Library Harmonization Project

Proposal of energy as an independent library cell characterization dimension

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Introduction

Energy is a common quantity. Energy conservation is an important "bottom line" quantity used to verify results of various computations or to measure various effects. Various forms of energy are commensurable:

Kinetic energy in mechanics: $U_k = \frac{1}{2} m v^2$; m is mass; v is speed. (1)

Potential energy in mechanics: $U_p = kx$; k is a constant; x is a distance. (2)

Heat energy: $U_T = \frac{3}{2} k_B T$; k_B is Boltzmann's constant; T is temperature in K.

Energy in an electrical circuit may be defined "kinetically" by the electromagnetic field, for example, by integrating the Poynting vector, $\vec{S} = \vec{E} \times \vec{H}$, which gives power per unit area A, so that,

$$U_{EM} = A \int dt \left|\vec{E}\right| \left|\vec{H}\right| \text{; often, } U_{EM} \cong A \cdot t \cdot E \cdot H . \quad (3)$$

We are more interested in forms easily expressed in layout terms: These forms of energy are calculated by kinetic-like formulae, as in Eq. (1), but they represent potential energy:

Energy stored in the electric field of a capacitor:

$U_C = \frac{1}{2} C V^2$; C is capacitance (farads); V is electric potential (volts). (4)

Energy stored in the magnetic field of an inductor:

$U_L = \frac{1}{2} L I^2$; L is inductance (henrys); I is current (amperes). (5)

The typical capacitance of a storage cell in deep submicron layout is in the femtoFarad to picoFarad range, somewhere around $50 \cdot 10^{-15}$ F to $1000 \cdot 10^{-15}$ F.

[jmw: not sure yet of inductance range of traces]. Both capacitance C and inductance I can be estimated from cell geometry and composition, or measured in-circuit.

Capacitance and inductance already are well defined as cell characteristics. However, the concept of energy is necessary to compare these two different characteristics as well as to convert one into the other.

Two Energy Characterization Problems

We wish to characterize a cell by energy in order to estimate (*a*) effects of ***electrical*** energy on normal operation as well as (*b*) effects of ***nonelectrical*** energy on operation and composition of the cell. Knowing how energy from outside affects a cell implies that we know how energy is used internally by the cell.

We assume that external electrical energy will be delivered on the connections of the cell. Nonelectrical energy would include conducted heat, mechanical motion (bending, compressing, stretching, sound, etc.), and particle invasion. Invasive particles may be photons (gamma rays, X-rays, light, radiant heat, microwaves, etc.) or massive particles such as alpha, beta, or neutrons.

It seems that all cell characterization problems should be describable either by cell functionality; or, failing that, by cell geometry and composition. The latter may be called structural for brevity.

Functional Characterization - Electrical Only

This requires description of a standard way to inject electrical energy on the pins of a cell, and a way of measuring the effect.

The input suggestion here is to apply a pulse with characteristics derived from normal operating conditions. For example, for a digital cell with rise time t_R and fall time t_F, perhaps a pulse of duration $t_R + t_F$ and variable height might be applied. The energy of such a pulse would be proportional to $(t_R + t_F) \cdot V$, with V the height in volts.

The output suggestion here is to measure switching thresholds for digital cells, and operating curves in various (amplifier?) configurations for analogue cells.

Structural Characterization - Nonelectrical and Electrical

This requires a description of the geometry and composition of a cell regardless of its overall functionality but attending to elementary substructures such as P-N junctions, FETs, trace lengths, via depths, oxide thicknesses, etc.

The input suggestion is localized application of nonelectrical energy.

The output suggestion is electrical, the same as in Functional Characterization above.