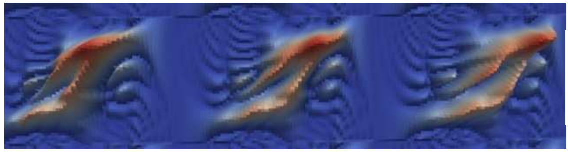

Near Field Scanning

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GGIEMR
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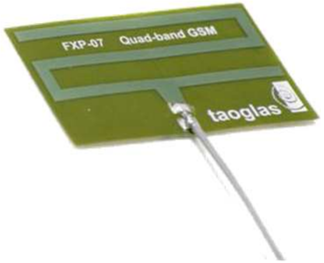
Contents

- Introduction
- Near-field Scanning
- Modeling in free space
- Modeling in a closed environment
- Accounting for Diffraction
- Time Domain
- Conclusion

Introduction

EUTs: radiators at PCB level

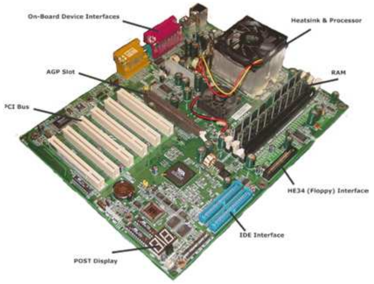
printed antennas



RF components

fast clock circuits

complete electronic systems



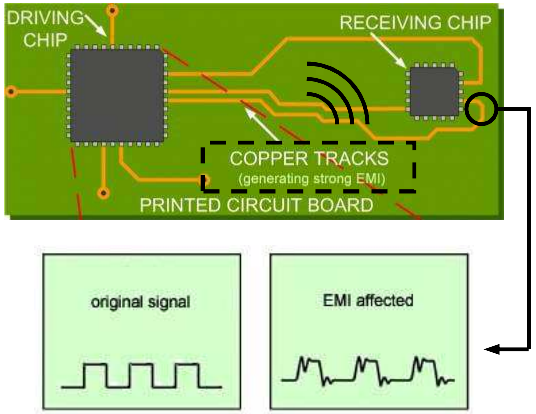
packages

Common characters:

electrically small, approximately **2D**
complex structure, high coupling effects

- intential radiations:
  - antenna design
  - remote control

- unintentional radiations:
  - by-product of fast clock circuits
  - EM interference (EMI)
  - signal integrity (SI)



Awareness of chip manufactures

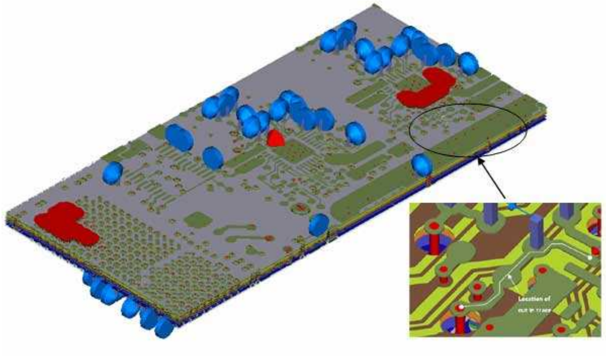
intel	***EMC*** *test in early design phase*	nVIDIA ASUS	*collaborative program on graphic chip improvement, including* ***EMC***

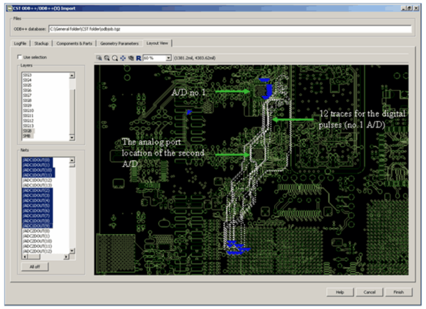
First of all, it is essential to predict the radiations from PCBs.

Two ways to simulate:
direct simulation & equivalent methods

- directly modeling in a full field solver

3D EM simulation of mixed analog / digital PCB





ODB++ database: C:\General folder\CST folder\odbjob.tgz

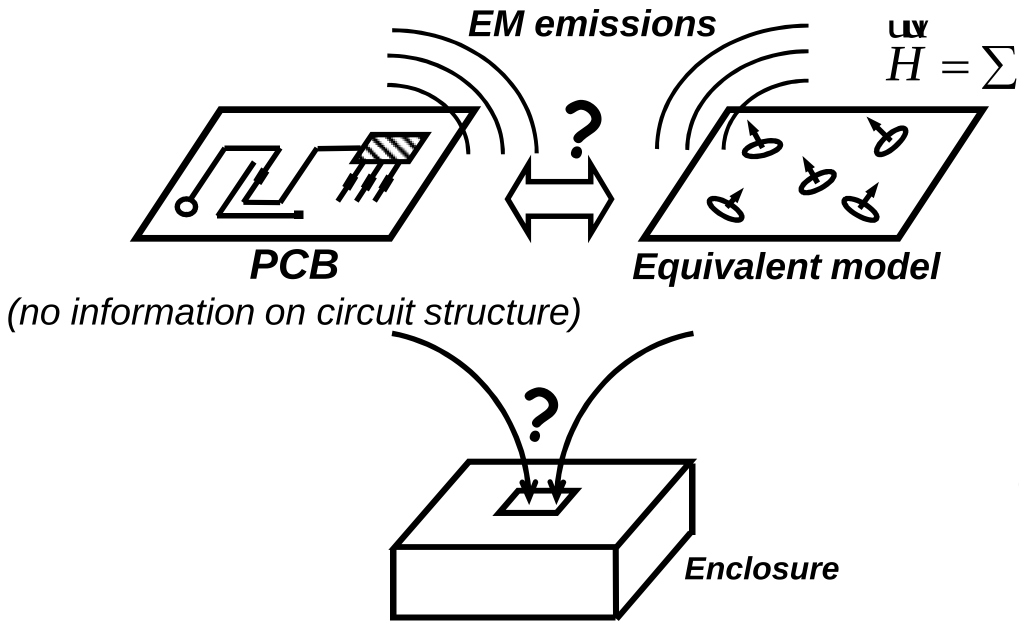
modeling time	running time	memory required
1 week	10 h	3 GB

Difficulties

- unrealistic computational resources and time due to increasingly complex circuit structure
- unknown characteristics of the circuit
- confidential reasons

Equivalent modeling

- not modeling the complete complexity of PCBs
- representing the radiations by equivalent sources
- fast and computationally low-cost
- general for radiators at printed board level



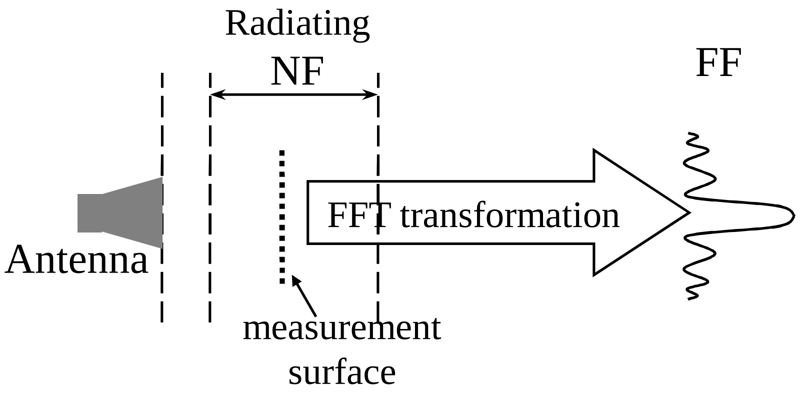
$$\vec{H} = \sum \vec{J}_i \iint \nabla \times \ldots\ldots$$

?

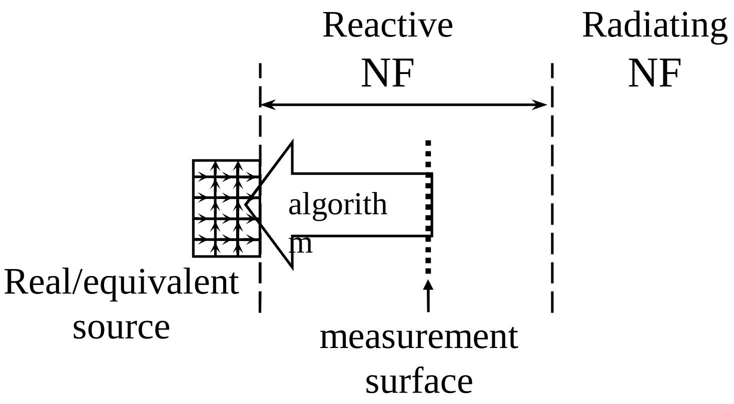
1. To find an efficient equivalent configuration to represent the PCB
2. Simple formulation
3. Interactions with packages

Near-field Scanning

Popular technique for providing EM fields closely surrounding DUTs



NF – FF transformation



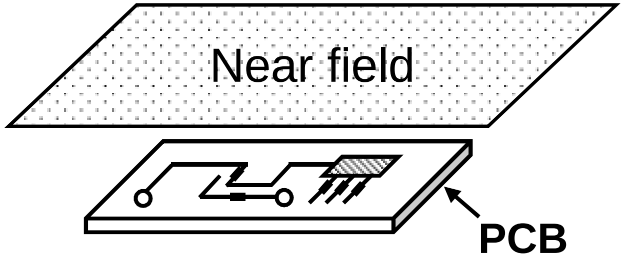
Source model from NF

X. Tong, et. al, “Modeling EM Emissions from PCBs in Closed Environments Using Equivalent Dipoles”, IEEE Trans. EMC, Special Issue on PCB Level EMC

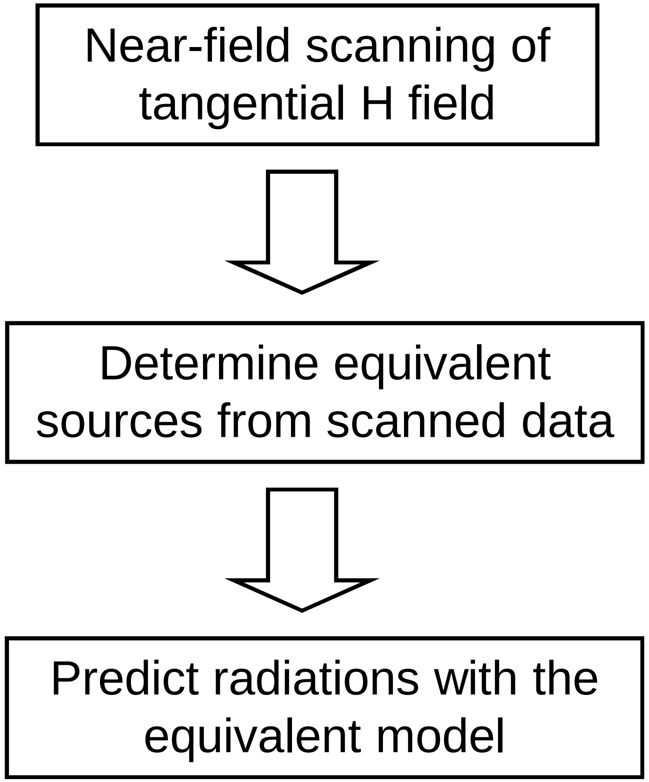
Basic idea: to replace the PCB with an array of equivalent dipoles

- Why dipole? – the simplest radiator
- Where? – the component side of the PCB (except possibly multi-layered boards)
- How many dipoles? – with resolution of about λ /10 (but depends on scan height)
- How to determine? – from near-field scanning

The scanned near fields contain sufficient information for characterizing the emissions from a PCB



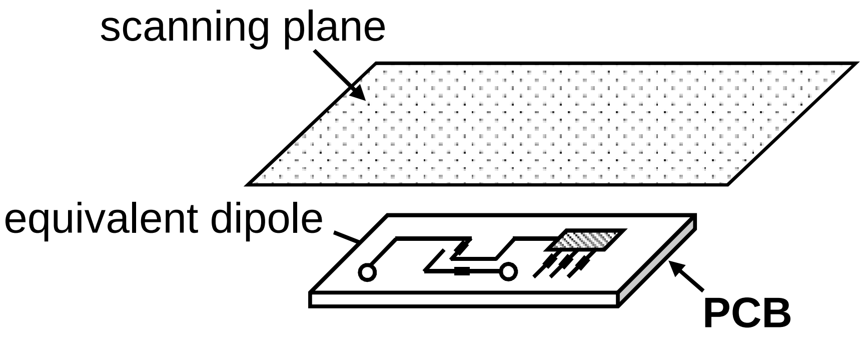
Modeling procedure



Near-field scanning of tangential H field

Determine equivalent sources from scanned data

Predict radiations with the equivalent model



equivalent source:

infinitesimal magnetic dipoles

(the simplest radiator)

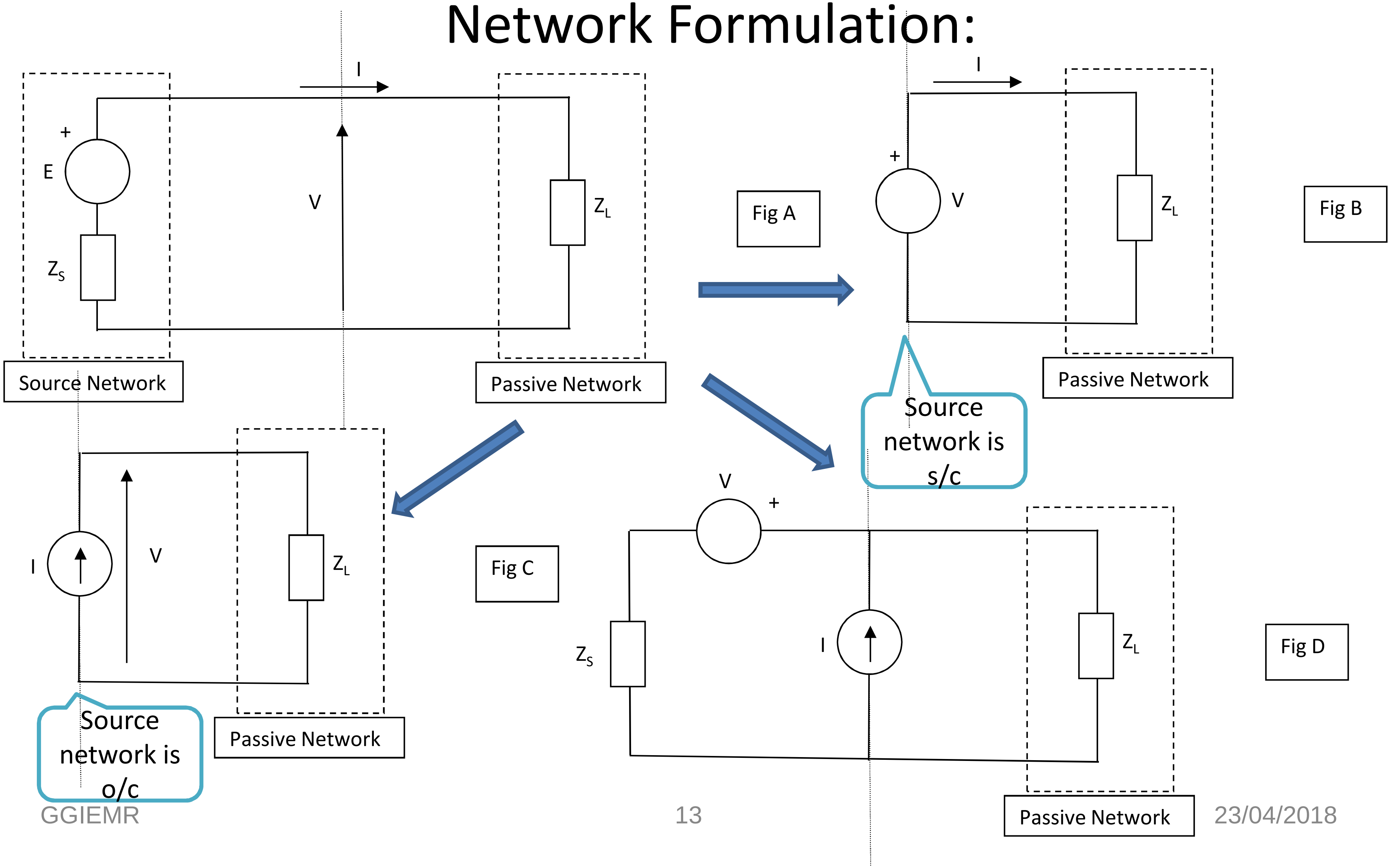
Number, position, moment, orientation
of equivalent dipoles

Near-Field Scanning

Equivalence Principle

- In many EM problems, such as the near-field scanning, we seek to calculate the field in the region of space above the PCB and thus we seek a distribution of sources that does that and we are not concerned for other parts of space.
- This distribution of sources is not unique-we have several options as is discussed in the next few slides
- We start with illustrating the principles from circuit theory, as it is easier to comprehend, and then extend the ideas to fields-the case of interest here!

The Equivalence Principle-how to replace sources inside a volume by equivalent currents on its surface! Network Formulation:



We see that the original circuit in Fig A can be replaced, as far as conditions at the load ZL are concerned, by either of three circuits (equivalents) shown in Figures B, C, D. All we have do is to impose voltage (V) and/or current (I) sources at the boundaries beyond which we wish to evaluate conditions (the surface fields in the field problem).

We see that we can get away by specifying either V (tangential electric field in the field problem) or I (tangential magnetic field in the field problem) or both if we so wish.

Since measurements and scanning are time consuming we normally measure only one (E or H). This is illustrated in the next slide for the field case…

Equivalence Principle-Field Formulation:

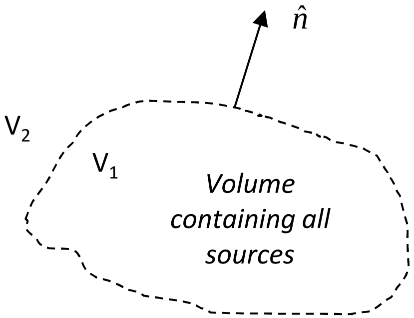


Fig AA

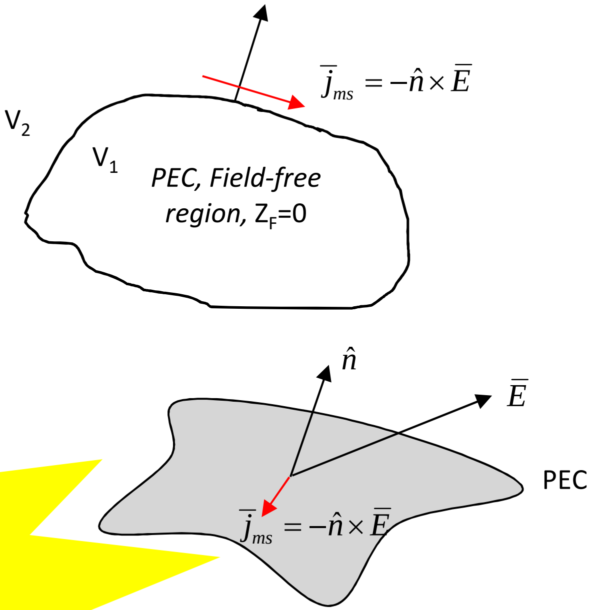


Fig BB

Either tangential E-field or tangential H-field are required for a full description!

