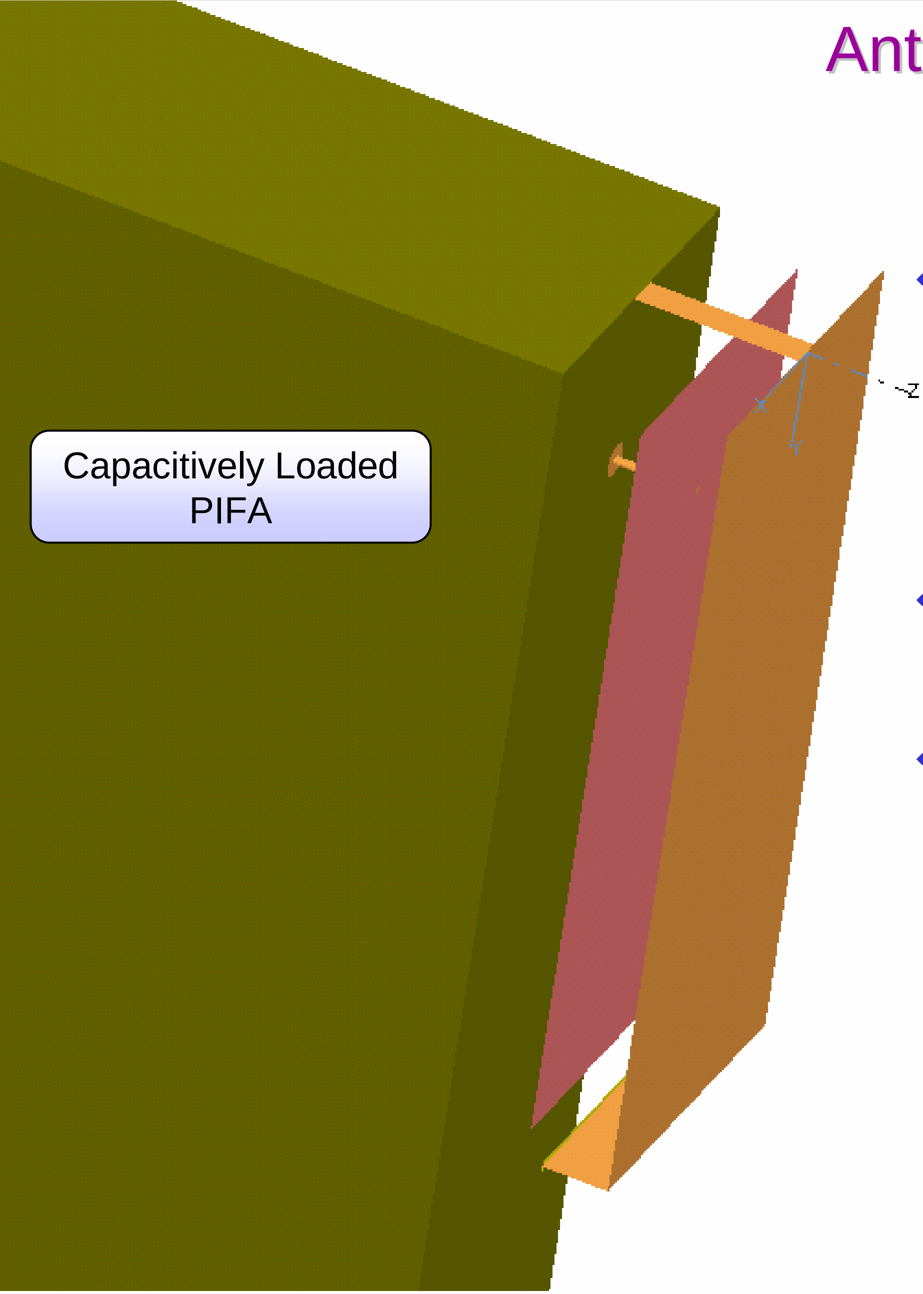
•Quick measurement technique to determine cross correlation for the antenna terminals

- •Doesn't require an antenna range

•Can not account for the instantaneous changes in the XPD

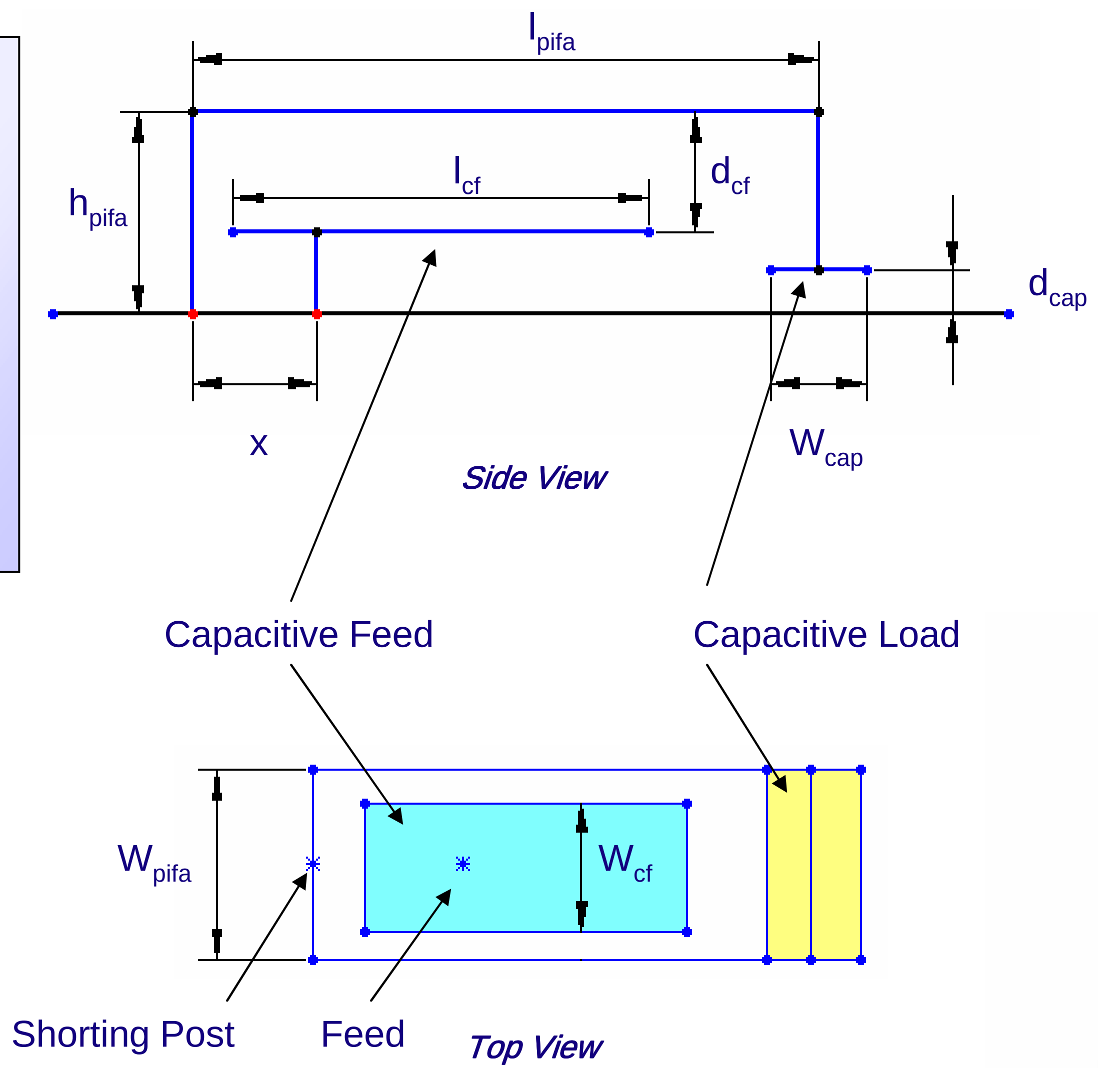
•For simulations, it may be useful for the purposes of Optimization

Antenna Diversity: Antenna Geometry



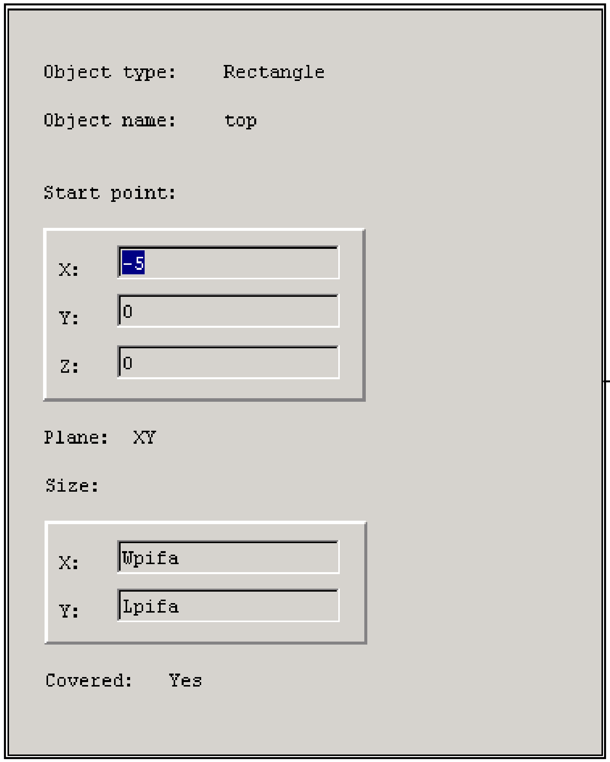
- The basic geometry for a single capacitively loaded PIFA antenna is shown here. It is mounted on a box 80x40x10mm which is representative of a compact mobile telephone handset
- The following slide outlines the nominal antenna dimensions
- To investigate the performance of the antenna we will use Ansoft HFSS, Ansoft Optimetrics, and Ansoft Serenade.

- l_{pifa} = 25mm
- W_{pifia} = 10mm
- h_{pifia} = 5mm
- W_{cap} = 4mm
- d_{cap} = 0.5mm
- l_{cf} = 23mm
- W_{cf} = 10mm
- d_{cf} = 2.5mm



Antenna Diversity: Antenna Geometry

- Using the Parametric Geometry Editor, the model is quickly parameterized to allow for quick and efficient control of the antenna configuration.
- The resulting parametric model can be controlled directly by Ansoft Optimetrics(Optimization/Parameterization/Sensitivity)



Parametric Geometry Editor

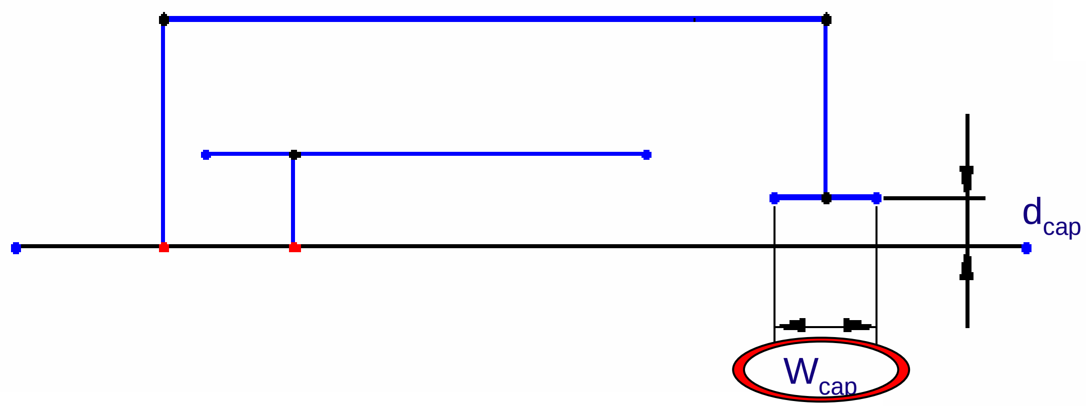
```

# BEGIN: LINES ADDED BY MACRO EDITOR. DO NOT EDIT THE BELOW TEXT!
Assign fYPatch 1
Assign lc 1
Assign ll 19
Assign lv 31
Assign x1 9
Assign x2 9
Assign thy 75
Assign hc 1
Assign wl 17
Assign wv 17
Assign h 7
# END: LINES ADDED BY MACRO EDITOR. DO NOT EDIT THE ABOVE TEXT!

NewObjColor 192 192 192
Rectangle Pos3 msh mwld2 0 2 tmph wl "rect1" 1
FitAllViews
NewObjColor 0 255 0
Rectangle Pos3 ll mwld2 hc 0 wl hmhc "cap1" 1
Rectangle Pos3 ll mwld2 hc 2 lc wl "cap_1" 1
Select { "cap1" }
DupLine Vec3 mtmpl 0 0 2
Select { "cap_1" }
DupLine Vec3 mtmplplc 0 0 2
Select { "cap2" "cap_2" }
SelCopy
SelPaste
DeSelect { "*" }
NewObjColor 255 0 0
Rectangle Pos3 0 mwld2 0 2 mlv wv "rect2" 1
Select { "rect2"}
SelCopy
SelPaste
Select { "+cap2" "+cap_2"}
Origin Pos3 0 mwld2 0
Rotate 2 thyd2
```

