



MOTOROLA LABS

UHF Handset Monopole Antenna Designed for SAR Compliance

Dr. Soo Liam Ooi
Center for Wireless Access
Motorola Labs
SooLiam.Ooi@Motorola.com



MOTOROLA LABS

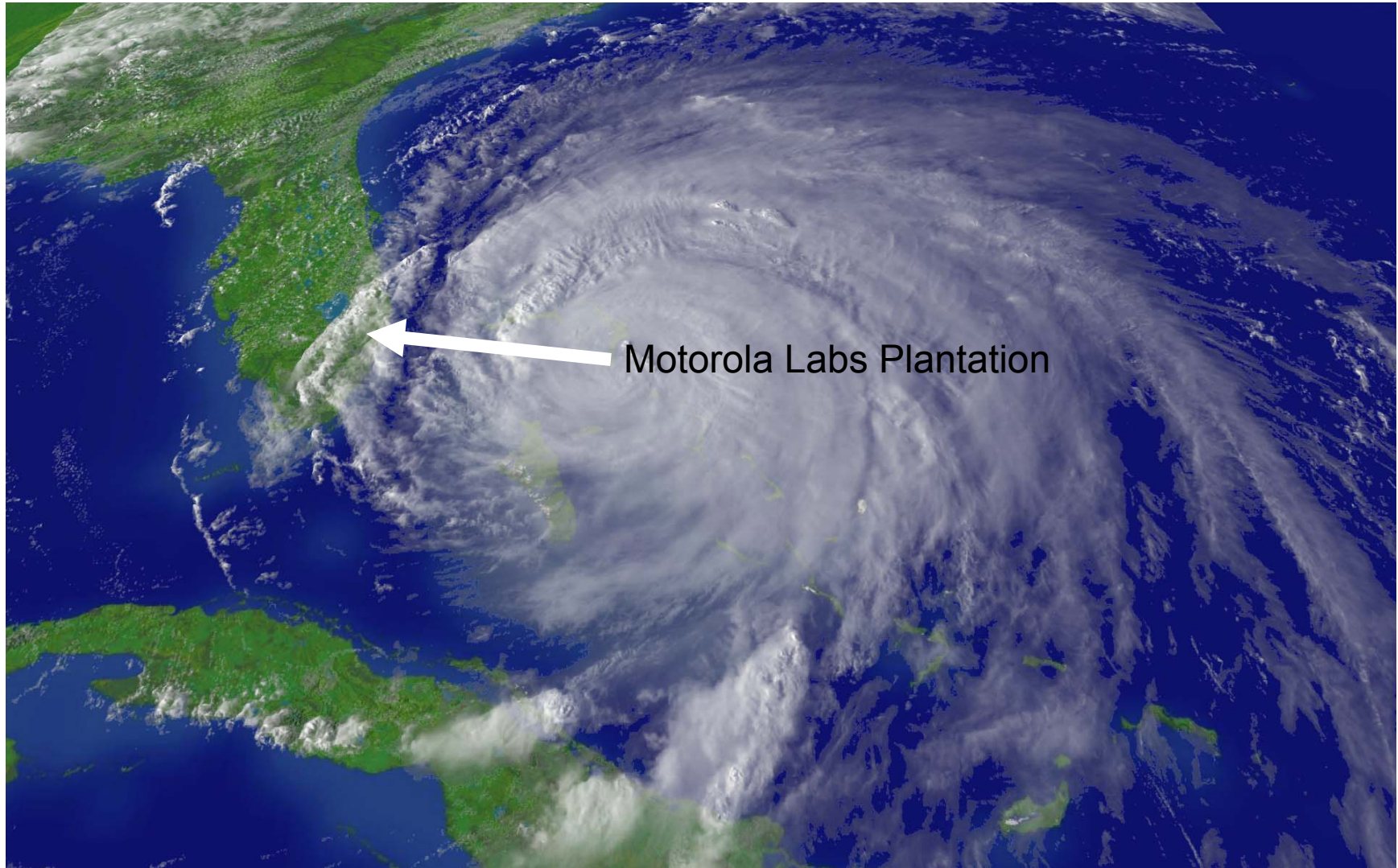
UHF Handset Monopole Antenna Designed for SAR Compliance

***A Radio-Independent
Virtual Testbench and Design Flow
for pre-Prototype SAR Compliance***

Motorola Labs is [was] here !



MOTOROLA LABS



High Power Public Safety Radio



MOTOROLA LABS

- ▶ **Target Products are ...**



Hand held



MOTOROLA LABS



Waist mounted



MOTOROLA LABS

Radio! Not cell phone!

OWN IT
ON DVD AND VIDEO
MARCH 8



JOHN TRAVOLTA JOAQUIN PHOENIX

LADDER

49

Specific Absorption Rate Prediction



MOTOROLA LABS

- ▶ **Products must show SAR compliance before commercial shipments.**
- ▶ **Design for Compliance:**
 - early prediction of SAR characteristics ensures compliance without time consuming design-test iterations
 - early prediction of SAR issues ensures compliance through cost-effective pre-prototype platform/antenna changes
- ▶ **SAR compliance limit for occupational environment 8W/kg (*general public* 1.6 W/kg)**
- ▶ **SAR is scalable by the transmitted power.**
 - for a specific frequency with a given platform/antenna
- ▶ **FDTD is a popular tool for SAR assessment.**



Purposes of presentation:

- ▶ **Demonstrate the practical application of “Virtual Testbench” to assess SAR during design.**
- ▶ **Testbench is radio-independent**
 - simply add a different platform and/or antenna
- ▶ **Testbench is parametric and scalable.**
- ▶ **Dielectric constant and conductivity of human tissue are set according to IEEE 1528 specifications.**
- ▶ **Current radio is UHF, 403 MHz to 470 MHz.**

Why HFSS?



MOTOROLA LABS

- ▶ **Proven**
- ▶ **Handles low frequencies and 2D structure with ease**
- ▶ **Inherently parametric design environment**
 - parametric solid models
 - optimization and parametric analyses
- ▶ **Mesh controls available**
 - surface approximation, aspect ratio
- ▶ **Analysis setup/control easily modified**
- ▶ **Frequency-dependent maximum average SAR easily determined throughout entire tissue volume**
- ▶ **One package for both antenna development and SAR assessment**

SAR calculations using HFSS



MOTOROLA LABS

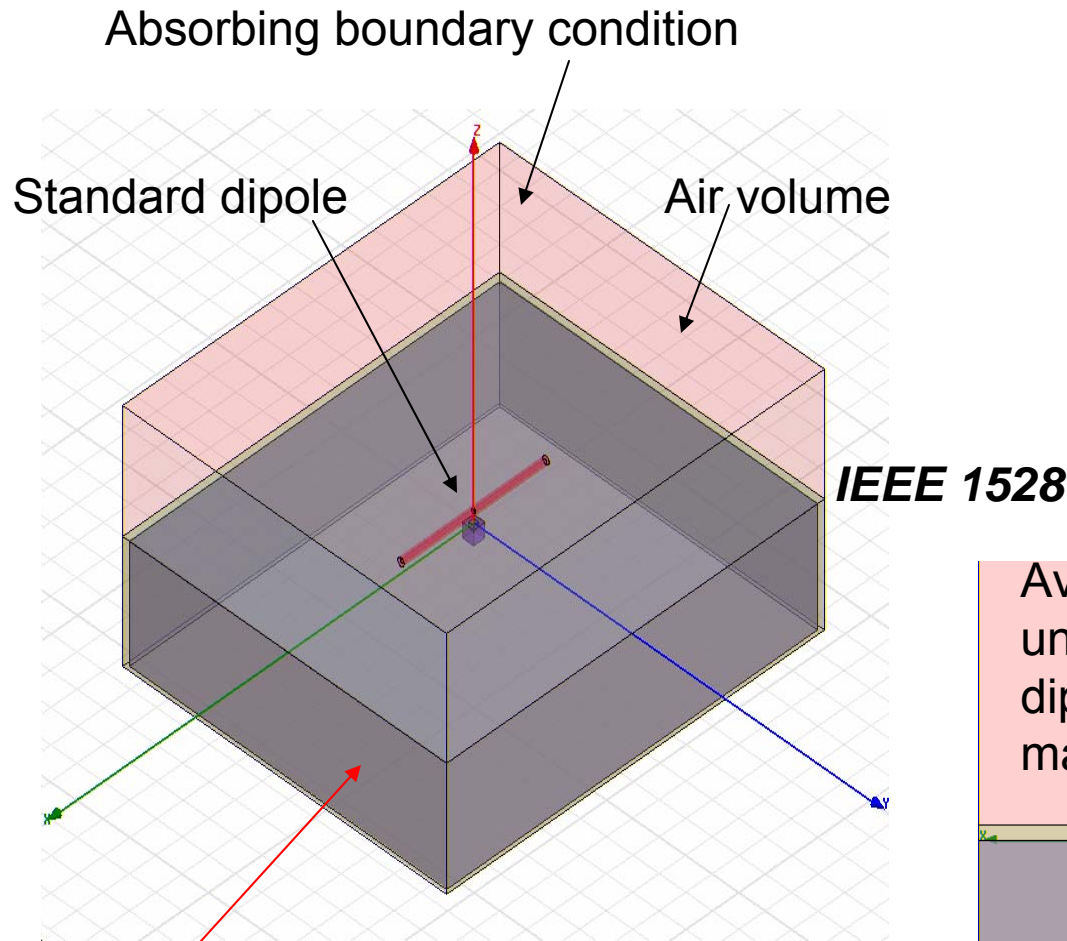
- ▶ **IEEE 1528 Calibration standards were reproduced using HFSS 9.2. (Matt Commens) for the Dipole and Phantom Model. Measured data in parenthesis.**

Frequency (MHz)	1g SAR	10g SAR	Local SAR at surface (above feedpoint)	Local SAR at surface (y= 2cm offset from feedpoint)
300	3.06 (3.0)	2.07 (2.0)	4.63 (4.4)	2.20 (2.1)
450	4.98 (4.9)	3.31 (3.3)	7.59 (7.2)	3.28 (3.2)
835	9.62 (9.5)	6.26 (6.2)	14.71 (14.1)	4.93 (4.9)
900	10.98 (10.8)	7.02 (6.9)	17.01 (16.4)	5.47 (5.4)
1450	29.83 (29.0)	16.50 (16.0)	53.90 (50.2)	6.54 (6.5)
1800	39.36 (38.1)	20.45 (19.8)	74.39 (69.5)	6.85 (6.8)
1900	40.97 (39.7)	21.21 (20.5)	78.02 (72.1)	6.54 (6.6)
2450	55.42 (52.4)	25.42 (24.0)	115 (104.2)	8.09 (7.7)
3000	65.81 (63.8)	26.48 (25.7)	157.66 (140.2)	8.8 (9.5)

