TCF Tutorial

Rev 0.1

Revision History

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

Contents

Overview

This tutorial tends to show the use of TCF searching a near optimal device efficiently.
Through this tutorial, most function in TCF will be demonstrated.
There is a design objective at the beginning. This tutorial will show user how to configure TCF to search device that meet design objective as well as use of **refinement** function, variable sweep and plotter step by step.
There is a result analysis section at the end to verify correctness of TCF output. Result will be verified with initial design objectives.

Objective

Assume target device has the following characteristic:
Device: **crtmom_rf**
Working frequency: **2.4 GHz**
Capacitance (C) = **500 fF ± 5%**
Minimun Q: **10**
Corner: **TT**
MoM width: **1 ~ 100 uM**
MoM height: **1 ~ 100 uM**
Metal density: **30% ~ 50 %**

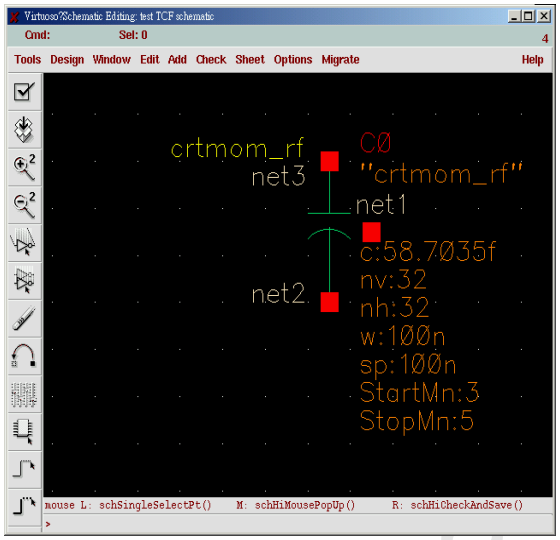
Goal: Find a capacitor satisfies above conditions and occupies smallest area.

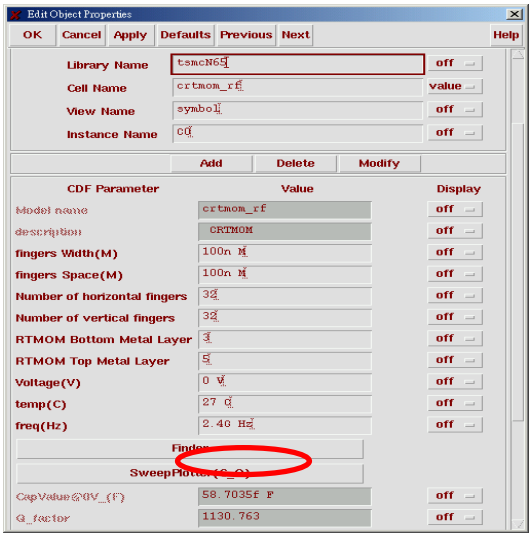
Open TSMC PDK MoM Capacitor Finder form

The environment used in this tutorial is IC5141_USR4. User can open a **TSMC PDK MoM Capacitor Finder** Form by following TCF User Guide -> how to use TCF -> step 1 ~ step 4. Here is the brief description of the steps.

1. Source shell library used by TCF. There is a source file *tif_tcf.csh* provided with PDK. This file locates in PDK install directory.
   In terminal window, enter the following line:
   source tif_tcf.csh
2. Open a design schematic view that contains *crtmom_rf* capacitor. Or user can create a new schematic design and instantiate a *crtmom_rf* capacitor.
3. Select capacitor and press bind-key **'q'** to query the capacitor. CDF form appears.
4. Locate **Finder** button in CDF from and click it, TSMC PDK MoM Capacitor Finder form

should appear.

