TIF Tutorial

Rev 0.1

Revision History

Rev.No.	History	Draft Date
Rev0.1	Initial Document	09/28/2007

Contents

Overview

This tutorial tends to show the use of TIF searching a near optimal device efficiently. Through this tutorial, most function in TIF will be demonstrated.
There is a design objective at the beginning. This tutorial will show user how to configure TIF 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 TIF output. Result will be verified with initial design objectives.

Objective

Assume target device has the following characteristic:
Device: **spiral_std_mu_z**
Working frequency: **2.4 GHz**
Inductance (L) = **4 nH ± 3%**
Minimum SRF: **10 GHz**
Minimun Q: **10**
Working frequency falls on left hand side of F(Qmax) within **300 MHz** range.
Corner: **TT**

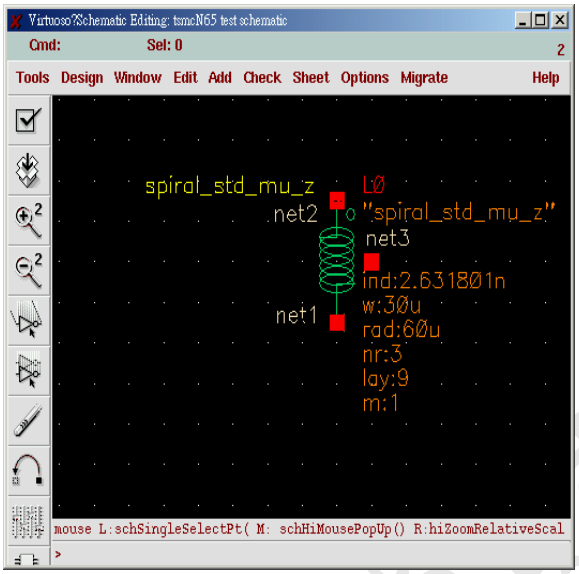
Goal: Find an inductor satisfies above conditions and occupies smallest area.

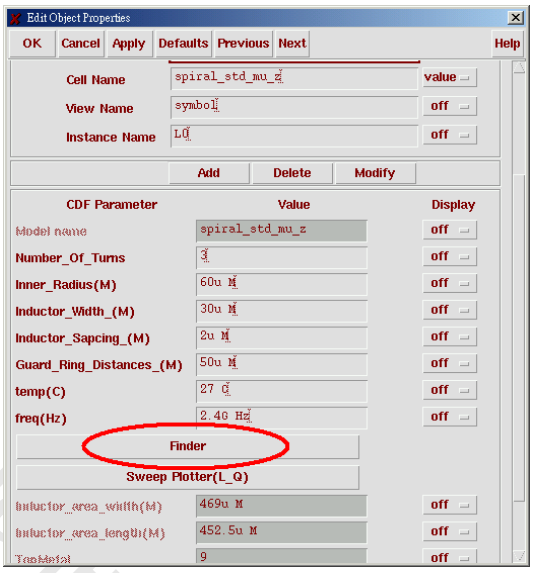
Open TSMC PDK Inductor Finder form

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

1. Source shell library used by TIF. 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 *spiral_std_mu_z* inductor. Or user can create a new schematic design and instantiate a *spiral_std_mu_z* inductor.

3. Select inductor and press bind-key **'q'** to query the inductor. CDF form appears.
4. Locate **Finder** button in CDF from and click it, **TSMC PDK Inductor Finder** form should appear.

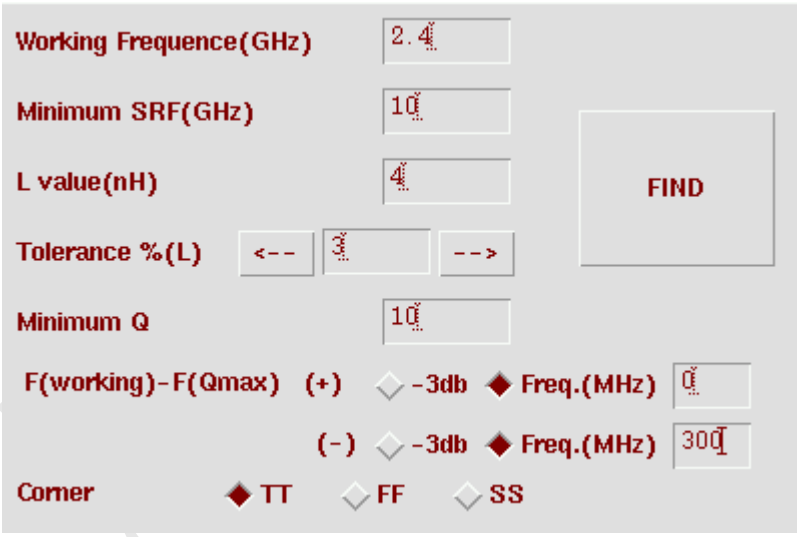




Fill in TSMC PDK Inductor Finder form

Fill in TIF form with design constrain.

