EM VIRTUAL PROTOTYPING ENVIRONMENT FOR THE INTERACTIVE DESIGN OF VERY HIGH SPEED CIRCUITS

- **user-centered**, **task driven** point of view;
- **interactive functions**:

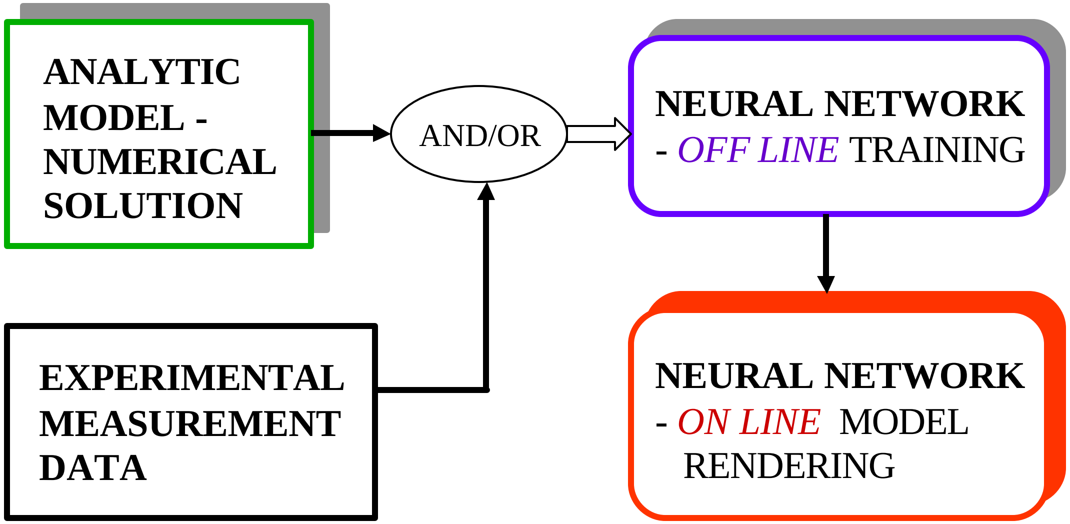
(i) walk-through the 3D virtual world;
(ii) specify material, electrical, and thermal specifications of circuit components;
(iii) 3D manipulation of the position, shape, size, of the circuit components and layout;
(iv) visualization the electrical wave forms, **3D Electromagnetic (EM) field** and thermal field effects in different regions of the electronic circuit.

- Multiple PCBs can be integrated in any way as desired to define a complete electronic system, including mechanical parts.

- The final system can be ***interactively*** tested on an ***enhanced-reality virtual work-bench*** as a final product, by ***concurrently*** running what-if experiments in a ***multi-domain*** (mechanical, electrical, thermal)environment.

⇨ The design cycle is shortened, the cost of the tests is reduced, the quality of the product is improved, and the time-to-market is reduced.

NEURAL NETWORK MODELS



ANALYTIC MODEL - NUMERICAL SOLUTION

EXPERIMENTAL MEASUREMENT DATA

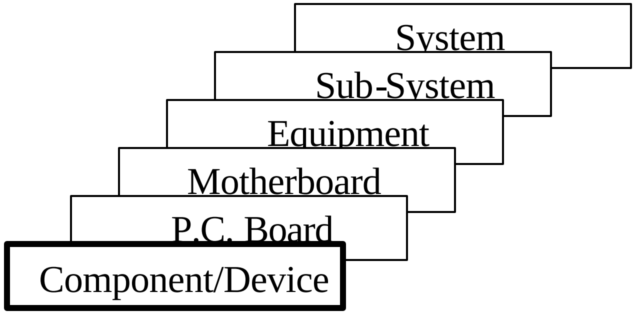
AND/OR

NEURAL NETWORK - *OFF LINE* TRAINING

NEURAL NETWORK - *ON LINE* MODEL RENDERING

EMC Modelling for Electronic Design Automation

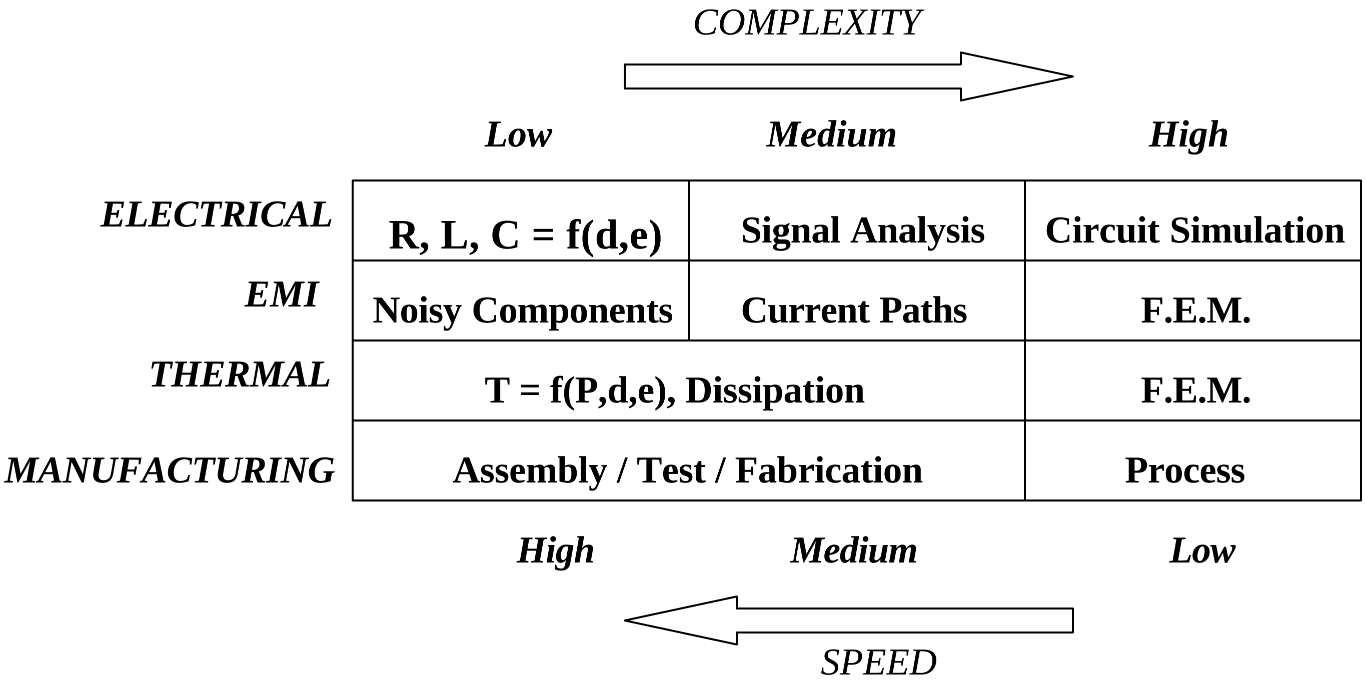
EMC Design Levels



Optimum Approach to EMC Design

- {Design+Test+Analysis} **Synergy**
- **EMC_Behavior** = F (Design_Principle, Analysis&Modeling&Simulation_Tools, Test_Methodology&Instrumentation)

