# *Constructing the Lagrangian of VLSI Devices from Near Field Measurements of the Electric and Magnetic Fields*


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### *Abstract*

*This paper describes a method whereby the Lagrangians of a set of near field measurements over the surfaces of VLSI devices are constructed. By studying the Lagrangian of a VLSI device, and applying least action principles, one is able to determine packaging effects over a broad frequency range and make a decision as to which package type is better in terms of its electromagnetic compatibility.*


### Introduction

Classical mechanics operates with two types of parameters; a complete system of equations of motion and a complete set of initial conditions. The Lagrangian is defined as the sum of kinetic and potential energies:

$$L = KE - PE = T - V$$

The kinetic energy is a function of $\dot{x}$, but not of $x$, whereas potential energy is a function of $x$, but not of $\dot{x}$.

The Lagrangian has the property that

$$\frac{\partial L}{\partial \dot{x}} = \frac{\partial T}{\partial \dot{x}}$$

$$\frac{\partial L}{\partial x} = -\frac{\partial V}{\partial x}$$

Proceeding by analogy, since the magnetic field, $\vec{H}$, is proportional to $\frac{dq}{dt}$, and $\vec{E}$ to $q$, we have for the Lagrangian

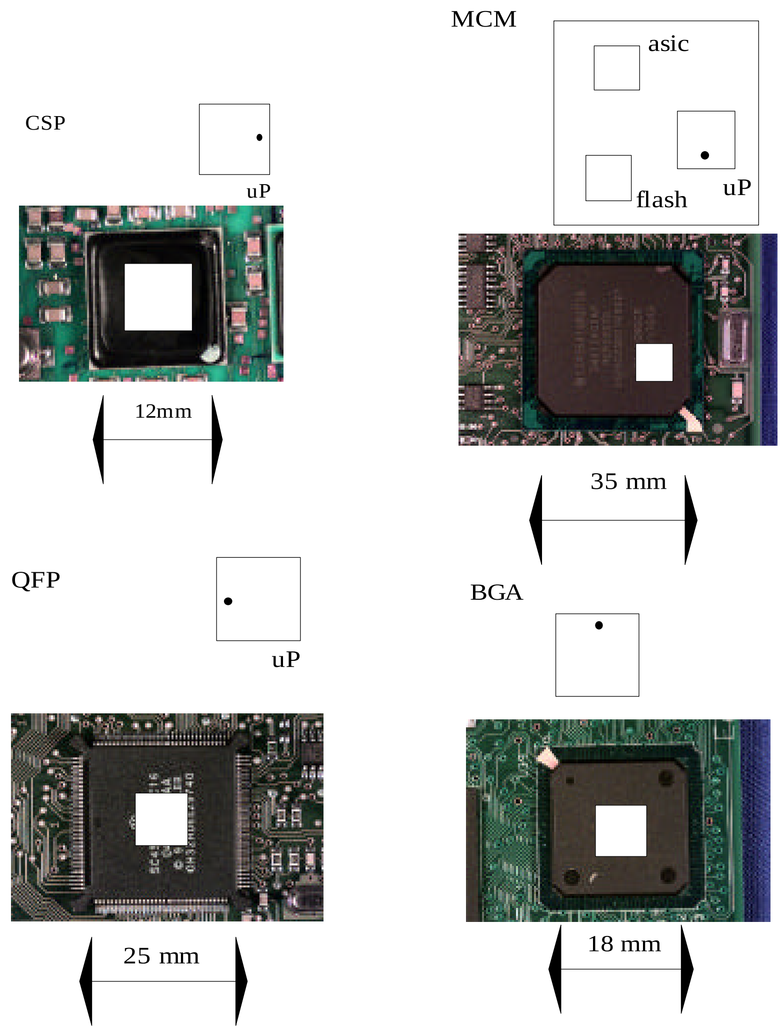
$$L(\dot{q}, q) = T(\dot{q}) - V(q)$$

We then assign the mean normalized arrays of the measured field quantities to the kinetic and potential energy terms

$$L(\dot{q}, q) = \langle |H| \rangle^2 - \langle |E| \rangle^2$$

Where $\langle |H| \rangle$ is the summation of each measured array of the magnetic field, mean normalized, at a discrete set of frequencies. And similarly for the electric field array. In constructing the summation we have assumed a weighting factor =1.

