Modelling the propagation of random electromagnetic emissions

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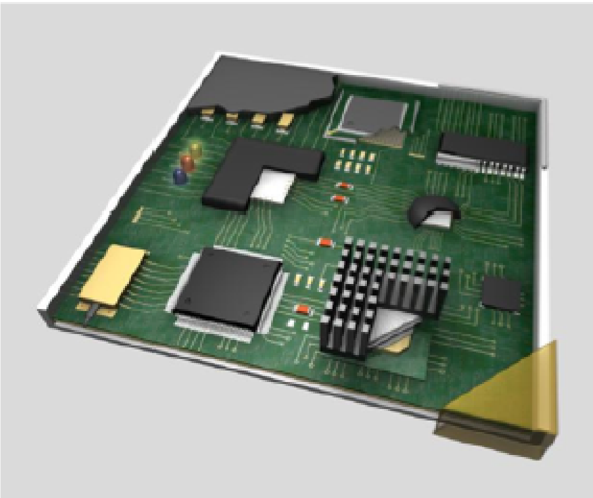
Wave Modelling Group

Problem: characterising complex sources

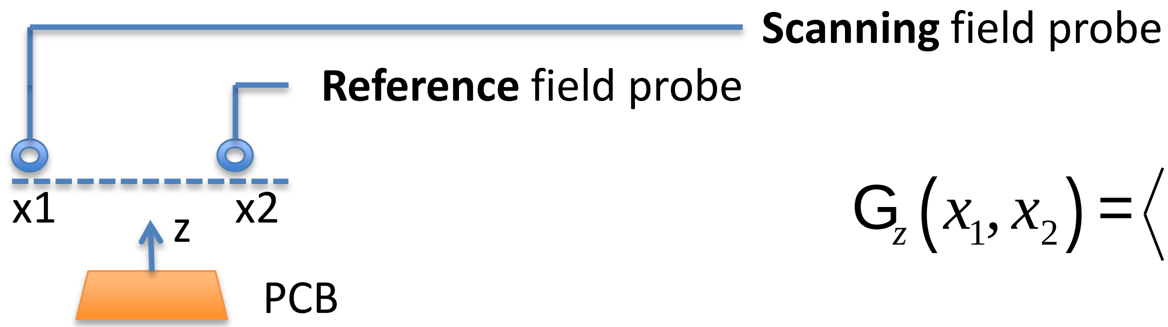


A **complex source** such as a PCB producing EM emissions is

- spatially extended
- stochastic
- broadband in frequency

Question: How to characterize random emissions from arbitrary printed circuit boards (PCBs)?

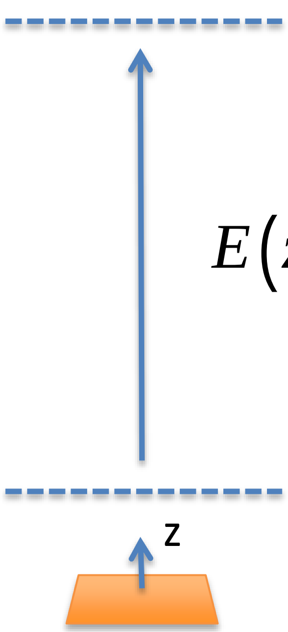
Answer: Electronic emissions radiating at RF/microwave frequencies are characterized by measurement of **field-field correlation functions**



$$G_z(x_1, x_2) = \left\langle E(z, x_1, t)\, E^*(z, x_2, t) \right\rangle_t$$

Free-space propagator: EM fields

Goal: predict noisy energy generated by complex spatio-temporal statistical sources.



$$E(z, x_1, t) = ?$$

$$E(z_0, x_1, t)$$

Using second Green identity:

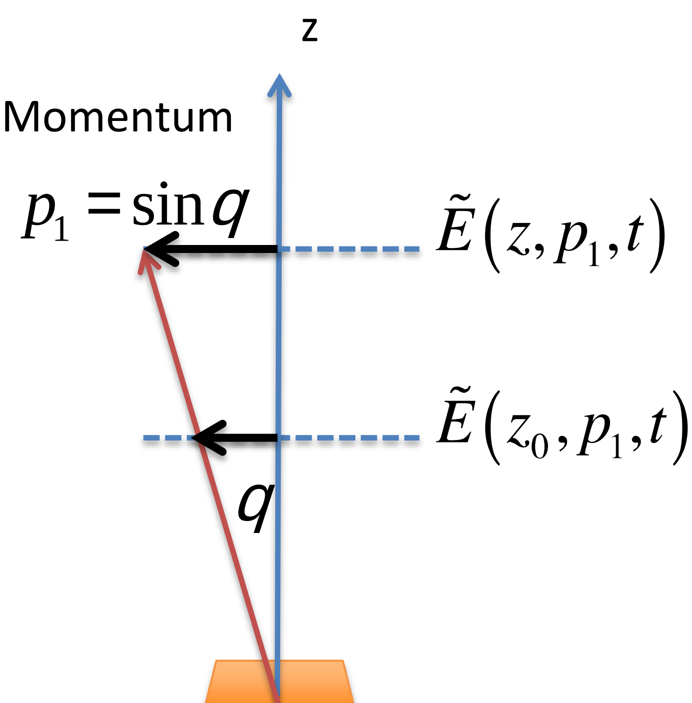
$$E(z, x_1, t) = \int G_0(z - z_0)\frac{\partial E(z_0, x_1, t)}{\partial z} - \frac{\partial G_0(z - z_0)}{\partial z} E(z_0, x_1, t)\, dx_1$$

