TCF User Guide

Rev 0.1

Revision History

Rev.No.	History	Draft Date
Rev0.1	Initial Document	09/29/2007

Contents

What is TCF?

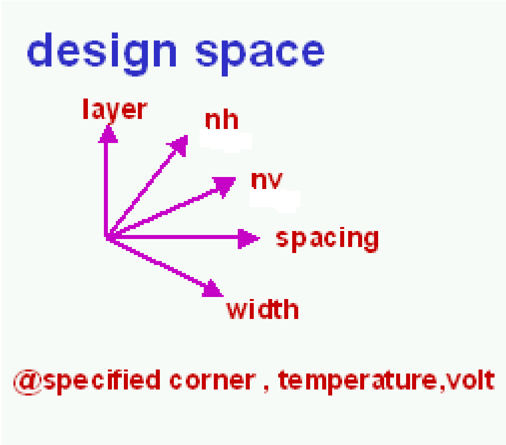
TCF (TSMC Capacitor Finder) is a passive device search tool developed by TSMC to provide efficient capacitor search. User can search capacitors under own defined constrains. TCF returns list of qualified capacitors, if any, with their geometry and electrical parameters, additionally there is a plotter plotting capacitors' C and Q verses frequency.
User then can choose a capacitor from result list and put it in design. TCF comes with a user friendly GUI integrated with TSMC PDK. User can interact with TCF through comprehensive GUI forms. With build-in plotter, TCF users are able to view C and Q behavior against frequency before plugging device in design.

Why TCF?

TCF is accurate. TCF results have same accuracy as spectre.
TCF is powerful. TCF can deliver a near optimal solution very quickly.
TCF is convenient. TCF result can be sent back to PDK then perform sweep calculation and sensitivity analysis. Also there is no need to setup an initial database.
Without TCF, finding a "right" and "good" capacitor to suit a particular design requires a lot of time and experience. Many try & error process involved and result qualities are not guarantied. With TCF, designers can save heaps of time on searching capacitors still having a better suitable device for design.

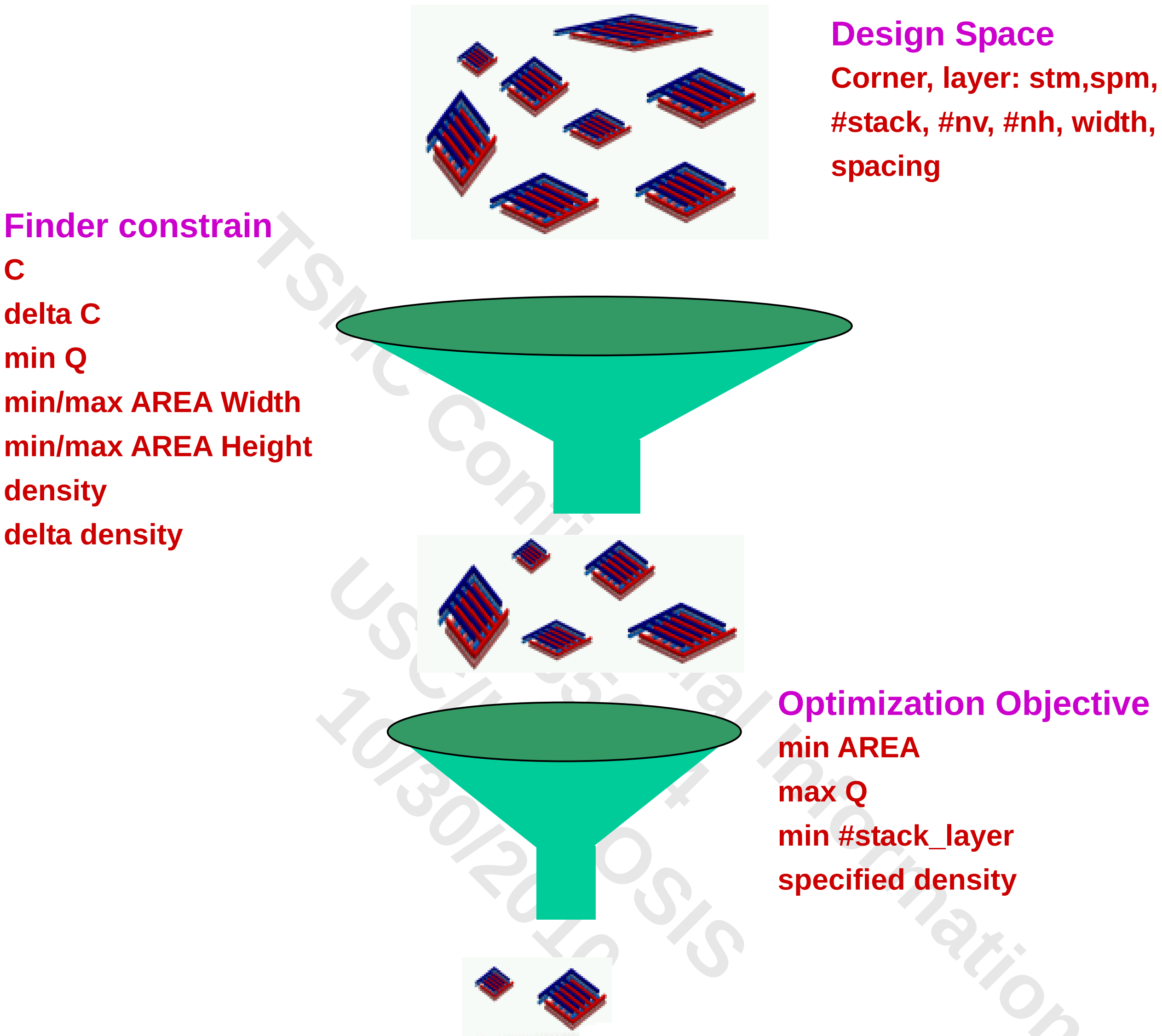
TCF Terminology

design space:



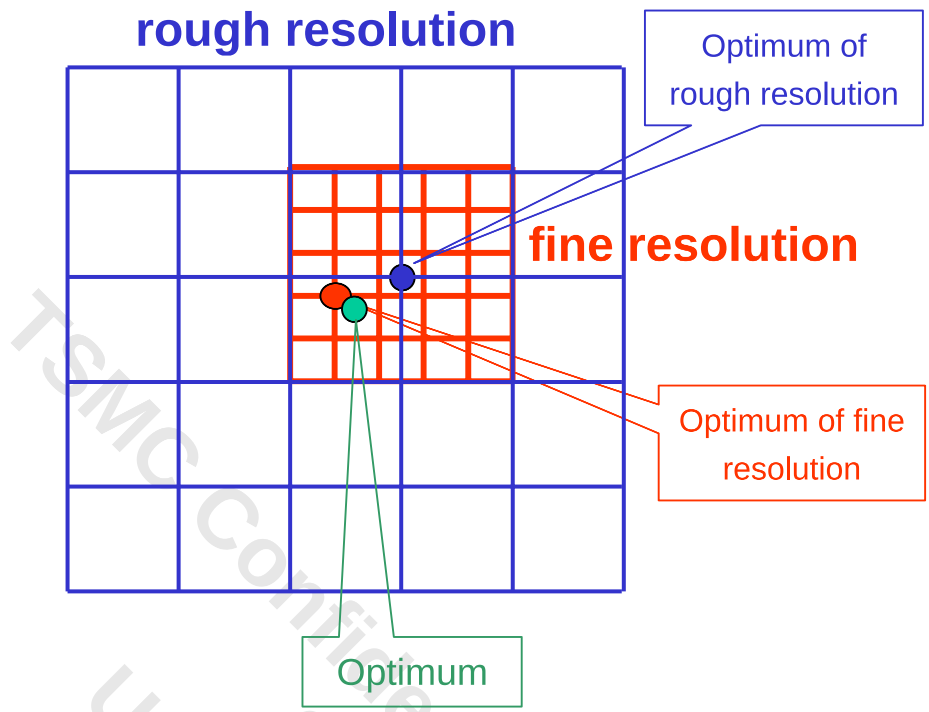
Capacitor design space is the combination of capacitors with all possible layout parameters. Currently there are following layout parameters: stack layer, nh, nv, width and spacing, therefore gives a five dimensional design space. Each dimension has its own range and step. Size of design space depends on range and step of each dimension. User can specify them in TCF. Large Range and small step size will result large design space. Oppositely small range and large step size will give small design space. TCF searches capacitors in design space specified by user. This design space is so called a search space for TCF.

TCF Overview



Graph above shows how TCF search capacitors in design space. TCF verifies every capacitor in design space with **Finder Constrains (**first filter). For all capacitors pass first filter, TCF applies **Optimization Objective** to order results. User should define **Finder Constrains** in order to specify desire capacitor characteristics. **Finder Constrains** includes target capacitance (C), minimum Q value, area limitation and density restrictions … etc. They are the descriptions of desire device. **Optimization Objective**, the second filter, is also user defined. It can be one of minimum area, Maximum Q valve, target density or minimum stack layer. Each represents different comparison standard of optimal device. TCF uses one of above comparison standards to rank capacitors.

Refinement



TCF provides a timesaving **refinement** option to help user approach optimum quickly. In the graph above, green dot represents global optimum i.e. the target device; blue grids and red grids represent two design spaces with different range and resolution. Designer's goal is to reach global optimum (green dot). The straightforward method is brute force search in design space with very fine resolution. Unfortunately it is very time consuming. It may take few days to find a device. A smarter way will be doing a rough search first then do a fine second search around first optimum as above graph shown. This method is called **refinement**. Rough search space has maximum range and rough resolution. Refinement search space has range around "optimum of Rough" with fine resolution.

