–P. 758–760. 3. Haykin S., Stehwien W., Deng C., Weber P., Mann R. Classification of Radar Clutter in an Air Traffic Control Environment, Proc. of the IEEE. – Vol.79. – №.6. June 1991.– P. 742–771. 4. Bouvier C., Martinet L., Favier G., Sedano H., Artand M. Radar Clutter Classification Using Autoregressive Modelling, K-distribution and Neural Network, Proc. IEEE, Int. Conf. Acoustic, Speech & Signal Processing – ICASSP'95, Detroit, USA, May 1995. – P.1820–1823. 5. Jakubiak A. et. al. Radar clutter classification using Kohonen neural network, in Proc. RADAR'97 Conf., Edinghburg, UK, Oct. 1997. – P. 185–188. 6. Conte E. et. al. Modelling and simulation of non-Rayleigh radar clutter, Proc. Inst. Electr. Eng. Part F. – Vol. 138. Apr. 1991. – P. 121–131. 7. Sekine M. et. al. On Weibull-distributed weather clutter", IEEE Trans. on AES. – Nov. 1979. – Vol. AES-15. – P. 824–828.

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MODELLING OF GEOMETRIC DEPENDENCIES OF PARASITIC CAPACITANCES IN INTERCONNECTION BUSES

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Зростання складності сучасних інтегральних схем призводить до зростання важливості таких ефектів, що виникають між з'єднаннями, як затримки та перехресні завади. Ці ефекти визначаються паразитними елементами відповідно до з'єднувальних ліній. Аналізується вплив геометричної конфігурації шин на паразитні ємності. Для цього була виведена формула для покращання точності ємнісних моделей.

Increasing complexity of modern integrated circuits causes that importance of effects occurring in interconnections, such as delay and crosstalk, grows. These effects are determined by parasitic elements corresponding to the connection lines. In this paper we discuss influence of geometrical configuration of the bus on parasitic capacitances. Suitable formulas improving accuracy of capacitance models have been developed.

Introduction

Continuous progress in VLSI technology enables increasing of the circuits' scale of integration. Modern chips including millions of transistors become more and more complex and their area grows. As a result, complexity of the net of conductive lines connecting devices in the subcells and leading signal between the subcells rapidly grows too. In effect propagation parameters of the interconnections are even crucial for performance of the circuit. These parameters strongly depend on values of parasitic elements corresponding to the interconnection lines. For this reason availability of effective models allowing to determine parasitic capacitances is indispensable for correct verification of the circuit.

In our previous works [1-3] we discussed some problems of interconnection capacitance modelling. Numerical methods, used in such computer programmes as CAPCAL [4] and FastCap [5-7] are too time-consuming for verification of large circuits, especially during statistical verification. For such purposes empirical models have to be used. But existing empirical models [8-12] determine the capacitance values basing only on line dimensions (width (W) and thickness (T)) and on spacing between the line and closest neighbours (spacing between lines (S) and distance to the plane (H)). In our works we have shown this approach is not justified for lines on one plane (Fig. 1). In such a case further lines intercept part of the flux and influence the values of *Caf* (capacitance between the line and the plane) and *Ccoup* (capacitance between the lines). It is less important for connections inside the subcells, because of their relatively low lengths. But lines leading signal between subcells may be long (even several centimetres) and these effects should not be neglected.

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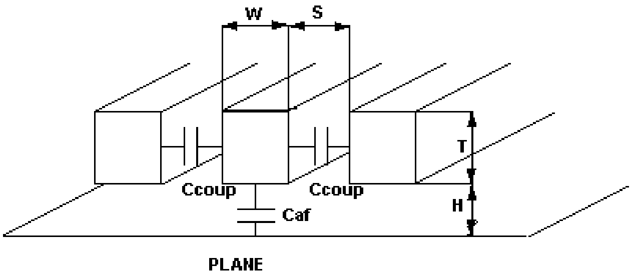

Fig. 1. Parallel lines on one plane. Ccoup-*capacitance between the lines,*
Caf -*capacitance between the line and the plane*

Earlier we considered the influence of the line's neighbourhood on the *Caf* values and created a model of this influence, presented in [3]. It allows to evaluate the *Caf* values for connection lines with different number of neighbour lines on both sides.

