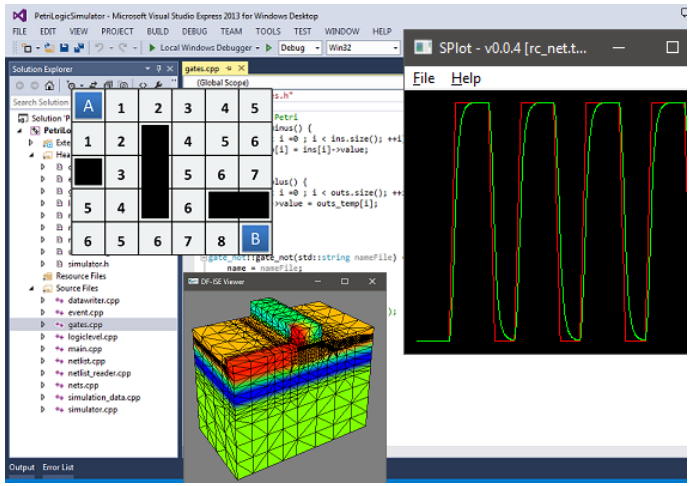
Национальный исследовательский университет «МИЭТ»

Институт интегральной электроники (группы ЭН-34-35, каф. ПКИМС)

Программные средства САПР

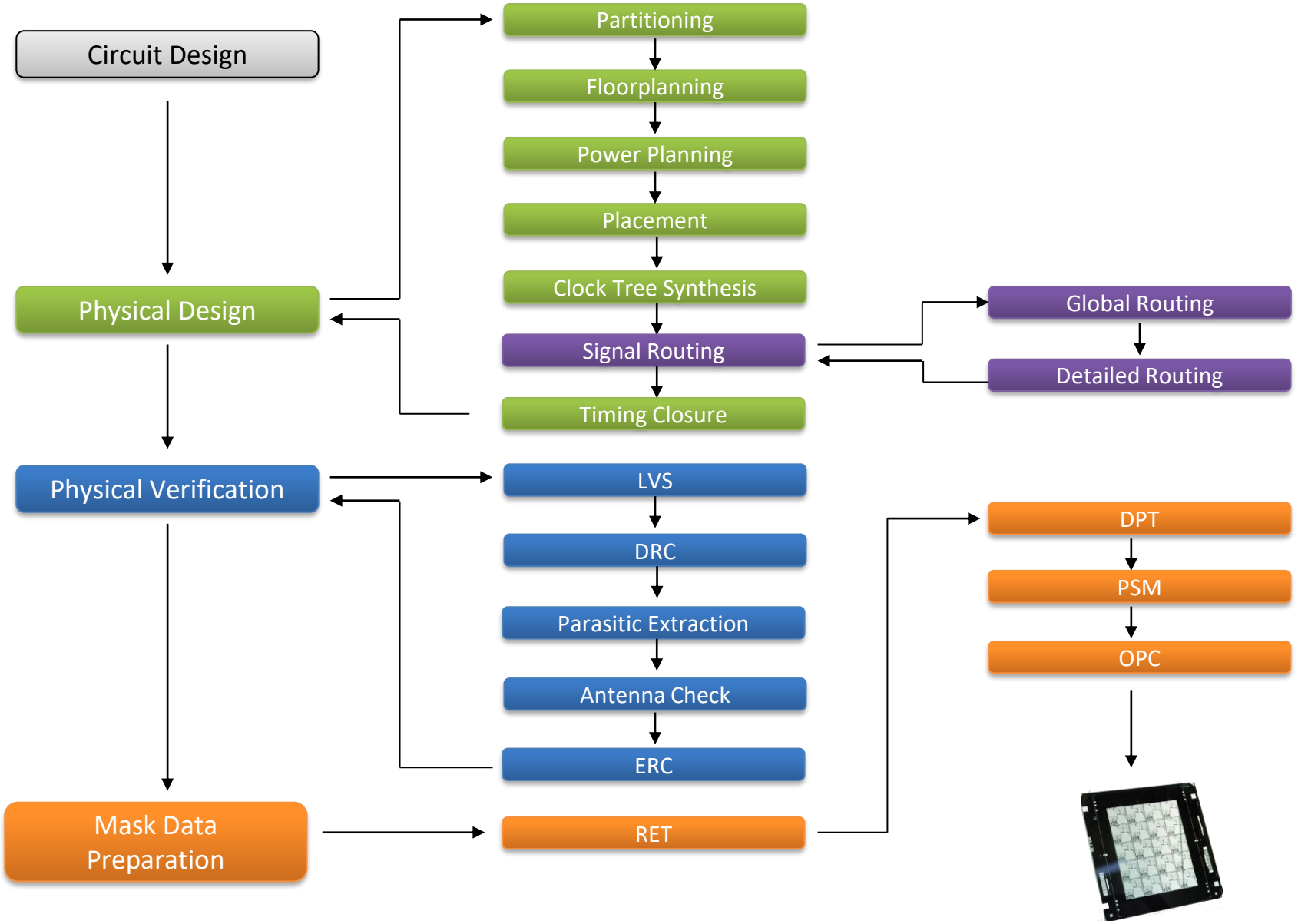


Лекция 7

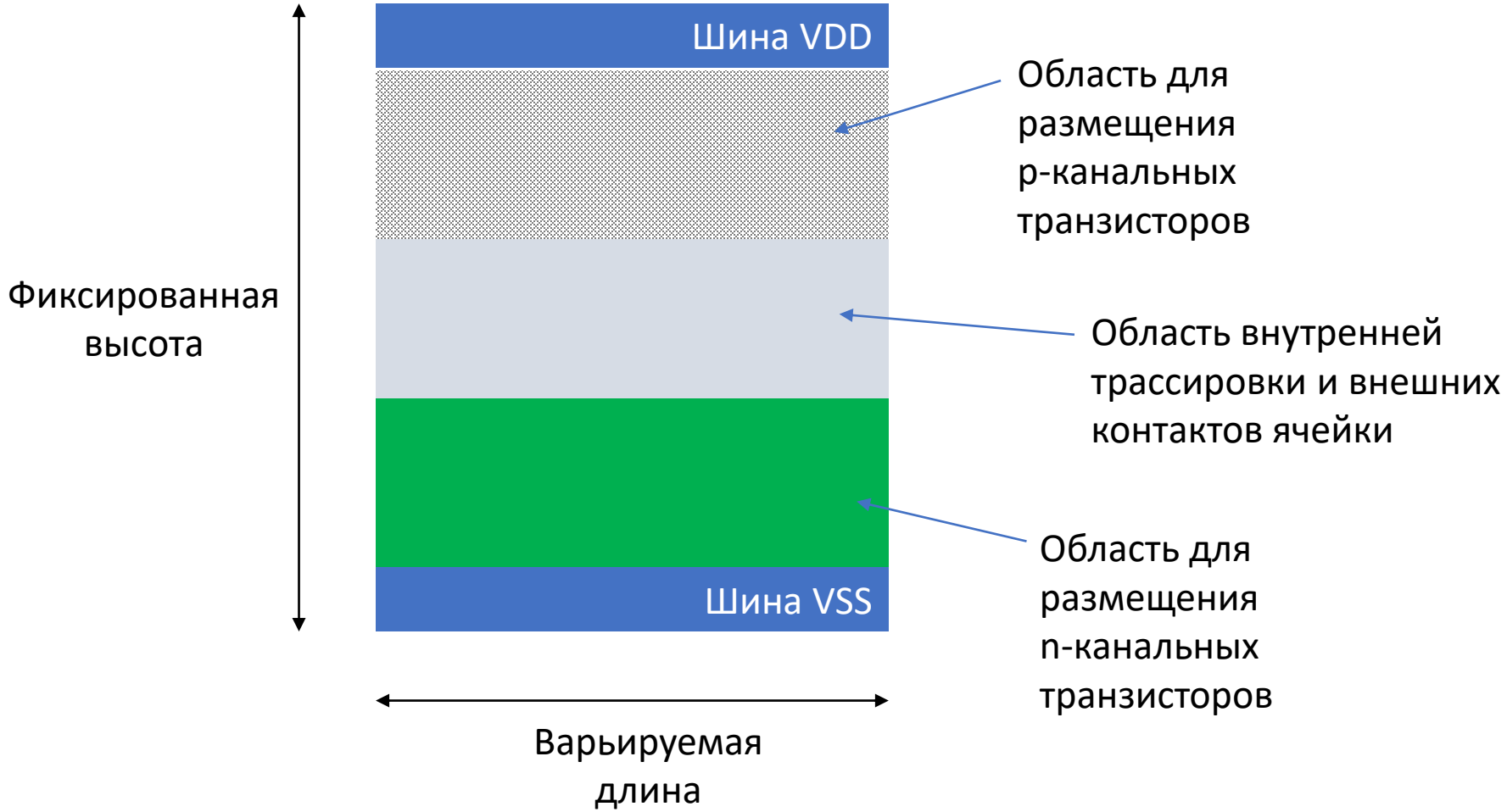
Этап проектирования топологии

Часть 2