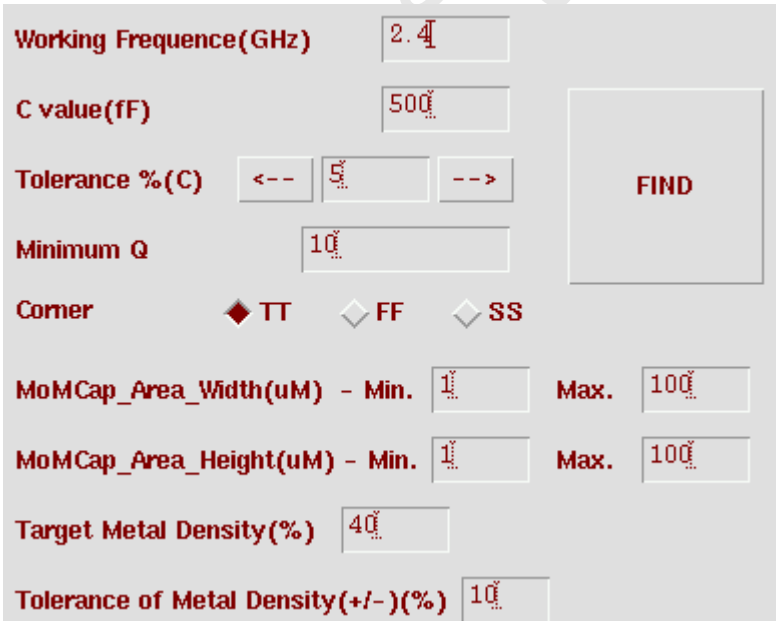




Fill in TSMC PDK MoM Capacitor Finder form

Fill in TCF form with design constrain.

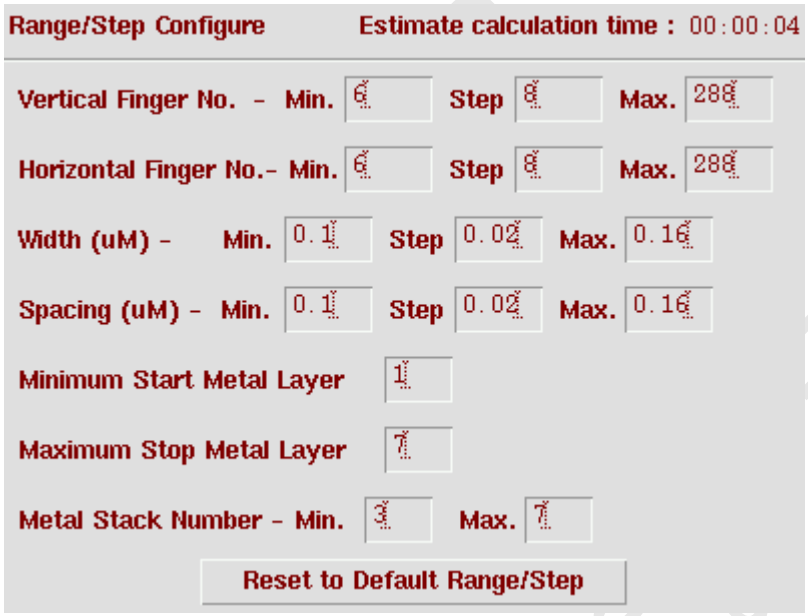
1. In **Working Frequency (GHz)** text field, enter **2.4**.
2. In **C value (fF)** text field, enter **500**.
3. In **Tolerance % (C)** text field, enter **5**.
4. In **Minimum Q** text field, enter **10**.
5. For **Corner** select **TT**.
6. In **MoMCap_Area_Width (uM)**, enter 1 for **Min.** and 100 for **Max.**
7. In **MoMCap_Area_Height (uM)**, enter 1 for **Min.** and 100 for **Max.**
8. In **Target Metal Density (%)** text field, enter **40**.
9. In **Tolerance of Metal Density(+/-) (%)** text field, enter **10**.



Set layout parameters as following graph shows for the 1st round rough search.

Vertical Finger No. - **Min.** 6 **Step** 8 **Max.** 288
Horizontal Finger No. - **Min.** 6 **Step** 8 **Max.** 288
Width (uM) - **Min.** 0.1 **Step** 0.02 **Max.** 0.16
Spacing (uM) - **Min.** 0.1 **Step** 0.02 **Max.** 0.16
Minimum Start Metal Layer 1
Maximum Stop Metal Layer 7
Metal Stack Number - **Min.** 3 **Max.** 7

Note that ranges are based on model card range. Initial design space will have maximum range with rough resolution. The estimate time cost for this search is 4 seconds.