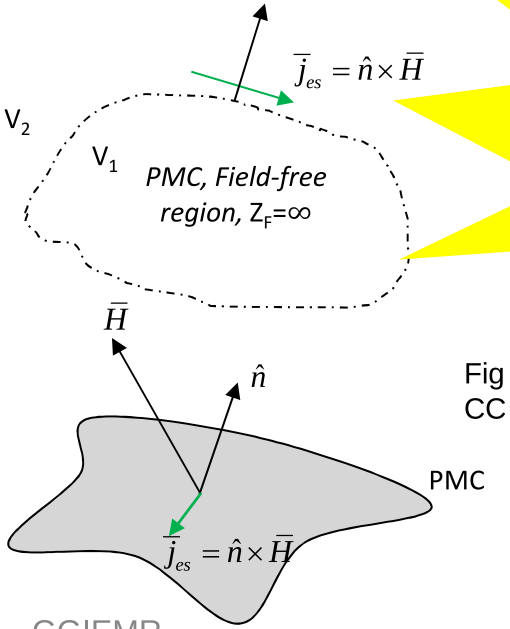


Fig CC

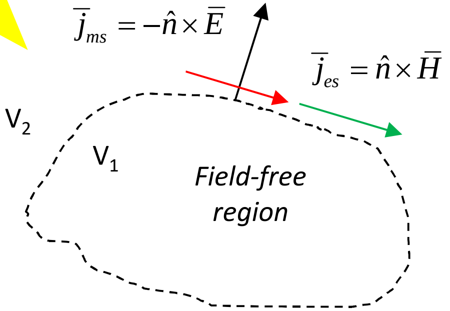
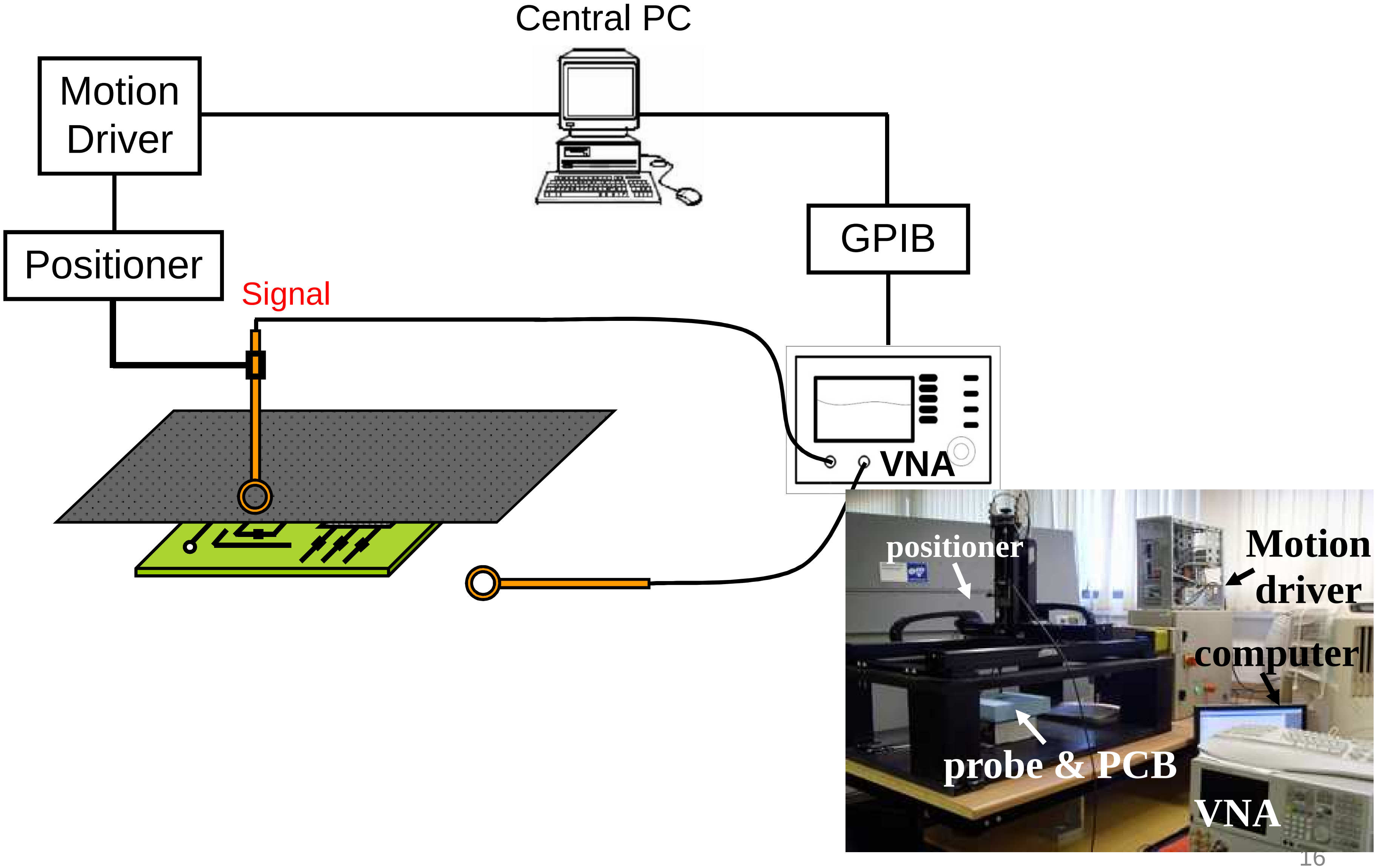
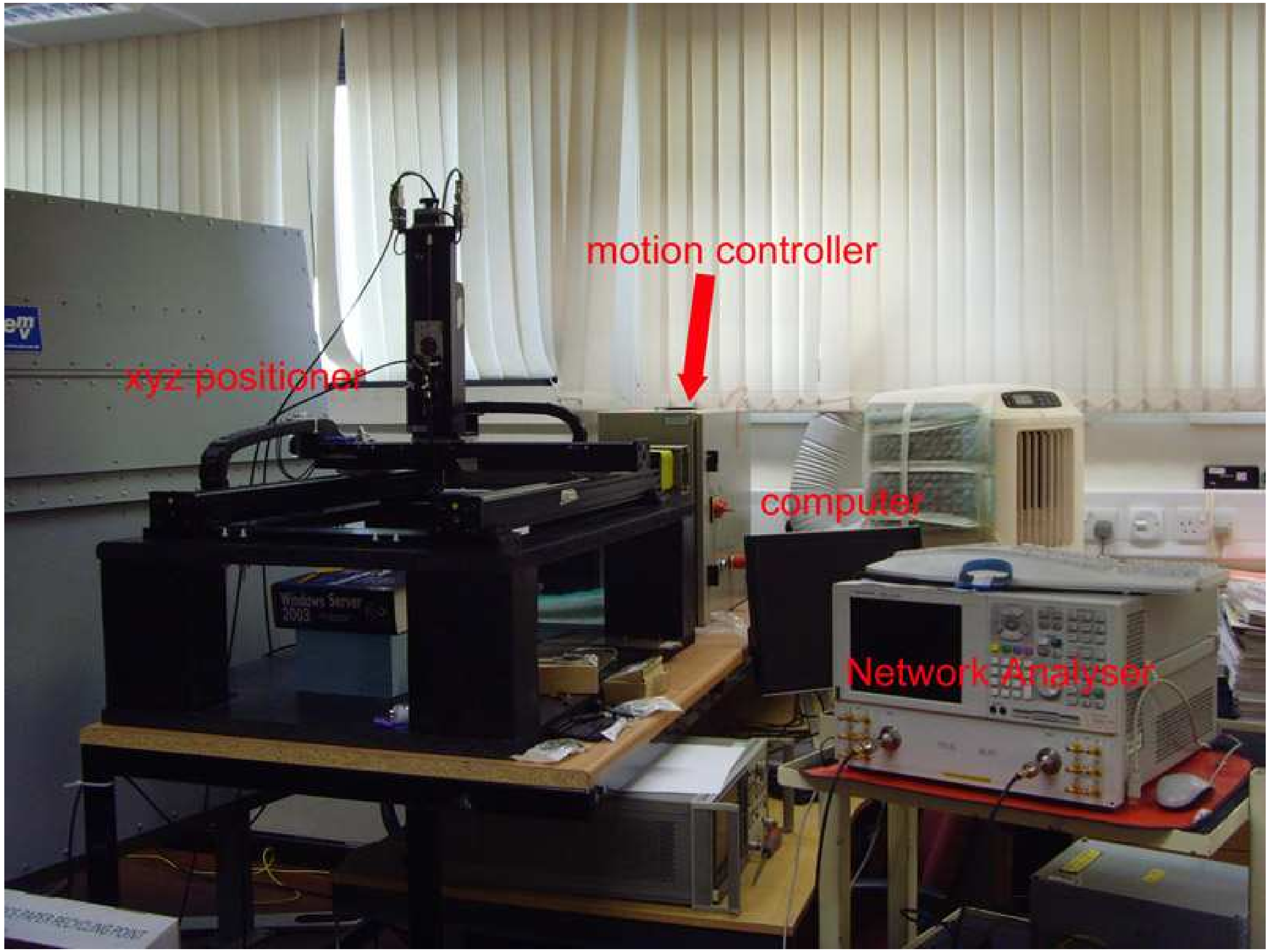


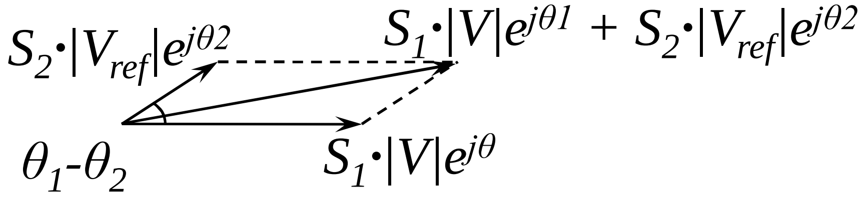
Fig DD

Near-Field Scanning System




motion controller
xyz positioner
computer
Network Analyser

With a spectrum analyzer (amplitude-only)



- 3-step measurement for phase

1. Field signal |V|

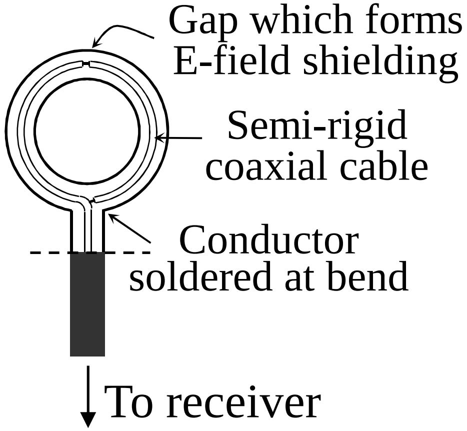
2. Combined signal $|V_{sum}|$

$$|\theta_1 - \theta_2| = \arccos\left(\frac{|V_{sum}|^2 - |S_1|^2 \cdot |V|^2 - |S_2|^2 \cdot |V_{ref}|^2}{2|S_1| \cdot |S_2| \cdot |V| \cdot |V_{ref}|}\right)$$

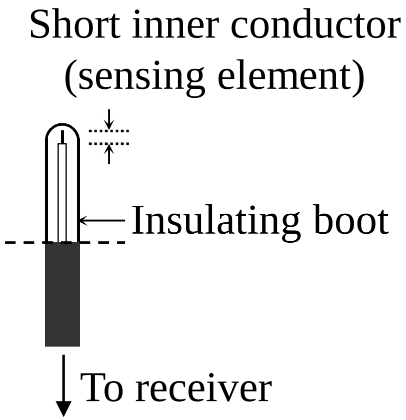
3. $|V'_{sum}|$ with a phase shifter

$$|\theta_1 - \theta_2 - \Delta\theta| = \arccos\left(\frac{|V'_{sum}|^2 - |S_1|^2 \cdot |V|^2 - |S_2|^2 \cdot |V_{ref}|^2}{2|S_1| \cdot |S_2| \cdot |V| \cdot |V_{ref}|}\right)$$

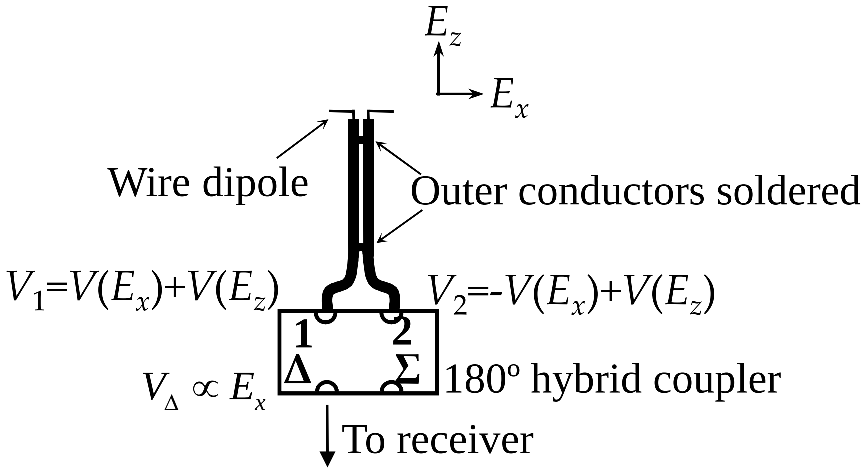
Near-field probes



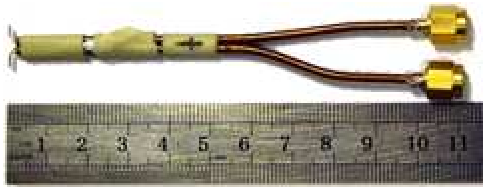
a) Loop H probe



b) Rod E probe



c) balanced dipole E probe



Response of ideal probes

$V_i = C \cdot E_i$ or $V_i = C \cdot H_i$ ($i = x, y, z$)

Probe characterization

- Spatial accuracy & sensitivity: tradeoff, probe size

- H/E rejection ability: intrinsic character, GTEM cell test

$$V = V_H + V_E = C_H \cdot H + C_E \cdot E = \left(C_H + \eta C_E\right) \cdot H$$

Response to H field (wanted)

Response to E field (unwanted)

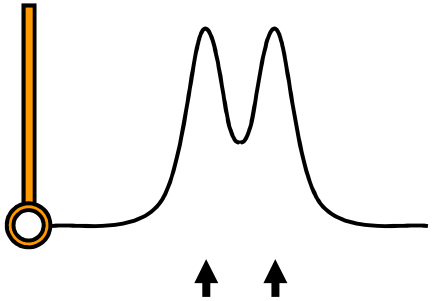
- Disturbance effect: $V_i = C \cdot H_i = C \cdot H_{0i} \left(1 - \rho\right)$

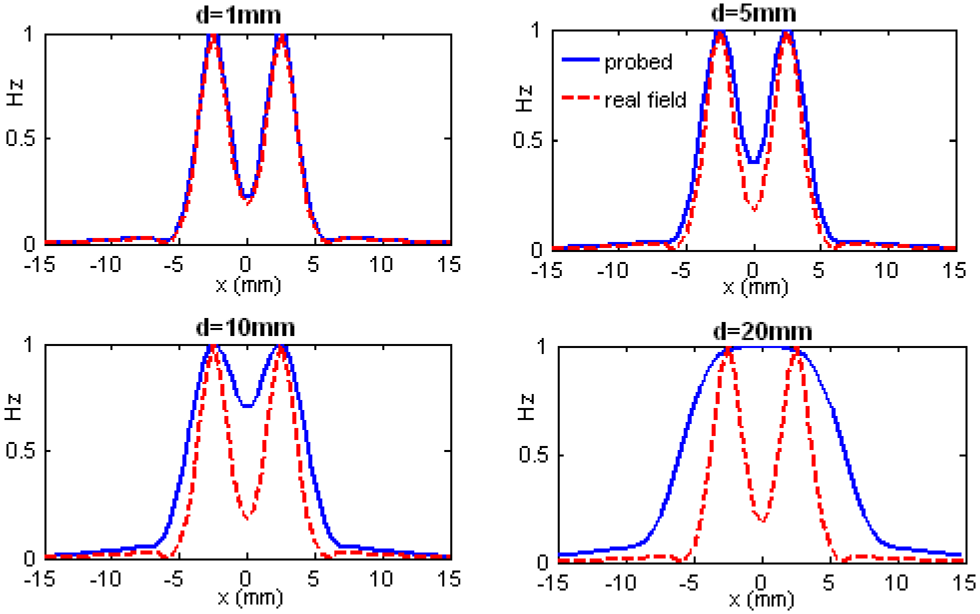
a function of scanning height, frequency, probe size, wave impedance

3% error in typical near-field range

Probe characterization

- Spatial accuracy vs Sensitivity





2 magnetic dipoles

Probe with different diameter *d*

Simulation

-> min meaningful scanning spacing > *d*/4

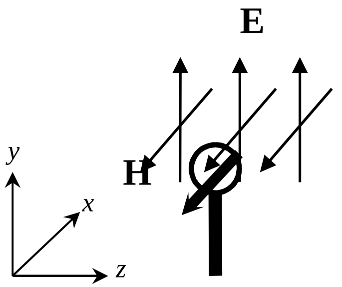
- H/E rejection ability

$$V = V_H + V_E = C_H \cdot H + C_E \cdot E = \left(C_H + \eta C_E\right) \cdot H$$

Response to H field (wanted)

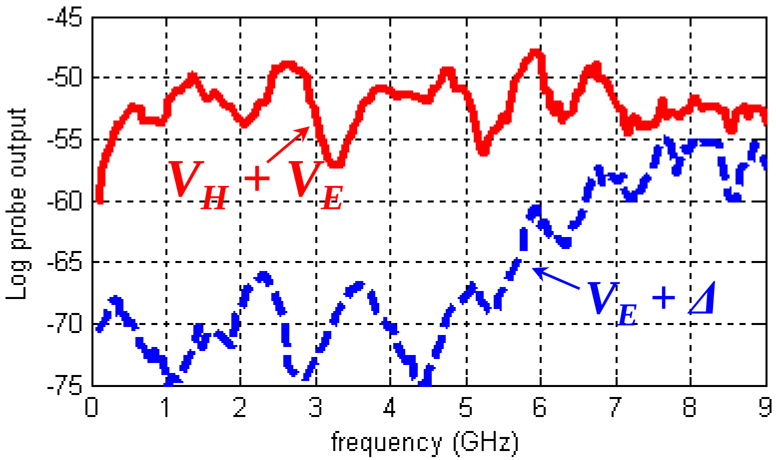
Response to E field (unwanted)

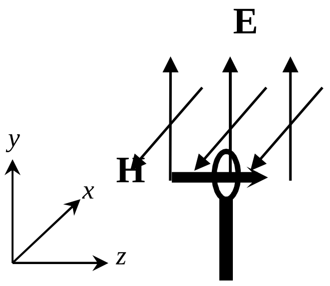
GTEM cell test



a) Aperture perpendicular to H

$V = V_H + V_E$





b) Aperture parallel to H

$V = V_E + \mathbf{\Delta}$

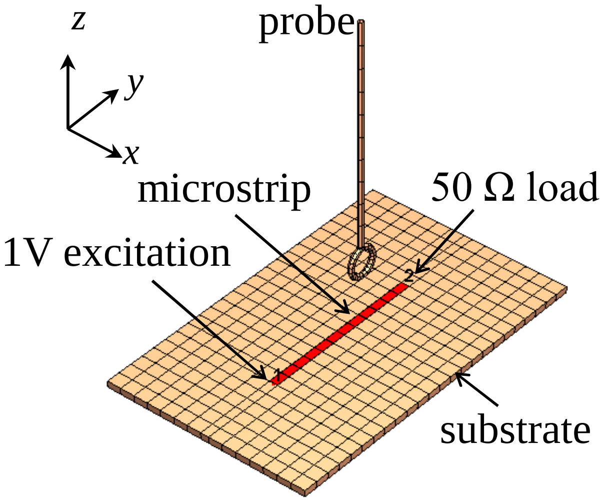
$$R = \frac{V_H}{V_E} = \frac{C_H H}{C_E E} = \frac{C_H}{C_H \eta_0}$$