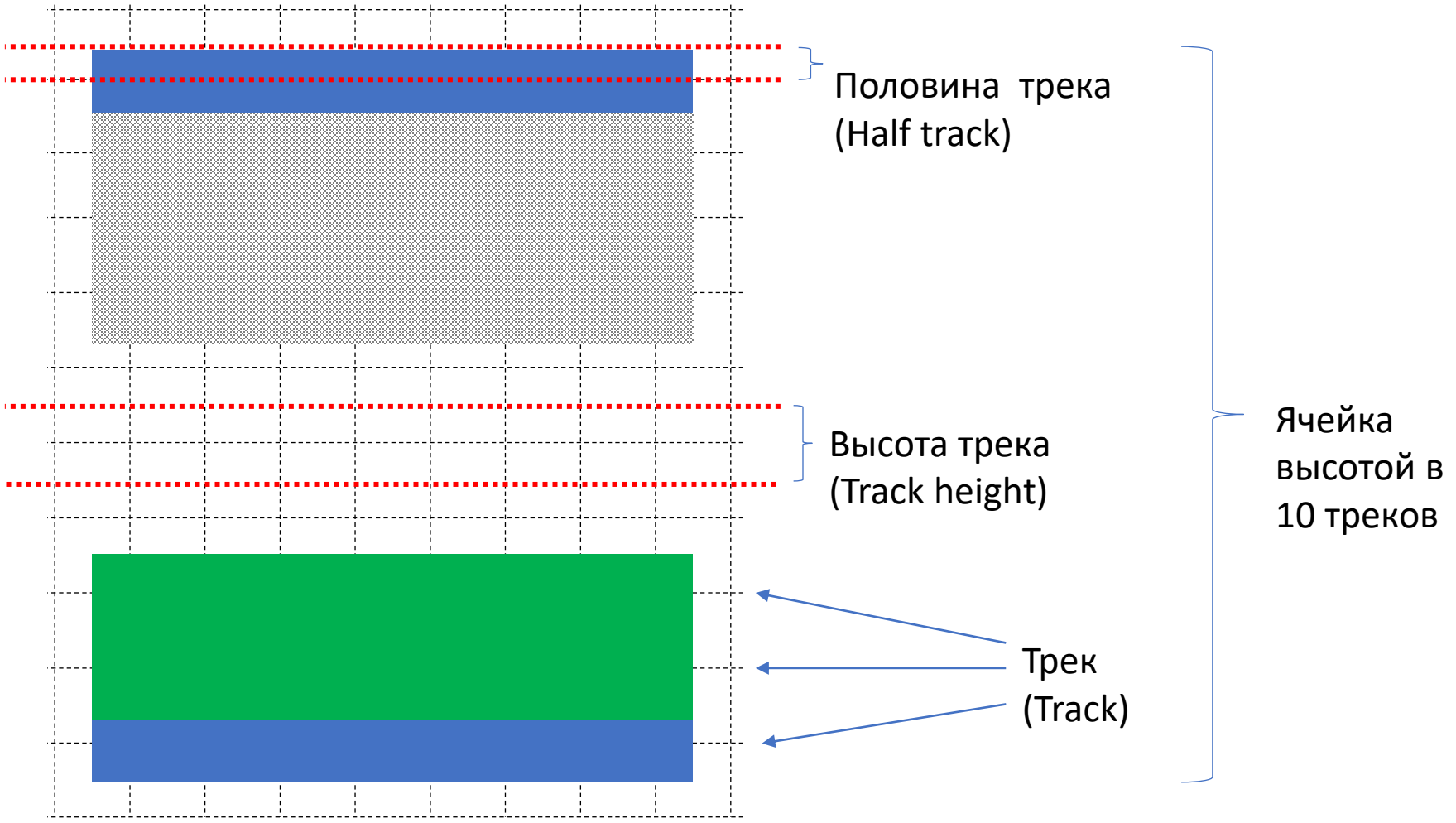
Задачи этапа топологического проектирования (как есть)



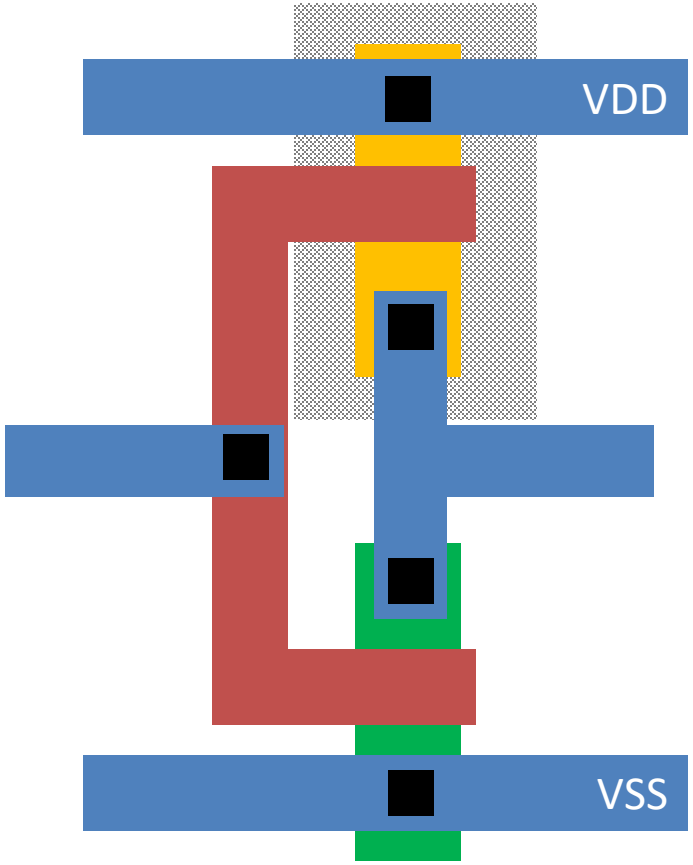
Идея методологии стандартных ячеек (1)

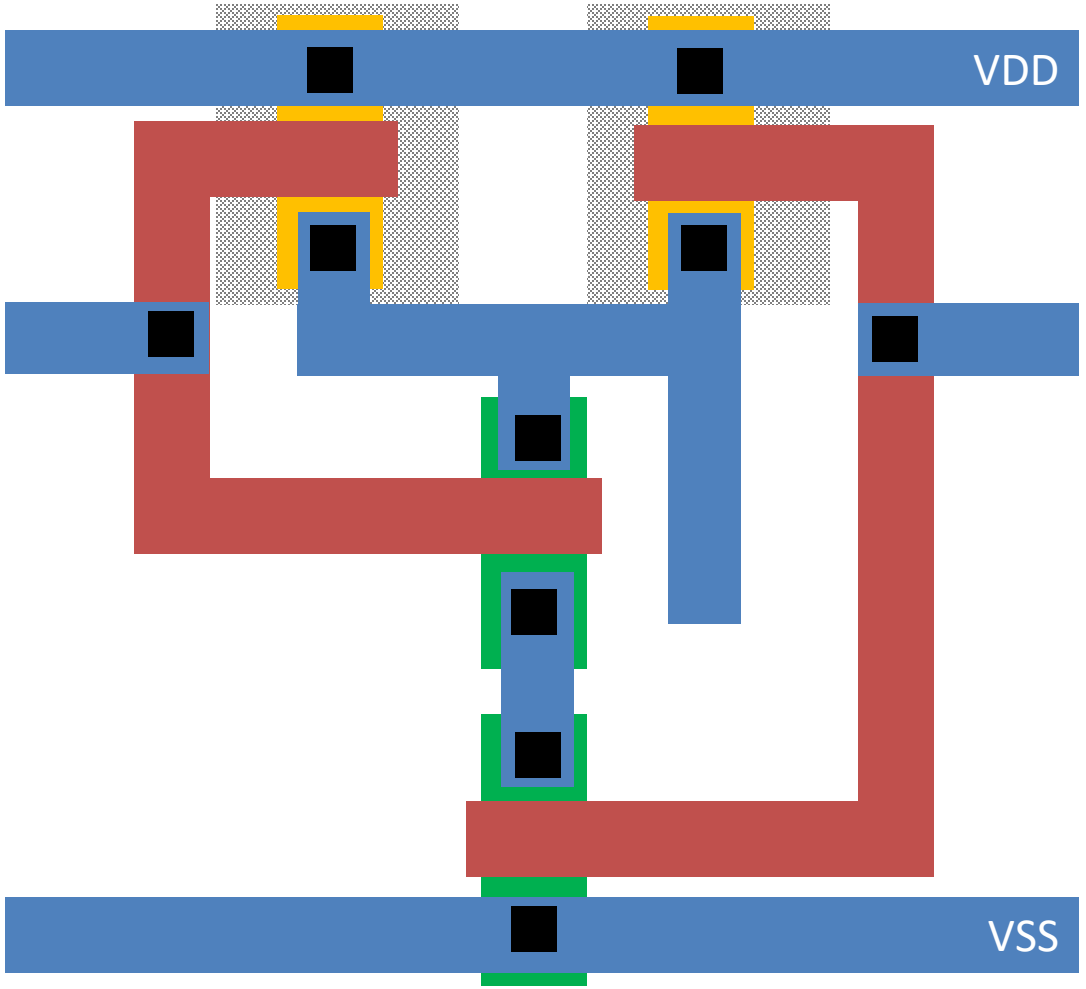


Идея методологии стандартных ячеек (2)

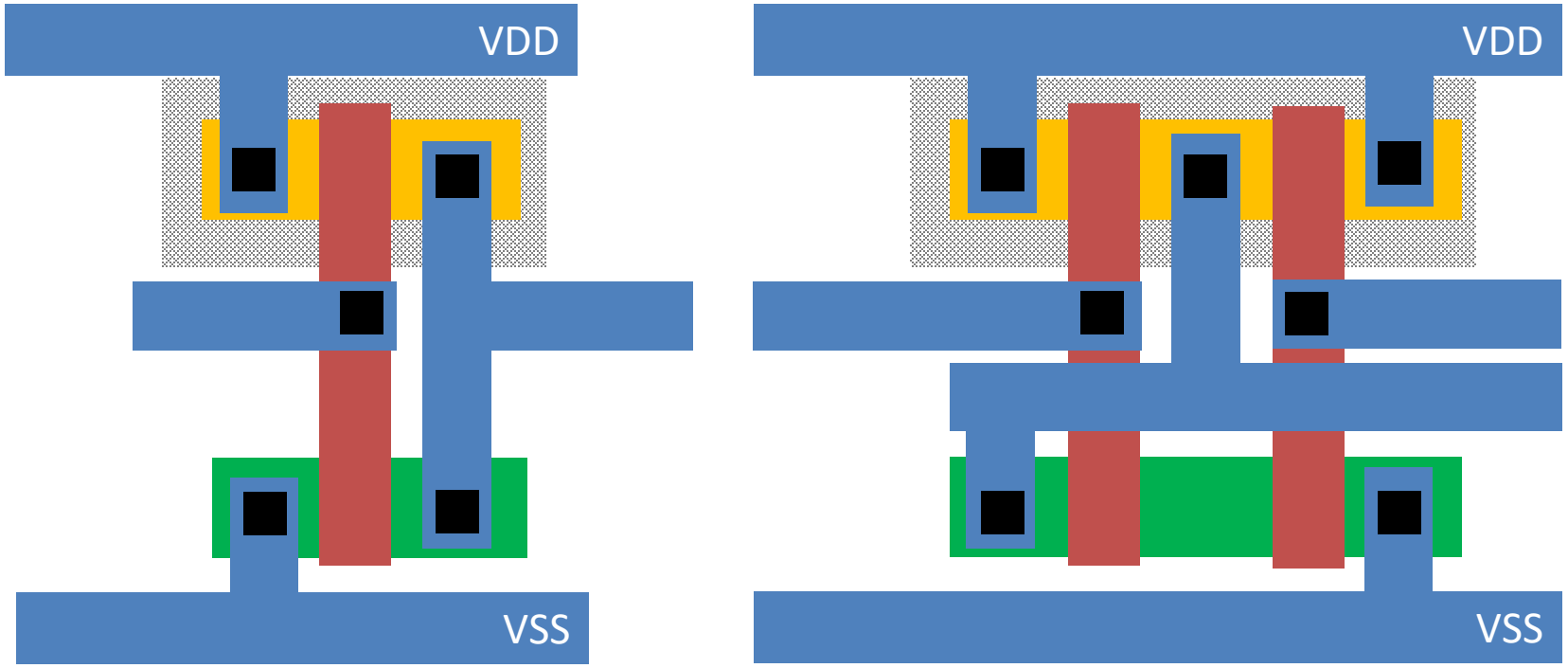


Как разместить на кристалле различные элементы?

