TIF User Guide

Rev 0.2

Revision History

Rev.No.	History	Draft Date
Rev0.1	Initial Document	09/28/2007
Rev0.2	Add information in How to Use TIF	10/26/2007

Contents

What is TIF?

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

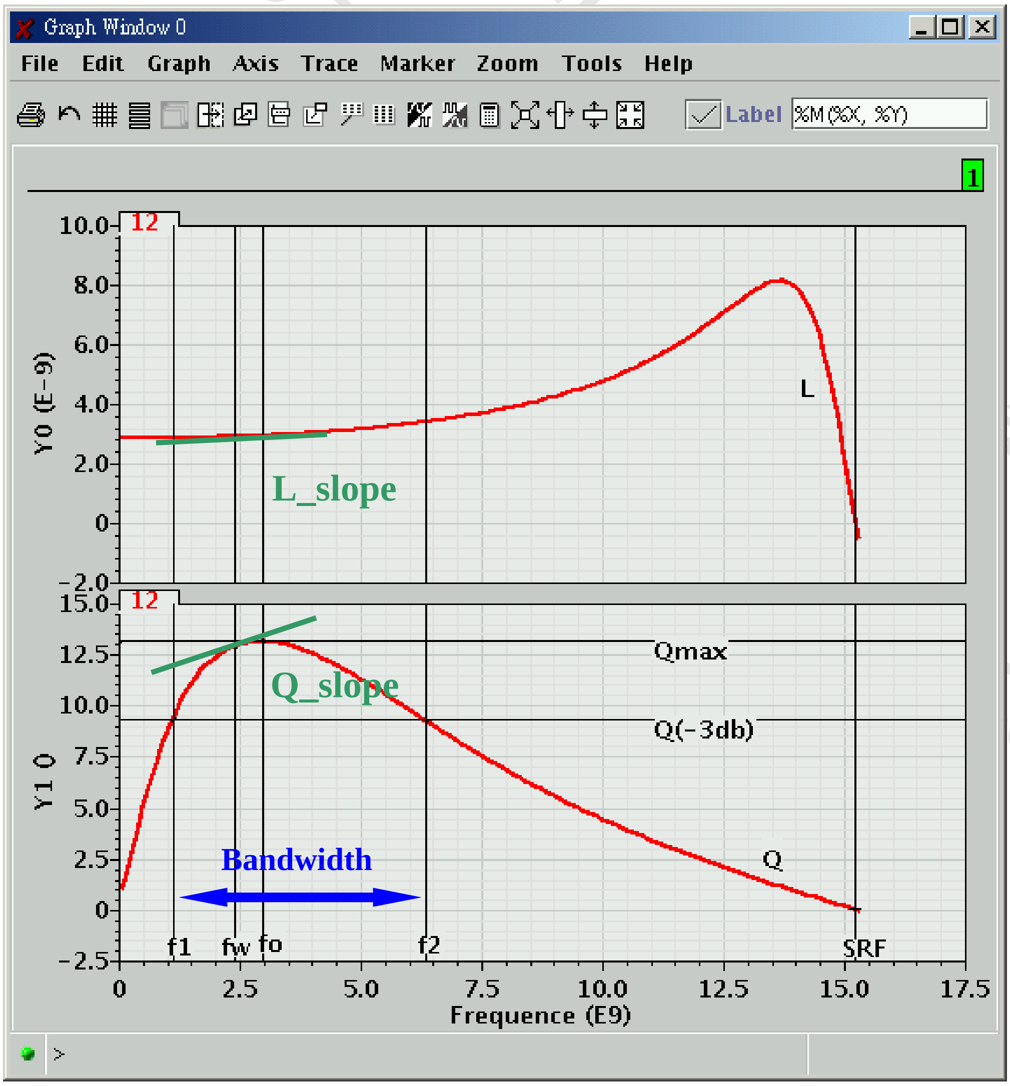
Why TIF?

TIF is accurate. TIF results have same accuracy as spectre.
TIF is powerful. TIF can deliver a near optimal solution very quickly.
TIF is convenient. TIF 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 TIF, finding a "right" and "good" inductor to suit a particular design requires a lot of time and experience. Many try & error process involved and result qualities are not guarantied.
With TIF, designers can save heaps of time on searching inductors still having a better suitable device for design.

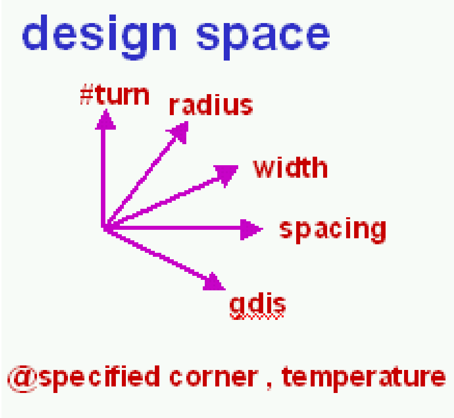
TIF Terminology

There are a few terminologies to be clarified before using TIF. These terminologies are used to define meaning of design constrains and optimal objective. By understanding these terminologies, user can then modify design constrain values in order to get desire device.