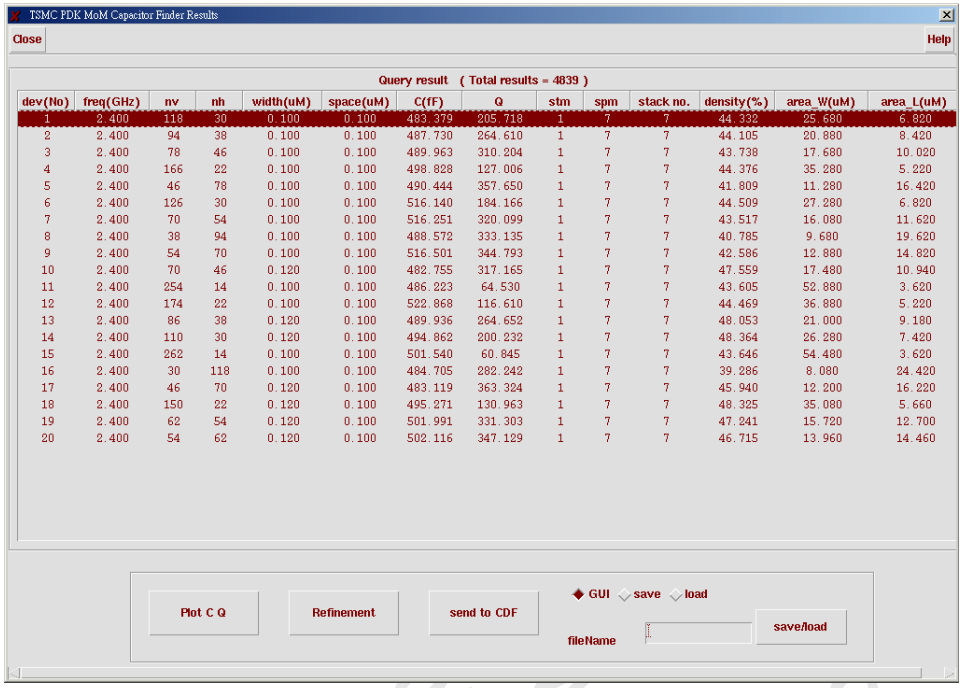


Configure TCF form to output small capacitors

1. For **Optimal Objective**, select **AREA.**
2. Set **Maximum Display Number** to be **20**.

View TCF Search result

1. Click '**find'** button. Wait for result browser to appear. Each row represents a capacitor. Above results there exists a line "Query result (Total results = 4839)" stating 4839 capacitors in design space satisfy design constrains. Because **Maximum Display Number** is set to 20 and **Optimal Objective** set to **AREA**, the 20 smallest capacitors are displayed.



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	94	38	0.100	0.100	487.730	264.610	1	7	7	44.105	20.880	8.420
3	2.400	78	46	0.100	0.100	489.963	310.204	1	7	7	43.738	17.680	10.020
4	2.400	166	22	0.100	0.100	498.828	127.006	1	7	7	44.376	35.280	5.220
5	2.400	46	78	0.100	0.100	490.444	357.650	1	7	7	41.809	11.280	16.420
6	2.400	126	30	0.100	0.100	516.140	184.166	1	7	7	44.509	27.280	6.820
7	2.400	70	54	0.100	0.100	516.251	320.099	1	7	7	43.517	16.080	11.620
8	2.400	38	94	0.100	0.100	488.572	333.135	1	7	7	40.785	9.680	19.620
9	2.400	54	70	0.100	0.100	516.501	344.793	1	7	7	42.586	12.880	14.820
10	2.400	70	46	0.120	0.100	482.755	317.165	1	7	7	47.559	17.480	10.940
11	2.400	254	14	0.100	0.100	486.223	64.530	1	7	7	43.605	52.880	3.620
12	2.400	174	22	0.100	0.100	522.868	116.610	1	7	7	44.469	36.880	5.220
13	2.400	86	38	0.120	0.100	489.936	264.652	1	7	7	48.053	21.000	9.180
14	2.400	110	30	0.120	0.100	494.862	200.232	1	7	7	48.364	26.280	7.420
15	2.400	262	14	0.100	0.100	501.540	60.845	1	7	7	43.646	54.480	3.620
16	2.400	30	118	0.100	0.100	484.705	282.242	1	7	7	39.286	8.080	24.420
17	2.400	46	70	0.120	0.100	483.119	363.324	1	7	7	45.940	12.200	16.220
18	2.400	150	22	0.120	0.100	495.271	130.963	1	7	7	48.325	35.080	5.660
19	2.400	62	54	0.120	0.100	501.991	331.303	1	7	7	47.241	15.720	12.700
20	2.400	54	62	0.120	0.100	502.116	347.129	1	7	7	46.715	13.960	14.460

2. Check the parameters of first capacitor appear in result browser. Layout parameter values are: nv = 118, nh = 30, width = 0.100 uM, space = 0.100 uM, stm = 1 and spm = 7. Capacitance 483.379 fF is within 500 fF ± 5% and Q value 205.718 is larger than 10 as objective stated. Also metal density 44.332% falls in desire range 30%~50%.

