Hazard analysis in CLC via time dependant logic variables

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Abstract: -The present paper considers the problem of hazard in combinatorial logic structures. We shall define an improvement for the time constants method, improvement that will consider, among other features, the specific function implemented by the gates used (we are mostly interested by the inverting characteristic). In this endeavor we shall define a new type of operator and a new type of variable, both of them applicable when propagating the switching times for a specific circuit. The time constants method is a very laborious one (considers all the possibilities disregarding the specific function implemented by a circuit). We shall prove that only a strictly limited number of situations should be considered –in conjunction with the function that is being implemented by the circuit analyzed. In order to achieve this goal we shall express the logic function with respect to a new logic variable that is time dependent. Operations with this new variable prove to have some very interesting properties (shown in the paper) that will allow us to restrain the window of possibilities for hazardous functioning to a very narrow one.

Keywords: - Combinational logic circuits, hazard, primary input vector, secondary input vector, time dependant logic variables.

1.Foreword

Our endeavor is to improve the time constants method for hazard analysis (J.Beister [4]), method based on the consideration of pure delay circuit model (McGhee [5]) and the replication of gates having fan out larger than one (McCluskey [6]) in order to define all the distinct input towards output signal paths. As known this approach implies the propagation of the delays on each distinct path from the output towards the input, in order to determine the delay array that defines the secondary input vector that is afterwards applied on the inputs of an ideal combinatorial circuit (instantaneous). Analysis of the output response of the ideal circuit to the sequence of secondary input vectors determined by a change of the primary input vector will eventually show us the presence of hazardous functioning of the circuit.

2. Definitions

2.1. Real gates & Ideal gates:

We shall maintain the equivalence between a real gate and an ideal gate + delay, as defined by the pure delay model. However because the propagation times for a gate are not identical for both transitions possible ("0"↑"1"and "1"↓"0") we shall consider the propagation time as a fraction that includes the times for each of the two transitions possible (t_{LH}/t_{HL}). Propagation of this fraction through a gate with an inverting characteristic implies the change of the nominator with the denominator (Galupa[2]).

2.2. Inverting variable & operator:

Propagating the delay from the output towards the input of a gate implies the interchange of the nominator with the denominator of the fraction expressing the delay times in case of an active inverting characteristic. In order to analyze the propagation time along a path implemented by a complex chain of gates we define variables INV and NINV and an operator marked by "⊗" for instance. When INV is applied by means of operator ⊗ to a fraction a/b it will induce the interchange of a with b while applying NINV by means of ⊗ will leave the fraction unchanged.

$$\mathbf{(a/b)\otimes INV=b/a \; ; \; a/b\otimes NINV=a/b}$$

2.3.Time dependant logic variables:

The output of a logic gate will maintain its value, from the moment that the input changes, for a period equal to the specific propagation time for that gate. Evidently this situation is disturbing if we expect the output to change towards its complementary value as a result of changing the input vector. In order to express this situation and considering that the evolution of the output should be described with respect to time we define a logic variable τ that evolves in time as follows:

$$\tau_x=\tau(t_x-t)=\begin{cases}1 & \text{for } t<t_x\\ 0 & \text{for } t>t_x\end{cases}$$

Also we define another logic variable δ defined as follows – Let there be t_a, t_b two distinct moments of time that respect the inequality $t_a<t_b$. Than $\delta(t_a,t_b)=1$ for any moment of time that respects the inequality $t_a<t<t_b$ and it has the value 0 otherwise.

3.Properties

3.1. Properties of INV, NINV and ⊗

INV⊗INV=NINV

$$\left(\frac{a}{b}\otimes INV\right)\otimes INV=\frac{b}{a}\otimes INV=\frac{a}{b}=\frac{a}{b}\otimes NINV$$

NINV⊗NINV=NINV

$$\left(\frac{a}{b}\otimes NINV\right)\otimes NINV=\frac{a}{b}\otimes NINV=\frac{a}{b}$$

INV⊗NINV=NINV⊗INV=INV

$$\left(\frac{a}{b}\otimes INV\right)\otimes NINV=\frac{b}{a}\otimes NINV=\frac{b}{a}=\frac{a}{b}\otimes INV$$

$$\left(\frac{a}{b}\otimes NINV\right)\otimes INV=\frac{a}{b}\otimes INV$$

3.2. Properties of variable τ

We shall present the properties for τ in a particular case first and we shall generalize afterwards. Let there be t_1,t_2,t_3 – moments of time – that respect the inequality $t_1<t_2<t_3$. Operation with variable τ will have the following results. Please note that we have considered the conjunctive and the disjunctive form to express a logical term.