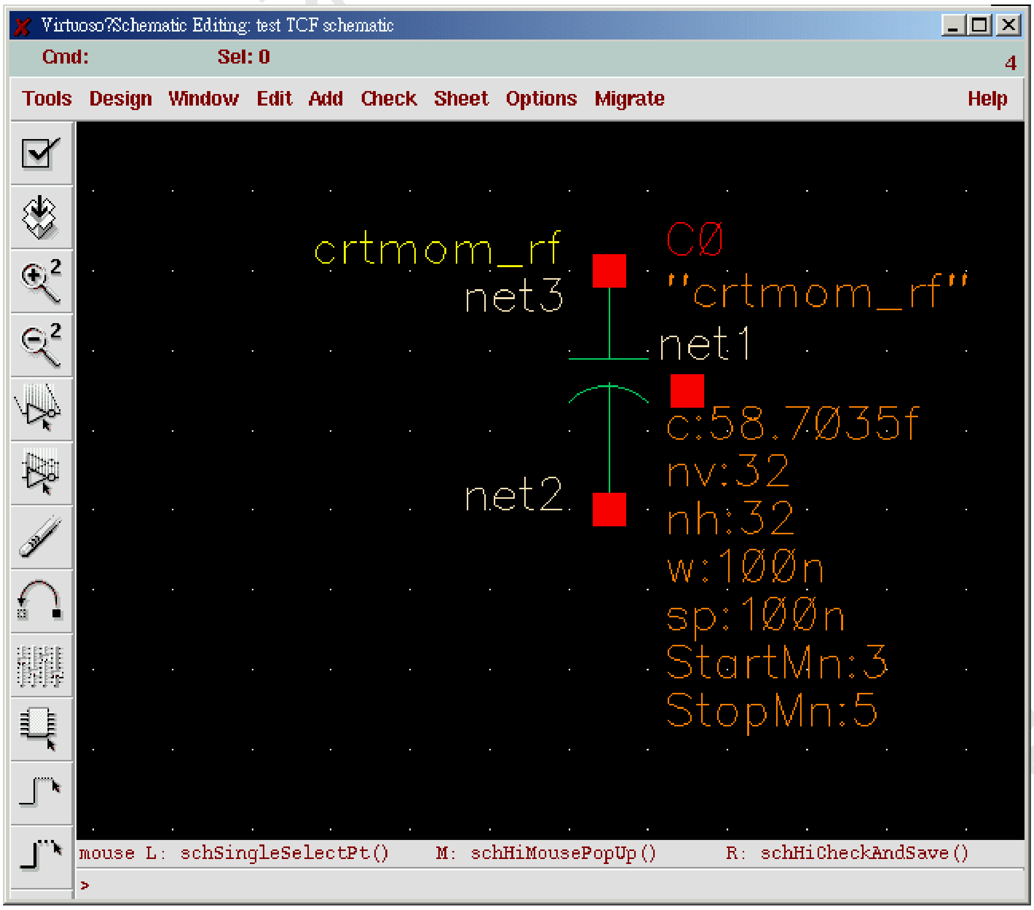
The advantage **refinement** is that time not wasted in searching design spaces far away from global optimum. Every refinement brings optimum closer to global optimum.

TCF provides a one-button refinement setting for user. It is easy to configure refinement setting around a particular device.

How to use TCF

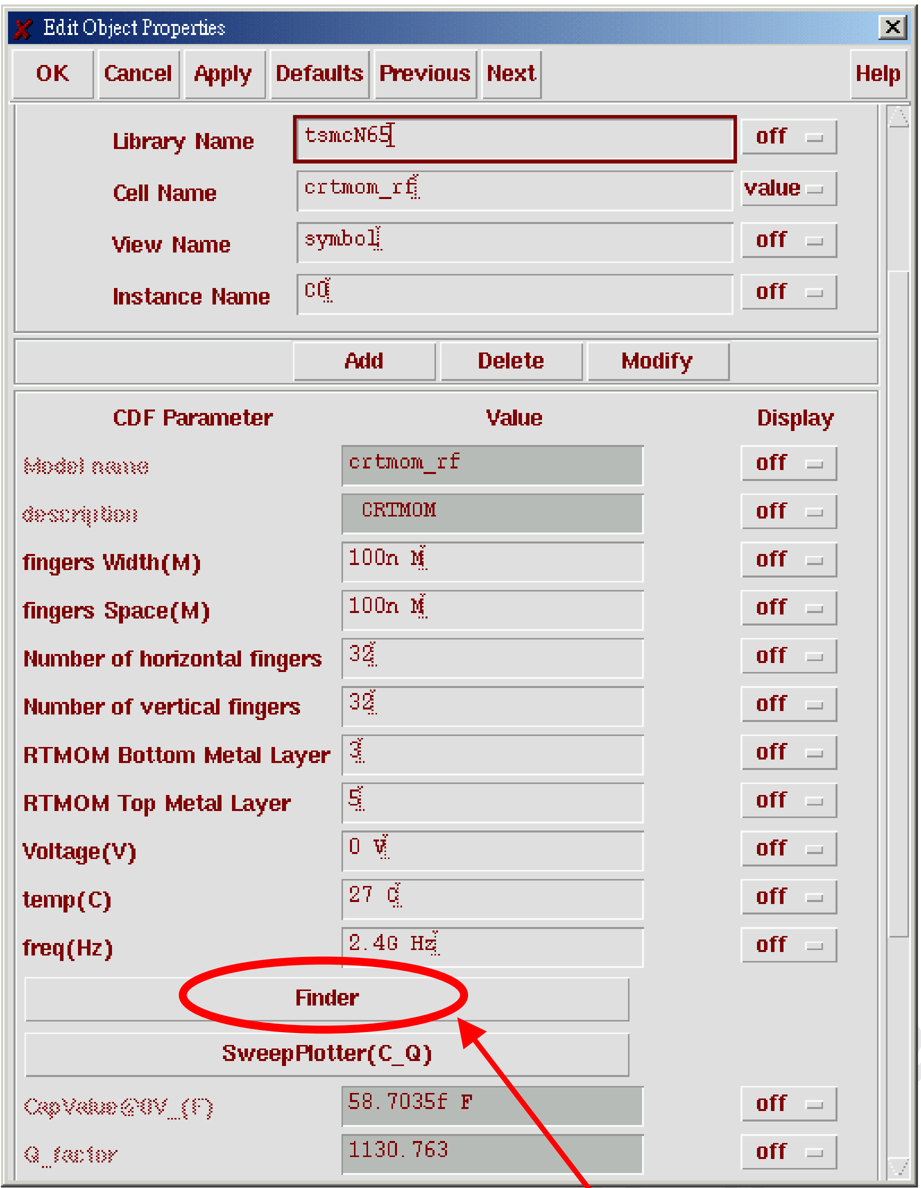
This document will show the usage of TCF step by step and explain the meaning of each field.