Parametric Geometry Macro

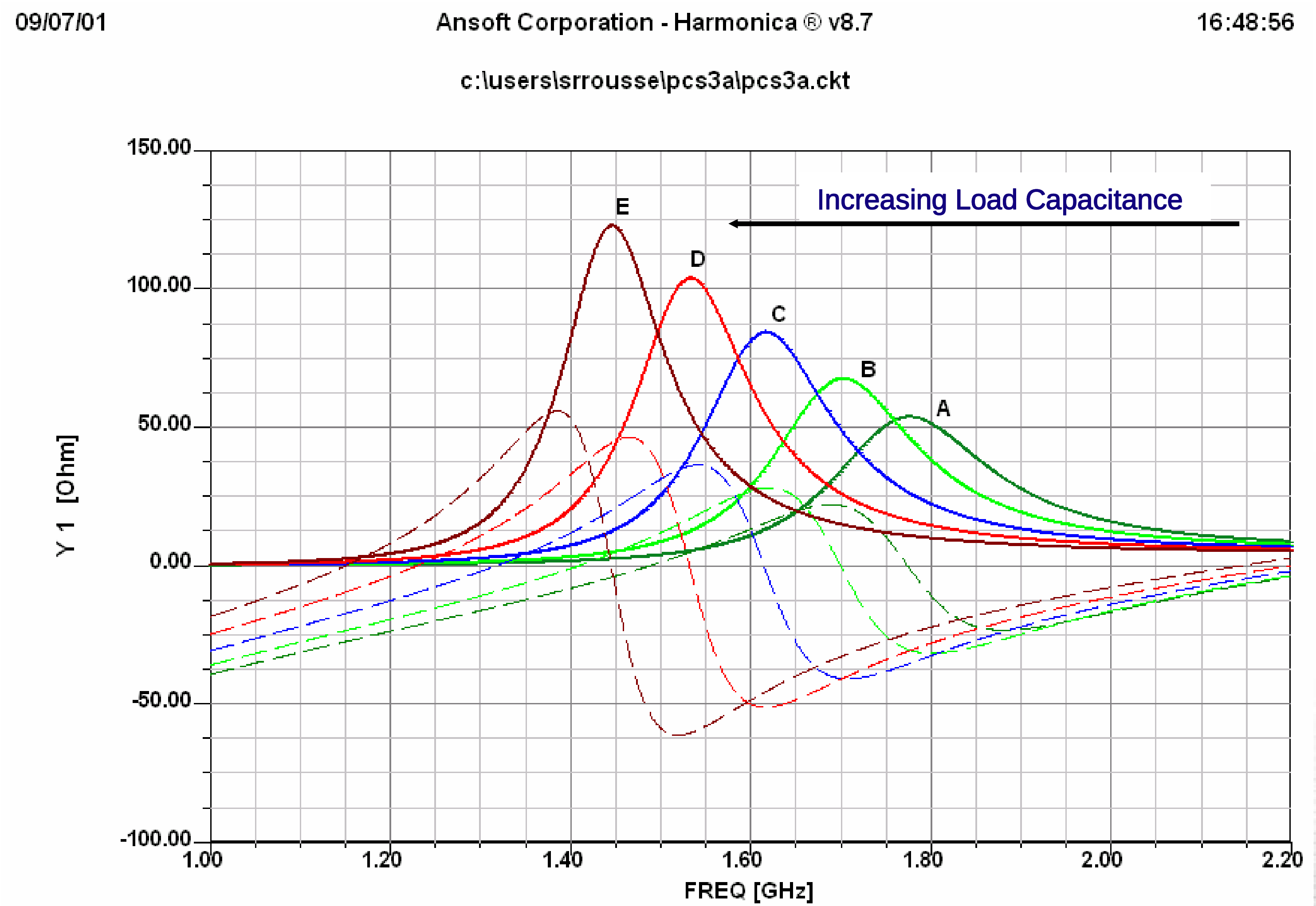
Parametric 3D Model

Antenna Diversity: Antenna Geometry

- To study the affects of the capacitive load on the antenna performance, Ansoft Optimetrics will be used to generate sets of design curves:
  - Vary the capacitive load width(W_{cap}) for a fixed plate separation(d_{cap})
    - Investigate Impedance vs. Bandwidth tradeoffs
    - Cases: (W_{cap}, d_{cap}) [mm]
      - A: (0.5,3)
      - B: (2,3)
      - C: (4,3)
      - D: (6,3)
      - E: (8,3)

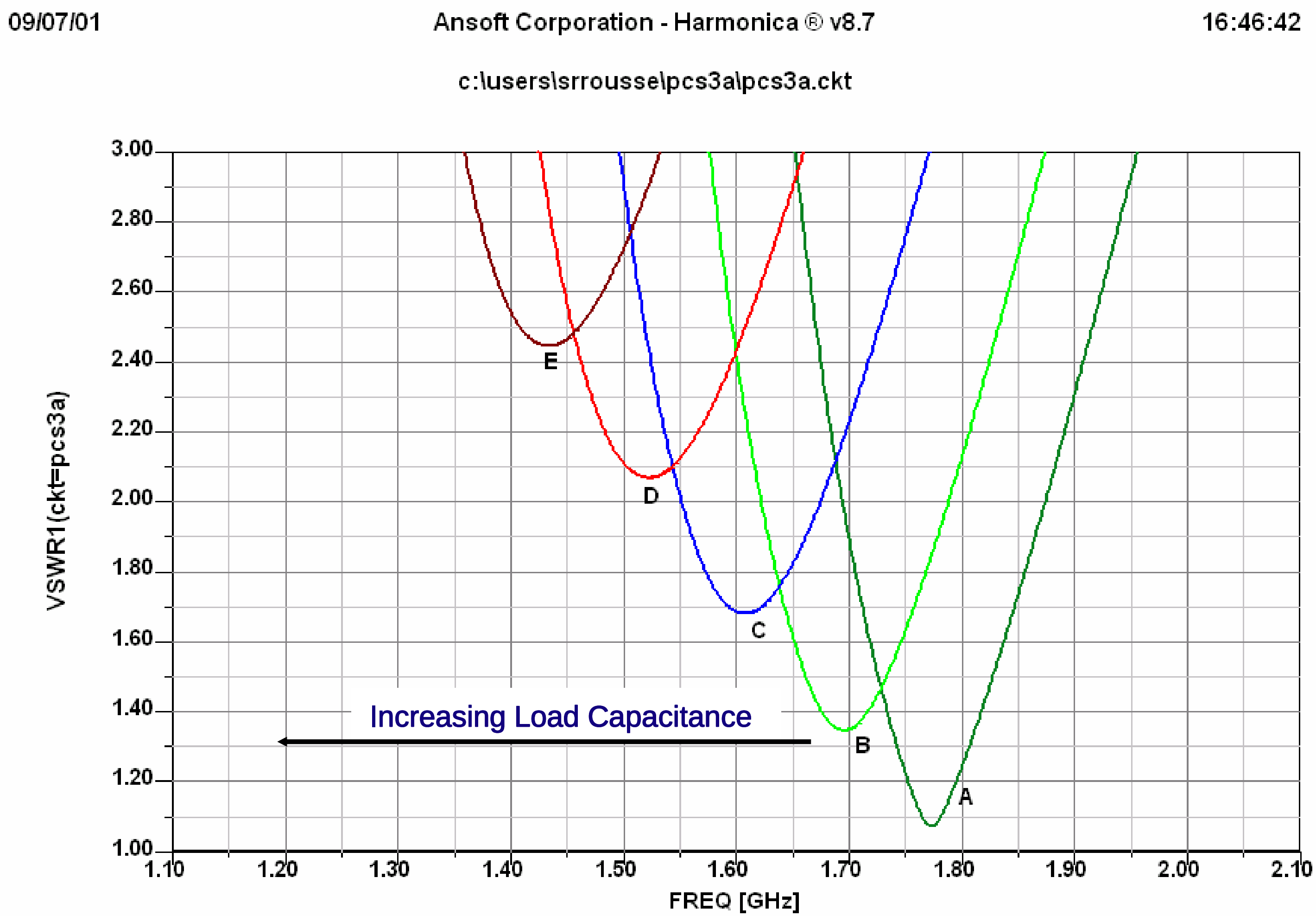


Capacitive Load Width(W_{cap}) vs. Plate Separation(d_{cap})

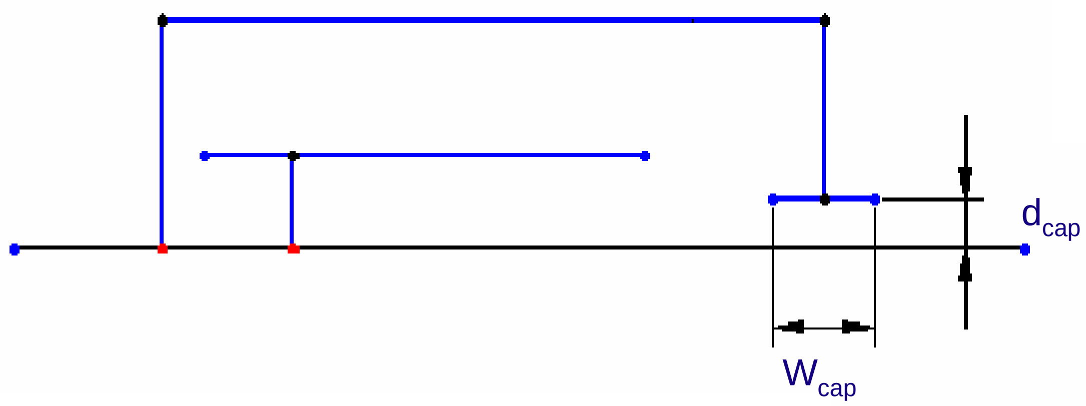


Antenna Diversity: Antenna Results

Capacitive Load Width(W_{cap}) vs. Plate Separation(d_{cap})

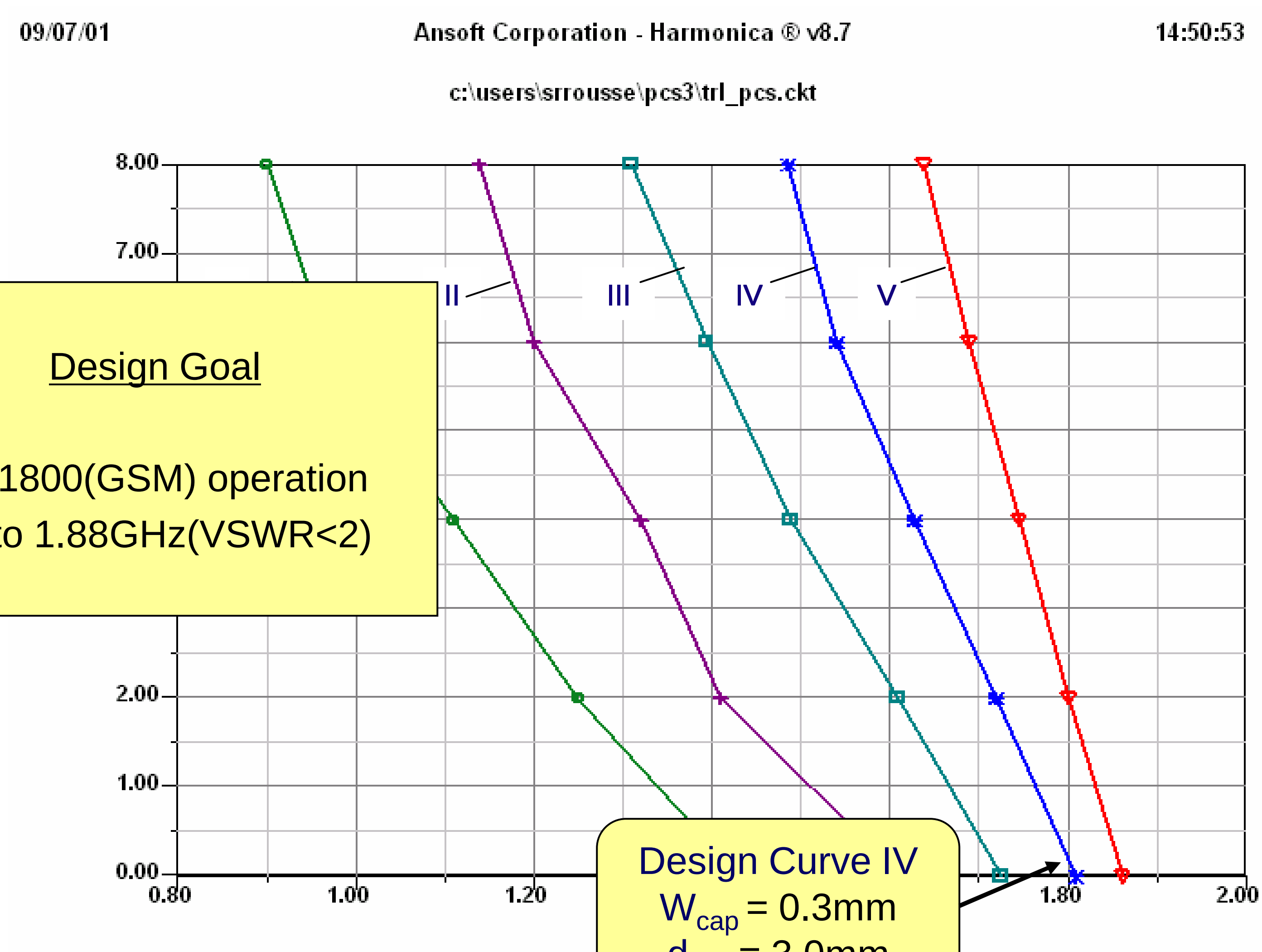


- Vary the capacitive load width (W_{cap}) for various plate separations(d_{cap})
  - Investigate resonant frequency(where the phase of the input impedance is equal to zero)
  - Cases: (d_{cap}), (W_{cap} = 0, 2, 4, 6, 8) [mm]
    - I: (0.5)
    - II: (1.0)
    - III: (2.0)
    - IV: (3.0)
    - V: (4.0)



Antenna Diversity: Antenna Results

Capacitive Load Width (W_{cap}) for Various Plate Separations(d_{cap})



Design Goal

- DCS 1800(GSM) operation
- 1.71 to 1.88GHz(VSWR<2)

Design Curve IV
W_{cap} = 0.3mm
d_{cap} = 3.0mm

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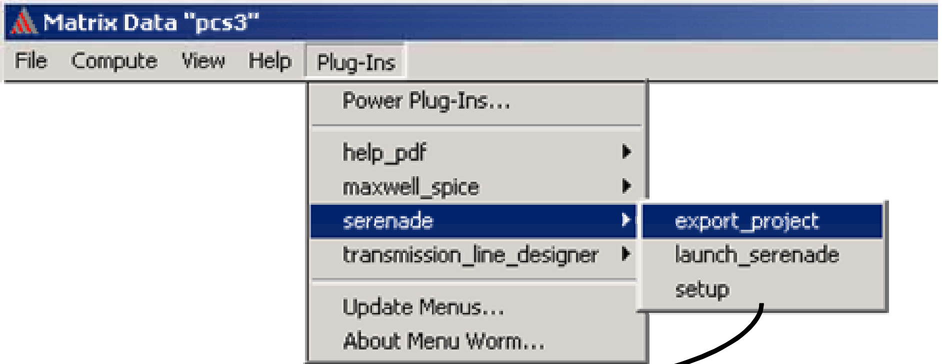
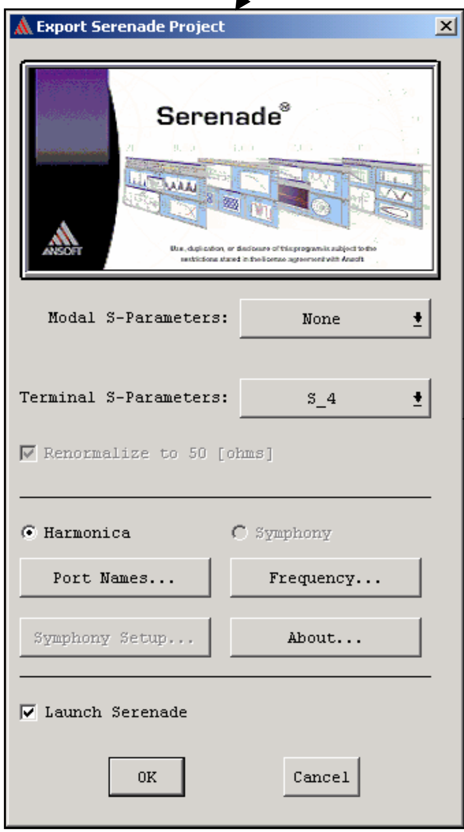
Antenna Diversity: Antenna Geometry

