

Fast Substrate Noise-Aware Floorplanning with Preference Directed Graph for Mixed-Signal SOCs

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Abstract—In this paper, we introduce a novel substrate noise estimation technique during early floorplanning, based on the concept of Block Preference Directed Graph (BPDG) and Sequence Pair (SP) floorplan representation. Given a set of analog and digital blocks, we can construct the BPDG, which suggests the preferred relative block locations for substrate noise minimization, based on the inherent noise characteristics between these blocks. For each sequence pair instance during floorplanning evaluation, we can count its number of violations against BPDG very efficiently. We observe that the number of violations obtained in this manner highly correlates with the substrate noise from accurate modeling. Thus we can use it to guide fast substrate noise-aware floorplanning instead of expensive model-based substrate noise simulation. Experimental results show that our approach is over 60 times faster than conventional floorplanning with even fast/compact substrate noise model. The proposed approach also provides smaller area and less total substrate noise than a conventional approach for most tested benchmarks.

I. INTRODUCTION

Continuing demand for data and telecommunication application is driving the need for integrating many functions into a single system-on-chip. Since pre-designed IP cores of different nature such as sensitive front-end RF circuits, high-performance analog/mixed-signal circuits and complex digital circuits are integrated into a single chip, designers must consider interference between heterogeneous cores, which may adversely affect overall performance [1]. Large amount of switching activity in the high speed digital cores may inject considerable amount of current noise into the power and ground, as well as the substrate of integrated circuits. Such currents can potentially degrade the reliability and performance of other sensitive analog/mixed-signal/RF IPs [2]. As a result of higher clock frequency requirement, more accurate analog precision, and deeper technology scaling, this coupling noise is an increasingly serious concern in the design of mixed-signal SOCs [3]–[5]. The problem becomes more acute if front-end RF is integrated with digital blocks. Many effects that corrupt RF signal such as DC offset, oscillator pulling and pushing, local oscillator leakage, are proven to be due to the substrate-coupled noise [2].

The accurate evaluation of substrate coupling noise in sensitive analog cores, and consideration of its optimization in physical design has become a crucial part of mixed-signal SOC design, in order to avoid expensive over-design and multiple design iterations. Such optimization processes include floorplanning and placement phases, and it is known that

floorplanning is an adequate physical synthesis stage to apply several noise optimization techniques effectively [6].

Although there has been a significant amount of work on modeling and simulation of substrate noise, there is not much in the literature on substrate noise optimization in early floorplanning stages. Lin et al. [7] proposed an optimization technique that incorporates substrate noise minimization into optimization loops. This technique, however, requires the detailed circuit simulation to estimate the coupled noise. Blakiewicz et al. [8] proposed a floorplanning algorithm which includes substrate noise as a cost function. This cost function was estimated based on scalable substrate model and frequency-dependent sensitivity function of analog and digital blocks. While these methods provide optimized area as well as noise, extensive computation overhead is required to estimate and evaluate the cost function.

To overcome such computational overhead, we propose a concept of block preference directed graph (BPDG), and an algorithm to compute the number of violations in sequence pair against BPDG. This approach accelerates substrate noise estimation by comparing preferred relative block locations in BPDG with sequence pair, resulting in fast floorplanning without accurate geometric information. Our contributions are the following.

- We introduce the novel concept of block preference directed graph (BPDG) to represent the preferred relative block locations in floorplanning. In BPDG, all the preferences are decided to minimize the substrate noise and each preference is specified as a directed edge.
- We propose a fast substrate noise estimation algorithm by combining BPDG and sequence pair. We simply count how many preferences in BPDG are not held in a sequence pair with simple bitwise-OR operation.
- We show that our approach has surprisingly high fidelity to the substrate noise calculated by a most recent noise model [5].
- We propose a fast substrate noise-aware floorplanning algorithm with BPDG and sequence pair. Our experimental results show the proposed approach is significantly (at least 60 times) faster than a conventional simulation-based, substrate noise-aware floorplanning.

The remainder of the paper is organized as follows. In Section II, preliminaries are described. In Section III, the concept of block preference directed graph is introduced.

The fast substrate noise estimation algorithm is proposed in Section IV and the overall floorplanning flow is described in Section V. Experimental results are discussed in Section VI. Section VII concludes this paper with future work.