1. Source shell library used by TCF. The source file *tif_tcf.csh* is provided with PDK. User can find *tif_tcf.csh* in directory where PDK is installed. The command would be:
   source tif_tcf.csh
2. Open a design that contains capacitors. In this example, only one capacitor is placed.

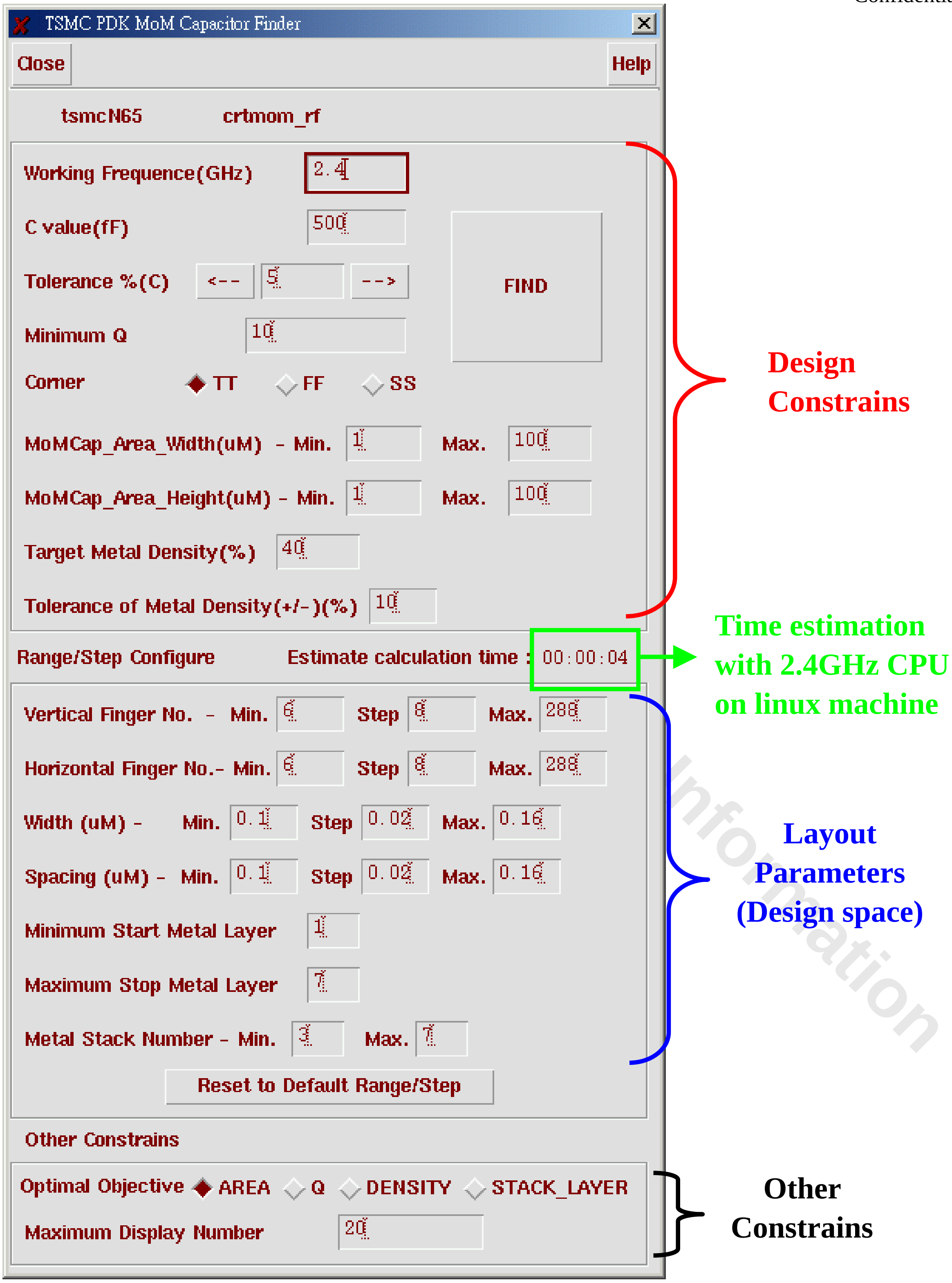


3. Choose one capacitor by clicking left mouse button on it.

4. Edit capacitor property by press bind-key **‘q’** or select **Edit** -> **Properties** -> **Objects…** from the menu banner.