- Probe disturbance to field

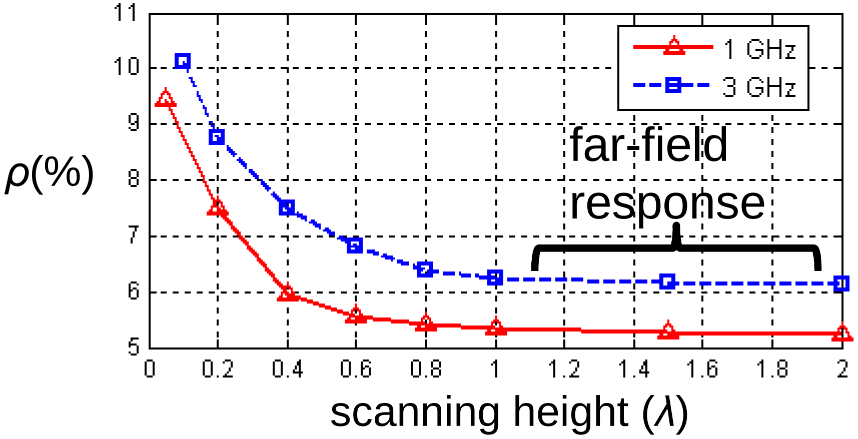
Disturbance effect $H = H_0 - \Delta H = H_0\left(1-\rho\right)$

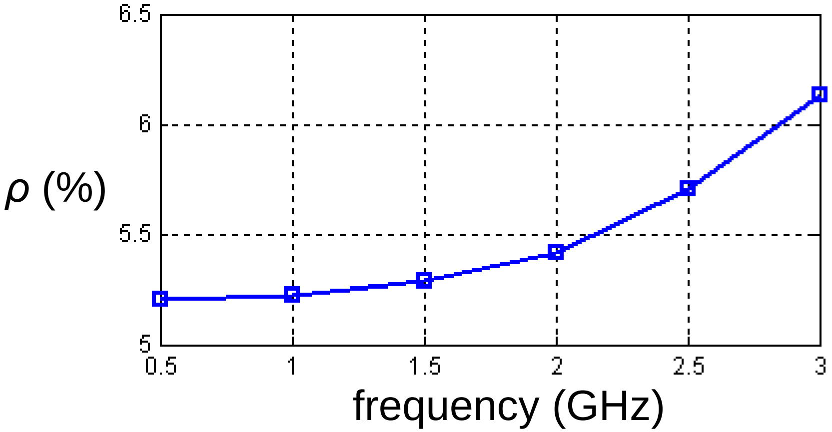
Actual response $V_i = C \cdot H_i = C \cdot H_{0i}\left(1-\rho\right)$

Disturbance factor $\boldsymbol{\rho}$ is not constant



Simulation setup:
Calibration configuration proposed in IEC-61967-3

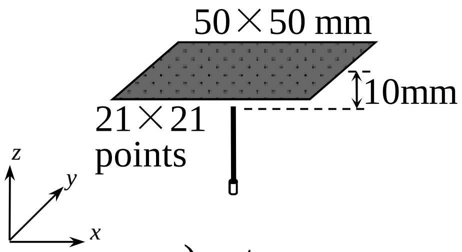




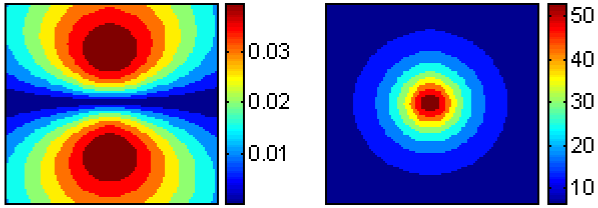
Statistical result: variation of ρ in typical near-field region = 3%
The far field response would be corrected in the calibration process

Probe calibration

- illuminating the probe with a known reference field
- comparing probe output with reference field



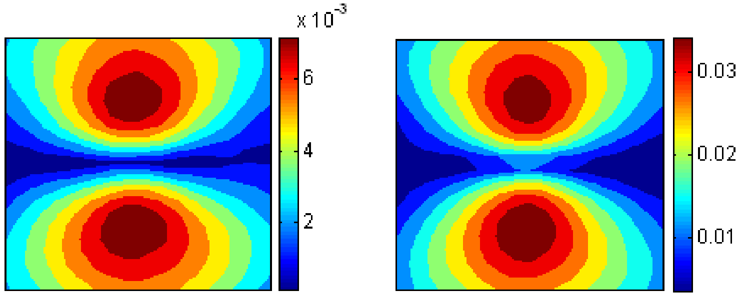
a) setup



b) H_x (A/m)   c) E_z (V/m)

Reference field

Probe output



H probe 1
(high E rejection)

H probe 2
(low E rejection)

$$V_x = C_T \cdot H_x$$

$$C_T = \max([V_x]) / \max([H_x])$$

$$C_T = \frac{\int V_x dxdy}{\int H_x dxdy} = \frac{\sum [V_x]}{\sum [H_x]}$$

$$C_T = \left(\sum_{i=1}^{N} \frac{Vx_i}{Hx_i} \right) / N$$

$$V_x = C_H \cdot H_x + C_E \cdot E_z$$

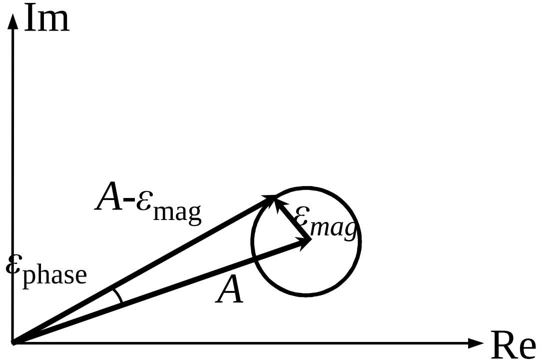
$$\begin{bmatrix} Hx_i & Ez_i \end{bmatrix}_{N\times 2} \cdot \begin{bmatrix} C_H \\ C_E \end{bmatrix} = [V_x]_{N\times 1}$$

Measurement errors of the system

Category	Source	Typical value (dB)
Probe	Probe positioning	0.05
	Antenna parameter	0.13
	Response to the variation of E/H	
	Disturbance effect to the field	0.13
Receiver	Dynamic range	0.00
	Receiver imperfections	0.25
	Mismatch / joint	
	Receiver random errors	
Test conditions	Room scattering	0.05
	Leakage and crosstalk	0.05

$$\varepsilon_{\text{total}} = \sqrt{\sum_i 3\sigma_i^2 + \sum_j \varepsilon_j^2} = 0.35\text{dB}$$

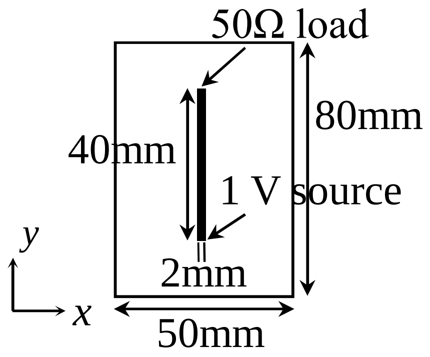
Phase error



$$\varepsilon_{\text{phase}} = \sin^{-1}\left(\frac{\varepsilon_{\text{mag}}}{A}\right) = 5°$$

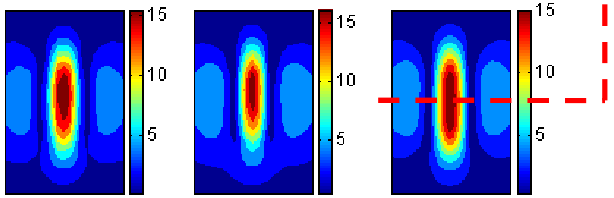
Measurement results

- A test board, compared with simulations

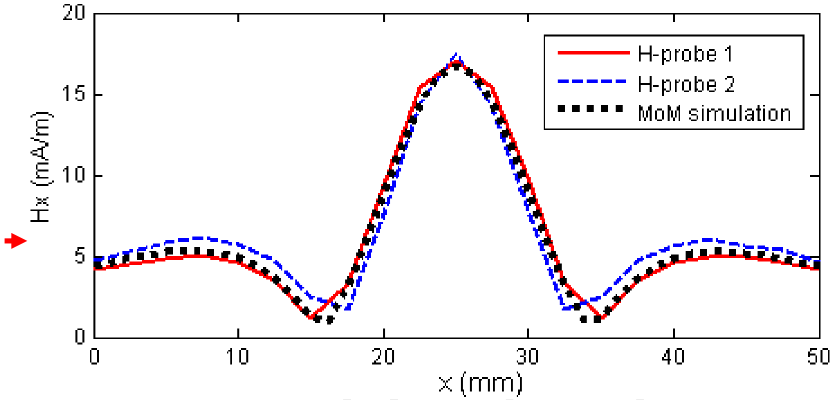


@ 1GHz

a) H_x

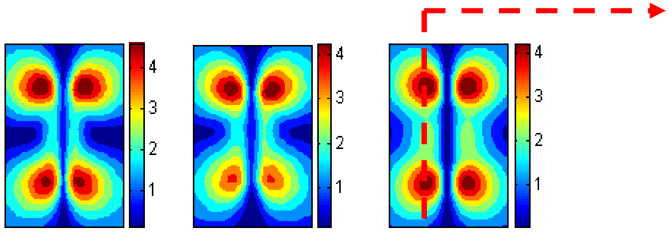


H-probe 1 H-probe 2 MoM

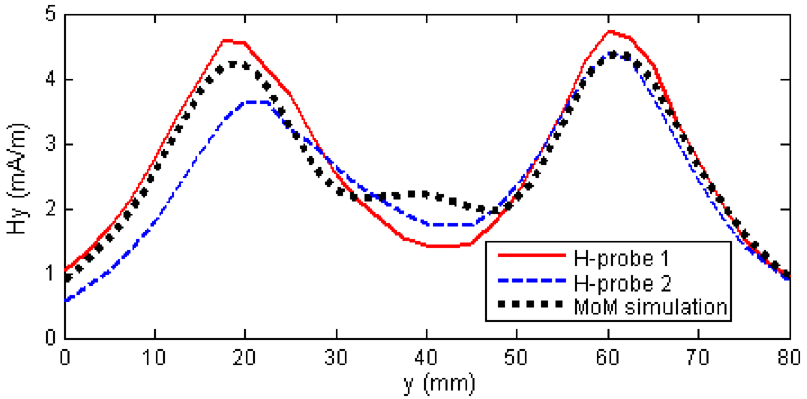


Detailed Hx along a line

b) H_y



H-probe 1 H-probe 2 MoM



Detailed Hy along a line

Dependence on measurement parameters

- The equivalent model is built from scanned near-field data
- Scanned near-field contains EM information of the EUT
- Sufficient information needed to fully characterize the EUT

Information theory	Near-field sampling
Sampling rate	Scanning resolution
Information volume	Scanning plane size
SNR	SNR

To study the dependence …

equivalent model built from NF data with different parameters

A correlation coefficient between FF given by &

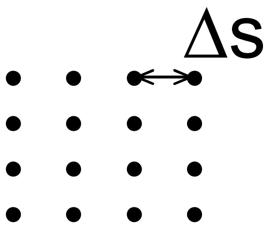
direct model

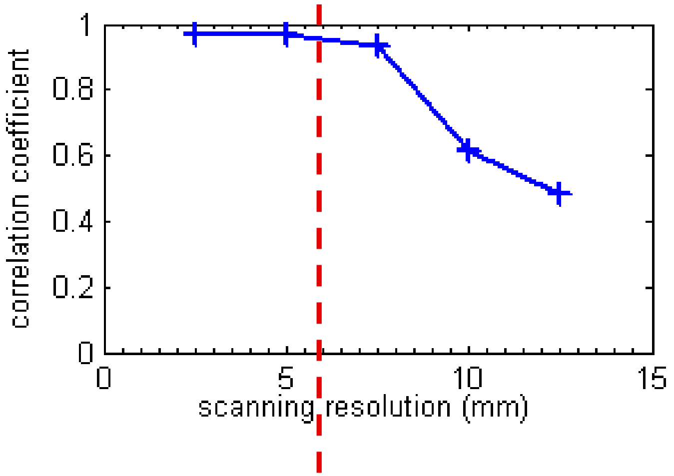
$$\gamma = \frac{\sum_{i=1}^{N}\left(E_i - \overline{E}\right)\left(E_i^{'} - \overline{E}^{'}\right)}{\sqrt{\sum_{i=1}^{N}\left(E_i - \overline{E}\right)^2 \cdot \sum_{i=1}^{N}\left(E_i^{'} - \overline{E}^{'}\right)^2}}$$

$\gamma > 90\%$, NF data are sufficient

Dependence on scanning resolution (sampling rate)

2D spatial sampling





Critical point given by the sampling criterion

A criterion of near-field sampling

(similar to the Nyquist criterion in information theory)

Max space allowed for obtaining sufficient NF information:

$$\Delta s = \frac{\lambda}{2\sqrt{1+\left(\lambda/d\right)^2}}$$

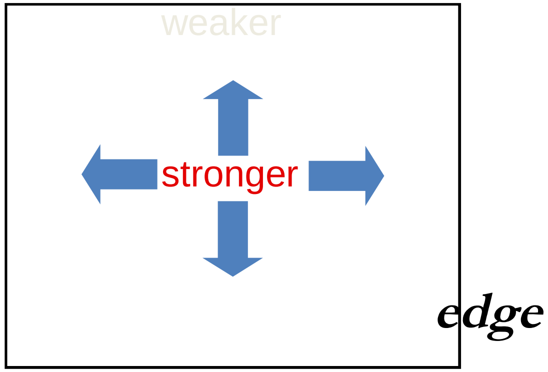
λ: wavelength

d: separation distance from EUT to probe

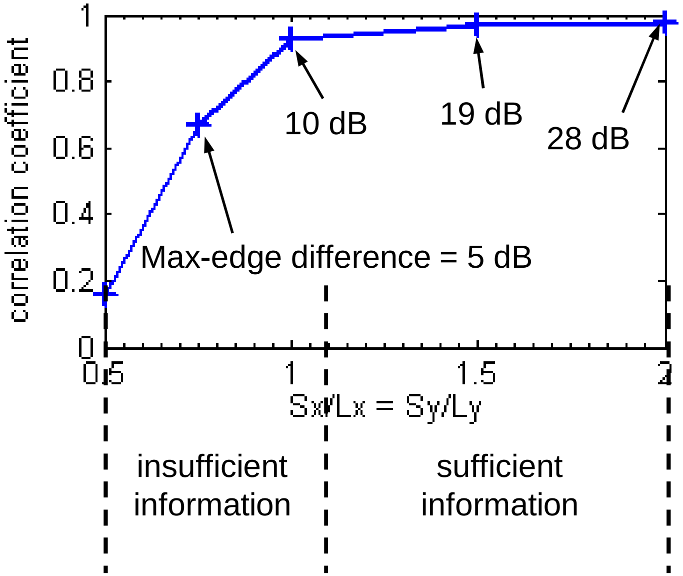
=5.7 mm for the case above

Dependence on scanning plane size (information volume)

H field vertically above a PCB



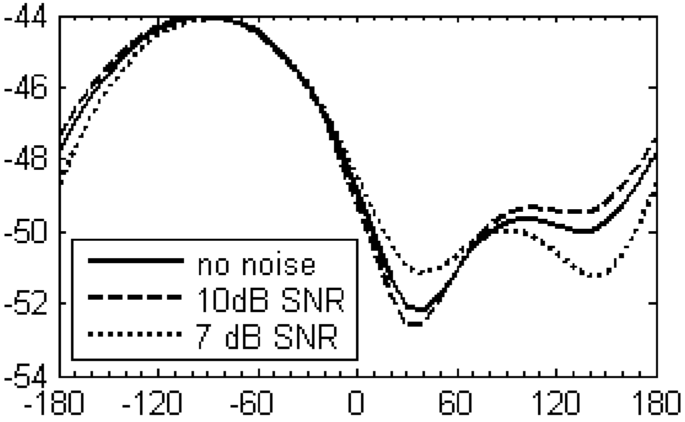
- Ideally scan until min measurable level reached
- Max – edge difference: H(max) – H (edge)



max-edge > 15 dB

Effect of SNR

- Intentionally add normally distributed noise
- σ= 10% -> 10 dB SNR
- σ= 20% -> 7 dB SNR



FF of the test board

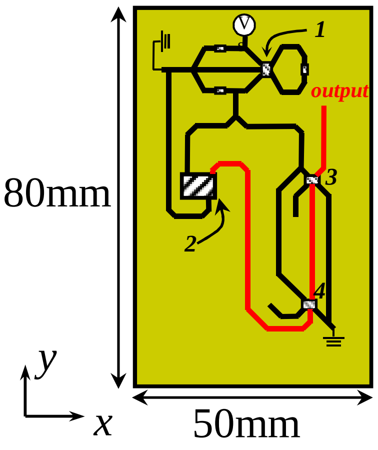
7 dB SNR: ±2dB uncertainty

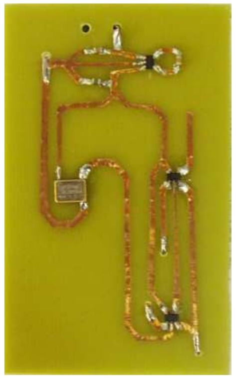
10 dB SNR: ±1dB uncertainty

Typical dynamic range: >30 dB

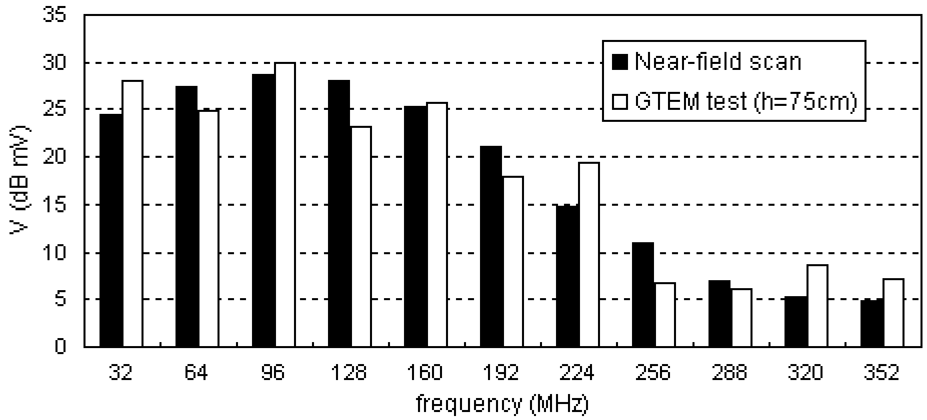
The method is stable enough
to measurement noise

- Fast clock digital circuit, compared with GTEM test



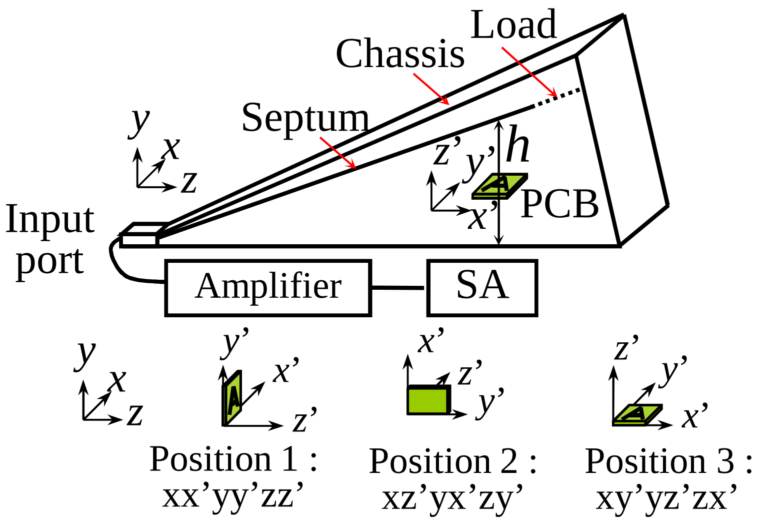


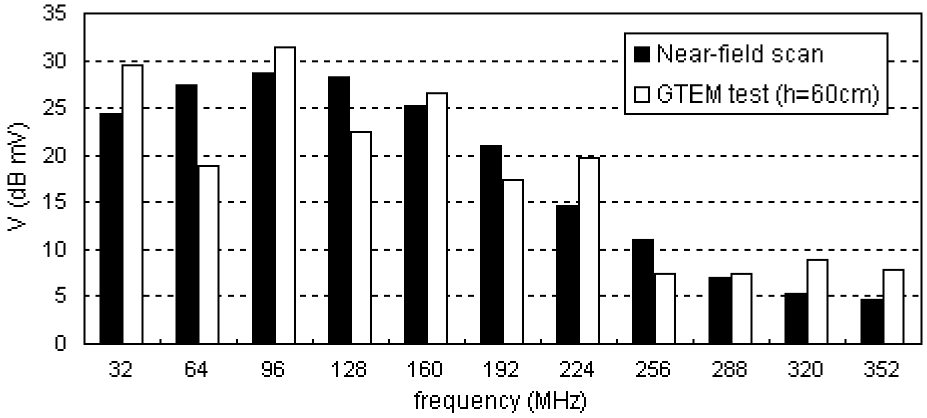
f=32*N MHz



h=75cm, correlation=87%

- 3-position GTEM emission test





h=60cm, correlation=79%

Modeling in Free space

Equivalent dipole identification (1) – GA

- Radiated H field from a dipole

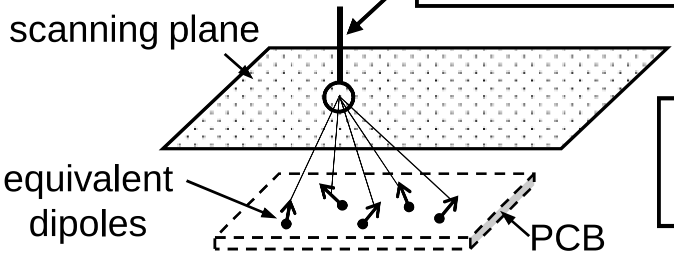
$$\vec{H}(\vec{r}) = \frac{k^2}{4\pi}\left[\left(1+\frac{j}{kr}-\frac{1}{(kr)^2}\right)\vec{M} - \left(1+\frac{3j}{kr}-\frac{3}{(kr)^2}\right)\frac{(\vec{r}\cdot\vec{M})\vec{r}}{r^2}\right]\frac{e^{jkr}}{r}$$