II. PRELIMINARIES

A. Sequence Pair and Block Alignment

A sequence pair [9] is a pair of sequences of n elements representing a list of n blocks. Two sequences specify the geometric relations between each pair of blocks. For example, ($\dots A \dots B \dots$, $\dots A \dots B \dots$) means that A is to the left of B and ($\dots B \dots A \dots$, $\dots A \dots B \dots$) implies that A is below B. A sequence pair can be translated into a placement by constructing horizontal and vertical constraint graph [9].

Conditions for block alignments in sequence pair are studied in [10]. H/V alignment constraints and abutting constraint between blocks are introduced and applied for performance-aware floorplanning.

B. Substrate Noise Model

Several techniques have been proposed to model substrate noise accurately and analyze it in integrated circuit level [11]–[13]. However, these techniques require the detailed implementation information in transistors and transistor-level simulation, which is time intensive. In this paper, we use compact substrate coupling model [5] to evaluate floorplanning as a conventional approach and to verify the final floorplan. The model in [5] is known to be highly scalable with dimensions and separations.

A two-port lumped resistor network, modeling substrate is illustrated in Fig. 1. The resistance R_{DA} , models the coupling between two blocks, and R_A and R_D model the coupling from the blocks to the backplane. The resistances, R_{DA} , R_A and R_D can be derived from the scalable macromodel, which is based on Z-parameters.

$$Z = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} G_D + G_{DA} & G_{DA} \\ G_{DA} & G_A + G_{DA} \end{bmatrix} \quad (1)$$

where $\Delta = G_A G_{DA} + G_D G_{DA} + G_A G_D$ and any Z_{ij} can be calculated with equations in [5], [14], [15].

The coupling gain (propagation gain) of the substrate can be calculated from the value of resistors in the two-port lumped network shown in Fig. 1. The coupling gain of i th digital block to j th analog block, $CG_{i,j}$ is given by:

$$CG_{i,j} = \frac{R_A}{R_A + R_{DA}} = \frac{G_{DA}}{G_{DA} + G_A} = \frac{Z_{12}}{Z_{22}} \quad (2)$$

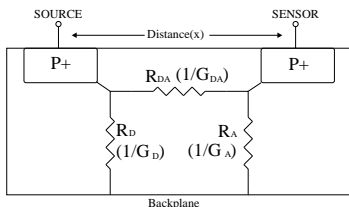


Fig. 1. Macromodel for the substrate

Although $CG_{i,j}$ exhibits frequency-dependent characteristics, it is constant under a few gigahertz [4]. In this paper, we assume that the bands of interest are within this limit. The quantity of the substrate noise can be estimated using a simple analytical formula based on $CG_{i,j}$ and frequency-dependent characteristics of noise source and sensor block. The substrate noise of j th analog block from switching of i th digital block, $N_{i,j}$ can be approximated by [8]:

$$N_{i,j} = (CG_{i,j}) \cdot \sqrt{\int_0^\infty (S_i(f) \cdot H_j(f))^2 df} \quad (3)$$

where $S_i(f)$ and $H_j(f)$ are Power Spectral Density (PSD) of noise source and transfer function of noise sensor respectively. Also, the total noise from all digital blocks is:

$$N_{total} = \sum_i \sum_j N_{i,j} \quad (4)$$

As shown in Eq.(3), $CG_{i,j}$ is scaled by average power of noise with regard to the frequency. The frequency-dependent noise generated by a digital block, $S_i(f)$ is shaped by the transfer function of the noise sensor. The integration of the shaped power of noise represents the quantity of noise injected into analog block, when $CG_{i,j}$ is equal to 1.

In this paper, we use a piecewise-linear approximation of PSD to estimate $S_i(f)$, and Power/Ground(P/G) bounce limits to determine its parameters.

III. BPDG: BLOCK PREFERENCE DIRECTED GRAPH

The substrate noise model in Section II-B is one of the most compact models with high scalability and accuracy. However, it is still computationally expensive to perform a substrate noise estimation even with such an efficient model during simulated annealing-based floorplanning, because every noise estimation after a movement requires the accurate location of every block (substrate noise is exponentially sensitive to geometric distance [5], [14], [15]), whereas area and wire-length can be calculated approximately. Furthermore, computing noise itself with Eq.(2, 3) is not computationally trivial.