In this paper in Section II we discussed further neighbourhood influence also on *Ccoup* values. This influence is much less significant than in the case of the *Caf* value (Section III). In Section IV we discussed usability of our model of further neighbourhood influence on *Caf* value [3] when spacings between the lines in the bus are not the same.

Further neighbourhood influence on *Ccoup*

In [1-3] we have shown that neglecting the further neighbourhood influence on *Caf* may introduce significant errors of circuit simulation results. Here we verify this influence for *Ccoup* too. In our work we used numerical simulator CAPCAL [4]. Borders of the solution area were placed far enough to make simulation results practically independent of them.

We observed that practically only two closest lines on every side of *Ccoup* capacitance influence its value (Figs. 2 and 3). We decided to check significance of this influence for different sets of line dimensions. The result *Ccoup* values for the middle line in 3-lines and 15-lines bus are presented in Table I. Deviation between *Ccoup* for line with large number and with minimal number of neighbours on every side depends on lines dimensions but is only several percent. In the case of successive lines in one bus these deviations would be much smaller.

It may be observed that increasing distance to the plane (H) increases the deviation. That is because the plane intercepts less of the flux and influence from the further line is stronger. But still this influence is rather weak. Our observations indicate that we may neglect further neighbourhood influence evaluating capacitances between parallel lines on one plane.

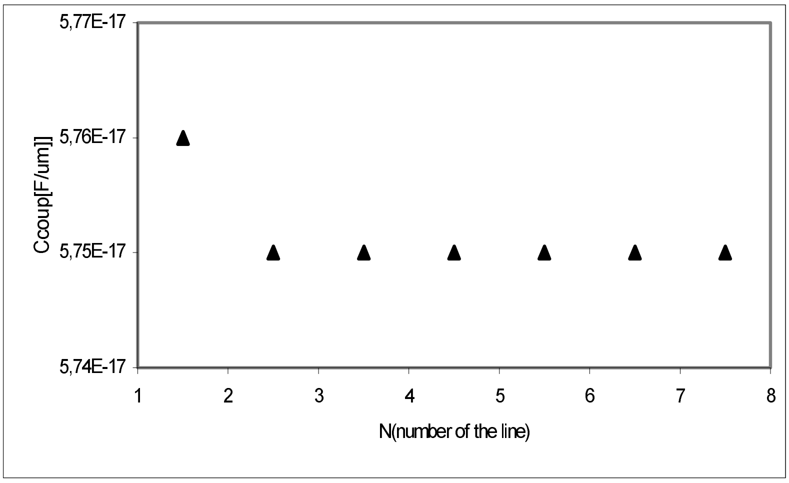

Fig. 2. Capacitances between successive lines in 15-lines bus. Lines on one plane,
W=*0.4μm,* T=*0.7μm,* S=*0.6μm,* H=*0.6μm*

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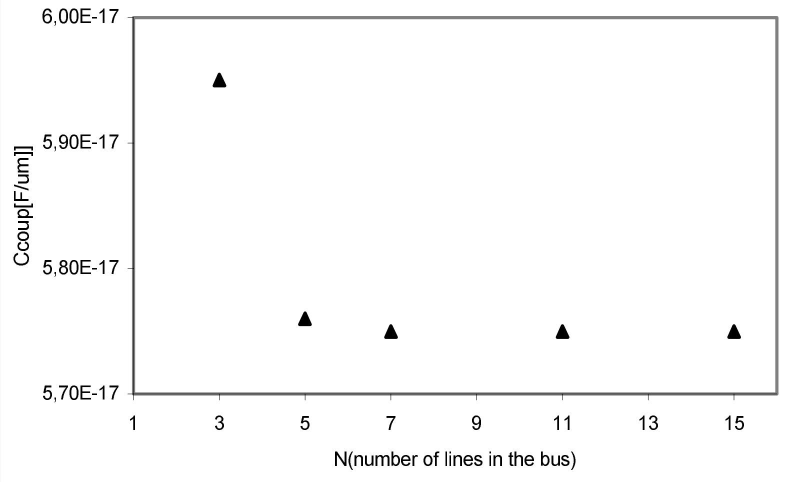

Fig. 3. Capacitances for the middle line for different number of lines in the bus. Lines on one plane, W=*0.4μm,* T=*0.7μm,* S=*0.6μm,* H=*0.6μm.*