Multiple Domain Models for EDA Applications

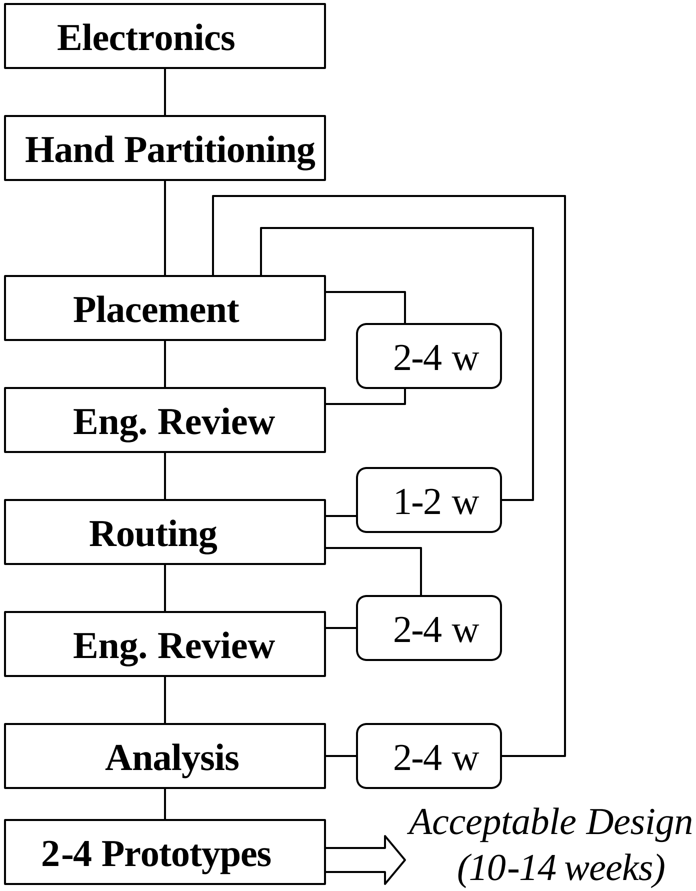


COMPLEXITY

	Low	*Medium*	*High*
ELECTRICAL	**R, L, C = f(d,e)**	**Signal Analysis**	**Circuit Simulation**
EMI	**Noisy Components**	**Current Paths**	**F.E.M.**
THERMAL	**T = f(P,d,e), Dissipation**		**F.E.M.**
MANUFACTURING	**Assembly / Test / Fabrication**		**Process**
	High	*Medium*	*Low*

SPEED

Product Design Cycles for Traditional and Virtual Prototyping



Electronics

Hand Partitioning

Placement

2-4 w

Eng. Review

1-2 w

Routing

2-4 w

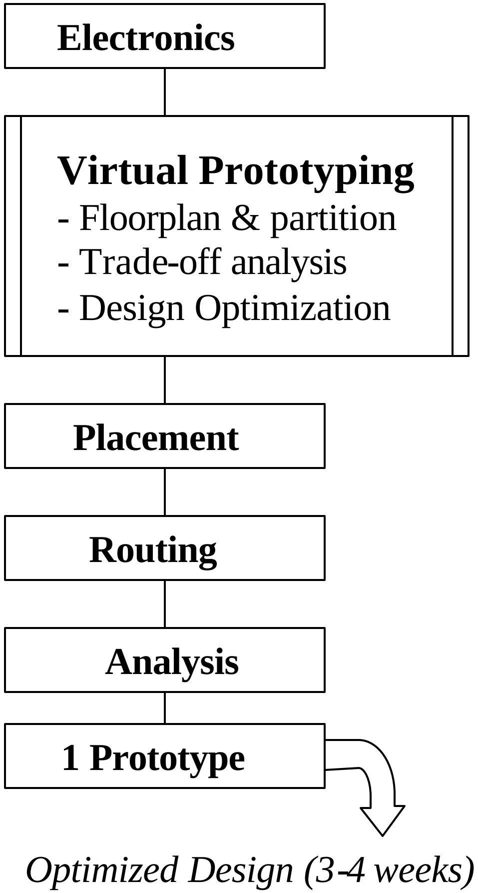
Eng. Review

Analysis

2-4 w

2-4 Prototypes

Acceptable Design
(10-14 weeks)



Electronics

Virtual Prototyping
- Floorplan & partition
- Trade-off analysis
- Design Optimization

Placement

Routing

Analysis

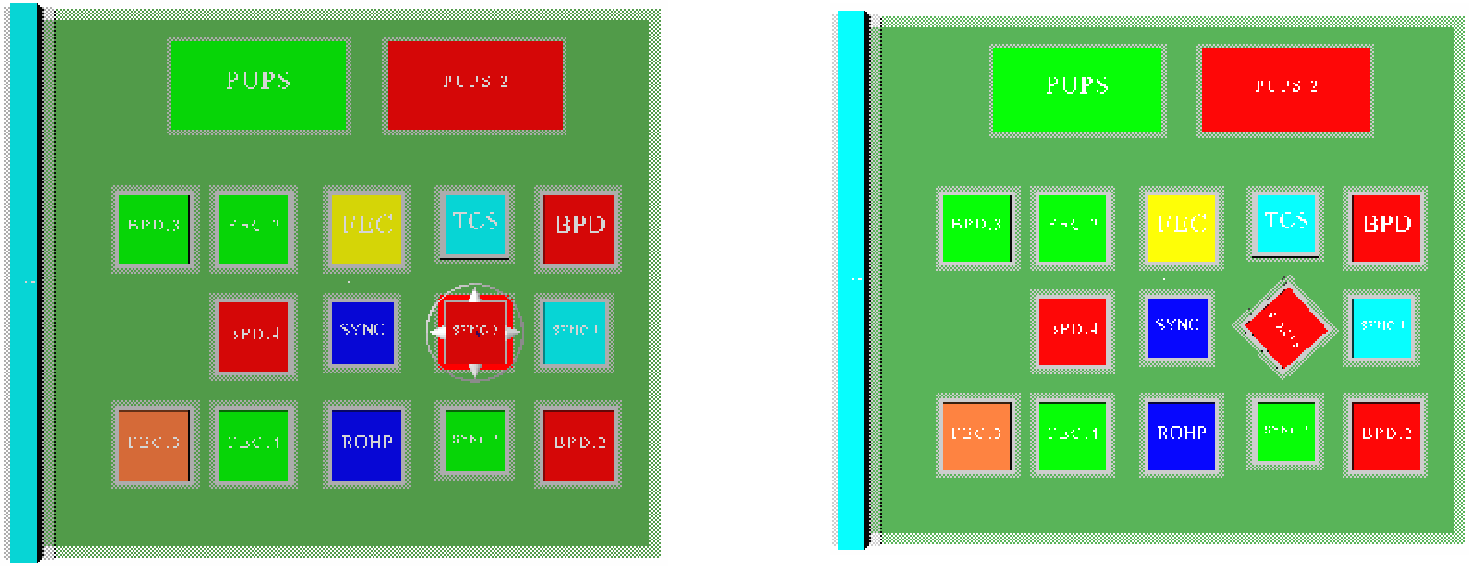
1 Prototype

Optimized Design (3-4 weeks)