1. In **Working Frequency (GHz)** text field, enter **2.4**.
2. In **Minimum SRF (GHz)** text field, enter **10**.
3. In **L value (nH)** text field, enter **4**.
4. In **Tolerance % (L)** text field, enter **3**.
5. In **Minimum Q** text field, enter **10**.
6. In **F(working) – F(Qmax)**, select **Freq. (MHz)** for both (+/-) side. Enter **0** in text field for **(+)** side, **300** for **(–)** side.
7. For **Corner** select **TT**.



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

Number of Turn - **Min.** 0.5 **Step** 0.25 **Max.** 5.5

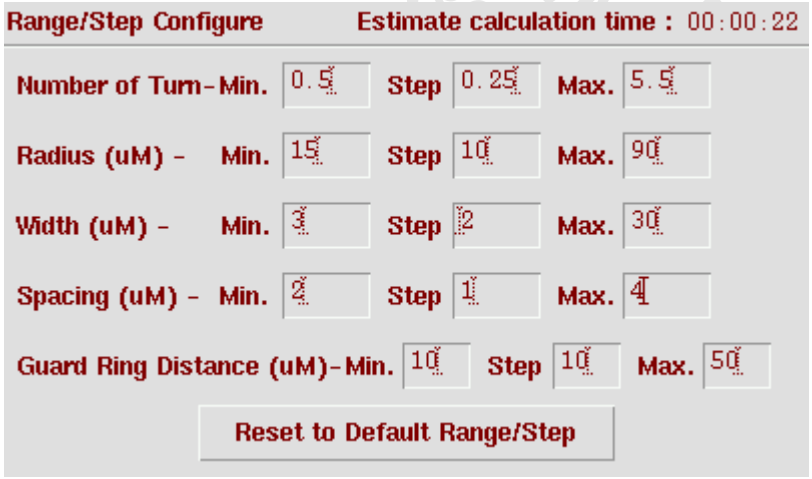
Radius (uM) - **Min.** 15 **Step** 10 **Max.** 90

Width (uM) - **Min.** 3 **Step** 2 **Max.** 30

Spacing (uM) - **Min.** 2 **Step** 1 **Max.** 4

Guard Ring Distance (um) - **Min.** 10 **Step** 10 **Max.** 50

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 22 seconds.

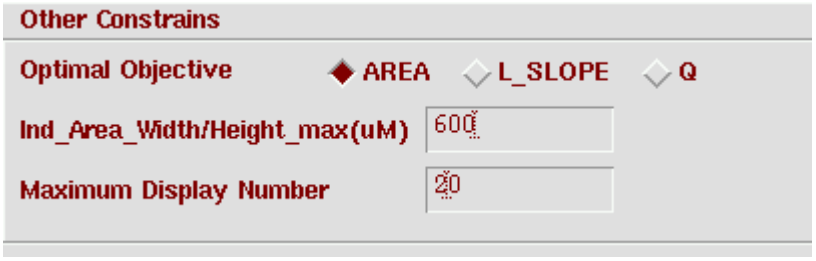


Configure TIF form to output small inductors

1. For **Optimal Objective**, select **AREA.**
2. Leave **Ind_Area_Width/Height_max** a reasonably high value such as **600**. This limitation is not important in this case since the goal is to minimize area hence width and

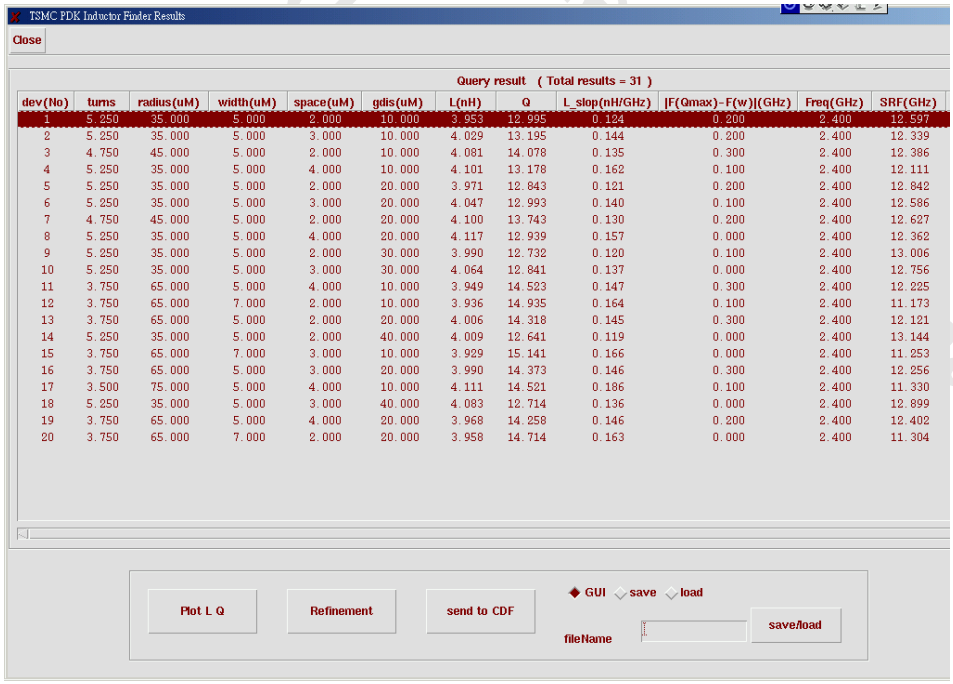
height will be minimized.

