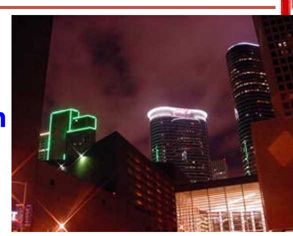
EMC/EMI in Wireless Communications

Ji Chen
Department of Electrical and Computer Engineering
University of Houston
Houston, TX 77204
Email: jchen18@uh.edu

UH: close to downtown of Houston
35,066 students



ECE Department: 35 faculty members, 250 graduate students

Electromagnetic Research at University of Houston:

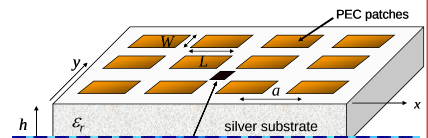
NSF Center For Electromagnetic Compatibility Research

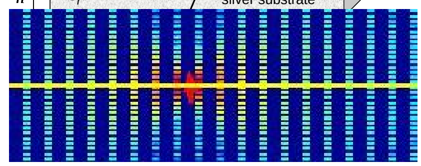
Areas:
Computational Electromagnetics
Antennas
High-Speed Signal Propagation
Bioelectromagnetics
Nano-devices
Wireless Propagation

Faculty Members:
6 faculty members
IEEE Board of Directors
past president of AP society
4 IEEE Fellows

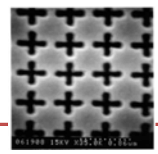
Medical safety in MRI

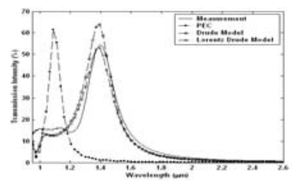
Design of periodic structures





Nano-scale FSS modeling

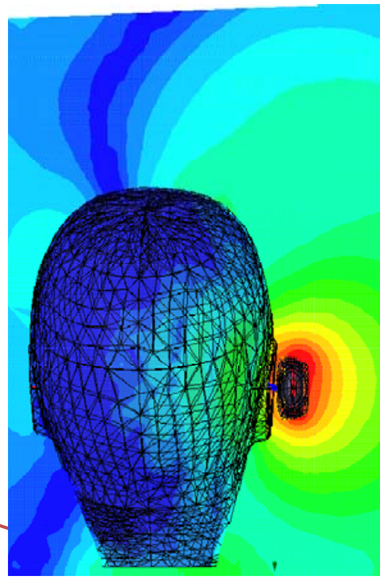




Outline

- Introduction
- SAR Inter-lab comparison for wireless device
- MIMO SAR for future multi-antenna systems
- Telemetry interactions
- Wireless PCB Modeling
- Summary

Electric fields produced by cell phone near SAM head.



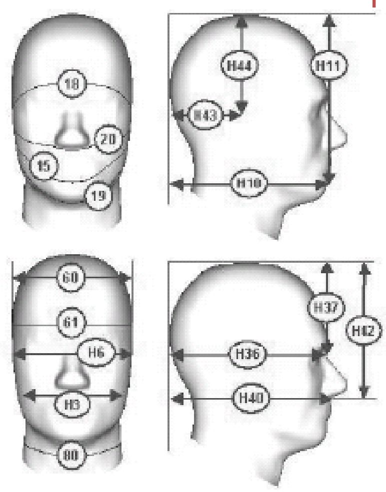
$$SAR = \frac{\sigma |E|^2}{2\rho}$$

	USA	Europe	Japan
	ANSIC95.1	ENV50166	TTC/MPT
Whole Body	0.08 W/kg	0.08 W/kg	0.04 W/kg
Spatial Peak	1.6 W/kg	2 W/kg	2 W/kg

Commercial SAR measurement systems

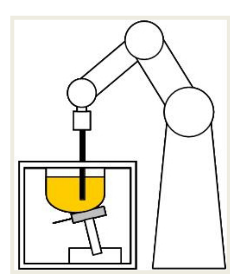
IEEE 1528 - Body modeling

- Purpose
  - Must result in conservative over-estimate of SAR compared to real person
- Development of head model
  - Anthropomorphic vs. simplified
  - Large head gives higher SAR
  - Dimensions from US Army data
  - Compressed lossless ear model
  - CAD model available
- No hand model
  - Hand absorbs energy



IEEE 1528 - Tissue equivalent liquid

- Dielectric parameters
  - Representative of human tissue
  - Selected to result in conservative exposure
  - Consistent over time and temperature
  - Homogeneous to allow movement of E-field probe
- Other parameters
  - Low viscosity to allow easy probe movement
  - Safe to use
  - Not reactive with phantom or probe materials



ICES – TC34 – SC2 - Computational Standards

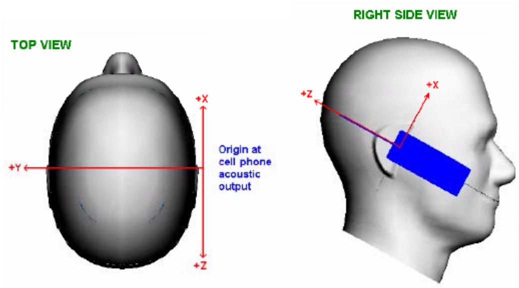
- IEEE 1528.1: Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz - 6 GHz: **General Requirements for using the Finite Difference Time Domain (FDTD) Method for SAR Calculations**
- IEEE 1528.2: Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz - 6 GHz: **Specific Requirements for Finite Difference Time Domain (FDTD) Modeling of Vehicle Mounted Antennas**
- IEEE 1528.3: Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz - 6 GHz: **Specific Requirements for Finite Difference Time Domain (FDTD) Modeling of Mobile Phones/Personal Wireless Devices**
- IEEE 1528.4: Recommended Practice for Determining the Peak Spatial Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz – 6 GHz: **Requirements for Using the Finite-Element Method for SAR Calculations**

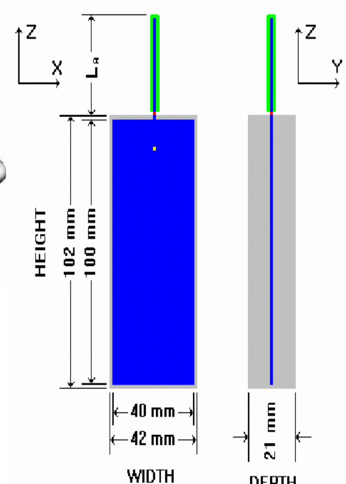
IEEE 1528.1 - General Requirements for using the Finite Difference Time Domain (FDTD) Method for SAR Calculations

Purpose: *... is to describe the **concepts**, **anatomical models** for compliance assessments, **techniques**, **validation procedures**, **uncertainties** and **limitations** of the **FDTD** method when used for determining the **spatial-peak SAR** in standardized human anatomical models exposed to wireless communication devices. 1528.1 recommends and provides **standardized anatomical models** and provides **general benchmark data** for these models. 15281.1 will **not recommend specific SAR values** since these are found in other documents, e.g., IEEE C95.1-1999.*