Working Frequency (fw): Frequency of device working on.
SRF: Self Resonant Frequency, the frequency that L and Q both degrade to zero.
F(Qmax): f0, Frequency happened to have maximum Q.
Bandwidth: bandwidth is determined by **f2 – f1**, where f1 and f2 are derived from f0. There are two methods to assign f1 and f2, Method 1 shown in graph using **–3db** rule, the other method is directly assigning freq difference with f0 i.e. (f0-f1) and (f2-f0).
L_slope: the change rate of L (inductance) at fw.
Q_slope: the change rate of Q at fw.

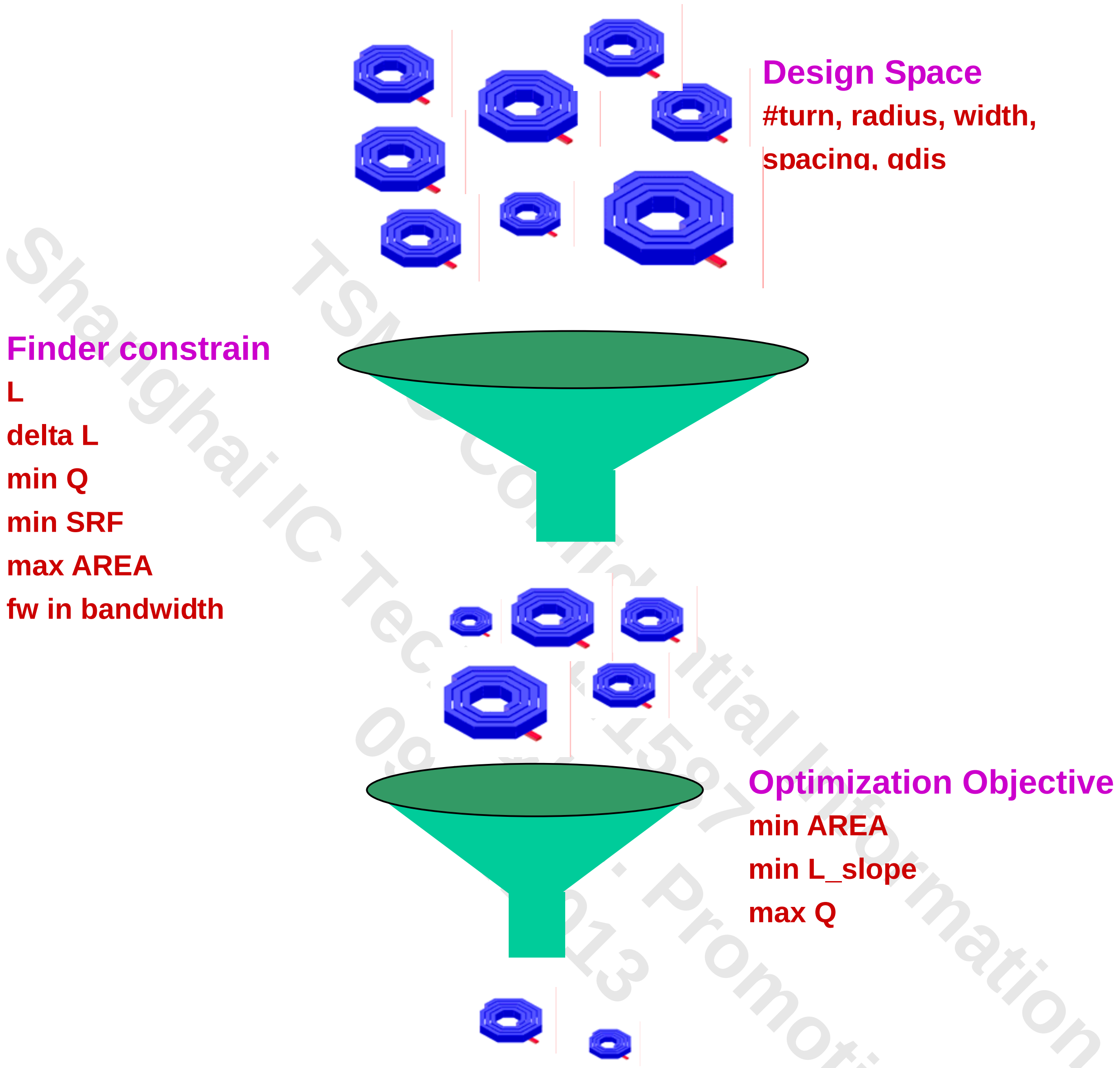


design space:



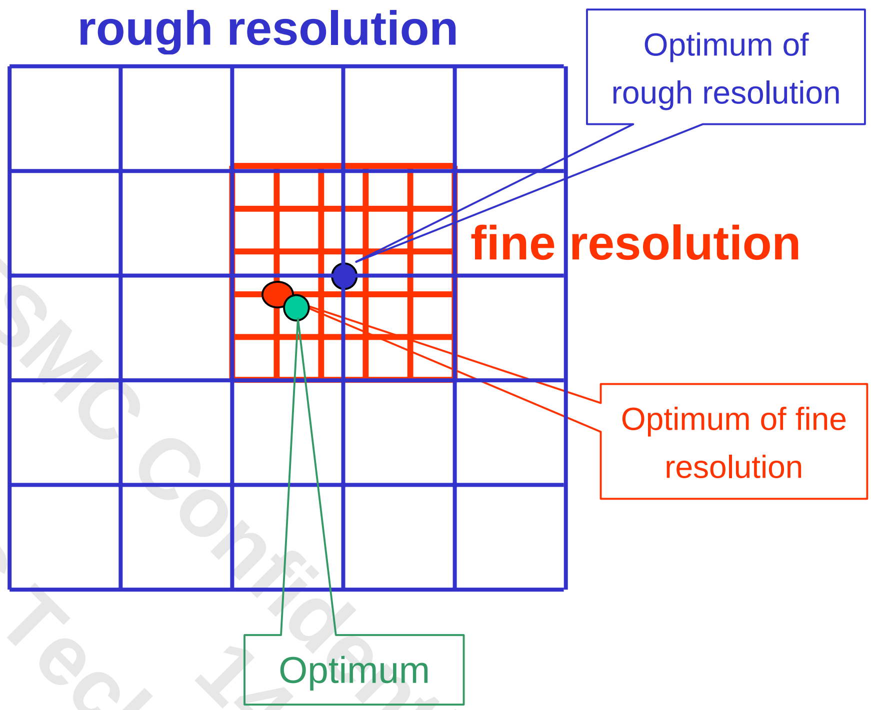
Inductor design space is the combination of inductors with all possible layout parameters. Currently there are five layout parameters: #turn, radius, width, spacing and gdis, therefore gives a five dimensional design space. Each dimension has its own range and step. Size of design space depends on range and step of each dimension. User can specify them in TIF. Large Range and small step size will result large design space. Oppositely small range and large step size will give small design space. TIF searches inductors in design space specified by user. This design space is so called a search space for TIF.

TIF Overview



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

Refinement



TIF 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.

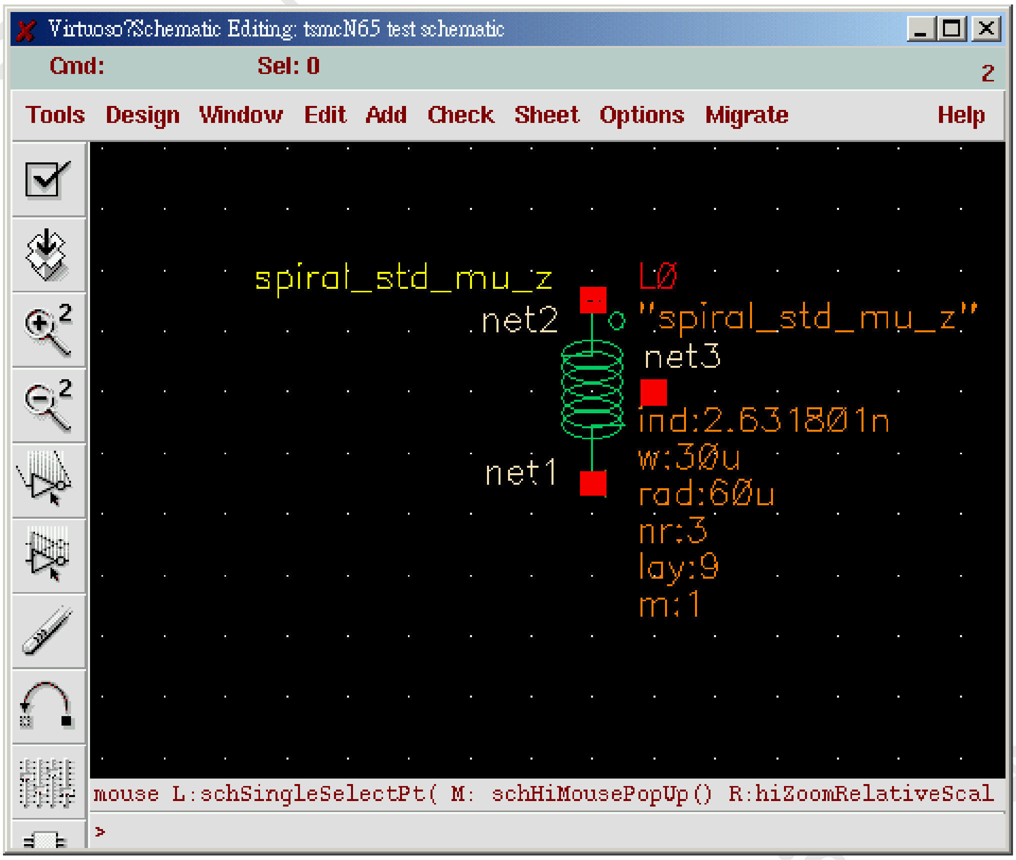
The advantage **refinement** is that time not wasted in searching design spaces far away from global optimum. Every refinement brings optimum closer to global optimum.