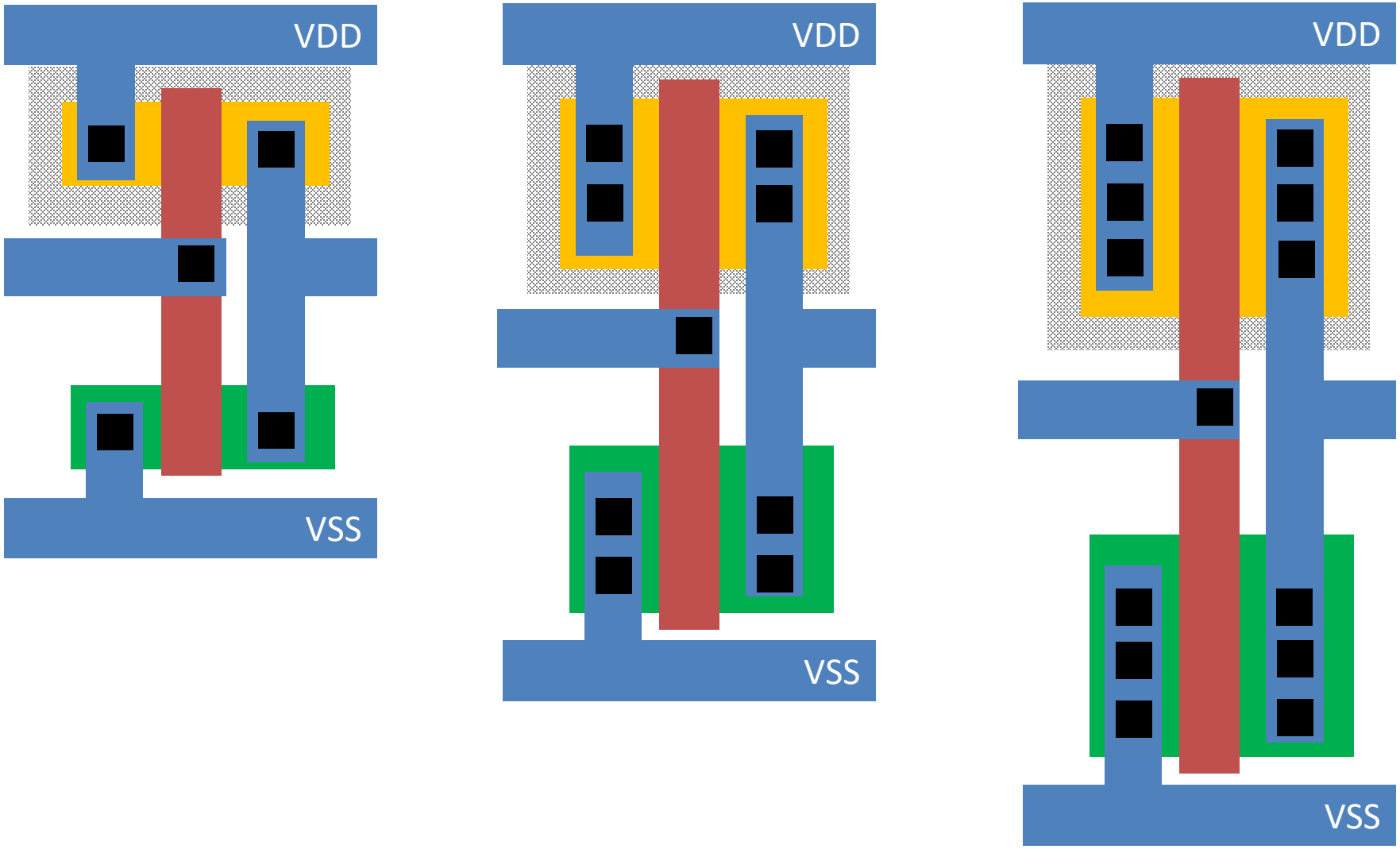




Стандартные ячейки для различных логических функций



Варьирование высоты стандартных ячеек

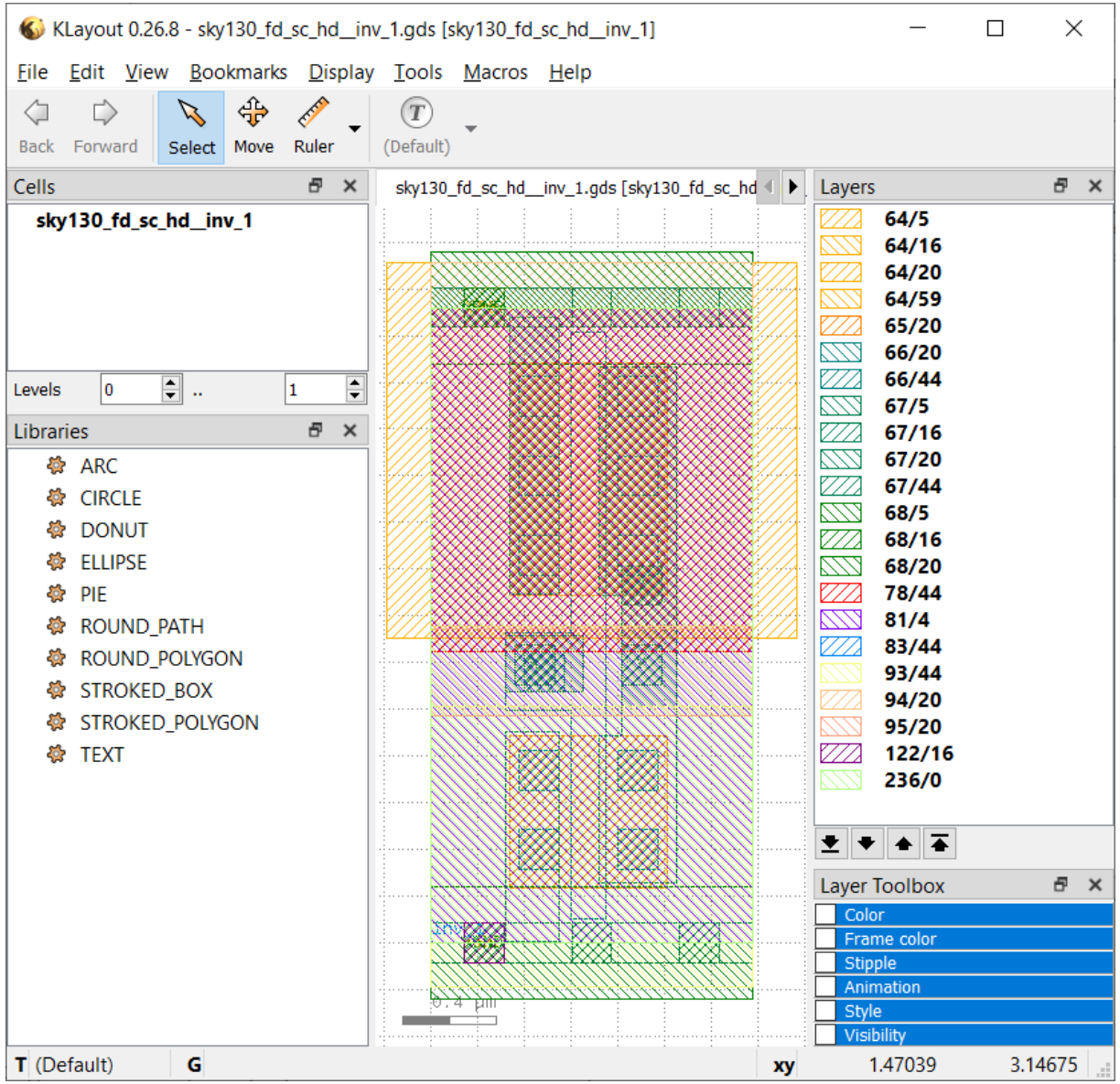


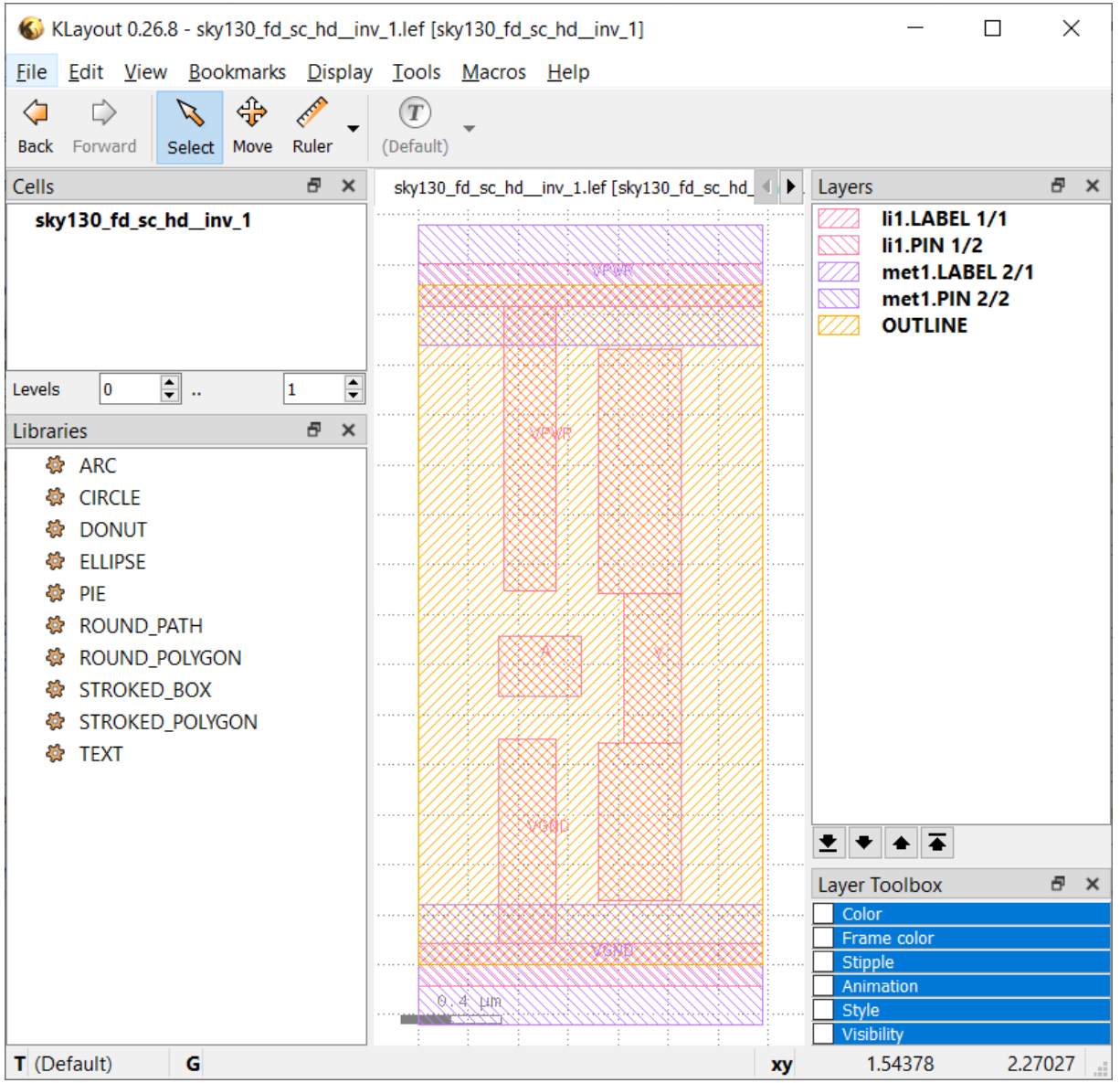
Описание стандартных ячеек: формат LEF (1)

```
VERSION 5.5 ;
NAMESCASESENSITIVE ON ;
BUSBITCHARS "[]" ;
DIVIDERCHAR "/" ;


MACRO sky130_fd_sc_hd__inv_1
  CLASS CORE ;
  SOURCE USER ;
  ORIGIN  0.000000  0.000000 ;
  SIZE  1.380000 BY  2.720000 ;
  SYMMETRY X Y R90 ;
  SITE unithd ;

  PIN A
    ANTENNAGATEAREA  0.247500 ;
    DIRECTION INPUT ;
    USE SIGNAL ;
    PORT
      LAYER li1 ;
        RECT 0.320000 1.075000 0.650000 1.315000 ;
    END
  END A
  ...
END sky130_fd_sc_hd__inv_1
```

```
VERSION 5.5 ;
NAMESCASESENSITIVE ON ;
BUSBITCHARS "[]" ;
DIVIDERCHAR "/" ;

MACRO sky130_fd_sc_hd__inv_1


  PIN A ... END A

  PIN Y ... END Y

  PIN VGND ... END VGND

  PIN VPWR ... END VPWR

END sky130_fd_sc_hd__inv_1
```