5. In the **Edit Object Properties** form, locate **Finder** button and click it. Notice the TCF form with title '**TSMC PDK MoM Capacitor Finder'** pops out.



6. Fill **TSMC PDK MoM Capacitor Finder** form. Note this form is divided into 3 parts, Design Constrains, Range/Step Configure and Other Constrains. User can specify design constrains and design space in this form. Fields in Other Constrains limits the number of search result in certain order. Meaning of each field are explained as follow:

Fields determine constrains for target capacitors:

Working Frequency (GHz) Capacitor's working frequency.

C value (fF) Target capacitance.

Tolerance %(C) Tolerance allowed between TCF result capacitance and target capacitance in percentage. User can directly input numbers in the text field or click <-- and --> to decrease/increase tolerance percentage.

Minimum Q Minimum Q at working frequency.

Corner Model card corner.

MoMCap_Area_Width(uM) Minimum and maximum width of capacitor.

MoMCap_Area_Height(uM) Minimum and maximum height of capacitor.

Target Metal Density (%) Target metal density.

Tolerance of Metal Density (+/-) (%) Metal density tolerance allowed from target density.

Range/Step Configure

Range/Step fields determine search space of TCF. Each field as a capacitor layout geometry parameter is also a dimension for search space. User needs to specify lower bound (**Min.**), upper bound (**Max.**) and step size (**Step**) for each dimension. Large range and small step size can result large search space hence require more CPU time. Layout parameters have the same meaning as they do in PDK. Following example illustrates how Min, Step and Max been translated to design space.

Example:

Vertical Finger No. Number of vertical fingers

Min. 6 **Step** 8 **Max.** 288

=> Vertical Finger No. = 6, 14, 22, … , 286

Horizontal Finger No. Number of horizontal fingers

Min. 6 **Step** 8 **Max.** 288

=> Horizontal Finger No. = 6, 14, 22, … , 286

Width (uM) Capacitor finger width

Min. 0.1 **Step** 0.02 **Max.** 0.16

=> Width = 0.1, 0.12, 0.14, 0.16

Spacing (uM) Capacitor finger spacing

Min. 0.1 **Step** 0.02 **Max.** 0.16

=> Spacing = 0.1, 0.12, 0.14, 0.16

Following three parameters determine stack layer combinations. Default setting enables all valid MoM stack combinations in model card (list in example below). That is from M1 to M7 at least 3 stack layers and at most 7 stack layers.

Minimum Start Metal Layer 1

Maximum Stop Metal Layer 7

Metal stack Number **Min.** 3 **Max.** 7

=> Stack= (1, 2, 3), (2, 3, 4), (3, 4, 5), (4, 5, 6), (5, 6, 7), ……… stack number = 3

(1, 2, 3, 4), (2, 3, 4, 5), (3, 4, 5, 6), (4, 5, 6, 7), ……… stack number = 4

(1, 2, 3, 4, 5), (2, 3, 4, 5, 6), (3, 4, 5, 6, 7), ……… stack number = 5

(1, 2, 3, 4, 5, 6), (2, 3, 4, 5, 6, 7), ……… stack number = 6

(1, 2, 3, 4, 5, 6, 7) ……… stack number = 7

Reset to Default Range/Step resets layout parameters to their initial range and step

Other constrains

Sometimes there will be large amount of capacitors in search space that satisfy design constrains. User can apply **other constrains** to filter the result capacitors again therefore not wasting time on reviewing numerous results.

Optimal Objective User must select optimization goal from one of **AREA**, **Q, DENSITY** and **STACK_LAYER**. They can be seen as comparison standards.

Area – Give high priority to capacitors occupying small area.