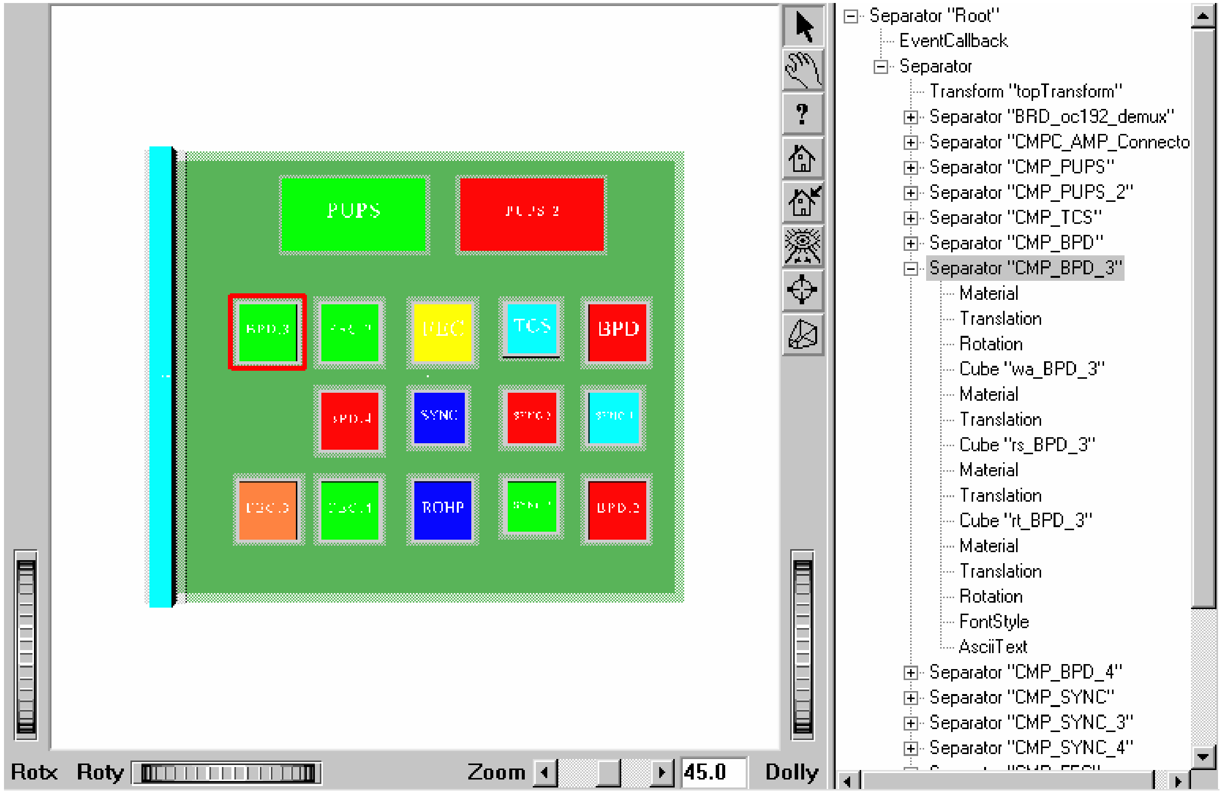
3D INTERACTIVE VIRTUAL ENVIRONMENT

[E.M. Petriu, M. Cordea, D.C. Petriu, Lou McNamee, "Modelling Issues in Virtual Prototyping Environments," Proc. VIMS'99, IEEE Workshop Virtual and Intell. Meas. Syst., pp. 1-5, Venice, Italy, May 1999]

- 3D scenes are composed of multiple objects: boards, components, connectors.
  - any object is characterized by its usual 3D geometric shape and *safety-envelopes* (the 3D geometric space points where the intensity of a given field radiated by that object becomes smaller than a specified threshold value), each type of field (EM, thermal) will have its own safety-envelope (the geometric safety-envelope being the object shape itself);
  - any object can be selected/becomes *active* by attaching a manipulator to it;
- The ***main objective*** is to detect a collision caused by a linear transformation (translation, rotation or scaling) between the selected object and the other objects in the scene.
  - for each transformation of the selected/active object, the program updates the 3D geometric parameters and the bounding box of the object;
  - then the program checks for collision between the safety-envelopes selected object and those of the other objects in the scene;
  - when a collision is detected, the active object returns to its position just before the collision



Rotation-translation manipulator dragger



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    EventCallback
  ⊟ Separator
      Transform "topTransform"
    ⊞ Separator "BRD_oc192_demux"
    ⊞ Separator "CMPC_AMP_Connecto
    ⊞ Separator "CMP_PUPS"
    ⊞ Separator "CMP_PUPS_2"
    ⊞ Separator "CMP_TCS"
    ⊞ Separator "CMP_BPD"
    ⊟ Separator "CMP_BPD_3"
        Material
        Translation
        Rotation
        Cube "wa_BPD_3"
        Material
        Translation
        Cube "rs_BPD_3"
        Material
        Translation
        Cube "rt_BPD_3"
        Material
        Translation
        Rotation
        FontStyle
        AsciiText
    ⊞ Separator "CMP_BPD_4"
    ⊞ Separator "CMP_SYNC"
    ⊞ Separator "CMP_SYNC_3"
    ⊞ Separator "CMP_SYNC_4"
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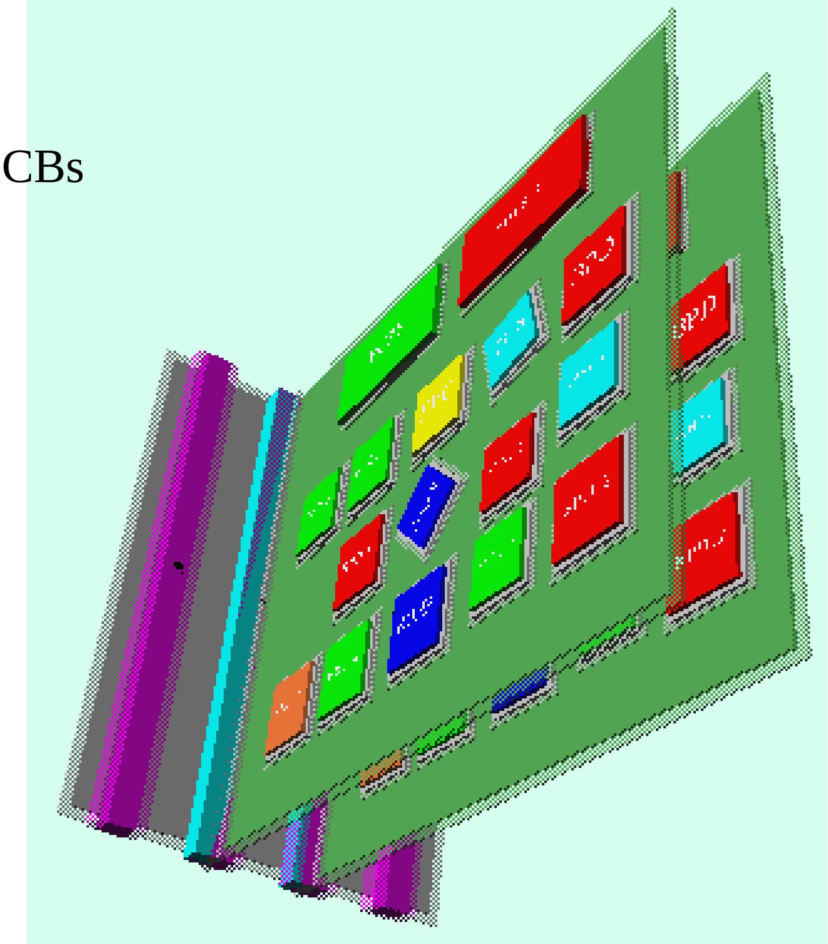
Editing material properties

Assembling multiple PCBs



Electromagnetic Compatibility (EMC) Modelling Methods

- *circuit theory* to describe the conducted disturbances (such as overvoltages, voltage dips, voltage interruptions, harmonics, common ground coupling);

- *equivalent circuit* with either *distributed* or *lumped parameters* (such as in low frequency electromagnetic field coupling expressed in terms of mutual inductances and stray capacitances, field-to-line coupling using the transmission line approximation, and cable crosstalk);

- formal solutions to *Maxwell's equations* and the appropriate field boundary conditions (as for example in problems involving antenna scattering and radiation).