In the devices that we will compare, the actual VLSI dies are identical but they are embedded within quite different topologies. The package types that we show are: QFP, quad flat pack; BGA, ball grid array; CSP, chip scale package: MCM, multi-chip module. They are shown in Figure 1.




16 bit microcontroller in 4 packages

Figure 1

We start with the observables, two arrays of 100 x 100 discrete points of the electric and magnetic fields measured over the surface of the VLSI devices. These quantities were measured using the surface scan technique as described in [1].

Our aim is to study the effect of different package topologies on a given VLSI die, running identical code in each implementation. Each of the devices described has been measured at the module level for conducted emissions at the I/O connector.
A comparison is given in Figure 2.

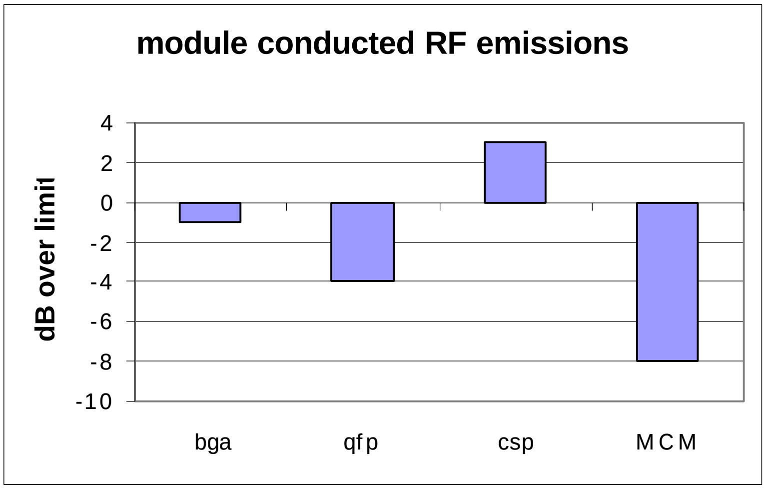



Figure 2

For the surface scan measurements, the devices were measured at multiples of the system clock, 16 MHz. The full set of measured frequencies is {32, 48, 64, 80, 96, 112, 128, 144, 160, 176, 192}. Figures 3-10 show the measured electric and magnetic fields for the four devices.