- Mixed/unknown boundary conditions
- Random spatio-temporal behavior

Free-space propagator: correlation functions

Approach: propagate wave field correlation functions – average power density plus phase information [*]

$$\tilde{E}(z,p_1,t)=\int e^{ikp_1x_1}E(z,x_1,t)\,dx_1$$



Solve second Green Identity with Dirichlet-to-Neumann condition

$$\left.\frac{\partial\tilde{E}(z,p_1,t)}{\partial z}\right|_{z=0}=-ikT(p_1)\left.\tilde{E}(z,p_1,t)\right|_{z=0}$$

yields the field propagator

$$\tilde{E}(z,p_1,t)=e^{ikzT(p_1)}\tilde{E}(z_0=0,p_1,t)$$

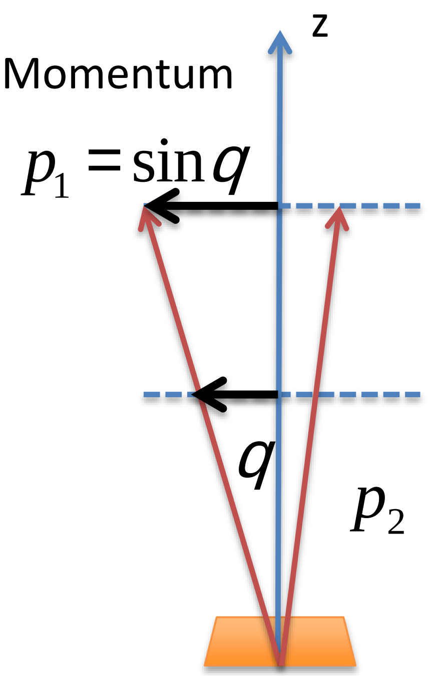
$$T(p)=\begin{cases}\sqrt{1-p^2}, & p<1\\ i\sqrt{p^2-1}, & p>1\end{cases}$$

[*] E. Wolf, Introduction to the Theory of Coherence and Polarization of Light, Cambridge University Press, 2007.

Free-space propagator: correlation functions

Approach: propagate wave field correlation functions – average power density plus phase information [*]

$$\tilde{\Gamma}_z(p_1,p_2) = \left\langle \tilde{E}(z,p_1,t)\,\tilde{E}^*(z,p_2,t)\right\rangle_\tau$$



$$\tilde{\Gamma}_z(p_1,p_2) = e^{ikz[T(p_1)-T(p_2)]}\,\tilde{\Gamma}_0(p_1,p_2)$$

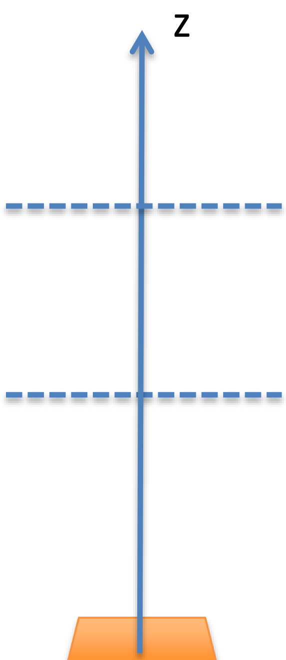
$$T(p) = \begin{cases} \sqrt{1-p^2}, & p<1 \\ i\sqrt{p^2-1}, & p>1 \end{cases}$$

[*] E. Winston & R. Littlejohn (1997).

Free-space propagator: Wigner functions

Approach: propagate wave field correlation functions – done efficiently in phase-space through Wigner functions

$$W_z(x,p) = \left(\frac{k}{2\pi}\right)^d \int_{-\infty}^{\infty} \tilde{\Gamma}_z\left(p+\frac{q}{2}, p-\frac{q}{2}\right)\exp(-ikpq)\,dq$$



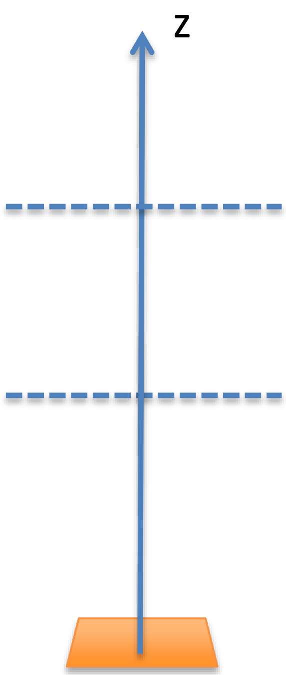
$$\tilde{\Gamma}_z(p_1,p_2) = e^{ikz[T(p_1)-T(p_2)]}\tilde{\Gamma}_0(p_1,p_2)$$

$$\tilde{\Gamma}_{z=0}\left(p+\frac{q}{2}, p-\frac{q}{2}\right) = \int_{-\infty}^{\infty} W_{z=0}(x,p)\exp(ikqx)\,dx$$

Free-space propagator: Wigner functions

Approach: propagate wave field correlation functions – done efficiently in phase-space through Wigner functions

From April's seminar…



Cascaded substitution yields:

$$W_z(x,p) = \int_{-\infty}^{\infty} G_z(x,x';p)\, W_{z=0}(x',p)\, dx'$$

At leading order, quasi-homogeneous sources:

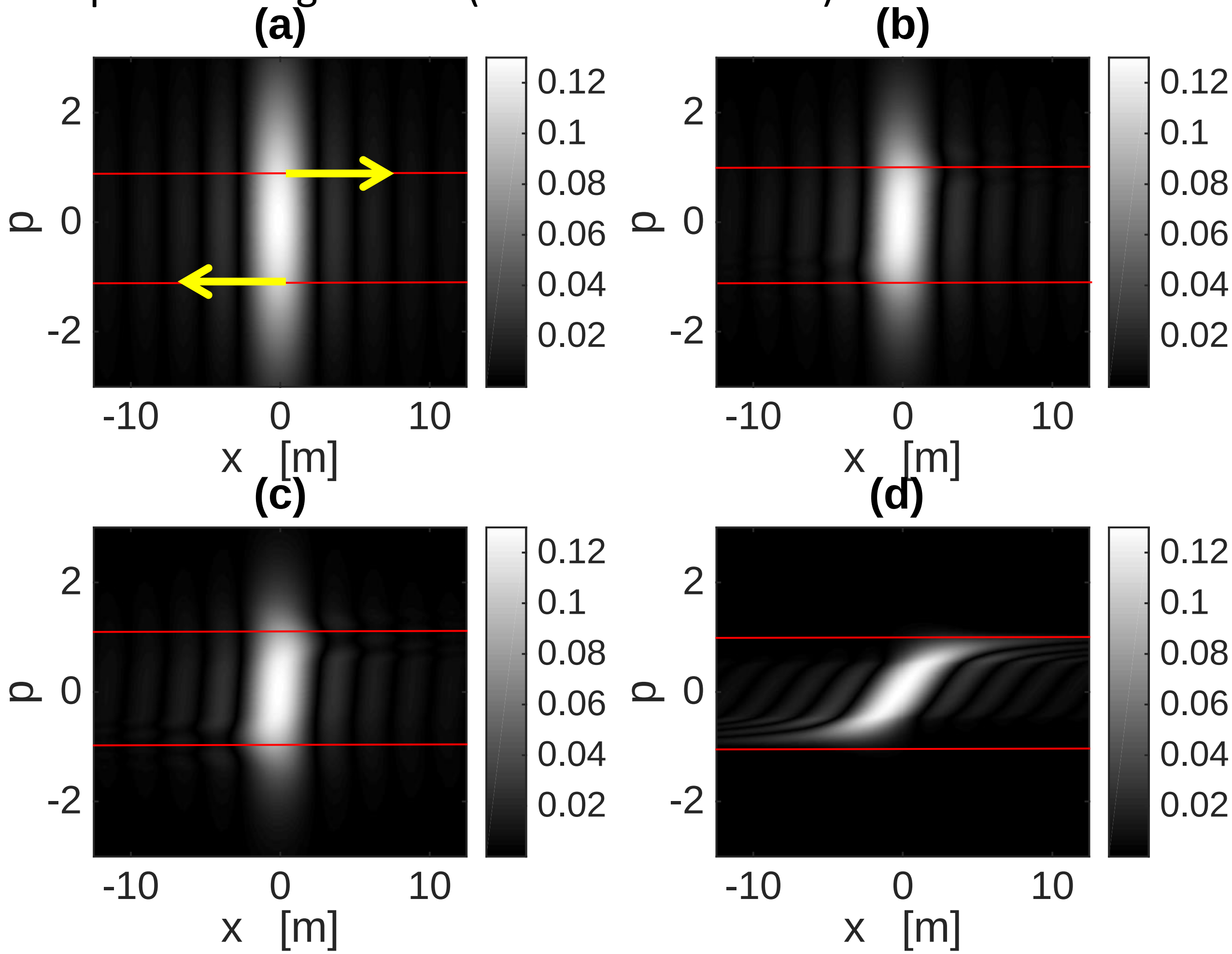
Tangent of ray

$$W_z(x,p) \approx \begin{cases} W_{z=0}\left(x - z\dfrac{p}{\sqrt{1-p^2}}, p\right), & p<1 \quad \text{Perron-Frobenius operator} \\ W_{z=0}(x,p)\, e^{-2kz\sqrt{|p|^2-1}}, & p>1 \quad \text{Evanescent operator} \end{cases}$$

Propagation of partially coherent correlations

In free space, propagation of phase-space distributions results in rotation and shearing [*]

An example for quasi homogeneous (Gaussian CF & WF) random sources

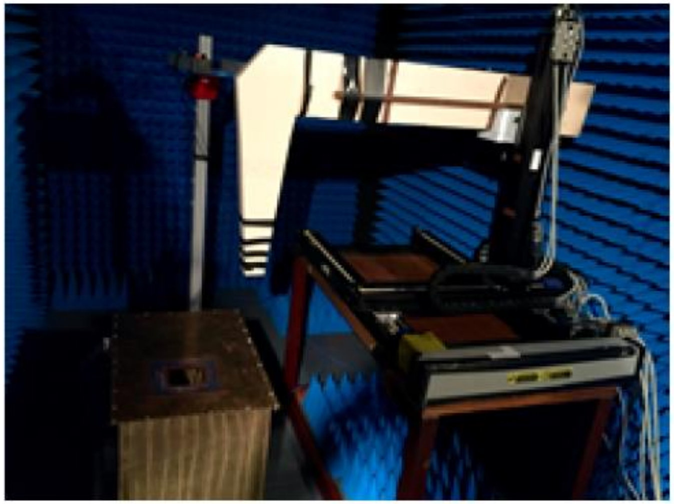


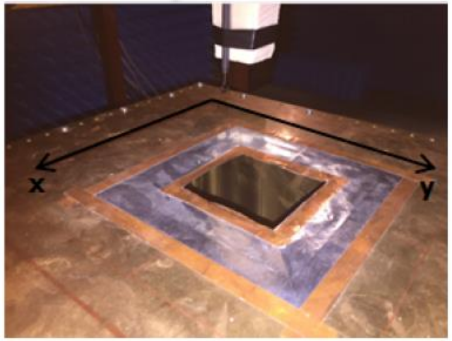
[*] G. Gradoni *et al.*, New J. Phys., (2015).

