

# Crosstalk Minimization in Three-Layer HVH Channel Routing \*

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## Abstract

*Crosstalk has become a major issue in VLSI design due to the high frequency, long interconnecting lines and small spacing between interconnects in today's integrated circuits. In this paper, we study the problem of crosstalk minimization in 3-layer HVH channel routing. A heuristic algorithm that combines layer reassignment and track reassignment is presented. This algorithm can iteratively modify the layout so that the crosstalk in the channel is minimized. Experimental results show that the proposed approach can reduce the crosstalk by an average of 16.4% on a set of benchmark examples.*

## 1: Introduction

Due to the scaling down of device geometry in deep-submicron technologies, the crosstalk noise between adjacent nets has become a major concern in high performance VLSI circuit design. Increased coupling noise can cause signal delays, logic hazards and even malfunctioning of circuits [1, 6], and thus controlling the level of crosstalk noise in a chip has become an important task for IC designers.

In this paper we study the problem of crosstalk minimization in 3-layer HVH channel routing. This routing style allows using two horizontal layers (layer 1 and layer 3) and one vertical layer (layer 2) for routing. Another popular 3-layer routing style is VHV where two vertical layers and one horizontal layer are available. Both routing styles can be found in various designs, but HVH routing can usually achieve a smaller routing area than VHV routing. Though there are several reports on crosstalk minimization in 2-layer channel routing [4, 5], only a very limited number of papers have been published on crosstalk minimization in 3-layer routing. In [7], Thakur et. formulated the layer reassignment problem in 3-layer VHV routing as a longest path problem. This formulation, however, is invalid for HVH routing. In [2], we proposed a layer reassignment algorithm for antenna effect minimization in 3-layer HVH routing, and this algorithm can be modified to minimize crosstalk as well. But we found that the quality of the solution achieved by this method is usually unsatisfactory. Another approach that has been used for crosstalk minimization in 2-layer channel routing is track permutation [4], which can also be modified and used in reducing crosstalk noise in 3-layer HVH routings. However, this approach has its limitations too [8].

In this paper, we present an algorithm that combines layer reassignment and track reassignment techniques. This algorithm can iteratively modify the layout so that the crosstalk in the channel can be minimized.

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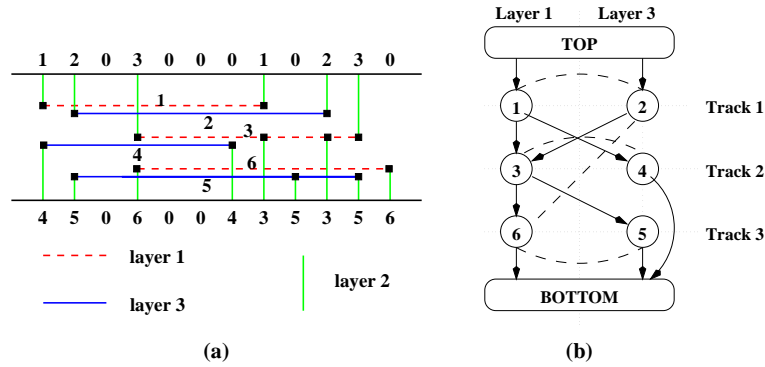


Figure 1: Routing in a channel can be represented by a graph: (a) layout of the channel; (b) graph representation of the layout.

## 2: Algorithm for Crosstalk Minimization

The routing in a channel can be represented by a graph as follows. Let each node represent a horizontal wire segment. The relationship among these horizontal wire segments can be represented by horizontal and vertical constraints. A vertical constraint from wire segment  $i$  to wire segment  $j$  means that segment  $i$  must be placed on top of segment  $j$ . A horizontal constraint between two wire segments means that these two segments can not be placed in the same track. In the graph representation of the 3-layer channel, there is a directed arc from node  $V_i$  to node  $V_j$  if there is a vertical constraint from  $V_i$  to  $V_j$ . Similarly, there is a undirected arc between two nodes if there is a horizontal constraint between these two nodes. Nodes representing wire segments can be divided into two groups, one is for those nodes whose corresponding wire segments are in layer 1 and the other one is for those whose corresponding wire segments are in layer 3. An example shown in Figure 1 illustrates the graph representation of a channel, where Figure 1(a) is the layout of the channel and Figure 1(b) is its corresponding graph representation. In this figure, solid lines with arrows represent vertical constraints, dashed lines represent horizontal constraint, horizontal dotted lines represent tracks, and the vertical dotted line shows the division between group layer\_1 and group layer\_3.

