OpenPCells

A Technology-Indendent Layout Generator for Integrated Circuits

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Motivation

- Design re-use quite poor in analog design
- Still many repetitive tasks, especially in layout
- Designs usually subject to restrictive non-disclosure agreements

Goals

- Enable design re-use
- Provide reference implementations of common circuits
- Port complex systems to other technology nodes
- Share circuits with other researchers/companies/...

Difficulties in Layout Automation for Integrated Circuits

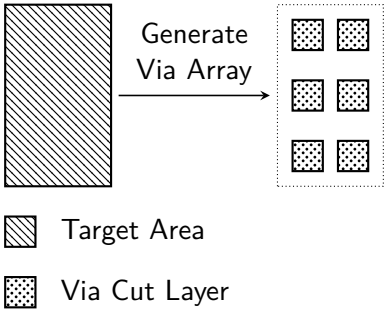
- Integrated circuits are complex
- Many, many, many different ways to do the same thing
- Even more design rules, especially in modern technology nodes

Principles of Maintainable Circuit Layouts

1. Simplify the schematic
2. Simplify the schematic
3. Simplify the schematic
4. DRY in layout (don't repeat yourself)
   - Draw everything only once (instances, vias, etc.)
   - Make extensive use of symmetry, only draw half/quarter/... layouts
   - Find minimum common representation of sub-blocks (e.g. transistors without implants)
   - Hard to do and can result in very steep instance hierarchies
   - More special cases make this even harder

Vias and Contacts

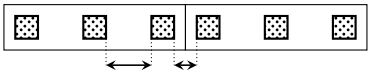
- Resolve via cuts with set of simple rules
- Fit via: $R = \left\lfloor \frac{W + S_{\min} - 2 \cdot E_{\min}}{C + S_{\min}} \right\rfloor$
- Continuous via: $R = \left\lfloor \frac{W + S_{\min} - 2 \cdot E_{\min}}{C + S_{\min}} \right\rfloor$



Continuous Vias

- Simple cut fitting not suitable in some applications (for example merging/aligning guard rings)
- Specialized via translation ensures equal spacing

Fitted Via Array
(Enclosure $<$ Space / 2)



Fitted Via Array
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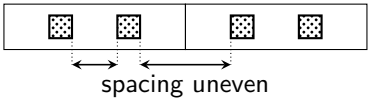

Continuous Via Array
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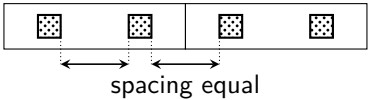


Basic Cell Code

```
function parameters()
    -- parameter definitions go here
end

function layout(cell, _P, env)
    -- layout descriptions go here
end

function config()
    -- special stuff
end
```

- Cells are described by defining public (global) functions
- Every cell *must* define `layout()`
- `parameters()` defines the parameters of the cell (and some minor other things)
- A cell without any parameters always represents the same layout
- In rare cases, `config()` is used, but this is only required for special cells

Adding Parameters

```
function parameters()
    pcell.add_parameter("width", 100)
    pcell.add_parameter("height", 100)
end
```

or with a shorthand:

```
function parameters()
    pcell.add_parameters({
        { "width", 100 },
        { "height", 100 } -- <--- uses varargs function call,
    })                    --      no comma after last argument
end
```

Parameters – Allowed Values

- Per default, numeric parameters can take any values
- Allowed parameters can be limited to `even` or `odd` values, intervals (`interval`) or explicit sets (`set`)

```
function parameters()
    pcell.add_parameters({
        { "width", 100, posvals = even() },
        { "height", 100, posvals = interval(1, inf) },
        { "rep", 2, posvals = set(2, 4, 8, 16) }
    })
end
```

The Layout Function

- First argument is the cell buing built (it is created by the calling code)
- The first argument is in theory optional, but a cell without a cell argument makes no sense
- Second (optional) argument is the table holding all parameters with their current value (default or user-given values)
- Third (optional) argument is the environment, similar to parameters but concerns values that are defined by cell higher up in the hierarchy

```
function layout(cell, _P, env)
end
```

Adding Shapes

- Basic shapes are added with the `geometry` module
- All `geometry` functions take the cell as first argument
- The layer as second argument
- Shape parameters (for example width and height for a rectangle) as remaining parameters
- All sizes are in nanometers (only integers allowed)

```
function layout(cell)
    geometry.rectangle(cell, layer, 100, 100)
end
```

But what do we put into the layer?

Digression: Generic Layers

- Shapes need to have layer information
- Can't put in specific technology layers (for example metal 1)
- Can't put in layers for the specific format (for example GDSII)
- Need a system to represent chip layers technology-independent and format-independent
- This is achieved by using *generic* layers

```
function layout(cell)
    geometry.rectangle(cell, generics.metal(1), 100, 100)
end
```

Digression: Generic Layers

- Metals indexed by a number (1 being at the bottom of the metal stack, closest to the bulk wafer)
- Generic layers for gates, active regions, implants, threshold voltage markings, oxide thickness
- Generics layers are translated into specific technology-bound layers
- Mapping described in layermap file with simple syntax
- Layermap has to be created for every technology node

Layermap example with only one layer (gate):

```
return {
    gate = { layer = { gds = { layer = 6, purpose = 0 } } },
    -- more layers here
}
```