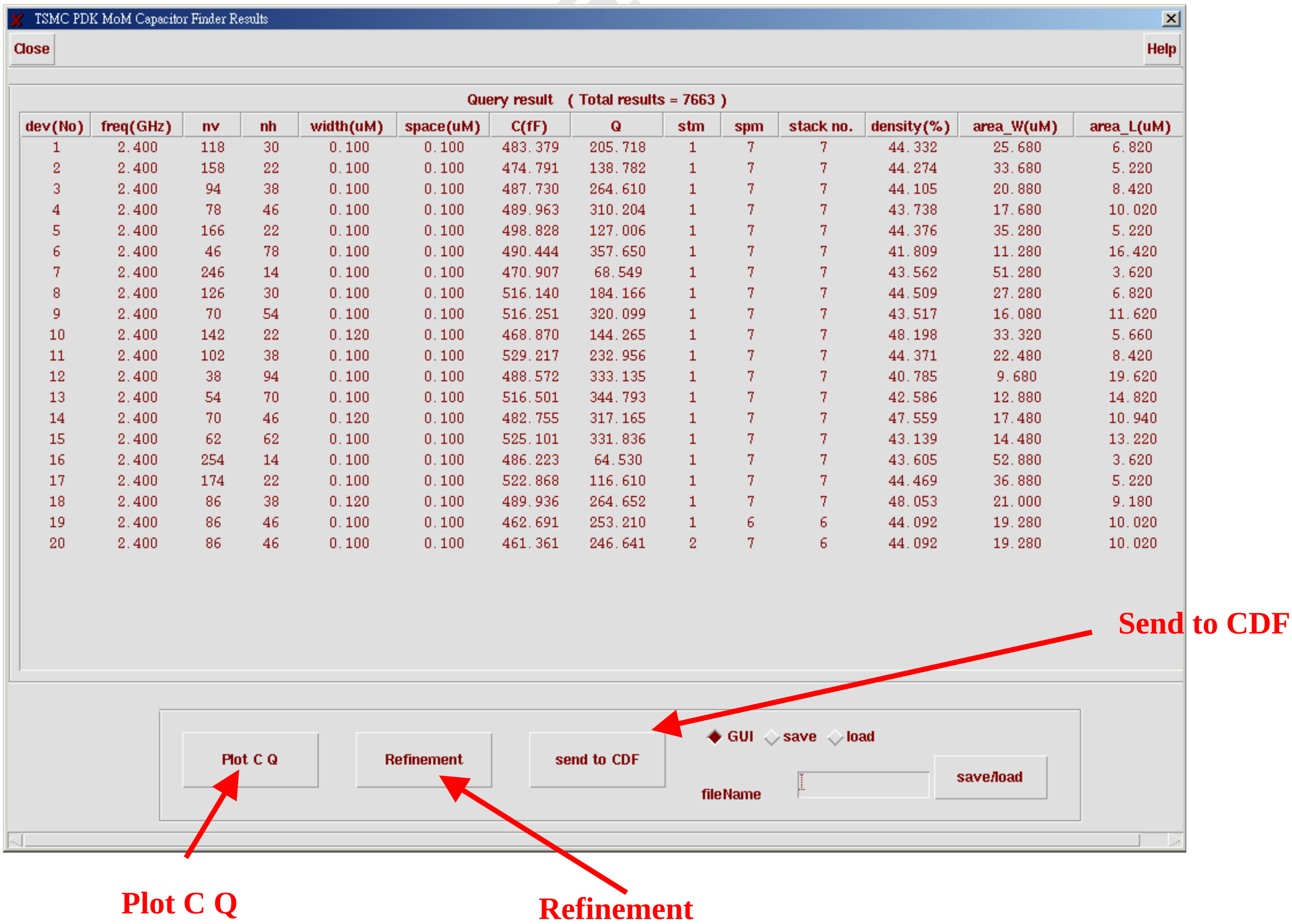
Q – Simply ranks high for capacitors with large Q value.

DENSITY – Rank capacitors with metal density difference from target density. In other words, capacitor that has metal density close to target metal density gets high priority.

STACK_LAYER – Give high priority to capacitors with small stack number.

Maximum Display Number User can specify how many capacitors being shown in result browser. Note that results orders are defined in **Optimal Objective**. For example: If user set **Optimal Objective** to **'Area'** and **Maximum Display Number** to '10'. TCF will display the smallest 10 capacitors among search result.

7. Click **Find** button. When user finishes filling TCF form, by clicking **'Find'** button TCF begins searching capacitors based on search space and constrains. It may take a while if search space is large. Search time is estimated in **Estimate calculation time**. This estimation is under Linux system with 2.4 GHz CPU. Time may vary for different CPU and OS.
   When TCF finish searching, the **TSMC PDK MoM Capacitor Finder Results** window appears.