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

How to use TIF

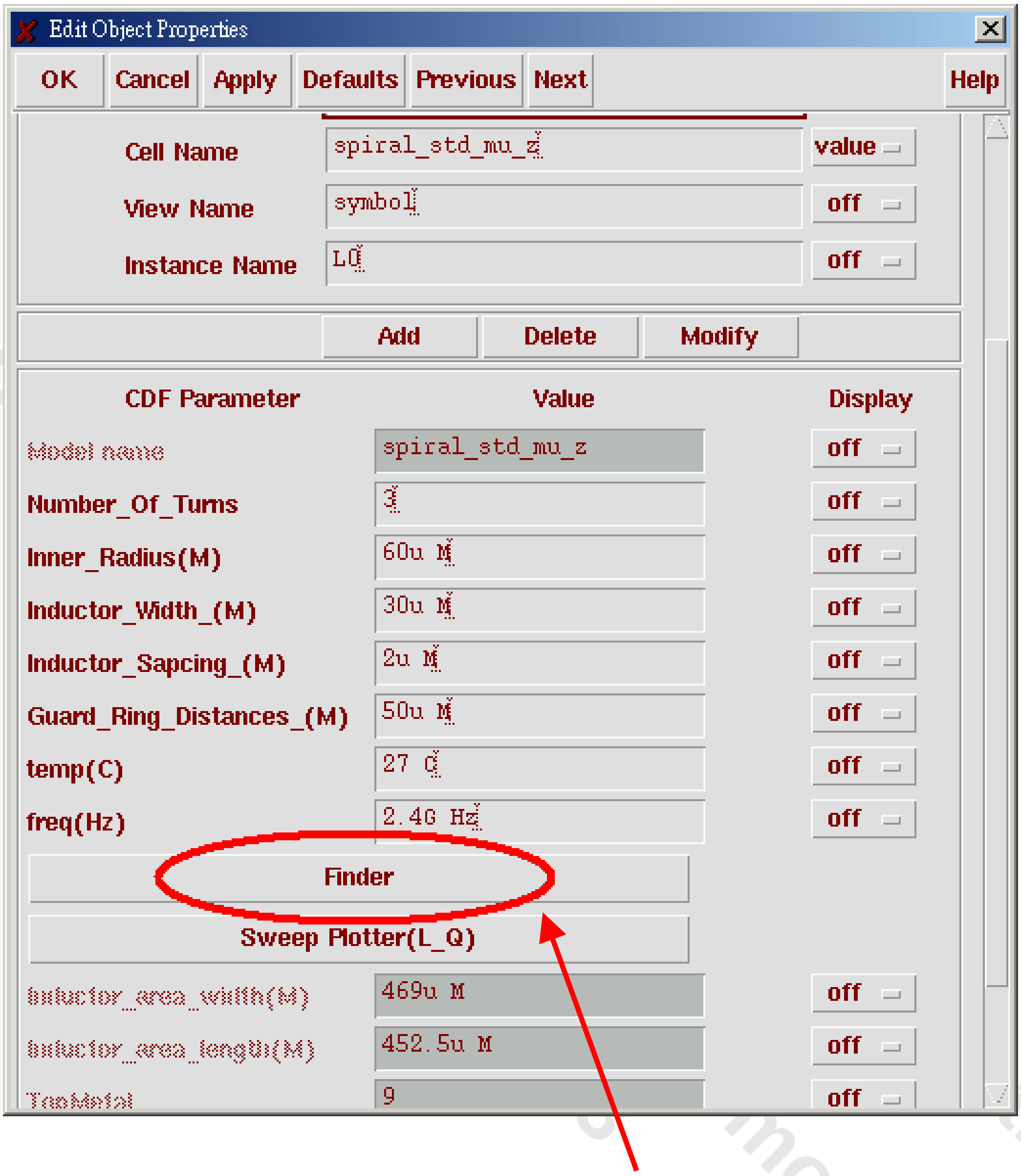
This document will show the usage of TIF step by step and explain the meaning of each field.
Important: TIF can only run in 64-bit environment.

1. Source shell library used by TIF. 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 inductors. In this example, only one inductor is placed.