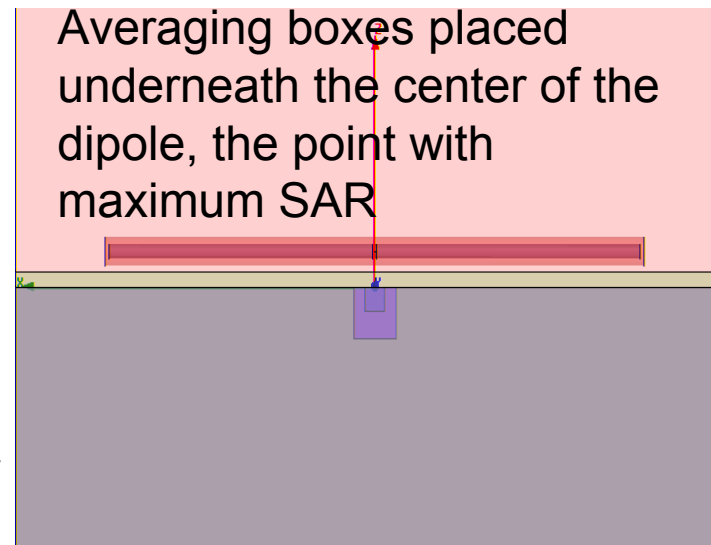
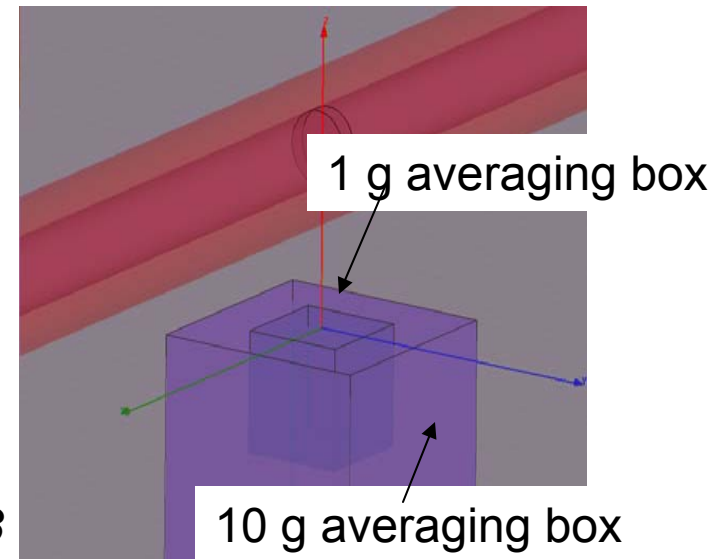
Dipole and Phantom Testbench



MOTOROLA LABS



Flat phantom filled with tissue,
Tissue property varies for different frequency



Specifying 1g SAR calculation



MOTOROLA LABS

A screenshot of a software dialog box titled "Specific Absorption Rate Setting". The dialog has a blue header bar with the title and a close button (X). The main area is light gray and contains two input fields. The first field is labeled "Material Density (gram/cm^3)" and contains the value "1". To its right is a button labeled "Set as default". The second field is labeled "Mass of Tissue (gram)" and also contains the value "1". At the bottom of the dialog are two buttons: "OK" and "Cancel".

Specific Absorption Rate Setting

Material Density (gram/cm³)

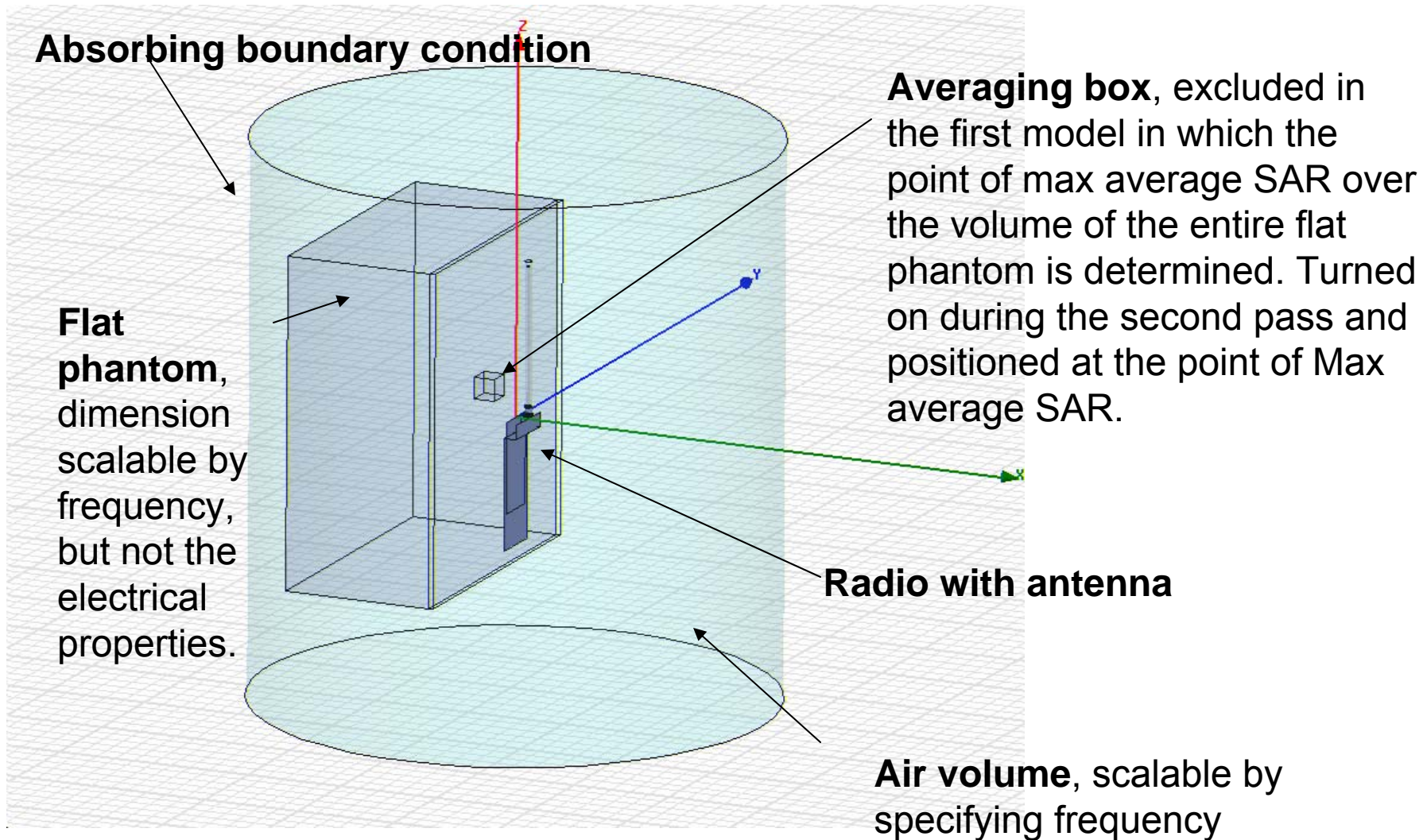
Mass of Tissue (gram)

Averaging 1g SAR in a cube with the volume of 1cm³
A 1cm³ averaging box is used.

“Virtual Testbench” with a generic Radio for SAR prediction in UHF band



MOTOROLA LABS



Design parameters



MOTOROLA LABS

Input frequency information

Air box size is set.

Phantom width 0.4 wavelength
length 0.6 wavelength

Tuning the length of the antenna

Position of maximum SAR

Ho_outerbraid	101	mm
Ho_moulding	108	mm
lowest_freq	400	MHz
max_wavelength	$3e8 / \text{lowest_freq}$	
airboxradius	$\text{max_wavelength}/3$	
airboxheight	$0.6 * \text{max_wavelength}$	
box10gside	21.54	mm
d_phantom	150	mm
w_phantom	$0.4 * \text{max_wavelength}$	
L_phantom	$0.6 * \text{max_wavelength}$	
maxsar_y_offset	12	mm
maxsar_z_offset	10	mm
monopole_length	165	mm
maxSARx	-38.5	mm
maxSARy	11.05	mm
maxSARz	7.391	mm

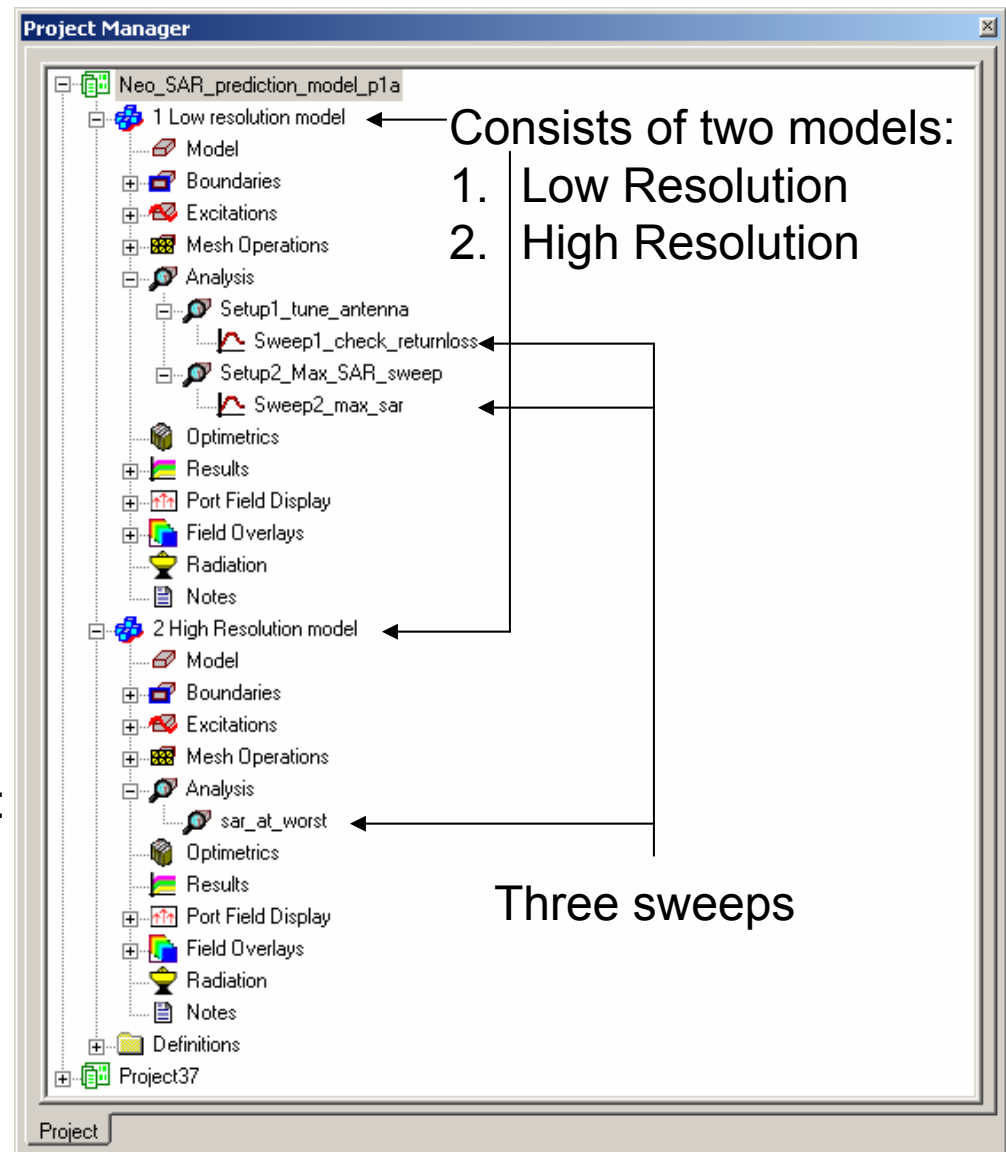
Add... Remove

SAR assessment Design Flow with HFSS based “Virtual Testbench”



MOTOROLA LABS

1. Rapid **Interpolating Sweep**:
Verify/tune radiation and circuit behavior of antenna and/or platform, max delta-S11=0.05.
2. Accurate **Fast Sweep**:
Saves fields over frequency and volume to determine frequency and location of max-avg-SAR.
3. Highly Accurate **Single Frequency**:
Frequency for max-avg-SAR.
Averaging box placed at location of max-avg-SAR.
Reduced delta-S for high accuracy.