Table I

***Ccoup* for middle line in 3-lines and 15-lines bus**

T[μm]	*S*[μm]	*H*[μm]	*W*[μm]	*Ccoup*, **3 lines** [aF/μm]	*Ccoup*, 15 lines [aF/μm]	deviation [%]
0.2	0.2	0.3	0.2	61.3	59.3	3.4
0.2	0.2	0.3	1	73.5	72.2	1.8
0.2	0.2	1.3	0.2	71.5	66.6	7.4
0.2	1	1.3	0.2	21.4	20.1	6.5
0.5	0.5	0.3	1	55.3	54.1	2.2
0.5	0.5	1	1	68.2	66.2	3
0.5	1	0.3	0.2	20.5	19.8	3.5
0.5	1	1	0.2	30.3	28.8	5.2
0.6	1	1	0.4	36.7	35.1	4.6
0.6	1	2.5	0.4	44	40.9	7.6
0.6	0.5	1	0.4	68.3	65.6	4.1
0.7	0.6	0.6	0.4	59.5	57.5	3.5
0.7	0.6	1.6	0.4	67.9	64.5	5.3

Model of further neighbourhood influence on *Caf*

Further neighbourhood influence on the *Caf* values is significantly stronger than in the case of *Ccoup*. Distinctions between *Caf* for the lines with different number of neighbours may be much larger (Table II) and more neighbour lines affects every *Caf* value (Figs. 4 and 6). Neglecting this influence may introduce significant errors so we created model of this effect (Eqs. 1-4), allowing to determine *Caf* for lines with different number of neighbours [3]. In [3] we assumed the spacing between parallel lines (*S*) to be constant. In next section we present modification of the model for different S values.

$$Caf(N)=\frac{\frac{NL-1}{4}}{\frac{3}{Caf(3)}+B*\frac{NL-7}{2}}+\frac{\frac{NR-1}{4}}{\frac{3}{Caf(3)}+B*\frac{NR-7}{2}} \tag{1}$$

where

$$B = X + 0.9 * Y * H \tag{2}$$

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Table 2

Caf for middle line in 3-lines and 15 lines bus

T[µm]	S[µm]	H[µm]	W[µm]	Caf, **3 lines** [aF/µm]	Caf, 15 lines [aF/µm]	deviation [%]
0.2	0.2	0.3	0.2	55.2	46.6	18.5
0.2	0.2	0.3	1	14.9	13.9	7.2
0.2	0.2	1.3	0.2	21.9	12.7	72.4
0.2	1	1.3	0.2	39.4	3.02	30.5
0.5	0.5	0.3	1	172	162	6.2
0.5	0.5	1	1	61.5	52.6	16.9
0.5	1	0.3	0.2	103	94.2	9.3
0.5	1	1	0.2	47.4	38.1	24.4
0.6	1	1	0.4	54.4	45.1	20.6
0.6	1	2.5	0.4	29.9	20.3	47.3
0.6	0.5	1	0.4	40.4	32	26.3
0.7	0.6	0.6	0.4	63.4	54.7	15.9
0.7	0.6	1.6	0.4	31.6	22.9	38

$$X = \frac{1}{W^{1.5}} E14 + \left(\frac{5}{\exp\left(W^{1.6}\right)} - \frac{1}{W^{0.7}} \right) E15 * S \qquad (3)$$

$$Y = \frac{1}{\left(1.65 + 29 * (S + W)\right) E(-18)} \qquad (4)$$

Caf(3) – *Caf* value for the middle line in 3-lines bus.

NL, *NR* – numbers of parallel lines on left and right side of the modelled one

Caf(3) may be determined analytically, but to avoid error of *Caf*(3) evaluation, for verification of our model we used CAPCAL values.

In Figs. 4-7 capacitances achieved with our model and one of existing empirical models (Wong's model [12]) are compared to CAPCAL results. Wong's model does not depend on further neighbourhood configuration. Presented results shows that using our formula allows to strongly decrease errors of modelling.