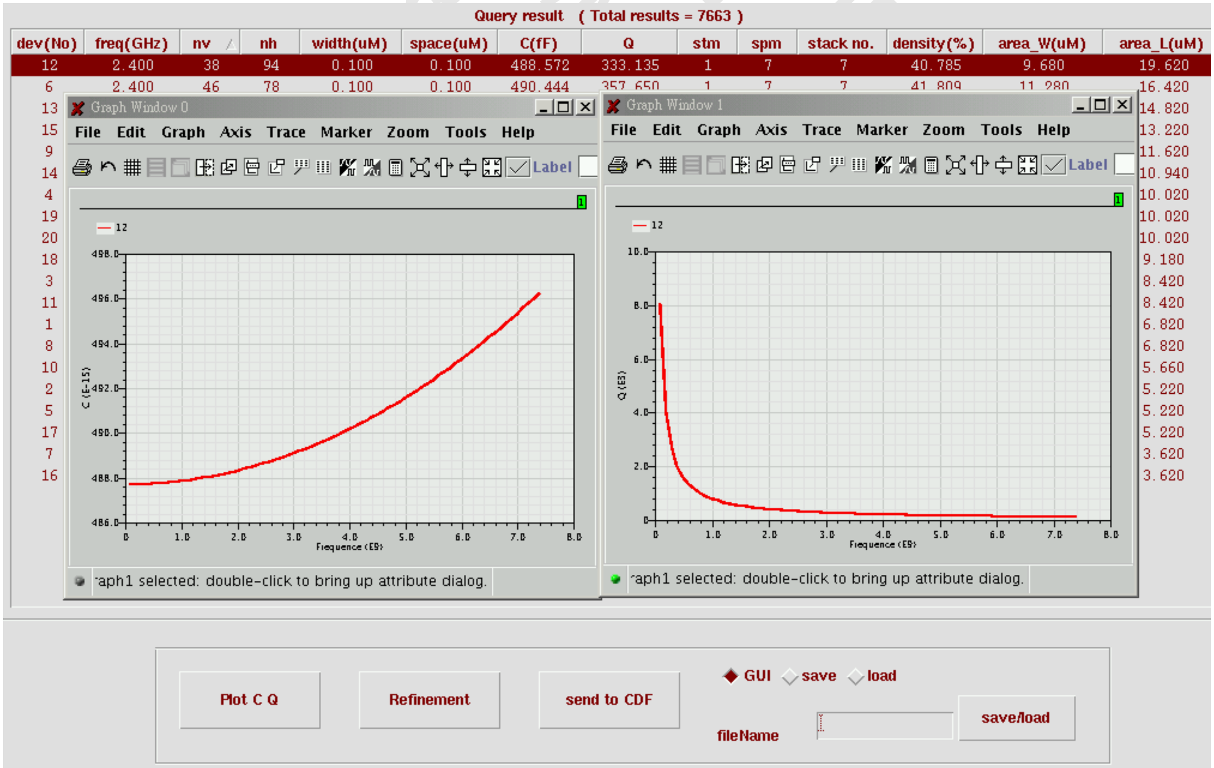
dev(No)	freq(GHz)	nv	nh	width(uM)	space(uM)	C(fF)	Q	stm	spm	stack no.	density(%)	area_W(uM)	area_L(uM)
1	2.400	118	30	0.100	0.100	483.379	205.718	1	7	7	44.332	25.680	6.820
2	2.400	158	22	0.100	0.100	474.791	138.782	1	7	7	44.274	33.680	5.220
3	2.400	94	38	0.100	0.100	487.730	264.610	1	7	7	44.105	20.880	8.420
4	2.400	78	46	0.100	0.100	489.963	310.204	1	7	7	43.738	17.680	10.020
5	2.400	166	22	0.100	0.100	498.828	127.006	1	7	7	44.376	35.280	5.220
6	2.400	46	78	0.100	0.100	490.444	357.650	1	7	7	41.809	11.280	16.420
7	2.400	246	14	0.100	0.100	470.907	68.549	1	7	7	43.562	51.280	3.620
8	2.400	126	30	0.100	0.100	516.140	184.166	1	7	7	44.509	27.280	6.820
9	2.400	70	54	0.100	0.100	516.251	320.099	1	7	7	43.517	16.080	11.620
10	2.400	142	22	0.120	0.100	468.870	144.265	1	7	7	48.198	33.320	5.660
11	2.400	102	38	0.100	0.100	529.217	232.956	1	7	7	44.371	22.480	8.420
12	2.400	38	94	0.100	0.100	488.572	333.135	1	7	7	40.785	9.680	19.620
13	2.400	54	70	0.100	0.100	516.501	344.793	1	7	7	42.586	12.880	14.820
14	2.400	70	46	0.120	0.100	482.755	317.165	1	7	7	47.559	17.480	10.940
15	2.400	62	62	0.100	0.100	525.101	331.836	1	7	7	43.139	14.480	13.220
16	2.400	254	14	0.100	0.100	486.223	64.530	1	7	7	43.605	52.880	3.620
17	2.400	174	22	0.100	0.100	522.868	116.610	1	7	7	44.469	36.880	5.220
18	2.400	86	38	0.120	0.100	489.936	264.652	1	7	7	48.053	21.000	9.180
19	2.400	86	46	0.100	0.100	462.691	253.210	1	6	6	44.092	19.280	10.020
20	2.400	86	46	0.100	0.100	461.361	246.641	2	7	6	44.092	19.280	10.020

8. In **TSMC PDK Capacitor Finder Results** window, each row represents a qualified capacitor. Move mouse to any property column and left click, results are sorted by the

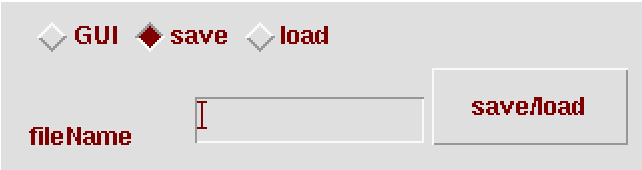
property. Graph shown result sorted by **nv** (Number of vertical fingers).

dev(No)	freq(GHz)	nv	nh
12	2.400	38	94
6	2.400	46	78
13	2.400	54	70
15	2.400	62	62
9	2.400	70	54
14	2.400	70	46
4	2.400	78	46
19	2.400	86	46
20	2.400	86	46
18	2.400	86	38
3	2.400	94	38
11	2.400	102	38
1	2.400	118	30
8	2.400	126	30
10	2.400	142	22
2	2.400	158	22
5	2.400	166	22
17	2.400	174	22
7	2.400	246	14
16	2.400	254	14

9. TCF result browser supports plotting C and Q vs. Freq graph. To do so, select a capacitor with mouse left click on the row. Notice that selection is highlighted. Click **'Plot C Q'** button to plot C and Q graph.



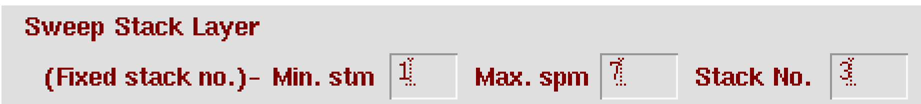
10. User can save current search result in a text file. Saved result file can be loaded and display later. To save/load result user need to choose **save** or **load** in radio button and specify a file name in **filename** field. Then click **save/load**.
    Important: Save/Load does not work for TCF plotter. Plotter plots result base on latest TCF search.