CONTENTS

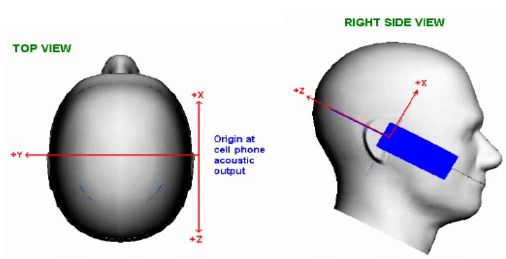
Inter-Lab Numerical SAR calculation project

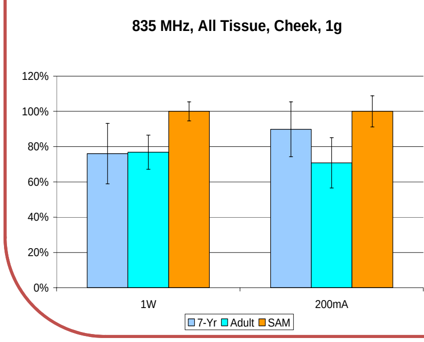


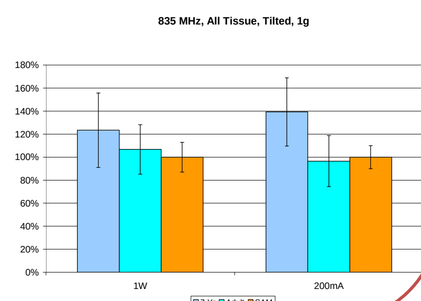


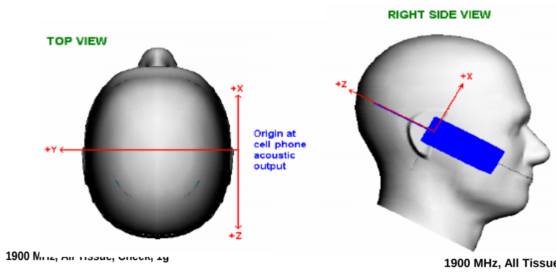
16 teams from the world involved to determine

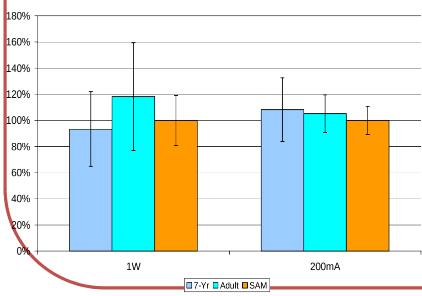
1. Head model (SAM, Adult, 7 year old)
2. Software packages (XFDTD, SemCAD, homegrown…)

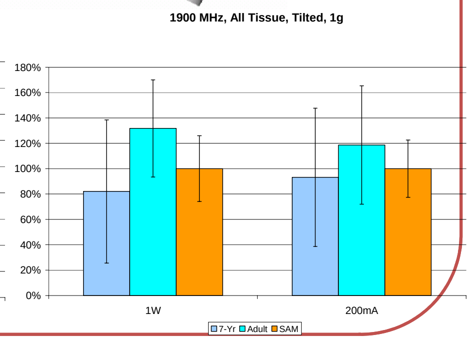




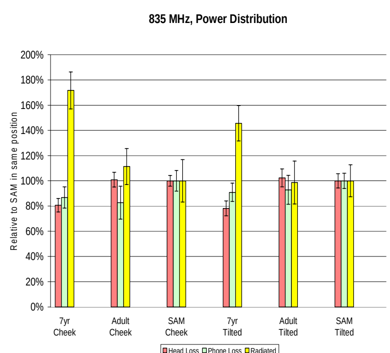


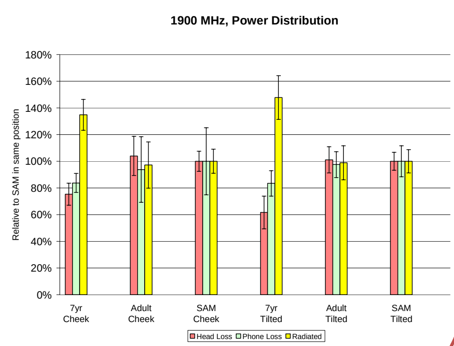

TOP VIEW
+X
+Y
+Z
Origin at
cell phone
acoustic
output
RIGHT SIDE VIEW
+Z
+X


180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
1W
200mA
7-Yr Adult SAM


1900 MHz, All Tissue, Tilted, 1g
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
1W
200mA
7-Yr Adult SAM

Power


835 MHz, Power Distribution
Relative to SAM in same position
200%
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
7yr Cheek
Adult Cheek
SAM Cheek
7yr Tilted
Adult Tilted
SAM Tilted
Head Loss Phone Loss Radiated


1900 MHz, Power Distribution
Relative to SAM in same position
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
7yr Cheek
Adult Cheek
SAM Cheek
7yr Tilted
Adult Tilted
SAM Tilted
Head Loss Phone Loss Radiated

SAR Sensitivity:

SAR sensitivity on spacing and user effects provides information of what SAR change can be expected due to small variation of environment

Definition of Sensitivity:

$$S(x) = \frac{\partial SAR}{\partial x} \cdot \frac{x}{SAR}$$

Example:

Sensitivity: S(ε) = 0.4
Dielectric constant change: $\varepsilon \pm 5\%$

SAR = SAR(ε) ± 2%

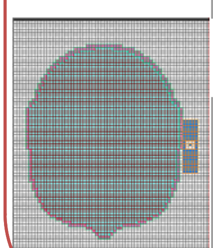
Evaluation

$$\frac{\partial SAR}{\partial x} = \frac{SAR(x+\Delta x) - SAR(x-\Delta x)}{2\Delta x} - \frac{2}{3!} dx^2 SAR'''\Big|_x + \ldots$$

SAR Sensitivity Analysis

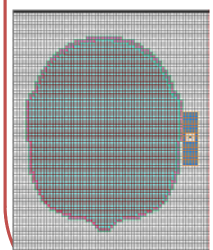
Spacing Effect

Distance from Head	Peak SAR	1g SAR average(normalized)	Absorption power
d =0 mm	1	0.66	68%
d =3 mm	0.58	0.39	52%



*User effect :Head Size_*

Head Size	Peak SAR (normalized)	1g average SAR (normalized)	Absorption power
Small	0.96	0.64	67%
Regular	1	0.66	68%
Large	0.96	0.64	71%



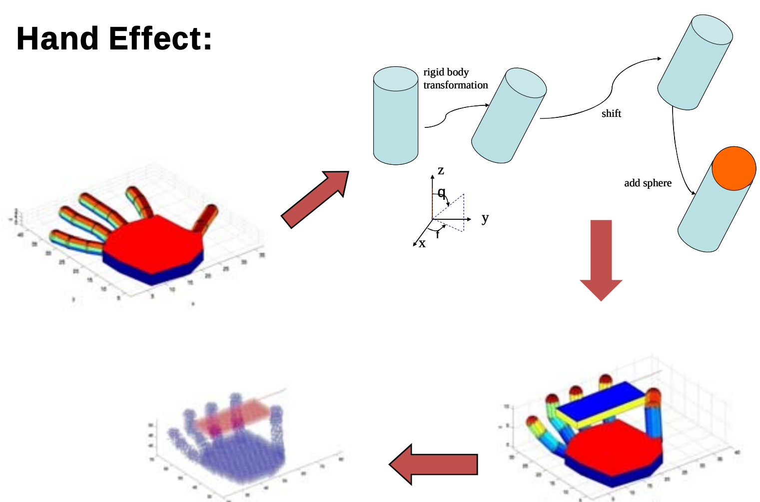
*User effect : materials effect_*

Dielectric	Peak SAR (normalized)	1g average SAR (normalized)	Absorption power
36	1	0.65	69%
40	1	0.65	68%
44	0.99	0.65	68%