Experiments: emission from enclosures

The George Green Institute scanner

Scanner has been operated inside an anechoic chamber[*]





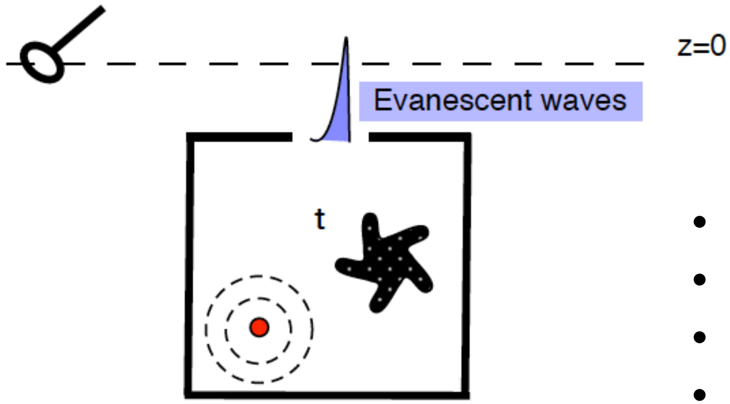
10 mm probe, high sensitivity,
Magnetic field selective, electric field immune,
low interferences

[*] G. Gradoni *et al.* Wigner function approach to propagate the correlation of random emissions, *to be submitted* IEEE TEMC (COST Ack).

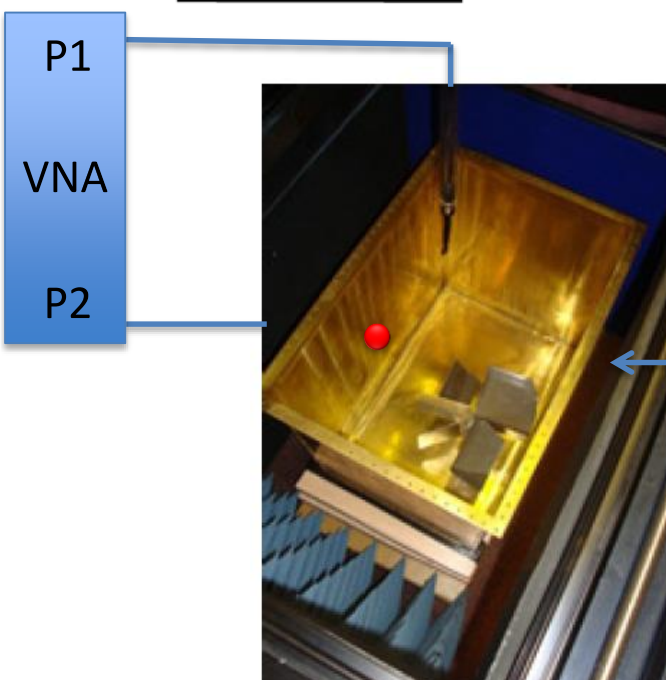
Experiments: emission from enclosures

The George Green Institute scanner

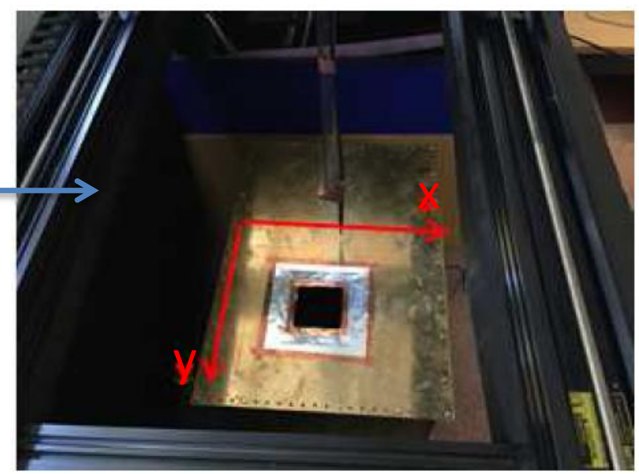
Experiments in free space



- Aperture dimensions 8 cm X 8 cm
- RC dimensions 1 m X 1 m X 0.5 m
- Langer EMV-Technik RF R50-1 magnetic field probe
- Agilent E5062A VNA



Top plate with a square aperture



[*] G. Gradoni *et al.* Wigner function approach to propagate the correlation of random emissions, *to be submitted* IEEE TEMC (COST Ack).