Parallel and Distributed Processing Techniques for Electromagnetic Field Solution

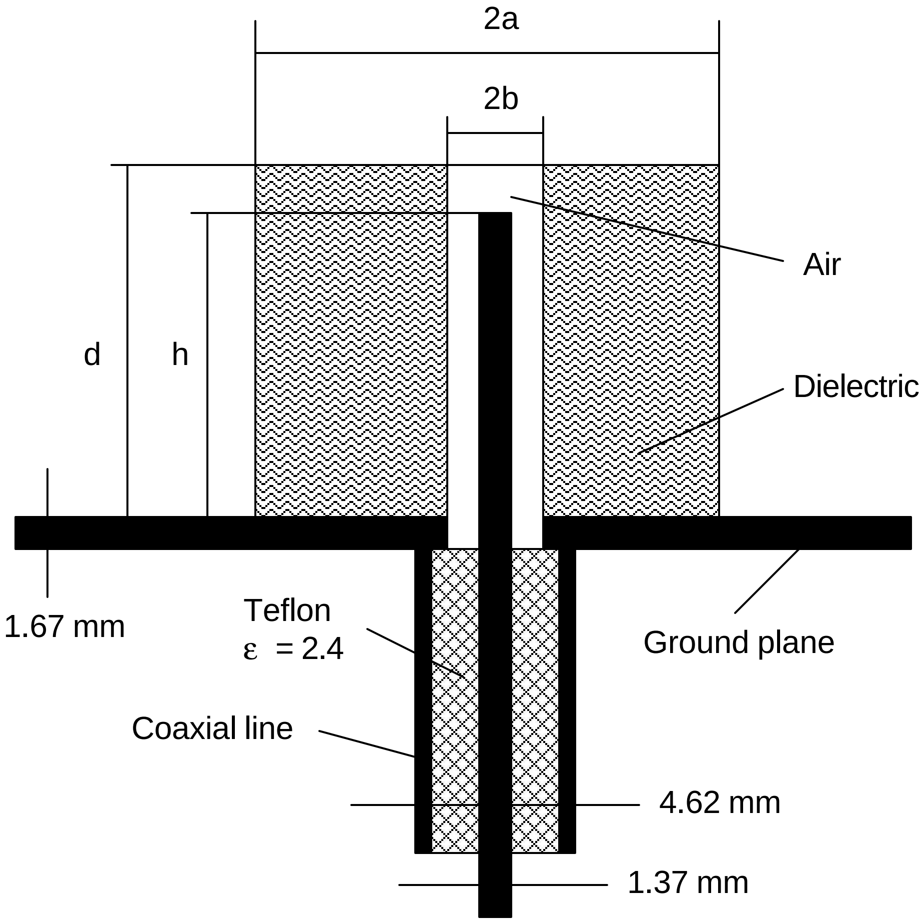
- **Classical numerical EM modelling** using sequential algorithms such as TLM (transmission-line matrix) or FEM (finite element method) is computer intensive, particularly as spatial discretization, geometry complexity, and domain size requirements become more demanding.

⇩

- More efficient **parallel and distributed computing** techniques must be developed to reduce the execution time for these methods so that they can be used in commercial CAD software. Speed of execution is particularly important when the field analysis is to be coupled with optimization, which may require several hundred analyses to be performed within a reasonable time. ⇨ **NN models**

☆ NN modeling of the 3D EM field radiated by a dielectric-ring resonator antenna

[I. Ratner, H.O. Ali, E.M. Petriu, "Neural Network Simulation of a Dielectric Ring Resonator Antenna," J. Systems Architecture, vol. 44, No. 8, pp. 569-581, 998.]



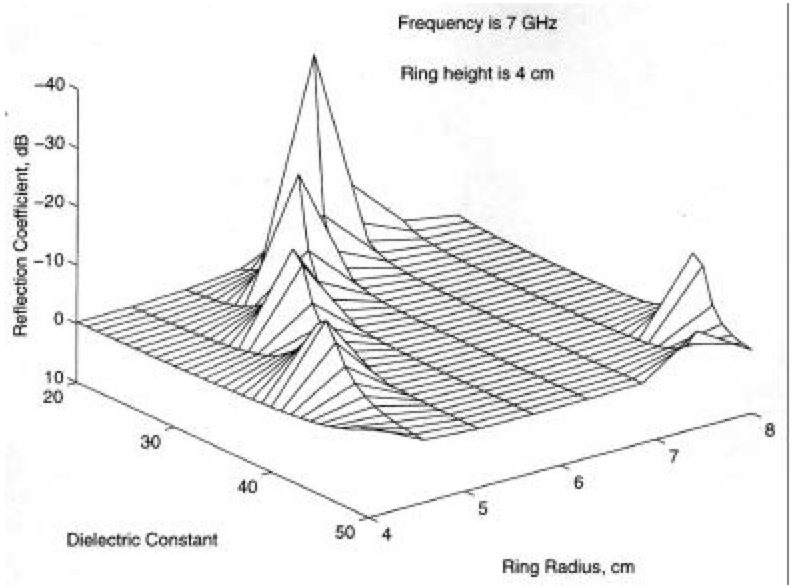
>> NN modeling of dielectric-ring resonator antenna EMF

Maxwell's equations: $\nabla \times \overline{H} = (\sigma + j\omega\varepsilon)\overline{E}$

$\nabla \times \overline{E} = -j\omega\mu\overline{H}$

$$\nabla \times \nabla \times \overline{H} = -j\omega\mu\,(\sigma + j\omega\varepsilon)\overline{H}$$

Finite Element Method (*FEM*)
1400 frequency steps 2-16 GHz;
31 dielectric constants; a = d = 5.14 mm