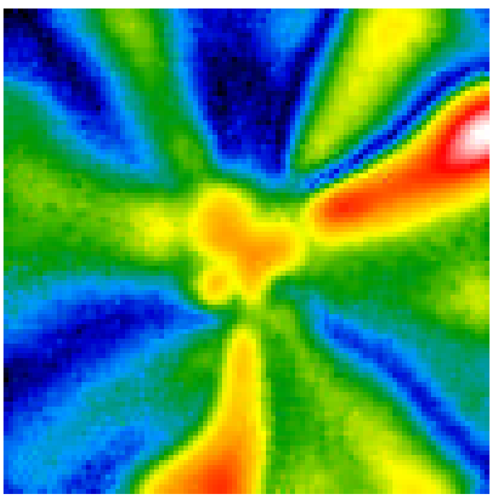


Figure3 BGA 64 MHz Electric

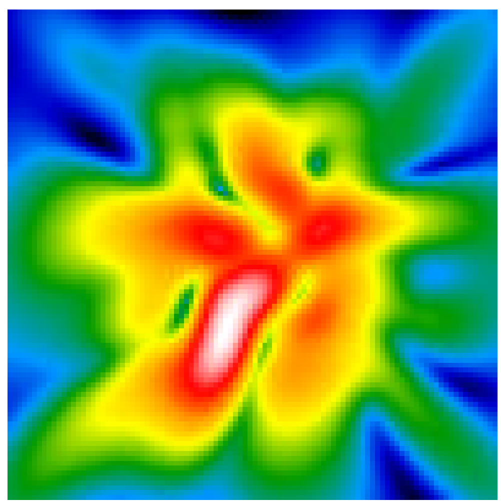


Figure4 BGA 64 MHz Magnetic

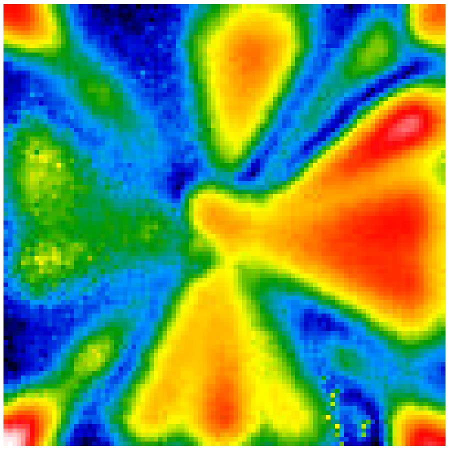


Figure 5  QFP 64 MHz Electric

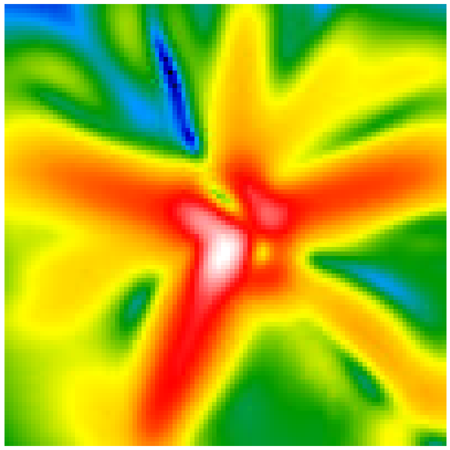


Figure 6  QFP  64 MHz  Electric

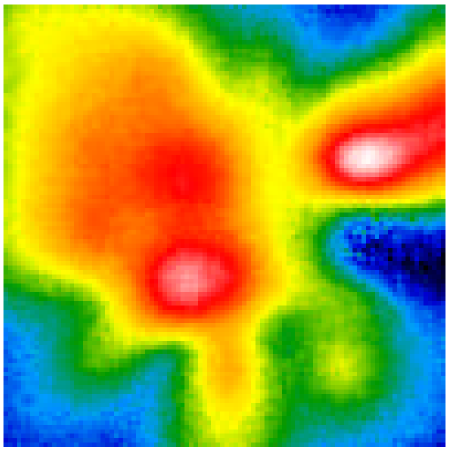


Figure 7  CSP  64 MHz Electric

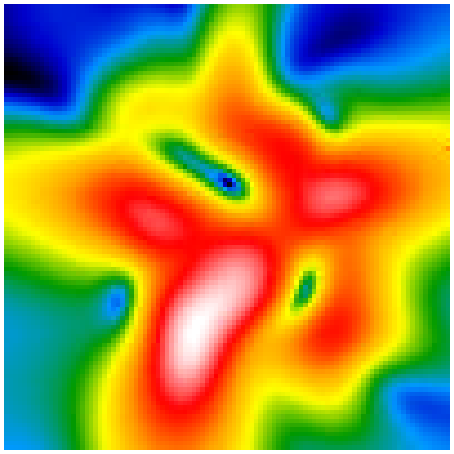


Figure 8  CSP  64 MHz magnetic

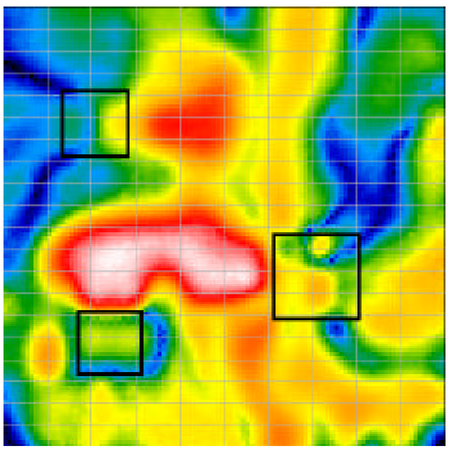


Figure 9  MCM  64 MHz  Electric

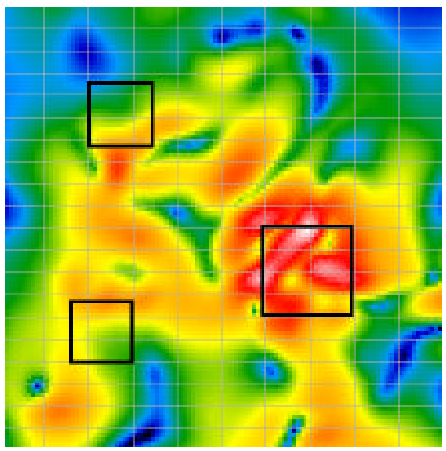


Figure 10  MCM  64 MHz  Magnetic

We construct the Lagrangian for the four devices in the following way:

$$[\mathrm{H}]_i \Rightarrow \sum_{i=1}^{n} [\mathrm{H}]_i = [\mathrm{H}]_T$$

$$[\mathrm{E}]_i \Rightarrow \sum_{i=1}^{n} [\mathrm{E}]_i = [\mathrm{E}]_T$$

$$[\langle \mathrm{H} \rangle] = \frac{[\mathrm{H}]_T}{\overline{[\mathrm{H}]_T}} \Rightarrow H(x,y)$$

$$[\langle \mathrm{E} \rangle] = \frac{[\mathrm{E}]_T}{\overline{[\mathrm{E}]_T}} \Rightarrow E(x,y)$$

$$L(x,y) = \frac{(m_0 H(x,y) - je_0 E(x,y))^2 - (e_0 E(x,y) + jm_0 H(x,y))^2}{((m_0 H(x,y) - je_0 E(x,y))(e_0 E(x,y) + jm_0 H(x,y)))}$$

H and E are the measured magnetic and electric matrices. The total matrix is a sum of each matrix measured at each frequency. The total matrix is then mean normalized.

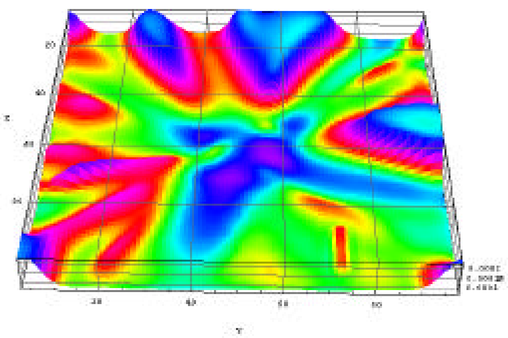


Figure 11 QFP Lagrangian

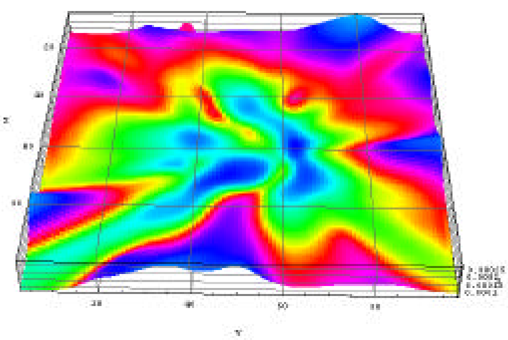


Figure 12 BGA Lagrangian

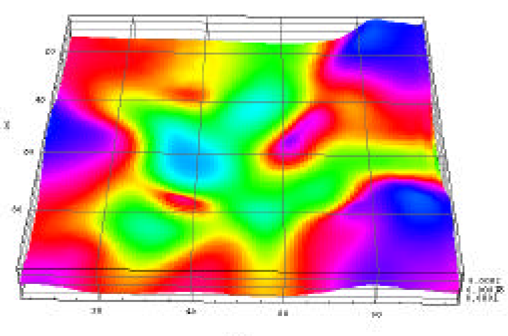


Figure 13 CSP Lagrangian

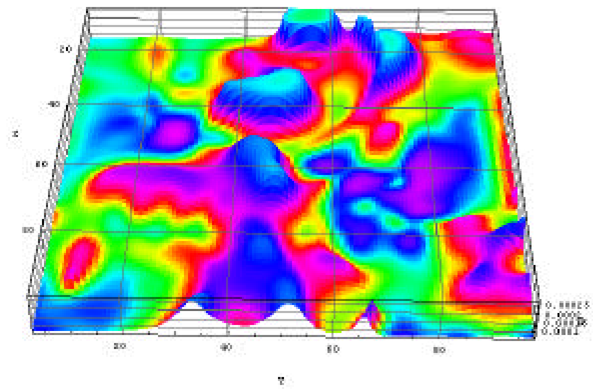


Figure 14 MCM Lagrangian

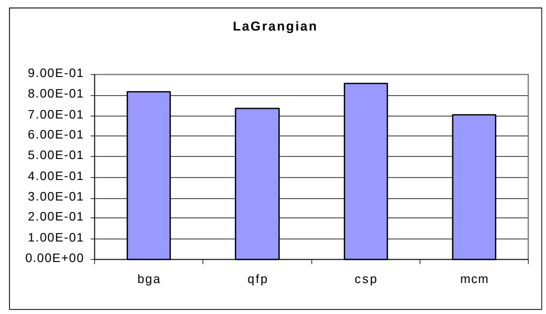



Figure 15 Comparison of Total Lagrangians across all packages

We can see that for those devices having low module emissions, and also a minimum Lagrangian, that the strong magnetic regions are closely balanced by strong electric regions.

