SA-1-3

Modeling of Inductive Interconnect Responses and Coupling Effects

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1. Introduction

Recently, with the parameter sizes entering Deep Sub-Micron (DSM) range, inductance has become an important consideration in the design and analysis of on-chip interconnects. Therefore, there is a need to model inductive interconnect and its responses. In this work, modeling of inductive interconnects is employed, analytical expressions are shown, and numerical calculation as well as circuit simulation are figured. Thus, inductive effects in single line and adjacent lines can be concluded analytically.

2. Notations

Fig. 1 shows gate driving inductive interconnects and load capacitance. The parameters are described as shown in Table 1. For analyzing, however, instead of using the real parameters, normalized parameters, which are ones normalized by R and C, can be used to simplify expressions.

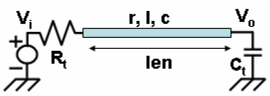

Fig. 1 Single interconnect

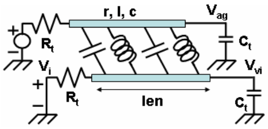

Fig. 2 Two adjacent interconnects

Table 1 Notations

R_t = input buffer resistance	τ = t / (R·C) = normalized t
C_t = load capacitance	r_T = R_t / R = normalized R_t
R = r · len = int. resistance	c_T = C_t / C = normalized C_t
L = l · len = int. self inductance	l_T = L / (R^2·C) = normalized L
M = m · len = int. mut. inductance	m_T= M / (R^2·C) = normalized M
C = c · len = int. capacitance	η = C_c / C = normalized C_c
C_c= c_c · len = int. coupling cap.	ζ = 1+2 η, χ = x / len,
len= int. length	$\mu_\pm$ = $l_T \pm m_T$, σ' = $\sigma \cdot \zeta$, τ' = τ / ζ,
σ = s·R·C = normalized s	c_T'= c_T / ζ, μ_-' = μ_- / ζ

3. Transient response in single line

Expression (1) shows output transient response expression V_o, using normalized parameters. Note that this expression is derived from transfer functions with telegrapher's equations for interconnect part, and step function is given for input voltage V_i.

$$V_o(\sigma) = \frac{V_{DD}}{\sigma}\frac{1}{A} \tag{1}$$

where

$$A = (1+\sigma r_T c_T)\cosh\sqrt{\sigma(1+\sigma l_T)} + \sqrt{\frac{\sigma}{1+\sigma l_T}}\{r_T + c_T(1+\sigma l_T)\}\sinh\sqrt{\sigma(1+\sigma l_T)}\,.$$

Since output response can be figured only in time domain, so we have to inverse Laplace function (1) to time domain function. However, inversing Laplace function (1) results in very difficult and complicated expressions [1]. Thus, instead of using A-function as in (1), approximation function of A needs to develop. Let's call this approximation function as D-function in this paper as follows. For $0 \le \tau \le l_T^{1/2}$, $V_o(\sigma) = 0$, and for $l_T^{1/2} \le \tau$,

$$V_o(\sigma) = \frac{V_{DD}}{\sigma}\frac{1}{l_T(c_T+0.5)\sigma^2 + (r_T \cdot c_T + r_T + c_T + 0.5)\sigma + 1}\,. \tag{2}$$

4. Coupling in two adjacent interconnects

Fig. 2 shows two adjacent interconnects. V_{ag} and V_{vi} are output response of aggressor and victim lines respectively. Crosstalk occurs in victim line due to inductive and capacitive coupling from aggressor line. To model adjacent interconnects analytically, two new parameters, fast wave and slow wave, are introduced as follows, $V_+ = V_{ag}+V_{vi}$, and $V_- = V_{ag}+V_{vi}$. Since V_+ (V_-) can be expressed with expression (1) by substituting V_+ (V_-) in V_o, A_+ (A_-) in A_o, μ_+ (μ_-') in l_T, c_T (c_T') in c_T, and σ (σ') in σ. Thus by using D-function, waveform of crosstalk in victim line can be figured and calculated analytically.

5. Results

50% propagation delay is calculated using D-function and compared to data from circuit simulation result using distributed lossy element, which is so-called W element in Star-Hspice. The parameters are r_T=c_T={0.0, 0.2, 0.5, 0.8, 1.0} and l_T= {0.01, 0.5, 1.0, 1.5, 2.0}, so total is 125 cases. The result is as follows. For $c_T \ge 0.5$, error can be kept less than 10%. Others, the error range is increasing to 30%, but still most part is less than 10%. Similar result is obtained if 50% propagation delay expression proposed in [2] is compared to circuit simulation result. Especially for two adjacent optimally buffered global interconnects, waveform of crosstalk in victim line can be also generated as shown in Fig. 3.

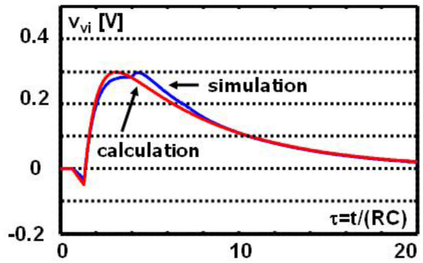

Fig. 3 Crosstalk in victim line where V_{DD}=1V

6. Conclusion

Proposed approximation function (D-function) not only can be used for calculating propagation delay as accurate as expression in [2], but also can figure the waveform of transient response. Applying two D-functions, waveform of crosstalk can be generated and crosstalk peak can be calculated. More accurate approximation functions are also being developed.

7. References

[1] J. A. Davis and J. D. Meindl, "Compact Distributed RLC Interconnects Model — Part I and II," IEEE Trans. ED, vol. 47, no. 11, pp. 2078-2087, Nov. 2000.
[2] Y. I. Ismail and E. G. Friedman, "Effects of Inductance on the Propagation Delay and Repeater Insertion in VLSI Circuits," IEEE Trans. VLSI Systems, vol. 8, pp. 195-206, Apr. 2000.