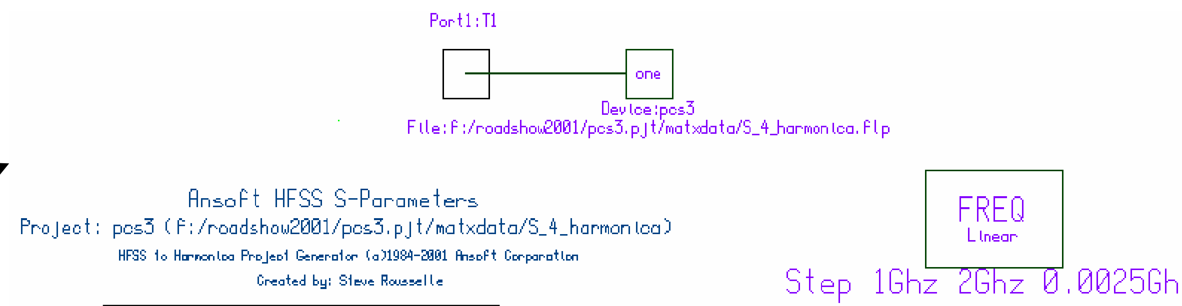
- From the design curves created by Ansoft Optimetrics, the dimensions for the antenna can be determined to achieve a specific operating band(resonant frequency)
- For this study, we will select a capacitively loaded PIFA design for DCS 1800(GSM) operation(frequency band 1.71 to 1.88GHz).
  - From design curve IV, this would correspond to W_{cap} = 0.3mm and d_{cap} = 3.0mm
- By updating the Parametric 3D Model with the new design values, the single antenna Ansoft HFSS simulations will be used to determine the performance
- After the simulations are completed, an Ansoft Serenade project is created directly from HFSS for plotting and further analysis.
- The following slides outline the performance of the single capacitively loaded PIFA

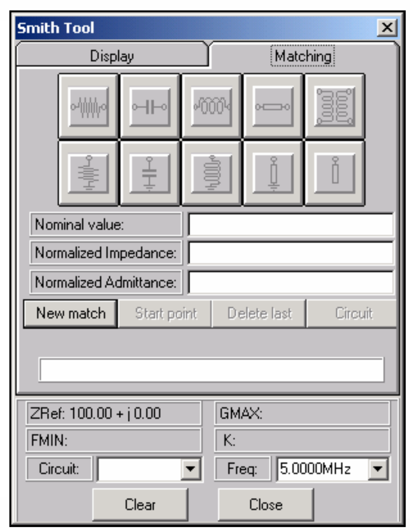
Antenna Diversity: Integration



- Using an Ansoft HFSS Power Plug-In, an Ansoft Serenade Project can be created and launched directly from HFSS.
- Visit the Ansoft web site(www.ansoft.com) to learn more about this and other Power Plug-Ins for Ansoft HFSS



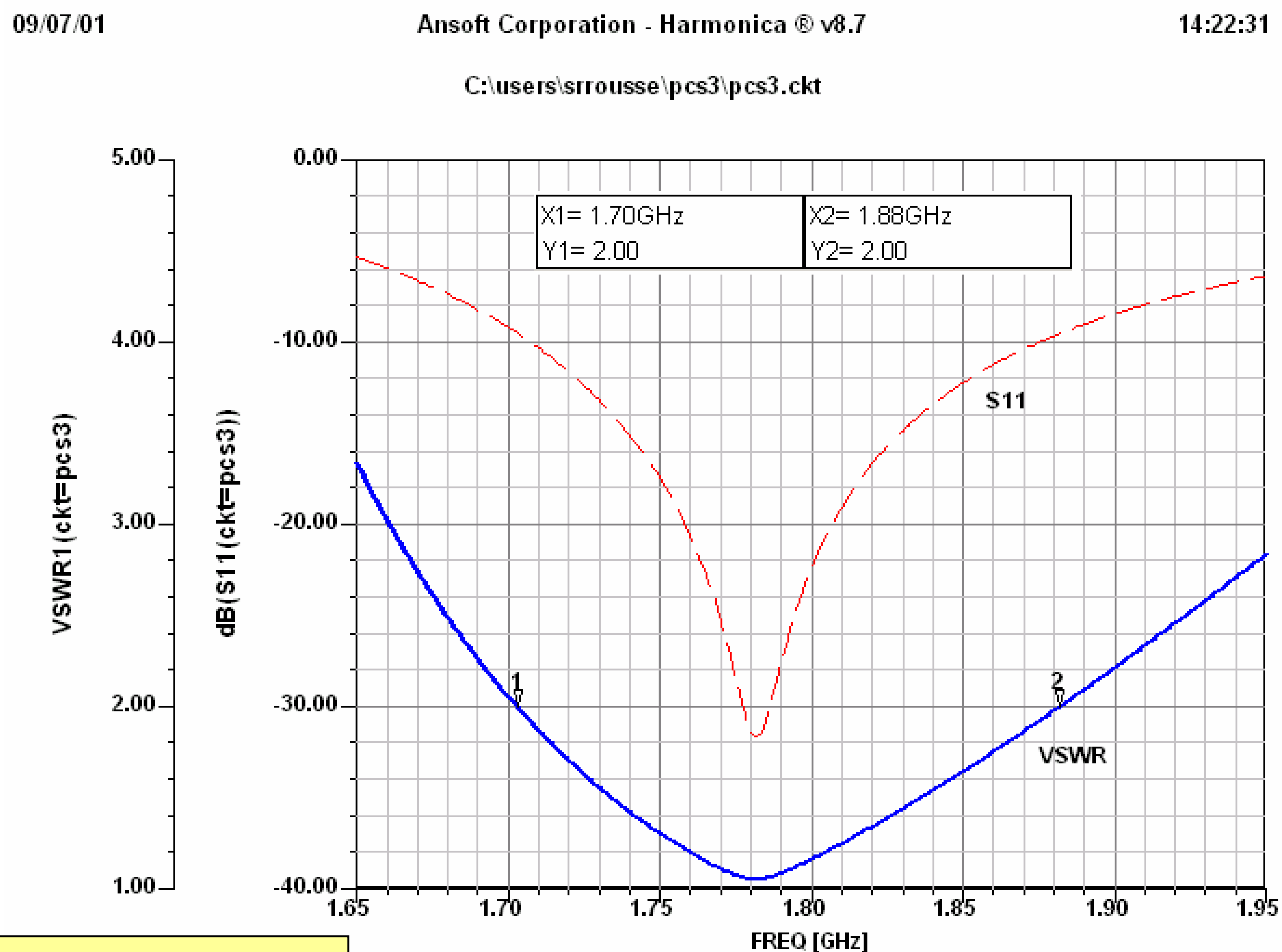




Quickly design matching networks using Smith Tool

Antenna Diversity: Antenna Results

VSWR/Return Loss

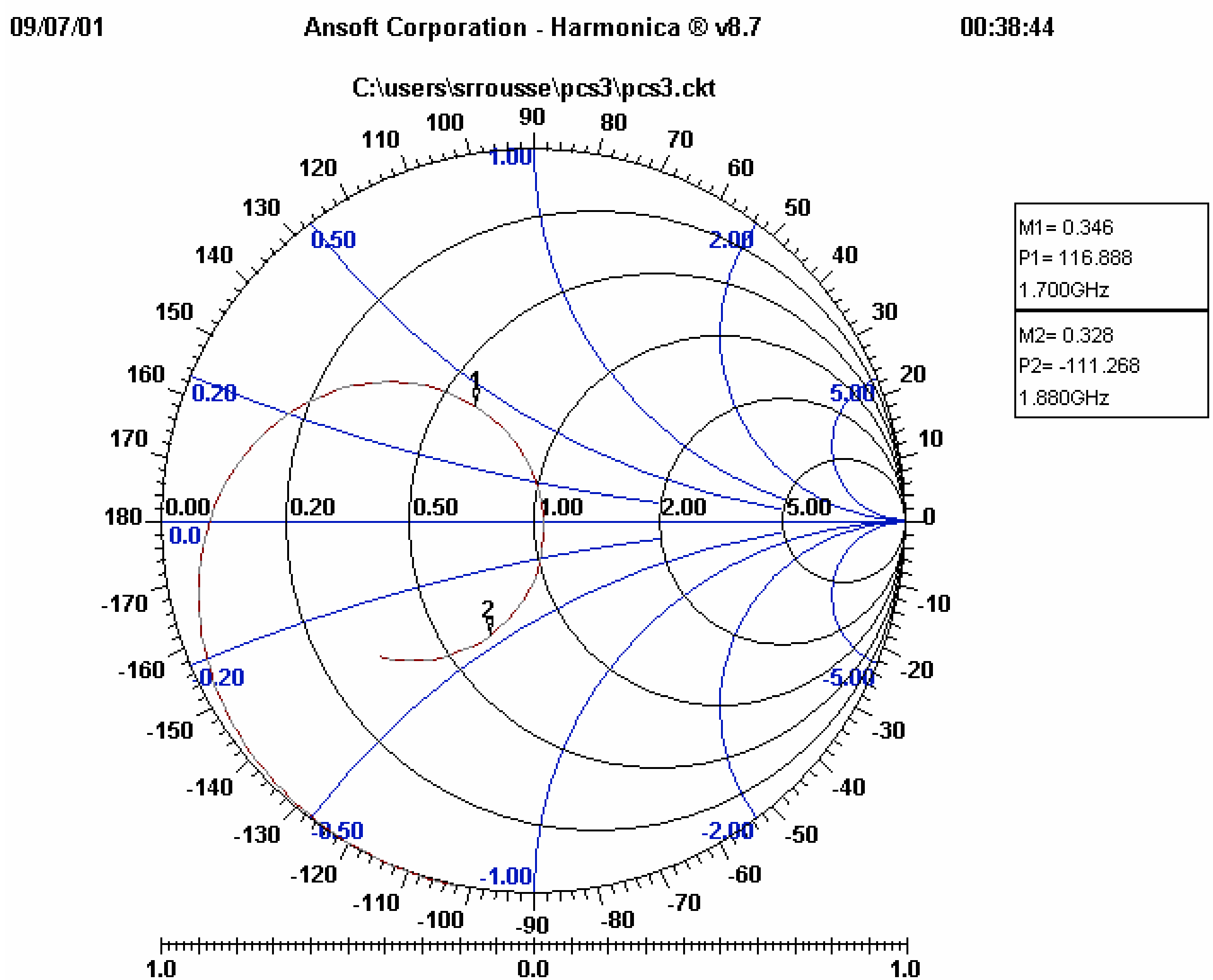


VSWR < 2 for 1.70-1.88GHz

Bandwidth: 180MHz

Antenna Diversity: Antenna Results

Smith Chart - S11



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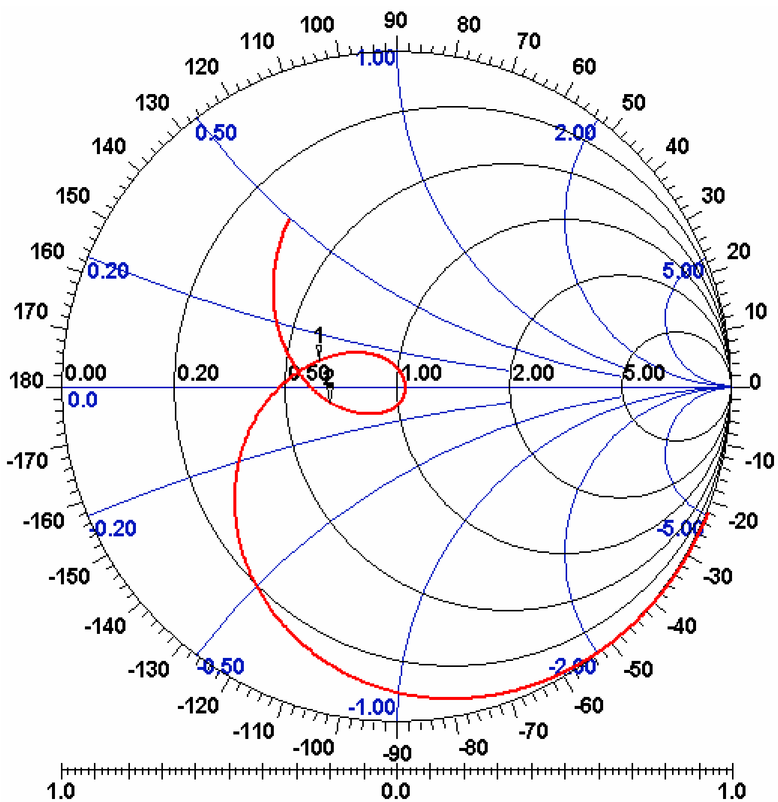
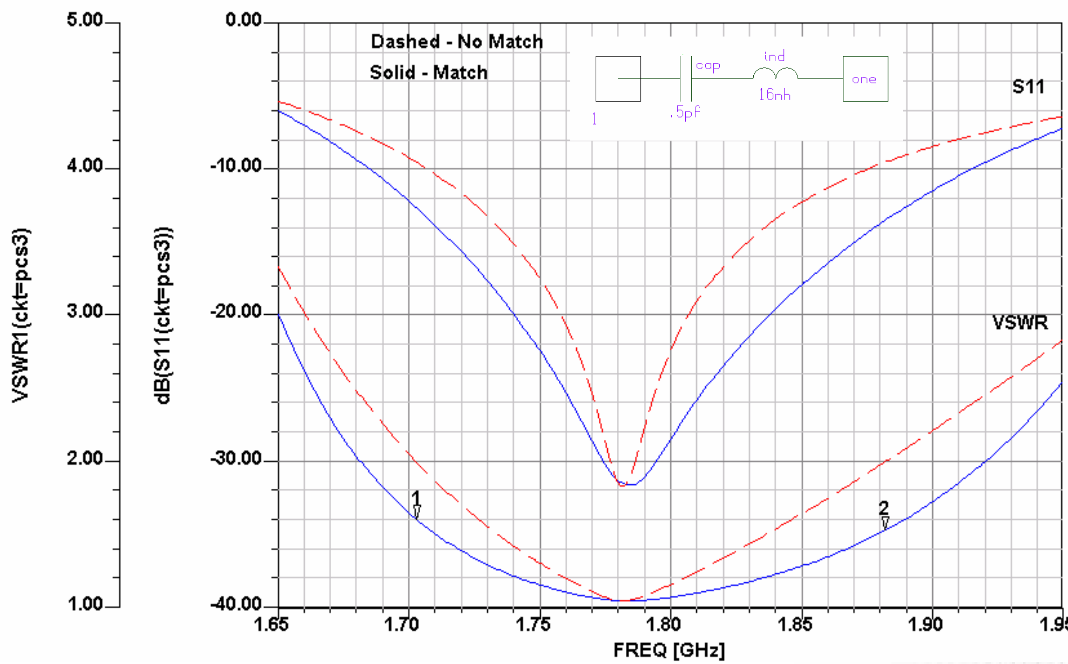
Antenna Diversity: Antenna Results