If the device has good local energy storage, it will not demand energy from outside the device during high frequency switching. Demands for energy external to the device will lead inevitably to noise propagation throughout the entire module.

We show this in Figure 16, where the total Lagrangian has been calculated.

$$\text{Total Energy} = \sum_{k=1}^{n} \left| m_0 H(x,y)^2 - e_0 E(x,y)^2 \right|$$

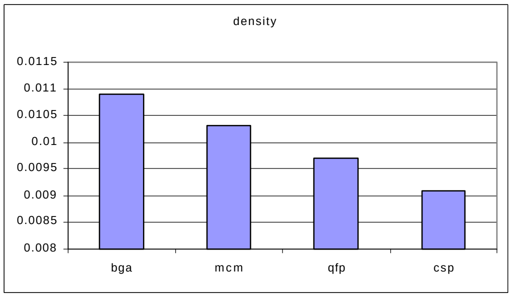



Figure 16 A comparison between devices of the Total Lagrangian

Clearly, the CSP package has the least amount of local energy storage at high frequency.

Finally, Figure 17 shows artwork for a layer from the MCM with the MCM total Lagrangian overlaid.

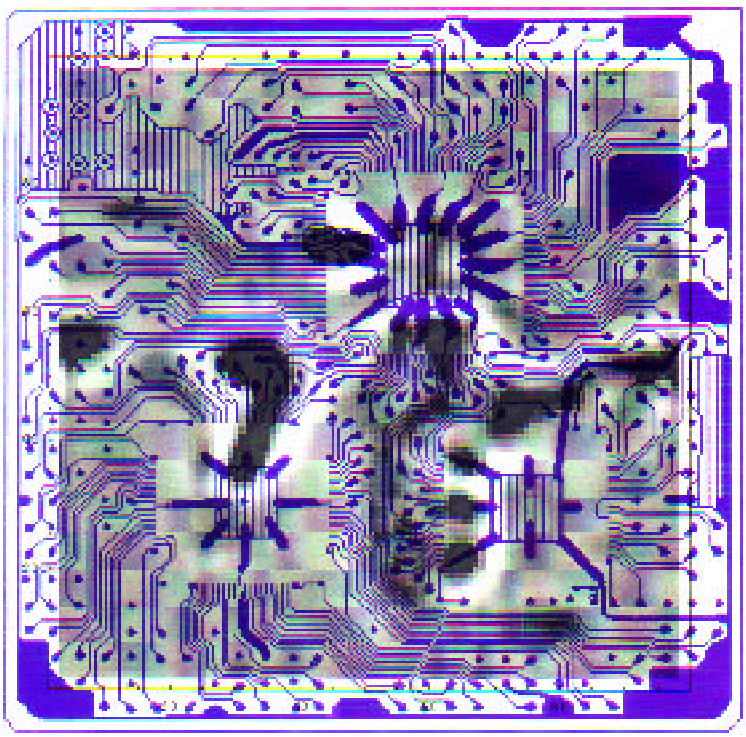


Figure 17 Overlay of MCM Lagrangian with upper layer artwork

**Conclusion**

Different packaging schemes can have a significant effect upon module level EMC. The technique of the Lagrangian may allow for EMC considerations to applied during IC layout. By associating the characteristic inductance matrix with the magnetic field component, and the characteristic capacitance matrix with the electric field component, the Lagrangian could be calculated during either IC or PCB layout. By building an algorithm that seeks a minimum Lagrangian, we should be able to ensure better EMC when the module is tested.

**References**

1. Measuring the Electric and Magnetic Near fields in VLSI Devices, K. Slattery, W. Cui, 1999 IEEE EMC Symposium, Seattle.