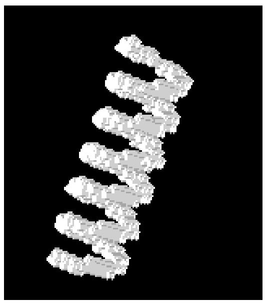
*User effect : materials effect_*

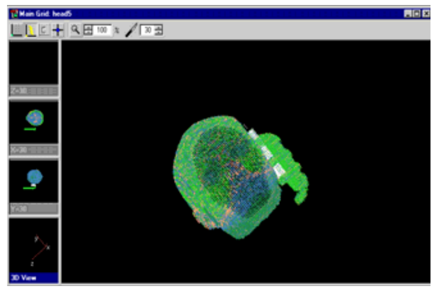
Conductivity	Peak SAR (normalized)	1g average SAR (normalized)	Absorption power
1.26	0.92	0.63	67%
1.4	1	0.66	68%
1.56	1.08	0.68	71%

Hand Effect:

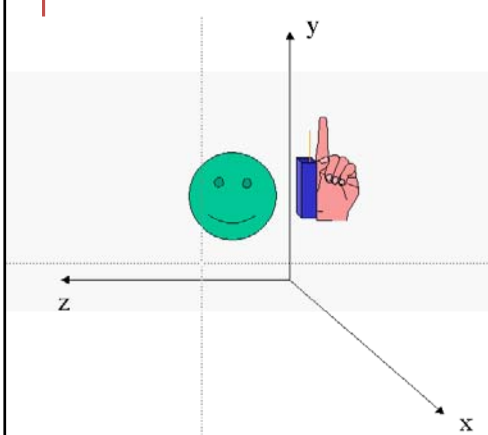


Sub-grid (helical Antenna)





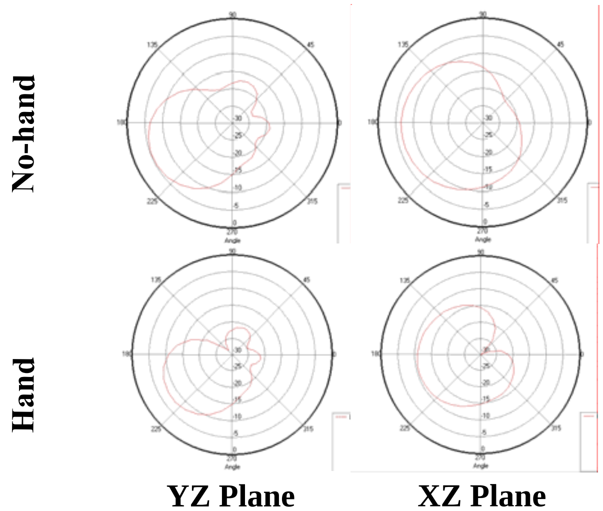
Radiation Pattern



yz plane (ϕ=90°, θ changes from 0° – 360°)

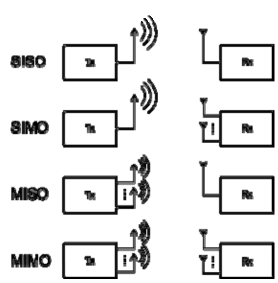
xz plane (ϕ=0°, θ changes from 0° – 360°)

Radiation Pattern



Multi-Antenna SAR Evaluation

MIMO (Multiple input and multiple output)



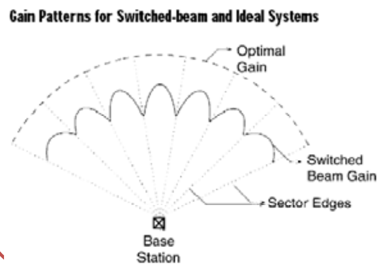
4G required

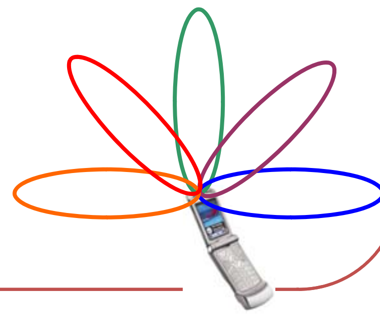
22

Challenges in SAR estimations

1) For fast switching multi-transmitter systems, how to simulate these SAR distributions when SAR patterns are changing

2) How to effectively measure all possible SAR patterns generated by these new technologies





23

Decomposition and Superposition Approach

Technique

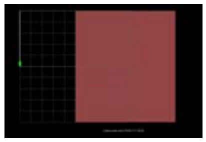
1. Electric field/SAR simulation from each antenna with unit excitation
2. Superposition results from individual simulation

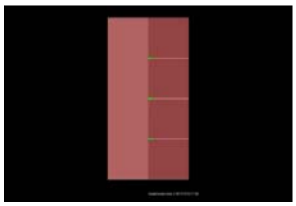
Advantage:

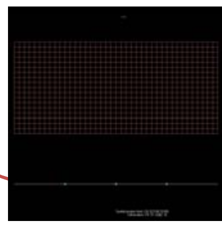
1. Minimum measurement required
2. Worst SAR estimation

24

Modeling







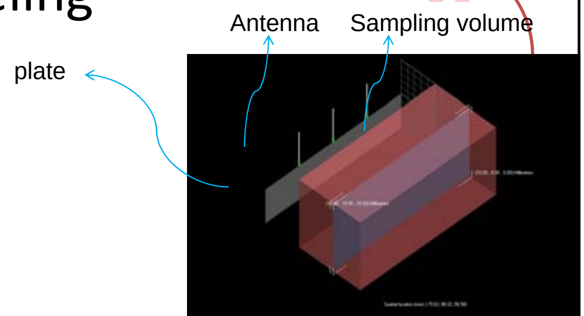
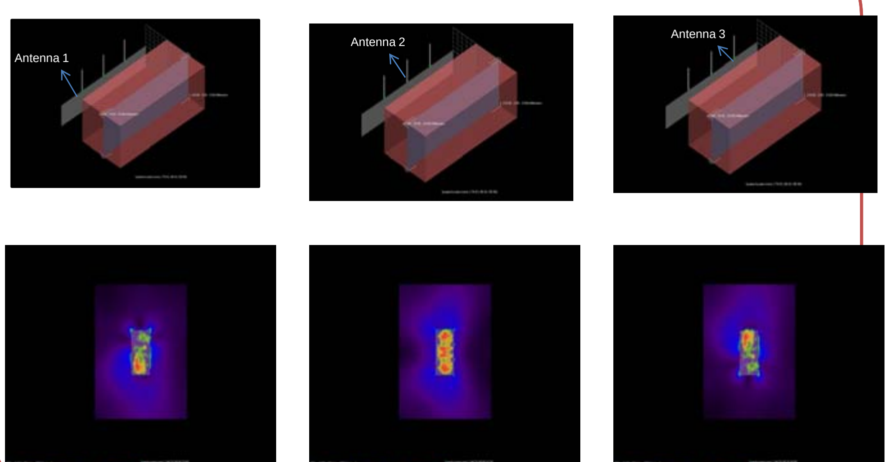