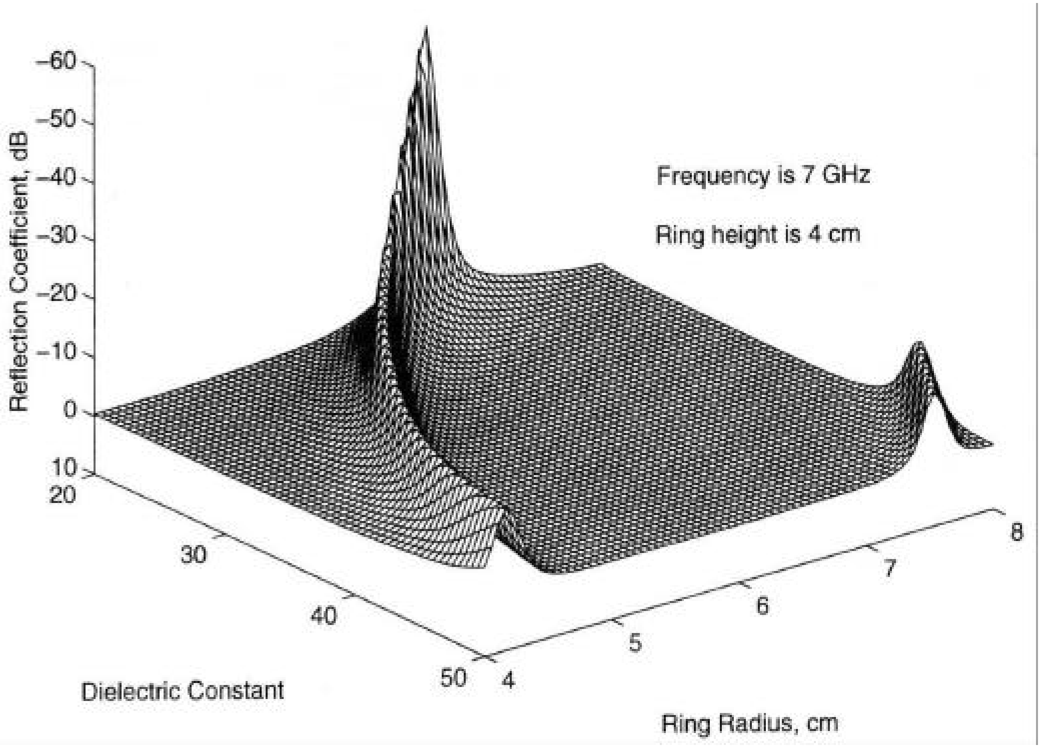


\>> NN modeling of dielectric-ring resonator antenna EMF

FEM numerical Solution => **$1.3{\times}10^5$ s** on SPARC 10 UNIX

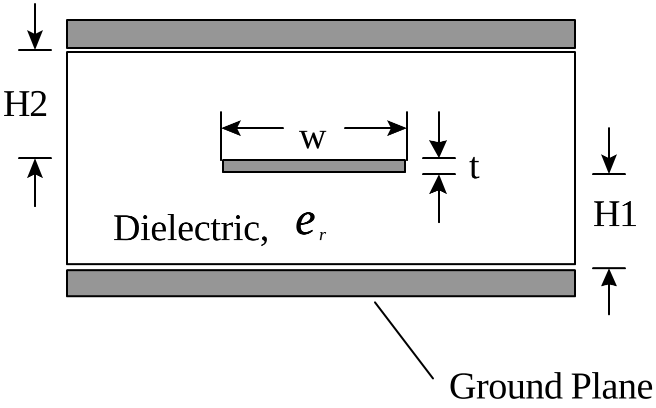
NEURAL NETWORK

- Two input neurons (frequency, dielectric constant) + Two hidden layers (5 neurons each, with hyperbolic tangent activation function) + One output linear neuron;
- Backpropagation using the Levenberg-Marquard algorithm;
- **55 s** /200 epochs to *train the NN off line* on SPARC 10 UNIX station;
- **0.5 s** to *render on line 5,000 points* of the EM field surface- model, SPARC 10 UNIX.



Modeling Single Stripline Interconnects

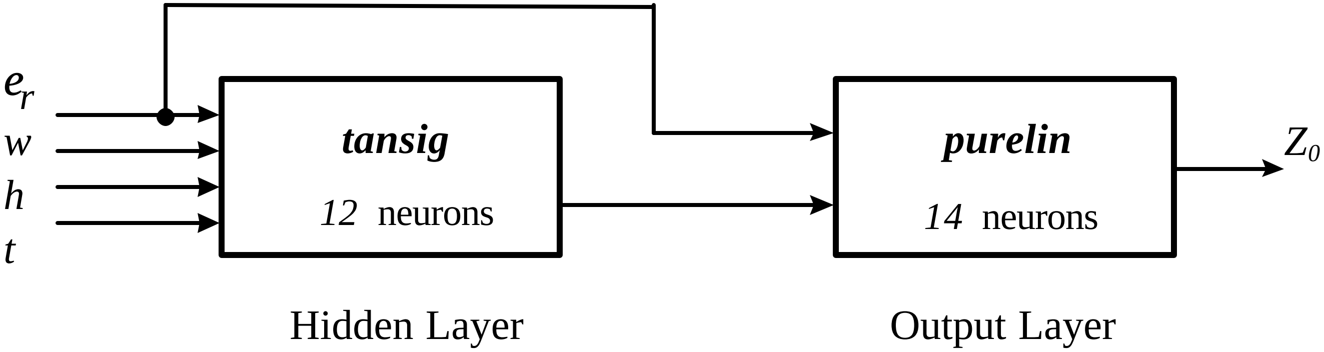
[Mao Jie, “NN Modeling of Single Stripline Interconnects,” Technical Report, SMRLab, SITE, University of Ottawa, 1998



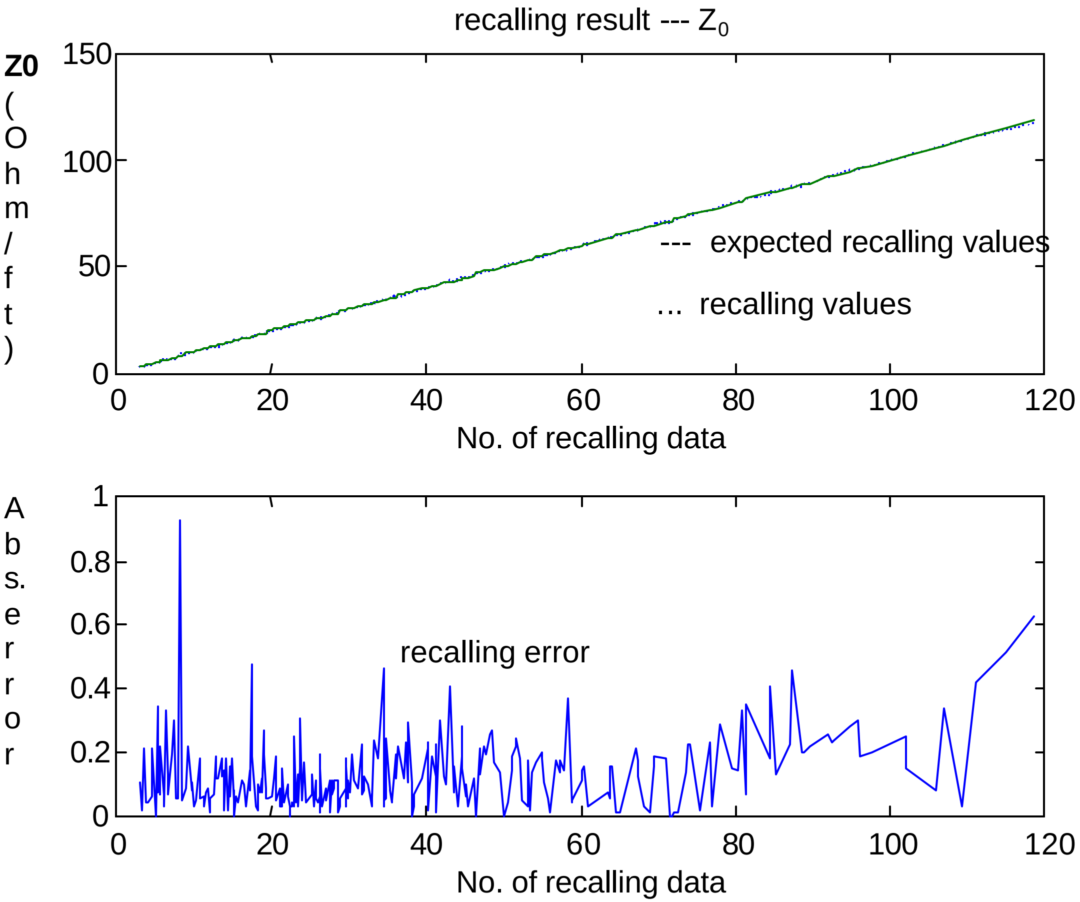
⇨ Model for $\mathbf{Z_0}$.

⇨ Model for $\mathbf{C_0}$ and $\mathbf{L_0}$.