For fast substrate noise estimation, a novel concept of block preference directed graph, BPDG is introduced and described in this section. BPDG represents preferred relative locations of blocks and guides substrate noise-aware floorplanning with fast substrate noise estimation with sequence pair. BPDG construction consists of three steps.

- 1) A substrate noise table of between all analog and digital blocks is constructed.
- 2) Analog block orderings and digital block orderings are created separately with substrate noise table.
- 3) BPDG is constructed by finding common orders from block orderings.

The following subsections illustrate each step with detailed examples in Table I and Fig. 2, 3, 4.

A. Substrate Noise Table Construction

Since substrate noise is heavily related to the distance between blocks, we assume that the nominal distance is fixed to eliminate the effect of distance. With such fixed distance, the substrate noise between a digital block and an analog block purely depends on frequency coupling and geometric properties. Under such assumption, for each digital block D_i and analog block A_j , a substrate noise on A_j due to D_i can be computed from Eq.(3) assuming fixed distance x between D_i and A_j . Table I shows an example of substrate noise table of between digital blocks ($D_1, D_2, D_3, D_4, D_5, D_6$) and analog blocks (A_1, A_2, A_3).

TABLE I
SUBSTRATE NOISE TABLE

	D_1	D_2	D_3	D_4	D_5	D_6
A_1	5	2	6	3	10	1
A_2	2	1	3	10	8	5
A_3	3	8	7	11	9	12

B. Analog Block Ordering

Based on the substrate noise table, analog blocks can be sorted for each digital block by *descending* order of substrate noise. Consider the example in Table I. Analog block A_1, A_3 and A_2 are ordered by the substrate noise from D_1 , because D_1-A_1 is 5, D_1-A_2 is 2 and D_1-A_3 is 3. The other five orderings can be obtained in the same fashion. All analog block orderings are shown in Fig. 2. This pushes more sensitive blocks to the head and less sensitive blocks to the tail of block orderings.

$$\begin{aligned}
 D_1 : A_1 \leftarrow A_3 \leftarrow A_2 & \quad , \quad D_2 : A_3 \leftarrow A_1 \leftarrow A_2 \\
 D_3 : A_3 \leftarrow A_1 \leftarrow A_2 & \quad , \quad D_4 : A_3 \leftarrow A_2 \leftarrow A_1 \\
 D_5 : A_1 \leftarrow A_3 \leftarrow A_2 & \quad , \quad D_6 : A_3 \leftarrow A_2 \leftarrow A_1
 \end{aligned}$$

Fig. 2. Analog block orderings

C. Digital Block Ordering

In similar way, digital blocks can be sorted for each analog block by *ascending* order of substrate noise. Again considering the example in Table I, digital block D_6, D_2, D_4, D_1, D_3 and D_5 are ordered such that the substrate noise on A_1 is increasing. All digital block orderings are shown in Fig. 3. This pushes less aggressive blocks to the head and more aggressive blocks to the tail of block orderings.

$$\begin{aligned}
 A_1 : D_6 \leftarrow D_2 \leftarrow D_4 \leftarrow D_1 \leftarrow D_3 \leftarrow D_5 \\
 A_2 : D_2 \leftarrow D_1 \leftarrow D_3 \leftarrow D_6 \leftarrow D_5 \leftarrow D_4 \\
 A_3 : D_1 \leftarrow D_3 \leftarrow D_2 \leftarrow D_5 \leftarrow D_4 \leftarrow D_6
 \end{aligned}$$

Fig. 3. Digital block orderings

Algorithm 1 BPDG Construction

Input: Analog, Digital block orderings O_a and O_d

- 1: Analog BPDG $G_a \leftarrow \phi$, Digital BPDG $G_d \leftarrow \phi$
- 2: **for** each analog block $A_i, A_j, i \neq j$ **do**
- 3: **if** A_i is before A_j in all O_a **then**
- 4: Add a directed edge from A_j to A_i to G_a
- 5: **end if**
- 6: **end for**
- 7: **for** each digital block $D_i, D_j, i \neq j$ **do**
- 8: **if** D_i is before D_j in all O_d **then**
- 9: Add a directed edge from D_j to D_i to G_d
- 10: **end if**
- 11: **end for**
- 12: Add a virtual vertex D_0 for G_a to G_d
- 13: Add directed edges from all root vertices to D_0

Output: G_d

D. BPDG Construction

The two key ideas behind BPDG construction are: first, to find common block location patterns in order to minimize the substrate noise; second, to make less aggressive digital blocks and less sensitive analog blocks interfaced. An analog and digital BPDG are constructed with analog and digital block orderings by using Algorithm 1.