Plate: 5*20mm
Antenna length: 5mm
Sampling volume:
 relative dielectric constant : 40
 conductivity : 0.1s/m
Feeding: sinusoid, frequency: 1.5GHz, magnitude: 1V

25

Simulation Results



Electric field excited by each individual antenna

26

Electric Field Optimization

$$\vec{E}_{total}\left(x,y,z\right)=\sum_{i=1}^{N} w_i \vec{E}_i\left(x,y,z\right)$$

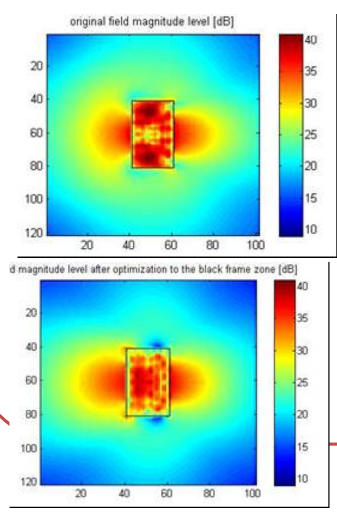
Constraint: $$\sum_{i=1}^{N} \left|w_i\right|^2 = P_{in}$$

$$w_i = R_i \angle \theta_i$$

27

Electric Field-Compare The Results

The minimization of the summation of E field in the region



The minimized summation of field is less than 25.78% of the original one.

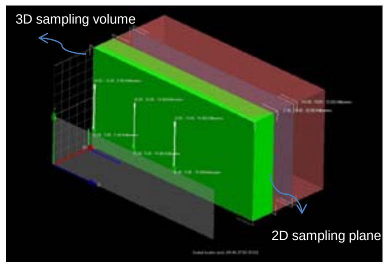
Complex coefficient

$$w_1 = 0.8918\angle -29°$$
$$w_2 = 1.1887\angle 43.5°$$
$$w_3 = 0.88974\angle -30°$$

28

SAR minimization

1) Electric field available only
2) SAR available only



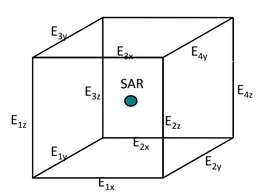
29

Electric Field Available Only

$$\vec{E}_{total}(x,y,z)=\sum_{i=1}^{N} w_i \vec{E}_i(x,y,z)$$

$$SAR_x = \frac{1}{4}\left(\frac{\sigma_{1x}|E_{1x}|^2}{2\rho_{1x}}+\frac{\sigma_{2x}|E_{2x}|^2}{2\rho_{2x}}+\frac{\sigma_{3x}|E_{3x}|^2}{2\rho_{3x}}+\frac{\sigma_{4x}|E_{4x}|^2}{2\rho_{4x}}\right)$$

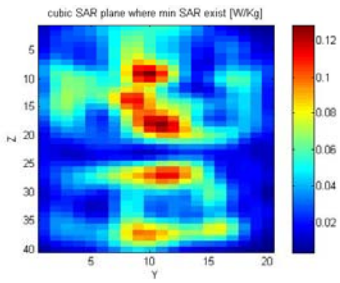
$$SAR = SAR_x + SAR_y + SAR_z$$

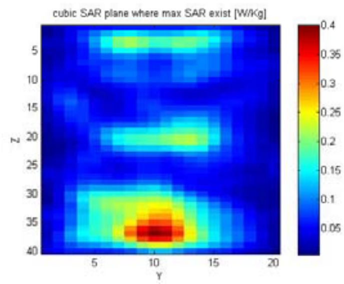


IEEE P1528.1™/D1.0

30

Upper Bound & Lower Bound of the SAR





$SAR_{lower\_bound} = 0.1288\text{W/Kg}$

$w_1 = 0.57071\angle -62.3°$

$w_2 = 0.28769\angle 44.3°$

$w_3 = 0.76911\angle 17.5°$

$SAR_{upper\_bound} = 0.4012\text{W/Kg}$

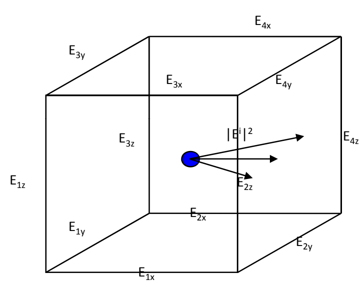
$w_1 = 0.75967\angle 12.9°$

$w_2 = 0.61093\angle -68°$

$w_3 = 0.22287\angle 55.7°$

31

SAR Available Only

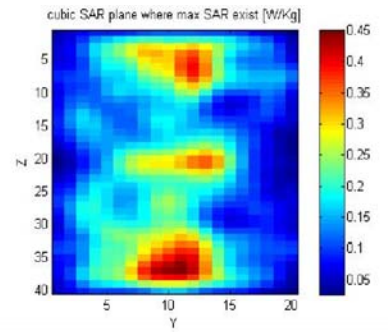


$$SAR_{total}^{worst}(x,y,z) = \frac{\sigma}{2\rho}\left|E_{total}^{worst}\right|^2 = \frac{\sigma}{2\rho}\left(\sum_{i=1}^{N}\left|E^i\right|\right)^2 = \left(\sum_{i=1}^{N}\sqrt{\frac{\sigma}{2\rho}}\left|w_i E^i\right|\right)^2 = \left(\sum_{i=1}^{N}\sqrt{\left|w_i\right|^2 SAR_i(x,y,z)}\right)^2$$

IEEE P1528.1™/D1.0

32

Worst SAR



$$SAR_{total}^{worst}(x,y,z) == \left(\sum_{i=1}^{N}\sqrt{|w_i|^2\, SAR_i(x,y,z)}\right)^2$$