Smith Chart - S11

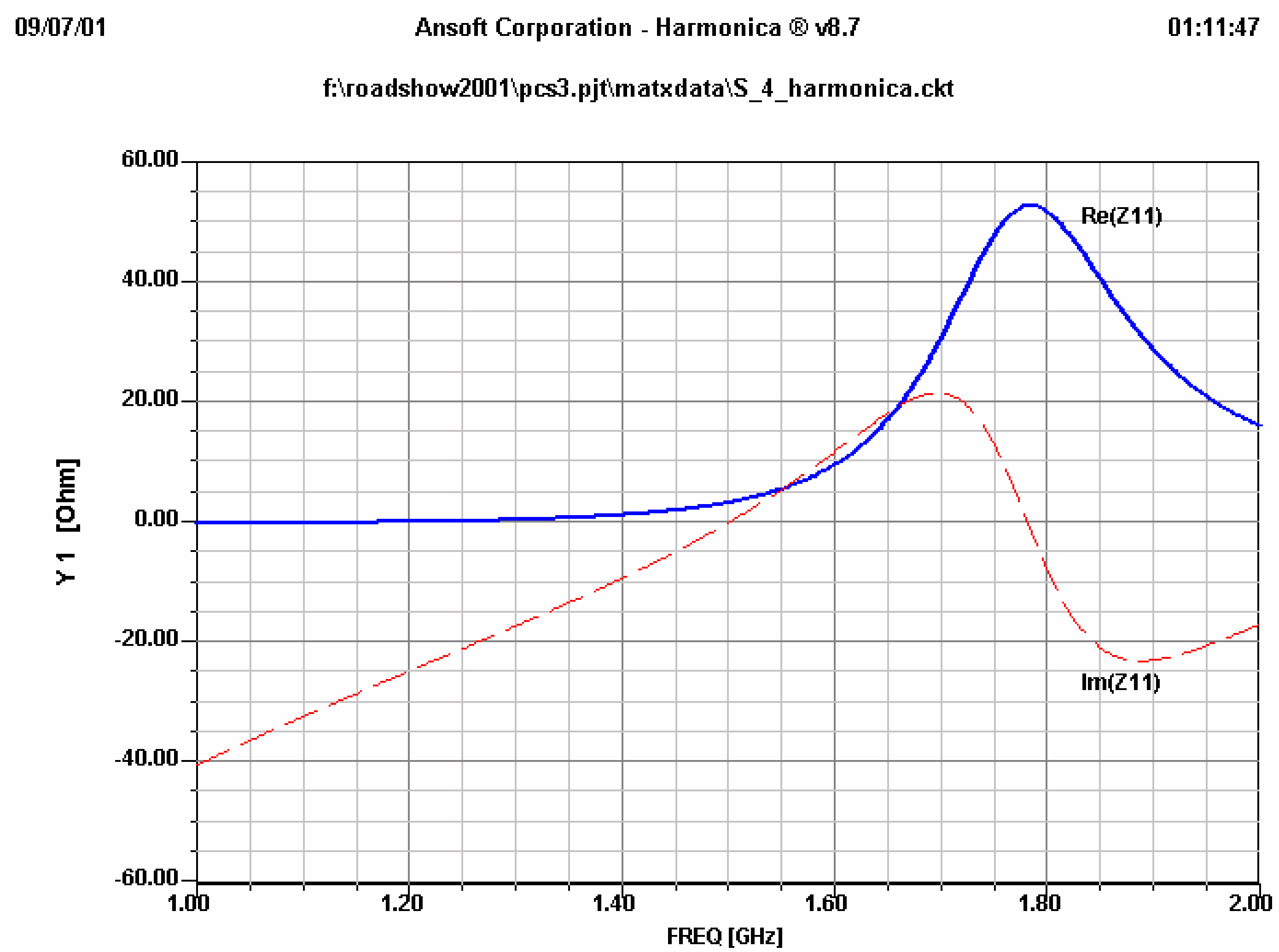
Matching Network Response





Antenna Diversity: Antenna Results

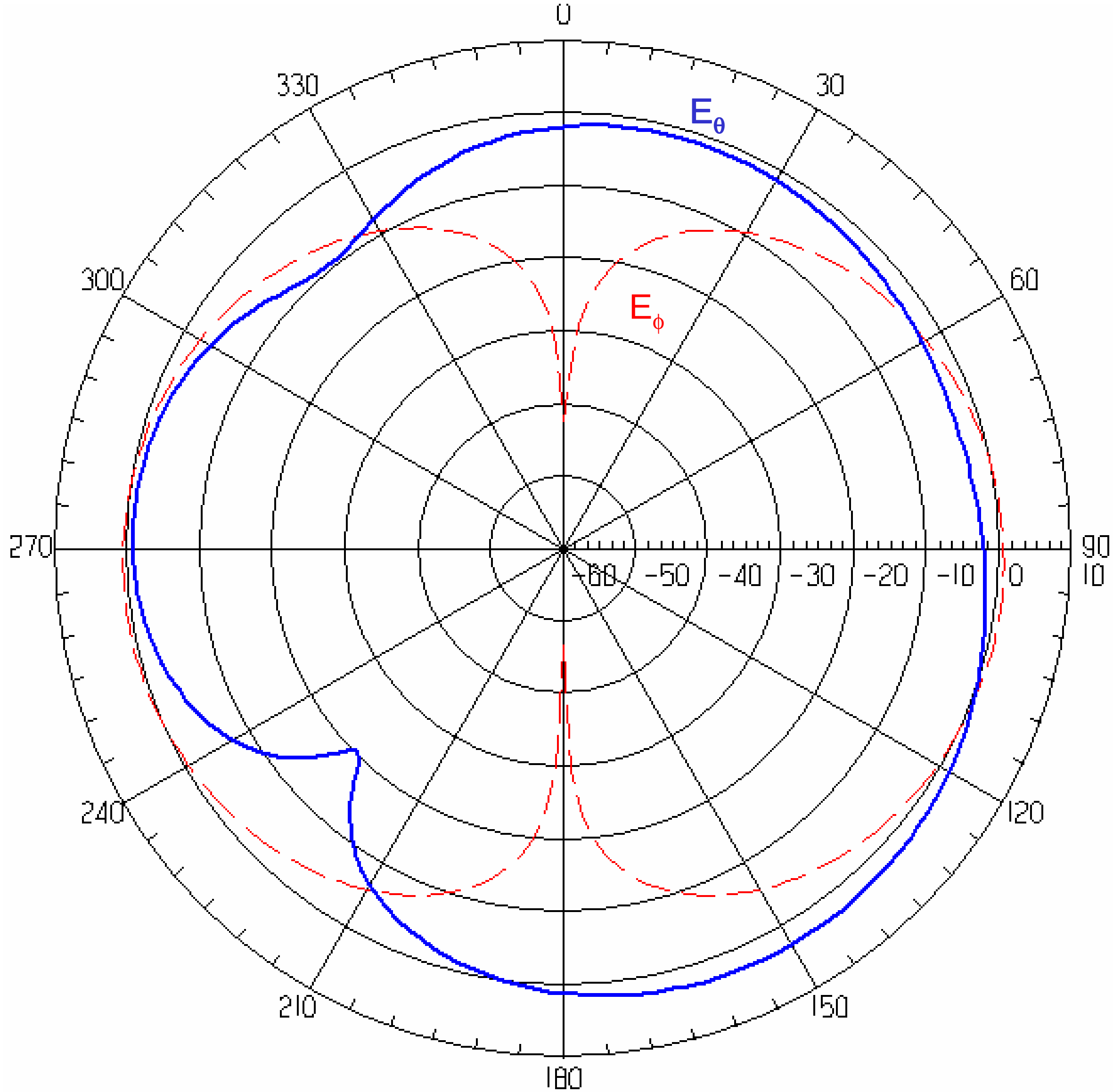
Impedance



Inspiring High-Frequency Design

Antenna Diversity: Antenna Results

Radiation Patterns
[dBi]



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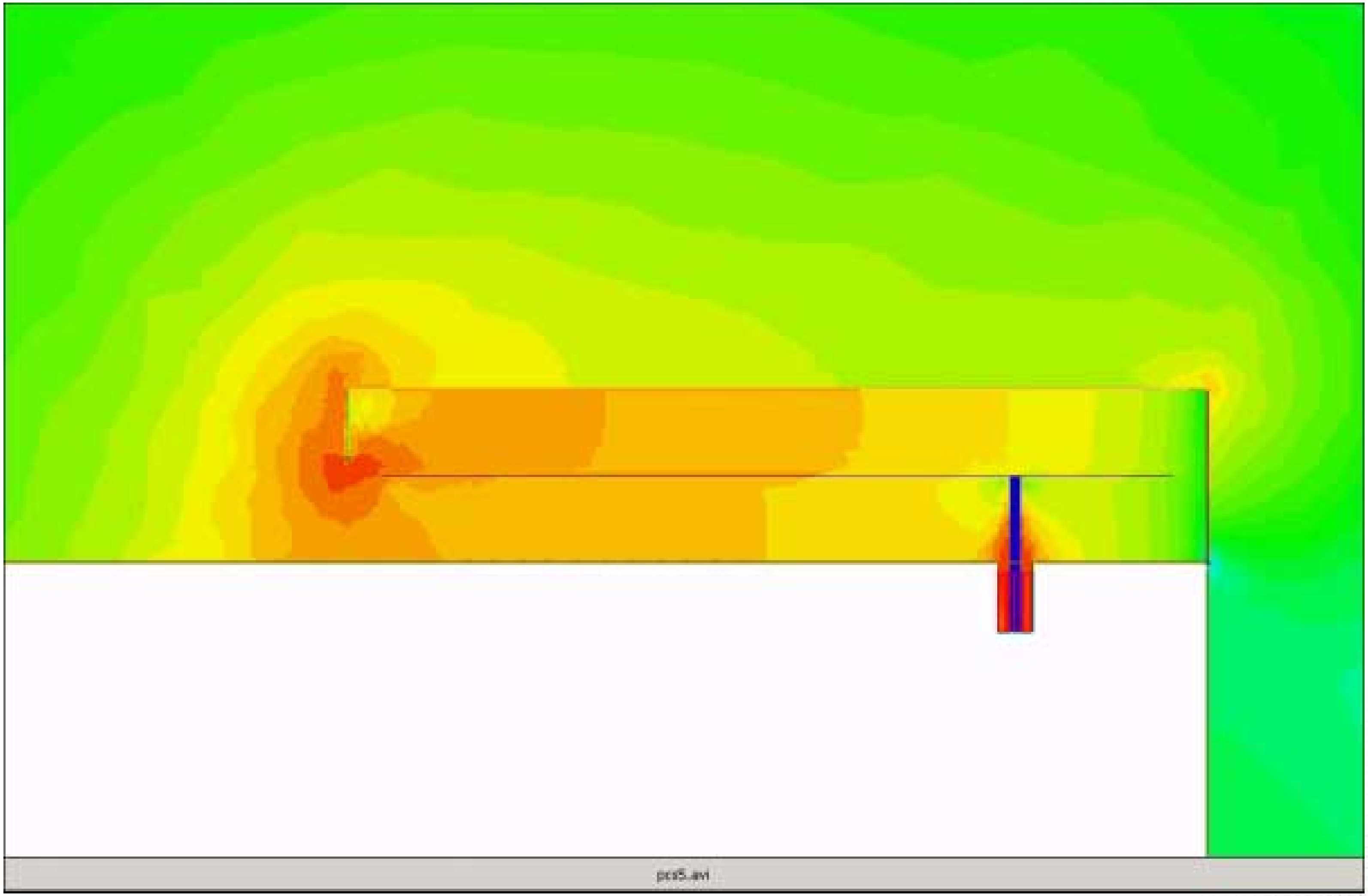
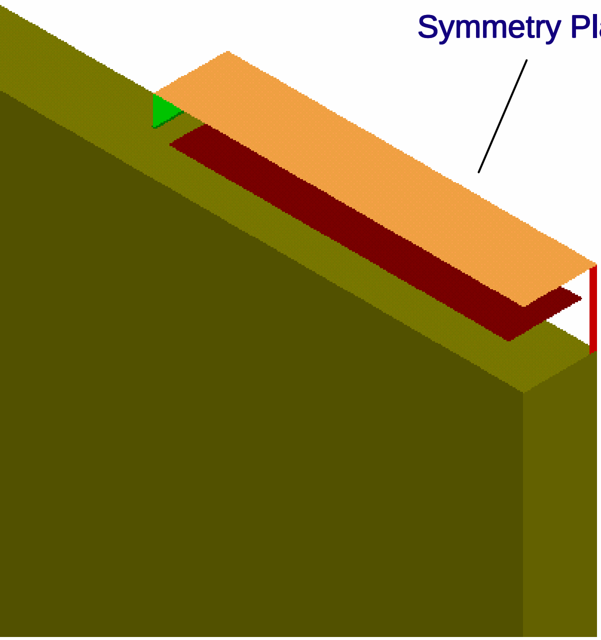
Antenna Diversity: Antenna Results