dev(No)	freq(GHz)	nv	nh	width(uM)	space(uM)	C(fF)	Q
1	2.400	118	30	0.100	0.100	483.379	205.718

stm	spm	stack no.	density(%)	area_W(uM)	area_L(uM)
1	7	7	44.332	25.680	6.820

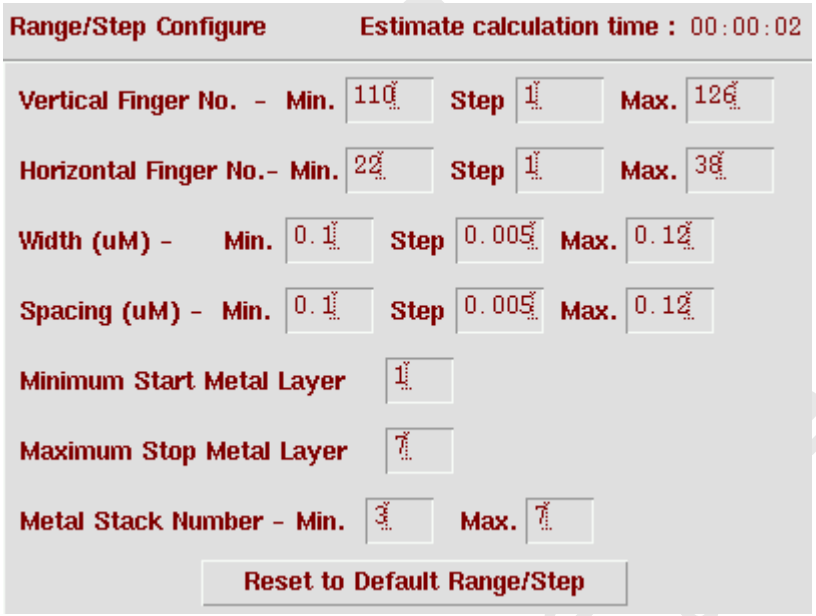
3. Check the width and height of first capacitor. area_W = 25.680 uM and area_L = 6.820 uM. It has the smallest size among results. Also they both satisfy design constrain range 1 ~ 100 uM.

   Note: Size information columns are located at very right end in result browser; resizing result window and use of scroll bar may be needed to see size information.

4. In save/load section. Select **save** and type *rough* in **filename** field then press **save/load** button.

Refinement

1. Select first capacitor and click **Refinement**. Notice only **Range/Step Configure** section in TCF from has been updated. New parameter range will cover original value ± step. New step size is one fifth of previous step size. **Refinement** does not affect **Start/Stop Metal Layer** and **Stack Numbers** parameters. The estimate time cost for this search is 2 seconds.



Example: previous **Vertical Finger No.** setting was **Min** 6 **Step** 8 **Max** 288. Best capacitor so far has **Vertical Finger No.** value 118. Refinement **Vertical Finger No.** range will then be (118-8) ~ (118+8), which is 110 ~ 126, while step become 8/5, which is 1.6. Because finger number should be an integer, callback function change step value from 1.6 to 1

2. Close result browser and press **Find** button in TCF from again to search with refinement range and resolution. Result browser should appear within seconds.

3. Check the parameters of first capacitor appear in result browser. Layout parameter values are: nv = 116, nh = 30, width = 0.100 uM, space = 0.100 uM, stm = 1 and spm = 7. Capacitance 475.190 fF is within 500 fF ± 5% and Q value 211.653 is larger than 10 as objective stated. Also metal density 44.285% falls in desire range 30%~50%.

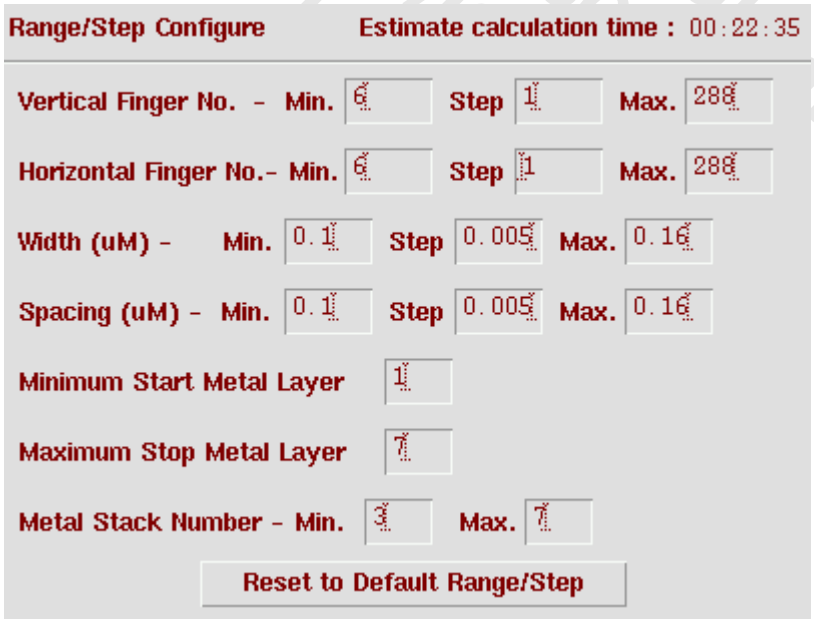
dev(No)	freq(GHz)	nv	nh	width(uM)	space(uM)	C(fF)	Q
1	2.400	116	30	0.100	0.100	475.190	211.653

stm	spm	stack no.	density(%)	area_W(uM)	area_L(uM)
1	7	7	44.285	25.280	6.820

4. Check the width and height of first capacitor. area_W = 25.280 uM and area_L = 6.820 uM. It has the smallest size among results. Also they both satisfy design constrain range 1 ~ 100 uM.
   Notice this capacitor has smaller area compare with previous one. Area improvement is (25.680*6.820 - 25.280*6.820) / (25.680*6.820) = 1.56 %