In order to generalize the properties of τ we shall define the weight of a term (either product or sum) as being the vector $w=(w_1,w_2,\ldots,w_{n-1},w_n)$ where $w_k\in(0,1)$. A term is defined by its weight in the following way – if $w_k=0$ then the k-position component of the term is inverted. Otherwise if $w_k=1$ that component is present in its direct form. For example in a four component term if w=0101 then the term is $\overline{a_1}\bullet a_2\bullet\overline{a_3}\bullet a_4$.

Let there be n distinct moments of time satisfying the inequality: $t_1<t_2<t_3<\ldots<t_{n-2}<t_{n-1}<t_n$. The values for the n-rank terms are:

w= 000…000	$\overline{\tau(t_1-t)}\bullet\overline{\tau(t_2-t)}\bullet\ldots\bullet\overline{\tau(t_n-t)}=\overline{\tau(t_n-t)}$ $\overline{\tau(t_1-t)}+\overline{\tau(t_2-t)}+\ldots+\overline{\tau(t_n-t)}=\overline{\tau(t_1-t)}$
w= 000…001	$\overline{\tau(t_1-t)}\bullet\overline{\tau(t_2-t)}\bullet\ldots\bullet\tau(t_n-t)=\delta(t_{n-1},t_n)$ $\overline{\tau(t_1-t)}+\overline{\tau(t_2-t)}+\ldots+\tau(t_n-t)=1$
…	
w= 001…111	$\overline{\tau(t_1-t)}\bullet\overline{\tau(t_2-t)}\bullet\tau(t_3-t)\bullet\ldots\bullet\tau(t_n-t)=\delta(t_2,t_3)$ $\overline{\tau(t_1-t)}+\overline{\tau(t_2-t)}+\tau(t_3-t)+\ldots+\tau(t_n-t)=1$
…	
w= 001…110	$\overline{\tau(t_1-t)}\bullet\overline{\tau(t_2-t)}\bullet\tau(t_3-t)\bullet\ldots\bullet\overline{\tau(t_n-t)}=0$ $\overline{\tau(t_1-t)}+\overline{\tau(t_2-t)}+\tau(t_3-t)+\ldots+\overline{\tau(t_n-t)}=1$
w= 011…111	$\overline{\tau(t_1-t)}\bullet\tau(t_2-t)\bullet\ldots\bullet\tau(t_n-t)=\delta(t_1,t_2)$ $\overline{\tau(t_1-t)}+\tau(t_2-t)+\ldots+\tau(t_n-t)=1$
w= 100…000	$\tau(t_1-t)\bullet\overline{\tau(t_2-t)}\bullet\ldots\bullet\overline{\tau(t_n-t)}=0$ $\tau(t_1-t)+\overline{\tau(t_2-t)}+\ldots+\overline{\tau(t_n-t)}=\overline{\delta(t_1,t_2)}$
w= 100…001	$\tau(t_1-t)\bullet\overline{\tau(t_2-t)}\bullet\ldots\bullet\tau(t_n-t)=0$ $\tau(t_1-t)+\overline{\tau(t_2-t)}+\ldots+\tau(t_n-t)=1$
…	
w= 111…100	$\tau(t_1-t)\bullet\tau(t_2-t)\bullet\ldots\bullet\overline{\tau(t_n-t)}=0$ $\tau(t_1-t)+\tau(t_2-t)+\ldots\overline{\tau(t_n-t)}=\overline{\delta(t_{n-2},t_{n-1})}$
…	
w= 111…100	$\tau(t_1-t)\bullet\tau(t_2-t)\bullet\ldots\overline{\tau(t_n-t)}=0$ $\tau(t_1-t)+\tau(t_2-t)+\ldots+\overline{\tau(t_n-t)}=\overline{\delta(t_{n-2},t_{n-1})}$
w= 100…001	$\tau(t_1-t)\bullet\overline{\tau(t_2-t)}\bullet\ldots\bullet\tau(t_n-t)=0$ $\tau(t_1-t)+\overline{\tau(t_2-t)}+\ldots+\tau(t_n-t)=1$
…	
w= 111…100	$\tau(t_1-t)\bullet\tau(t_2-t)\bullet\ldots\bullet\overline{\tau(t_n-t)}=0$ $\tau(t_1-t)+\tau(t_2-t)+\ldots+\overline{\tau(t_n-t)}=\overline{\delta(t_{n-2},t_{n-1})}$
…	
w= 111…100	$\tau(t_1-t)\bullet\tau(t_2-t)\bullet\ldots\bullet\overline{\tau(t_n-t)}=0$ $\tau(t_1-t)+\tau(t_2-t)+\ldots+\overline{\tau(t_n-t)}=\overline{\delta(t_{n-2},t_{n-1})}$
w= 111…101	$\tau(t_1-t)\bullet\tau(t_2-t)\bullet\ldots\bullet\tau(t_n-t)=0$ $\tau(t_1-t)+\tau(t_2-t)+\ldots+\tau(t_n-t)=1$
w= 111…110	$\tau(t_1-t)\bullet\tau(t_2-t)\bullet\ldots\bullet\overline{\tau(t_n-t)}=0$ $\tau(t_1-t)+\tau(t_2-t)+\ldots+\overline{\tau(t_n-t)}=\overline{\delta(t_{n-1},t_n)}$
w= 111…111	$\tau(t_1-t)\bullet\tau(t_2-t)\bullet\ldots\bullet\tau(t_n-t)=\tau(t_1-t)$ $\tau(t_1-t)+\tau(t_2-t)+\ldots+\tau(t_n-t)=\tau(t_n-t)$