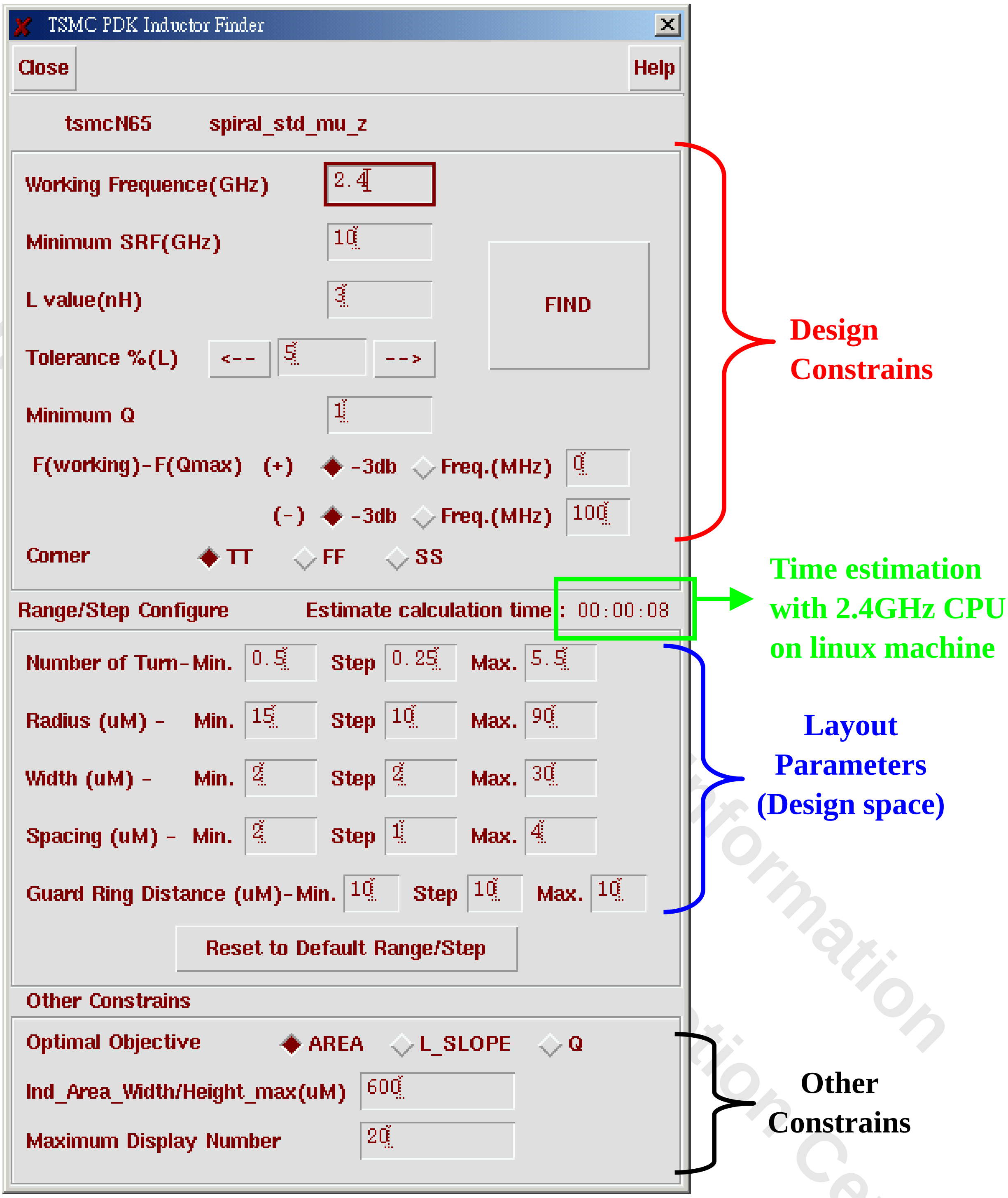


3. Choose one inductor by clicking left mouse button on it.

4. Edit inductor 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 TIF form with title '**TSMC PDK Inductor Finder'** pops out.



6. Fill **TSMC PDK Inductor 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 inductors:

Working Frequency (GHz) Inductor's working frequency.

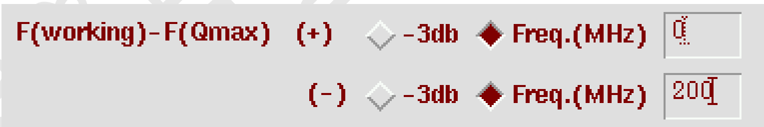
Minimum SRF (GHz) Minimum Self Resonant Frequency.

L value (nH) Target inductance.

Tolerance %(L) Tolerance allowed between TIF result inductance and target inductance 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.

F(working)-F(Qmax) Bandwidth setting. The allowed range of working frequency (fw) differ from frequency at Q maximum (f(Qmax)). There are two ways to express this constrain. One is to specify bandwidth directly in **Freq.(MHz)**, the other way is simply applying **–3db** rule. Notice this setting can be different on plus and minus side of f(Qmax). For example, some designers may like inductors having fw near f(Qmax) but not exceed it. This can be done by setting minus side 200 MHz and plus side 0 MHz as graph shown below.



Corner Model card corner.

Range/Step Configure

Range/Step fields determine search space of TIF. Each field as an inductor 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:

Number of Turn #turns of inductor.

Min. 0.5 **Step** 0.25 **Max.** 5.5

=> Number of Turn = 0.5, 0.75, 1.0, 1.25 … 5.25, 5.5

Radius (uM) Inner radius of inductor.

Min. 20 **Step** 10 **Max.** 90

=> Radius = 20, 30, 40 … 80, 90

Width (uM) Inductor line width.

Min. 2 **Step** 2 **Max.** 30

=> Width = 2, 4, 6 … 28, 30

Spacing (uM) Inductor line spacing.

Min. 2 **Step** 1 **Max.** 4

=> Spacing = 2, 3, 4

Guard Ring Distance (uM) Distance to guard ring

Min. 10 **Step** 10 **Max.** 10

=> Guard Ring Distance = 10

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

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Other constrains

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

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

Area – Give high priority to inductors occupying small area.