Digression: Generic Layers

- The technology layermap can define various export types (output formats)
- Most important is currently gds (GDSII)

More complex layermap example with only one layer (gate):

```
return {
    gate = {
        name = "poly",
        layer = {
            gds = { layer = 6, purpose = 0 },
            SKILL = { layer = "poly", purpose = "drawing" },
            svg = { style = "gate", order = 3, color = "ff0000" },
        }
    },
}
```

Digression: Generic Layers

- Unused layers can be marked as empty
- For example, non-SOI (silicon-on-insulator) technology nodes don't need a buried-oxide break (soiopen)

```
return {
    soiopen = {}, -- will be skipped
}
```

Adding Shapes – Basic Shapes

Rectangles:

```
-- width and height
geometry.rectangle(cell, generics.metal(1),
    width, height)
-- corner points (bottom left, top right)
geometry.rectanglebltr(cell, generics.metal(1),
    bl, tr)
```

Paths:

```
geometry.path(cell, generics.metal(1),
    { pt1, pt2, ..., ptN }, width)
```

Polygons:

```
geometry.polygon(cell, generics.metal(1),
    { pt1, pt2, ..., ptN })
```

Cell Hierarchies

- Often-used cells more efficiently represented by hierarchies (re-use)
- Put sub-layouts in objects with `object.create()` or re-use existing cells with `pcell.create_layout()`
- Create a reference handle with `pcell.add_cell_reference(ref, name)`
- Use `object.add_child()` to instantiate this reference
- The (light/proxy) object returned by `object.add_child()` can be use as a regular object (transformed, aligned, etc.)

```
function layout(cell)
    local child_reference = pcell.create_layout("libname/subname")
    local child_name = pcell.add_cell_reference(child_reference,
        "child")
    local child = cell:add_child(child_name)
    child:move_anchor("left")
end
```

Object Translations and Transformations

- Cells can be transformed (rotated, flipped, ...) and translated in x and y
- Vital for building complex hierarchies with many different sub-cells
- Implementation handles this efficiently by using transformation matrices

```
local cell = object.create()
-- add some shapes
cell:translate(100, 100) -- takes x and y
cell:rotate_90_left()
cell:mirror_at_xaxis()
```

Object Anchors for Relative Placement

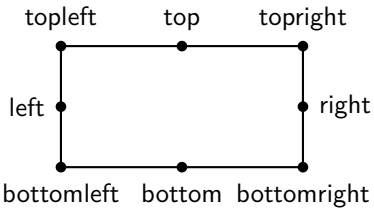
- Cells can define arbitrary *anchors* (points with a name)
- Can be used to position cells (`object.move_anchor`) or to query positions within cells (`object.get_anchor`)
- With both methods, cells can be placed relatively to each other

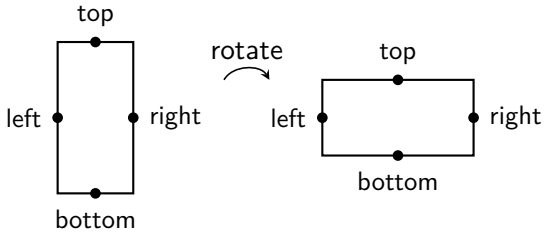
```
local cell1 = pcell.create_layout("cell1")
local cell2 = pcell.create_layout("cell2")

cell1:move_anchor("output", cell2:get_anchor("input"))
```

Object Alignment Boxes

- Define an object's main boundary (rectangular)
- Align with other similar objects (for example digital standard cells)
- Define eight special anchors
- Provide standardized means of object positioning
- Alignment boxes are transformed (rotated, mirrored, flipped), but the position of the special anchors is updated to reflect this

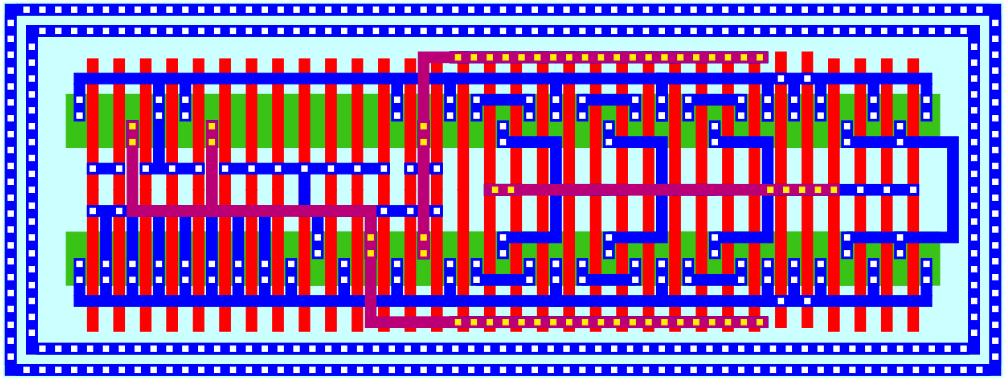




Relative Placements Everywhere

- Relative placement should be chosen wherever possible
- Absolute coordinates are usually only needed in fundamental/basic cells like transistors
- With relative placements (using alignment boxes), the cells "know" their own size
- This enables changes deeper in the hierarchy to propagate *up*
- Done correctly, child cells can be fixed/adapted without having to change the top cell

Current-Starved Ring Oscillator



Grated Coupler