3. Set **Maximum Display Number** to be **20**.



View TIF Search result

1. Click '**find'** button. Wait for result browser to appear. Each row represents an inductor. Above results there exists a line "Query result (Total results = 31)" stating 31 inductors in design space satisfy design constrains. Because **Maximum Display Number** is set to 20 and **Optimal Objective** set to **AREA**, the 20 smallest inductors are displayed.



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)	SRF(GHz)
1	5.250	35.000	5.000	2.000	10.000	3.953	12.995	0.124	0.200	2.400	12.597
2	5.250	35.000	5.000	3.000	10.000	4.029	13.195	0.144	0.200	2.400	12.339
3	4.750	45.000	5.000	2.000	10.000	4.081	14.078	0.135	0.300	2.400	12.386
4	5.250	35.000	5.000	4.000	10.000	4.101	13.178	0.162	0.100	2.400	12.111
5	5.250	35.000	5.000	2.000	20.000	3.971	12.843	0.121	0.200	2.400	12.842
6	5.250	35.000	5.000	3.000	20.000	4.047	12.993	0.140	0.100	2.400	12.586
7	4.750	45.000	5.000	2.000	20.000	4.100	13.743	0.130	0.200	2.400	12.627
8	5.250	35.000	5.000	4.000	20.000	4.117	12.939	0.157	0.000	2.400	12.362
9	5.250	35.000	5.000	2.000	30.000	3.990	12.732	0.120	0.100	2.400	13.006
10	5.250	35.000	5.000	3.000	30.000	4.064	12.841	0.137	0.000	2.400	12.756
11	3.750	65.000	5.000	4.000	10.000	3.949	14.523	0.147	0.300	2.400	12.225
12	3.750	65.000	7.000	2.000	10.000	3.936	14.935	0.164	0.100	2.400	11.173
13	3.750	65.000	5.000	2.000	20.000	4.006	14.318	0.145	0.300	2.400	12.121
14	5.250	35.000	5.000	2.000	40.000	4.009	12.641	0.119	0.000	2.400	13.144
15	3.750	65.000	7.000	3.000	10.000	3.929	15.141	0.166	0.000	2.400	11.253
16	3.750	65.000	5.000	3.000	20.000	3.990	14.373	0.146	0.300	2.400	12.256
17	3.500	75.000	5.000	4.000	10.000	4.111	14.521	0.186	0.100	2.400	11.330
18	5.250	35.000	5.000	3.000	40.000	4.083	12.714	0.136	0.000	2.400	12.899
19	3.750	65.000	5.000	4.000	20.000	3.968	14.258	0.146	0.200	2.400	12.402
20	3.750	65.000	7.000	2.000	20.000	3.958	14.714	0.163	0.000	2.400	11.304

2. Check the parameters of first inductor appear in result browser. Layout parameter values are: turns = 5.25, radius = 35 uM, width = 5 uM, space = 2 uM and gdis = 10 uM. Inductance 3.953 nH is within 4 nH ± 3% and Q value 12.995 is larger than 10 as objective stated.

dev(No)	turns	radius(uM)	width(uM)	space(uM)	gdis(uM)	L(nH)	Q
1	5.250	35.000	5.000	2.000	10.000	3.953	12.995