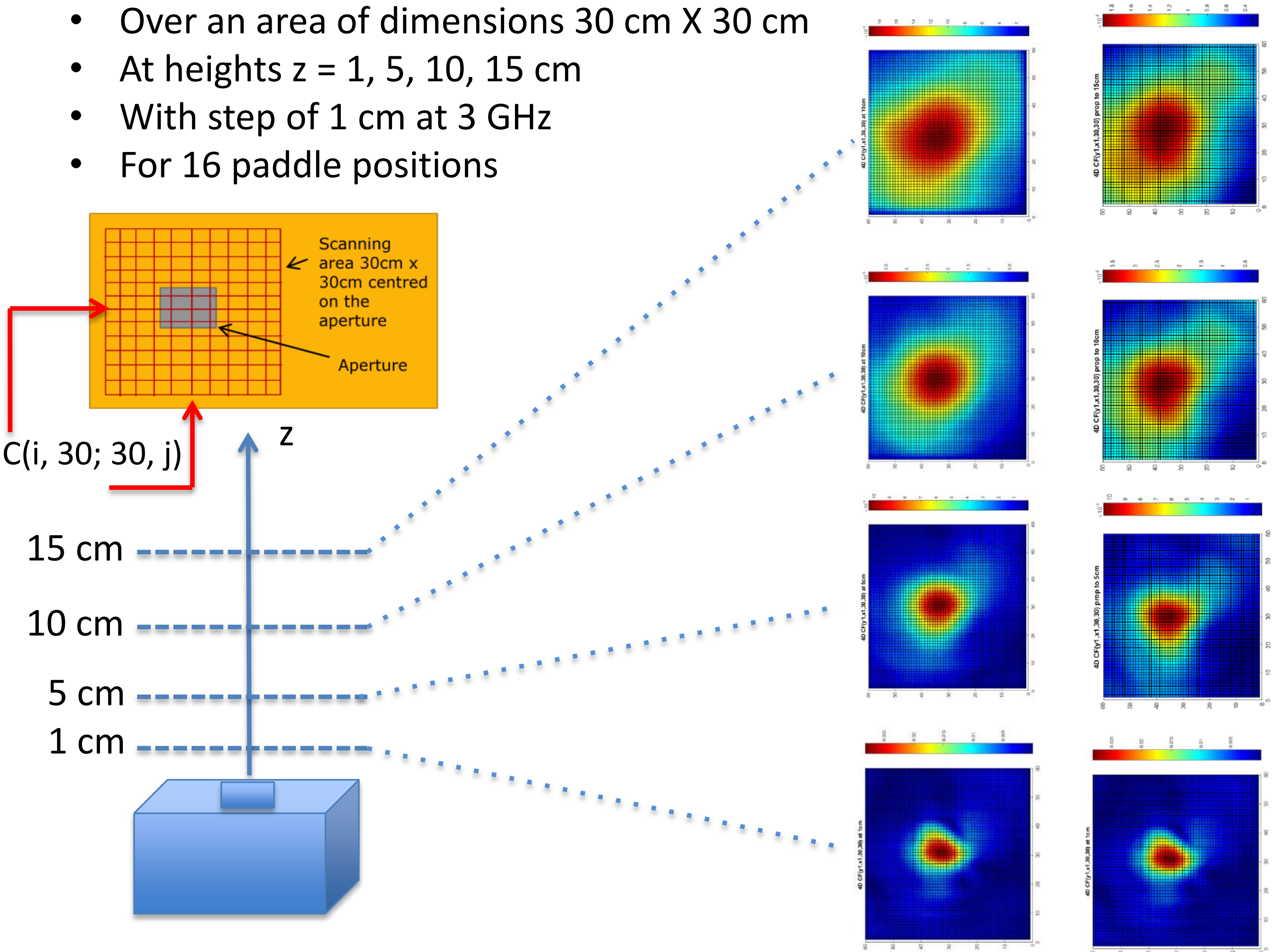
Experiments: emission from enclosures

The George Green Institute scanner

Scanning performed:

- Over an area of dimensions 30 cm X 30 cm
- At heights z = 1, 5, 10, 15 cm
- With step of 1 cm at 3 GHz
- For 16 paddle positions

Experiments Theory FP



Same scales!