5. At the bottom of result browser, choose **save** and type *refinement* for **filename** then press **save/load** button to save refinement result with file name *refinement*.

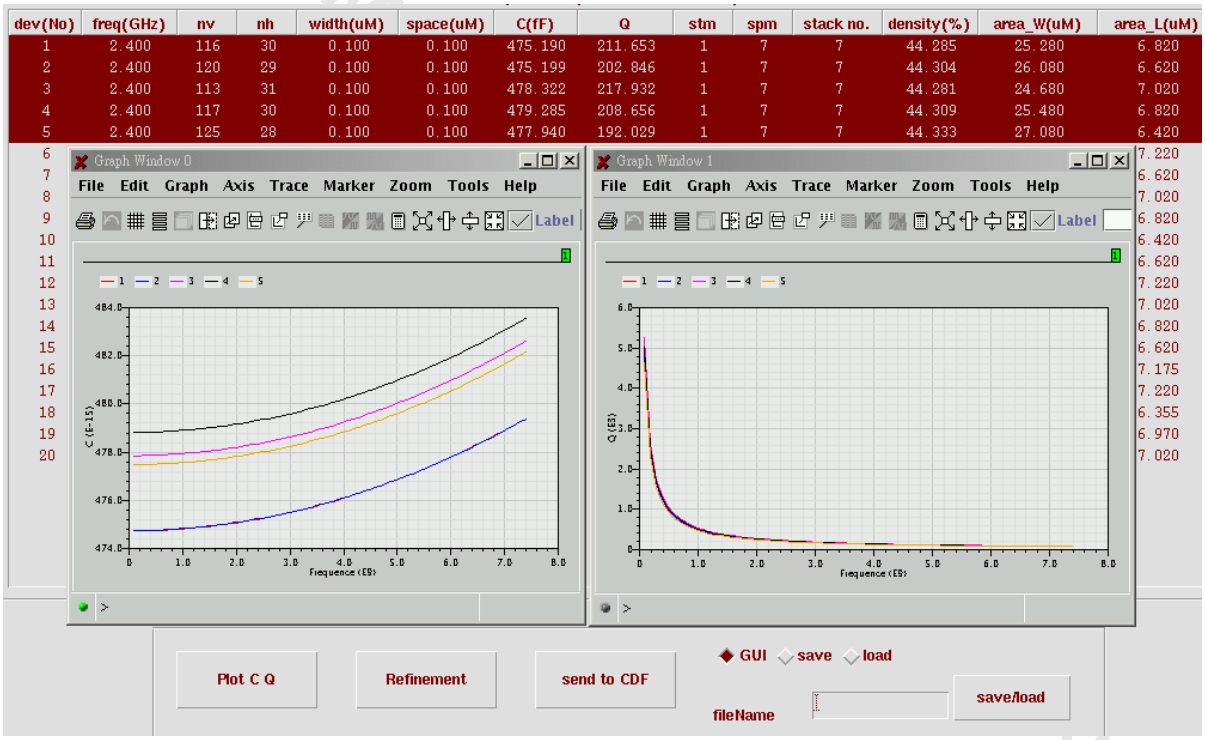
6. In TCF from. Change layout parameters to have maximum range with refinement step size. This search space covers full model card range with refinement resolution. Notice the Estimate calculation time is 00:22:35. Compare to previous Rough + Refinement time will be 00:00:04 + 00:00:02 = 6 seconds. It is about 226 times faster using refinement function.



7. **[Optional]** User can try additional refinement run based on current inductor. Second refinement gives same optimum inductor as first refinement does.