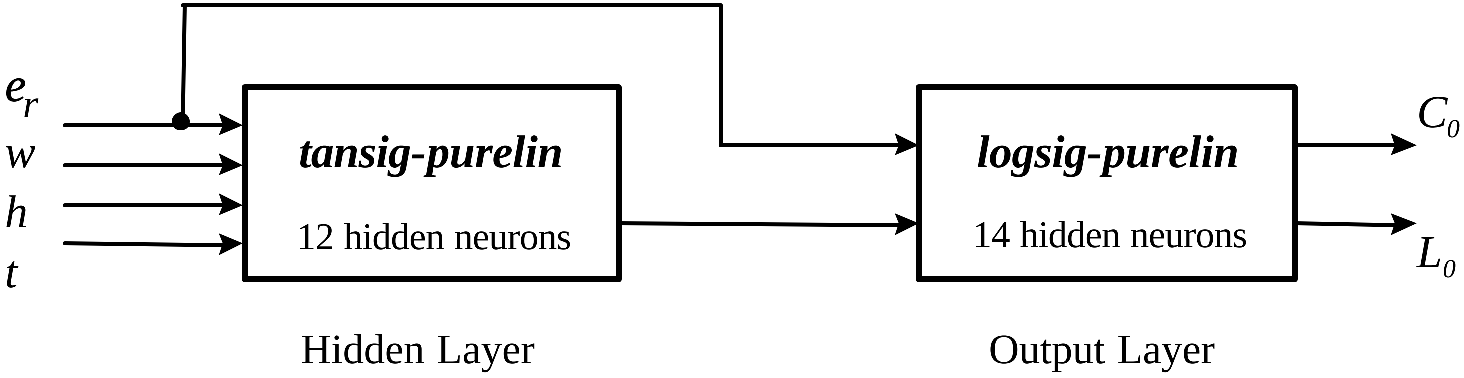
NN architecture modelling Z_0



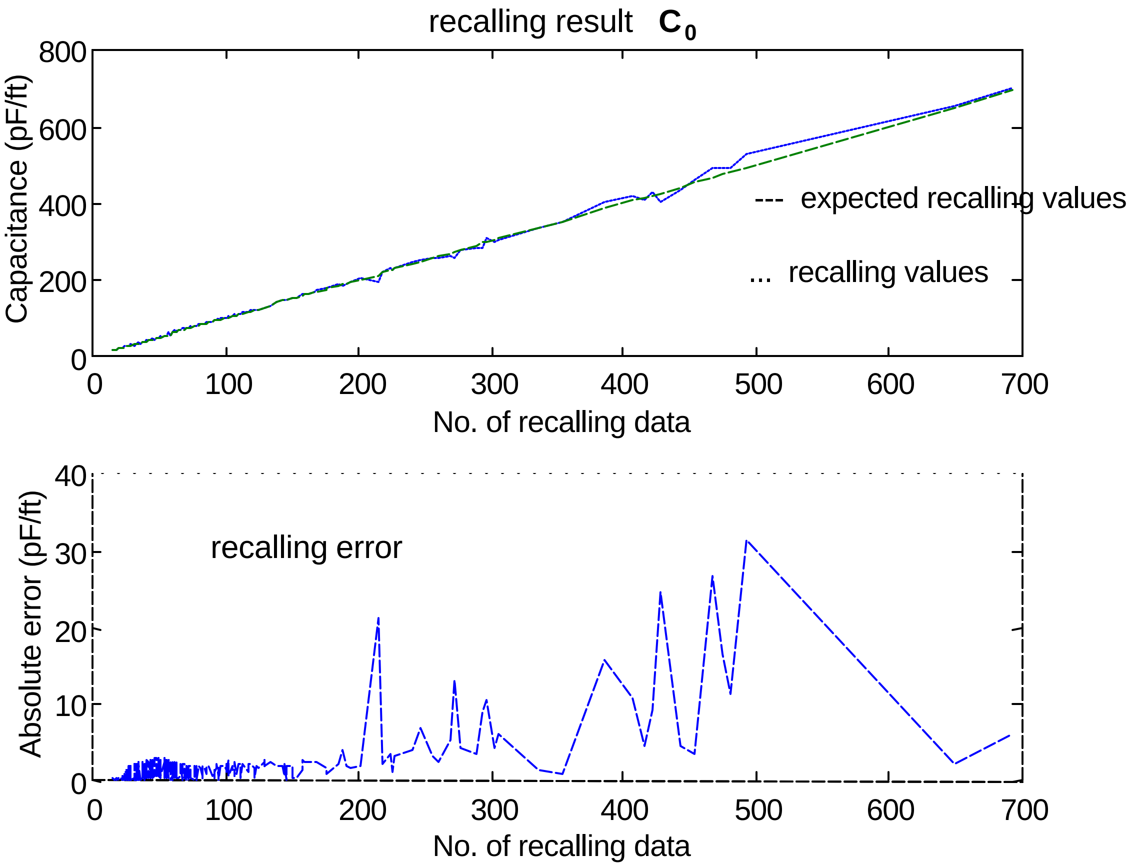
>> Modeling Single Stripline Interconnects