The reason to create a virtual vertex in Algorithm 1 is to force analog blocks isolated from digital blocks, which is very common in real mixed-signal design.

Consider the final BPDG in Fig. 4 as an example. Since A_3 is before A_2 for all analog block orderings in Fig. 2, vertices A_3 and A_2 are inserted into, G_a (analog BPDG) and connected with a directed edge. Again, vertices D_1 and D_3 are inserted into G_d (digital BPDG), and connected with a directed edge, because D_1 is before D_3 for all digital block orderings in Fig. 3. However, there is no preference on D_6 , because it is before all blocks in A_1 's block ordering and after all blocks in A_3 's block ordering in Fig. 3. Lastly, G_a and G_d are merged via virtual vertex D_0 .

IV. SUBSTRATE NOISE ESTIMATION WITH BPDG

The BPDG in Section III can be used to estimate substrate noise quickly by comparing it against a sequence pair which is one of the most popular floorplan representations. In this

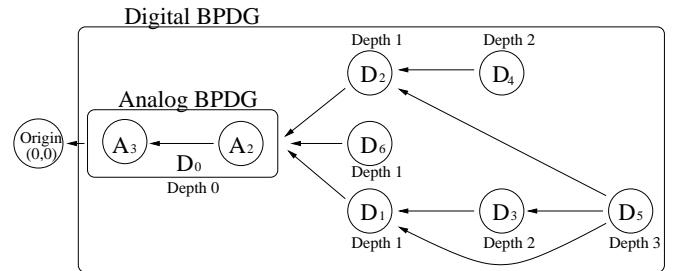


Fig. 4. Block preference directed graph

section, a theorem which returns the number of violations against preferences in a BPDG from a sequence pair is presented, and its high fidelity to substrate noise is shown. The number of violations is highly correlated to substrate noise quantity; intuitively, the more violations indicate the more noise because each directed edge from a block B_b to a block B_a in the BPDG means that B_a is preferred to be closer to the origin (left-bottom corner of floorplan) than B_b to reduce the substrate noise.

A. Sequence Pair with BPDG

In [10], the concept of *strictly ahead* is defined for block alignment in a floorplanning with sequence pair. Fig. 5(a) shows a compact floorplan with several blocks. In this example, B_a is strictly ahead of B_1, B_2, B_3 and B_4 . In fact, strictly ahead is a necessary condition for two blocks to be abutted (only B_1 and B_3 are abutted to B_a). Continuously, we introduce more definitions based on *strictly ahead* for easier explanation of this section.

DEFINITION α . Given a block B_a and a sequence pair (P,N), all the blocks which are both strictly ahead of B_a and below B_a form a **strictly below set** of B_a .

DEFINITION β . Given a block B_a and a sequence pair (P,N), all the blocks which are both strictly ahead of B_a and to the left of B_a form a **strictly left set** of B_a .

DEFINITION γ . Given a block B_a and a sequence pair (P,N), any block in a strictly below/left set of B_a and abutting to B_a is a **reference block**.

In Fig. 5(a), B_2, B_3 and B_4 are strictly below set of B_a , because they are strictly ahead of B_a as well as below B_a . Also, B_3 is a reference block of B_a . One intuitive property of the reference block is stated in Lemma α referring to [10].