11. **Refinement** button. User can do refinement search by selecting a capacitor from result then press **Refinement** button. TCF form Range/Step will automatically configured for next round search. New range will cover original value ± original step. New step size will become one-fifth of original step size. Stack layer parameters keep the same values. New Range/Step reflects refinement design space around selected capacitor with refinement resolution. Compare with using fine resolution at the beginning to search whole design space, use rough resolution as first round search then perform refinement saves lots of time. This will be demonstrated in **TCF tutorial**.

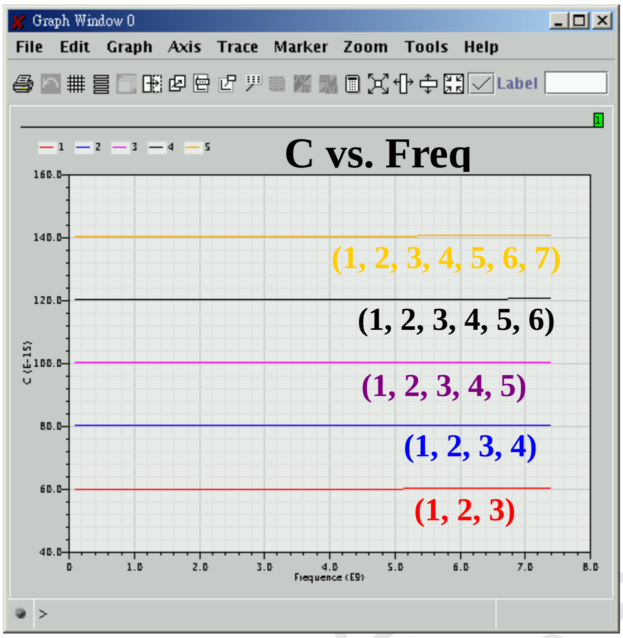
12. By selecting a capacitor in result browser and press **'send to CDF'** button, TCF updates layout parameters to CDF. User does not have to manually key-in these parameters.

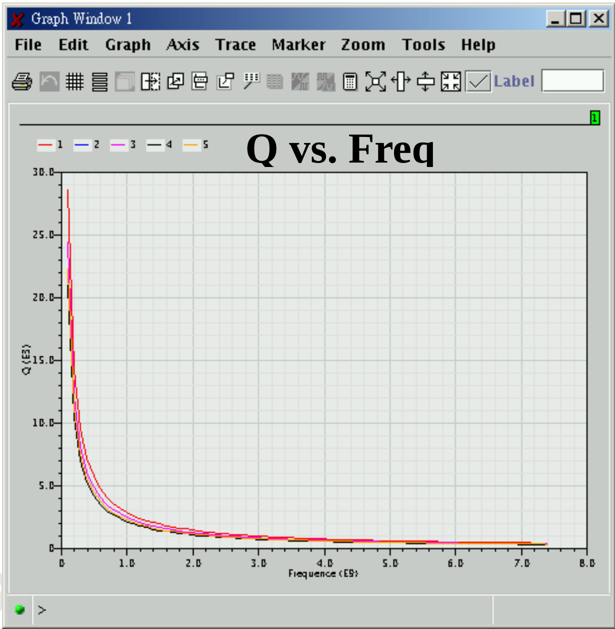
13. Sensitivity analysis can be done using sweep plotter in CDF. By clicking **'Sweep Plotter (C_Q)'** button in CDF, a TSMC PDK Capacitor Sweep Plotter from pop out. User selects which variable to sweep. Enter variable range (**Min**. and **Max**.) and **step** then click **PLOT**. C and Q vs. frequency for each sweep will then be plotted.
    There are two ways to sweep **Stack Layer**. Fix Stack No. Require user to specify number of stacks then sweep from minimum start layer to maximum stop layer. For example following setting: **Min stm** = 1, **Max. spm** = 7, **Stack No.** = 3 will sweep stacks (1, 2, 3), (2, 3, 4), (3, 4, 5), (4, 5, 6), (5, 6, 7).



The other method, **Fixed stm**, requires user to designate a start metal layer then sweep to maximum stop layer. For example following setting: **stm** = 1, **Max. spm** = 7 will sweep stacks (1, 2, 3), (1, 2, 3, 4) … (1, 2, 3, 4, 5, 6, 7)

C and Q vs. freq plots for above **Stack Layer** sweep are shown below. Each line represents crtmom with different stack layers.





Tips for TCF

1. Multi-plot

In TCF result browser, user can select multiple capacitors drag mouse or press <ctrl> / <shift> and select with mouse then click **'Plot C Q'** button. The C and Q vs. frequency graph for multiple capacitors chosen will then be plotted. User can observe different behavior of devices. This function will be demonstrated in **TCF tutorial**.

2. Callback

Just like PDK, there are callback functions that trigger user input. Unacceptable inputs will be corrected. User can input extreme values, such as 0 and 1000, in min and max fields of layout parameters, callback function will take effect changing values to model card min and max.