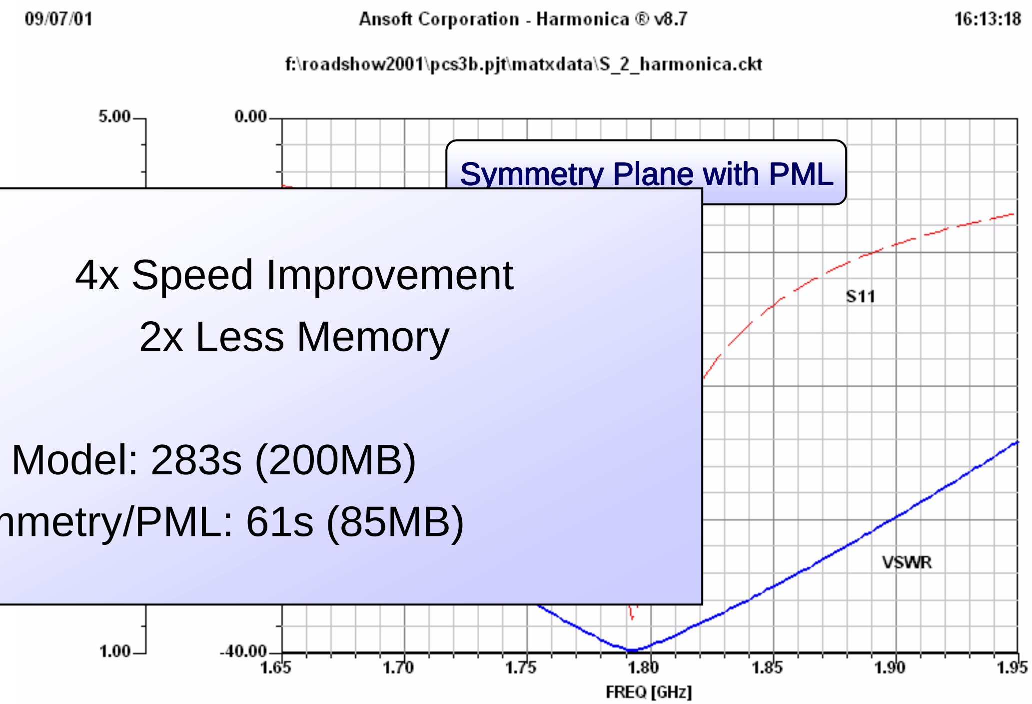
Field Animations



Antenna Diversity: Antenna Results

- When the handset is simulated in free space, the size of the simulation space can be reduced by taking advantage of the antennas symmetry





4x Speed Improvement

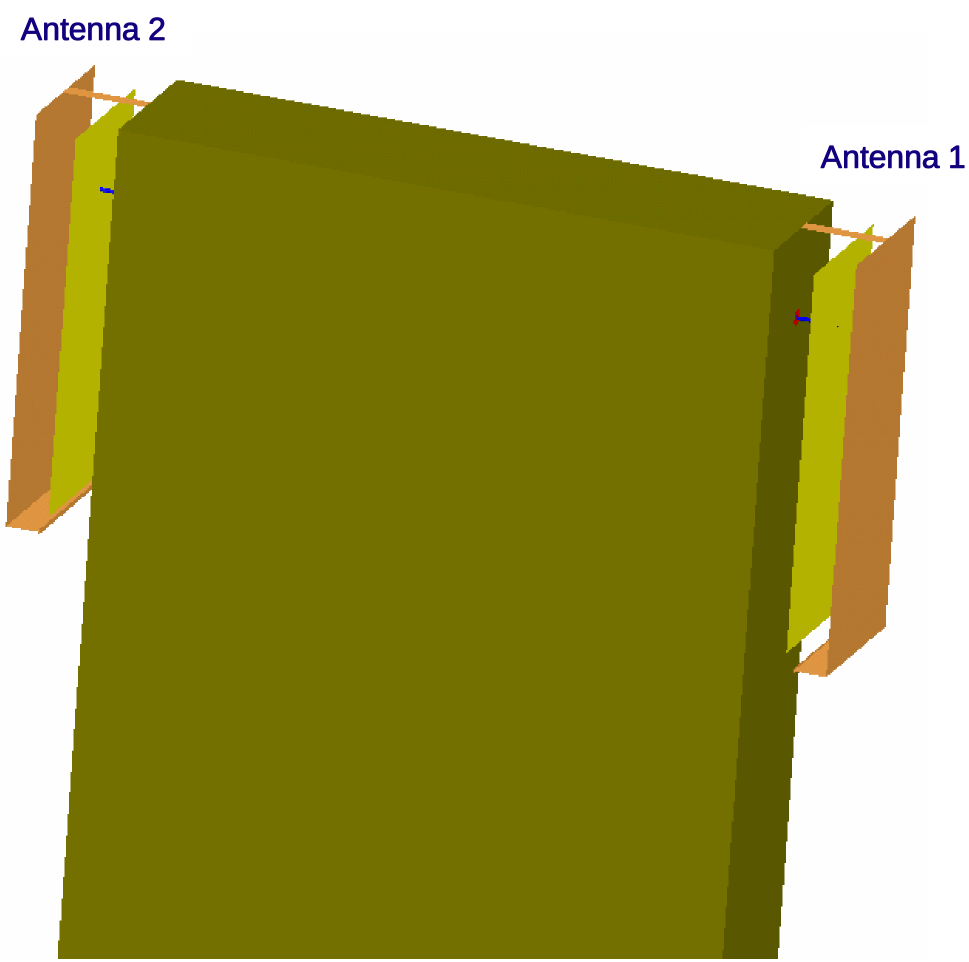
2x Less Memory

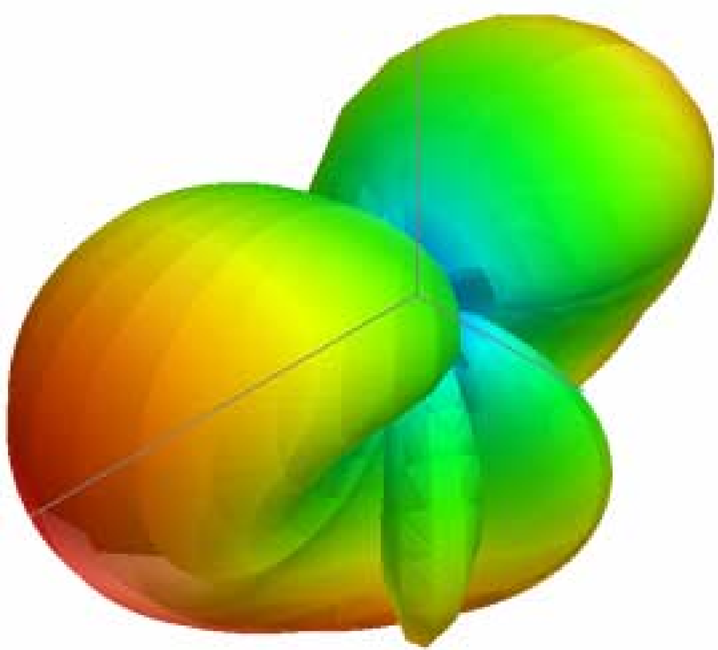
- Full Model: 283s (200MB)
- Symmetry/PML: 61s (85MB)

- In addition to symmetry, the simulation space can be reduced by using Perfectly Matched Layers(PML). The PML layer can be placed as close as $\lambda/8$-$\lambda/10$ compared to the minimum of $\lambda/4$ for a radiation boundary.
- When used in conjunction with the symmetry boundary, the overall simulation space can be reduced by a significant amount.

Antenna Diversity: Antenna Geometry

- By adding a 2nd antenna to the handset, Ansoft HFSS can be used to determine the performance of the antenna used in a diversity configuration.



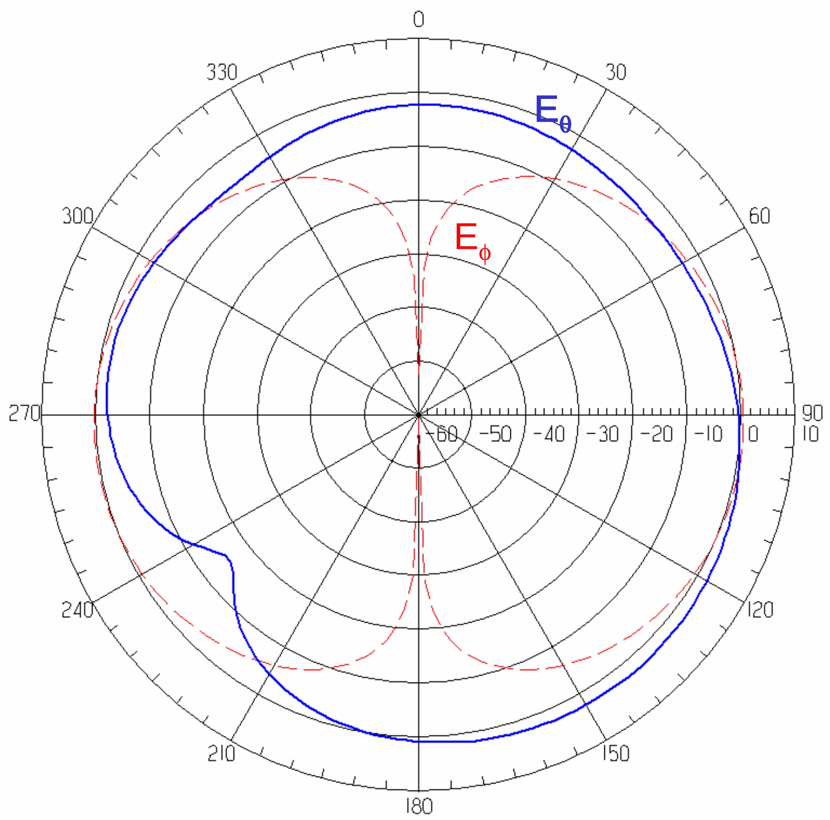


Antenna 1 - 3D Far-Field Pattern

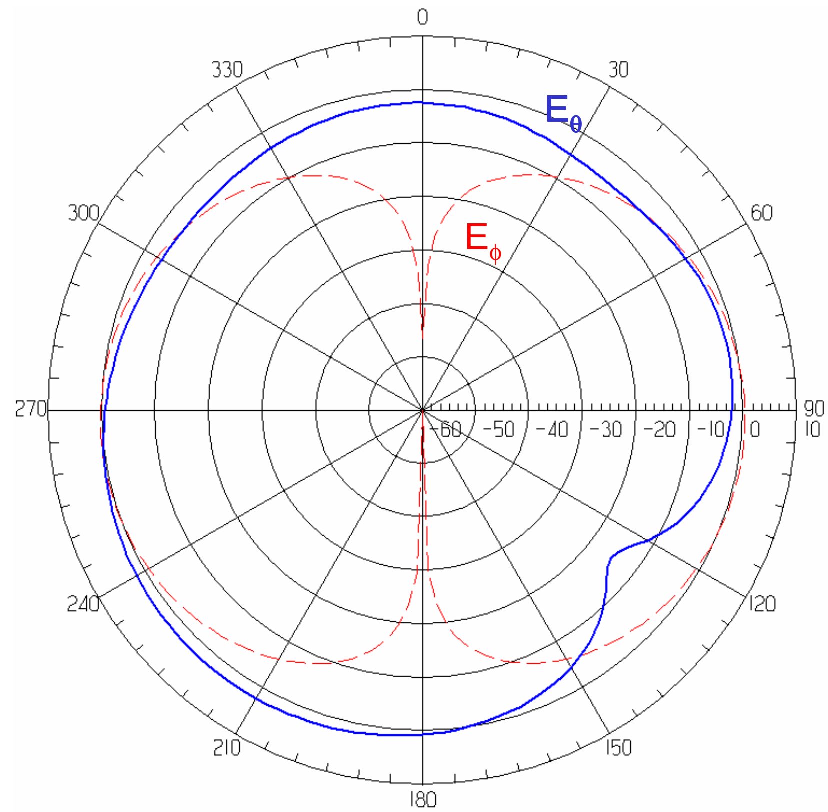
Antenna Diversity: Antenna Results

Radiation Patterns [dBi]