Crosstalk noise between two adjacent nets is determined by a number of factors including the coupling capacitance between them, the driving capacity of the two nets, timing of the signals, etc [8]. Among all these factors the coupling capacitance provides a first order estimation for the crosstalk value [4, 5] so we use it as the cost in our objective function. Since the coupling capacitance is determined by the overlap and the distance between these two wires, we use the overlapping length between two adjacent wires to represent the coupling capacitance between them, and the objective of the crosstalk minimization problem is thus defined as follows

$$\text{Minimize } \text{Max} (\text{Crosstalk of net } i) \quad \text{for every net } i \quad (1)$$

The 3-layer HVH routing crosstalk minimization problem can be stated as follows: given a graph representation of a channel, find an appropriate position for each node so that the crosstalk cost defined in (1) is minimized. The final layout should also satisfy all the vertical and horizontal constraints and should not increase the channel height.

Track permutation for crosstalk minimization in 2-layer routing has been proved to be NP-hard [4] and therefore, we need to resort to heuristics to solve our problem, which is

a generalized version of the track permutation problem. We found that several techniques can be adopted to reassign the layer and position of wire segments (or nodes in a graph) to reduce the crosstalk noise in a channel. To illustrate these techniques we use the channel routing example shown in Figure 2, where Figure 2(a) is the original layout, and Figure 2(b) is the modified layout by applying some of the layer reassignment and track reassignment techniques. In the original layout, net 3 has the worst crosstalk noise and the following techniques can be applied to reduce its crosstalk cost.

- layer reassignment: since wire segment 3 has a long overlap with segment 2, we can reassign wire segment 2 to the other layer to eliminate the overlap between these two wires. In the constraint graph, this layer reassignment operation is equal to moving node 2 from the group of layer<sub>3</sub> to that of layer<sub>1</sub>. Notice that this will force node 1 to move in the opposite direction to satisfy the horizontal constraints. Though this will introduce new crosstalk noise between net 1 and net 3, the crosstalk of net 3 will be reduced since segment 2 has a longer overlap with segment 3 than segment 1 does. Similar operations can be applied to nodes 6 and 7.
- track reassignment: the overlap between segment 3 and segment 12 can be eliminated if we reassign wire segment 12 from track 3 to track 4. This is equivalent to moving node 12 from track 3 to track 4 in the constraint graph.
- a combination of track reassignment and layer reassignment: we can move segment 10 to track 4 and reassign it to layer 1 eliminating the overlap between segments 10 and 3.
- reducing crosstalk between vertical wires: node 8 can be moved to track 2 (after node 12 has been moved to track 4) to reduce the crosstalk of net 3. Though this track reassignment has no effect on the overlap between the horizontal wire segments of net 3 and net 8, the overlap between the vertical wire segments of these two nets, however, is reduced, which leads to a reduction of the crosstalk for net 3.

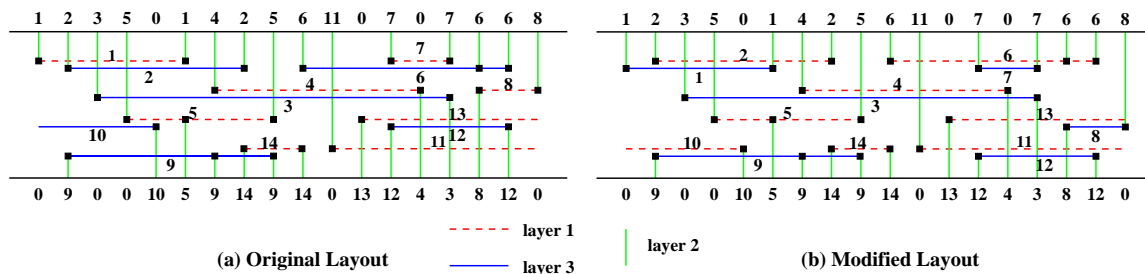


Figure 2: Various techniques for crosstalk minimization

The above are the basic operations we adopted to minimize crosstalk. More complicated layer/track reassignment such as swapping among two and more nodes is also allowed in our algorithm. Another technique we adopted is dogleg insertion. By introducing additional doglegs, we can overcome the situation when the up or down movement of horizontal wire segments are blocked by vertical/horizontal constraints, and this is illustrated in the example shown in Figure 3. In our algorithm dogleg candidates are introduced and they are added to the wire segments whose vertical/horizontal constraints block the movement of wire segments in and around critical nets.