$$|w_i|^2 = R_i^2 = W_i \,(0 \le W_i \le 1)$$

$$\sum_{i=1}^{N} W_i = P_{in}$$

$$SAR_{worst\_case\_bound} = 0.4511\text{W/Kg}$$

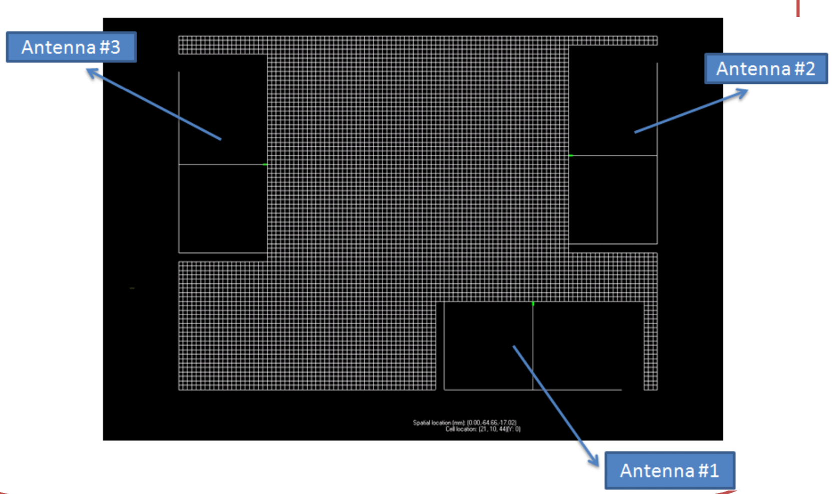
$$W_1 = 0.5170$$

$$W_2 = 0.3533$$

$$W_3 = 0.1297$$

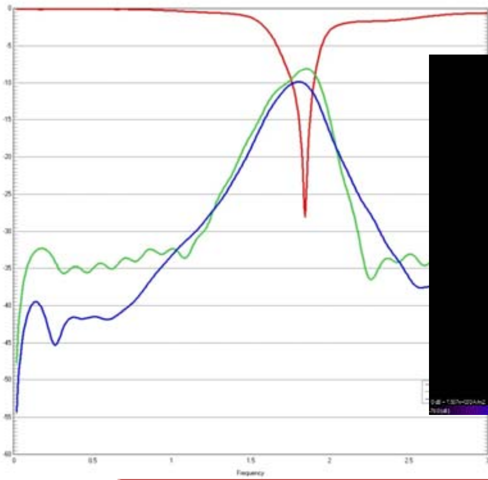
33

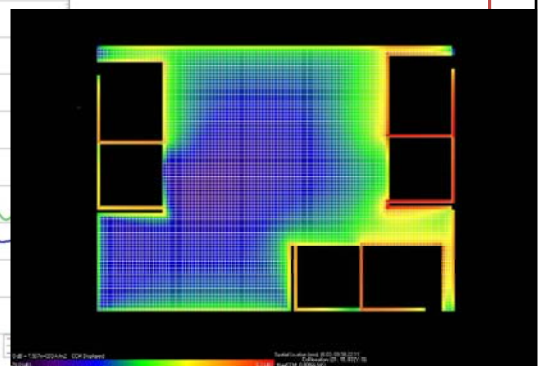
Multi-PIFA antenna model



34

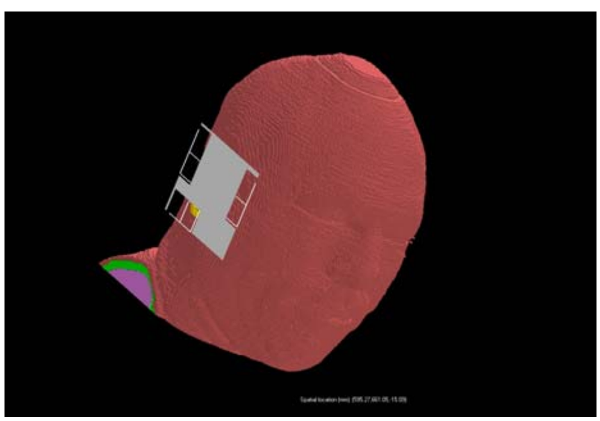
Antenna #1: S11 S21 S31

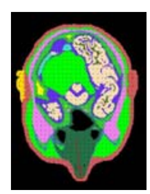


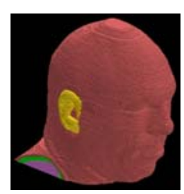


35

PIFA antenna and head model



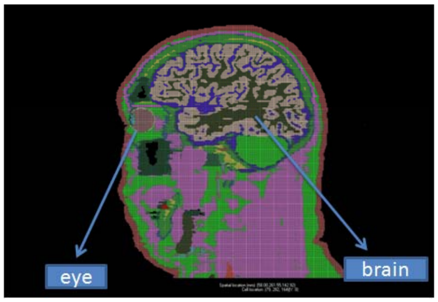


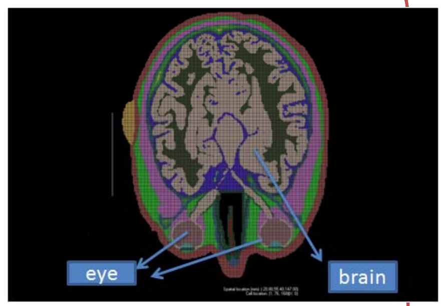


Adult Visible Human Head in above figure (IEEE SCC 34 SC-2 WG-2) is used especially for cell phone SAR simulation, tissue assigned to corresponding frequency.

36

1 mm head model

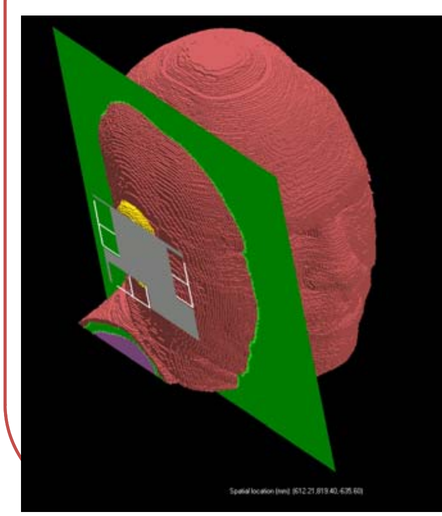




The figures above give two slices of the human head model (IEEE SCC 34 SC-2 WG-2).
The resolution of this head model is 1 mm. The different colors in the figures indicate the different tissues in human body.

37

Optimize the SAR close to the MIMO PIFA antenna



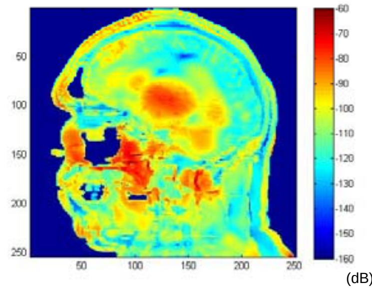
Optimize the SAR near the antenna, on the left side of the green plane.

Results:
w1= 0.5283 + 0.2833i
w2= 0.1607 + 0.0235i
w3= 0.6298 - 0.4665i

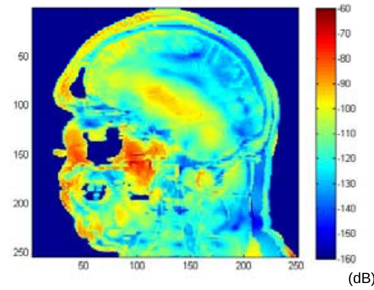
SAR before optimize is 0.3850 W/Kg
SAR after optimize is 0.2095 W/Kg, which is 45% smaller.

38

The SAR in the whole head volume



(dB)



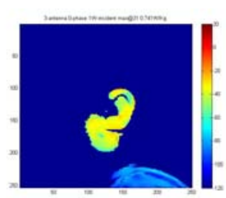
(dB)

Non-optimize SAR

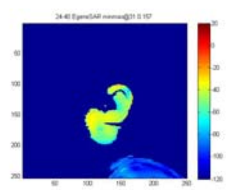
Optimized SAR

The maximum SAR after optimization is 45% of the SAR without optimization.