Lemma α : *If a block B_a has a strictly below/left set S , there must exist some reference block B_x in S under a completely packed floorplan.*

Based on Lemma α , the relative locations of two blocks can be determined. Consider a specific floorplan in Fig. 5(b) where B_a is to the left of B_b and B_x is a reference block of B_a . It can be easily proved that if a block such as B_x exists below B_b , it is guaranteed that B_a has a shorter distance to the origin (0,0) than B_b . This key idea to compare the relative location of two blocks **conservatively** with a sequence pair is presented as Theorem 1 by taking Theorem 1 and 3 in [10] a

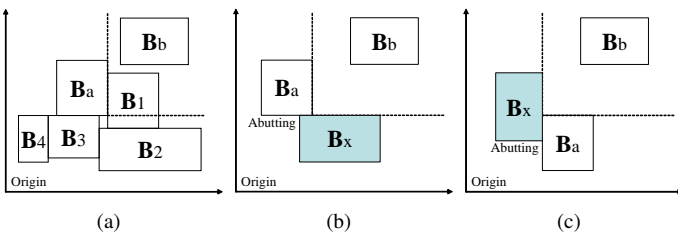


Fig. 5. Floorplan examples

steppingstone. Note that the condition 1 and 2 of Theorem 1 are corresponding to Fig. 5(b) and (c) respectively.

Theorem 1: *Let S_b a strictly below set of B_a and S_l a strictly left set of B_a . A block B_a is guaranteed to have shorter distance to the left bottom corner than a block B_b under a completely packed floorplan, if either of following conditions is satisfied.*

- 1) *for any block B_s in S_b , a sequence pair (P, N) is $(..B_a X_1 B_b X_2 B_s .., ..B_s Y_1 B_a ..B_b ..)$.*
- 2) *for any block B_s in S_l , a sequence pair (P, N) is $(..B_s X_3 B_b X_4 B_a .., ..B_s Y_2 B_a ..B_b ..)$.*

Thus, with a given sequence pair (P, N) and a BPDG G , the number of violations in (P, N) against G can be calculated by Theorem 1. The following sequence pairs show examples with the BPDG in Fig. 4. Note that the blocks you need to pay attention to are marked with *, and we highlight one violation, even though there can be more.

- $(D_0 D_6 D_1 D_2^* D_3 D_4^* D_5, D_4^* D_0 D_6 D_1 D_2^* D_3 D_5)$
This case has $D_2 \leftarrow D_4$ violation, because D_2 is after D_4 in the second sequence which does not match either of required sequence pair patterns in Theorem 1.
- $(D_4 D_5 D_1^* D_2 D_6 D_0^* D_3^*, D_0^* D_5 D_4 D_1^* D_2 D_6 D_3^*)$
This case has $D_1 \leftarrow D_3$ violation. D_0 is below D_1 and $LCS(D_2 D_6, D_5 D_4) = \phi$ But, D_0 is before D_3 in the first sequence which violates the required sequence pair pattern in case 1 of Theorem 1.

Theorem 1 can be further simplified into Theorem 2 by narrowing down the size of subsequences to scan.

Theorem 2: *A block B_a is guaranteed to have shorter distance to the left-bottom corner than a block B_b under a completely packed floorplan, if either of following conditions is satisfied.*

- 1) *there is no block B_s satisfying $LCS(X_1, Y_1) = \phi$ in a sequence pair $(P, N) = (..B_a X_1 B_s ..B_b .., ..B_s Y_1 B_a ..B_b ..)$.*
- 2) *there is no block B_s satisfying $LCS(X_2, Y_2) = \phi$ in a sequence pair $(P, N) = (..B_b ..B_s X_2 B_a .., ..B_s Y_2 B_a ..B_b ..)$.*

The significance of Theorem 1 and 2 is that a geometric distance from the origin to any two blocks in a sequence pair can be compared conservatively *without other geometric information*. Thus, whether an edge (preference) in a BPDG is held in a sequence pair can be checked efficiently. Note that in a real implementation, bitwise-OR can be used instead of *LCS* computation, since we are only interested in whether there is a common sequence.

B. Fidelity of BPDG

In order to measure fidelity of BPDG to substrate noise, *ami33* from MCNC benchmarks [16] was simulated with carefully generated noise characteristics.