From the above table we notice that only the border moments of time are coherent when operating with τ. That means that after reducing the terms only $\tau(t_1\text{-}t)$ and $\tau(t_n\text{-}t)$ will eventually appear in future calculus and that happens only in case of weight w=111…111 or w=000…000. Otherwise only singular intervals of time will be pinpointed when operating with τ by aid of variable δ. Those intervals are of the form (t_{k-1},t_k) and will appear only if the weight of that term is ordered. By that we understand that

$w_1=w_2=\ldots=w_{k-1}=1$ and $w_k=w_{k+1}=\ldots=w_n=0$ or the opposite. All other terms are either 1 for the disjunctive form or 0 for the conjunctive form. We can already notice that considering analysis of hazard by means of time constants method the ability to use τ and δ variables will minimize the number of situations to be considered and will pinpoint clearly the opportunities where hazard may appear (variable δ).

4. Method description

The improved time constants method (Galupa [2],[3]) has proved to be more efficient in pinpointing the presence of hazards in CLC. However it is a laborious method and we strongly suggest implementing it as CAD module. Otherwise we suggest using the INV, NINV and $\otimes$ for analisys when calculating the propagation times. That will considerably diminish the amount of work requested.

4.1. Using INV, NINV and $\otimes$

The best way to present INV, NINV and $\otimes$ is by aid of an example Let's consider the circuit presented in fig.1.

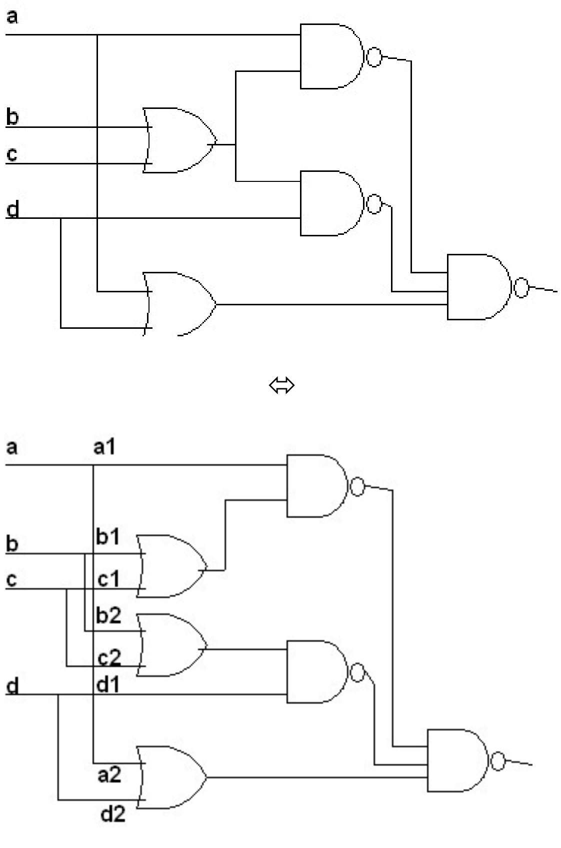

Fig.1.