Antenna 1



Antenna 2



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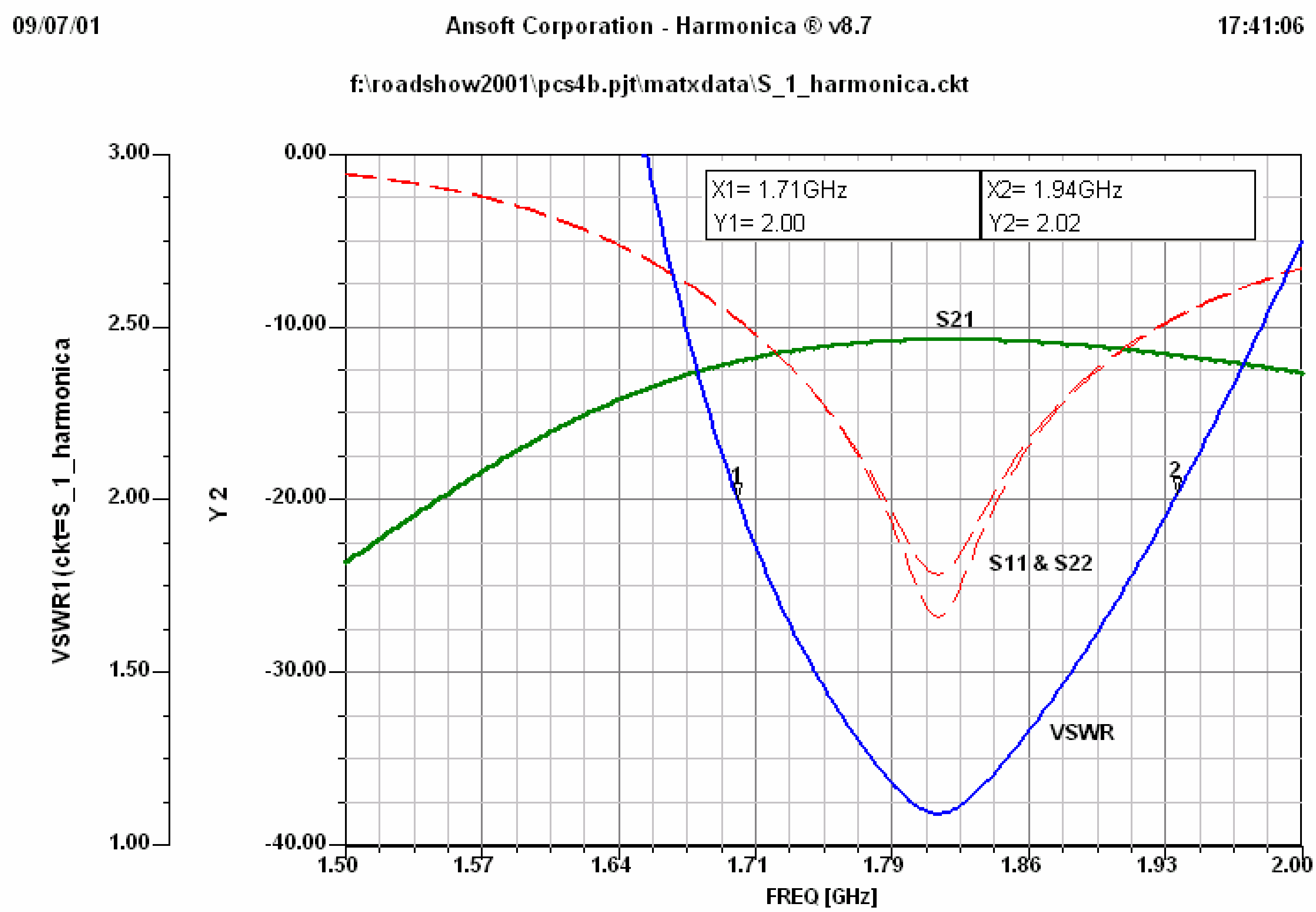
Antenna Diversity: Antenna Results

VSWR/S-Parameters



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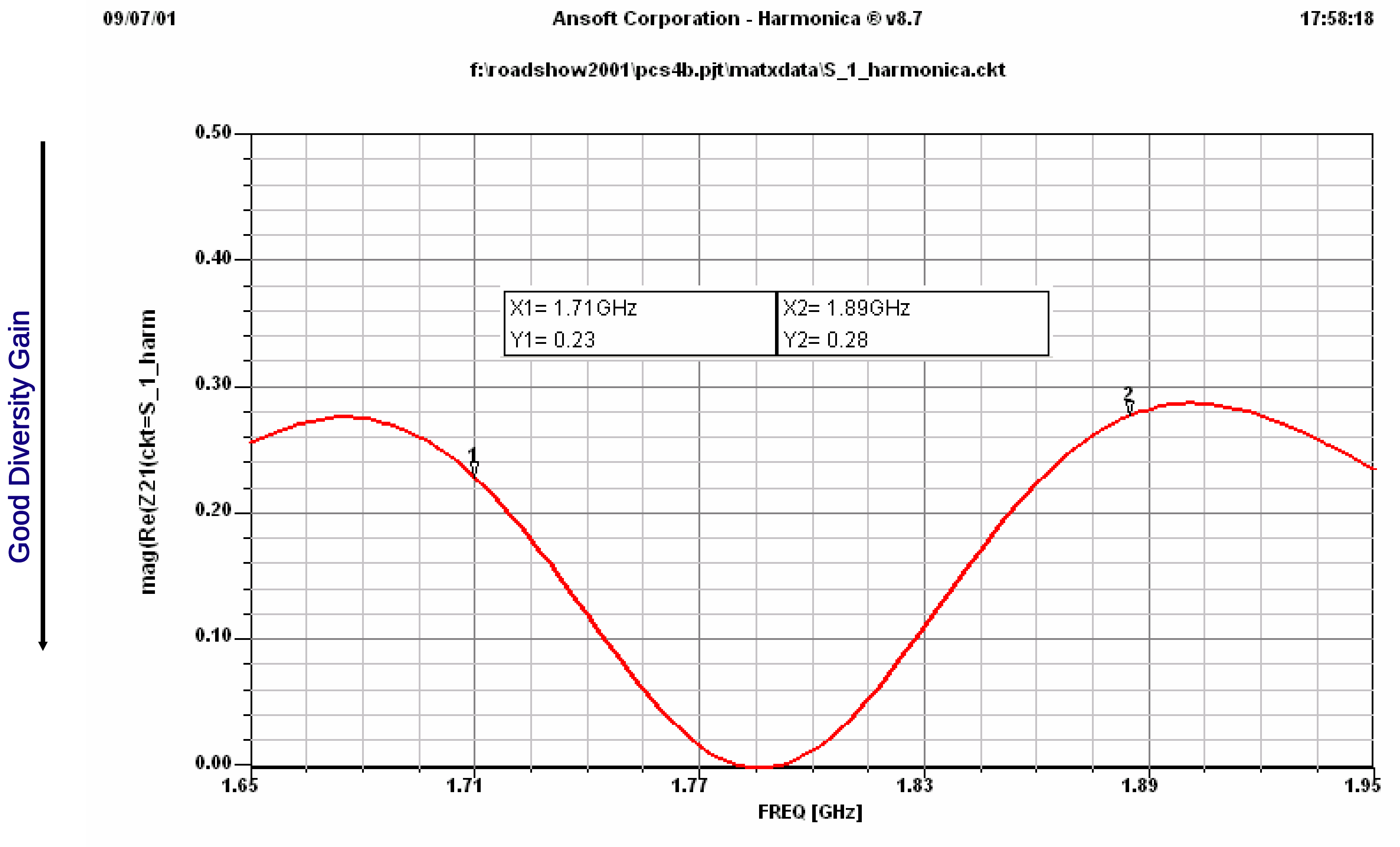
Antenna Diversity: Antenna Results

Port Impedance
Cross Correlation



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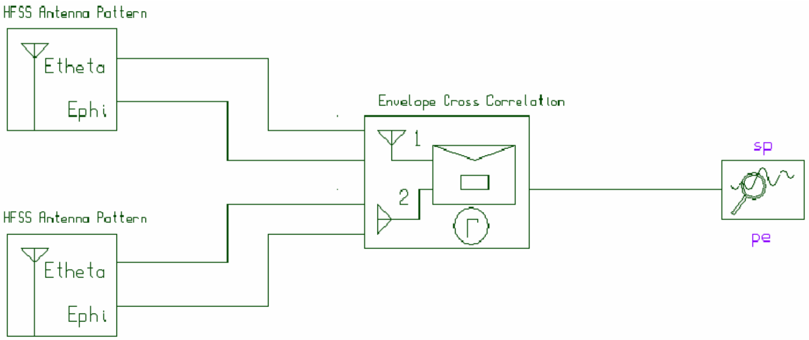
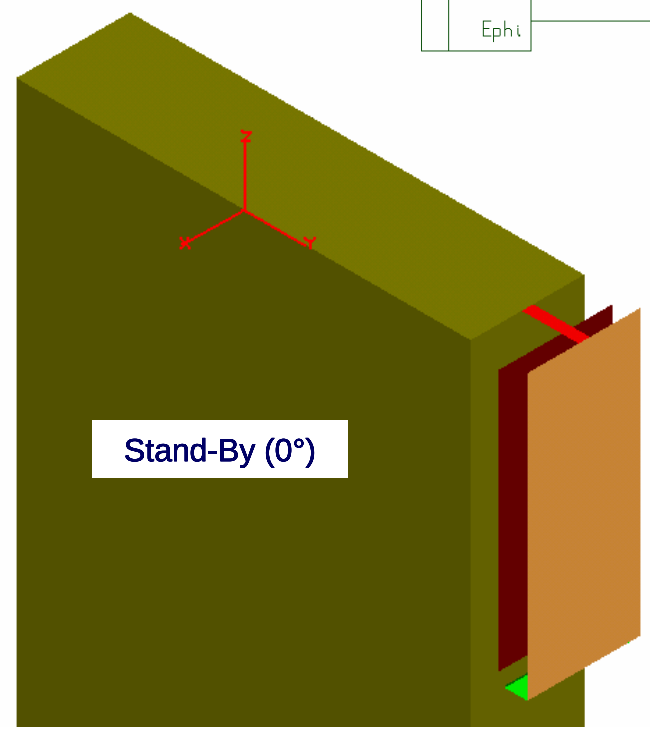
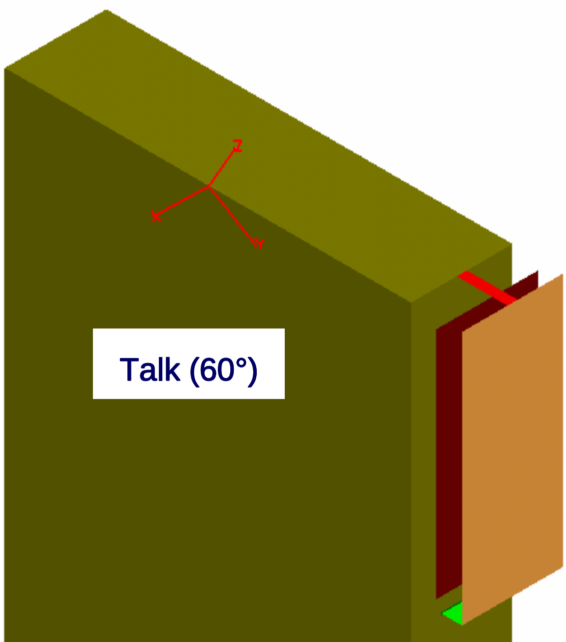
Antenna Diversity: Antenna Results

- Using (1), the Complex Cross Correlation is calculated from the Ansoft HFSS far-field antenna patterns.
- The calculations are performed for various values of XPD(-5 to 20dB)
- The calculations are performed for the stand-by(0°) and talk(60°) position



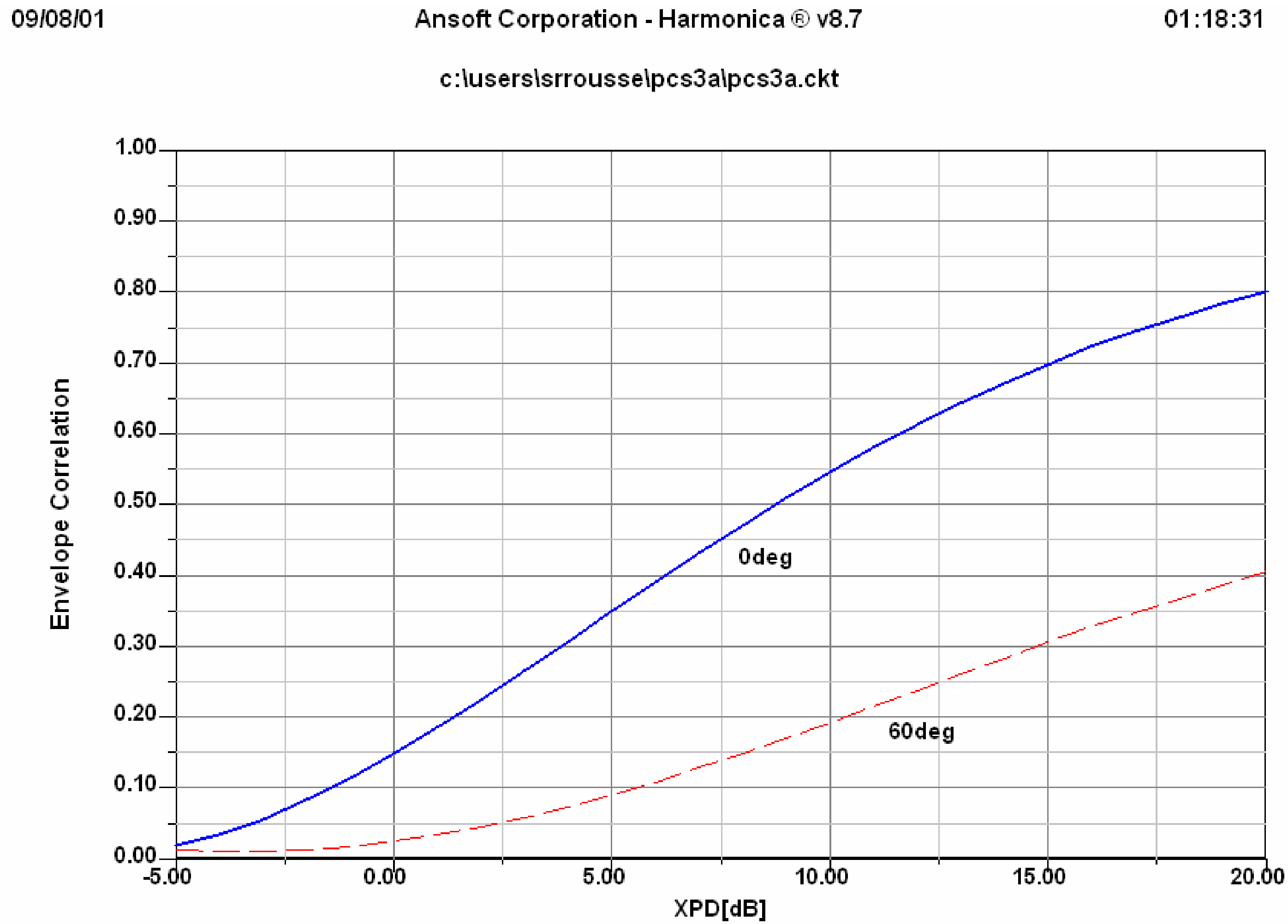
The Ansoft HFSS fields post processor allows far-field calculations to be performed on a local coordinate system. Utilizing this feature, the far-field patterns for these and other angles can be calculated without re-running the simulation.