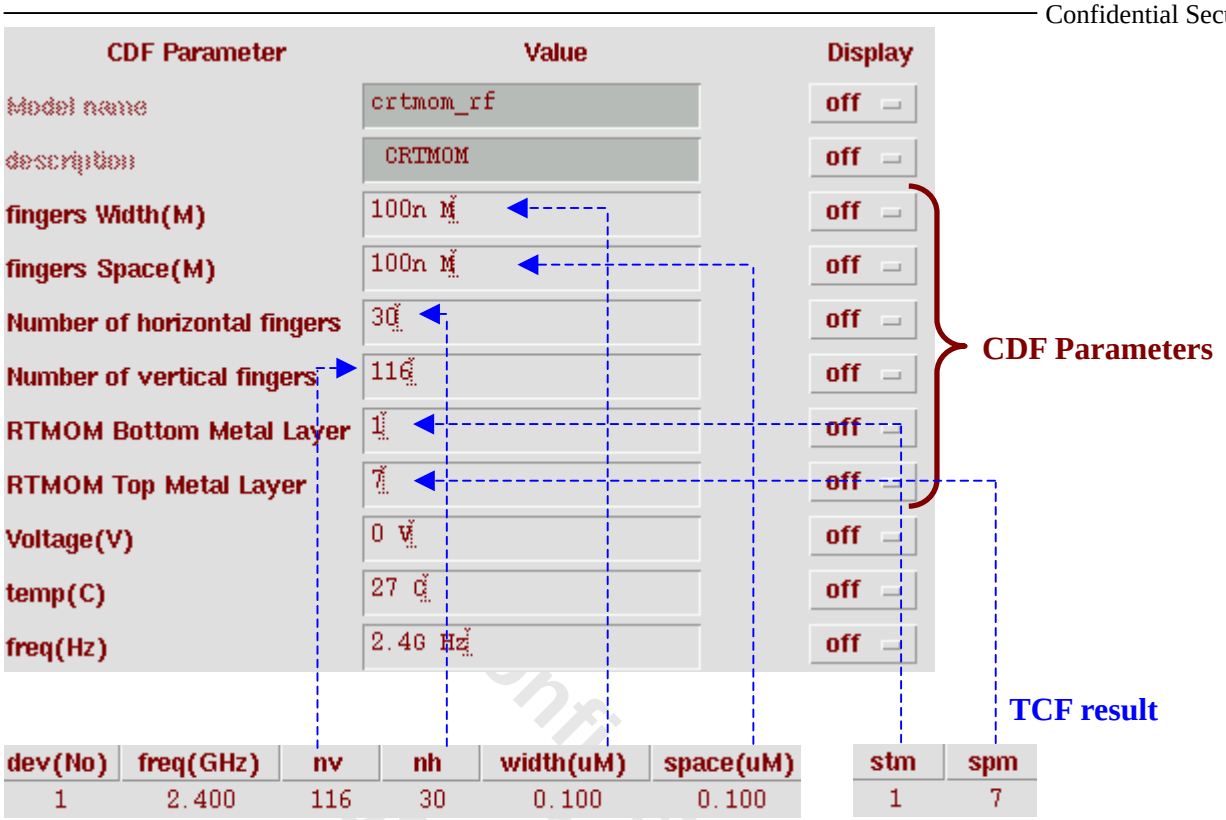
Result Plot and send to CDF

1. Drag mouse to select first five capacitors. Press **Plot C Q** button to plot C and Q vs. freq graph. Plots of selected capacitors appear as shown below. The C Q curves roughly overlap for first 2 capacitors. This indicates only small difference between these two devices' behavior.
   Close all plots and re-plot C and Q for first capacitor. They will be used later to analyze this capacitor and see if it meets all design objectives.
   For details, please refer to Result Analysis section in this document.



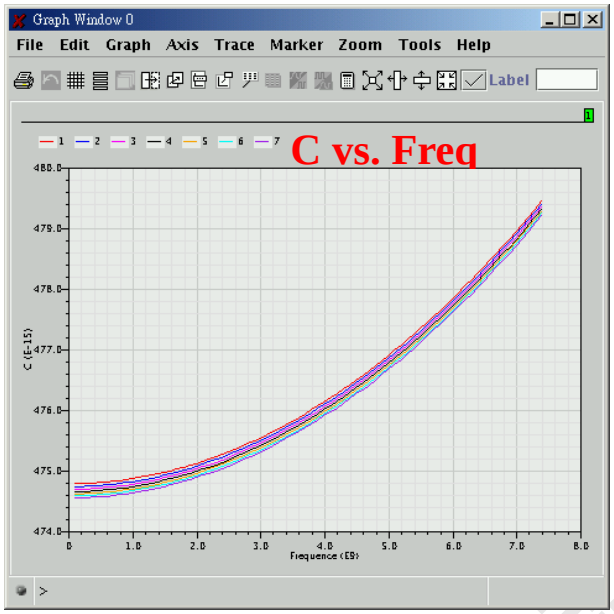
2. Make sure first capacitor is still selected, if not select it with mouse. Press **Send to CDF** button.