As we have seen before after replicating the gates with fan out greater than 1 we are able to define the secondary input vector and the individual input_towards_output path for each component of the secondary input vector. Theoretically now we should propagate the operator's specific propagation times from the output towards the input, defining in this manner the path's propagation time. Of course we must not forget about the inverting characteristic influence. Instead of doing it as presented above we can simply express the path's specific time as an ordered equation. For a better understanding we'll calculate the path's specific delays for the circuit analyzed above in fig.1.

$$\mathbf{t_{a1}=(t_{nand(5)}\otimes INV+t_{nand(4)})\otimes INV}$$

In order to reduce this equation we'll use the properties presented above for INV, NINV and $\otimes$.

$$\mathbf{t_{a1}=t_{nand}\otimes INV\otimes INV+t_{nand}\otimes INV=t_{nand}\otimes NINV+t_{nand}\otimes INV}$$

Following the same procedure we'll find:

$$\mathbf{t_{b1}=t_{b2}=t_{c1}=t_{c2}=t_{nand}\otimes NINV+t_{nand}\otimes INV+t_{or}\otimes NINV}$$
$$\mathbf{t_{d1}=t_{nand}\otimes INV+t_{nand}\otimes NINV}$$
$$\mathbf{t_{a2}=t_{d2}=t_{nand}\otimes INV+t_{or}\otimes NINV}$$

As you can see this methodology implies much less effort for calculating the propagation times. Tracing the value of the output will be done the same way as in the previously presented method.

5. The use of time dependent variables

Let us consider a switching function $y=f(x_1,x_2,\ldots,x_l)$. According to the time constants method after determining all the distinct input – output signal paths and after propagating the delays from the output towards the input we define the delay array generating the secondary input vector. Let us consider that $(a_1, a_2,\ldots,a_n)$ is the secondary input vector and $(t_1,t_2,\ldots,t_n)$ is the time vector associated with it. That means that if we set the time axis origin to the moment when the primary input vector changes its value than the secondary input variable a_k (derived from one primary input variable that changes) will change its value after t_k. We assume that the secondary input vector has been organized in such a manner that the moments of time associated with its components are ordered in arising form. So the inequality $t1<t2<\ldots<t_{n-1}<t_n$ is true.

A change in the primary input vector will imply a sequence of secondary input vectors, sequence determined by the delay array. The sequence of secondary input vectors are applied at the inputs of an ideal logic circuit (instantaneous). The ideal circuit will respond instantaneously (following the same sequencing in time) with a sequence of output values. Tracing in time that response will provide for us information whether we have or not hazardous functioning. In order to do this we shall express the logic circuit output with respect to time. Let us consider the secondary input variable a_x that switches after t_x from the initial moment. The following relation is obvious:

$$\mathbf{a_x(t)=a_{xfinal}\oplus\tau(t_x-t)}$$

where a_{xfinal}, as the notation expresses, is the final value towards which a_x evolves. That means that $a_x(t)$ will be equal to the complement of a_{xfinal} for any moment of time $t<t_x$ and equal to a_{xfinal} for any moment afterwards. In this case the function will be expressed with respect to time as follows:

$$\mathbf{y(t)=f(a_1(t),a_2(t),\ldots,a_n(t))=f(a_0\oplus\tau(t_0-t),a_1\oplus\tau(t_1-t),\ldots,a_n\oplus\tau(t_n-t))}$$

where the vector $(a_1,a_2,\ldots,a_n)$ is the final, stabilized secondary input vector. As we know ultimately this function can be expressed in a conjunctive or a disjunctive form. For a specific function only a limited and well-determined number of terms will be present.