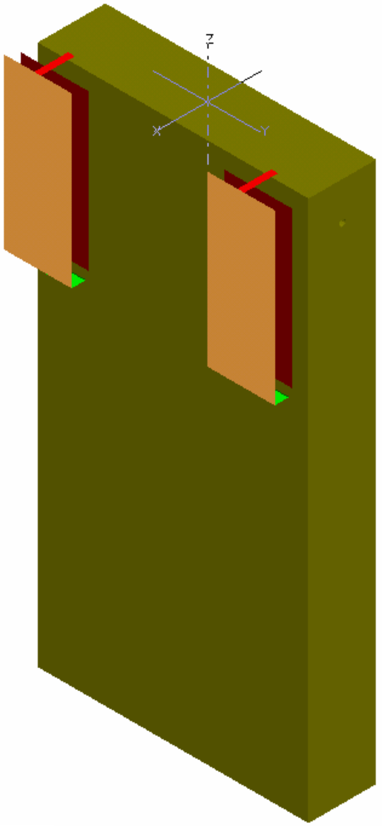
Antenna Diversity: Antenna Results

Cross Correlation Results



Antenna Diversity: Antenna Geometry

- With some minor modifications to the parametric 3D model, Ansoft Optimetrics can be used to control the antenna locations.
- This allows multiple antenna configurations to be efficiently analyzed.

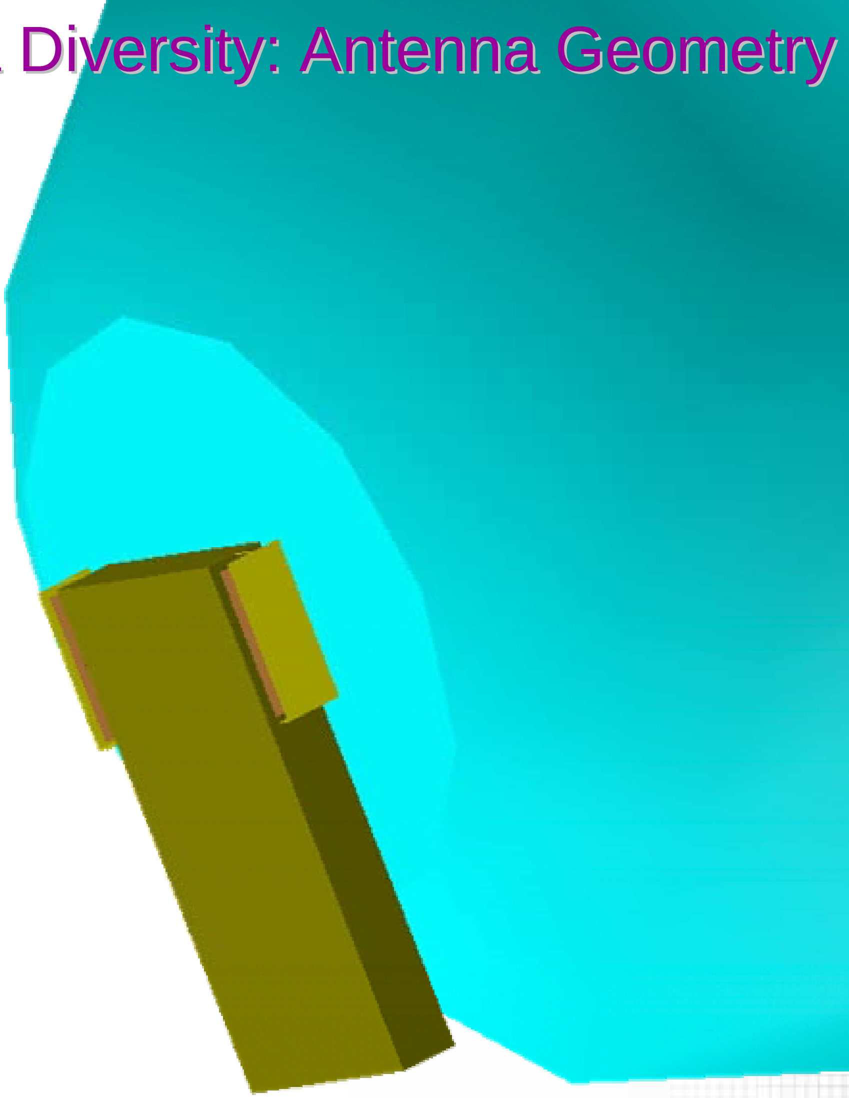


Ansoft Optimetrics Design Table

Setup	x	Dcap	Dcf
setup2	1	0.5	2.5
setup3	2	3	2.5
setup4	3	3	2.5
setup5	4	3	2.5
setup6	5	3	2.5
setup1	6	3	2.5

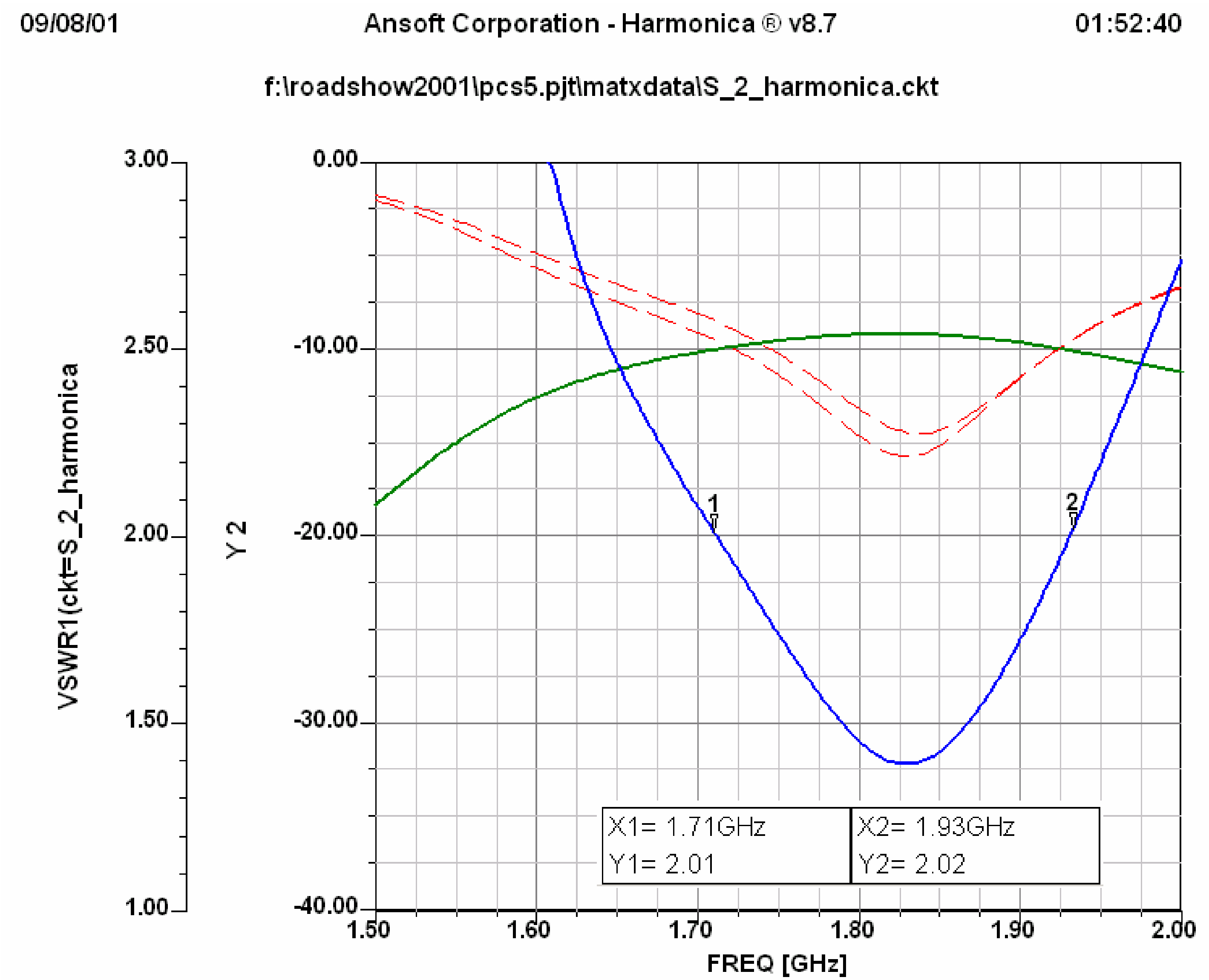
Antenna Diversity: Antenna Geometry

- While in use, most mobile handsets are not in a vacuum. Instead, they are in close proximity to a biological.
- To study the impact this has on the performance of the antenna system, a human head will added to the model.
- A spherical bowl filled with brain fluid will be used to model the head.
  - Brain Tissue
    - $\varepsilon_r = 42.9$
    - $\sigma = 0.9$
  - Bone(5mm thick)
    - $\varepsilon_r = 4.6$
  - Handset is placed 5mm from the surface of the head.