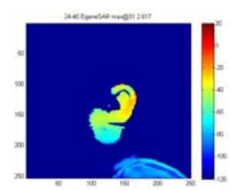
Optimize SAR close to the antenna, around ear



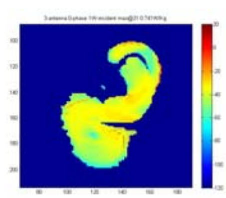
3-antenna 0-phase 1W-incident max@31 0.741W/Kg

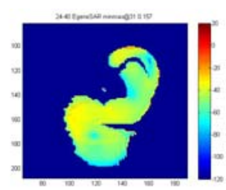


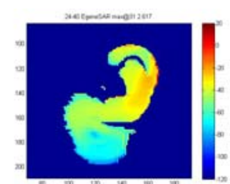
24-40 SAR minmax@31 0.157W/Kg



24-40 SAR max@31 2.617W/Kg

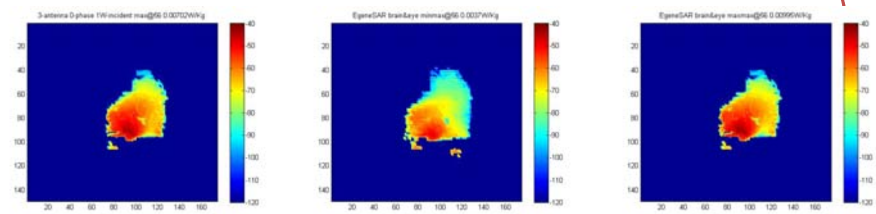




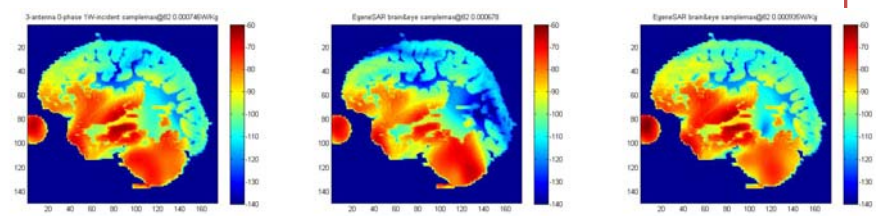


Increase the region to 24-40, the results show that the maximum and minimum of spatial maximum SAR would not change

SAR in brain and eyes



3-antenna 0-phase 1W-incident max@56 0.00702W/Kg SAR brain&eye minmax@56 0.0037W/Kg SAR brain&eye maxmax@56 0.00995W/Kg



3-antenna 0-phase 1W-incident samplemax@62 0.000746W/Kg SAR brain&eye samplemax@62 0.000678W/Kg SAR brain&eye samplemax@62 0.000935W/Kg

41

Telemetry EMC/EMI

www.ecri.org • Printed from *Health Devices Alerts* on Friday, February 13, 2009 Page 1

H0053 - High Priority Medical Device Alert

Medical Device Hazard Report

Updated: February 5, 2009

UMDNS Terms:

- Programmer/Testers, Implantable Cardiac Pacemaker [15993]
- Testers, Implantable Defibrillator/Cardioverter [17577]
- Transmitter/Receiver Systems, Telephone [17602]

Suggested Distribution:

- Cardiology/Cardiac Catheterization Laboratory
- Clinical/Biomedical Engineering
- CSR/Materials Management

Interference with Wireless Programming of Boston Scientific Implantable Cardiac Devices

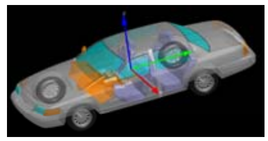
Product Identifier:
(1) Model 3120 Zoom Latitude Programmers; (2) Cardiac Resynchronization Therapy Defibrillators; (3) Implantable Cardioverter Defibrillators [Capital Equipment, Consumable]

Manufacturer: Boston Scientific Cardiac Rhythm Management Group [451637], One Boston Scientific Pl, Natick, MA 01760-1537, United States

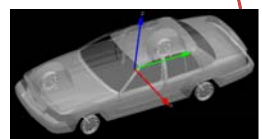
Problem: An ECRI Institute member hospital reports having difficulty establishing a wireless communication link between 2 Boston Scientific devices: an implantable cardioverter-defibrillator (ICD) and a Zoom Latitude programmer (Model 3120). The hospital's investigation concluded that the problem occurred because of radio-frequency (RF) interference from the hospital's Polycom SpectraLink 6000 wireless telephone system (formerly known as the SpectraLink Link Wireless Telephone System).

No patient harm was reported. Neither the programmer nor the defibrillator itself was affected by the interference, nor was the SpectraLink system. The interference was limited to the wireless communication link between the defibrillator and the programmer. This interference occurs when the Zoom Latitude programmer is using a technology called Zip wandless telemetry to communicate with certain Boston Scientific devices—specifically, some of its ICDs and cardiac resynchronization therapy defibrillators (CRT-Ds). It does not occur if Zip wandless telemetry is not used.

A typical police car (Ford Crown Victoria)



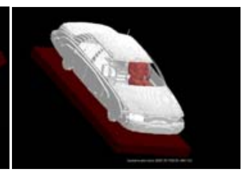
CAD model of the car



Car with medal parts only

According to IEEE P1528.2

Bystander



Passenger

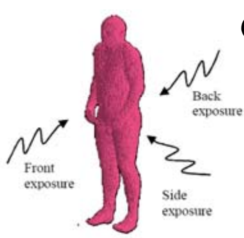
Ground is 30cm thick slab, with relative permittivity 8 and conductance 0.01 S/m, extend 10cm in x and y Direction beyond the car/bystander.

According to IEEE 1528.3 On the Ground Modeling Implementation

43

Antenna
1/4 30 MHz
1/4 75 MHz
1/4 150 MHz
1/4 450 MHz
1/4 900 MHz
5/8 150 MHz
5/8 450 MHz
5/8 900 MHz

d-distance
20cm away
100cm away



Three facing direction:

Bystander model 1 -->facing the car

Bystander model 2 --> facing front

Bystander model 3 --> face off the car

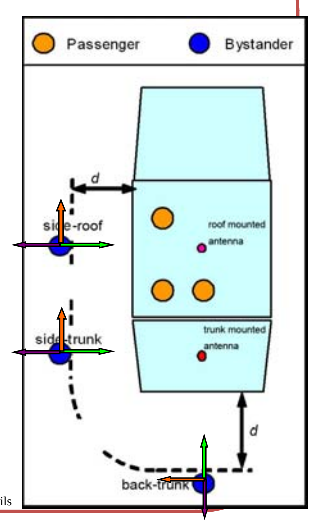
Four seat modeling:

Passenger no additional parts

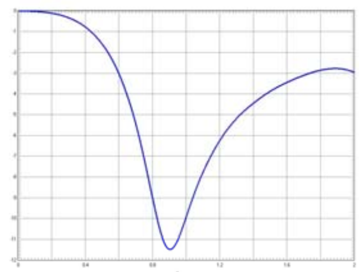
Passenger model 1 --> with medal seat

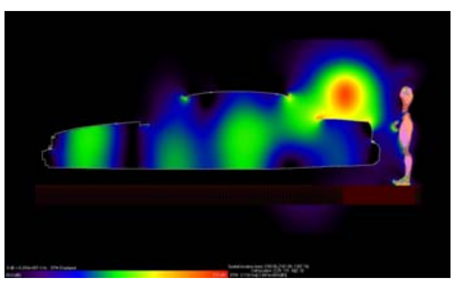
Passenger model 2 --> with spring coils

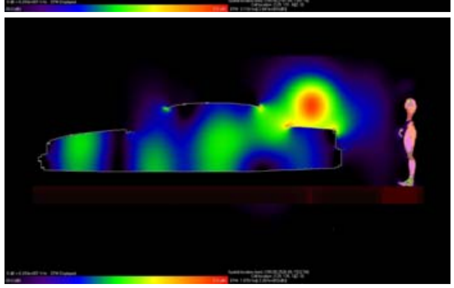
Passenger model 3 --> with both seat & coils



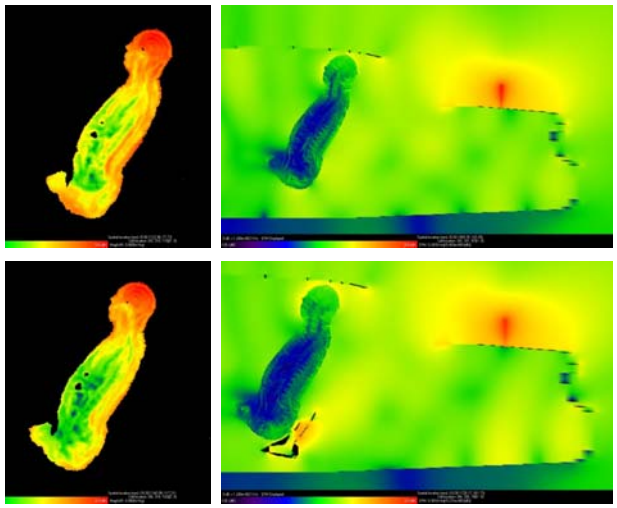
Design of Implantable Antenna





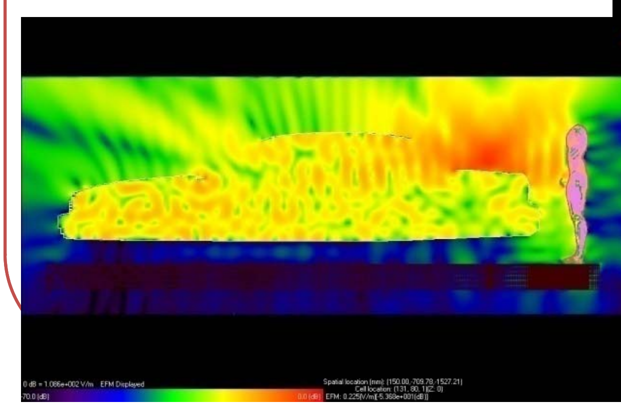


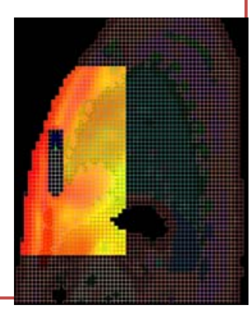
Trunk mounted antenna



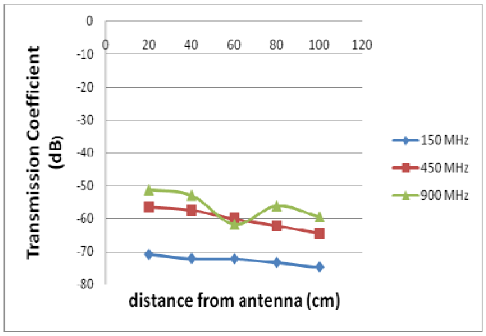
Passenger back center 1/4 antenna at 450MHz

Electric Field Distribution at 900 MHz

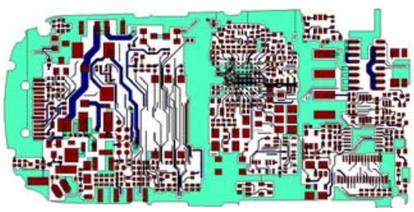


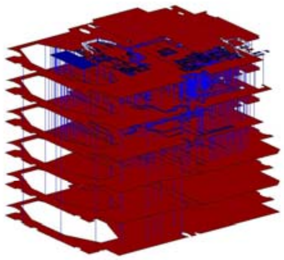


	SAR with Device (W/kg)	SAR W/O Device (W/kg)
150 MHz	0.0028	0.0020
450 MHz	0.0041	0.0034
900 MHz	0.0077	0.0067



Interconnect Modeling

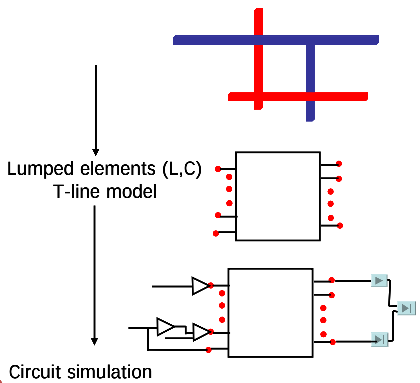




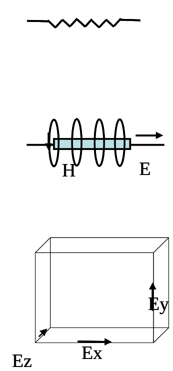
HW 07-02-2005

Interconnects Modeling Approaches

Circuit level



Electromagnetic level



Lumped element

$V=RI$

Quasi-static

$\int E \cdot dx = R \oint_c H \cdot dl$

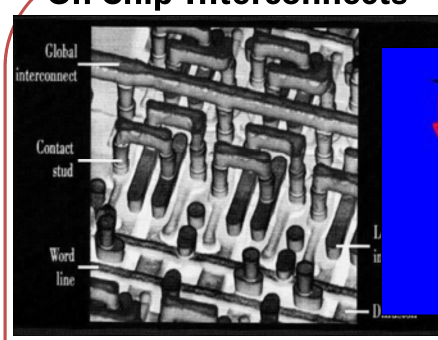
Full wave

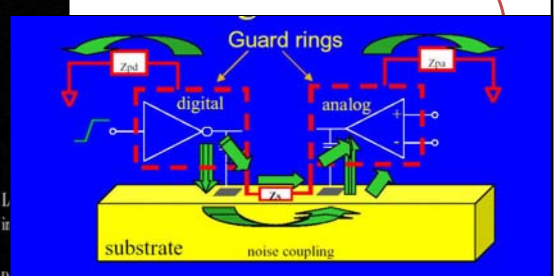
$\nabla \times E = \frac{\partial D}{\partial t} + J$