Design Phase 1: Lower resolution analysis with *INTERPOLATING* frequency sweep



MOTOROLA LABS

- ▶ **Lower Resolution Analysis**
 - less strict convergence criteria
 - faster analysis time
 - broader frequency range
- ▶ **Fields not necessarily saved**
 - circuit behavior verified
 - radiation behavior may be examined for saved fields
- ▶ **Tuning of Radio**
 - to adjust circuit or radiation response for platform/antenna combination
 - to compensate for presence of tissue

Frequency

Design Phase 2: Lower resolution analysis with *FAST* frequency sweep



MOTOROLA LABS

Fast Sweep

Edit Sweep

Sweep Type

- Discrete
- Fast
- Interpolating

Error Tolerance: 0.5 %
Max Solutions: 20

DC Extrapolation Options

- Extrapolate to DC
- Minimum Solved Frequency: 0.1 GHz
- Snap Magnitude to 0 or 1 at DC
- Snapping Tolerance: 0.01

Time Domain Calculation...

Frequency Setup

Type: Linear Step

Start: 0.4 GHz
Stop: 0.47 GHz
Step Size: 0.01 GHz

Save Fields

OK Cancel

Save field

Solution Setup

General Advanced Ports Defaults

Initial Mesh Options

- Do Lambda Refinement
- Target: 0.3333
- Use free space lambda

Adaptive Options

Refinement Per Pass: 20 %
Minimum Number of Passes: 5
Minimum Converged Passes: 2

- Use Matrix Convergence
- Use Low-Order Solution Basis

Edit Matrix...
Use Defaults

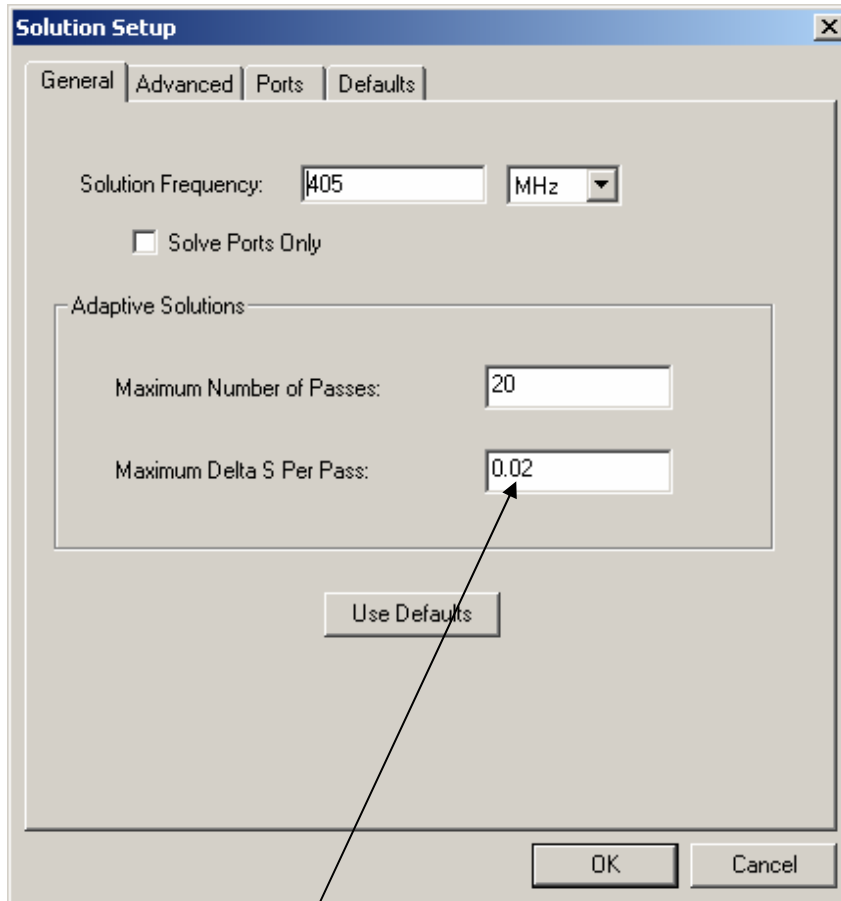
OK Cancel

Two consecutive converged passes

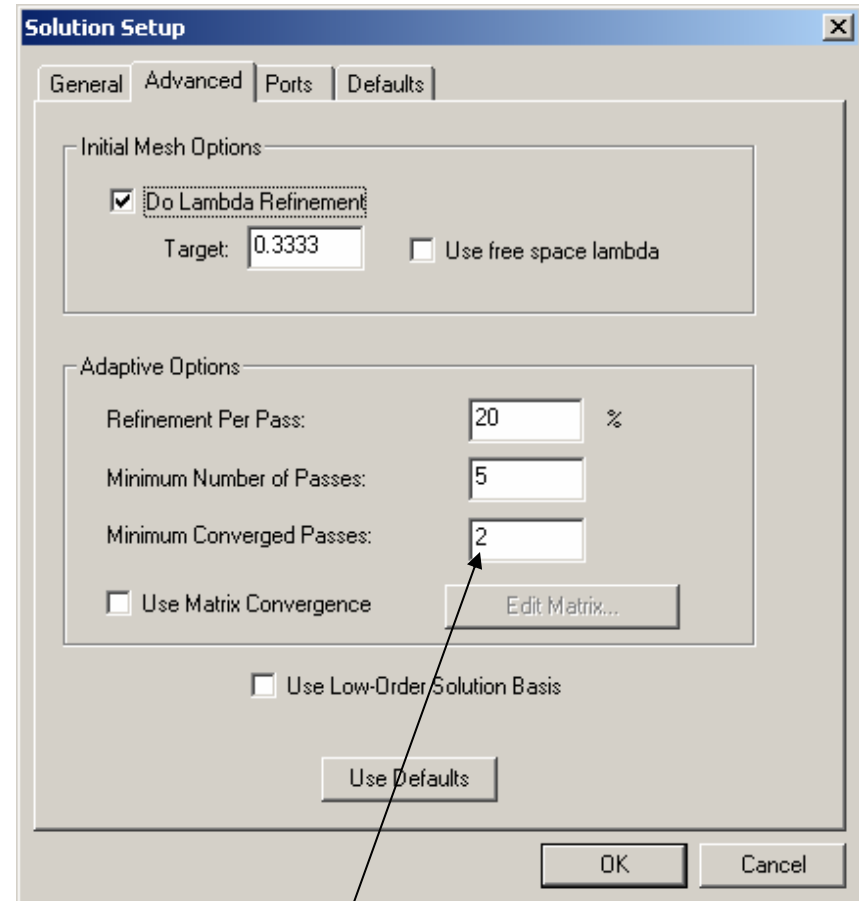
Design Phase 3: Higher resolution analysis with no frequency sweep