GDSII vs LEF


KLayout 0.26.8 - sky130_fd_sc_hd__inv_1.gds [sky130_fd_sc_hd__inv_1]
File Edit View Bookmarks Display Tools Macros Help
Back Forward Select Move Ruler (Default)
Cells
sky130_fd_sc_hd__inv_1
Levels 0 .. 1
Libraries
ARC
CIRCLE
DONUT
ELLIPSE
PIE
ROUND_PATH
ROUND_POLYGON
STROKED_BOX
STROKED_POLYGON
TEXT
sky130_fd_sc_hd__inv_1.gds [sky130_fd_sc_hd
Layers
64/5
64/16
64/20
64/59
65/20
66/20
66/44
67/5
67/16
67/20
67/44
68/5
68/16
68/20
78/44
81/4
83/44
93/44
94/20
95/20
122/16
236/0
Layer Toolbox
Color
Frame color
Stipple
Animation
Style
Visibility
T (Default) G xy 1.47039 3.14675


KLayout 0.26.8 - sky130_fd_sc_hd__inv_1.lef [sky130_fd_sc_hd__inv_1]
File Edit View Bookmarks Display Tools Macros Help
Back Forward Select Move Ruler (Default)
Cells
sky130_fd_sc_hd__inv_1
Levels 0 .. 1
Libraries
ARC
CIRCLE
DONUT
ELLIPSE
PIE
ROUND_PATH
ROUND_POLYGON
STROKED_BOX
STROKED_POLYGON
TEXT
sky130_fd_sc_hd__inv_1.lef [sky130_fd_sc_hd_
Layers
li1.LABEL 1/1
li1.PIN 1/2
met1.LABEL 2/1
met1.PIN 2/2
OUTLINE
VPWR
VGND
VNB
A
Y
Layer Toolbox
Color
Frame color
Stipple
Animation
Style
Visibility
T (Default) G xy 1.54378 2.27027

Технологические данные в формате LEF (1)

```
VERSION 5.7 ;

BUSBITCHARS "[]" ;
DIVIDERCHAR "/" ;

UNITS
  TIME NANOSECONDS 1 ;
  CAPACITANCE PICOFARADS 1 ;
  RESISTANCE OHMS 1 ;
  DATABASE MICRONS 1000 ;
END UNITS

MANUFACTURINGGRID 0.005 ;

SITE unithd
  SYMMETRY Y ;
  CLASS CORE ;
  SIZE 0.46 BY 2.72 ;
END unithd

LAYER nwell
  TYPE MASTERSLICE ;
  PROPERTY LEF58_TYPE "TYPE NWELL ;" ;
END nwell

LAYER pwell
  TYPE MASTERSLICE ;
  PROPERTY LEF58_TYPE "TYPE PWELL ;" ;
END pwell
```

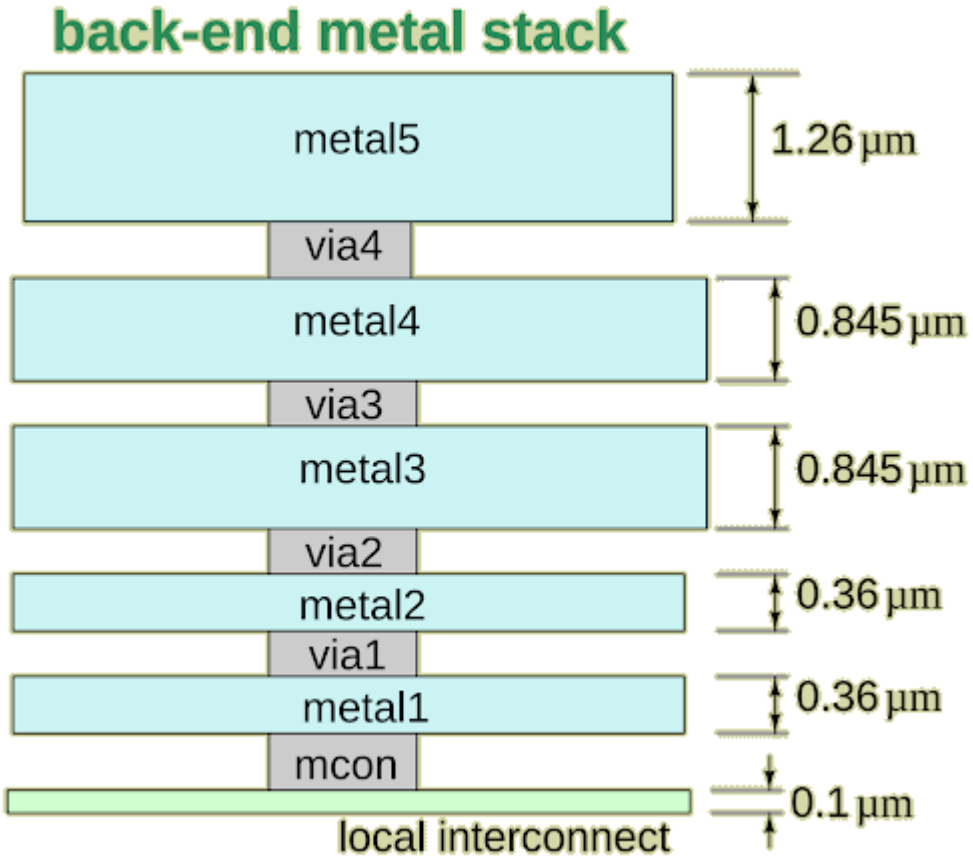
```
LAYER met1
  TYPE ROUTING ;
  DIRECTION HORIZONTAL ;

  PITCH 0.34 ;
  OFFSET 0.17 ;

  WIDTH 0.14 ;
  SPACINGTABLE
     PARALLELRUNLENGTH 0
     WIDTH 0 0.14
     WIDTH 3 0.28 ;
  AREA 0.083 ;
  THICKNESS 0.35 ;

  ANTENNAMODEL OXIDE1 ;
  ANTENNADIFFSIDEAREARATIO PWL ( ( 0 400 ) ( 0.0125 400 ) ( 0.0225 2609 ) ( 22.5 11600 ) ) ;

  EDGECAPACITANCE 40.567E-6 ;
  CAPACITANCE CPERSQDIST 25.7784E-6 ;
  DCCURRENTDENSITY AVERAGE 2.8 ;
  ACCURRENTDENSITY RMS 6.1 ;
  MAXIMUMDENSITY 70 ;
  DENSITYCHECKWINDOW 700 700 ;
  DENSITYCHECKSTEP 70 ;

  RESISTANCE RPERSQ 0.125 ;
END met1
```

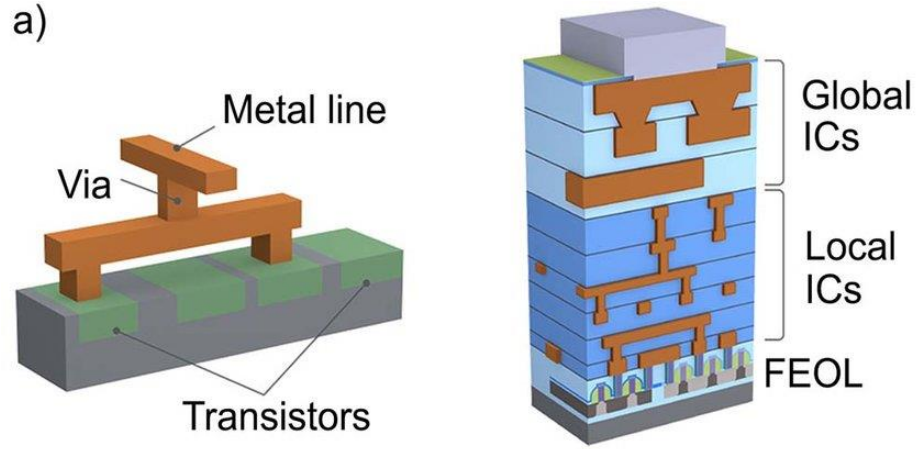
Технологические данные в формате LEF (3)