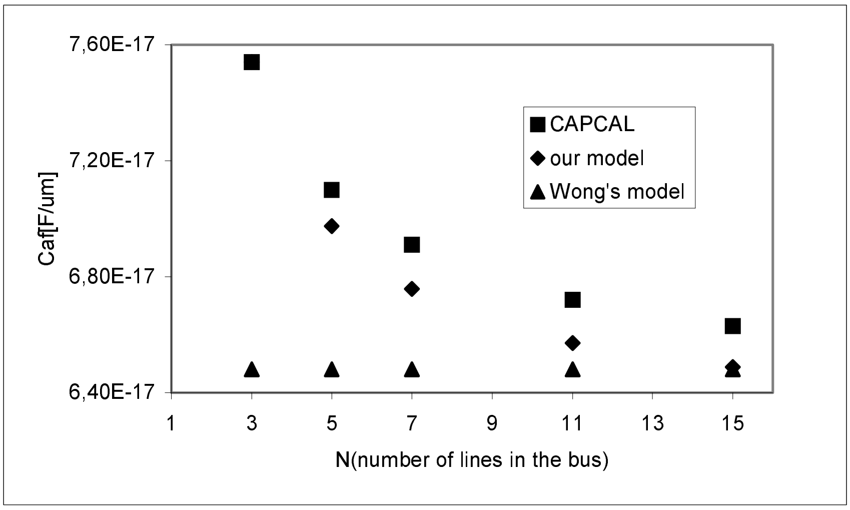

Fig. 4. Caf for the middle line in the bus for different N value, achieved with CAPCAL, our model and Wong's model [12]. T=S=H=W=*0.5µm. [3]*

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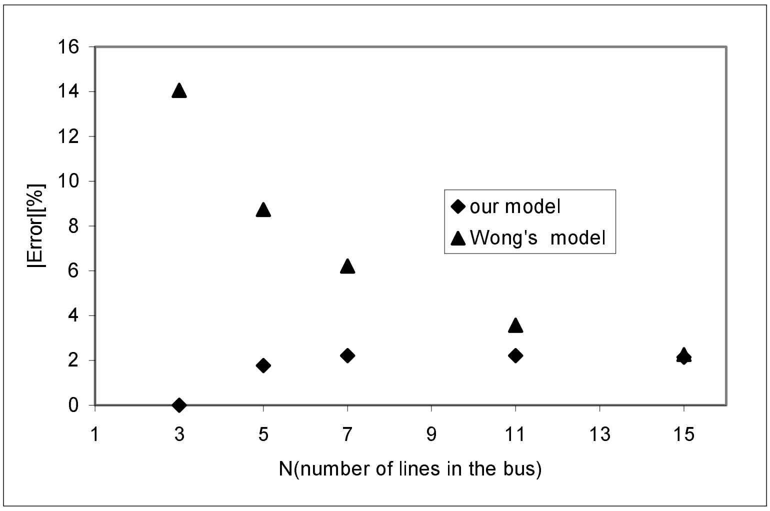

Fig. 5. Error of Caf value for the middle line in the bus obtained with our model and with Wong's model [12]. T=S=H=W=*0.5μm. [3]*

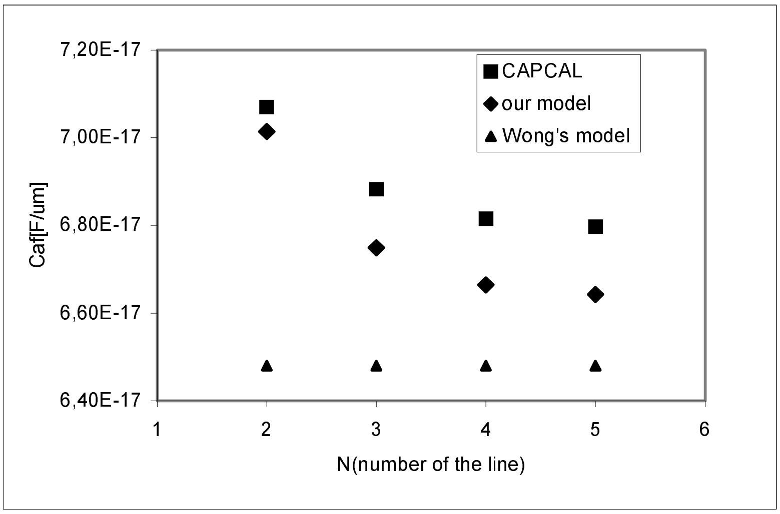

Fig. 6. Caf for successive lines in the 9-lines bus, from CAPCAL, our model and Wong's model [12]. T=S=H=W=*0.5μm. [3]*