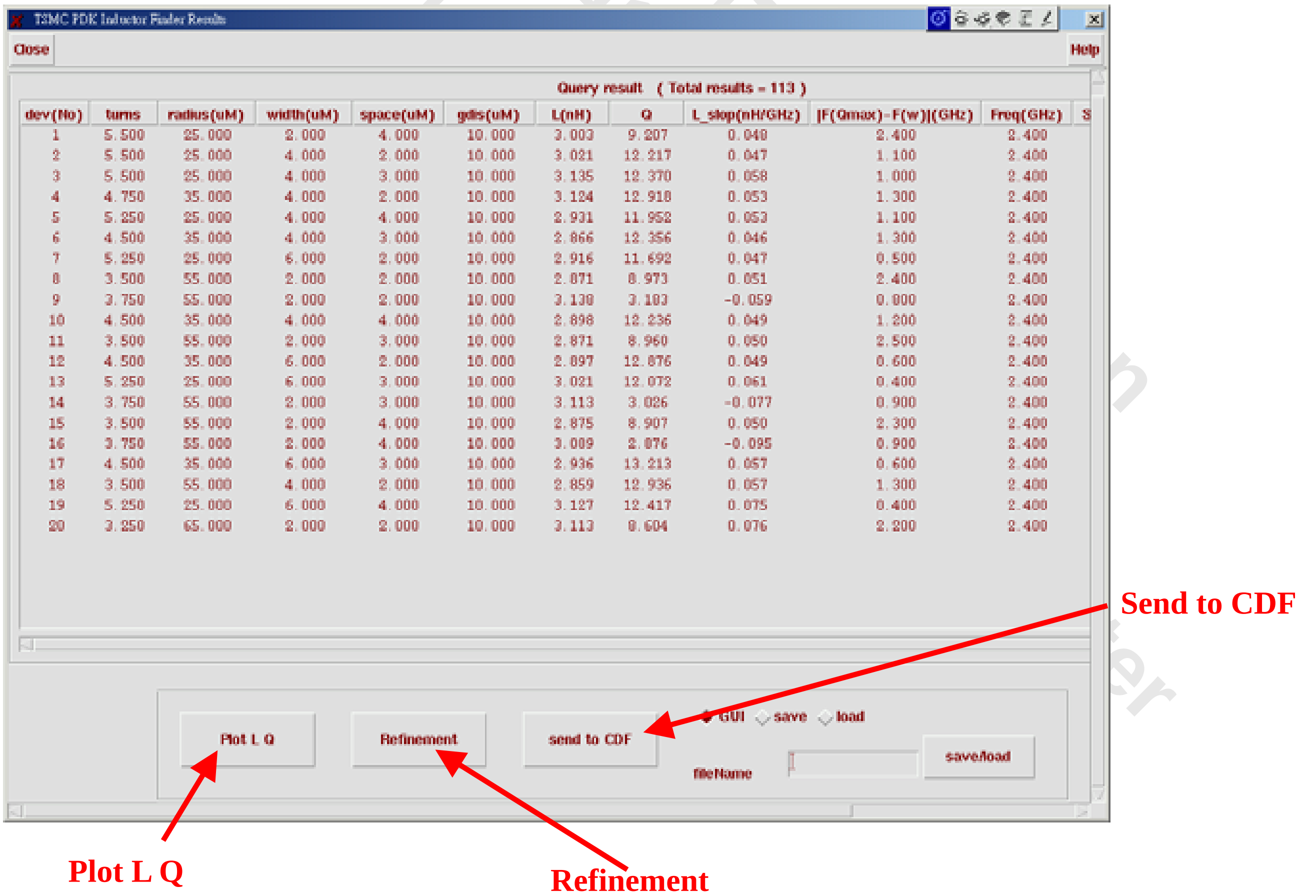
L_SLOPE – Compares the inductance change rate around working frequency. L slope is a good reference of inductor stability. Small L slope implies inductance does not vary rapidly at fw i.e. inductance stable. Oppositely large L slope indicate unstable inductance. Selecting L_SLOPE as optimal objective gives high priority to inductors with small L_SLOPE.

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

Ind_Area_Width/Height_max (uM) A size constrain to limit result inductors' width and height. Any inductor with width/height over this value will be filtered out.

Maximum Display Number User can specify how many inductors 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'. TIF will display the smallest 10 inductors among search result.

7. Click **Find** button. When user finishes filling TIF form, by clicking **'Find'** button TIF begins searching inductors 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 TIF finish searching, the **TSMC PDK Inductor Finder Results** window appears.