$\vec{M}$: moment of dipole in arbitrary orientation

$\vec{r}$: vector distance

r: scalar distance

k: wave number



Every measured point is the total contribution of all the equivalent dipoles

N dipoles
Q measurement points

Optimization problem: $\min\left\{\sum_{j}^{Q}\left[\sum_{i}^{N} H_{\text{dipole}}\left(\vec{M}_i, x_i, y_i\right)\right]_j - \left[H_{\text{measurement}}\right]_j\right\}$

Minimize the difference between dipole NF and measured NF

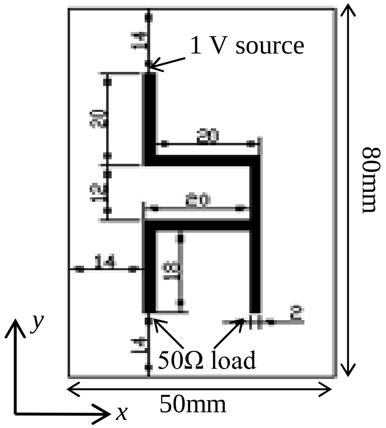
Nonlinear,

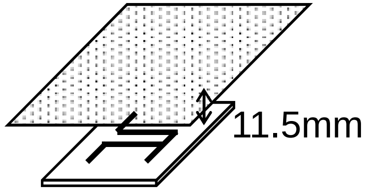
Non-differential,

Multiple variables

Results

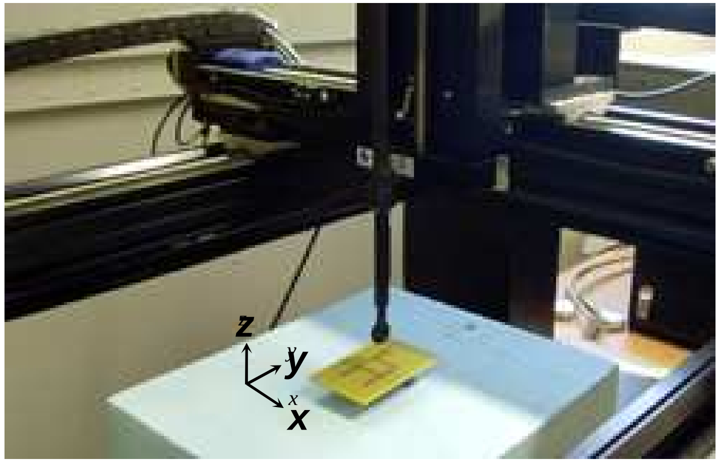
- A test board at 1 GHz (backed by a ground plane)





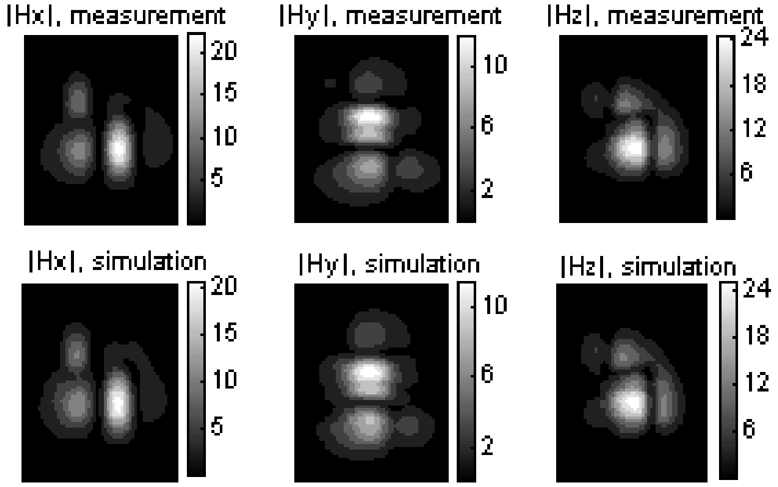
Equivalent source identification

Scanned components	Hx and Hy
Height of scanning plane	11.5 mm above the PCB
Size of scanning plane	120 * 75 mm
Scanning resolution	2.5 mm
Number of dipoles	28



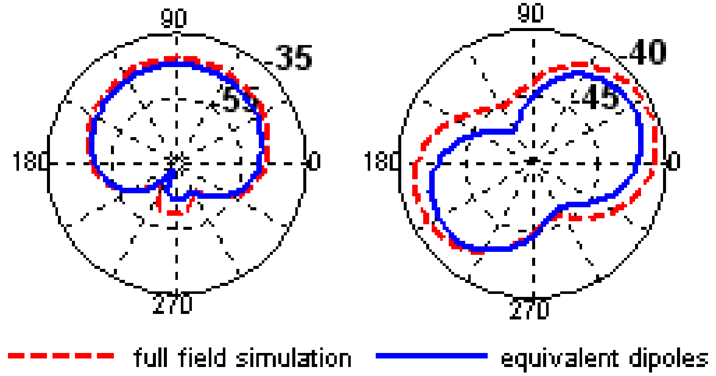
Compared with full-field
MoM simulation

Predicted NF

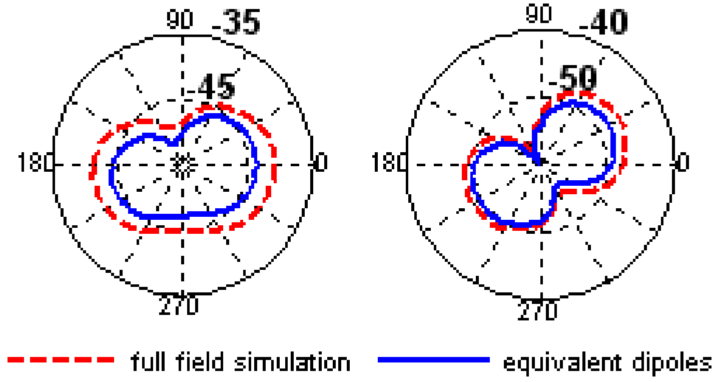


H fields (mA/m) over the scanning plane

Predicted FF

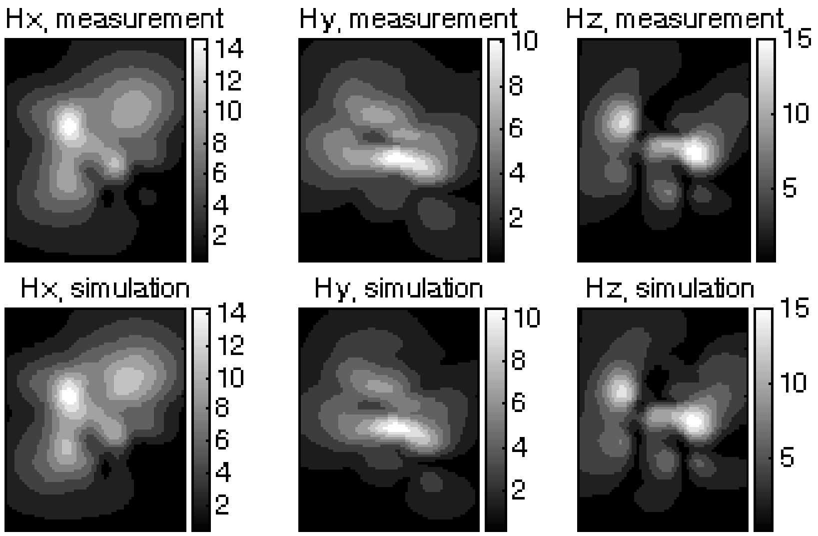


E field in the E plane (*xz*)

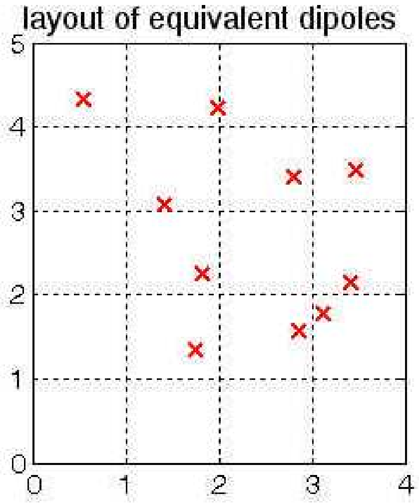


E field in the H plane (*yz*)

- Global optimization
    -> very accurate representation of equivalent sources
- Irregular positions of resulted dipoles
    -> difficulty in subsequent modeling

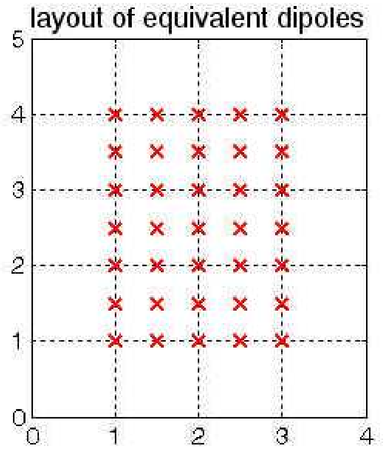


Correlation coefficient = 97%

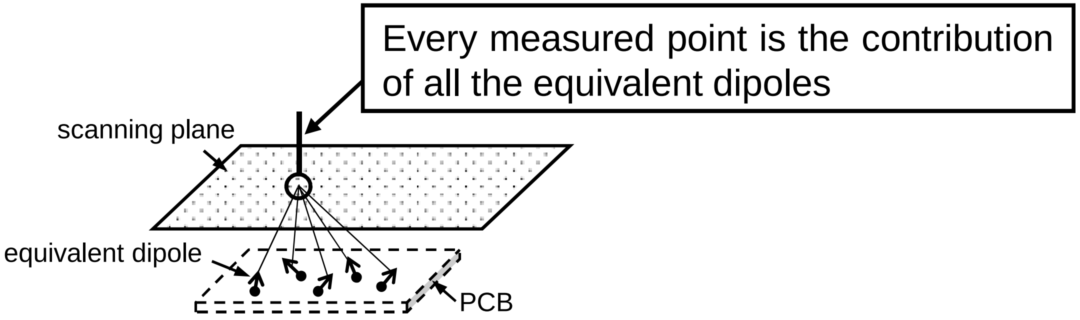


Equivalent source identification (2) – inverse solution

- Dipoles placed in a pre-fixed matrix grid
- H(dipole) = H(measure)



$$\left[\sum_{i}^{N} H_{dipole}\left(M_i,\theta_i\right)\right]=\left[H_{measurement}\right]$$


Every measured point is the contribution of all the equivalent dipoles

Position is fixed. Find the moment M_i and orientation θ_i of each dipole from an inverse problem

Computation:

- Decompose every dipole to 3 component Mx, My, Mz (eliminate θ, linear problem)
- H field radiated by a dipole component (z-directed for example):

$$H_x = M^z \frac{jke^{-jkr}}{4\pi r^4}(x-x_0)(z-z_0)\left(jkr+3+\frac{3}{jkr}\right) = M^z \boxed{\xi_x^z}$$

$$H_y = M^z \frac{jke^{-jkr}}{4\pi r^4}(y-y_0)(z-z_0)\left(jkr+3+\frac{3}{jkr}\right) = M^z \boxed{\xi_y^z}$$

$$H_z = M^z \frac{jk^2e^{-jkr}}{4\pi r}\left[\frac{(z-z_0)^2}{r^2}\left(j+\frac{3}{kr}+\frac{3}{jk^2r^2}\right)-\left(j+\frac{1}{kr}+\frac{1}{jk^2r^2}\right)\right] = M^z \xi_z^z$$

- After simplification: *m* measurement points & *n* dipoles

$$\begin{bmatrix}\xi_{x(field)}^{x(dipole)} & \xi_x^y & \xi_x^z\end{bmatrix}_{m\times n}\begin{bmatrix}M^x\\ M^y\\ M^z\end{bmatrix}_{n\times 1} = \left[H_x\right]_{m\times 1}$$

$$\underbrace{\begin{bmatrix}\xi_{y(field)}^{x(dipole)} & \xi_y^y & \xi_y^z\end{bmatrix}_{m\times n}}_{\text{calculated}}\begin{bmatrix}M^x\\ M^y\\ M^z\end{bmatrix}_{n\times 1} = \underbrace{\left[H_y\right]_{m\times 1}}_{\text{measured}}$$

Linear equations

p -> calculated

Hx and Hy -> measured

Solve M from an inverse problem

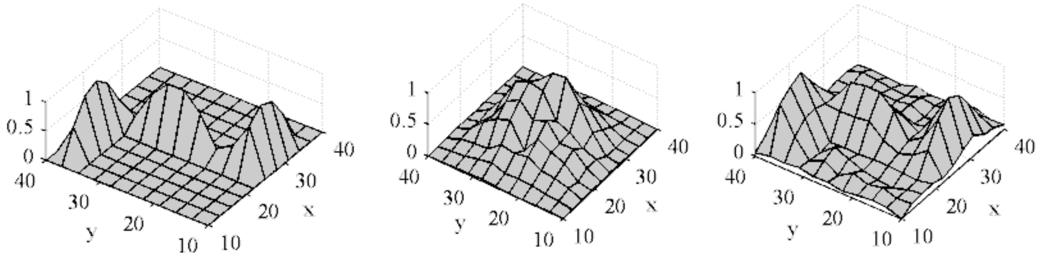
De-noising Experimental Data

The sort of problem encountered in obtaining the equivalent dipoles is solving equations of the type

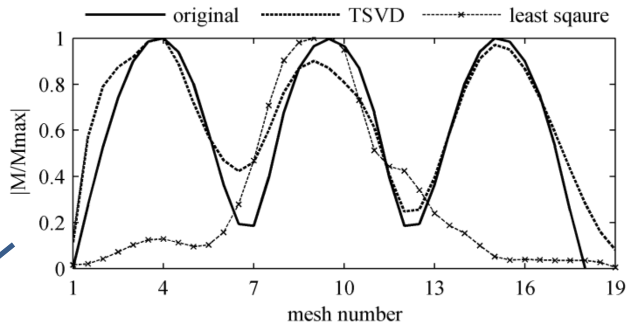
$$[A]\overline{x} = \overline{b}$$

Since the data come from measurements they are contaminated by noise. One approach for cleaning out some of the noise, known as Tikhonov regularization based on SVD has been found to be useful.

Current distribution on a bent microstrip obtained from near-field data with a 5dB SNR... Truncated Singular Value Decomposition (TSVD)



(a) Original (b) no regularization (c) regularized



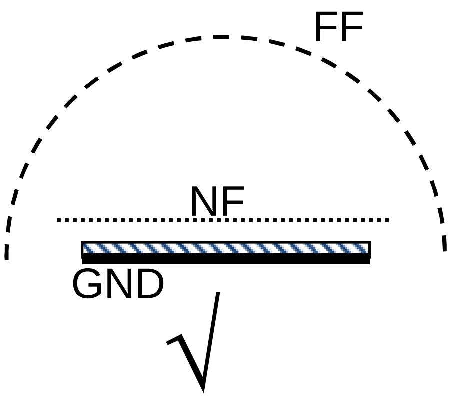
Without regularization we cannot recover the original distribution…

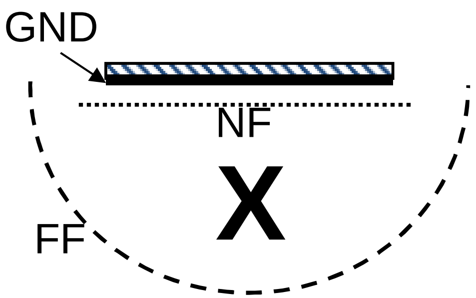
When a PCB has a ground plane …

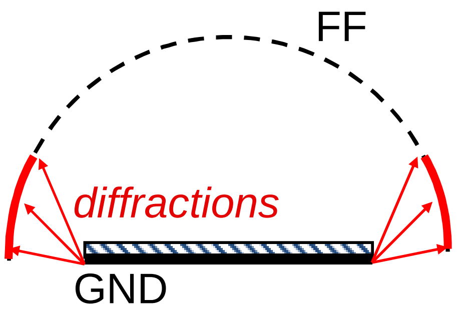
- Basic equivalent model only works for the upper half space

- Below the PCB, near field is too weak to measure
- Impossible to map the far field

- Diffractions near the PCB plane



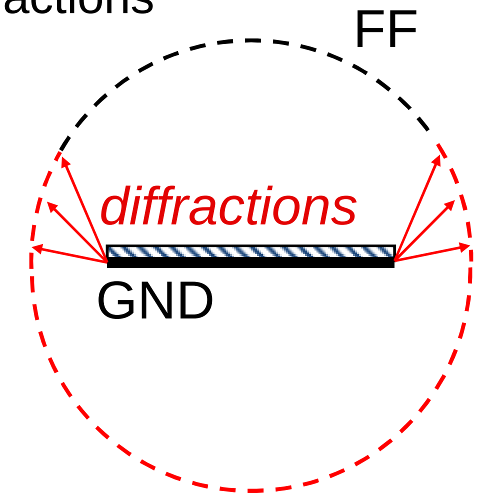




PCB with a ground plane

Very weak near field below GND

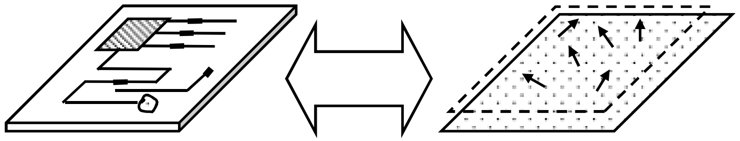
Diffractions

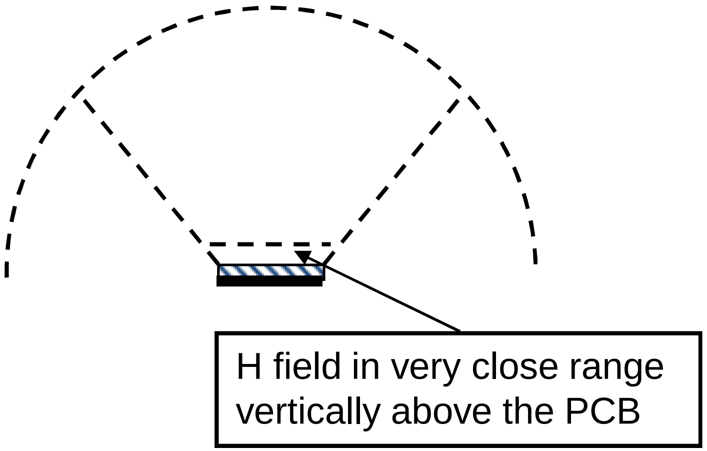


- Image theory for infinite GND:
  H (total) = H (direct) + H (image)
- Finite GND:
  H (total) = H (direct) + H (image) + H (diffraction)
- A region where diffractions take a negligible part
  H (total) ≈ H (direct) + H (image)
- Scan H field in this region
- Apply image theory with finite GND