MOTOROLA LABS



Smaller delta-S

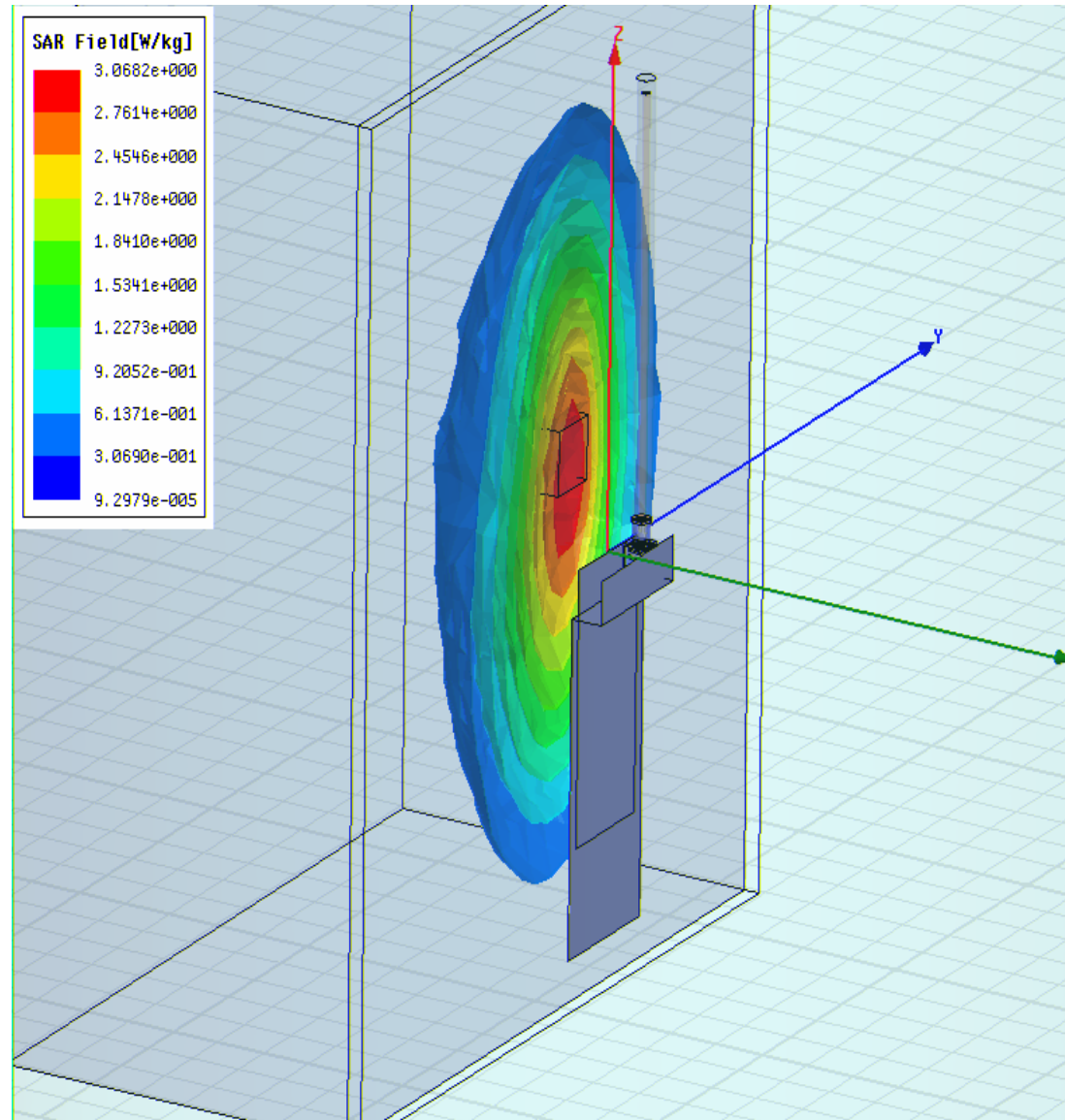


Two consecutive converged passes

Typical SAR plot



MOTOROLA LABS

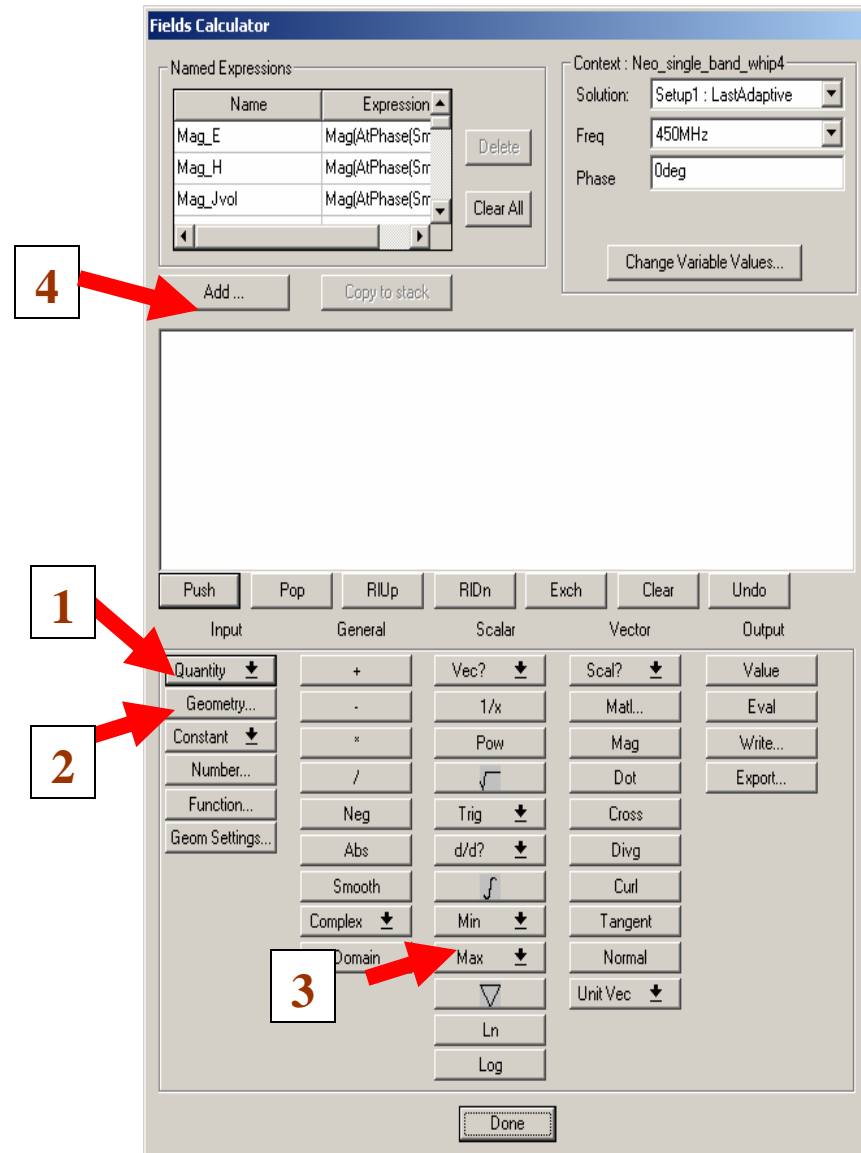


Create a saved expression for SAR using the HFSS field calculator



MOTOROLA LABS

1. Click on Quantity and choose AverageSAR
2. Click on Geometry and select **tissue**, or any other volume you would like to have your SAR calculated then click OK.
3. Click Maximum and choose value.
4. Click add and assign a name to it, e.g. **maxsar**



Create an *output variable* for SAR



MOTOROLA LABS

NOTE:

Calculated SAR is normalized to 1W. Must scale the SAR to actual power and adjust for duty cycle.

D. Edit expression

$Cal1gSAR5W = maxsar * 5 * 0.5$
(5 W power and 50% duty cycle)

A. Select Fields

B. Calculated Expression

E. Insert expression

	Name	Expression
1	gamm	0
2	MaxSARswp	maxsar
3	maxsarweep	sarsweep
4	sarsweep	0

Name: cal1gSAR5W Add Update Delete

Expression: maxsar*5*0.5

Design: [] Report Type: Fields Solution: Setup2_Max_SAR_sweep

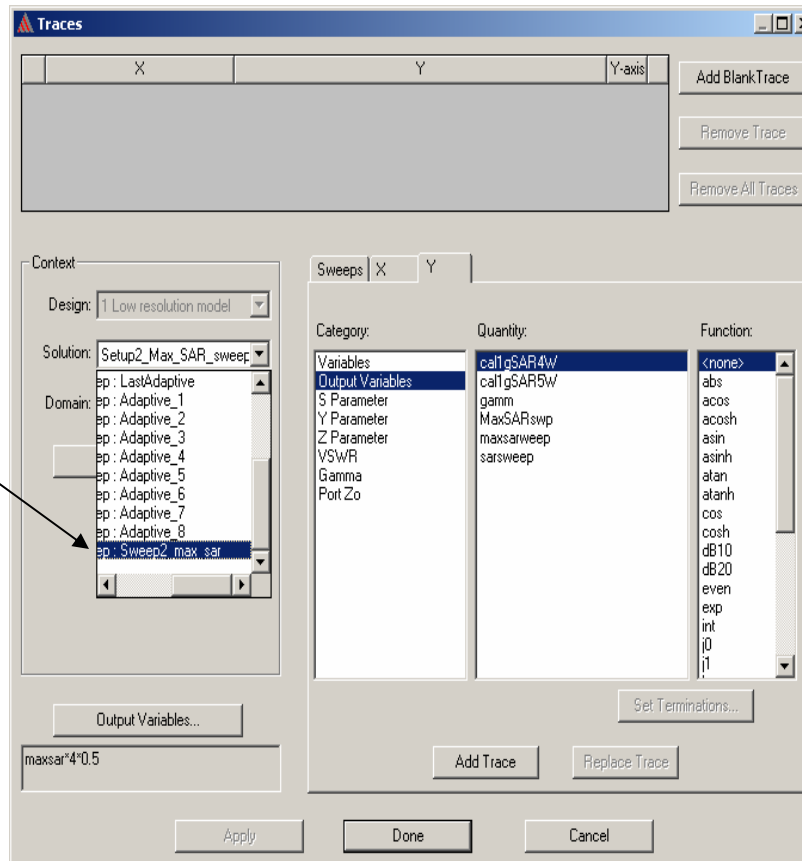
Function: abs Terminations (ohms): 50 ohms Done

C. Select the variable



Design Stage 2: Plotting Max Cal 1g SAR

Assure the fast frequency sweep is selected.



NOTE:

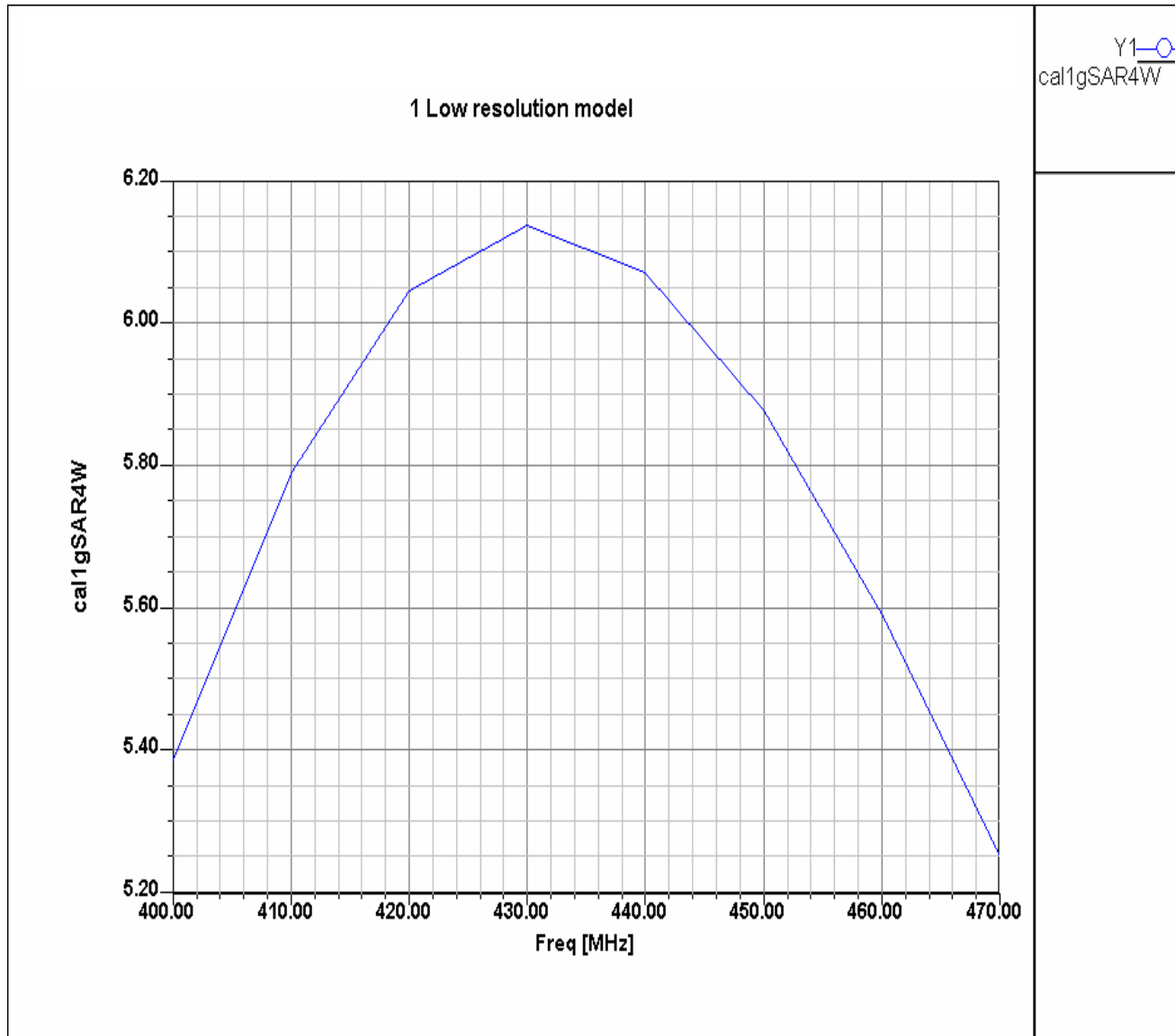
HFSS automatically computes the field calculator saved expression and plots the corresponding output variable as a function of frequency.

These computations may be time consuming so specify a reasonable number of frequencies (≈ 10 , not ≈ 100).

Design Stage 2: Plot of Max 1g SAR Scaled to 4 W



MOTOROLA LABS



Design Stage 2: Obtain Max Average SAR and its Position



MOTOROLA LABS

Fields Calculator

Context : 2 High Resolution model

Solution: sar_at_worst : LastAdaptiv...

Freq: 0.435GHz

Phase: 0deg

Name	Expression
Mag_E	Mag(AIPhase(Srr
Mag_H	Mag(AIPhase(Srr
Mag_Jvol	Mag(AIPhase(Srr

Buttons: Add..., Copy to stack, Delete, Clear All, Change Variable Values...

Output area: Vol : Volume(averaging_box)
Scl : AverageSAR

Buttons: Push, Pop, RIUp, RIDn, Exch, Clear, Undo

Input: Quantity, Geometry..., Constant, Number..., Function..., Geom Settings...

General: +, -, *, /, Neg, Abs, Smooth, Complex, Domain

Scalar: Vec?, 1/x, Pow, √, Trig, d/d?, ∫, Min, Max, Value..., Position..., Ln, Log

Vector: Scal?, Matl..., Mag, Dot, Cross, Divg, Curl, Tangent, Normal, Unit Vec

Output: Value, Eval, Write..., Export...

Done

Fields Calculator

Context : 2 High Resolution model

Solution: sar_at_worst : LastAdaptiv...

Freq: 0.435GHz

Phase: 0deg

Name	Expression
Mag_E	Mag(AIPhase(Srr
Mag_H	Mag(AIPhase(Srr
Mag_Jvol	Mag(AIPhase(Srr

Buttons: Add..., Copy to stack, Delete, Clear All, Change Variable Values...

Output area: Vec : <-0.025, 0.012, 0.01>
Pnt : MaxPos[Volume(averaging_box), AverageSAR]

Buttons: Push, Pop, RIUp, RIDn, Exch, Clear, Undo

Input: Quantity, Geometry..., Constant, Number..., Function..., Geom Settings...

General: +, -, *, /, Neg, Abs, Smooth, Complex, Domain

Scalar: Vec?, 1/x, Pow, √, Trig, d/d?, ∫, Min, Max, Value..., Position..., Ln, Log

Vector: Scal?, Matl..., Mag, Dot, Cross, Divg, Curl, Tangent, Normal, Unit Vec

Output: Value, Eval, Write..., Export...