Our algorithm works as follows. It first selects the net with the worst crosstalk noise, which is called the “critical” net. Then it tries to reduce its crosstalk by applying various

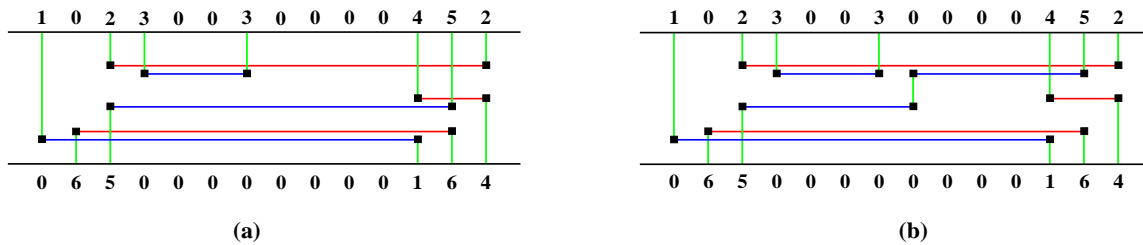


Figure 3: Additional doglegs can allow further reduction in crosstalk: (a) In the original layout, net 5 has a maximum coupling capacitance of 16 units; (b) After introducing a dogleg to net 5, we can reduce its maximum coupling capacitance to 11.

Examples [9]	Original Design		Modified Design			
	Max	Total	Max	% Reduce.	Total	% Reduc
exyk1	68	602	53	19.1	560	7.0
exyk3a	103	1040	84	18.4	958	7.9
exyk3b	123	1642	96	22.0	1648	- 0.0
exyk3c	156	2162	128	17.9	2124	1.8
exyk4b	223	2530	189	15.2	2336	7.7
exyk5	98	2328	84	14.2	2194	5.8
Deutsch	328	5886	302	7.9	5720	2.8
average				16.4		4.7

Table 1: Results on benchmark examples

techniques mentioned above. If the net is not “critical” any more after applying these techniques, we select a new critical net and work on it. This process continues until no further reduction of crosstalk cost is possible.

The time complexity of this algorithm is  $O(T(T + C)S^4)$  where  $T$ ,  $C$  and  $S$  are the numbers of tracks, columns and wire segments in the channel, respectively. For the sake of brevity we do not include the detailed complexity analysis here.

### 3: Experimental Results

We applied the proposed algorithm to a set of channel routing benchmark examples to test the efficiency of our algorithm. The results are shown in Table 1. In this table columns two and three include the values of the worst coupling capacitance and total coupling capacitance in the channel, respectively, in the original layouts, while their corresponding values for the modified layouts are shown in column 4 and column 6, respectively. The percentage improvements for the maximum and total crosstalk are shown in column 5 and column 7, respectively. In our examples, all the original HVH 3-layer routing layouts were obtained by using the router reported in [3]. As mentioned before we use the overlap length between adjacent wires to represent the crosstalk between them. From Table 1 we can see that an average of 16.4% reduction in maximum crosstalk can be achieved by our algorithm. The total crosstalk in the channel can also be reduced by 4.7% though it is not one of our objectives. The algorithm is fast and for all the benchmark examples reported here it takes less than a minute to get the results on a IBM RS6000 workstation.

The original and modified routing solutions for exyk1 are shown in Figure 4. In the

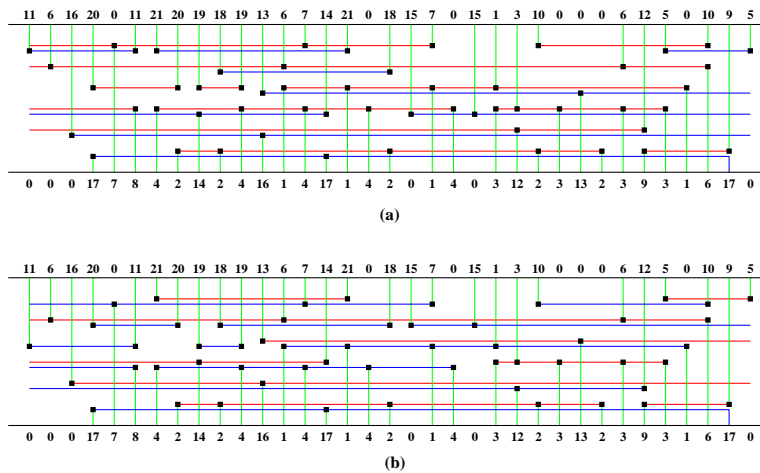


Figure 4: (a) Original layout and (b) modified layout for crosstalk minimization.

original layout, shown in Figure 4(a), net 6 has the largest crosstalk value which is 68 units. The modified layout, obtained by applying our algorithm, is shown in Figure 4(b) and it has a maximum crosstalk of 53 units occurring in net 12.

#### 4: Summary

We have presented a crosstalk minimization algorithm for 3-layer HVH channel routing. This algorithm can be used in layout post-processing and it iteratively modifies the layout to reduce the crosstalk in a channel without increasing the routing area. Experiment results show that the proposed algorithm can reduce the crosstalk cost by an average of 16.4% on a set of channel routing benchmark examples. Though a simplified crosstalk cost model has been adopted in the research, our approach, however, is valid when more accurate crosstalk models are applied.

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