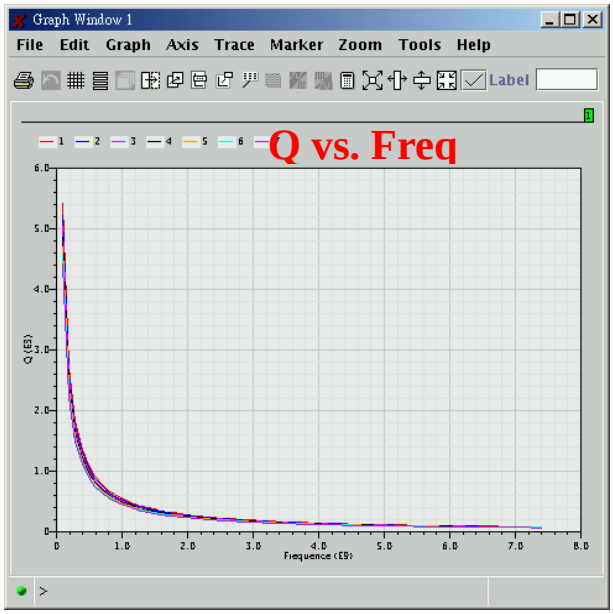
3. Check CDF layout parameters have been updated to capacitor chosen.



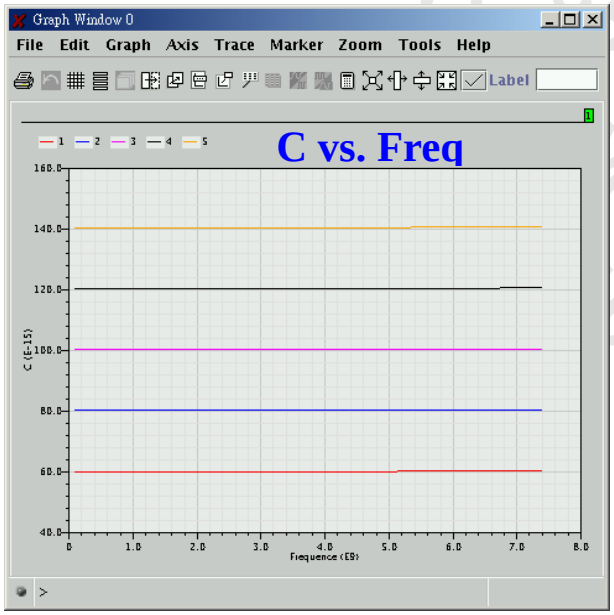
4. Press **Sweep Plotter (C_Q)** button in CDF form. **TSMC PDK MoM Capacitor Sweep Plotter** form appears. Select **Temperature** in Sweep Variable section. Make **min.** 10, **step** 10 and **max.** 70. Press **Plot** button. Sweep plots of C and Q for temperature appear. Plots show that capacitance slightly decreases when temperature increases.
   Select **Stack Layer (Fixed stm)** as Sweep Variable. Make **stm** 1 and **Max. spm** to be 7 then press **Plot** button. This sweeps stack layer from (1, 2, 3) to (1, 2, 3, 4, 5, 6, 7). Comparing sweep plots for above two variables. Observe that C and Q are much more sensitive for **Stack Layer** then **Temperature**.

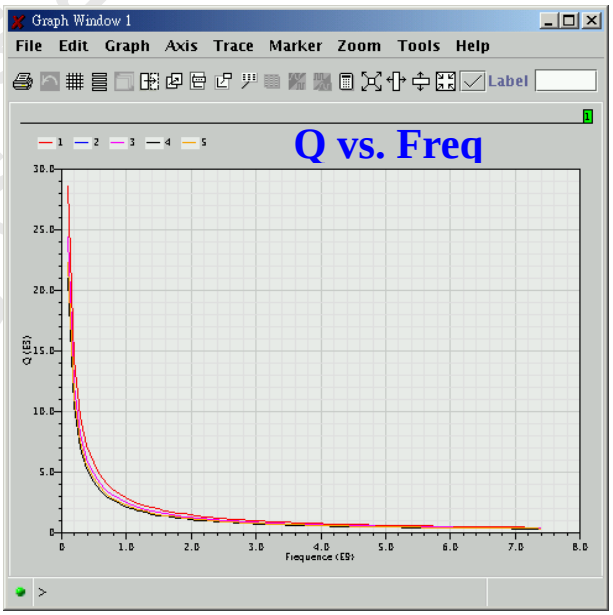
Sweep for Temperature





Sweep for Stack Layer (Fixed stm)