Antenna Diversity: Antenna Results

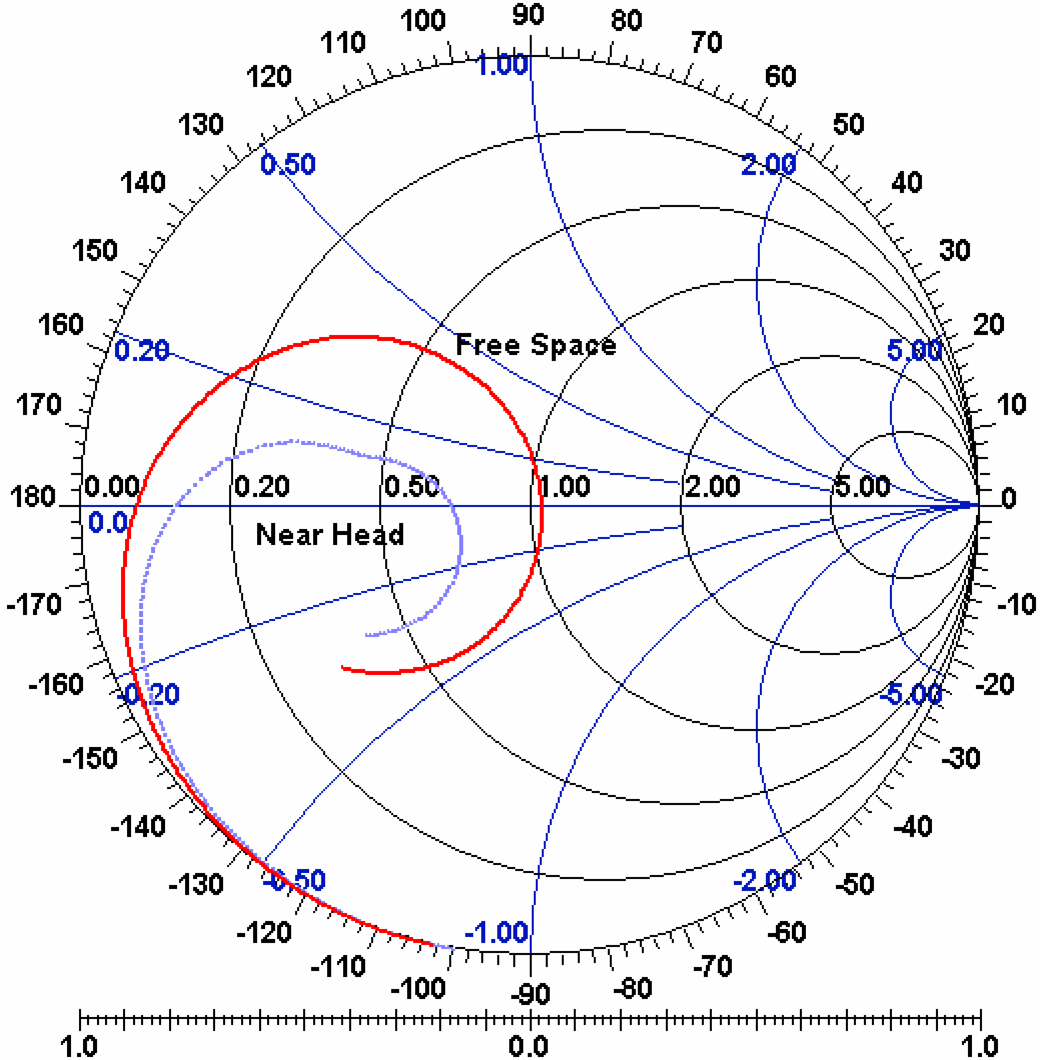
VSWR/S-Parameters



Inspiring High-Frequency Design

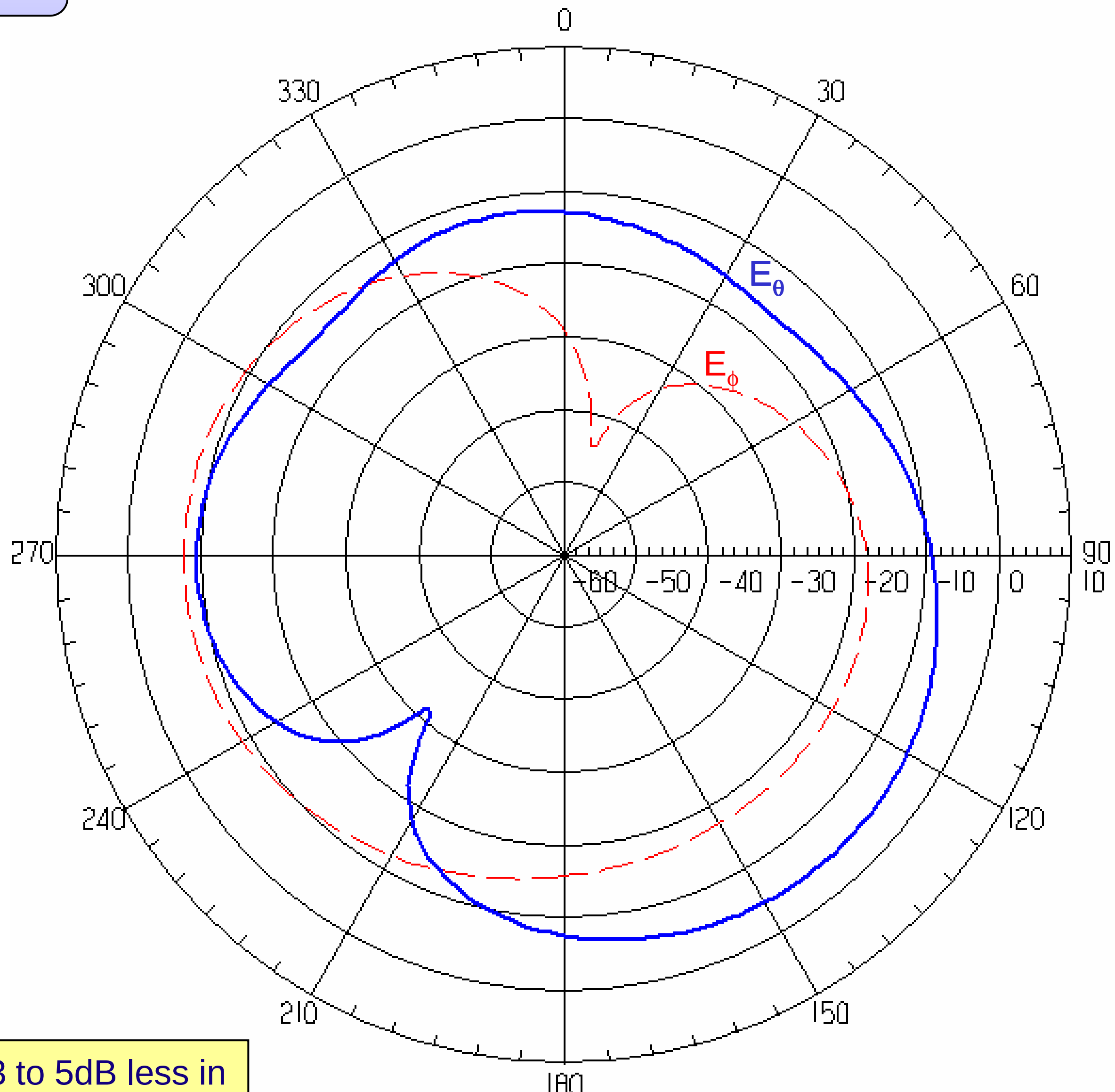
Antenna Diversity: Antenna Results

Smith Chart - S11



Antenna Diversity: Antenna Results

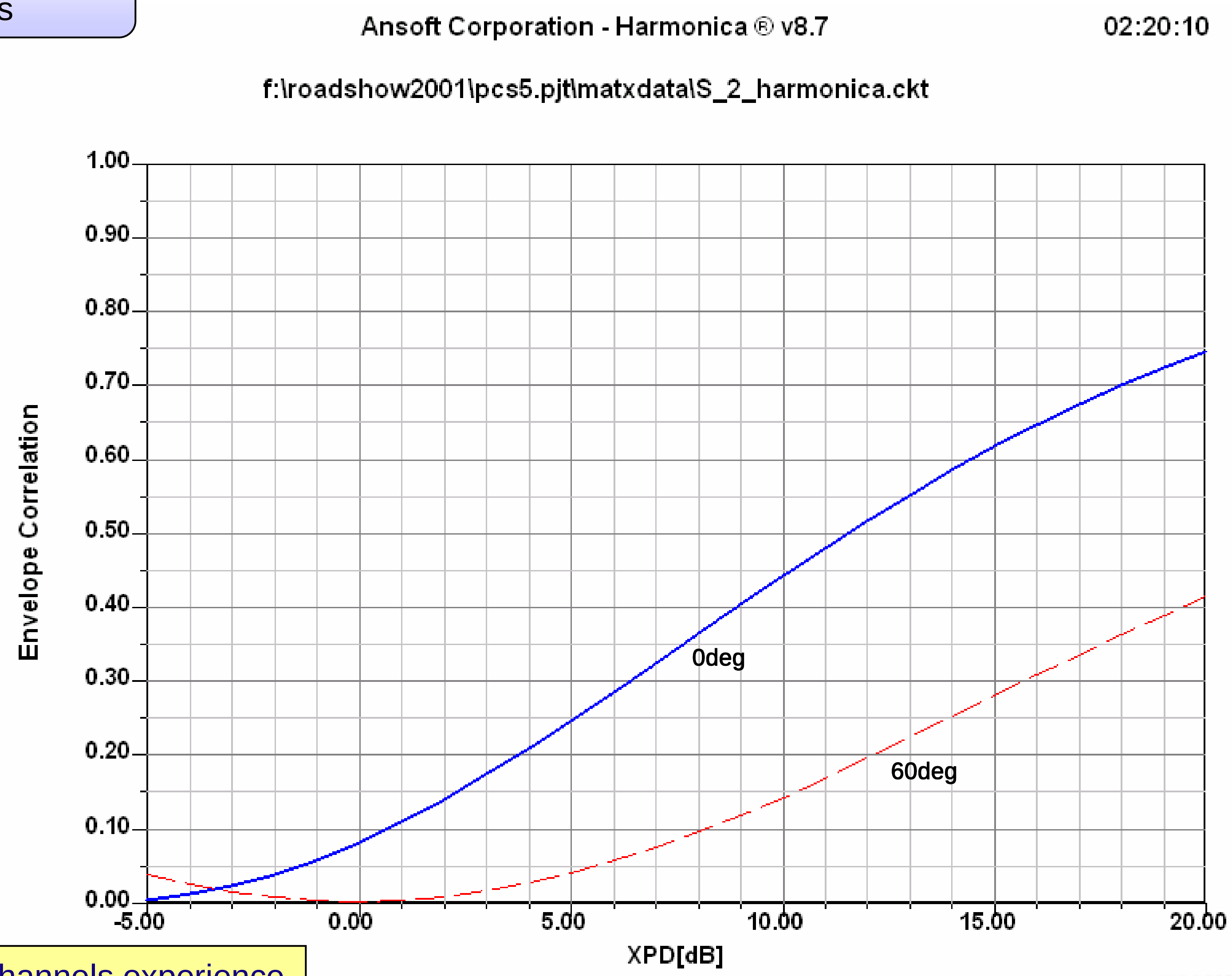
Radiation Patterns
[dBi]



Antenna Gain is 3 to 5dB less in the presence of the head model

Antenna Diversity: Antenna Results

Cross Correlation Results

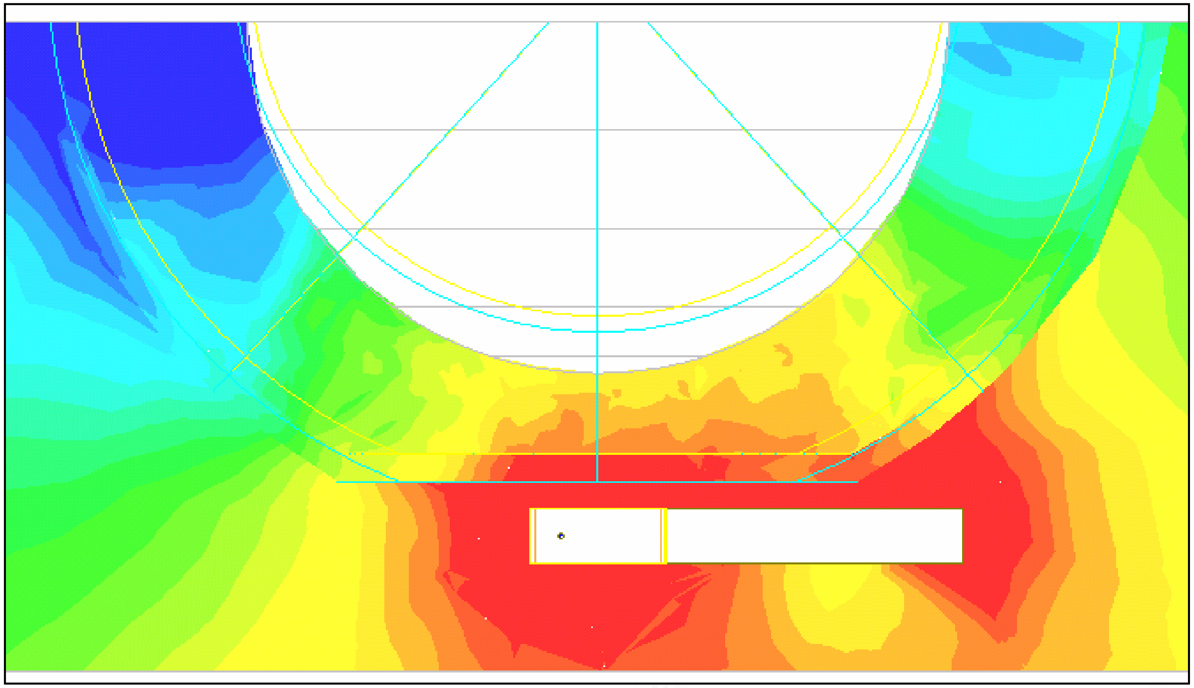


Since both channels experience the same loss the impact on the diversity performance is minimal

Inspiring High-Frequency Design

- When developing new PCS handsets, the Specific Absorption Rate(SAR) is an important design parameter. To help us understand the SAR performance, the fields post processor can be used to find and calculate the maximum SAR.

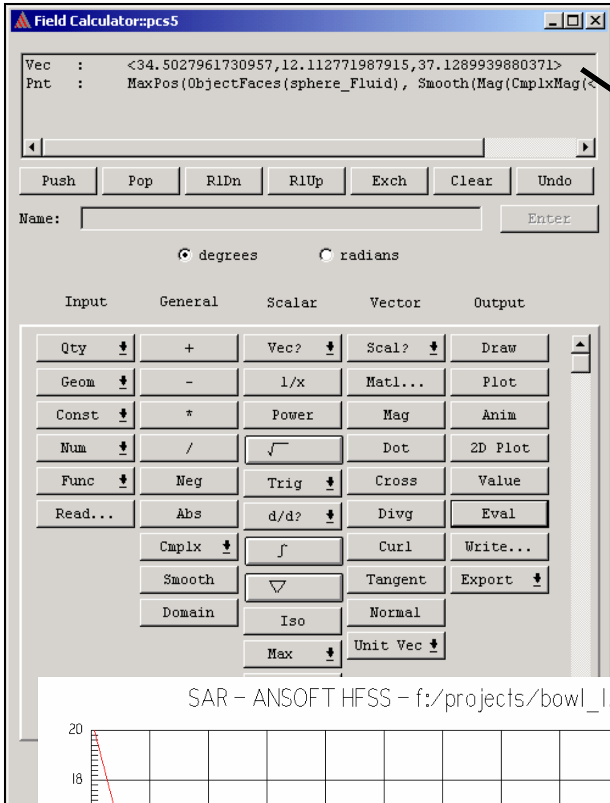
Specific Absorption Rate (SAR): Time rate of energy absorbed in an incremental mass, divided by that mass. Average SAR in a body is the time rate of the total energy absorbed divided by the total mass of the body. The units are watts per kilogram (W/kg)

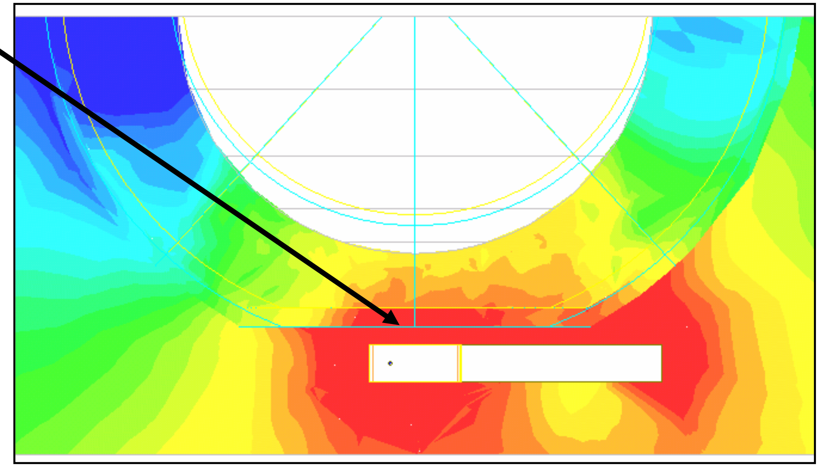


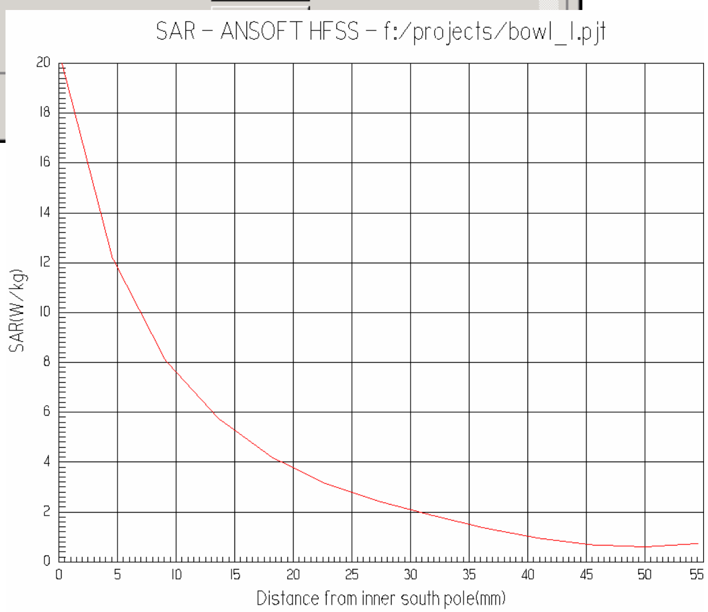
$$SAR = \frac{\sigma \, |E_{rms}|^2}{\rho}$$

- Where:
  - σ = conductivity of the tissue (S/m)
  - ρ = mass density of the tissue (kg/m^3)
  - E = rms electric field strength (V/m)

Antenna Diversity: Antenna Results







- The fields calculator identifies the maximum field location.
- By moving the origin to the maximum, the local SAR can then be computed using the calculator.
- Utilizing the Ansoft macro language, this can be automated or performed along a line as shown here.

Antenna Diversity: Summary

- The design and development of a PCS handset for use in the DCS-1800 band was presented. Using Ansoft's Electronics Design Automation(EDA) software, the engineer has the ability to perform end-to-end design simulations. This avoids costly prototypes and allows the engineer to investigate more "what-if" designs - Thereby increasing the likelihood of producing superior products that cost less and take less time to develop.

- Using the software an antenna designer can evaluate:
  - S-Parameters
  - Antenna Patterns and Gain
  - Isolation
  - Optimize Antenna Design
  - Create Antenna Design curves
  - Complex Cross Correlation
  - Antenna Placement
  - Specific Absorption Rate(SAR)

- By applying software tools early in the development process, problems can be quickly identified and resolved prior to production. Thus decreasing a products time to market.

Antenna Diversity: References

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