Experiments: stochastic radiation pattern

The
George Green
Institute
scanner

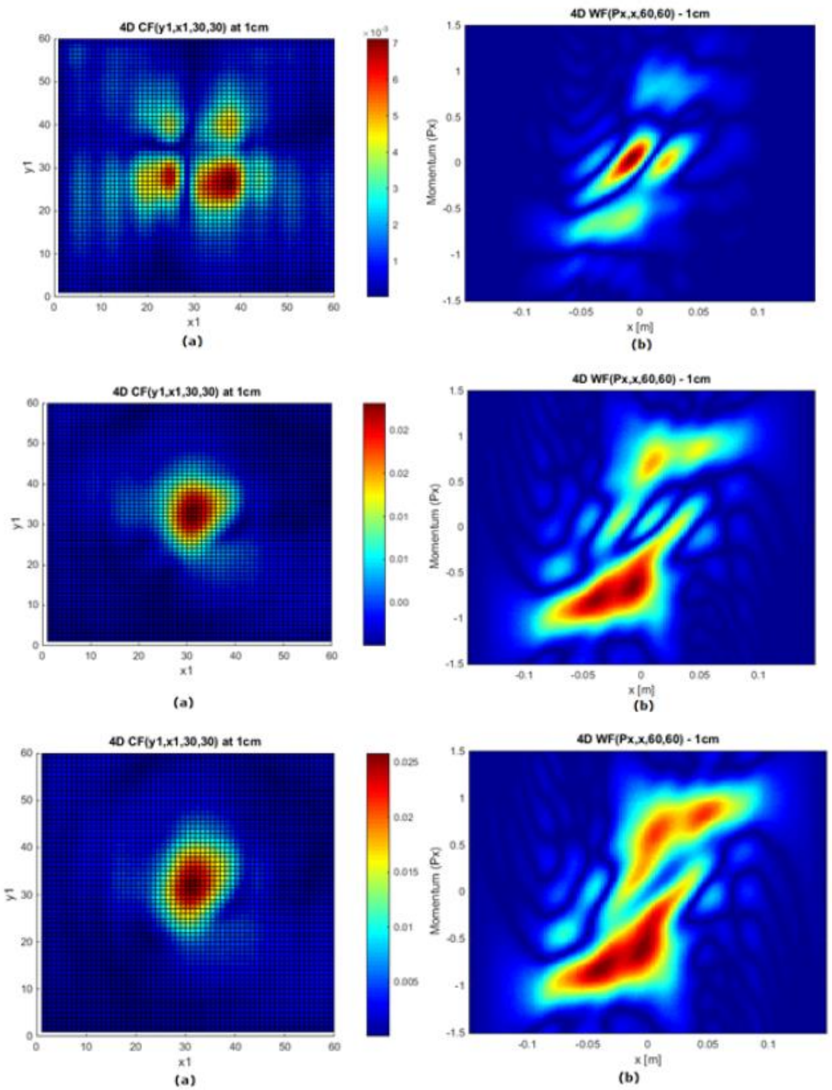
Positional and directional information

Increasing number of paddle positions

1

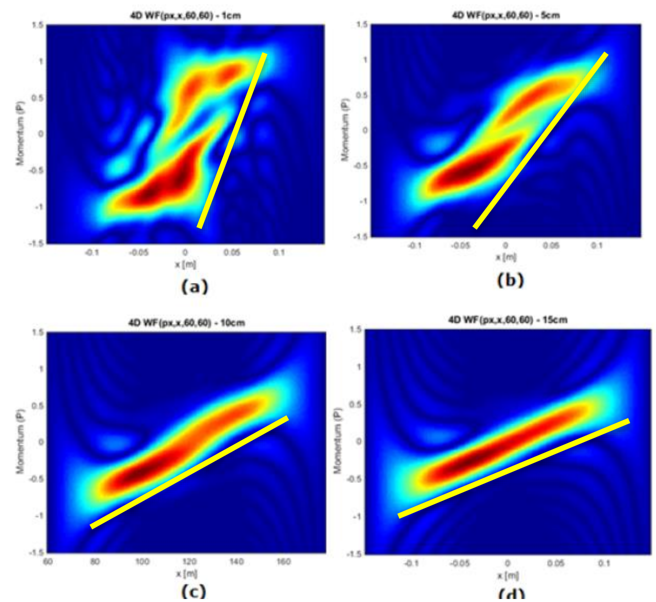
16

36



WF slope carries important information

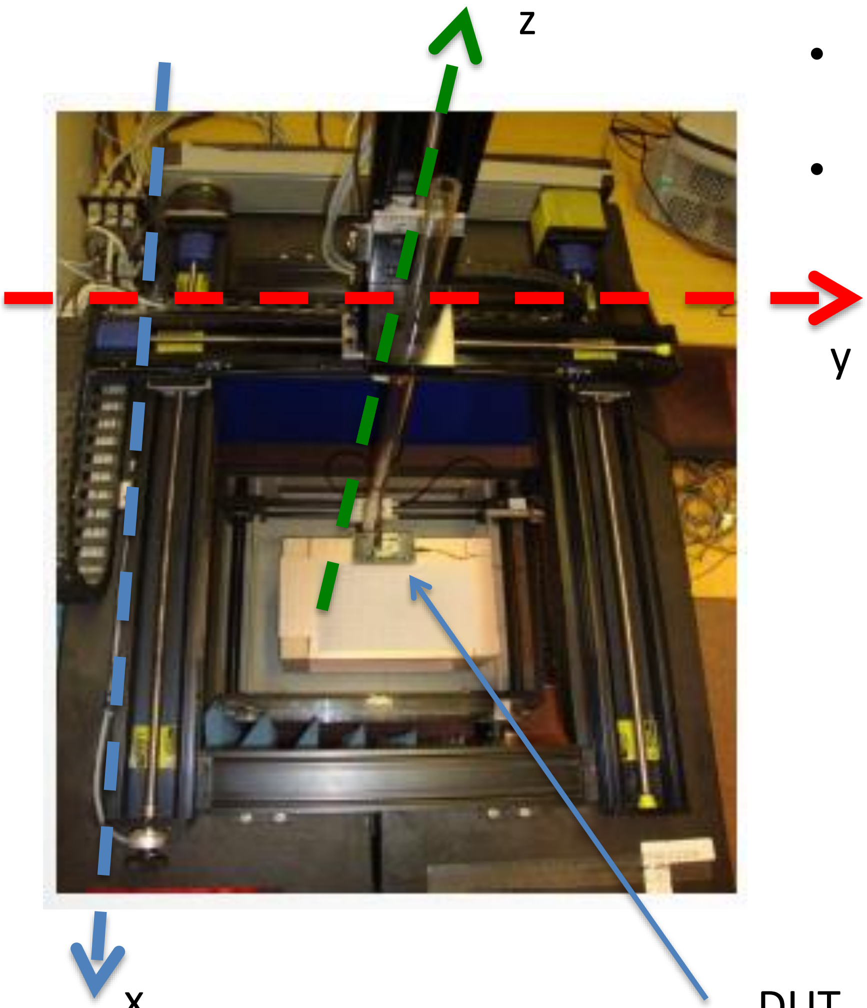
Increasing distance from the source



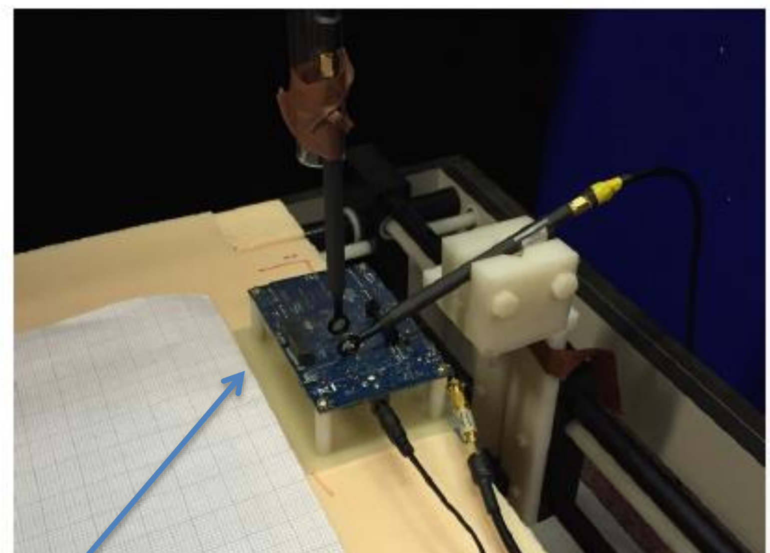
Experiments: the scanner

The George Green Institute scanner

Single and double probe scanner



- 2D scanner mounted underneath the 3D scanner
- Two identical magnetic field probes used to scan