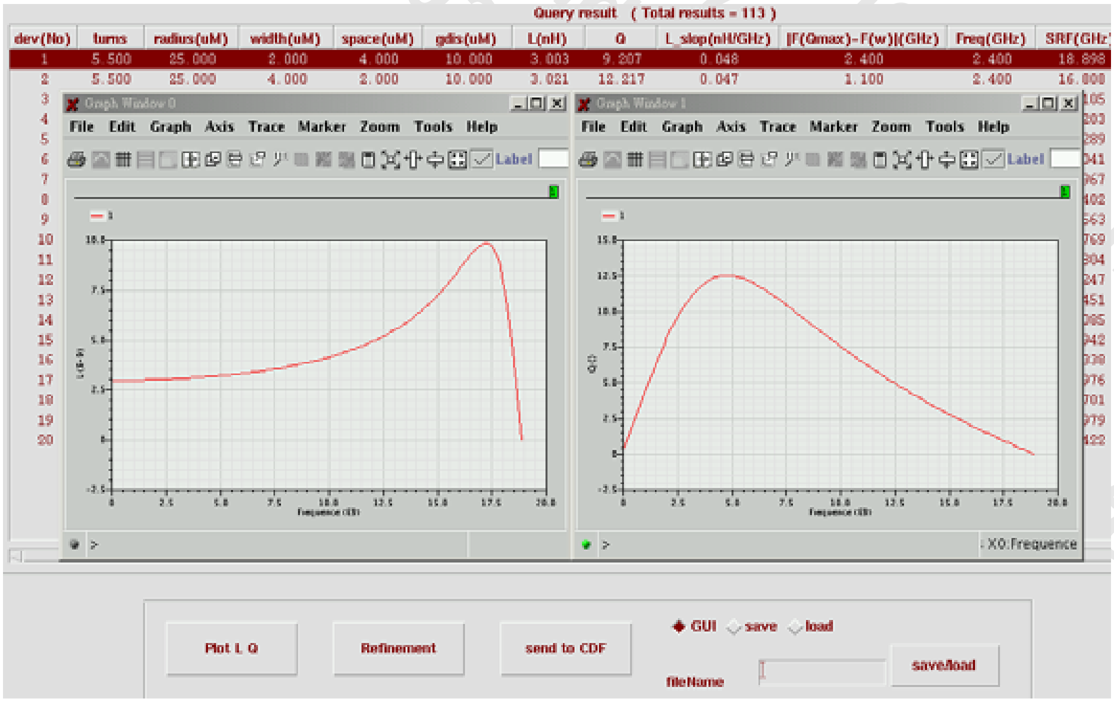


dev(No)	turns	radius(uM)	width(uM)	space(uM)	gdis(uM)	L(nH)	Q	L_slop(nH/GHz)	|F(Qmax)-F(w)|(GHz)	Freq(GHz)
1	5.500	25.000	2.000	4.000	10.000	3.003	9.207	0.048	2.400	2.400
2	5.500	25.000	4.000	2.000	10.000	3.021	12.217	0.047	1.100	2.400
3	5.500	25.000	4.000	3.000	10.000	3.135	12.370	0.058	1.000	2.400
4	4.750	35.000	4.000	2.000	10.000	3.124	12.918	0.053	1.300	2.400
5	5.250	25.000	4.000	4.000	10.000	2.931	11.952	0.053	1.100	2.400
6	4.500	35.000	4.000	3.000	10.000	2.866	12.356	0.046	1.300	2.400
7	5.250	25.000	6.000	2.000	10.000	2.916	11.692	0.047	0.500	2.400
8	3.500	55.000	2.000	2.000	10.000	2.871	8.973	0.051	2.400	2.400
9	3.750	55.000	2.000	2.000	10.000	3.138	3.183	-0.059	0.800	2.400
10	4.500	35.000	4.000	4.000	10.000	2.898	12.236	0.049	1.200	2.400
11	3.500	55.000	2.000	3.000	10.000	2.871	8.960	0.050	2.500	2.400
12	4.500	35.000	6.000	2.000	10.000	2.897	12.876	0.049	0.600	2.400
13	5.250	25.000	6.000	3.000	10.000	3.021	12.072	0.061	0.400	2.400
14	3.750	55.000	2.000	3.000	10.000	3.113	3.026	-0.077	0.900	2.400
15	3.500	55.000	2.000	4.000	10.000	2.875	8.907	0.050	2.300	2.400
16	3.750	55.000	2.000	4.000	10.000	3.009	2.876	-0.095	0.900	2.400
17	4.500	35.000	6.000	3.000	10.000	2.936	13.213	0.057	0.600	2.400
18	3.500	55.000	4.000	2.000	10.000	2.859	12.936	0.057	1.300	2.400
19	5.250	25.000	6.000	4.000	10.000	3.127	12.417	0.075	0.400	2.400
20	3.250	65.000	2.000	2.000	10.000	3.113	8.604	0.076	2.200	2.400

8. In **TSMC PDK Inductor Finder Results** window, each row represents a qualified inductor. Move mouse to any property column and left click, results are sorted by the property. Graph shown result sorted by **turns**.

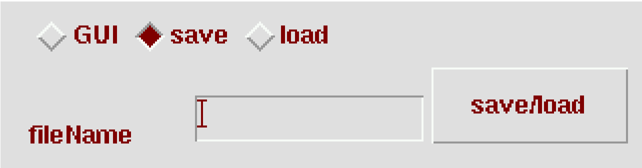
dev(No)	turns	radius(uM)	width(uM)	space(uM)
16	5.500	20.000	8.000	2.000
12	5.500	20.000	6.000	4.000
1	5.250	30.000	2.000	2.000
2	5.250	30.000	2.000	3.000
9	5.000	30.000	6.000	2.000
14	5.000	30.000	6.000	3.000
5	5.000	30.000	4.000	3.000
7	5.000	30.000	4.000	4.000
17	4.750	30.000	6.000	4.000
13	4.250	40.000	6.000	2.000
18	4.250	40.000	6.000	3.000
6	4.250	40.000	4.000	2.000
8	4.250	40.000	4.000	3.000
11	4.250	40.000	4.000	4.000
3	4.250	40.000	2.000	4.000
20	3.750	50.000	6.000	2.000

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



10. User can save current search result in a text file. Saved result file can be loaded and

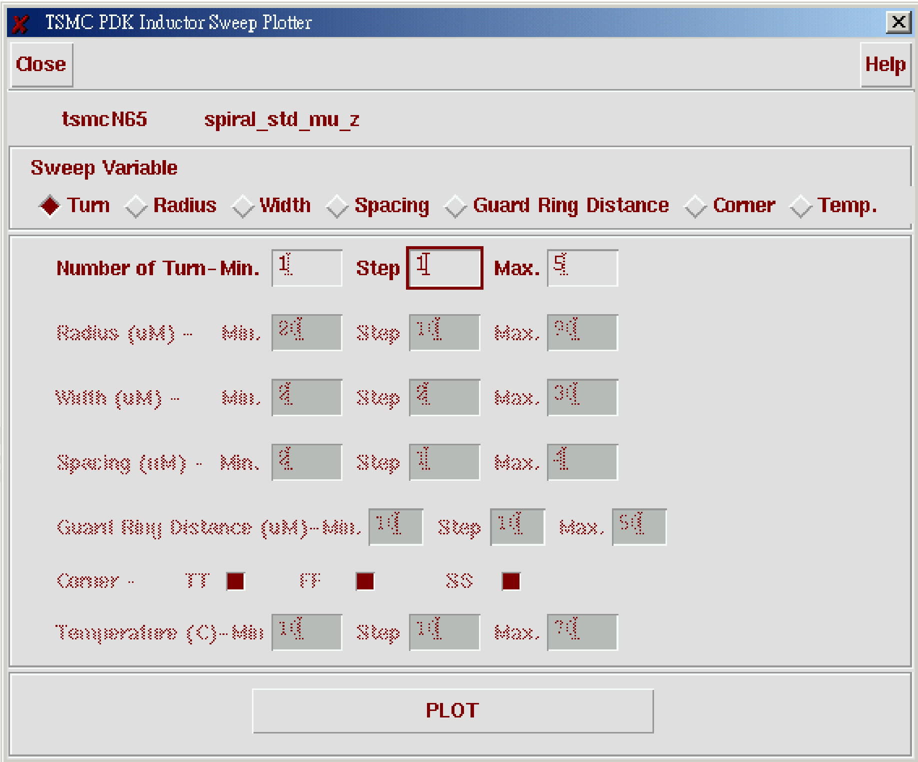
display later. To save/load result user need to choose **save** or **load** in radio button and specify a file name in **filename** field. Then click **save/load**.
Important: Save/Load does not work for TIF plotter. Plotter plots result base on latest TIF search.