Finite GND model: dipoles + GND

Image theory for source identification

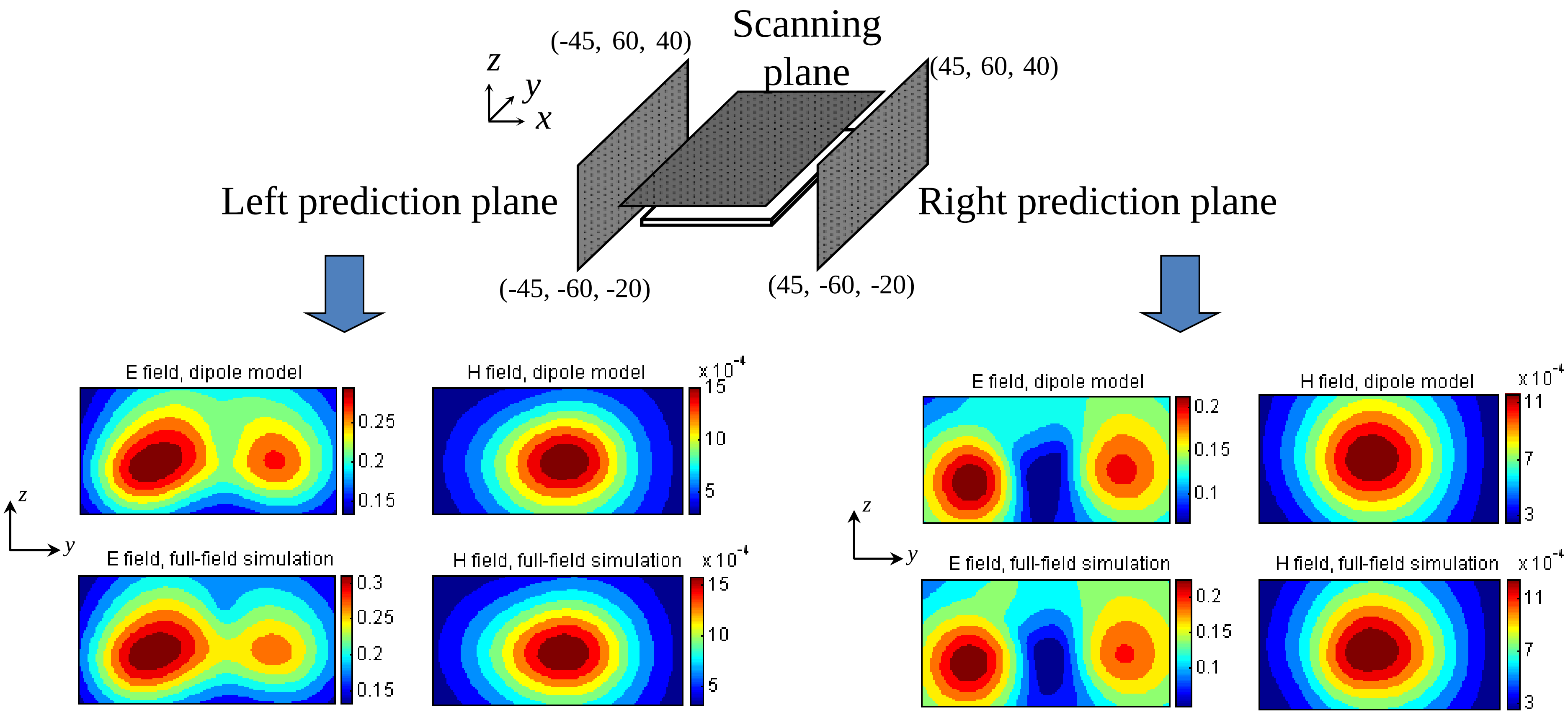




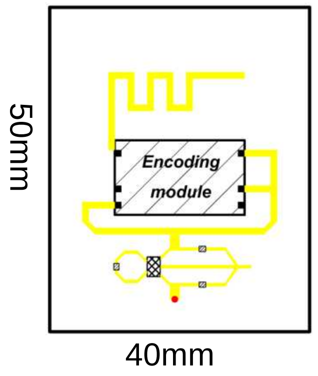
H field in very close range vertically above the PCB

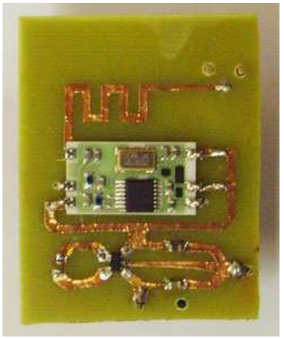
Results

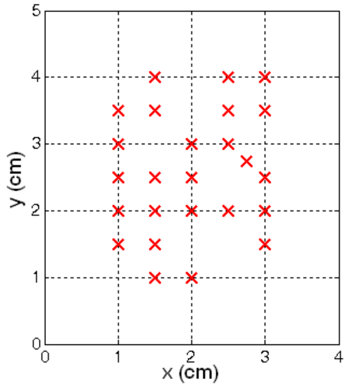
- L-shaped microstrip board, Near-field prediction



Telemetry PCB, Far-field prediction

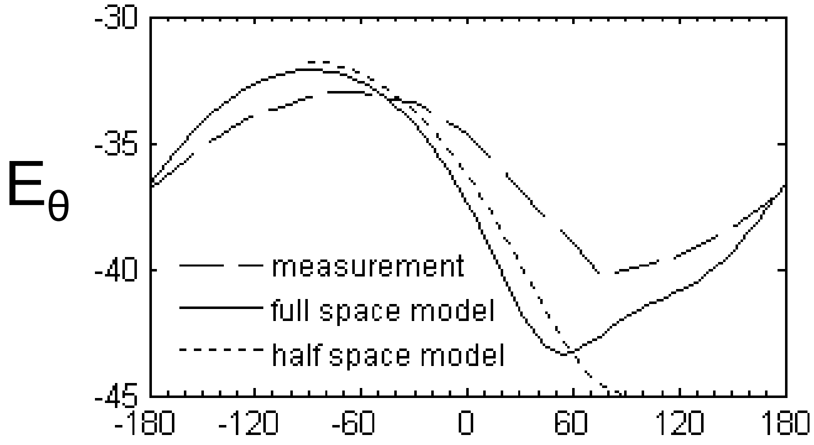


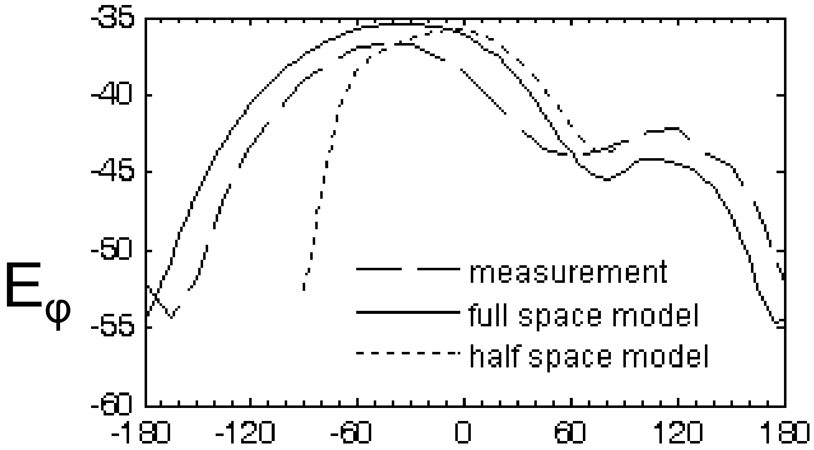




Equivalent source identification

Scanned components	Hx and Hy
Height of scanning plane	11.5 mm above the PCB
Size of scanning plane	100 * 80 mm
Scanning resolution	2.5 mm
Number of dipoles	26





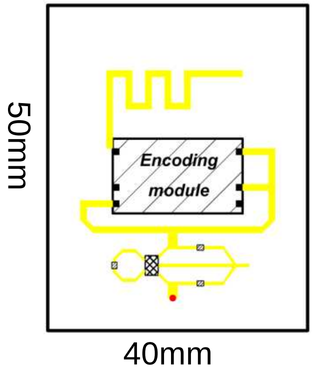
basic model:

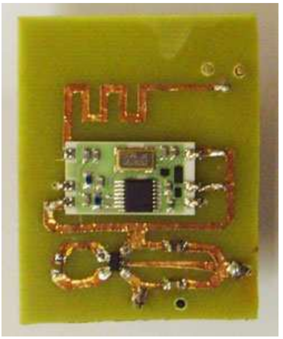
- works in half space
- infinite error when approaching +90 or -90

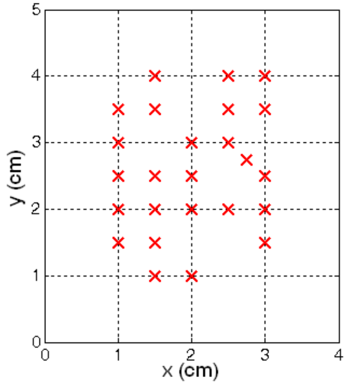
Dipole and GND model:

works in the whole space

- Test board (a telemetry PCB, 868.38 MHz)



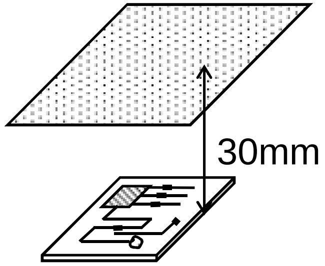


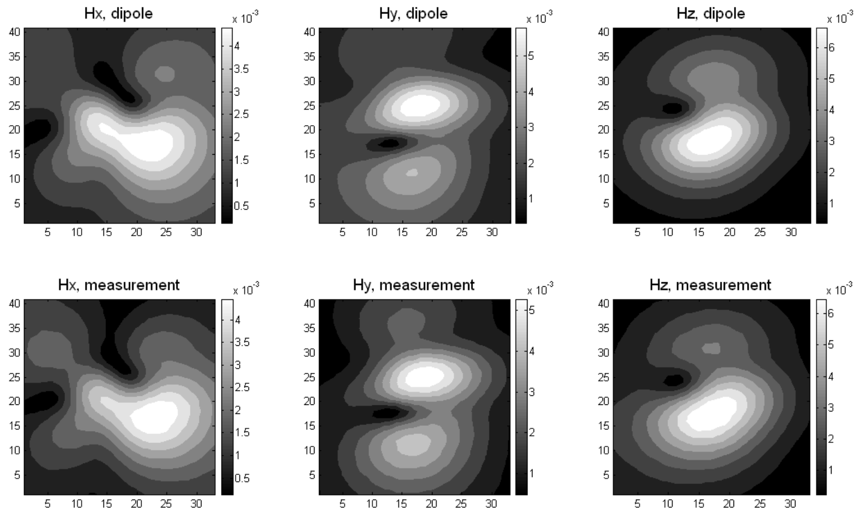


Equivalent source identification

Scanned components	Hx and Hy
Height of scanning plane	11.5 mm above the PCB
Size of scanning plane	100 * 80 mm
Scanning resolution	2.5 mm
Number of dipoles	26

Use the equivalent model to predict radiations from the PCB





Comparison of computational requirements

DUT	Method	Run time	Memory	Modeling time
Test board	Full field modeling	20 min	200 MB	30 min
	Equivalent modeling	1 min	10 MB	5 min
Telemetry PCB	Full field modeling	N/A	N/A	N/A
	Equivalent modeling	1 min	10 MB	5 min

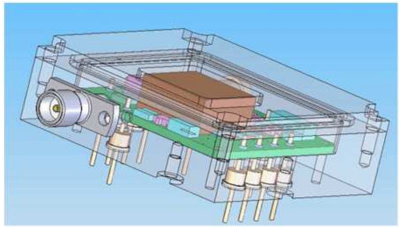
Comparison between GA and inverse solution

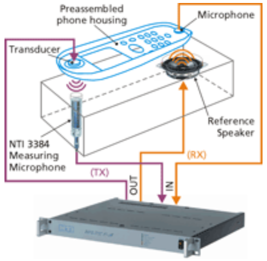
	GA	Inverse solution
Accuracy	★★★★★	★★★★⯨
Computational efficiency	★	★★★★★
Modeling convenience	★★	★★★★
Code re-use	★★★	★★★★

Modeling in Closed Environments

PCB working with packages and enclosures

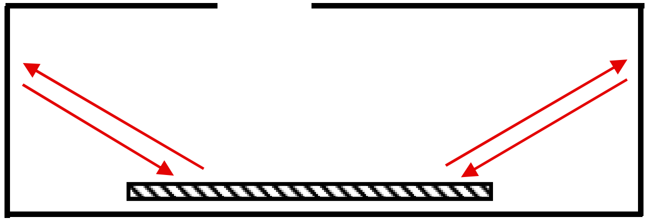
Component level





System level

- EMC mechanism: multiple interactions
- Model excitation + interactions



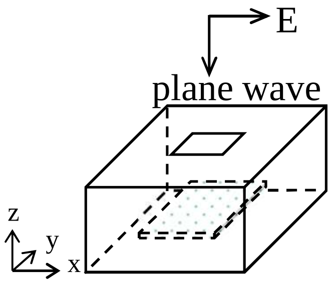
PCB – emissions – enclosure

Enclosure – emissions – currents on PCB

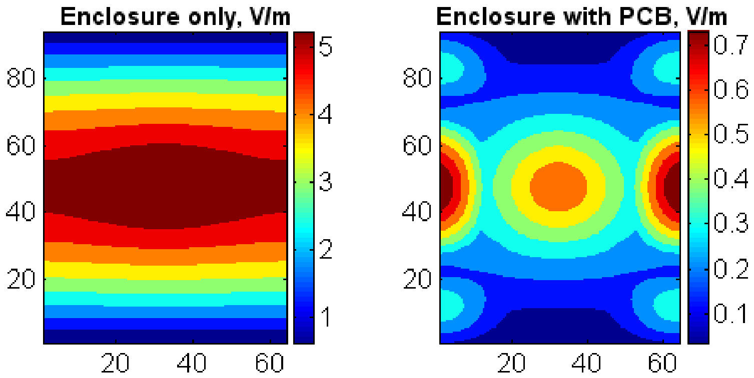
How to represent interactions between PCB and enclosure

Considering typical situations: not highly populated

- Change of PCB currents, power, impedance … -> negligible factors
- Physical presence of PCB dampening waveguide -> significant factor
- An approximate model to generally represent the interactions



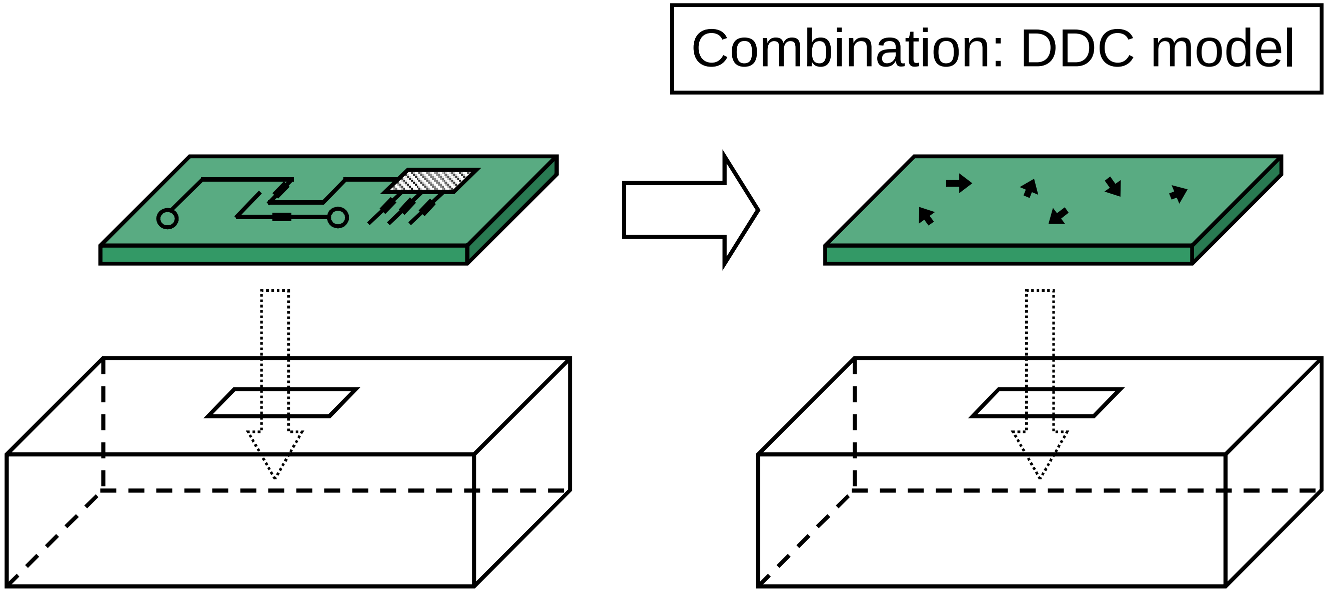
Enclosure: 100 * 70 * 40 mm
PCB: 1.5 mm thick with GND, z=8.5 mm
in the centre of the enclosure
Observation plane: z = 20 mm



Ex in the enclosure (TLM)

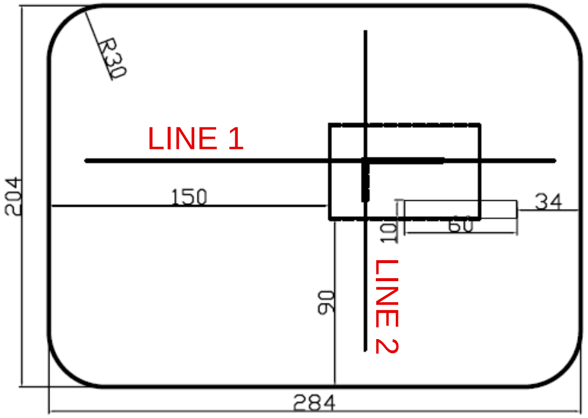
Modeling

- Enclosure -> regarded as a waveguide (above or below cut-off)
- PCB body -> modeled as a slab of homogeneous dielectric material (representing EM passive properties)
- Active emissions -> represented by equivalent dipoles



Combination: DDC model

Validation: resonance prediction



Configuration:

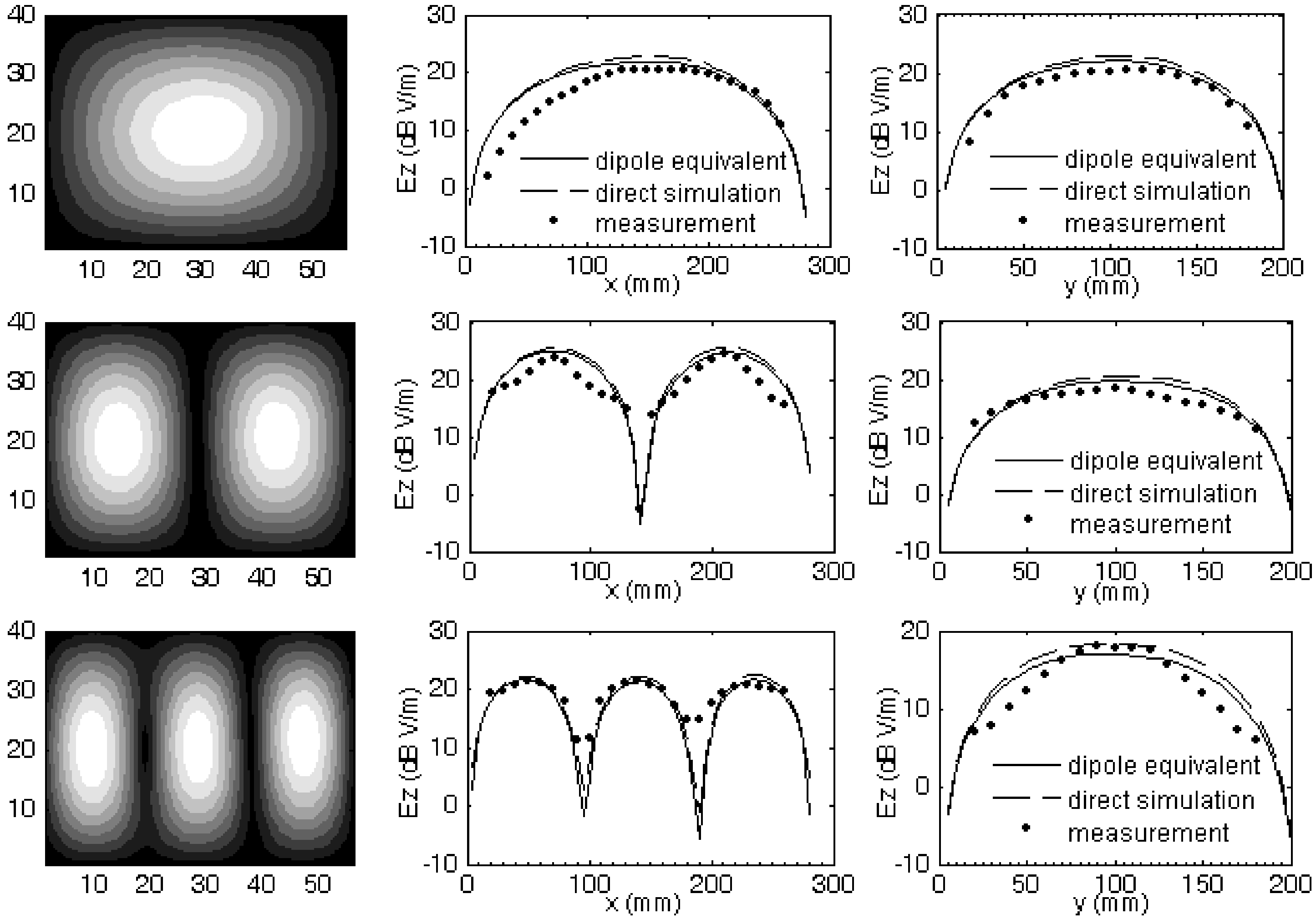
- 284 * 204 * 75 mm box with a 60 by 10 mm slot
- test board mounted on the bottom
- observation plane: 35 mm above the bottom
- 2 observation lines for more details

DDC model compared with full field model & measurement along 2 observation lines

0.9 GHz

1.29 GHz

1.74 GHz

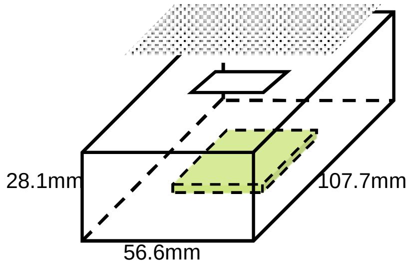


Full pattern given by equivalent model

Details in LINE 1

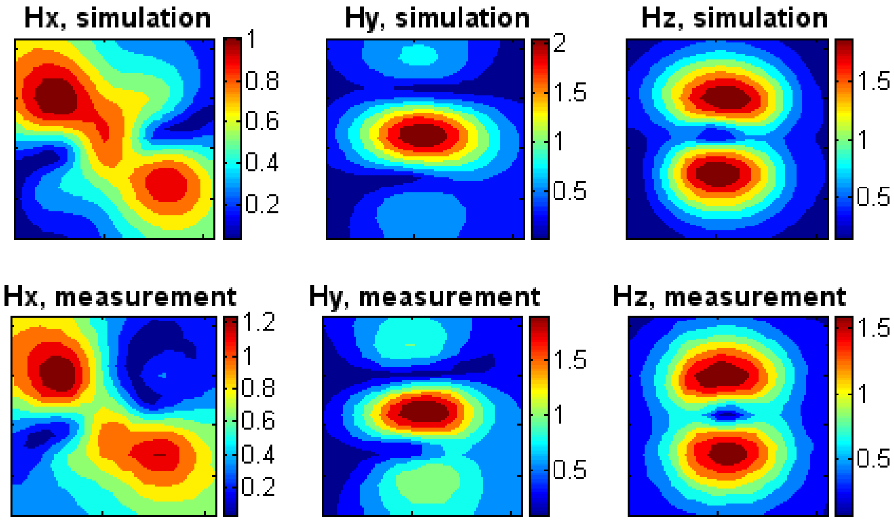
Details in LINE 2

Application 1: EM leak from an aperture



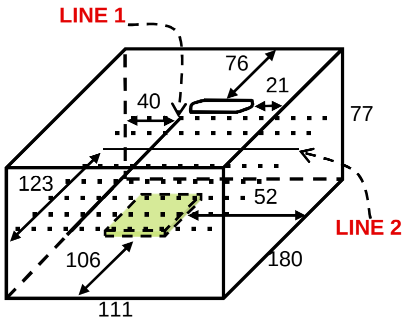
Configuration

- Telemetry PCB mounted on the bottom of an enclosure
- Predict emissions 10 mm above the aperture



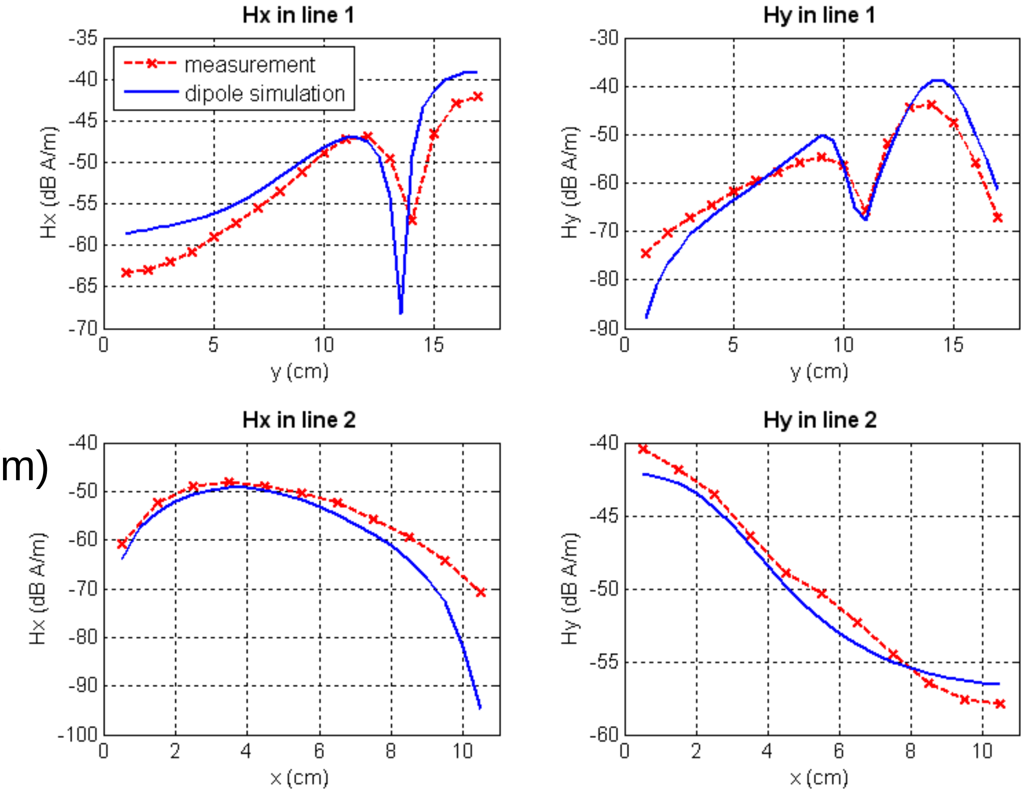
H field above the aperture (mA/m)

Application 2: emissions in a closed environment



Geometry of this configuration (mm)

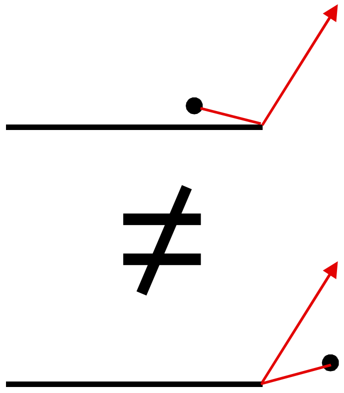
- PCB working in a larger enclosure
- DDC model to predict the field inside



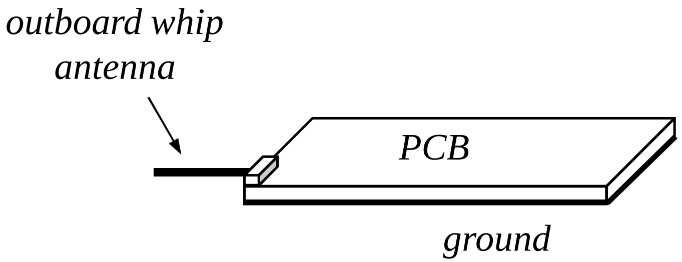
Agree above the noise floor of measurement system (-65 ~ -70 dB A/m)

Limitations

- 2D placement of equivalent dipoles -> single layered PCB only
- Approximations to the ground -> all the radiators must be onboard for a grounded PCB



diffraction mechanism of an onboard and outboard dipole

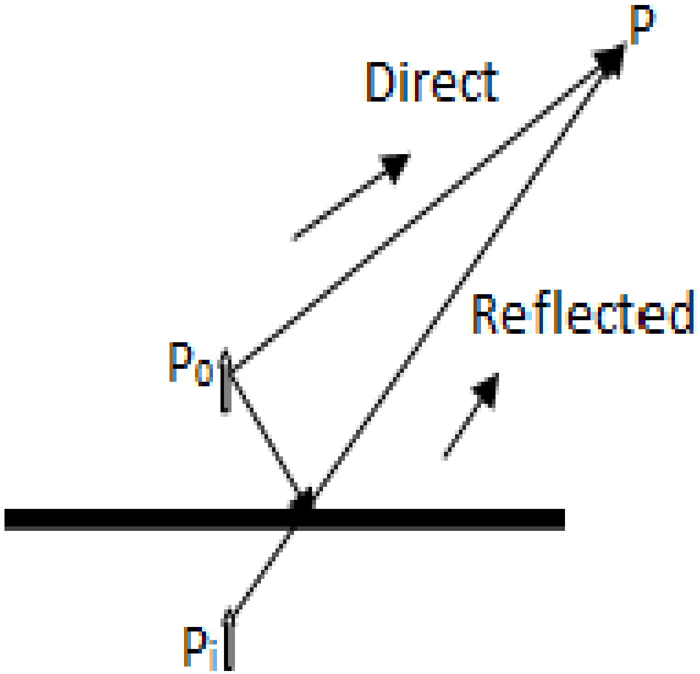


The outboard whip:

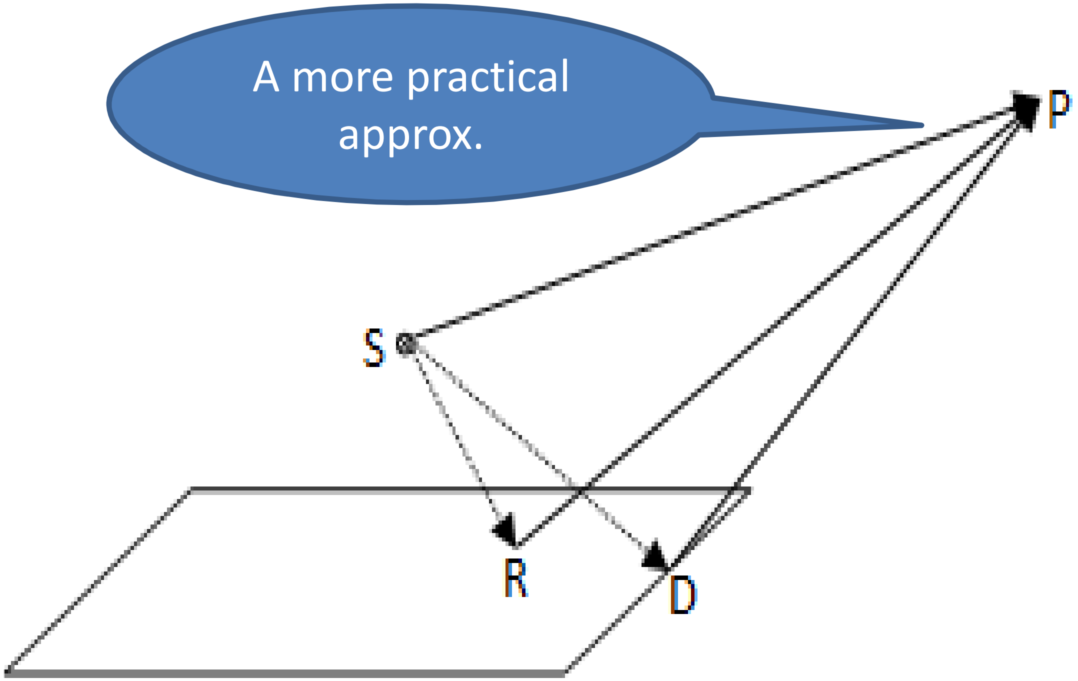
- Another radiator apart from the PCB
- Modeled separately

Accounting for diffraction

- Possible approximations

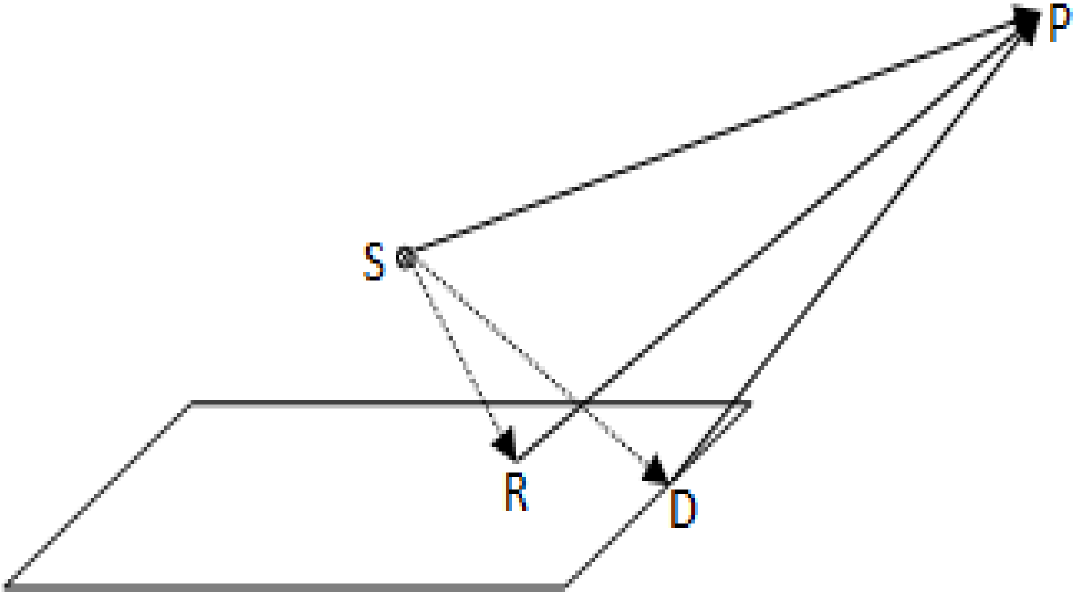


a) Infinite ground plane


A more practical approx.

b) Finite ground plane

Finite ground plane



$$H_T = H_{\overrightarrow{SP}} + H_{\overrightarrow{RP}} + H_{\overrightarrow{DP}} \qquad (1)$$

$$[H] = [G][D] \qquad (2)$$

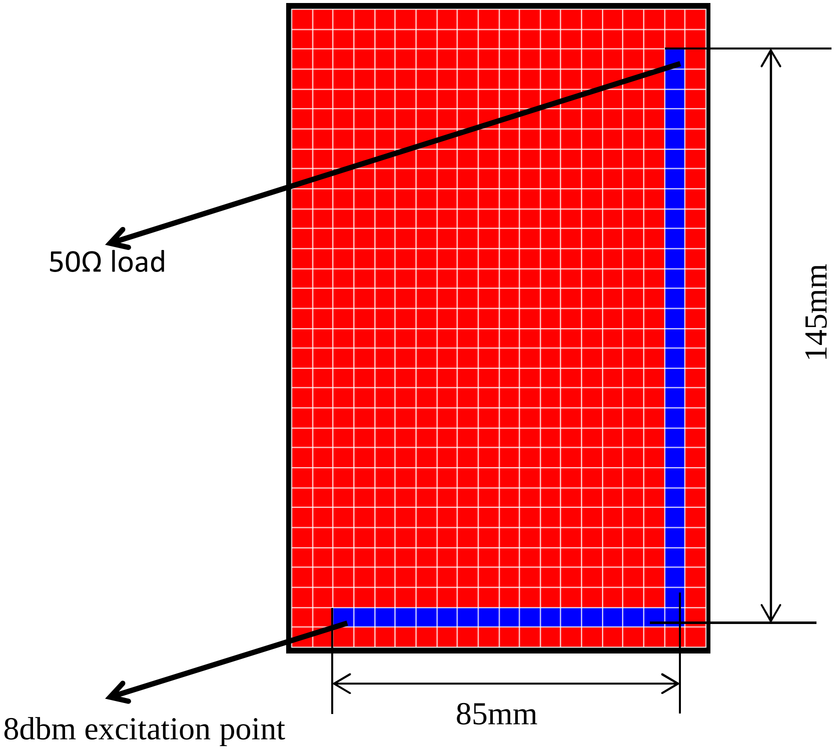
$$[G] = [G_{\overrightarrow{SP}}] + [G_{\overrightarrow{RP}}] + [G_{\overrightarrow{DP}}] \qquad (3)$$

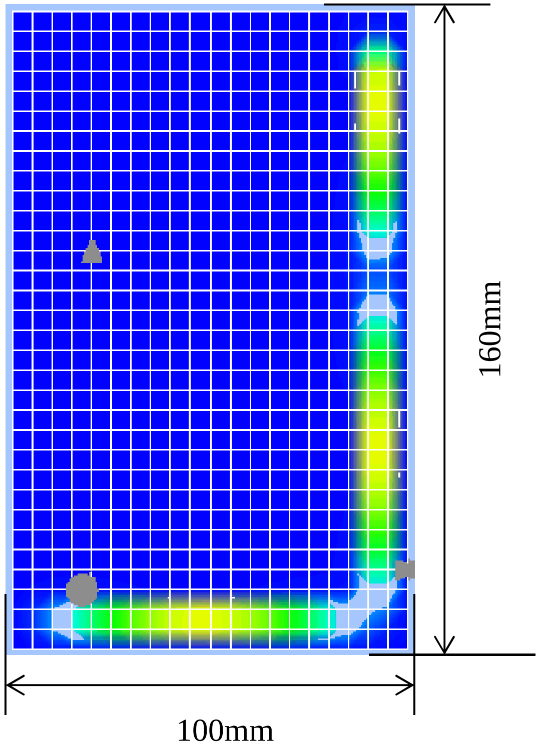
$$[\,D_n] = \begin{bmatrix} D_n^x \\ D_n^y \\ D_n^z \end{bmatrix} \qquad (4)$$

$$[H_m] = \begin{bmatrix} G_{m,n}^x & G_{m,n}^y & G_{m,n}^z \end{bmatrix} \begin{bmatrix} D_n^x \\ D_n^y \\ D_n^z \end{bmatrix} \qquad (5)$$