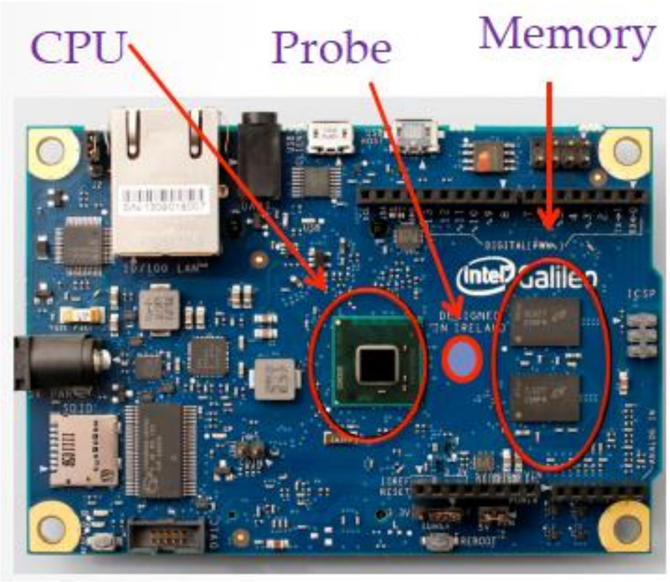


DUT

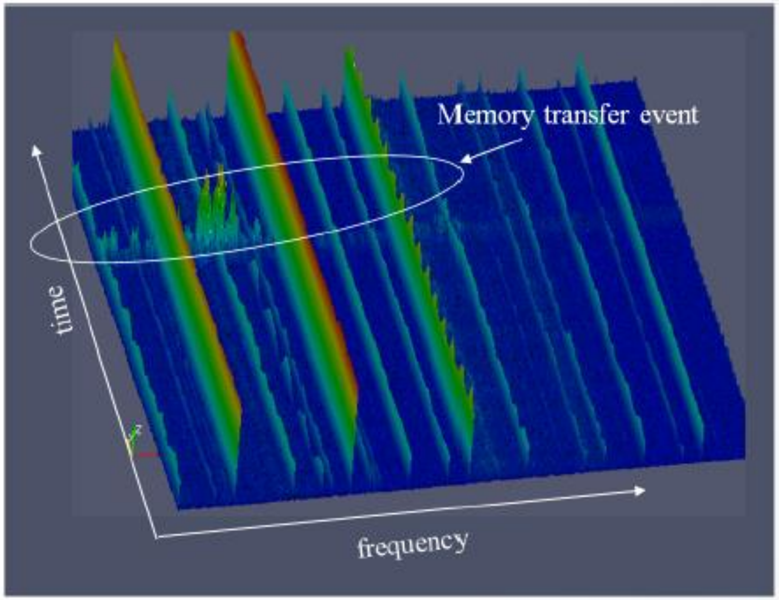
Experiments: Galileo board

The George Green Institute scanner

Galileo microcontroller



Time-frequency analysis

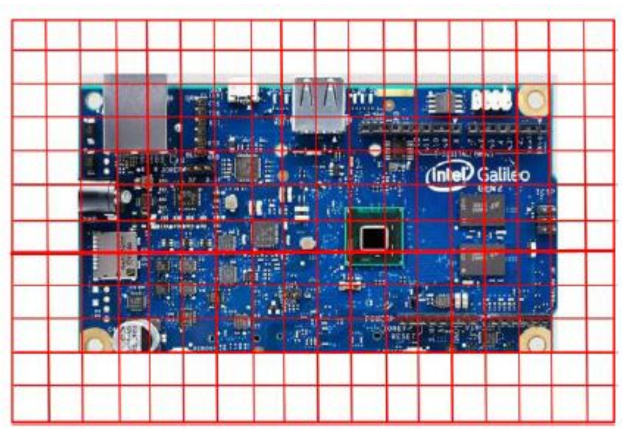


Intensive memory transfer processes generate non-stationary fields

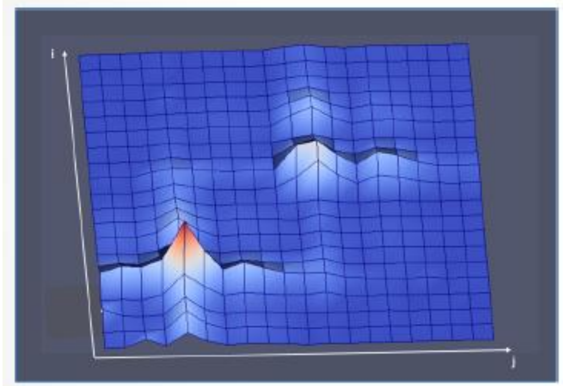
Experiments: Galileo board

The George Green Institute scanner

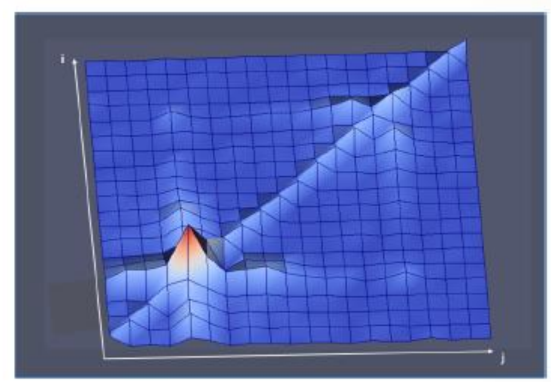
1D scan over 10 cm side area, step of 5 mm:
20 X 20 correlation matrix; 2Msa recorded
For each element of the correlation matrix



C(i, 5; 5, j)