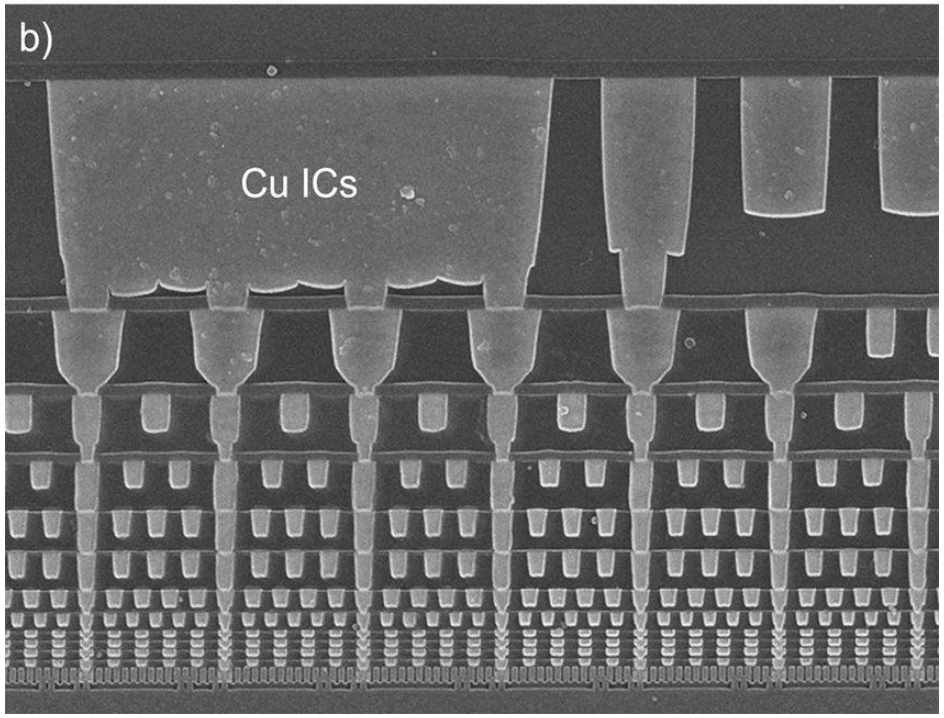
```
LAYER via
  TYPE CUT ;
  WIDTH 0.15 ;
  SPACING 0.17 ;
  ENCLOSURE BELOW 0.055 0.085 ;
  ENCLOSURE ABOVE 0.055 0.085 ;

  ANTENNADIFFAREARATIO PWL ( ( 0 6 ) ( 0.0125 6 ) ( 0.0225 6.81 ) ( 22.5 816 ) ) ;
  DCCURRENTDENSITY AVERAGE 0.29 ; # mA per via Iavg_max at Tj = 90oC
END via


LAYER via2
  TYPE CUT ;
  WIDTH 0.2 ;                  # Via2 1
  SPACING 0.2 ;                # Via2 2
  ENCLOSURE BELOW 0.04 0.085 ;  # Via2 4
  ENCLOSURE ABOVE 0.065 0.065 ; # Met3 4
  ANTENNADIFFAREARATIO PWL ( ( 0 6 ) ( 0.0125 6 ) ( 0.0225 6.81 ) ( 22.5 816 ) ) ;
  DCCURRENTDENSITY AVERAGE 0.48 ; # mA per via Iavg_max at Tj = 90oC
END via2
```

Технологические параметры

skywater

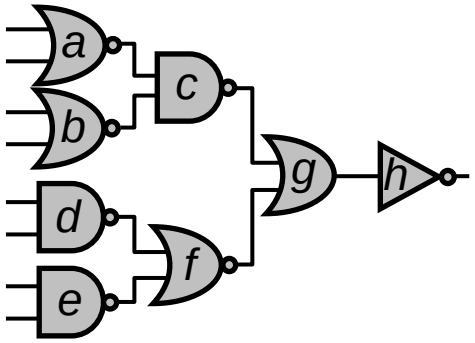




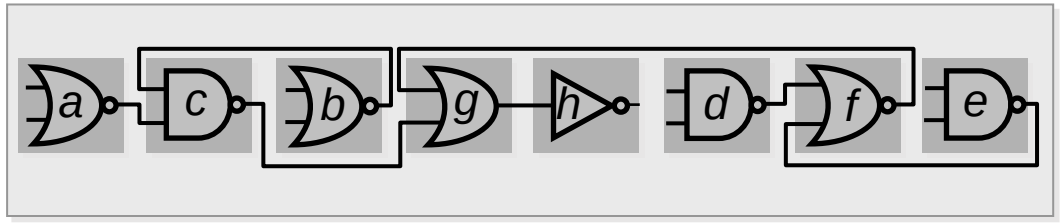


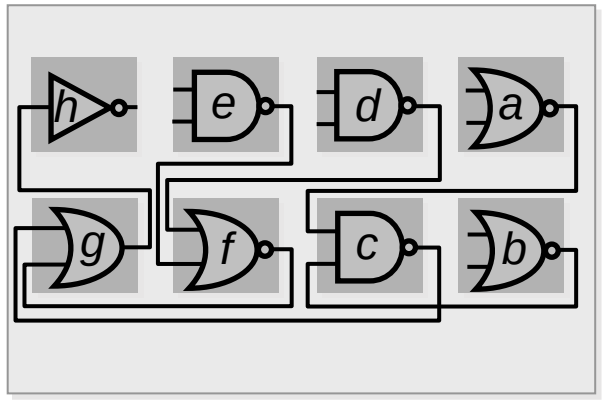
*Bernasconi, Roberto & Magagnin, Luca. (2019). Review—Ruthenium as Diffusion Barrier Layer in Electronic Interconnects: Current Literature with a Focus on Electrochemical Deposition Methods. Journal of The Electrochemical Society. 166. D3219-D3225. 10.1149/2.0281901jes.

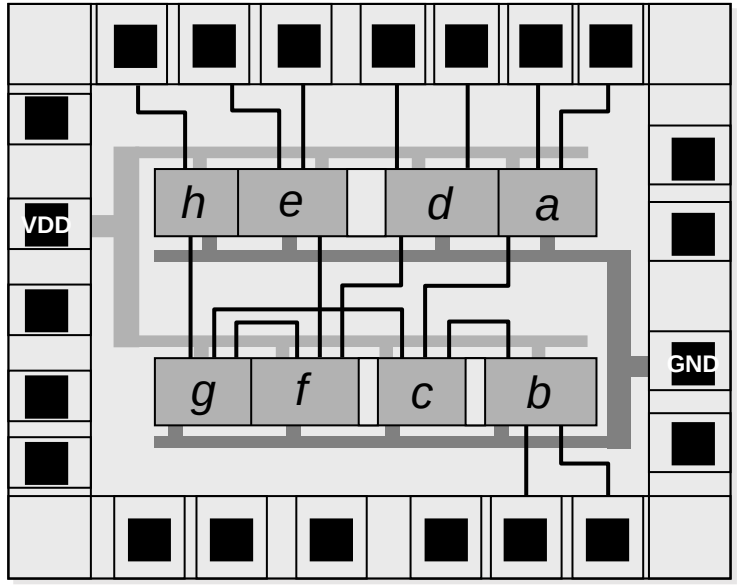
Задача размещения (Placement)



Линейное размещение







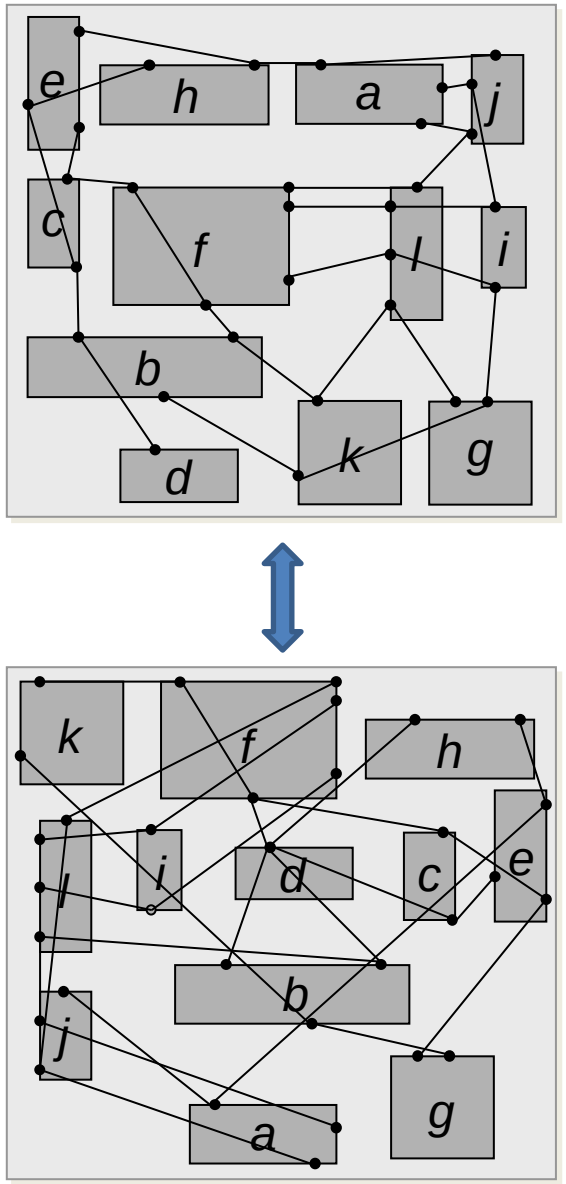
2D размещение

(размещение на плоскости)

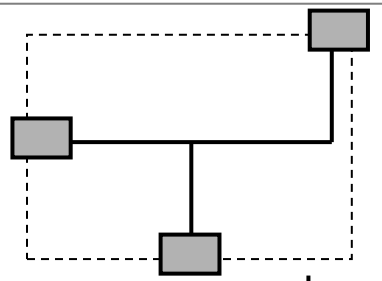
Результат размещения

(плюс трассировка)

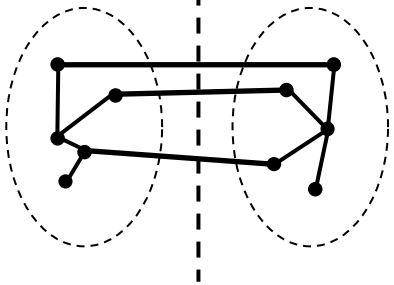
Глобальное размещение, оценка размещения



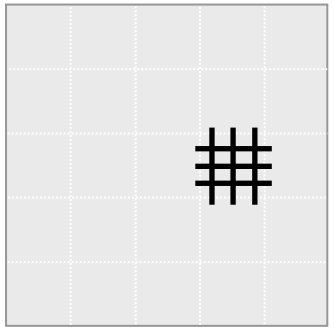
Уменьшение суммарной длины межсоединений:



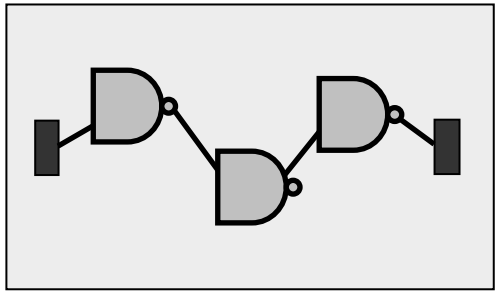
Минимизация числа цепей для разбиения:



Обеспечение равномерности распределения плотности цепей:



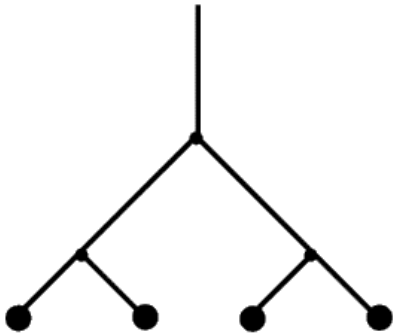
Минимизация времени распространения сигналов:



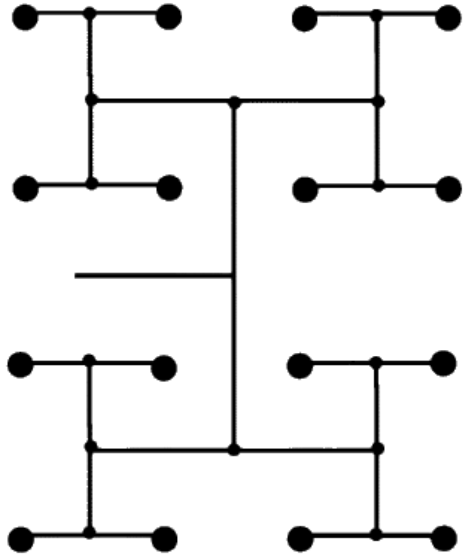
Результат размещения: файлы формата DEF (1)

```
VERSION 5.8 ;
DIVIDERCHAR "/" ;
BUSBITCHARS "[]" ;
DESIGN lut_s44 ;
UNITS DISTANCE MICRONS 1000 ;
DIEAREA ( 0 0 ) ( 202100 212820 ) ;

ROW ROW_0 unithd 5520 10880 N DO 415 BY 1 STEP 460 0 ;
ROW ROW_1 unithd 5520 13600 FS DO 415 BY 1 STEP 460 0 ;
ROW ROW_2 unithd 5520 16320 N DO 415 BY 1 STEP 460 0 ;
ROW ROW_3 unithd 5520 19040 FS DO 415 BY 1 STEP 460 0 ;
ROW ROW_4 unithd 5520 21760 N DO 415 BY 1 STEP 460 0 ;
...
COMPONENTS 3892 ;
    - FILLER_0_109 sky130_fd_sc_hd__decap_3 + SOURCE DIST + PLACED ( 55660 10880 ) N ;
    - FILLER_0_113 sky130_fd_sc_hd__decap_8 + SOURCE DIST + PLACED ( 57500 10880 ) N ;
    - FILLER_0_121 sky130_fd_sc_hd__fill_1 + SOURCE DIST + PLACED ( 61180 10880 ) N ;
    - FILLER_0_126 sky130_ef_sc_hd__decap_12 + SOURCE DIST + PLACED ( 63480 10880 ) N ;
...
    - _095_ sky130_fd_sc_hd__mux2_1 + PLACED ( 141220 176800 ) FS ;
    - _096_ sky130_fd_sc_hd__or2b_1 + PLACED ( 139840 174080 ) N ;
    - _097_ sky130_fd_sc_hd__o211a_1 + PLACED ( 141220 168640 ) FN ;
    - _098_ sky130_fd_sc_hd__mux4_1 + PLACED ( 148580 157760 ) FN ;
    - _099_ sky130_fd_sc_hd__and2b_1 + PLACED ( 148580 163200 ) FN ;
    - _100_ sky130_fd_sc_hd__mux2_1 + PLACED ( 161460 187680 ) FS ;
    - _101_ sky130_fd_sc_hd__mux2_1 + PLACED ( 160080 195840 ) N ;
    - _102_ sky130_fd_sc_hd__or2b_1 + PLACED ( 155480 195840 ) N ;
    - _103_ sky130_fd_sc_hd__o211a_1 + PLACED ( 155020 193120 ) FS ;
...
```

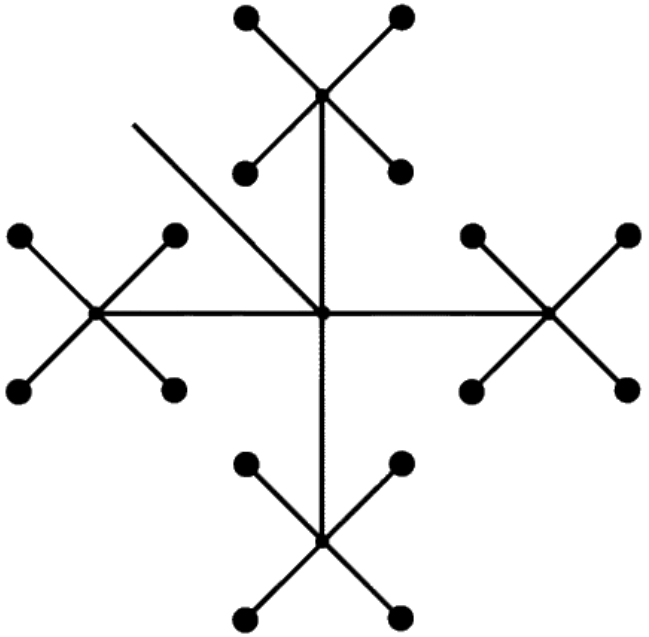
Виды деревьев синхронизации



Y-Tree

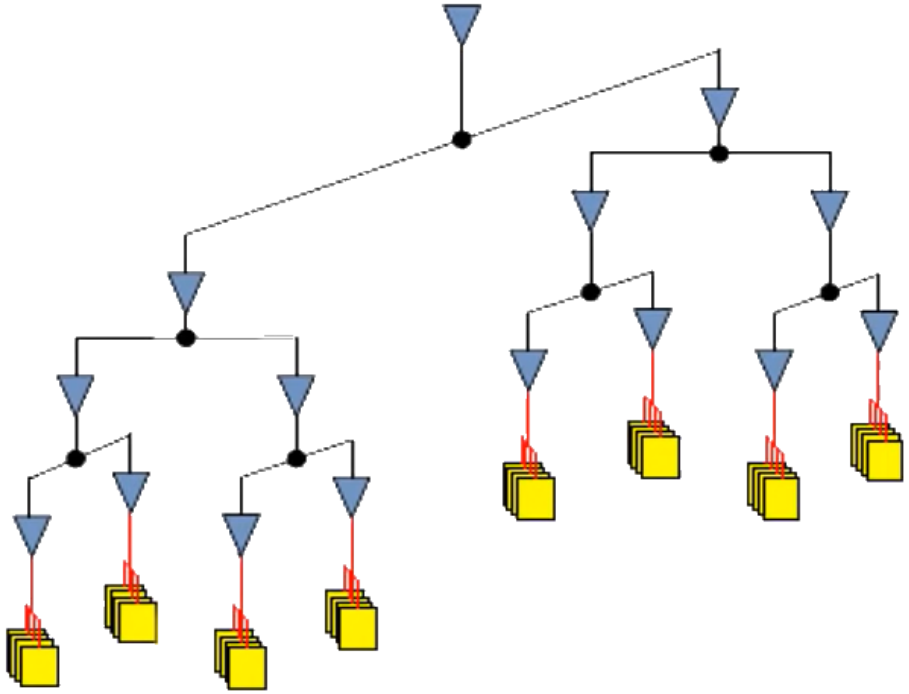


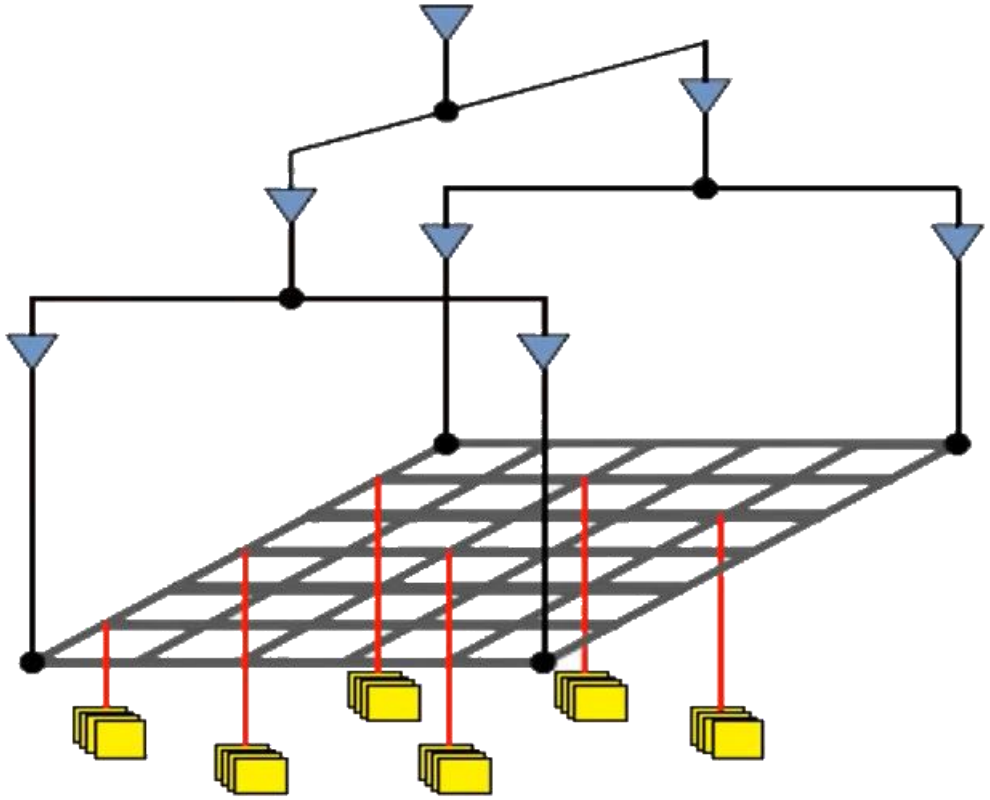
H-Tree



X-Tree

Clock Tree Synthesis (CTS)