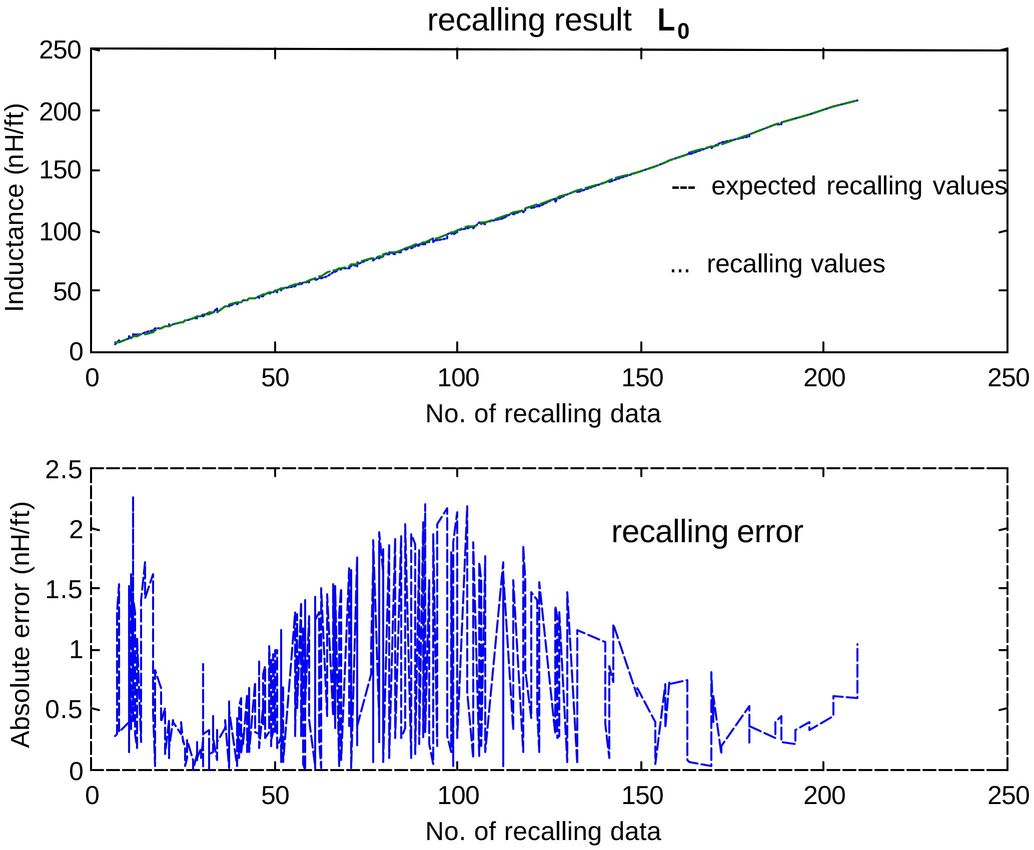
NN architecture modelling C_0 and L_0



>> Modeling Single Stripline Interconnects



>> Modeling Single Stripline Interconnects



☆ NEURAL NETWORK MODELLING OF PLAIN AND GROOVED MICROSTRIPS

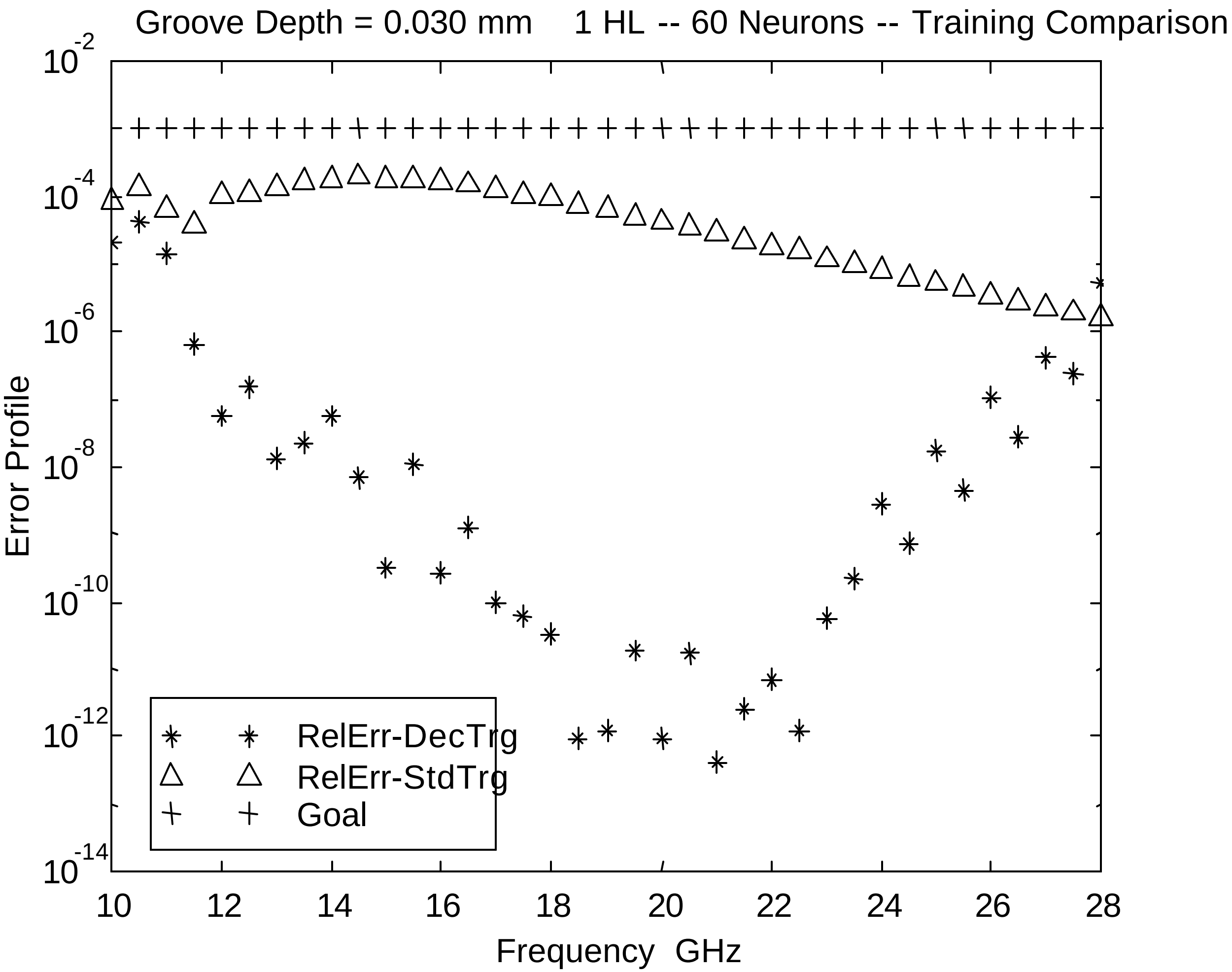
[A. Chubukjan, "Computational Aspects in Modelling Electromagnetic Field Parameters in Microstrips, " Ph.D. Thesis, University of Ottawa, 2000]

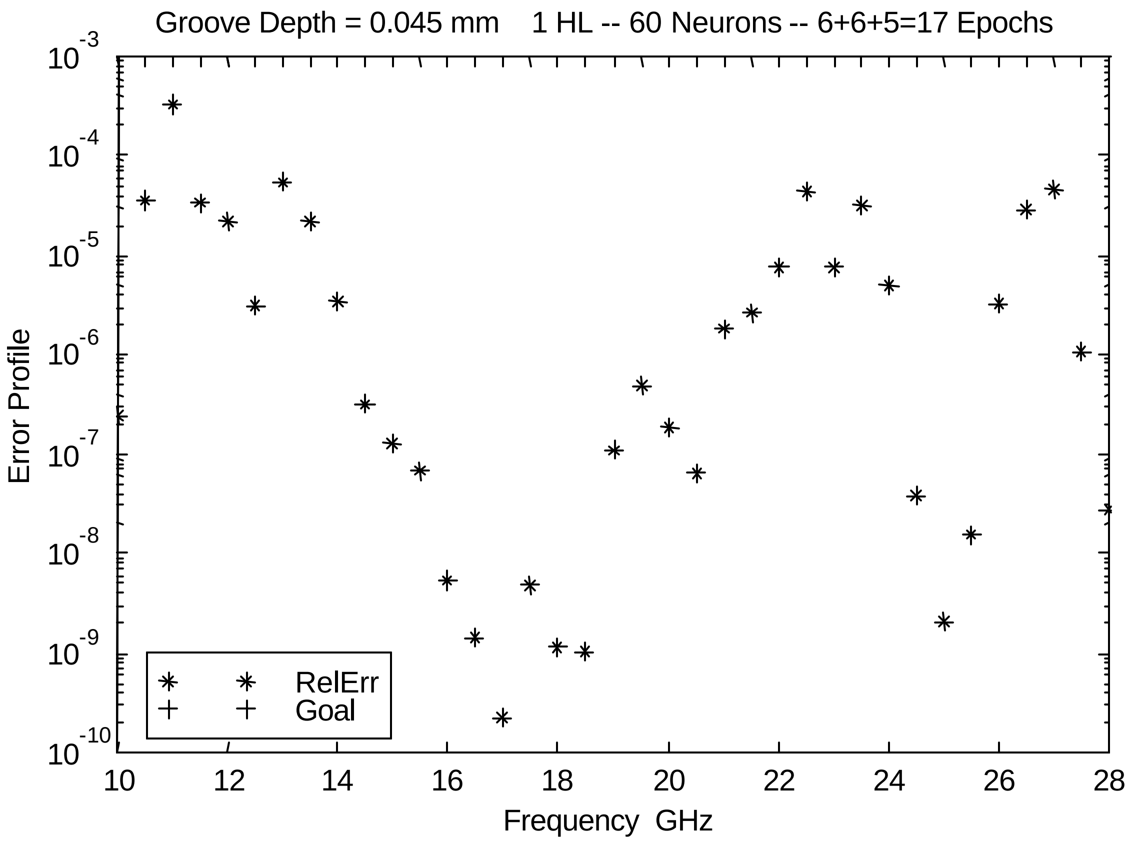
- The problem was solved by "Vector Finite Element Method" VFEM, and the values of the microstrip characteristic impedance for both plain and grooved geometries were obtained. These values describing both the frequency-dependent and/or groove-dependent behaviour of each microstrip geometry were used to train the NN models.

- A feedforward network with backpropagation, having one or more hidden layers with non-linear transfer functions and one output layer with a linear transfer function, is capable of approximating any function with a finite number of discontinuities with arbitrary accuracy. A two-layer sigmoid/linear NN can represent any functional relationship between inputs and outputs if the sigmoid layer has enough neurons.