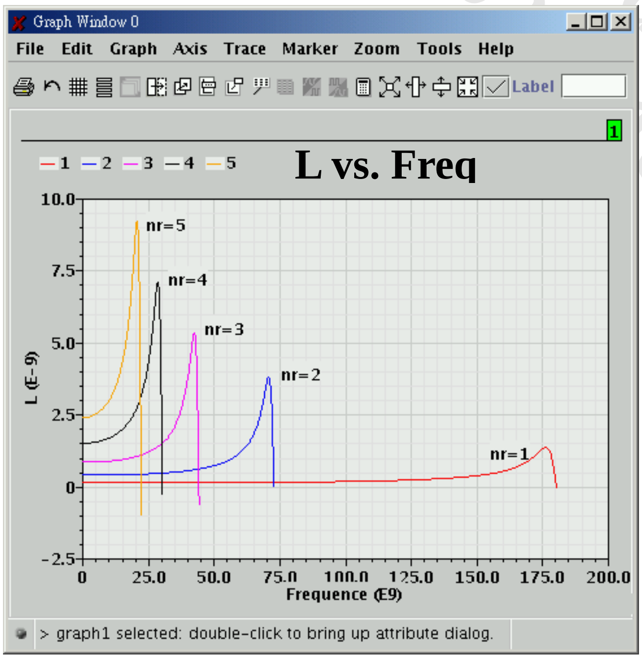
11. **Refinement** button. User can do refinement search by selecting an inductor from result then press **Refinement** button. TIF form Range/Step will automatically configured for next round search. New range will cover original value ± original step. New step size will become one-fifth of original step size. New Range/Step reflects refinement design space around selected inductor 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 **TIF tutorial**.

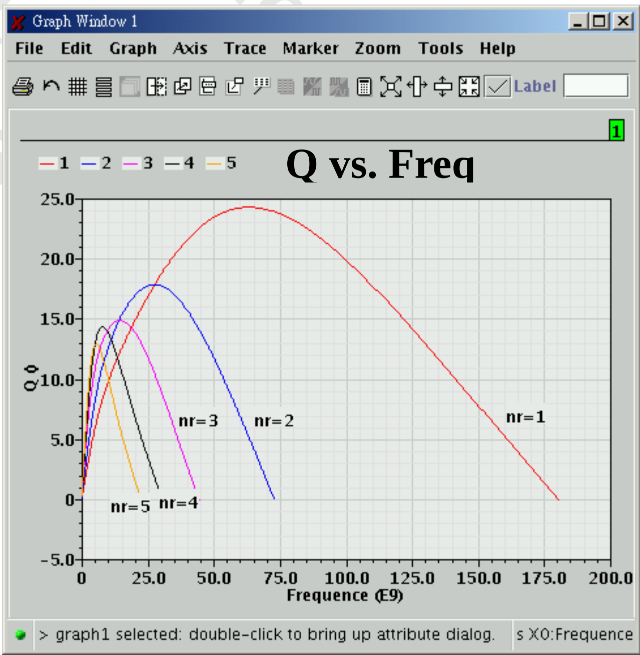
12. By selecting an inductor in result browser and press **'send to CDF'** button, TIF updates layout parameters to CDF. User does not have to manually key-in these parameters.

13. Sensitivity analysis can be done using sweep plotter in CDF. By clicking **'Sweep Plotter (L_Q)'** button in CDF, a TSMC PDK Inductor Sweep Plotter from pop out. User selects which variable to sweep. Enter variable range (**Min**. and **Max**.) and **step** then click **PLOT**. L and Q vs. frequency for each sweep will then be plotted.
Following graph shows setting of variable: **Number of Turn** (nr) sweep from 1 to 5 at step size 1.



L and Q vs. freq plots for nr sweep are shown below. Each line represents different number of turns.





Tips for TIF

1. Multi-plot

In TIF result browser, user can select multiple inductors drag mouse or press <ctrl> / <shift> and select with mouse then click **'Plot L Q'** button. The L and Q vs. frequency graph for multiple inductors chosen will then be plotted. User can observe different behavior of devices. This function will be demonstrated in **TIF 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 100, in min and max fields of layout parameters, callback function will take effect changing values to model card min and max.