Fig. 6 shows normalized substrate noise on all analog blocks by the number of violations from Theorem 2 with different total number of violations. It shows that normalized substrate noise increases near linearly as the number of violations increases. Notice that the range over 50% of maximum violations shows high fidelity with less than 6% error in Fig. 6(a), and 9% in Fig. 6(b). Since a typical number of violations

TABLE II
SIMULATION RESULT

Name	Algorithm Description	Cost ^a Function	Input (node)	Area (mm ²)	White Space(%)	Normalized Noise	CPU (sec)	Overhead (%)	
								CPU	Area
parq	Pure Parquet	$\frac{A}{A_r}$	ami33	1.19	3.2	821.1	0.8	0.0	0.0
			ami49	36.7	3.6	1629.9	2.6	0.0	0.0
			n75	42.04	4.0	3559.9	8.6	0.0	0.0
			n100	18.86	5.1	4697.5	24.6	0.0	0.0
bpdg^b	BPDG with Sequence Pair	$0.6 \frac{A}{A_r} + 0.4 \frac{NV}{NV_r}$	ami33	1.24	6.9	121.2	0.9	15.5	3.8
			ami49	37.9	7.1	72.2	2.7	6.6	3.4
			n75	43.12	6.6	173.1	9.2	7.1	2.6
			n100	19.22	6.9	202.5	26.4	7.1	1.9
modl	Substrate Noise Model with Sequence Pair	$0.6 \frac{A}{A_r} + 0.4 \frac{SN}{SN_r}$	ami33	1.23	6.1	143.9	73.0	8782.5	2.8
			ami49	38.4	8.4	90.8	158.3	6103.3	4.6
			n75	44.08	9.1	322.4	666.9	7692.5	4.9
			n100	19.94	11.1	696.1	1956.3	7844.1	5.8

^a A , NV and SN denote total area, the number of violations and total substrate noise on analog blocks respectively. A_r , NV_r and SN_r are the reference values of A , NV and SN respectively.

^b for **bpdg**, each side of the virtual analog block is inflated by 0.6% as a whitespace(guard ring) insertion.

during the simulated annealing remains in this high fidelity range, the number of violations in sequence pair is a good indicator of substrate noise. These two observations imply that by comparing BPDG of Section III against sequence pair, substrate noise can be estimated fast with high fidelity. Computational efficiency of proposed approach is two fold:

- Our approach estimates substrate noise without accurate geometric information such as x and y coordinates. As a result, all the efforts to compute the accurate locations of all blocks can be saved.
- Our approach needs only integer operations whereas model-based noise estimation requires floating point operations and transcendental functions like $\exp(x)$.

V. FAST SUBSTRATE NOISE-AWARE FLOORPLANNING

Our floorplanning is highlighted by fast substrate noise estimation based on discrepancy between BDPG in Section III and sequence pair in Section IV. Also, using block inflation, we insert whitespace around analog blocks as a guard ring. Note that our white space allocation is done as a preprocessing to minimize area overhead. Overall algorithm is described in Algorithm 2.

VI. EXPERIMENTAL RESULTS

We implemented the proposed algorithm in C++ by modifying Parquet [17] which is a simulated annealing-based

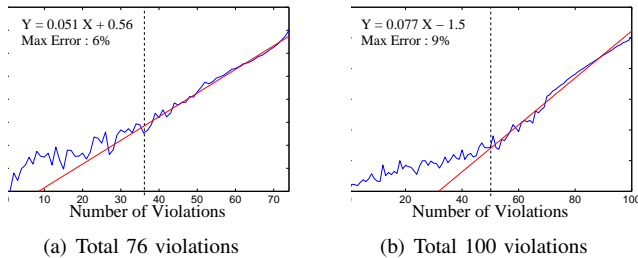


Fig. 6. Number of violations vs. Substrate noise

Algorithm 2 Fast Substrate Noise-Aware Floorplanning

Input: Analog BPDG Ag , Digital BPDG Dg

- 1: Do floorplanning with analog blocks with Ag
- 2: Inflate the analog block floorplan
- 3: Make the analog floorplan as a virtual block B_v
- 4: Do floorplanning with digital blocks and B_v with Dg

Output: Final floorplan

floorplanning package available in [18]. In order to compare our approach(**bpdg** in Table II) with other approaches, we also implemented the conventional model-based, substrate noise-aware floorplanning algorithm(**modl** in Table II). After every movement inside the simulated annealing loop, to estimate current floorplan instance's substrate noise on the analog blocks, the number of violations by Theorem 2 was *counted* for **bpdg**, whereas substrate noise was *computed* for **modl** based on the substrate noise model and Eq.(4) in Section II-B. The cost functions we used for each algorithm are summarized in Table II as well. Note that we disabled wirelength optimization, since real implementation of mixed-signal SOCs has sparse interconnection between analog blocks and digital blocks, which is not well reflected in MCNC benchmarks. However, our approach can be readily extended to include wirelength optimization, maintaining high computational efficiency.

all algorithms were tested on Pentium4 Linux machines (3.4GHz/2GMB) with two MCNC [16] benchmarks (ami33, ami49) and two randomly generated larger benchmarks (n75 with 75 blocks, n100 with 100 blocks). About 30% of the blocks in each benchmark were chosen as analog blocks and noise characteristics of all the blocks were carefully generated. All process dependent parameters were the same as in [5], [14], [15].