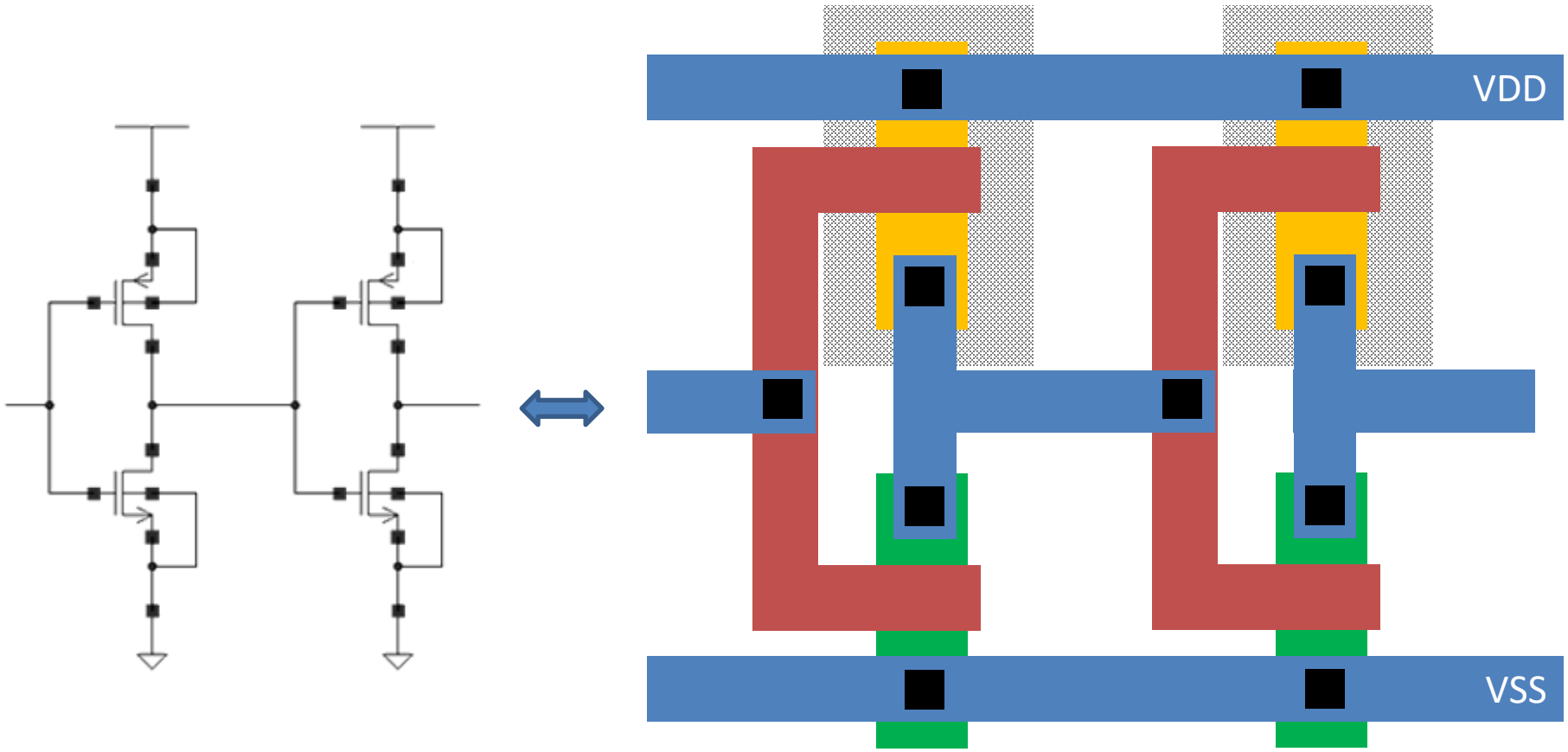




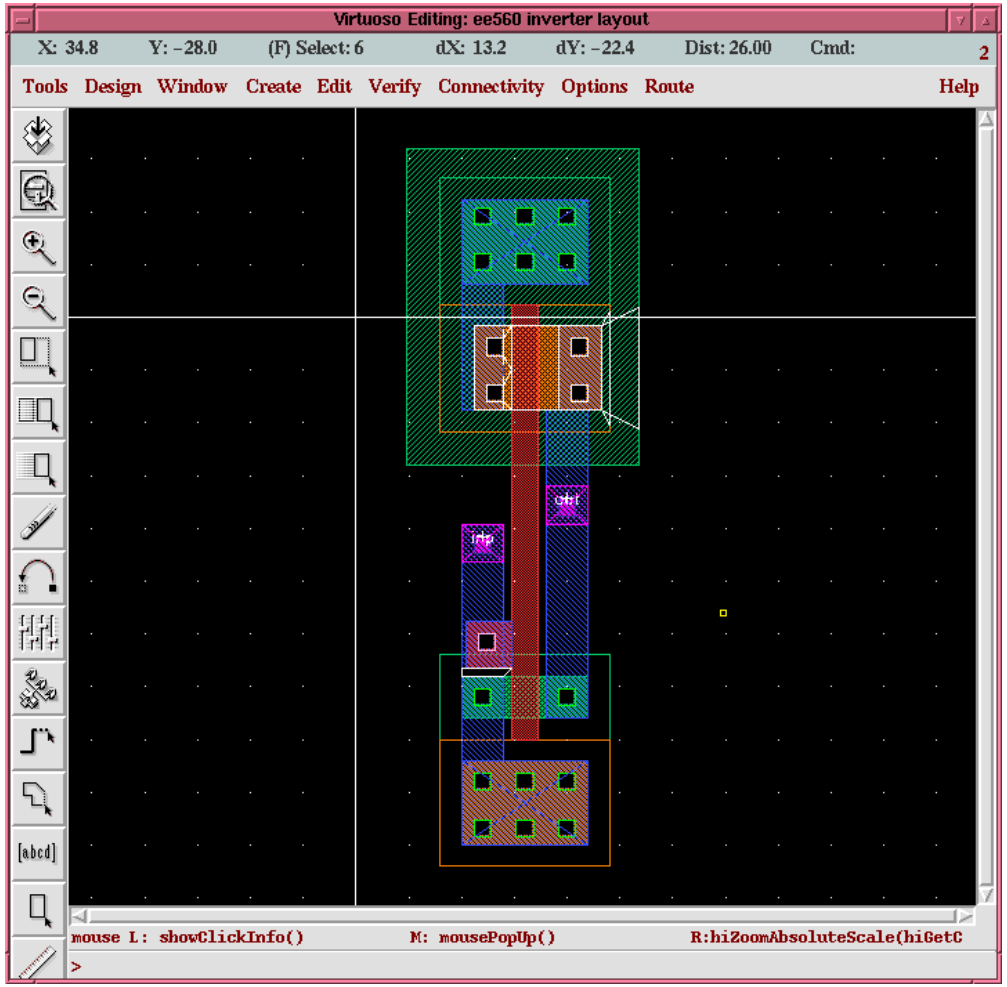
Результат трассировки в файле DEF

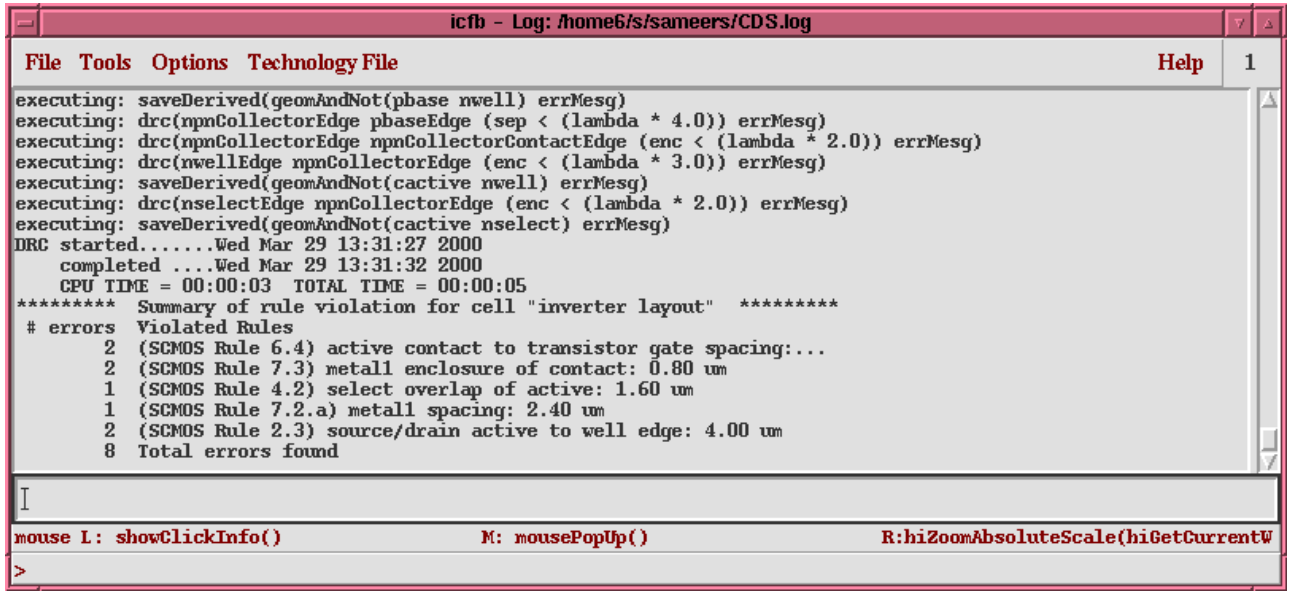
```
NETS 168 ;
- net15 ( input15 X ) ( _157_ A1 ) + USE SIGNAL
      + ROUTED met2 ( 168590 197370 ) ( * 199410 )
      NEW met1 ( 78890 199410 ) ( 168590 * )
      NEW li1 ( 78890 199410 ) L1M1_PR_MR
      NEW li1 ( 168590 197370 ) L1M1_PR_MR
      NEW met1 ( 168590 197370 ) M1M2_PR
      NEW met1 ( 168590 199410 ) M1M2_PR
      NEW met1 ( 168590 197370 ) RECT ( -355 -70 0 70 )  ;
 - net16 ( input16 X ) ( _159_ A1 ) + USE SIGNAL
      + ROUTED met1 ( 182390 15130 ) ( 192510 * )
      NEW met2 ( 182390 15130 ) ( * 139910 )
      NEW met1 ( 182390 15130 ) M1M2_PR
      NEW li1 ( 192510 15130 ) L1M1_PR_MR
      NEW li1 ( 182390 139910 ) L1M1_PR_MR
      NEW met1 ( 182390 139910 ) M1M2_PR
      NEW met1 ( 182390 139910 ) RECT ( -355 -70 0 70 )  ;
```

Layout Versus Schematic (LVS)