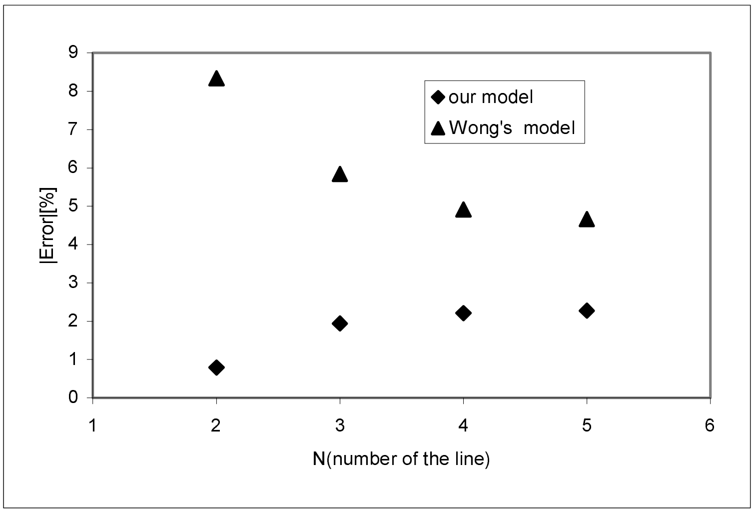

Fig. 7. Error of Caf for successive lines in 9-lines bus, obtained with our model and Wong's model [12]. T=S=H=W=*0.5μm. [3]*

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Evaluating of *Caf* values for different spacing between lines in the bus

In the case of interconnections leading signal between subcells assumption of constant spacing between the lines is usually justified. They are placed close to each other to save the area. But in some regions *S* values may change, for instant because of need to put contact to one of lines inside the bus. Our simulations have shown that when parallel lines are placed close to each other, not the number of lines but area covered by them decides about the *Caf value*. Capacitance values obtained for line with 7 neighbours on each side and with one neighbour on each side, but of width equal to area covered by those seven lines (Figs. 8a and 8b) are almost the same (Table III).

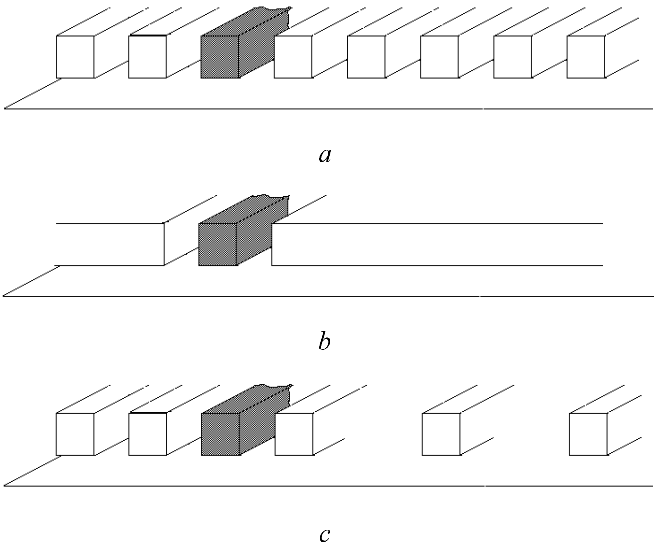

Fig. 8. Parallel lines on one plane

Table 3

***Caf* for middle line in the bus**

T[μm]	*S*[μm]	*H*[μm]	*W*[μm]	15-lines bus (Fig. 8a.) [aF/μm]	3-lines bus (Fig. 8b.) [aF/μm]
0.2	0.2	0.3	0.2	46.6	46.4
0.2	0.2	1.3	0.2	12.7	12.5
0.2	0.2	0.3	1	139	139
0.5	0.5	0.5	0.5	66.3	66.2
0.5	0.5	2.5	0.5	15.5	15.3
0.6	1	1	0.4	45.1	44.4
0.6	1	2.5	0.4	20.3	19.5
1	1	1	1	65.8	65.6

In Table IV the *Caf* values for middle line in 15-lines bus (Fig. 8a) and in modified bus, where every second line on one side of the modelled one was removed (Fig. 8c) are presented for different sets of dimensions. Even after such strong modification deviation between *Caf* for both cases is rather small.