Validation

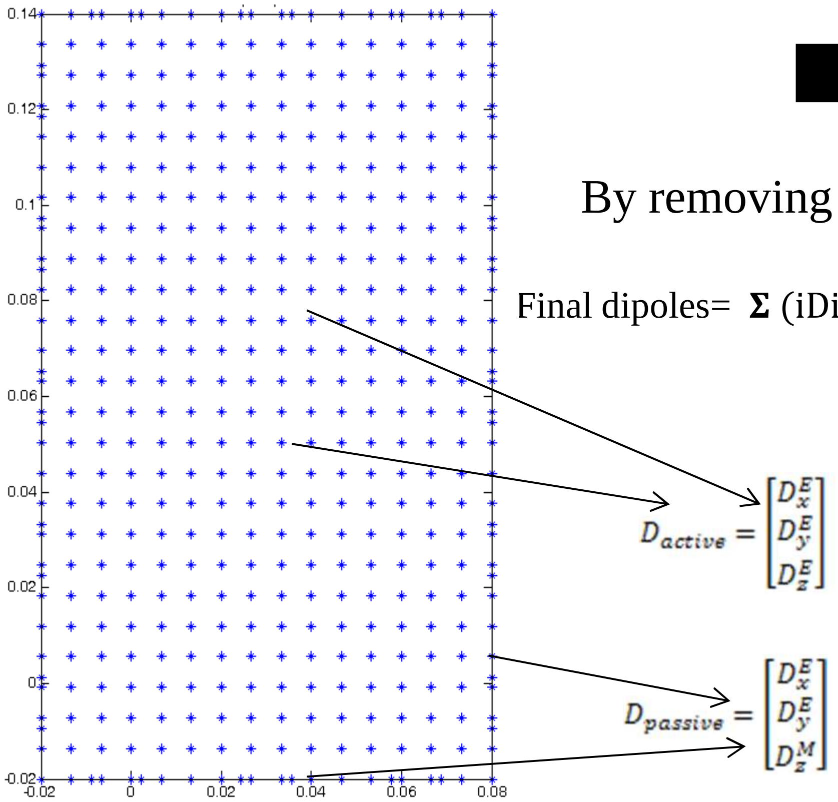
- Simulation : MoM-based Concept-II at 900MHz





Validation

- ➢ Equivalent Dipole Modeling



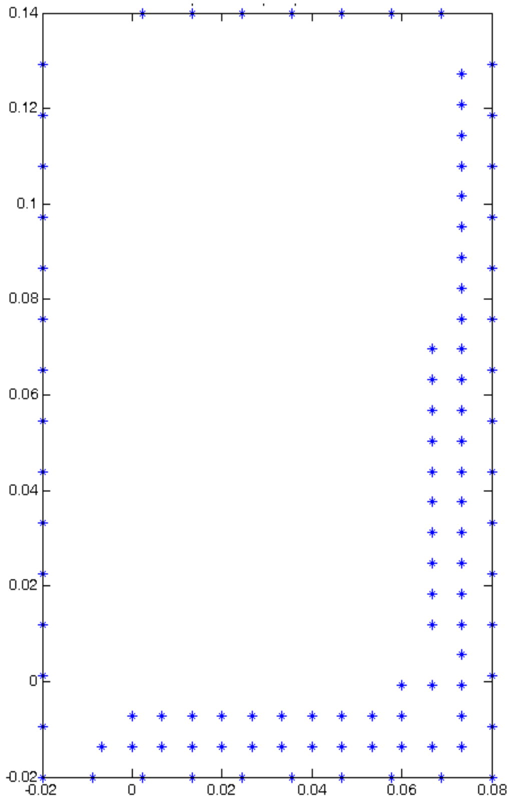
$$D_{active} = \begin{bmatrix} D_x^E \\ D_y^E \\ D_z^E \end{bmatrix}$$

$$D_{passive} = \begin{bmatrix} D_x^E \\ D_y^E \\ D_z^M \end{bmatrix}$$

iDip (initial dipoles) = 468 points

By removing the redundant dipoles

Final dipoles= **Σ** (iDip(n)>= 10% * max[iDip])

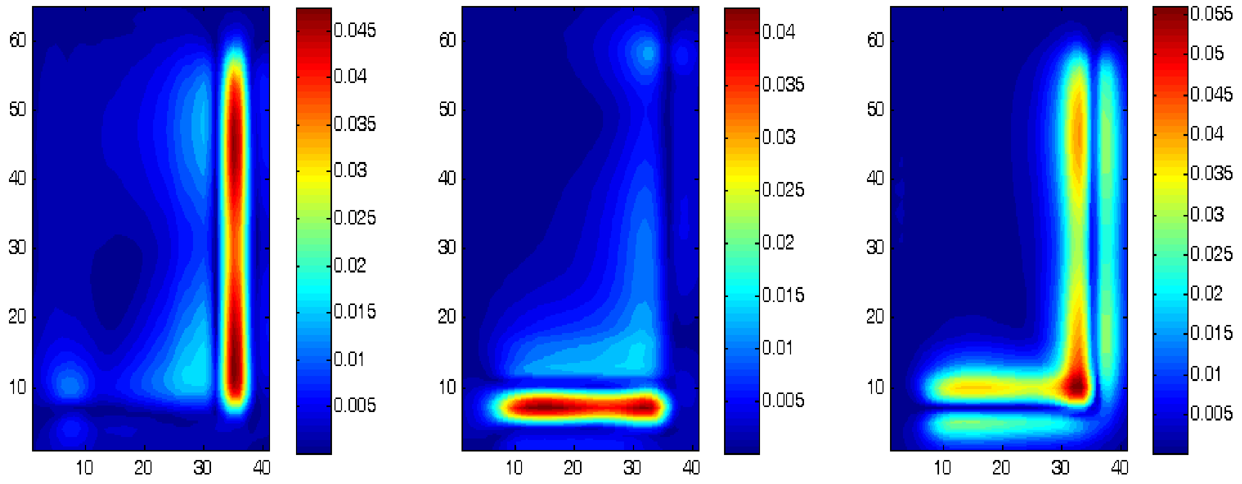


Final dipoles = 102 points

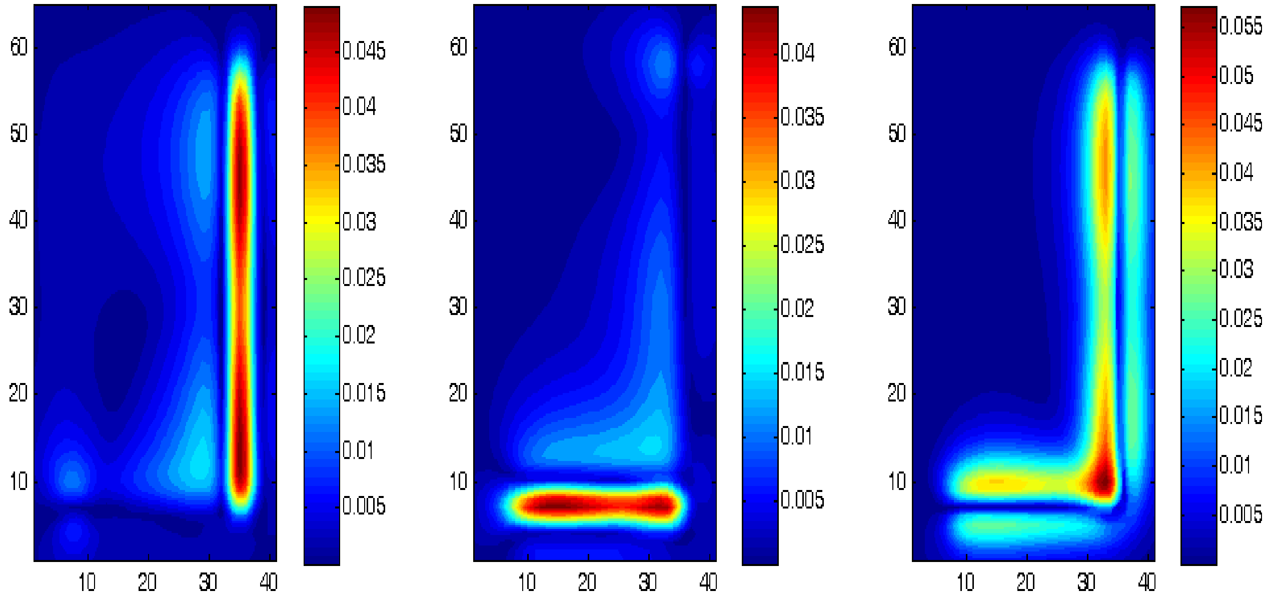
Results

- XY plane

- **Dipole Modeling at 10mm**



- **Simulation at 10mm**

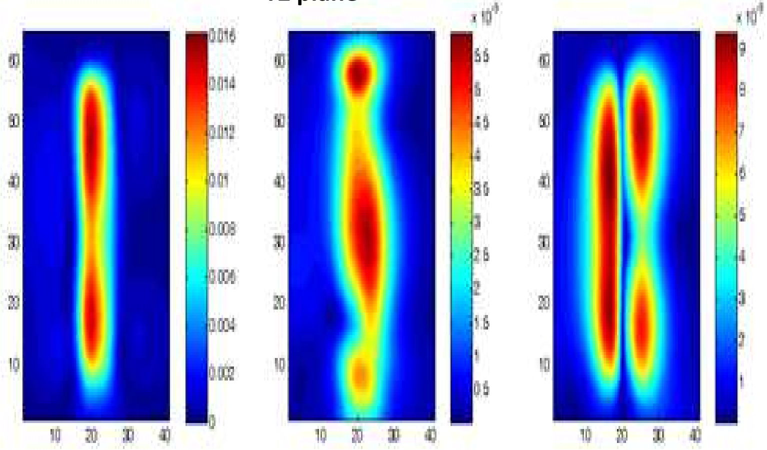


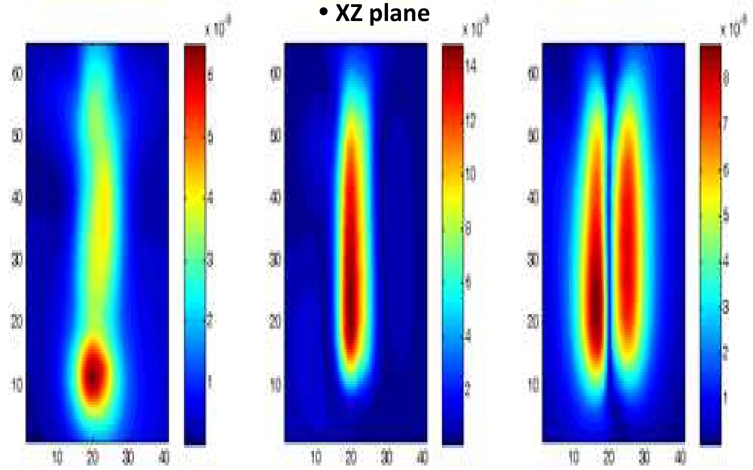
Results

- YZ plane

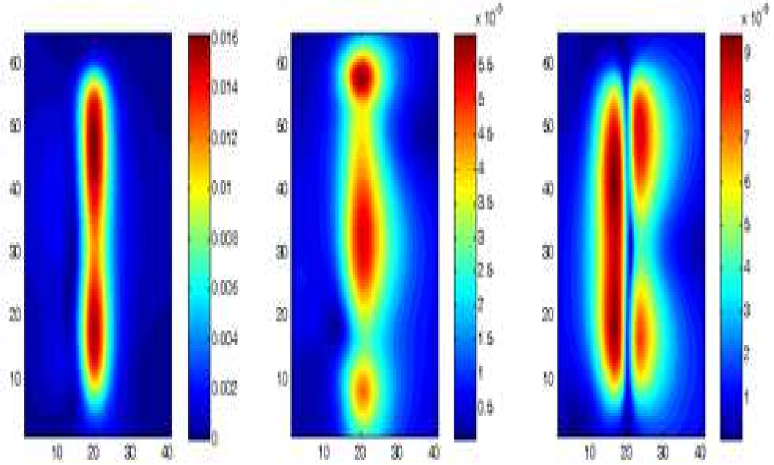
- XZ plane

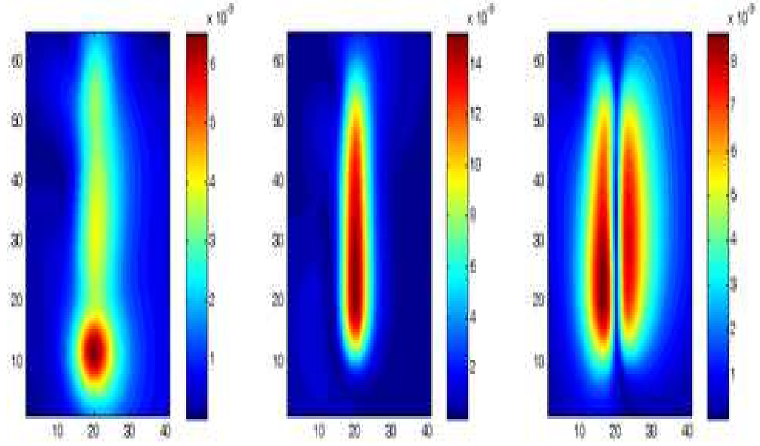
- **Dipole Modeling at 10mm**





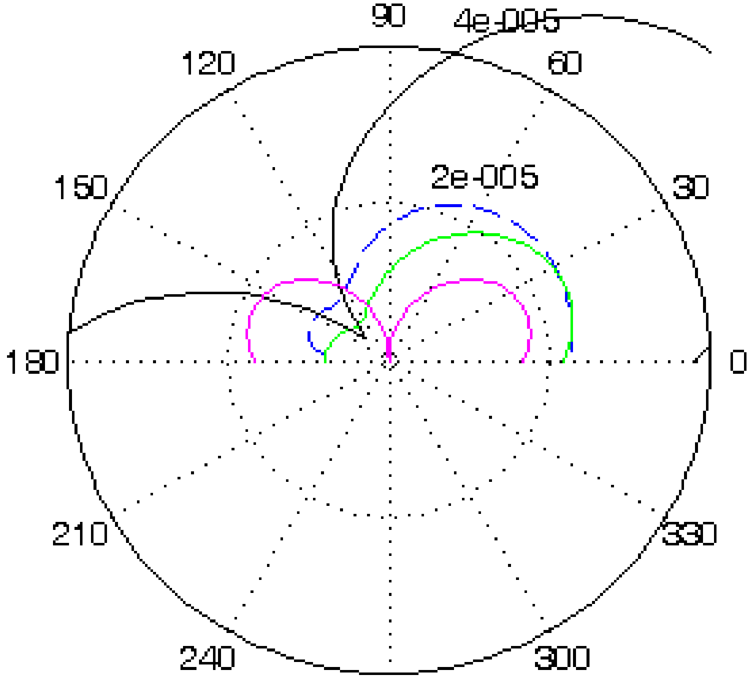
- **Simulation at 10mm**



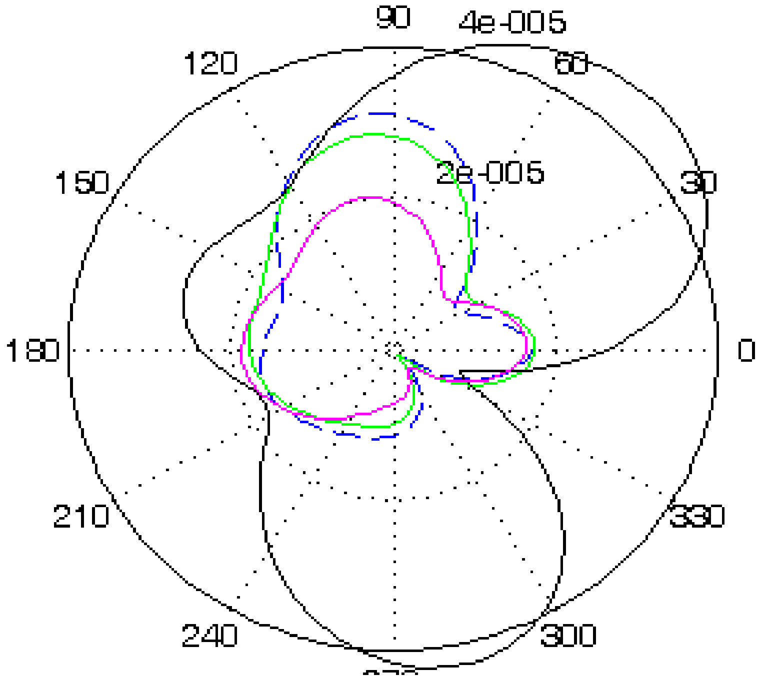


Results at 3m

H_θ



$H_\emptyset$



– – – Simulation

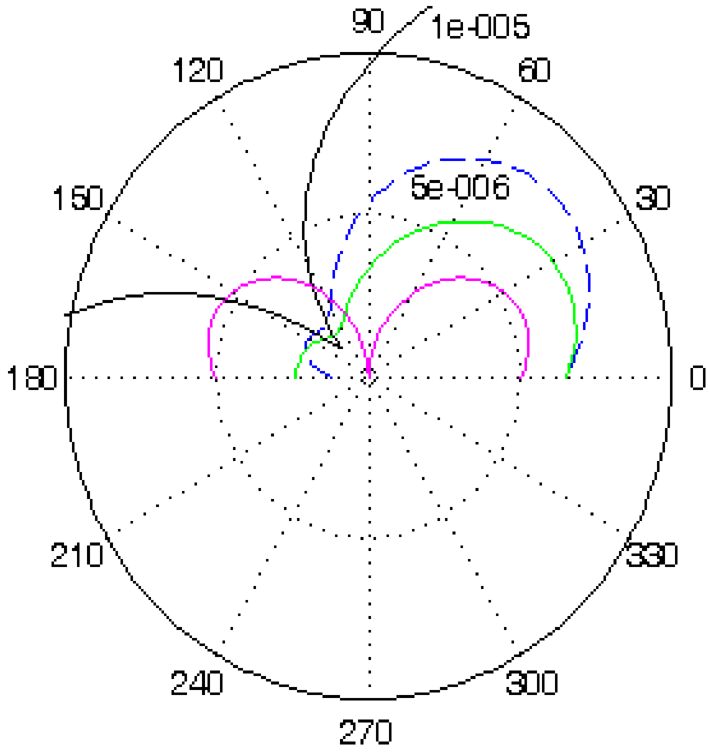
——— 102 dipole model

———Dipole model with field information from top plane

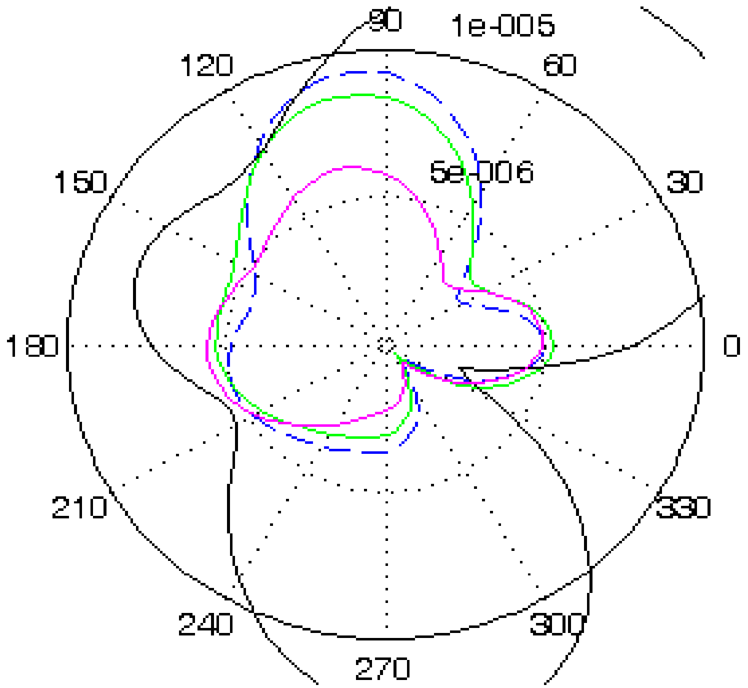
——— Dipole model without edge dipoles

Results at 10m

H_θ



$H_\emptyset$



– – – Simulation

——— 102 dipole model

———Dipole model with field information from top plane

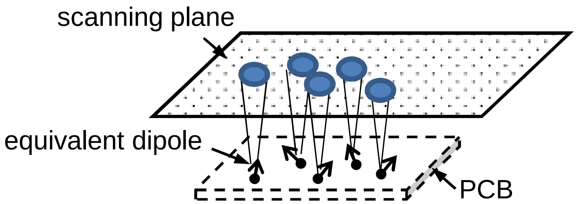
——— Dipole model without edge dipoles

Time Domain

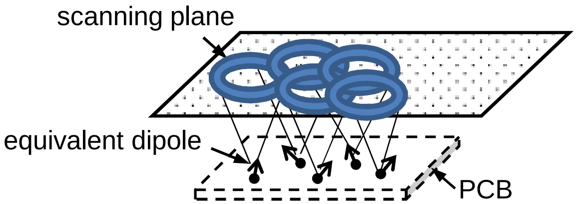
Time domain

- Equivalent dipole modelling well established in the frequency domain
- Interference and emissions can be time dependent
- Increasing interest in time domain characterisation
- Few if any approached for near field characterisation in the time domain