Done

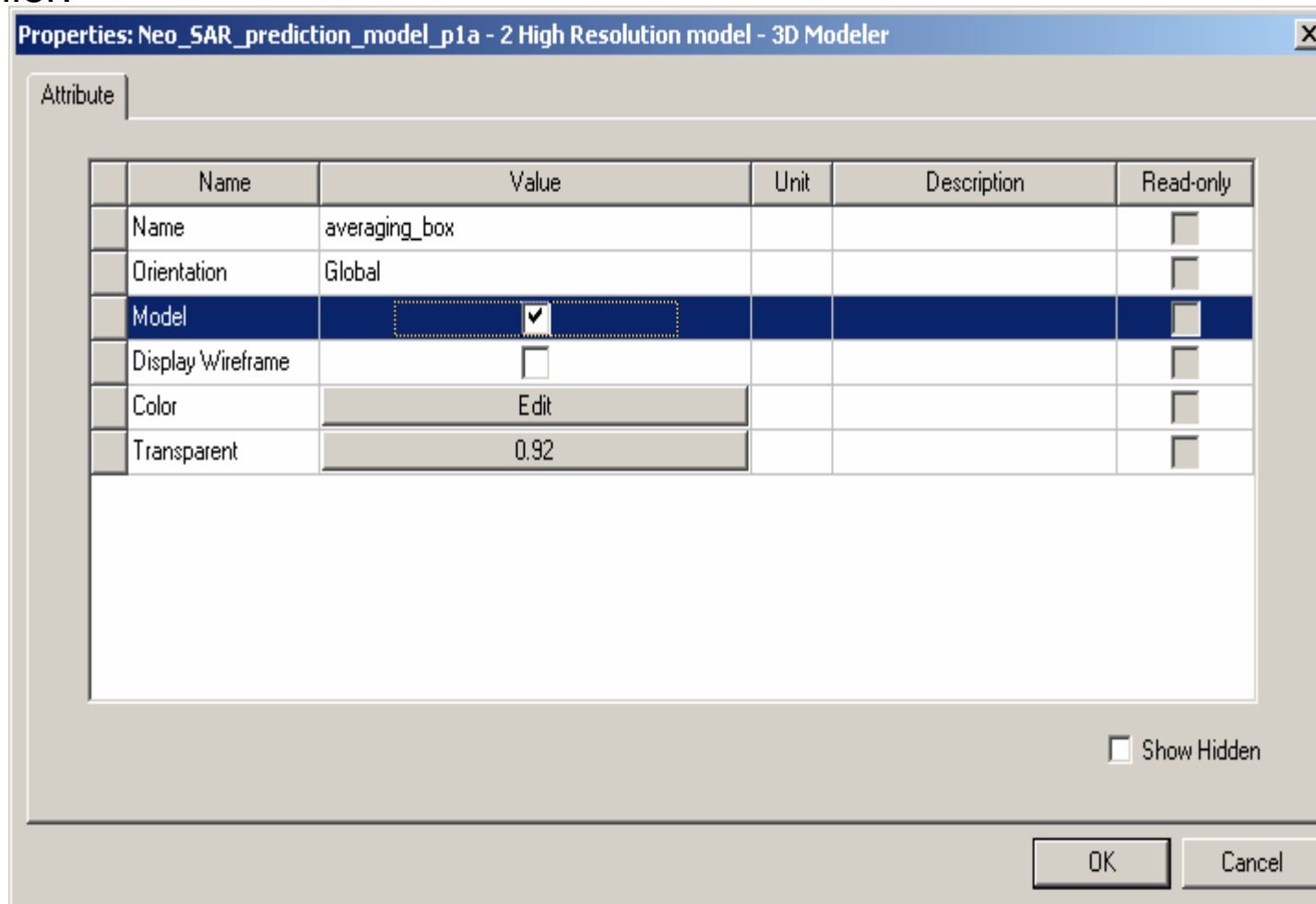
Used to position the averaging box

Design Stage 3: Add the averaging box to the high resolution design setup



MOTOROLA LABS

Create the high resolution model by duplicating the low resolution model and turned on the averaging box. Analyzing at the worst case frequency found earlier.



Design Stage 3: Extract the Maximum Average SAR in the tissue volume



MOTOROLA LABS

The worst case frequency, as determined in Stage 2.

The Max Average SAR, calculation shown previously.

Named Expressions	
Name	Expression
Mag_E	Mag(AIPhase(Sr
Mag_H	Mag(AIPhase(Sr
Mag_dvol	Mag(AIPhase(Sr

Context: 2 High Resolution model
Solution: sar_at_worst: LastAdaptiv...
Freq: 0.435GHz
Phase: 0deg

Max: 3.07721940992402
Max: Maximum(Volume(averaging_box), AverageSAR)

Technology Transfer



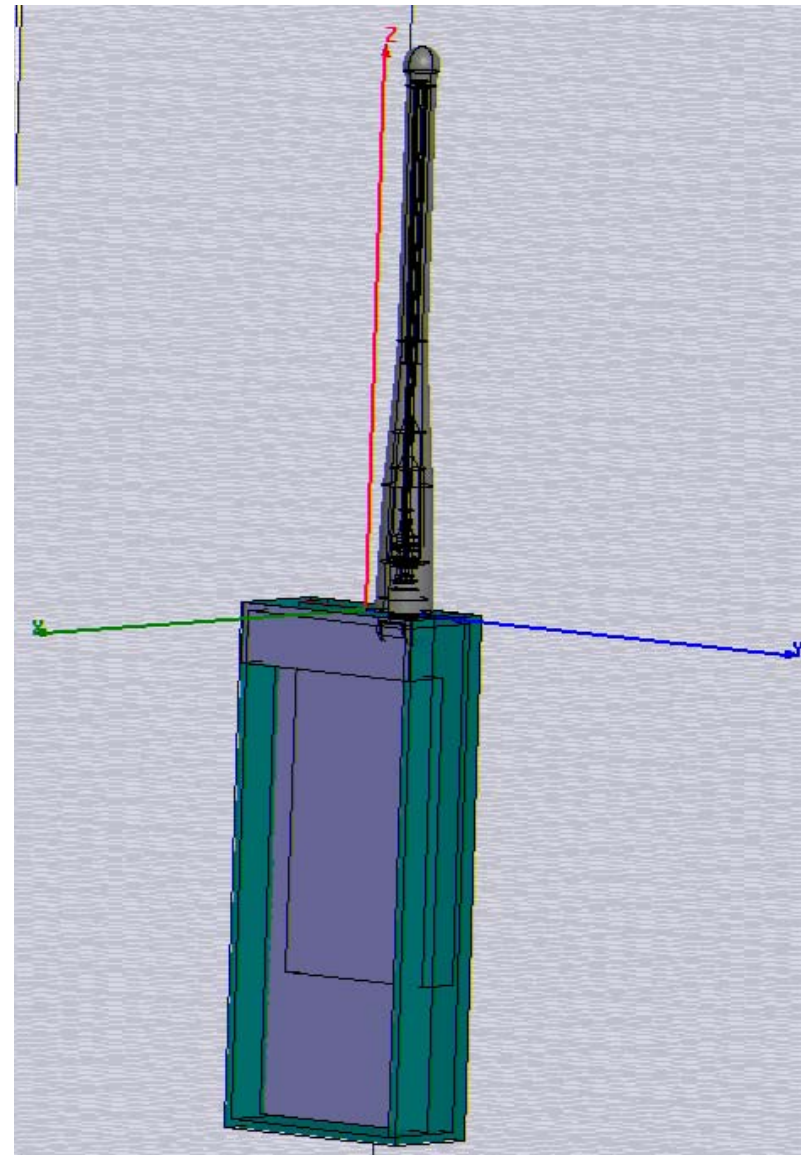
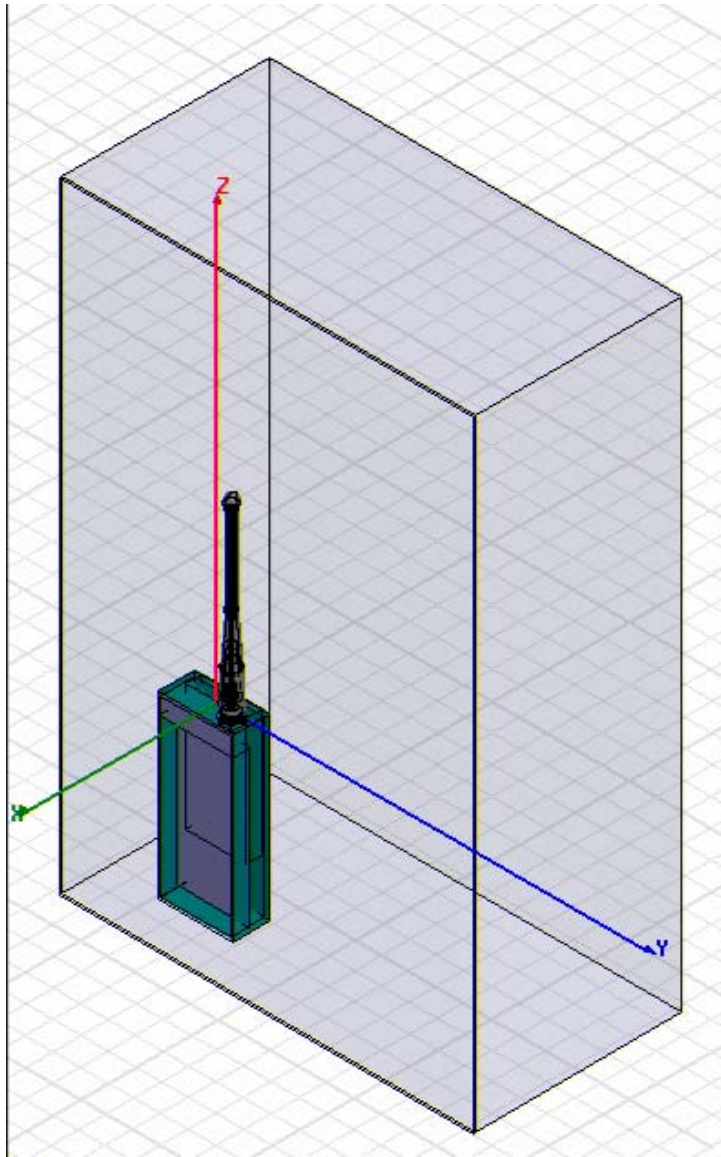
MOTOROLA LABS

- ▶ **The “Virtual Testbench” and companion design flow were verified with a generic radio and then passed to the Product Development group.**
- ▶ **The Antenna was replaced with a monopole of interest.**
- ▶ **The radio platform was replaced with the actual chassis, including the front housing.**
 - **solid model was imported to HFSS from Pro/E.**
 - **solid model was simplified**
 - **surface approximation was used to simplify the mesh.**
- ▶ **The antenna went through a few iterations of design change before finalization.**