For presentation purposes we shall first consider a particular case and afterwards we shall generalize. Let there be the secondary input vector (a_1,a_2,a_3). We shall assume that these secondary variables are derived from one primary input variable marked a. In order to analyze the function we shall express it as follows:

$$y(t)=\alpha_{000}\overline{a_1(t)}\,\overline{a_2(t)}\,\overline{a_3(t)}+\alpha_{001}\overline{a_1(t)}\,\overline{a_2(t)}a_3(t)+\alpha_{010}\overline{a_1(t)}a_2(t)\overline{a_3(t)}+$$
$$+\alpha_{011}\overline{a_1(t)}a_2(t)a_3(t)+\alpha_{100}a_1(t)\overline{a_2(t)}\,\overline{a_3(t)}+\alpha_{101}a_1(t)\overline{a_2(t)}a_3(t)+$$
$$+\alpha_{110}a_1(t)a_2(t)\overline{a_3(t)}+\alpha_{111}a_1(t)a_2(t)a_3(t) \text{ or}$$

$$y(t)=[\alpha_{000}+\overline{a_1(t)}+a_2(t)+\overline{a_3(t)}][\alpha_{001}+\overline{a_1(t)}+\overline{a_2(t)}+a_3(t)][\alpha_{010}+a_1(t)+a_2(t)+\overline{a_3(t)}]\bullet$$
$$\bullet[\alpha_{011}+\overline{a_1(t)}+a_2(t)+a_3(t)][\alpha_{100}+a_1(t)+\overline{a_2(t)}+\overline{a_3(t)}][\alpha_{101}+a_1(t)+\overline{a_2(t)}+a_3(t)]\bullet$$
$$\bullet[\alpha_{110}+a_1(t)+a_2(t)+\overline{a_3(t)}][\alpha_{111}+a_1(t)+a_2(t)+a_3(t)]$$

where $a_w\in(0,1)$ and expresses the presence or not of the term having weight w in the final expression of the function. Let us consider the first form of expression for y(t) and analyze it. For the second form operations are similar.

$$y(t)=\alpha_{000}\overline{a\oplus\tau(t_1-t)}\,\overline{a\oplus\tau(t_2-t)}\,\overline{a\oplus\tau(t_3-t)}+\alpha_{001}\overline{a\oplus\tau(t_1-t)}\,\overline{a\oplus\tau(t_2-t)}a\oplus\tau(t_3-t)+$$
$$+\alpha_{010}\overline{a\oplus\tau(t_1-t)}a\oplus\tau(t_2-t)\overline{a\oplus\tau(t_3-t)}+\alpha_{011}\overline{a\oplus\tau(t_1-t)}a\oplus\tau(t_2-t)a\oplus\tau(t_3-t)+$$
$$+\alpha_{100}a\oplus\tau(t_1-t)\overline{a\oplus\tau(t_2-t)}\,\overline{a\oplus\tau(t_3-t)}+\alpha_{101}a\oplus\tau(t_1-t)\overline{a\oplus\tau(t_2-t)}a\oplus\tau(t_3-t)+$$
$$+\alpha_{110}a\oplus\tau(t_1-t)a\oplus\tau(t_2-t)\overline{a\oplus\tau(t_3-t)}+\alpha_{111}a\oplus\tau(t_1-t)a\oplus\tau(t_2-t)a\oplus\tau(t_3-t)$$

where a is the final, stabilized value for the variable that changes during the process. Now we shall operate each term and reduce it according to the properties presented for τ above. **w=000** the term is:

$$\overline{a\oplus\tau(t_1-t)}\,\overline{a\oplus\tau(t_2-t)}\,\overline{a\oplus\tau(t_3-t)}=[a\tau(t_1-t)+\bar{a}\overline{\tau(t_1-t)}](\bar{a}\otimes\tau(t_2-t))(\bar{a}\otimes\tau(t_3-t))=$$
$$=a\tau(t_1-t)[a\tau(t_2-t)+\bar{a}\overline{\tau(t_2-t)}](\bar{a}\otimes\tau(t_3-t))+\bar{a}\overline{\tau(t_1-t)}[a\tau(t_2-t)+\bar{a}\overline{\tau(t_2-t)}](\bar{a}\otimes\tau(t_3-t))=$$
$$=a\tau(t_1-t)\tau(t_2-t)[a\tau(t_3-t)+\bar{a}\overline{\tau(t_3-t)}]+\bar{a}\overline{\tau(t_1-t)}\,\overline{\tau(t_2-t)}[a\tau(t_3-t)+\bar{a}\overline{\tau(t_3-t)}]=$$
$$=a\tau(t_1-t)a\tau(t_2-t)\tau(t_3-t)+\bar{a}\overline{\tau(t_1-t)}\,\overline{\tau(t_2-t)}\,\overline{\tau(t_3-t)}]=a\tau(t_1-t)+\bar{a}\overline{\tau(t_3-t)}$$