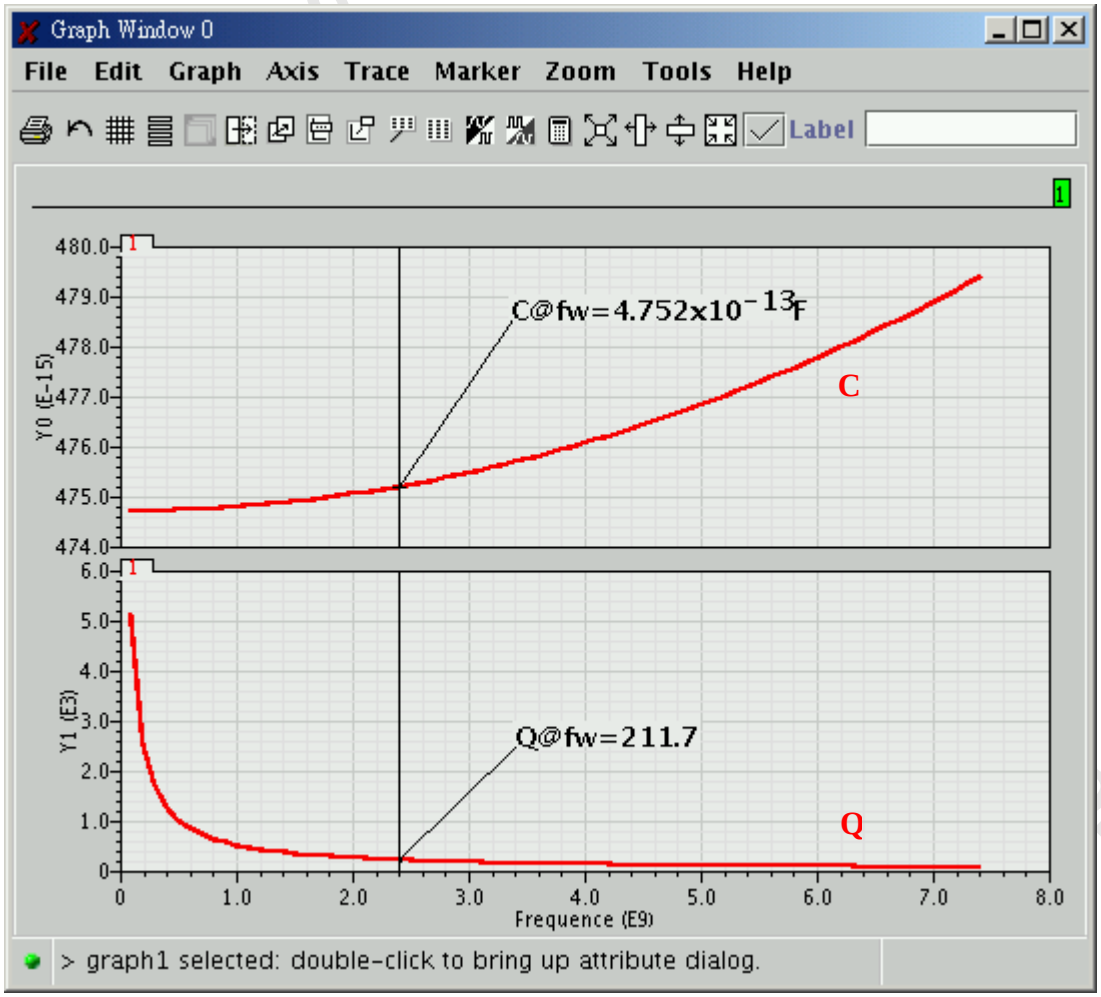


Result analysis

Below is the optimal device of refinement and its C Q plots. The capacitance and Q value shown in result browser match those in plots.

dev(No)	freq(GHz)	nv	nh	width(uM)	space(uM)	C(fF)	Q
1	2.400	116	30	0.100	0.100	475.190	211.653

stm	spm	stack no.	density(%)	area_W(uM)	area_L(uM)
1	7	7	44.285	25.280	6.820



This device also satisfies design objectives.

	Objective	Result	Meet Requirement?
Working Freq.	2.4 GHz	2.4 GHz	Yes
Capacitance (C)	500 fF ± 5%	475.190 fF	Yes
Q	Min. 10	211.653	Yes
MoM width	1~100 uM	25.280 uM	Yes
MoM height	1~100 uM	6.820 uM	Yes
Metal density	30%~50%	44.285%	Yes

Summary

In this tutorial, TCF successfully finds a capacitor that meets design objectives with optimized area size.

User should learn how to configure TCF to search desire device through comprehensive GUI forms. This tutorial also shows a good use of refinement function can save enormous search time. User learn how to use plotter to show behavior of device before deploy it in design. The use of sweep plotter for sensitivity analysis is also demonstrated in this tutorial. By completion of this tutorial user should be able to use TCF efficiently.