UHF Radio Solid Model in HFSS



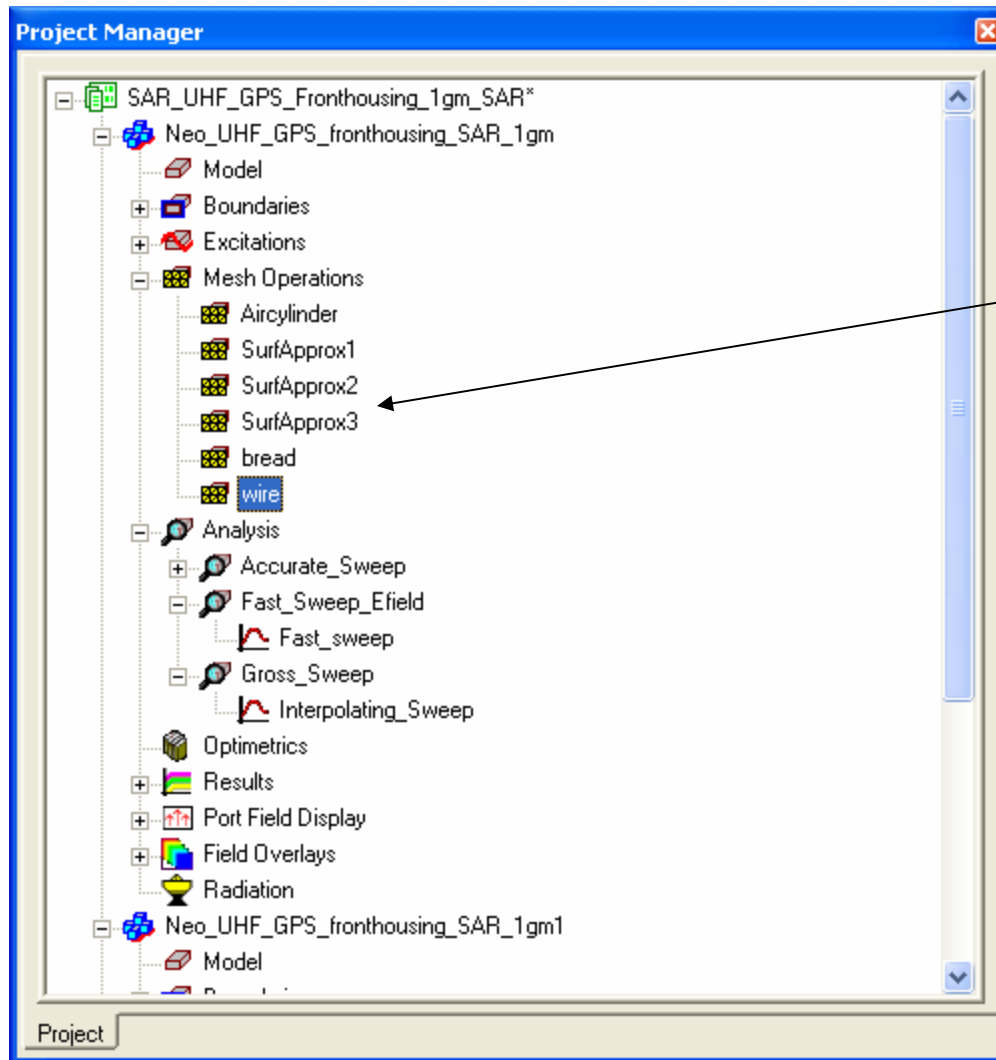
MOTOROLA LABS



Surface approximation for cylindrical parts



MOTOROLA LABS

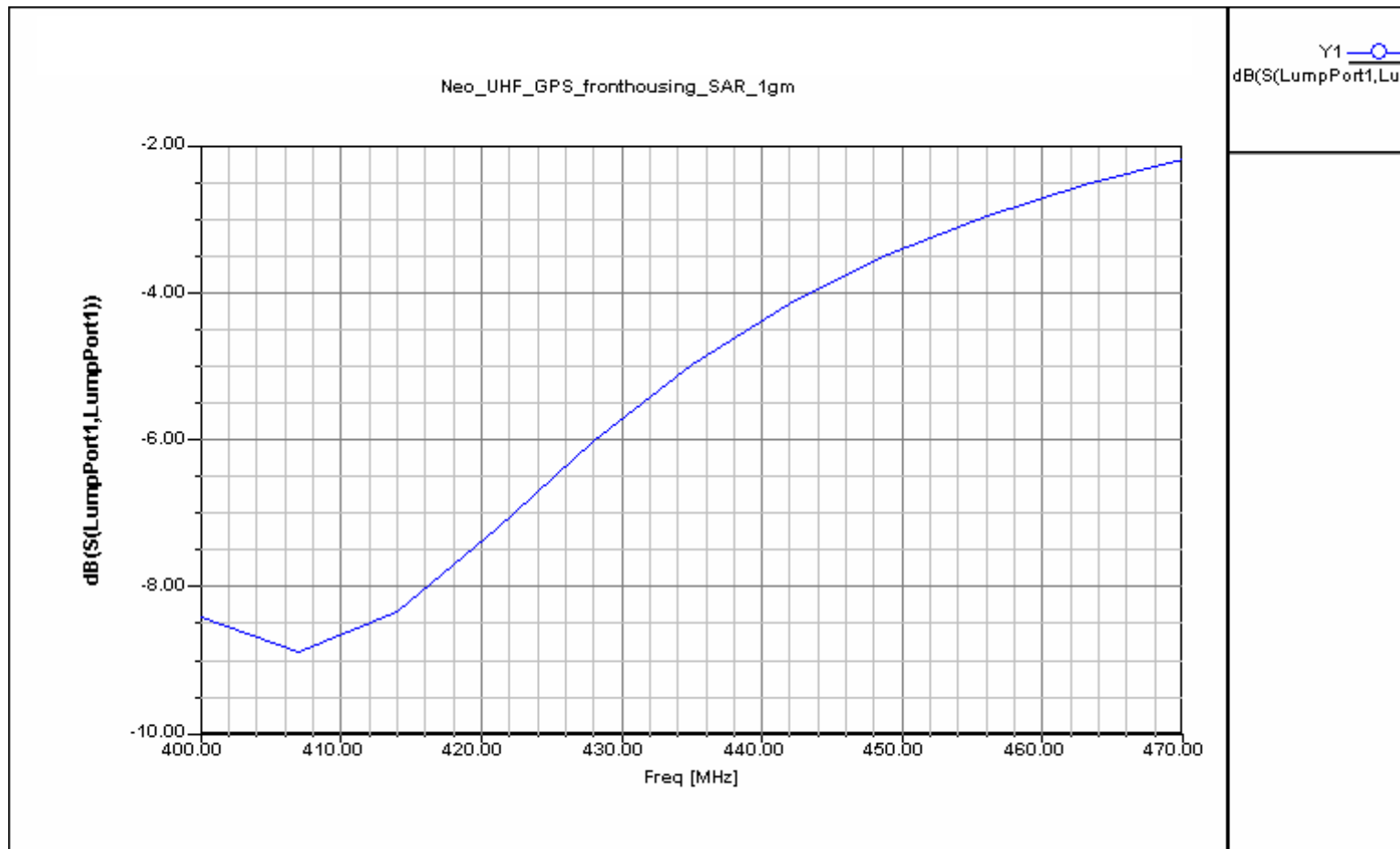


All cylindrical parts were assigned maximum of 45 degree deviation angle as circular surface approximation.

Design Stage 1: Return loss of UHF Monopole Antenna (*interpolating sweep*)



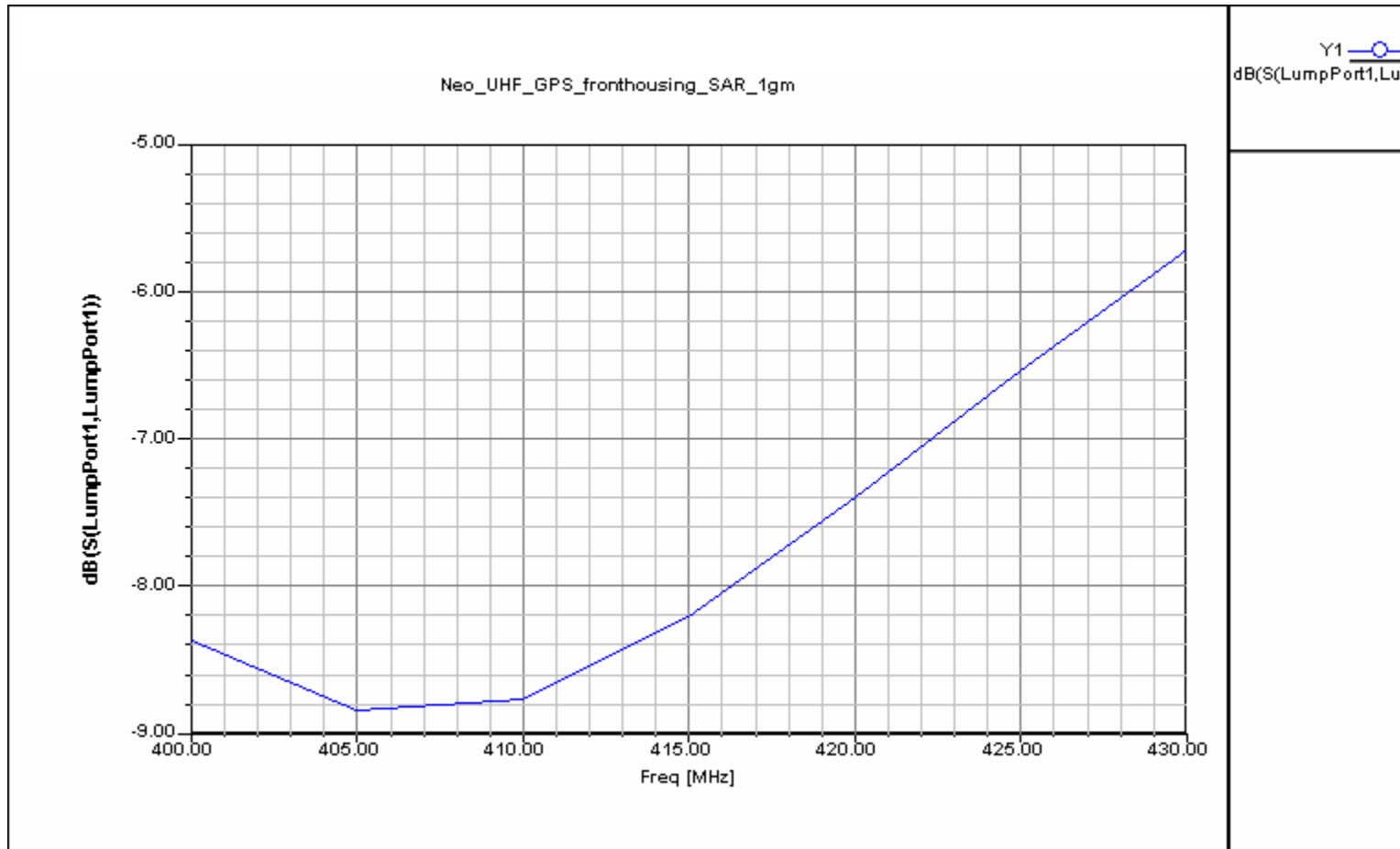
MOTOROLA LABS



Design Stage 2: Return loss of UHF Monopole Antenna (fast sweep)