C(i,j) at 100MHz



C(i,j) at 233MHz

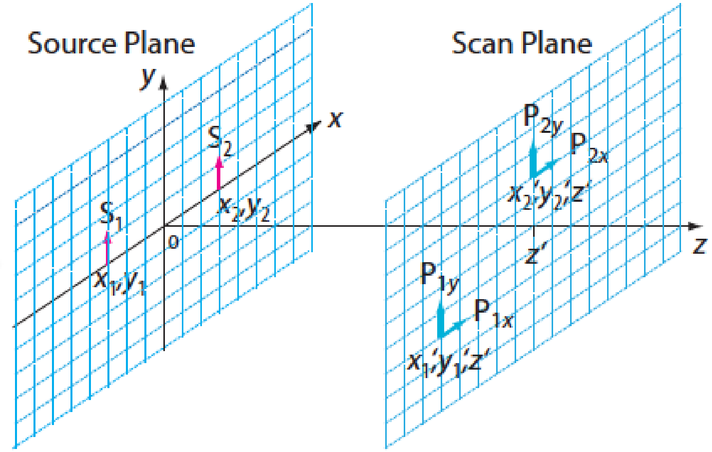
Scanning distances (~cm) << wavelength (~MHz): *near-to-near* transformation being derived

Source reconstruction (collaboration with TUM and Moscow Aviation)

Collaboration with TUM & Moscow Aviation

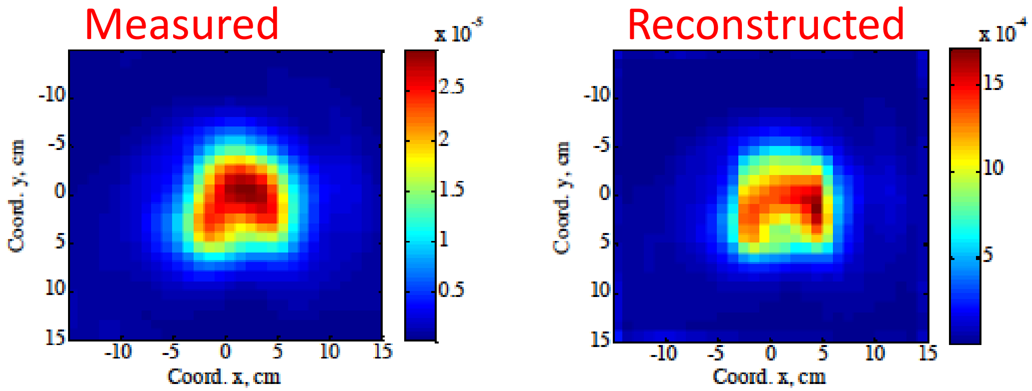
Comparison/integration with MoM implementation of Johannes and Peter

More dipoles added to create a large stochastic source



WF method

Application of Yuri's strategy to reconstruct sources in both near and far field



Journal Paper for IEEE MTT, COST Ack

Random Coupling Model (RCM) for stochastic ports

Collaboration with University of Maryland

Statistical model

$$\underline{\underline{Z}}^{cav} = i\Im\{\underline{\underline{Z}}^{rad}\} + [\Re\{\underline{\underline{Z}}^{rad}\}]^{1/2} \cdot \underline{\underline{\xi}} \cdot [\Re\{\underline{\underline{Z}}^{rad}\}]^{1/2}$$

$$\underline{\underline{\xi}} = \frac{i}{\pi} \sum_n \frac{\Delta\omega \underline{\Phi}_n \underline{\Phi}_n^T}{\omega - \omega_n + i\alpha\Delta\omega}$$

GRV's

RMT random spectrum:

Generated by eigenvalues of matrices from the Gaussian Orthogonal Ensemble (GOE), With specified average spacing $\Delta\omega$ depending on volume of cavity.

Average loss parameter:

Measures the average Q-width of a resonant mode relative to average mode spacing $\Delta\omega$.

$$\alpha = \frac{\omega}{2Q\Delta\omega}$$

Conference Proceedings Paper at EUMW 2016, London, COST Ack

Random Coupling Model (RCM) for stochastic ports

Collaboration with University of Maryland

Therefore, the procedure that we propose in order to employ the RCM in the characterisation of statistical sources radiating inside cavities can be summarised in the following steps:

1) Find an equivalent dipole model and the related current-current correlation matrix $\underline{\underline{\Gamma}}_I$ of the extended continuous source: this makes use of the measured field-field correlation matrix in the near field as described in [11], [12], and gives equivalent channels to be related to ports;
2) Calculate the $N \times N$ free-space radiation matrix for those N ports, $\underline{\underline{Z}}^{rad}$;
3) Estimate the loss factor factor of the environment α through (9);
4) Perform a Monte Carlo simulation of the cavity impedance matrix $\underline{\underline{Z}}^{cav}$ from (5);
5) Use $\underline{\underline{Z}}^{cav}$ for generating the voltage-voltage correlation matrix through (10);
6) Repeat the Monte Carlo simulation for many independent realisations and find the average cavity response by (12).

$$\alpha = \frac{k_0^2}{Q \Delta k^2}$$

$$\underline{\underline{Z}}^{cav} = i\Im\left\{\underline{\underline{Z}}^{rad}\right\} + \left[\Re\left\{\underline{\underline{Z}}^{rad}\right\}\right]^{1/2} \cdot \underline{\underline{\xi}} \cdot \left[\Re\left\{\underline{\underline{Z}}^{rad}\right\}\right]^{1/2}$$

$$\underline{\underline{\Gamma}}_V = \underline{\underline{Z}}^{cav}\, \underline{\underline{\Gamma}}_I\, \underline{\underline{Z}}^{cav,\dagger}$$

$$\left\langle \underline{\underline{\Gamma}}_V \right\rangle \approx \left[R^{rad}\right]^2 \left\langle \underline{\underline{\xi}} \cdot \underline{\underline{\Gamma}}_I \cdot \underline{\underline{\xi}}^\dagger \right\rangle \text{ High losses} \approx \frac{\left[R^{rad}\right]^2}{2\pi\alpha} \underline{\underline{\Gamma}}_I$$

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Website coming soon at:
http://wamoresearch.org/

http://www.nemf21.org/