w=001 the term is:

$$\overline{a\oplus\tau(t_1-t)}\,\overline{a\oplus\tau(t_2-t)}a\oplus\tau(t_3-t)=[a\tau(t_1-t)+\bar{a}\overline{\tau(t_1-t)}](\bar{a}\otimes\tau(t_2-t))(a\otimes\tau(t_3-t))=$$
$$=a\tau(t_1-t)[a\tau(t_2-t)+\bar{a}\overline{\tau(t_2-t)}](a\otimes\tau(t_3-t))+\bar{a}\overline{\tau(t_1-t)}[a\tau(t_2-t)+\bar{a}\overline{\tau(t_2-t)}](a\otimes\tau(t_3-t))=$$
$$=a\tau(t_1-t)\tau(t_2-t)[\bar{a}\tau(t_3-t)+a\overline{\tau(t_3-t)}]+\bar{a}\overline{\tau(t_1-t)}\,\overline{\tau(t_2-t)}[\bar{a}\tau(t_3-t)+a\overline{\tau(t_3-t)}]=$$
$$=a\tau(t_1-t)a\tau(t_2-t)\overline{\tau(t_3-t)}+\bar{a}\overline{\tau(t_1-t)}\,\overline{\tau(t_2-t)}\tau(t_3-t)]=a\bullet0+\bar{a}\delta(t_2,t_3)=\bar{a}\delta(t_2,t_3)$$

Using the same calculus methodology we find that:

w=000	$\overline{a\oplus\tau(t_1-t)}\,\overline{a\oplus\tau(t_2-t)}\,\overline{a\oplus\tau(t_3-t)}=a\tau(t_1-t)+\bar{a}\overline{\tau(t_3-t)}$	
w=001	$\overline{a\oplus\tau(t_1-t)}\,\overline{a\oplus\tau(t_2-t)}a\oplus\tau(t_3-t)=a\bullet0+\bar{a}\delta(t_2,t_3)=$	$\bar{a}\delta(t_2,t_3)$
w=010	$\overline{a\oplus\tau(t_1-t)}a\oplus\tau(t_2-t)\overline{a\oplus\tau(t_3-t)}=a\bullet0+\bar{a}\bullet0=$	0
w=011	$\overline{a\oplus\tau(t_1-t)}a\oplus\tau(t_2-t)a\oplus\tau(t_3-t)=a\bullet0+\bar{a}\delta(t_1,t_2)=$	$\bar{a}\delta(t_1,t_2)$
w=100	$a\oplus\tau(t_1-t)\overline{a\oplus\tau(t_2-t)}\,\overline{a\oplus\tau(t_3-t)}=a\bullet\delta(t1,t2)+\bar{a}\bullet0=$	$a\delta(t1,t2)$
w=101	$a\oplus\tau(t_1-t)\overline{a\oplus\tau(t_2-t)}a\oplus\tau(t_3-t)=a\bullet0+\bar{a}\bullet0=$	0
w=110	$a\oplus\tau(t_1-t)a\oplus\tau(t_2-t)\overline{a\oplus\tau(t_3-t)}=a\bullet\delta(t_2,t_3)+\bar{a}\bullet0=$	$a\delta(t_2,t_3)$
w=111	$a\oplus\tau(t_1-t)a\oplus\tau(t_2-t)a\oplus\tau(t_3-t)=a\overline{\tau(t_3-t)}+\bar{a}\tau(t_1-t)$	

That means that we can express the function as follows:

$$y(t)=\alpha_{000}[a\tau(t_1-t)+\bar{a}\overline{\tau(t_3-t)}]+\alpha_{001}\bar{a}\delta(t_2,t_3)+\alpha_{011}\bar{a}\delta(t_1,t_2)+$$
$$+\alpha_{100}a\delta(t_1,t_2)+\alpha_{110}a\delta(t_2,t_3)+\alpha_{111}[a\overline{\tau(t_3-t)}+\bar{a}\tau(t_1-t)]$$