Table II also shows simulation results for all benchmarks with three algorithms. Each of the numbers in the table is generated by taking the average of numbers obtained over 250 floorplans. The simulated annealing of each floorplanning is scheduled by Parquet, and stopped after the same number of

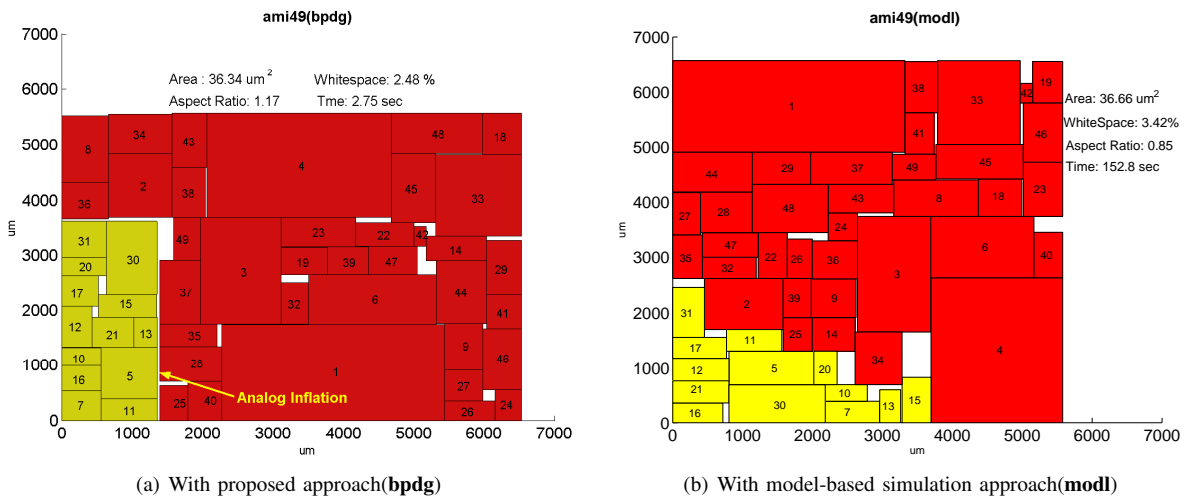


Fig. 7. Result of packing ami49

movements for each benchmark. The final noise quantities for all algorithms were estimated based on Eq.(4) for comparison.

The last two columns show the overhead of each algorithm in terms of cpu time and area with respect to the result of **parq**. From the table, **parq** shows the best area and cpu time (thus, 0% overhead), but the worst noise for all benchmarks as expected. The cpu time of **bpdg** is significantly smaller than that of **modl** for all benchmarks; **bpdg** is approximately 60-80 times faster than **modl**. The area overhead of **bpdg** is slightly smaller for the 3 larger benchmarks as well than **modl**. Lastly **bpdg** shows less total substrate noise than **modl**. The reason why the proposed algorithm overall shows both smaller area and less substrate noise is that whitespace is more efficiently utilized. By making an analog floorplan inflated as a preprocessing step as in Section V, the substrate noise becomes less in the beginning of annealing and this allows the simulated annealing engine to optimize the area further without increasing substrate noise. An analogy of this kind of effect can be found in congestion-aware placement [19].

VII. CONCLUSION

In order to cope with significant substrate noise impact on analog circuits from digital circuits, we propose substrate noise-aware floorplanning with fast substrate noise estimation powered by block preference directed graph (BPDG) and sequence pair. Compared with Parquet [17], the proposed approach has in average only 9% cpu time overhead, whereas naive model-based simulation approach shows over 6000% overhead. Also, the proposed approach shows smaller area overhead due to the efficient utilization of whitespace.

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