$\nabla \times H = -\frac{\partial B}{\partial t}$

HW 07-02-2005

On Chip Interconnects

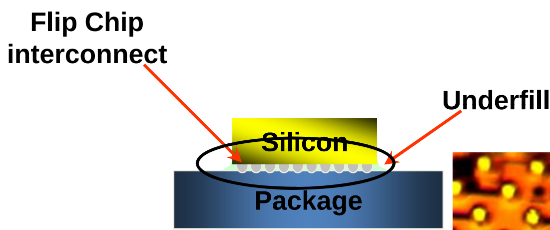


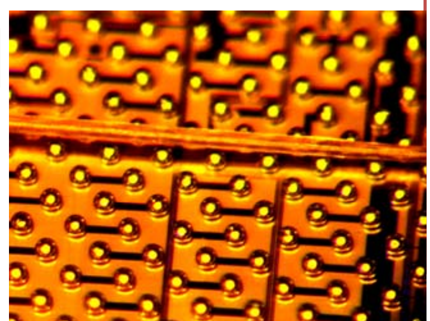


Capacitance extraction
Inductance extraction
Developing Rigorous/Efficient EM modeling
(skin effects, nonlinearity, substrate coupling)

HW 07-02-2005

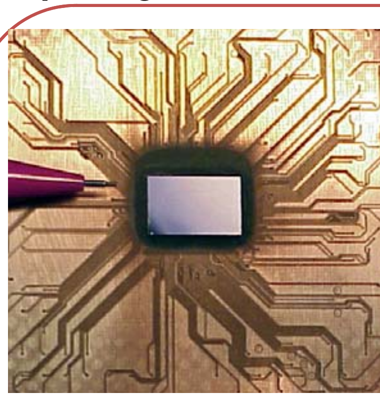
Silicon to package interconnects

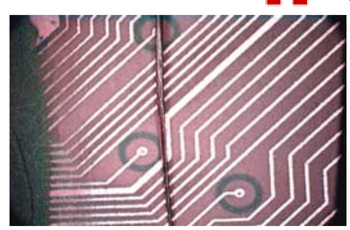


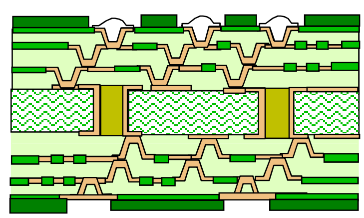


Effects of solder bumps with full-wave simulation

On package interconnects

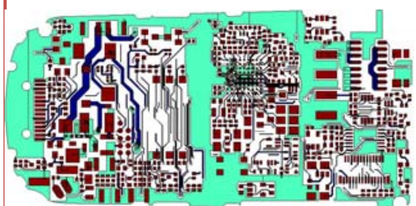


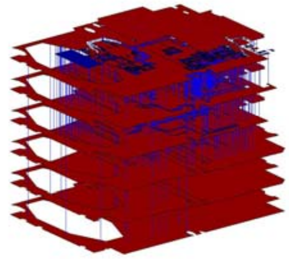


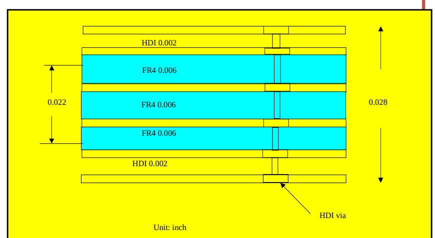


T-line
via- inductance

System board interconnects



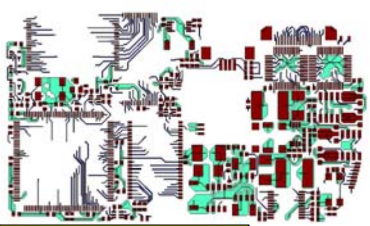


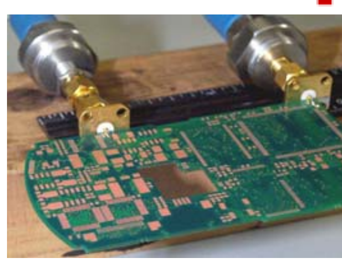


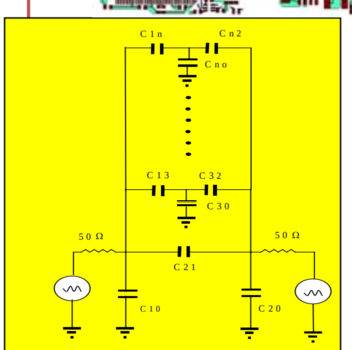
Low frequency → lumped
Higher freq. → T-line
Extreme freq. → full wave

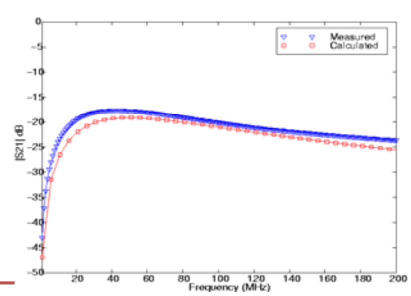
HW 07-02-2005

Examples





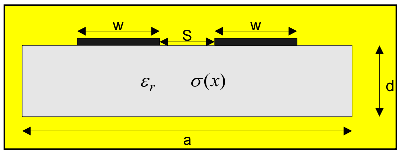


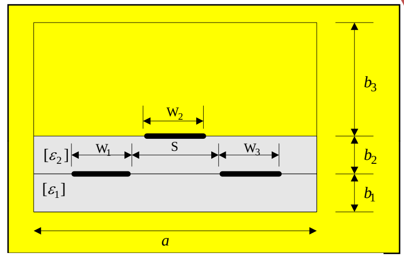


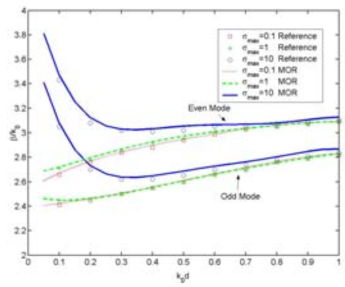
HW 07-02-2005

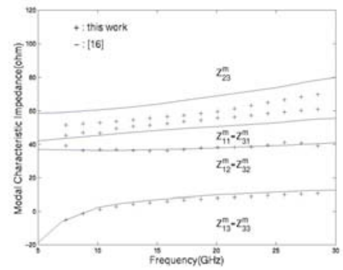
Examples

T-line parameter extraction (RLGC)



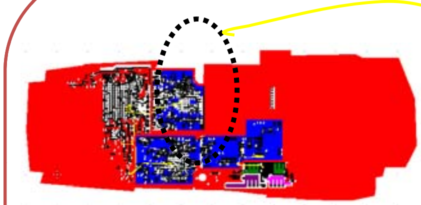






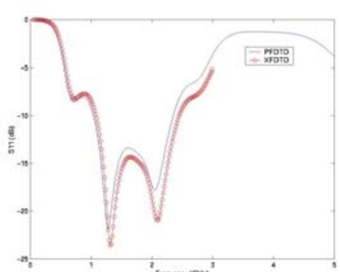
HW 07-02-2005

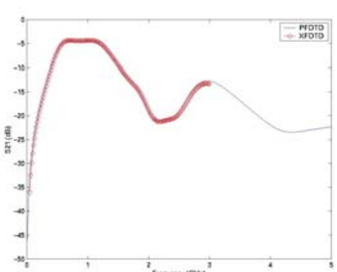
Examples→ full wave



Reflection

Transmission





HW 07-02-2005

Summary

1. Various challenges EMC/EMI Issues in the design of wireless products
2. Accurate EM modeling techniques may help understanding these issues
3. Many challenges