Now we can see that coherent for the function expression are only the border terms (w=000 and w=111) and the terms that define the singular and distinct time intervals determined by the delay array – in this case having three distinct times t_1,t_2,t_3 we have two such intervals (t_1,t_2) and (t_2,t_3). As mentioned when presenting τ properties those terms have the weight ordered as a result of physical commutation possibilities for the secondary input variables. Now we have the ability to trace the output of the circuit and that is presented in the table bellow.

t_{init} t_1 t_2 t_3 t_{final} →

$\alpha_{111}=1\Rightarrow y(t)=$	$\bar{a}$	0	0	a	Time axis
$\alpha_{011}=1\Rightarrow y(t)=$	0	$\bar{a}$	0	0	
$\alpha_{001}=1\Rightarrow y(t)=$	0	0	$\bar{a}$	0	
$\alpha_{110}=1\Rightarrow y(t)=$	0	0	a	0	
$\alpha_{100}=1\Rightarrow y(t)=$	0	a	0	0	
$\alpha_{000}=1\Rightarrow y(t)=$	a	0	0	$\bar{a}$	

Now we can see that the border terms (w=111 and w=000) will never generate hazard by themselves indifferent of the final value for variable a. However terms with weight w=011 and w=001 will generate a static 0 hazard in case the final value for a is 0 (transition for a "1"↓"0"). So their presence by themselves in the final expression of the function ($\alpha_{011}=1$ or $\alpha_{001}=1$ only) will be an indication of hazardous functioning. Also the complement of the previous statement will have the same effect. That means that terms with weight w=110 and w=100 will produce a static 0 hazard in case o transition "0"↑"1" for a. In this particular case we can also see the way to mask those hazards – simply by finding a way to introduce the border terms in the expression (if algebraically possible).

ATTENTION - We started from the hypothesis that terms containing all the secondary variables are present in the function expression. Evidently this is not always the situation when analyzing a real circuit. However the presence of a term that lacks one or more components from the secondary input vector should first of all be analyzed to see if the weight of that term is ordered. If this is not the case no further inquiries regarding this term should be made because it will be eliminated when operating with τ. In case its weight is ordered we remind that an incomplete term may be obtained via an operation (AND or OR depending on the form of expression for the function) from the complete terms containing the lacking secondary variable in its direct and complementary form. So these terms (incomplete but with ordered weight) should be considered for further analysis as they may contain hazards even if masked ones.

Generally if the secondary vector $(a_1,a_2,\dots,a_n)$ is derived from a primary input variable a and has the associated switching time vector ordered in a rising form we shall be able to express the function as follows:

$$y(t)=\alpha_{000.000}\left[a\tau(t_1-t)+\bar{a}\tau(t_n-t)\right]+\alpha_{011.111}\bar{a}\delta(t_1,t_2)+\alpha_{001.111}\bar{a}\delta(t_2,t_3)+$$
$$+\dots+\alpha_{000.011}\bar{a}\delta(t_{n-2},t_{n-1})+\alpha_{000.001}\bar{a}\delta(t_{n-1},t_n)+\alpha_{111.111}\left[a\overline{\tau(t_n-t)}+\bar{a}\tau(t_1-t)\right]$$

and the output trace will be:

t_{init} t_1 t_2 t_3 .. t_{n-1} t_n

$\alpha_{111\dots111}=1\Rightarrow y(t)=$	$\bar{a}$	0	0	0	a
$\alpha_{011\dots111}=1\Rightarrow y(t)=$	0	$\bar{a}$	0	0	0
………………………………………..					
$\alpha_{001\dots111}=1\Rightarrow y(t)=$	0	0	$\bar{a}$	0	0
$\alpha_{000\dots001}=1\Rightarrow y(t)=$	0	0	0	$\bar{a}$	0
………………………………………..					
$\alpha_{111\dots110}=1\Rightarrow y(t)=$	0	0	0	a	
$\alpha_{110\dots000}=1\Rightarrow y(t)=$	0	0	a	0	0
$\alpha_{100\dots000}=1\Rightarrow y(t)=$	0	a	0	0	0
$\alpha_{000\dots000}=1\Rightarrow y(t)=$	a	0	0	0	$\bar{a}$

Now we ca express a condition for the presence of hazard:

<u>The singular presence of a term with the weight ordered is a sufficient condition for the presence of static hazard.</u>

Further more combinations of such terms in the function expression may lead to dynamic hazard. However what is mostly important is that we have drastically reduced the possibilities to be searched for hazard and simply viewing the presence of specific terms is sufficient for us to conclude whether we have or not hazard present. More in particular cases we can easily see the terms that need to be added in order to mask that hazard.