❖ The grooved microstrip was modelled initially by two separate one hidden-layer NN architectures, having 50 and 60 hidden neurons respectively. These networks were trained both by decimation and by the standard way. The resulting error obtained by decimation was comparable to that obtained by standard training, and at times, was superior. The networks reached the desired error goal easily, with excellent sum-squared error figures. Nevertheless, the NN architecture with 60 neuron hidden-layer gave better results compared to the 50 neuron hidden-layer architecture, and it was selected for further modelling.

Error performance for standard and decimated training of a “60 neuron one hidden-layer” NN model of grooved microstrip.





Error performance for standard and decimated training of a "60 neuron one hidden-layer" NN model of grooved microstrip.

MODEL CALIBRATION

The whole idea of virtual prototyping relies on the ability to develop ***models conformable to the physical objects and phenomena*** which represent reality very closely.

⇓

There is a need for ***calibration techniques able to validate the conformance with the physical reality of the models*** incorporated in the new prototyping tools.

Experimental Measurements

- The EM field training data are conveniently obtained as analytical estimations of far-field values in 3D space and frequency from near-field data using the finite element method combined with method of integral absorbing boundary conditions.
- The near field data could be obtained analytically and/or by physically measuring EM field values at for given frequency values and 3D space locations.
- This approach allows to replace the usual cumbersome open site far-field measurement technique by anechoic chamber measurements.

The amount and extent of the area of measurements is significantly reduced by collecting data in the near-field only and calculating then the far-field values using Poggio's equation:

$$H(r') = \frac{1}{4\pi}\int_{s1}\left[G(r,r')\frac{\partial H(r)}{\partial n} - H(r)\frac{\partial G(r,r')}{\partial n} \right] dS_1$$

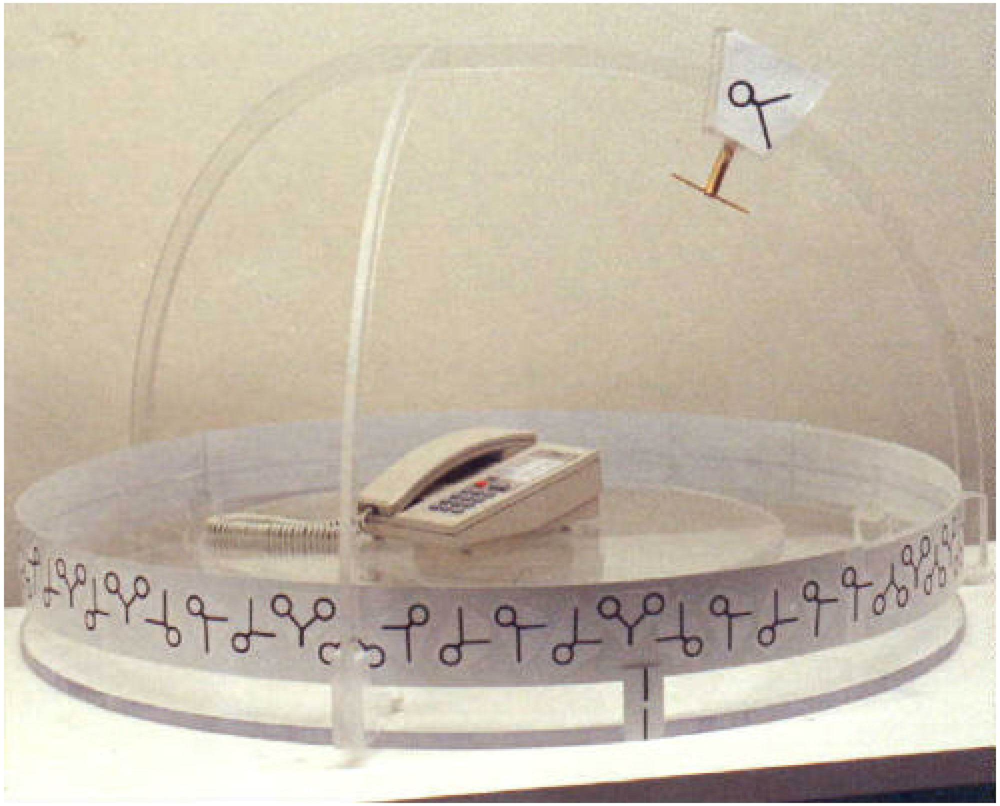
where:

-S_1 is the surface on which measurements are made, closed or made closed,

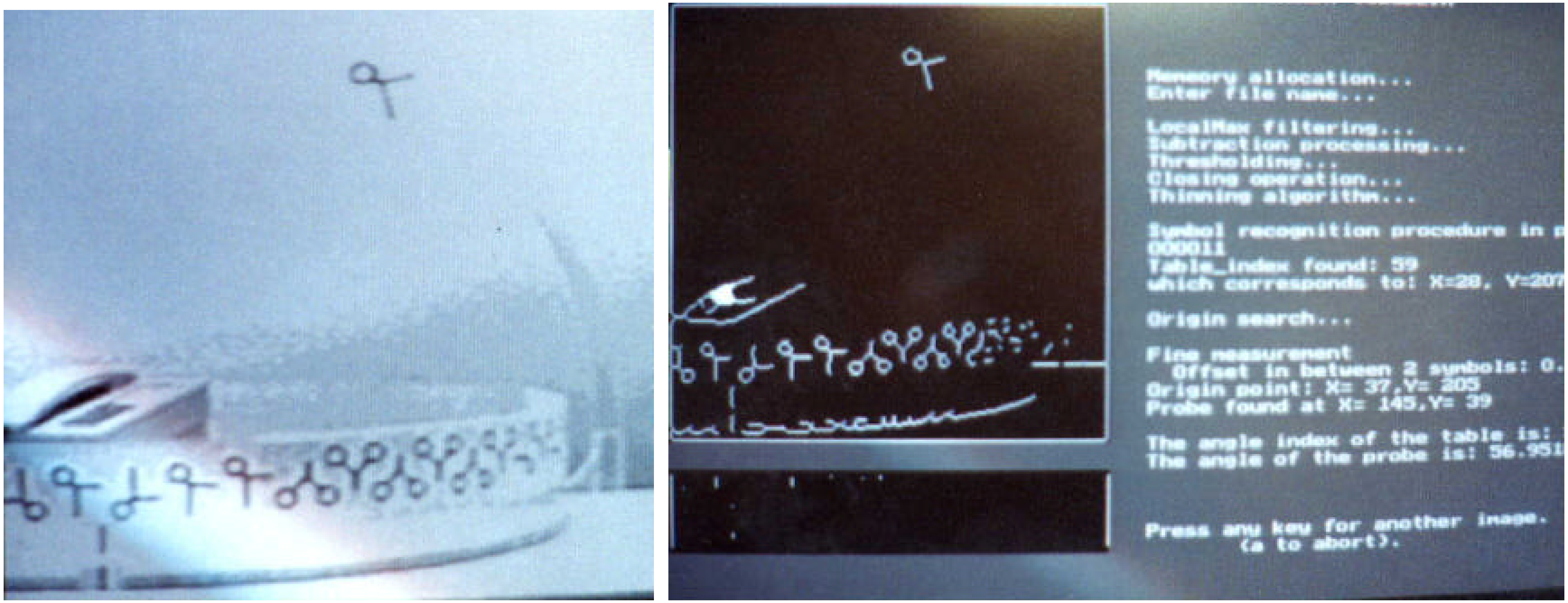
-n is the normal to S_1 and

is the free space Green’s function.

- *This equation states that if the field values and their derivatives are known on a closed surface enclosing all inhomogeneities, then the field outside the surface can be calculate*



Experimental setup for the noninvasive measurement of the 3D near field data



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Subtraction processing...
Thresholding...
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Origin search...

Fine measurement
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Computer vision recovery of the 3D position of the EM probe