Achieved results indicate that when lines in the bus are close to each other, changes of the width and spacing between further neighbours of the modelled line have a weak influence on the *Caf* value for this line. The area covered by those further lines determines this value. So in such cases our formula (Eq. (1))

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may be modified by defining parameters *NL* and *NR* not as number of lines on both sides of the modelled one, but from the equations:

$$NL = \frac{AreaL}{S+W} \tag{5}$$

$$NR = \frac{AreaR}{S+W} \tag{6}$$

where *AreaL*, *AreaR* – width of the area covered by lines on left and right side of the modelled line.

Table 4

Caf for middle line in the bus

T[µm]	*S*[µm]	*H*[µm]	*W*[µm]	15-lines bus (Fig.8a.) [aF/µm]	modified bus (Fig.8c.) [aF/µm]	deviation [%]
0.2	0.2	0.3	0.2	46.6	47.4	1.7
0.2	0.2	1.3	0.2	12.7	13.2	3.9
0.2	0.2	0.3	1	139	140	0.7
0.5	0.5	0.5	0.5	66.3	67.4	1.7
0.5	0.5	2.5	0.5	15.5	16.1	3.9
0.6	1	1	0.4	45.1	46.4	2.9
0.6	1	2.5	0.4	20.3	21.3	4.9
1	1	1	1	65.8	66.8	1.5

Conclusions

Further neighbourhood of the interconnection line has weak influence on the coupling capacitance between lines on one plane. Numerical simulation results show that this "neighbourhood effect" may be neglected. Contrary to that neglecting influence of further neighbours configuration on capacitance between the line and the plane may introduce significant errors, especially for long lines between subcells. Our model allows taking this effect into account in verification process. As we have shown, it may by used even for buses with disturbed geometry. Such model may be useful in verification of circuit design.

Acknowledgement

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1. Jarosz A., Pfitzner A. On some Accuracy Problems of the Interconnection Capacitance Modeling, Proc.of the 8th Int. Conf. MIXDES 2001, June 2001. – P.383–388. 2. Jarosz A., Pfitzner A. Neighbourhood Problem in Interconnection Capacitance Modeling, Proc. of the Int. Conf. TCSET'2002, February 2002. – P. 65–67, and "Radioelectronics and Telecommunications" – Academic Journal of Lviv Polytechnic National University, no. 443, February 2002.– P. 228–233. 3. Jarosz A., Pfitzner A. Model of the further Neighbourhood Influence on Interconnection Capacitance, Proc.of the 9th Int. Conf. MIXDES 2002, June 2002. – P.463–466. 4. "CAPCAL – The 3-D Capacitance Calculator for VLSI Purposes – Users Guide", Oct. 1991. 5. K.Nabors, J.White "FastCap: A Multipole Accelerated 3-D Capacitance Extraction Program", IEEE Trans. on CAD of Int. Circ. and Syst., 10(11), Nov. 1991. 6. Nabors K., Kim S., White J. Fast Capacitance Extraction of General Three-Dimensional Structures , IEEE Trans. on Microwave Theory and Techn., 40(7), July 1992. 7. Nabors K., Kim S., White J., Senturia S. FastCap

Lviv Polytechnic National University Institutional Repository http://ena.lp.edu.ua

User's Guide", Massachusetts Institute of Technology, 18 Sep 1992. 8. Sakurai T., Tamaru K. Simple Formulas for Two- and Three-dimensional capacitances, IEEE Trans. on Electron Dev.,vol.30, 1983. 9. Sakurai T. Closed-form Expressions for Interconnection Delay, Coupling, and Crosstalk in VLSI's, IEEE Trans. on Electron Dev., Jan. 1993. – Vol..40. – №1. 10. Choudhury U., Sangiovanni-Vincentelli A. An Analitical-Model Generator for Interconnect Capacitances, IEEE Custom Integrated Circuits Conference, 1991. 11. Jue-Hsien Chern, Jean Huang, L.Arledge, Ping-Chung Li, Ping Yang "Multilevel Metal Capacitance Models For CAD Design Synthesis Systems", IEEE Electron Dev. Letters, vol.13, no.1, Jan. 1992. 12. Shyh-Chyi Wong, Gwo-Yann Lee, Dye-Jyun Ma "Modeling of Interconnect Capacitance, Delay and Crosstalk in VLSI", IEEE Trans. on Semicond. Manufact., Febr. 2000. – Vol. 13.

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