Example: Let there be the circuit presented in fig.2.

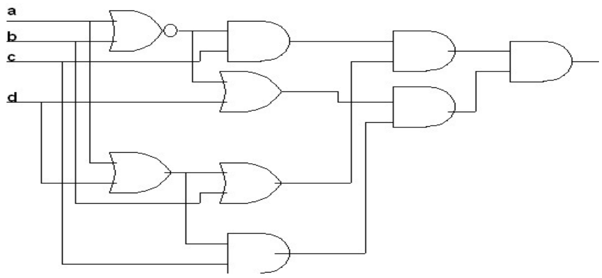

Fig.2

The function implemented by this circuit is:

$$y = f(a,b,c,d) = \overline{a+b}\,b(a+b+d)(\overline{a+b}+d)(a+d)c$$

By replicating the gates we determine the distinct input-output signal paths and we define the secondary input vector. The result is presented in fig.3.

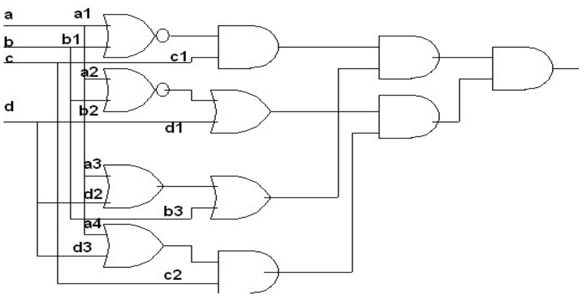

Fig.3

The function expressed with respect to the secondary input vector is:

$$y = \overline{a_1 + b_2}\, c_1 (a_3 + b_1 + d_2)(\overline{a_2 + b_3} + d_1)(a_4 + d_3) c_2$$

In order to determine the input delay array we propagate the specific delay of each gate from the output towards the input we shall neglect the delays specific for the connections between gates as they are negligible. However we must never forget that this assumption is not correct in case of VLSI implementations. The methodology works in this case but we must consider the specific delays induced by the internal wiring and by the connections between the operators used. Those delays will be added to the logic operator's specific delay and will be propagated towards the inputs as presented before.

$t_{a1}=(((t_{AND}\otimes NINV+t_{AND})\otimes NINV+t_{AND})\otimes NINV+t_{NOR})\otimes INV$

$t_{a1}=t_{b2}=3t_{AND}\otimes INV+t_{NOR}\otimes INV$

$t_{a2}=t_{b3}=2t_{AND}\otimes INV+t_{OR}\otimes INV+t_{NOR}\otimes INV$

$t_{a3}=t_{d2}=2t_{AND}\otimes NINV+2t_{OR}\otimes NINV$

$t_{a4}=t_{d3}=3t_{AND}\otimes NINV+t_{OR}\otimes NINV$

$t_{b1}=2t_{AND}\otimes NINV+t_{OR}\otimes NINV$

$t_{c1}=t_{c2}=3t_{AND}\otimes NINV$

$t_{d1}=2t_{AND}\otimes NINV+t_{OR}\otimes NINV$

Now we can see that variable c will not generate hazard because both paths crossed by this variable have identical delays. Also variable d will not generate hazard because all paths crossed are direct so this variable will not translate at the output the direct and the complementary value in the same time. That leaves us variable a and b to analyze. Let us assume that the propagation times specific for each path have already been organized in a rising form. When calculating the reduced functions dependent of variable a (by replacing d,c,b with fixed values) we find that if dcb=010 then the function is $f(a_1, a_2, a_3, a_4) = \overline{a_1}\,\overline{a_2} a_3 a_4$. That shows that in case of transition a "1"↓"0" and dcb=010 we have a static 0 hazard present.

By calculating the reduced functions dependant of variable b we find that if dca=010 the reduced function is $f(b_1, b_2, b_3) = b_1 \overline{b_2}\,\overline{b_3}$. So we have static 0 hazard in case of transition b "0"↑"1" and dca=010.

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