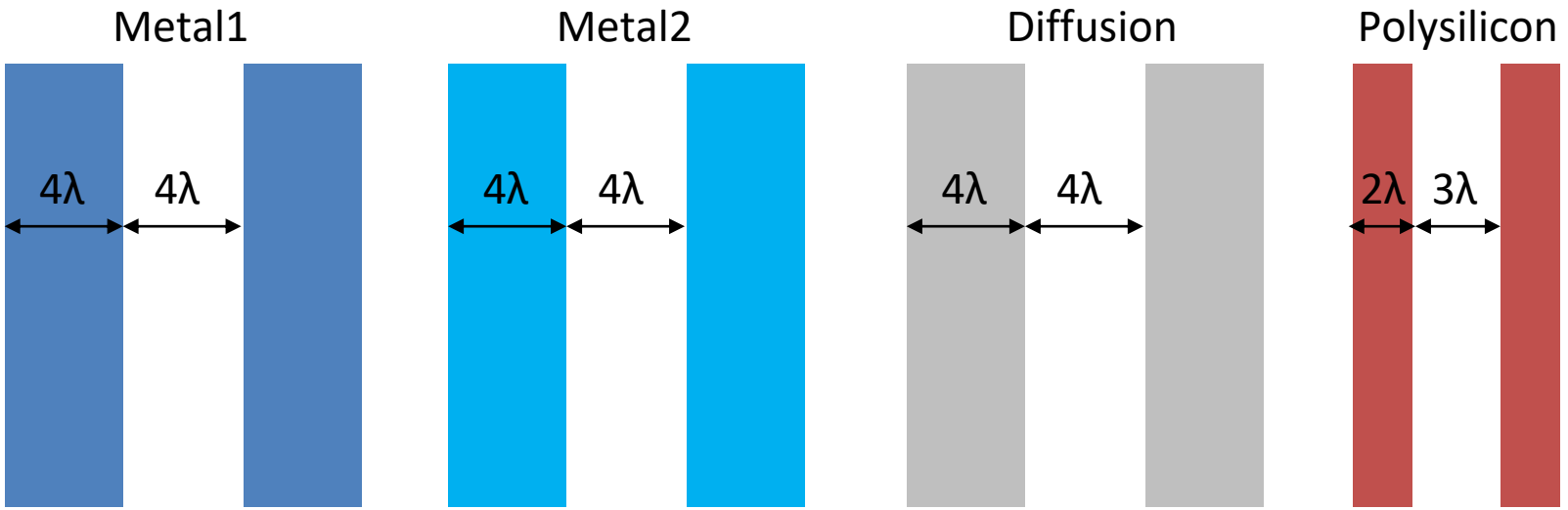


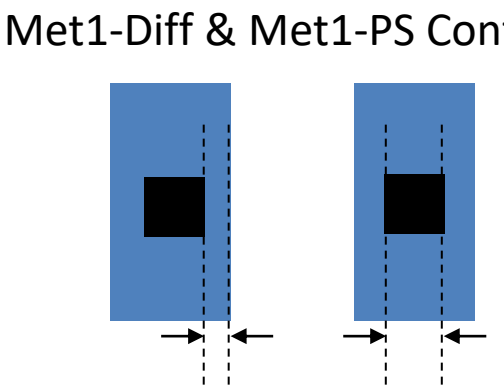
Design Rule Check (DRC)

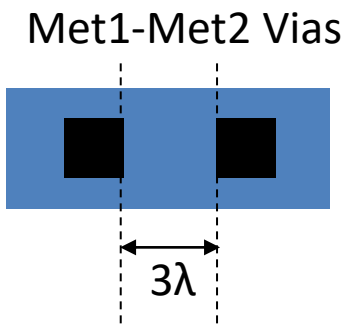




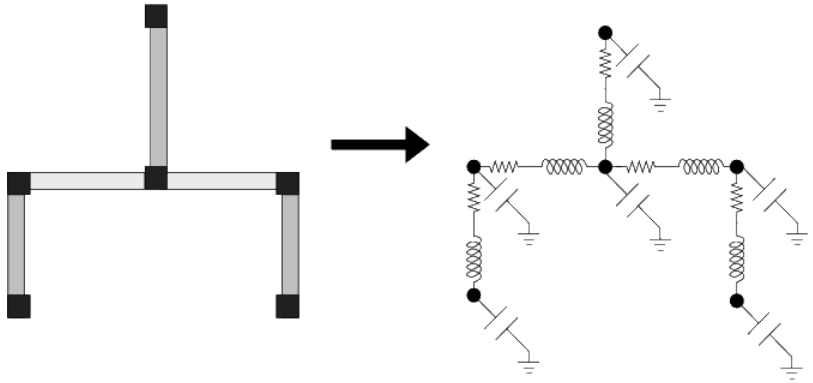
DRC: пример правил проектирования

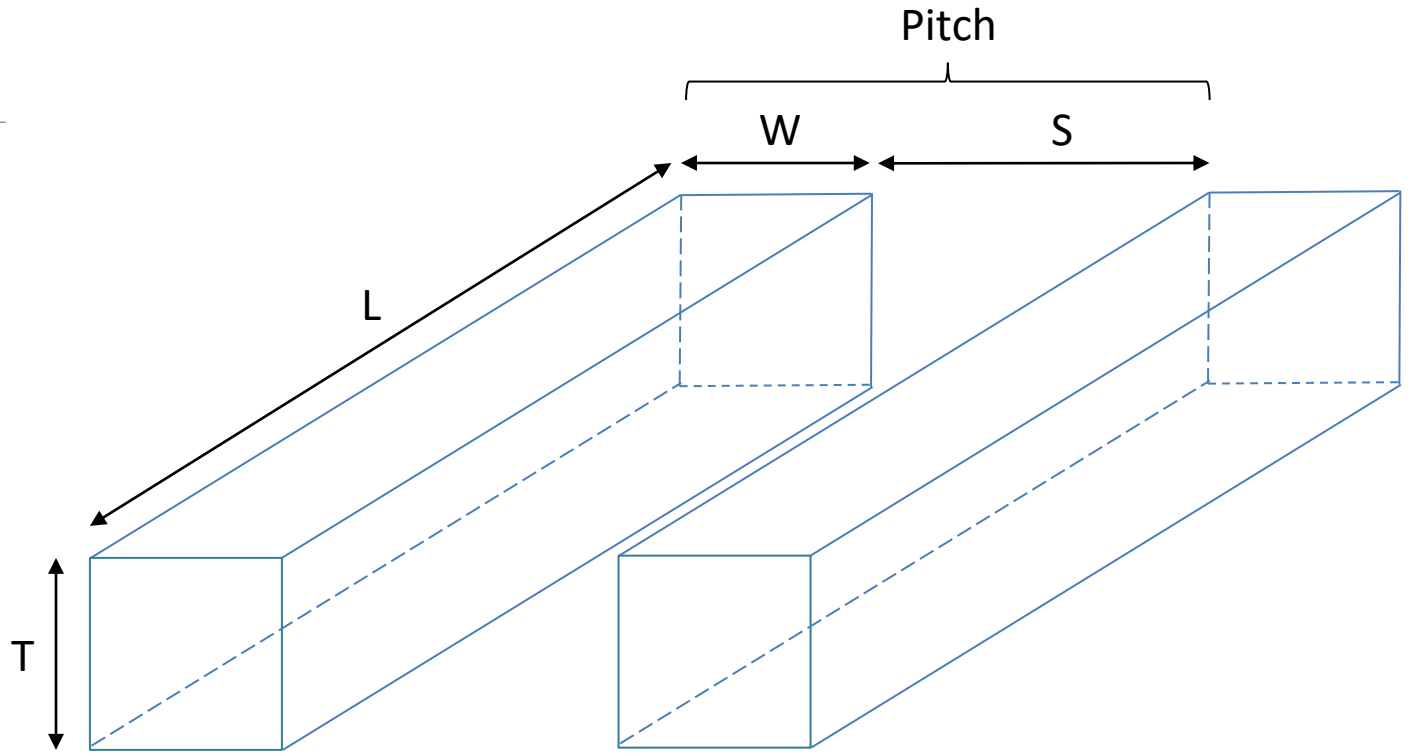






Parasitic Extraction





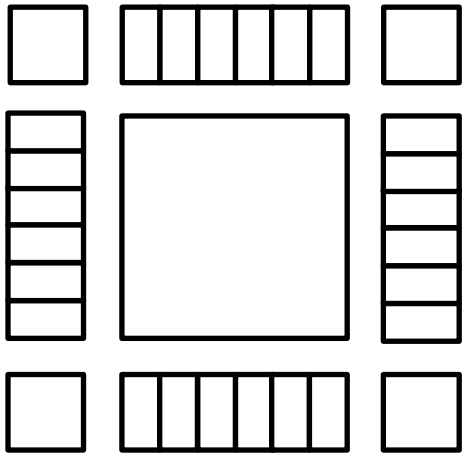
$$R = \frac{\rho}{T} \cdot \frac{L}{W}$$

$$C = \frac{\varepsilon}{T} \cdot \frac{L}{W}$$

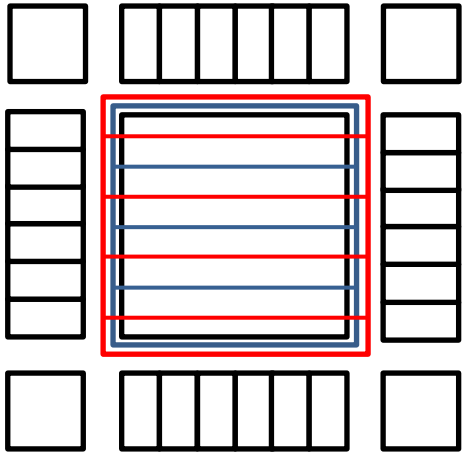
Время распространения сигнала:

$$\tau = R \cdot C$$

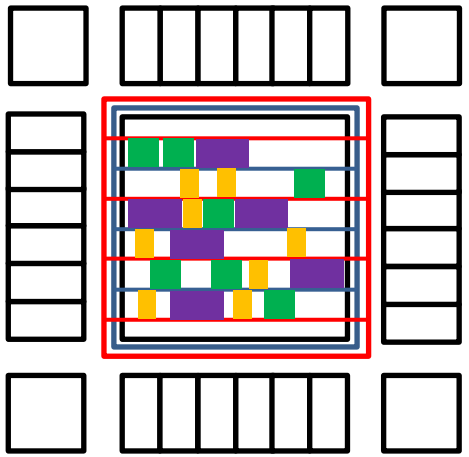
Общий маршрут проектирования цифровой топологии



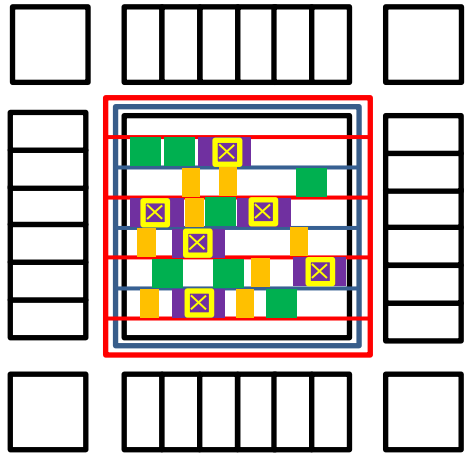
Начальное планирование кристалла
(Initial floorplan and pad ring)



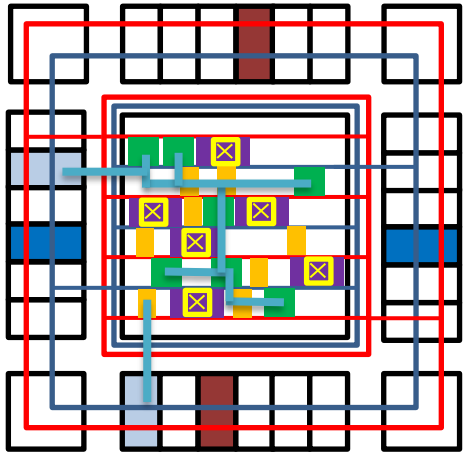
Планирование цепей питания
(Power planning)



Размещение
(Placement)



Синтез тактового дерева
(Clock tree synthesis)



Трассировка
(Routing)