One of the Challenges

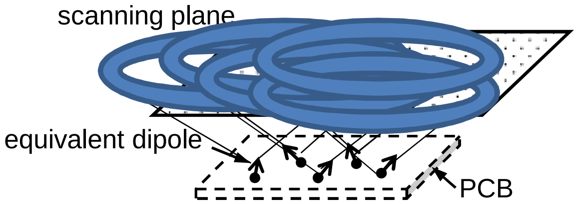


r/*c*=1



r/*c*=2

r/*c*=3



Relationships

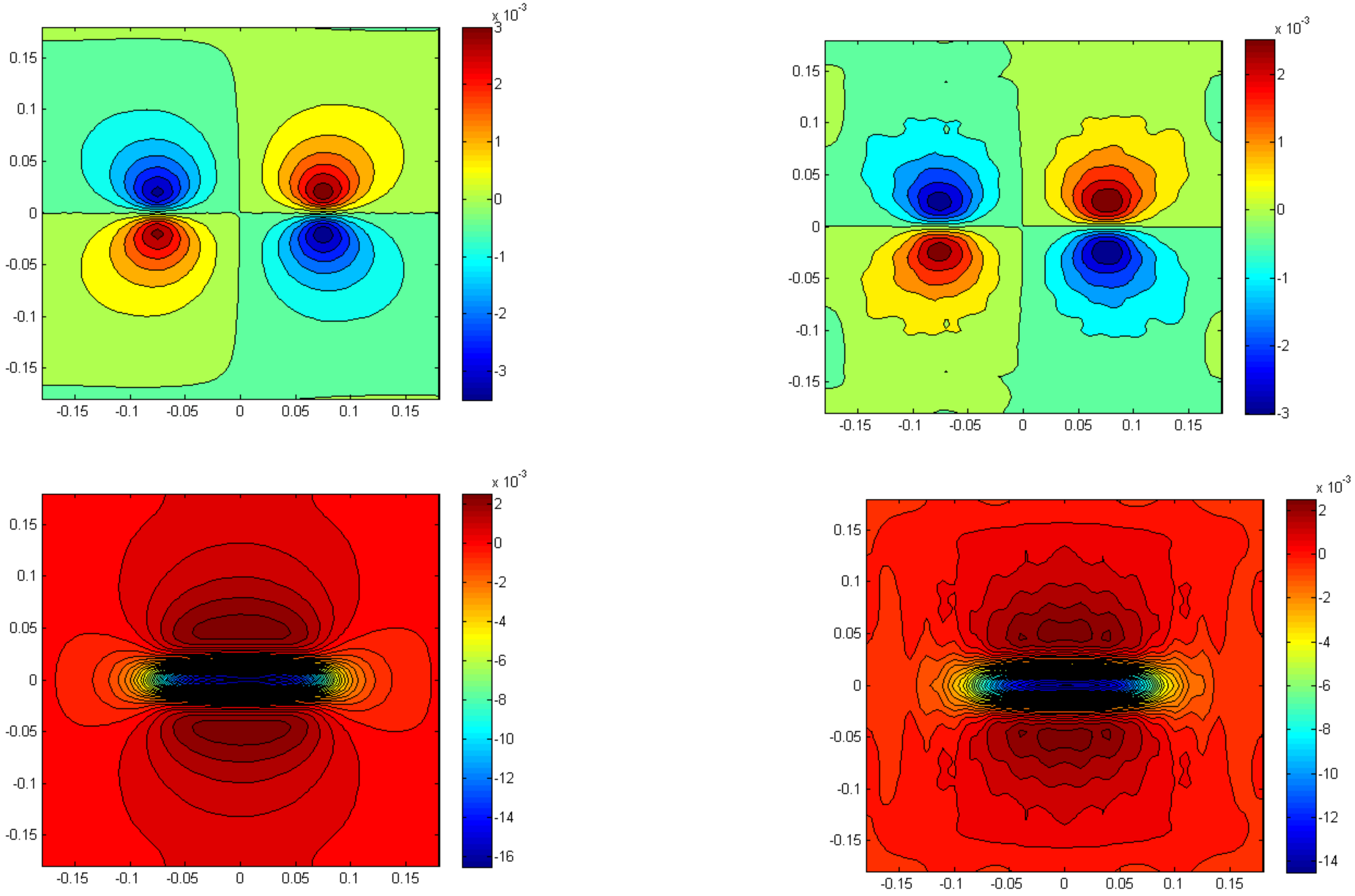
$$H_x(t) = \frac{z-z_0}{4\pi}\left[\frac{1}{r^3}D_y(t-r/c) + \frac{1}{cr^2}\frac{\partial D_y(t-r/c)}{\partial(t-r/c)}\right] - \frac{y-y_0}{4\pi}\left[\frac{1}{r^3}D_z(t-r/c) + \frac{1}{cr^2}\frac{\partial D_z(t-r/c)}{\partial(t-r/c)}\right]$$

$$\frac{\partial D(t)}{\partial t} = \frac{D(t)-D(t-\Delta t)}{\Delta t}$$

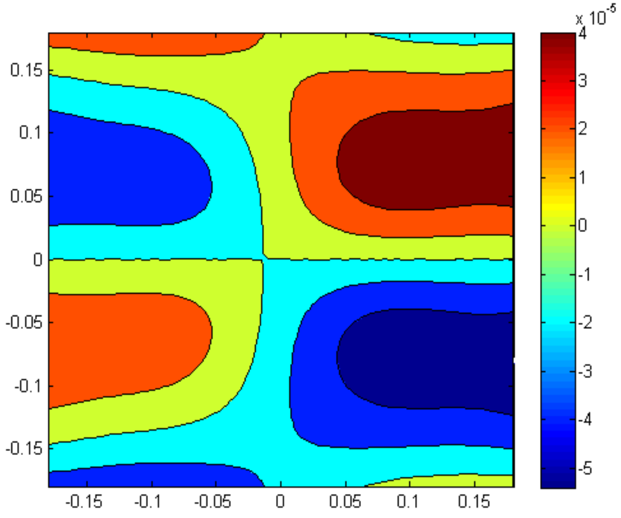
$$H_x(t) = \left[\eta_{x,a}(x,y)\right]\left[D\left(t - j_{x,y}\Delta t\right)\right] + [\eta_{x,b}(x,y)]\left[D\left(t - j_{x,y}\Delta t - 1\right)\right]$$

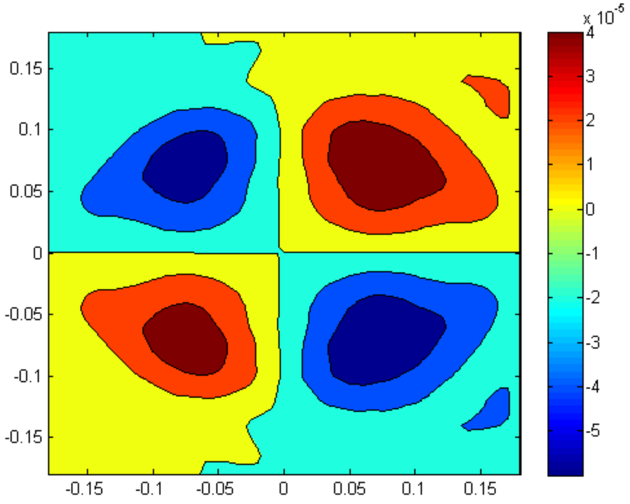
$$[D(t)] = [\xi_1]^{-1}\left(\left[H_{x,y}(t)\right] - [\xi_2][D(t-\Delta t)] + .. - [\xi_l][D(t-l\Delta t)]\right)$$

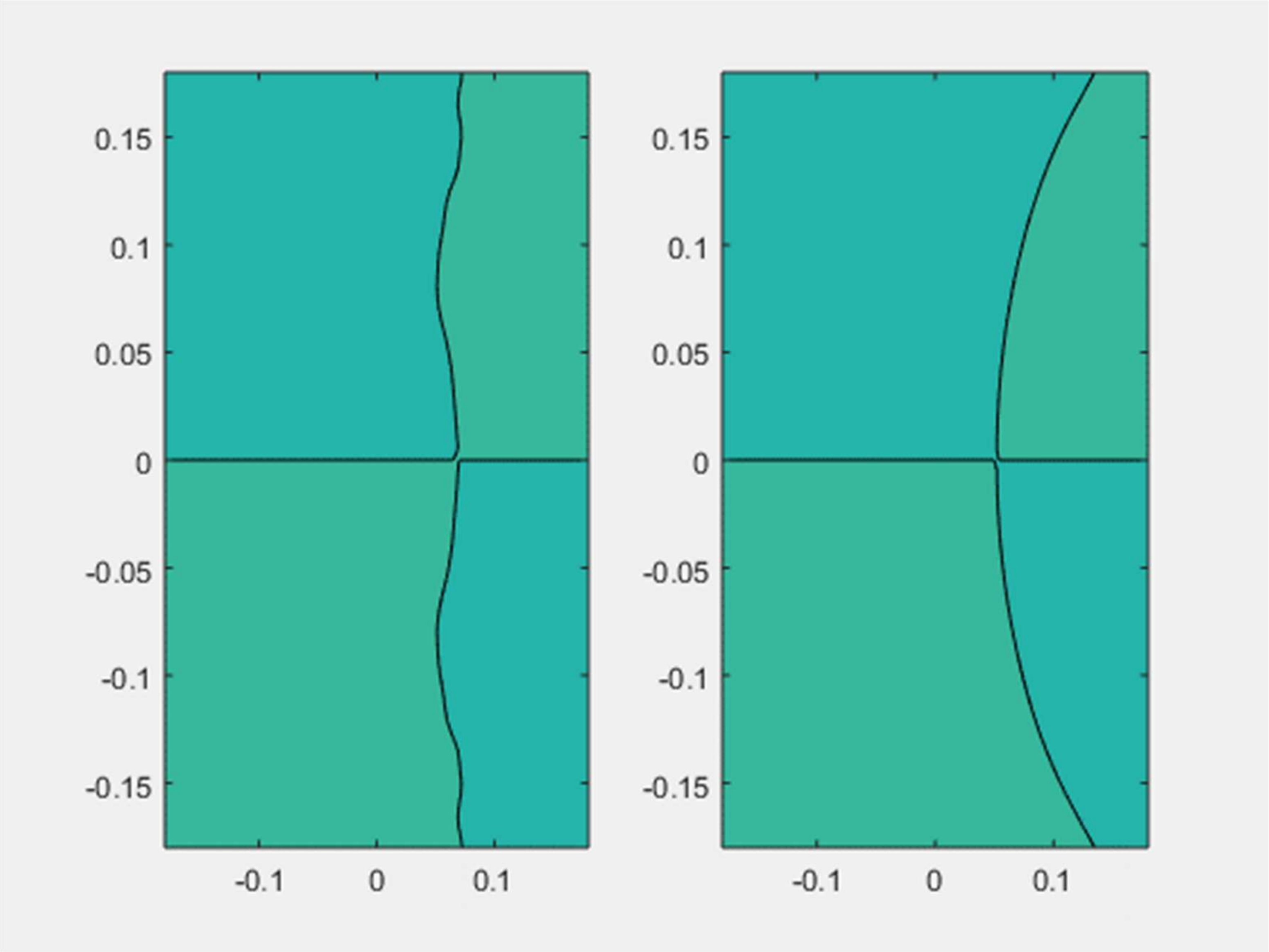
Results

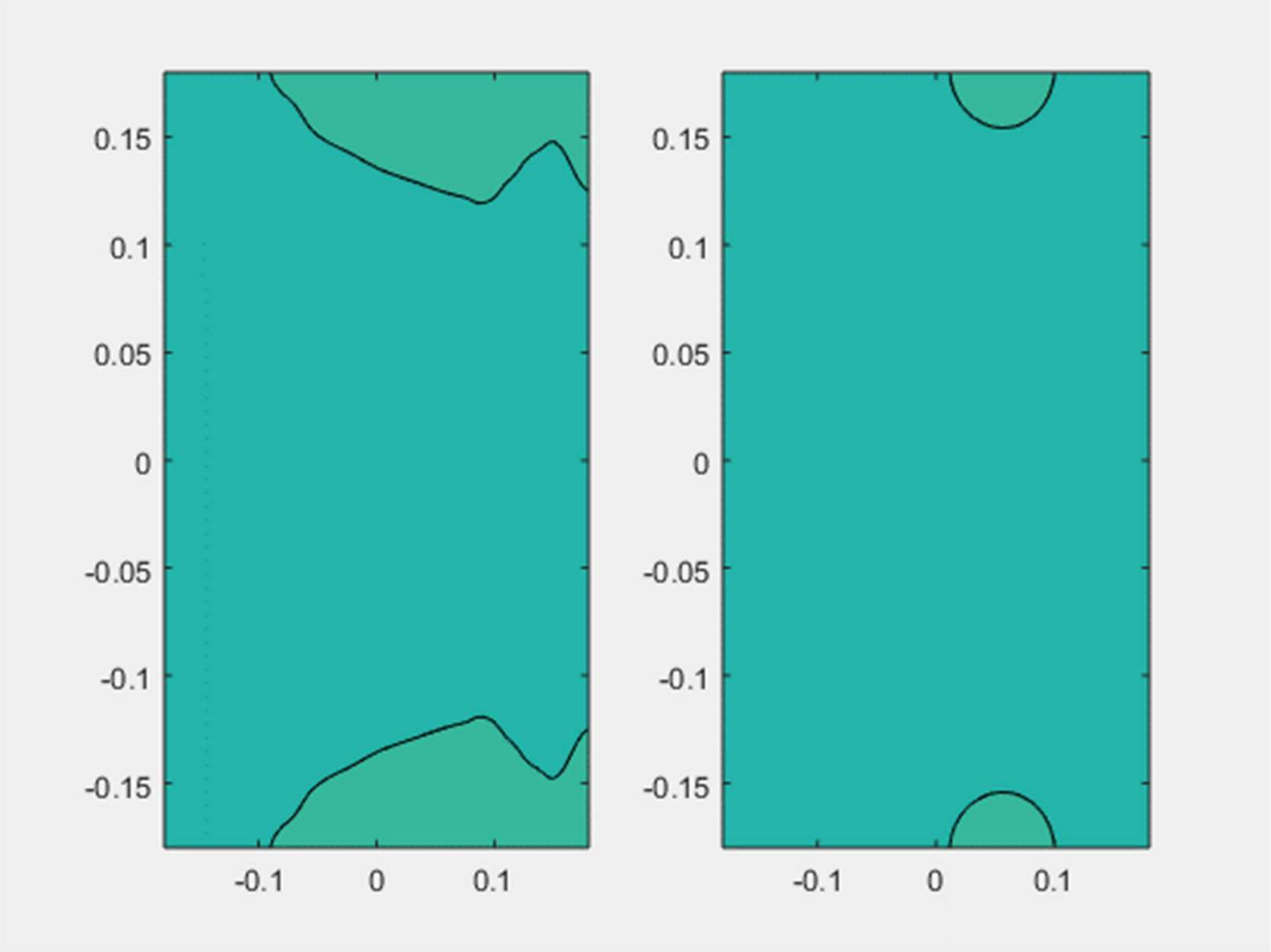

x 10^-3
3
2
1
0
-1
-2
-3
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
x 10^-3
2
1
0
-1
-2
-3
x 10^-3
2
0
-2
-4
-6
-8
-10
-12
-14
-16
x 10^-3
2
0
-2
-4
-6
-8
-10
-12
-14

Predictions



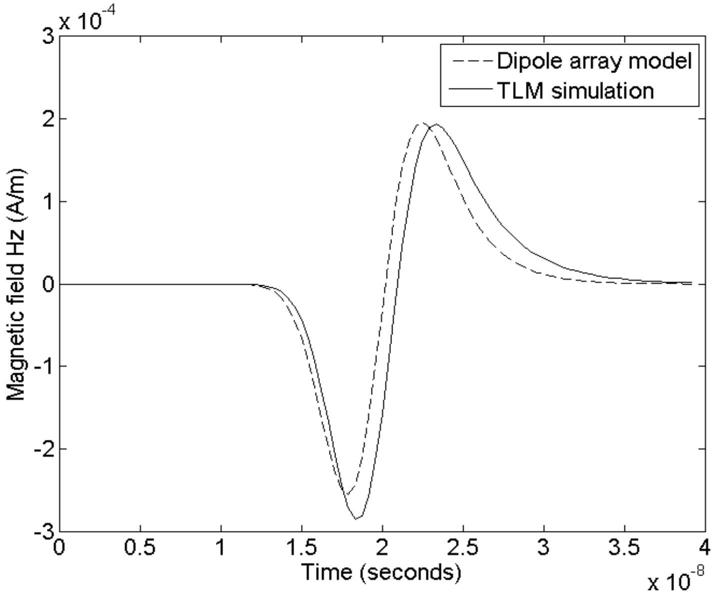


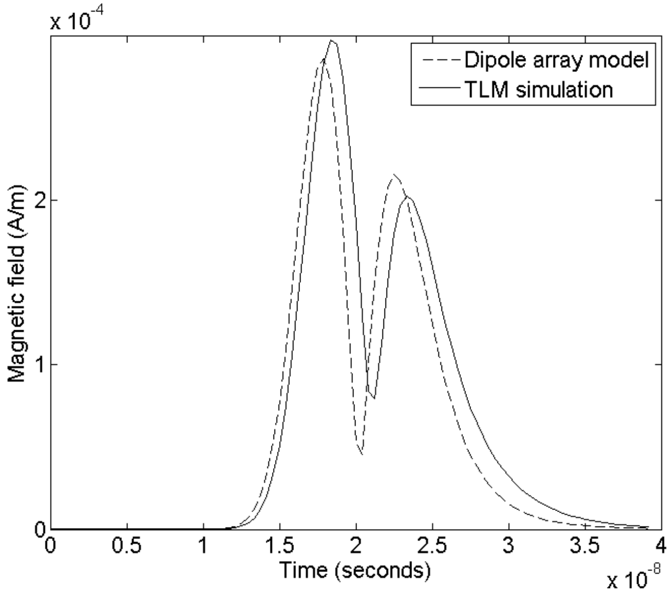

0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.1
0
0.1
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.1
0
0.1



0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.1
0
0.1
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.1
0
0.1

Results


x 10^-4
3
2
1
0
-1
-2
-3
Magnetic field Hz (A/m)
Dipole array model
TLM simulation
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (seconds)
x 10^-8


x 10^-4
2
1
0
Magnetic field (A/m)
Dipole array model
TLM simulation
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (seconds)
x 10^-8

Conclusions

- The principles of near field scanning discussed
- Discussed using the fields measured to produce equivalent models
- Frequency domain and time domain approaches described

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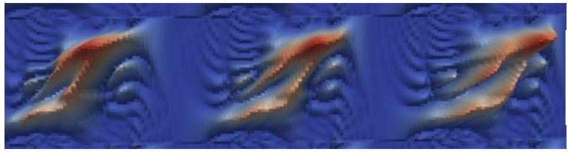

Thank You