MOTOROLA LABS

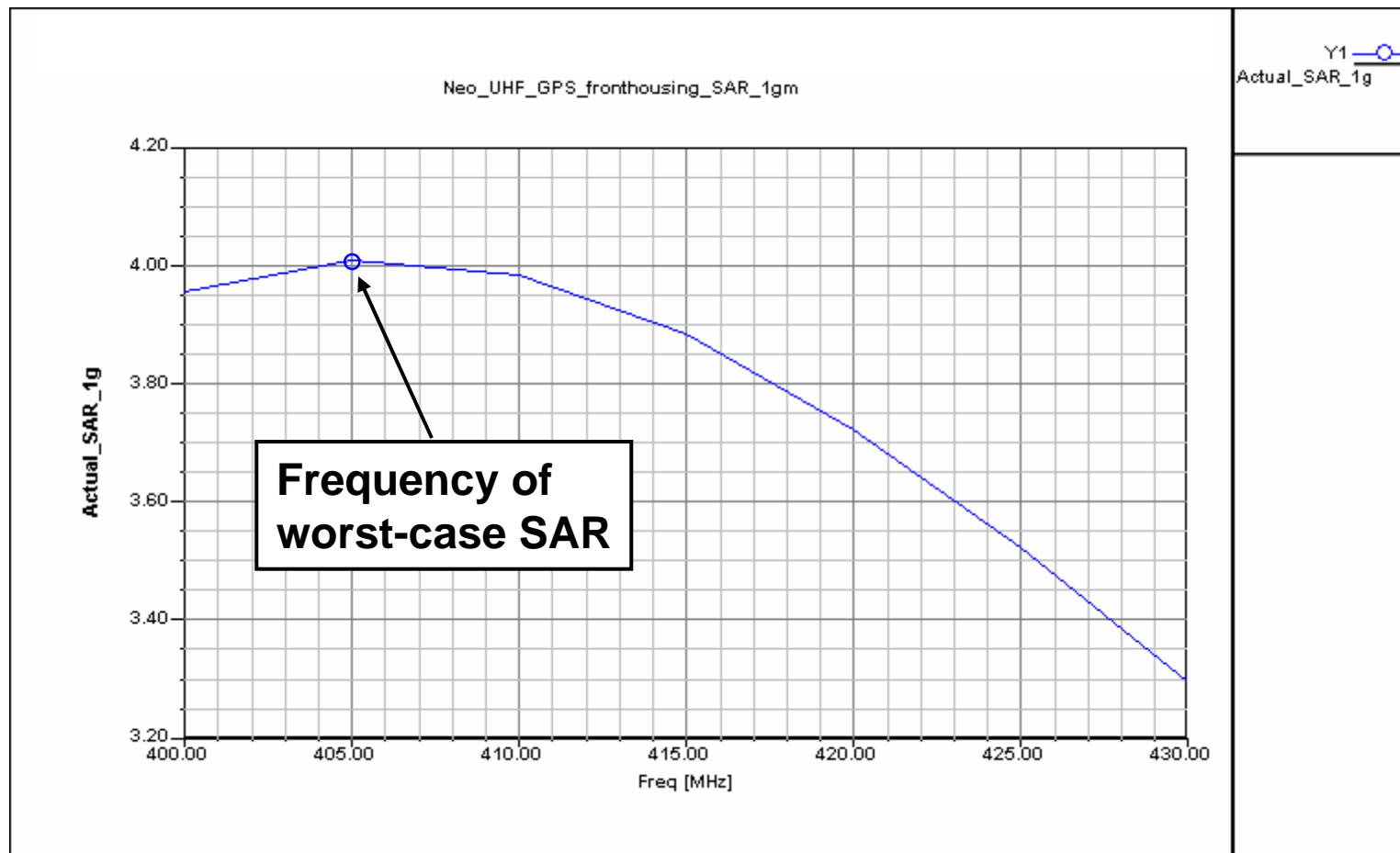


Design Stage 2: Frequency-dependent Max Average 1g SAR



MOTOROLA LABS

Scaled to 4.7 W with 50% duty cycle



Design Stage 2: Extract position of hot spot to define the averaging box for Stage 3



MOTOROLA LABS

Fields Calculator

Named Expressions

Name	Expression
Mag_E	Mag(AtPhase(Srr
Mag_H	Mag(AtPhase(Srr
Mag_Jvol	Mag(AtPhase(Srr

Context : Neo_UHF_GPS_fronthousing_

Solution: Fast_Sweep_Efield : Fast_

Freq 405MHz

Phase 0deg

Change Variable Values...

Vec : <-0.0385 0.0110588314301751 0.00739142099364502>

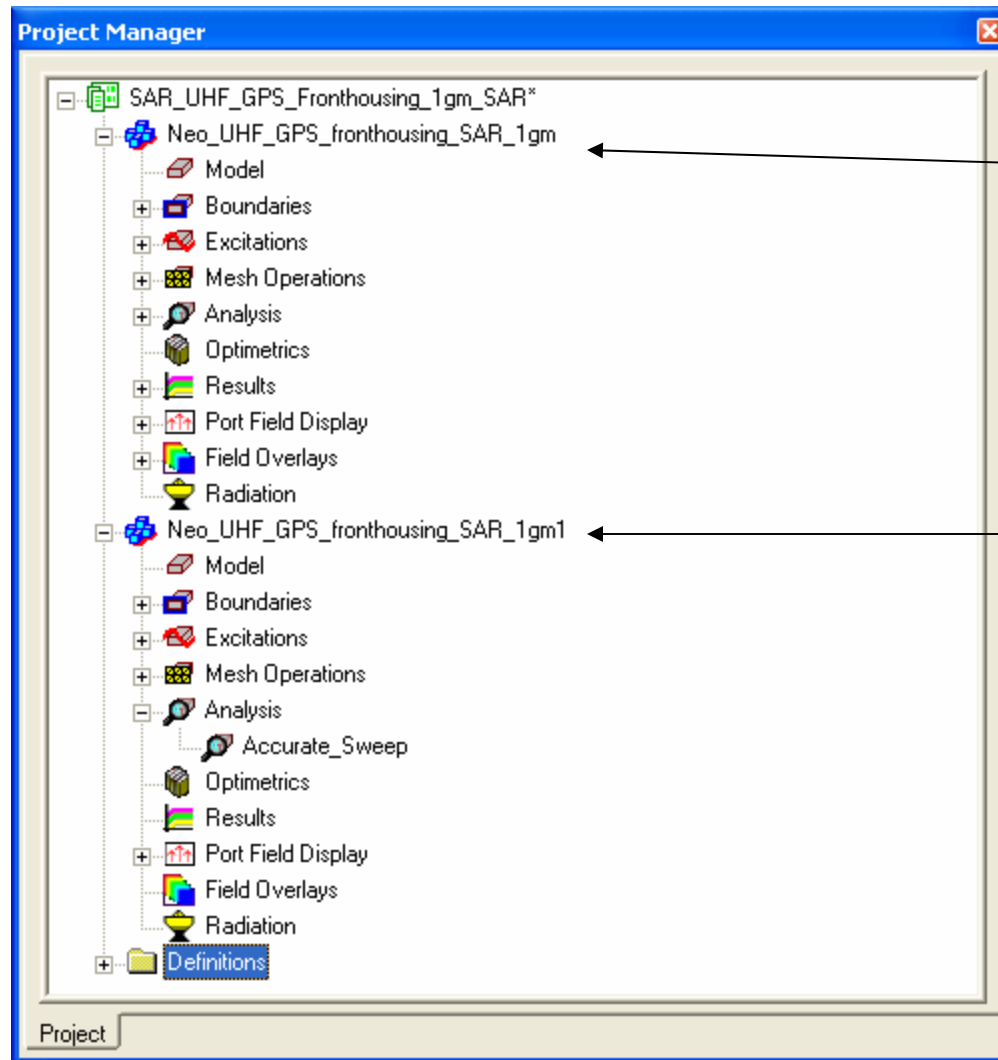
Pnt : MaxPos[Volume(tissue), AverageSAR]

maxsar_z_offset	10
monopole_length	165
maxSARx	-38.5
maxSARy	11.05
maxSARz	7.391

Add... Remove



Design Stage 3: Duplicate HFSS Design



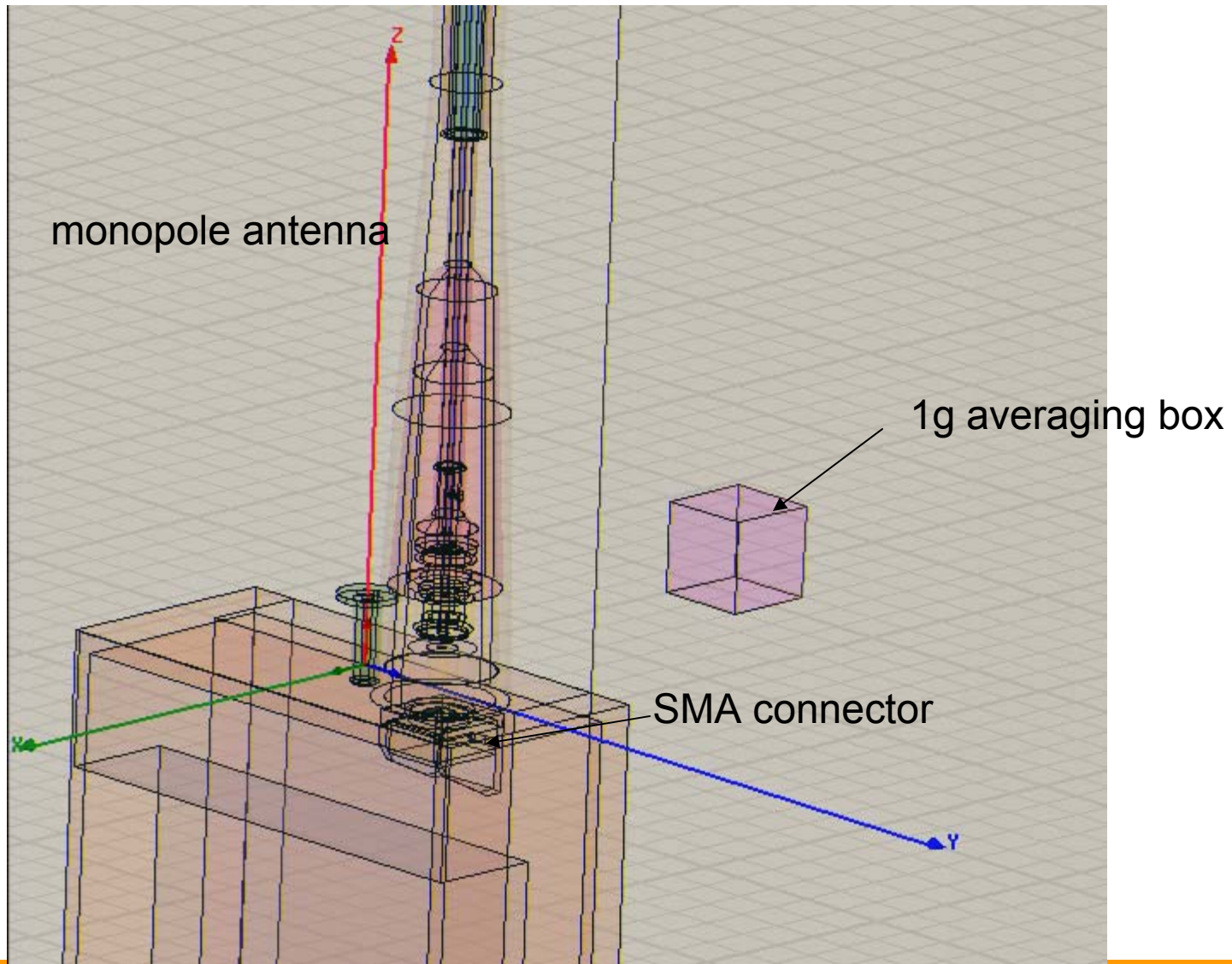
Low resolution model

High resolution model

Design Stage 3: UHF Radio with SAR averaging box



MOTOROLA LABS



Design Stage 3: High resolution analysis setup



MOTOROLA LABS

Solution Setup [X]

General | Advanced | Ports | Defaults

Solution Frequency: GHz

Solve Ports Only

Adaptive Solutions

Maximum Number of Passes:

Maximum Delta S Per Pass:

Use Defaults

OK Cancel

Solution Setup [X]

General | Advanced | Ports | Defaults

Initial Mesh Options

Do Lambda Refinement
Target: Use free space lambda

Adaptive Options

Refinement Per Pass: %

Minimum Number of Passes:

Minimum Converged Passes:

Use Matrix Convergence

Use Low-Order Solution Basis

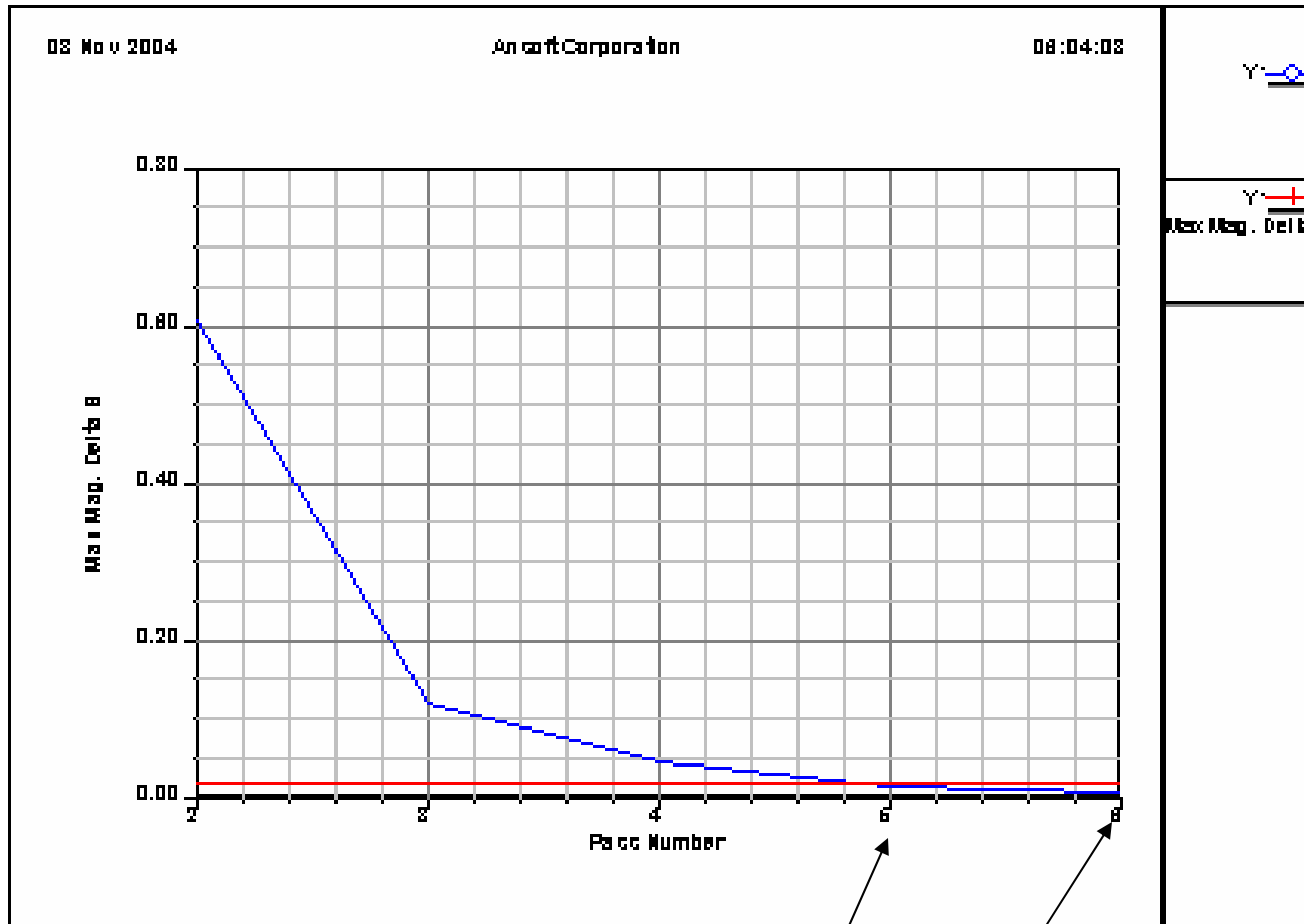
Use Defaults

OK Cancel

Two consecutive converged passes



MOTOROLA LABS

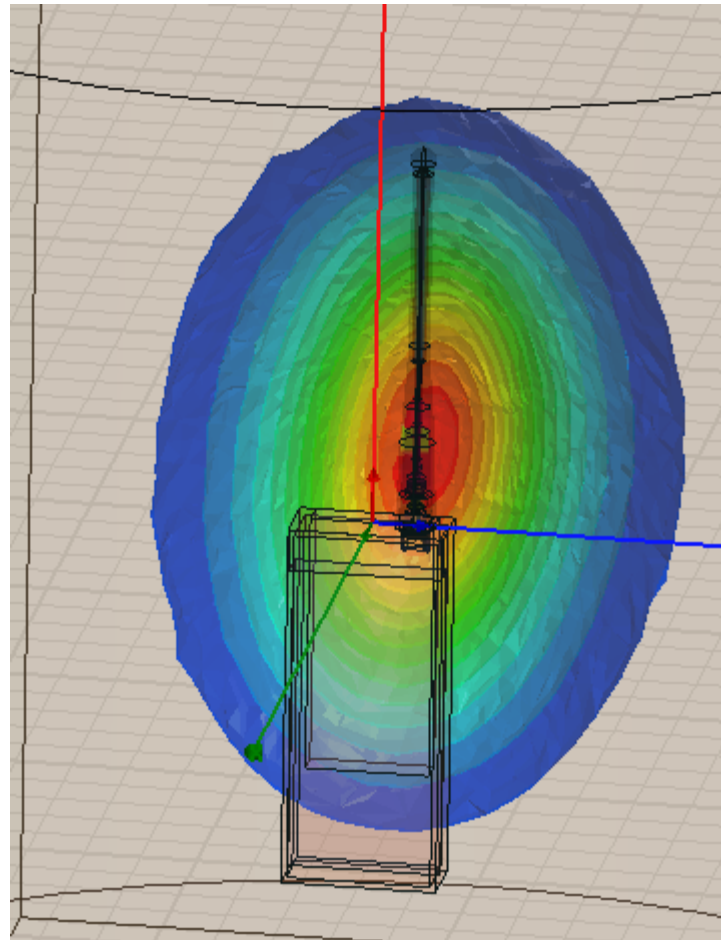


Two passes with max delta S11 of < 0.02

Design Stage 3: UHF Radio high resolution SAR at worst case frequency



MOTOROLA LABS



Design Stage 3: Final worst-case max-avg-SAR



MOTOROLA LABS

Fields Calculator

Named Expressions

Name	Expression
Mag_E	Mag(AtPhase(Srr
Mag_H	Mag(AtPhase(Srr
Mag_Jvol	Mag(AtPhase(Srr

Context : Neo_UHF_GPS_fronthousing_SAR
Solution: Accurate_Sweep : LastAd.
Freq: 405MHz
Phase: 0deg

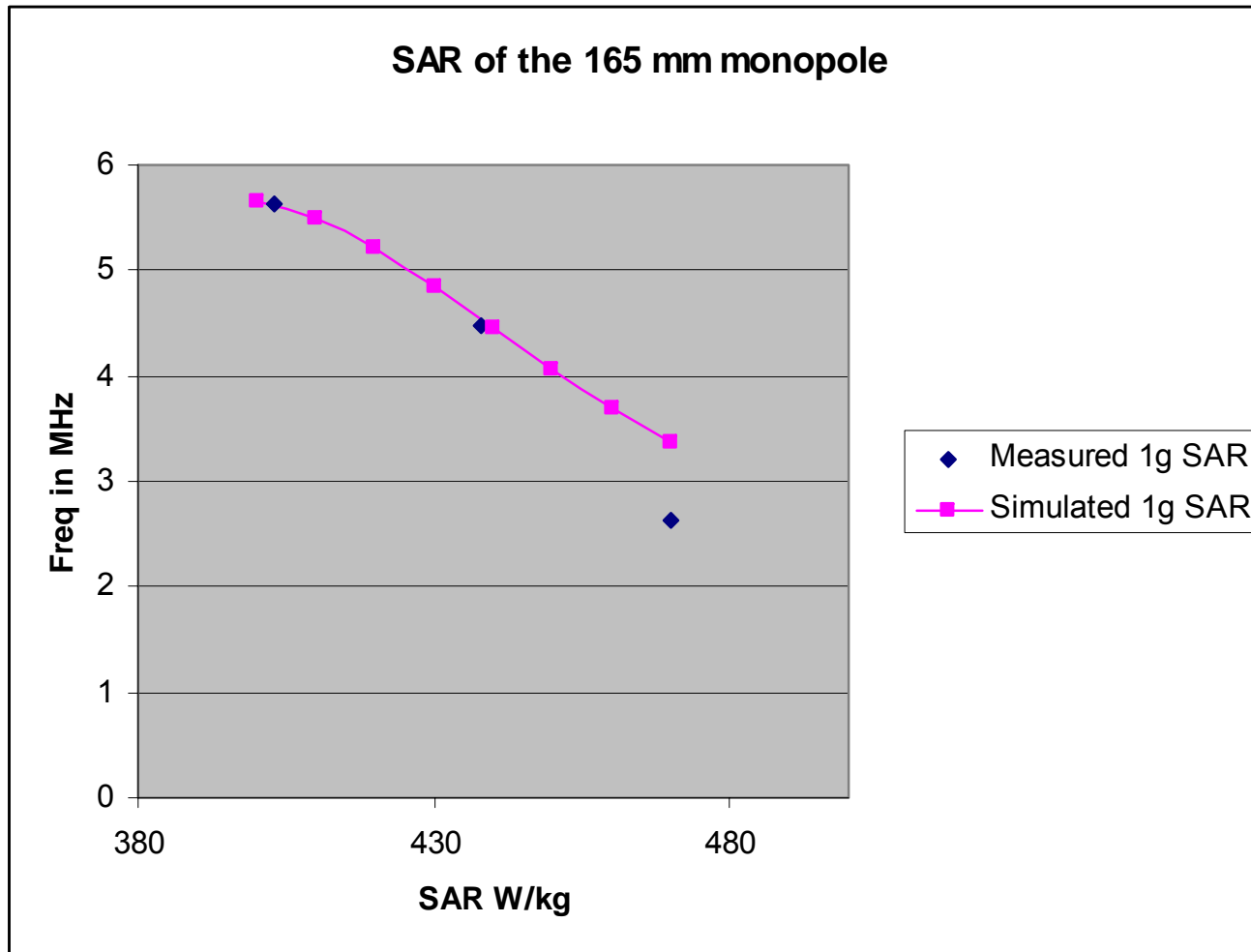
Actual SAR
 $1.6685 \times 4.7 \text{ W} \times 50\% = 3.921 \text{ W/kg}$

Push Pop RIUp RIDn Exch Clear Undo
Input General Scalar Vector Output

HFSS SAR Predictions Compared to Measured SAR



MOTOROLA LABS



HFSS Analysis Profile



MOTOROLA LABS

Solution Data: SAR_UHF_GPS_Fronthousing_1gm_SAR - Neo_UHF_GPS_frontho...

Design Variation: pitch_7='2mm' pitch_8='2mm' w_phantom='0.3'

Simulation: Accurate_Sweep LastAdaptive

Convergence Profile Matrix Data

Task	Real Time	CPU Time	Memory	Information
Adaptive Pass 6				Frequency: 0.405 GHz
mesh3d_adapt	00:03:38	00:03:35	257180 K	175447 tetrahedra
LumpPort1_solve	00:00:01	00:00:00	35888 K	26 triangles
adapt_part1	00:01:27	00:01:26	560652 K	175447 tetrahedra
Solver CSS	03:39:43	03:33:12	1208316 K	870330 matrix
Disk I/O.temp	00:00:00	00:00:00	0 K	2877179 K
adapt_part2	00:00:33	00:00:30	308704 K	175447 tetrahedra
				Adaptive Passes converged
Total	05:23:15	05:16:47		Time: 11/03/2004 03:27:57, Status: Normal Cor

Export...
Close

5 hours for the high resolution analysis

reduced dramatically by new 64-bit dual processor and/or dual core CPUs



- ▶ **Demonstrated successful application of a “Virtual Testbench” and associated design flow for pre-prototype SAR assessment.**
 - demonstrated for actual radio platform and antenna
 - verified with SAR measurements
- ▶ **Testbench is radio-independent.**
 - design flow and platform/antenna re-use is enabled
- ▶ **Testbench enables rapid monitoring of changes in SAR compliance as the radio is changed.**
 - enables SAR compliance to be considered and tracked throughout initial product design for early design tradeoffs
 - enables proposed changes to existing radios to be quickly characterized within individual product groups