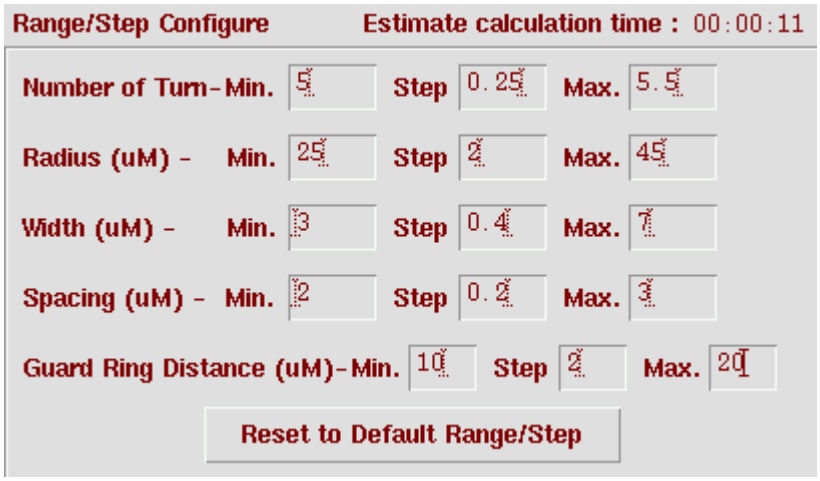
3. Check the width and height of first inductor. area_W = 187 uM and area_L = 190.5 uM. It has the smallest size among results.
   Note: Size information columns are located at very right end in result browser; resizing result window and use of scroll bar may be needed to see size information.

area_W(uM)	area_L(uM)
187.000	190.500
196.000	200.000
200.000	203.500
205.000	209.500
207.000	210.500
216.000	220.000
220.000	223.500
225.000	229.500
227.000	230.500

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

Refinement

1. Select first inductor and click **Refinement**. Notice only **Range/Step Configure** section in TIF from has been updated. New parameter range will cover original value ± step. New step size is one fifth of previous step size. The estimate time cost for this search is 11 seconds.



Example: previous **Radius** setting was **Min** 15 **Step** 10 **Max** 90. Best inductor so far has Radius value 35. Refinement Radius range will then be (35-10) ~ (35+10), which is 25 ~ 45, while step become 10/5, which is 2.

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

3. Check the parameters of first inductor appear in result browser. Layout parameter values are: turns = 5.5, radius = 33 uM, width = 4.6 uM, space = 2 uM and gdis = 10 uM. Inductance 4.097 nH is in 4 nH ± 3% and Q value 12.920 is larger than 10 as objective stated.

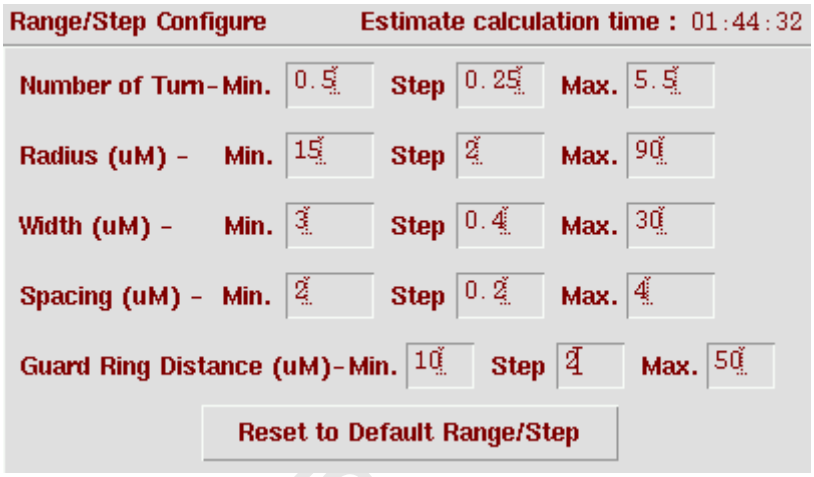
dev(No)	turns	radius(uM)	width(uM)	space(uM)	gdis(uM)	L(nH)	Q
1	5.500	33.000	4.600	2.000	10.000	4.097	12.920

4. Check the width and height of first inductor in this phase has area_W = 185.2 uM and area_L = 181.9 uM. Notice this inductor occupies smaller area compare to previous one. Area improvement is (187.0*190.5 – 185.2*181.9) / (187.0*190.5) = 5.43 %

area_W(uM)	area_L(uM)
185.200	181.900
186.000	182.500
187.200	183.800
188.000	184.400
189.200	185.900
186.200	189.700
190.000	186.300
190.000	186.500

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 TIF 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 01:44:32. Compare to previous Rough + Refinement time will be 00:00:22 + 00:00:11 = 33 seconds. It is about 190 times faster using refinement function.



7. **[Optional]** User can try additional refinement run based on current inductor.
   Note: If user is not satisfy with refinement result. It is easy to have additional refinement setting and run by select an inductor and press **Refinement**. But the improvement will decrease from phase to phase. In this tutorial, area improvement of 2nd refinement from 1st one is 1.74% while improvement of 1st refinement from rough is 5.43%.

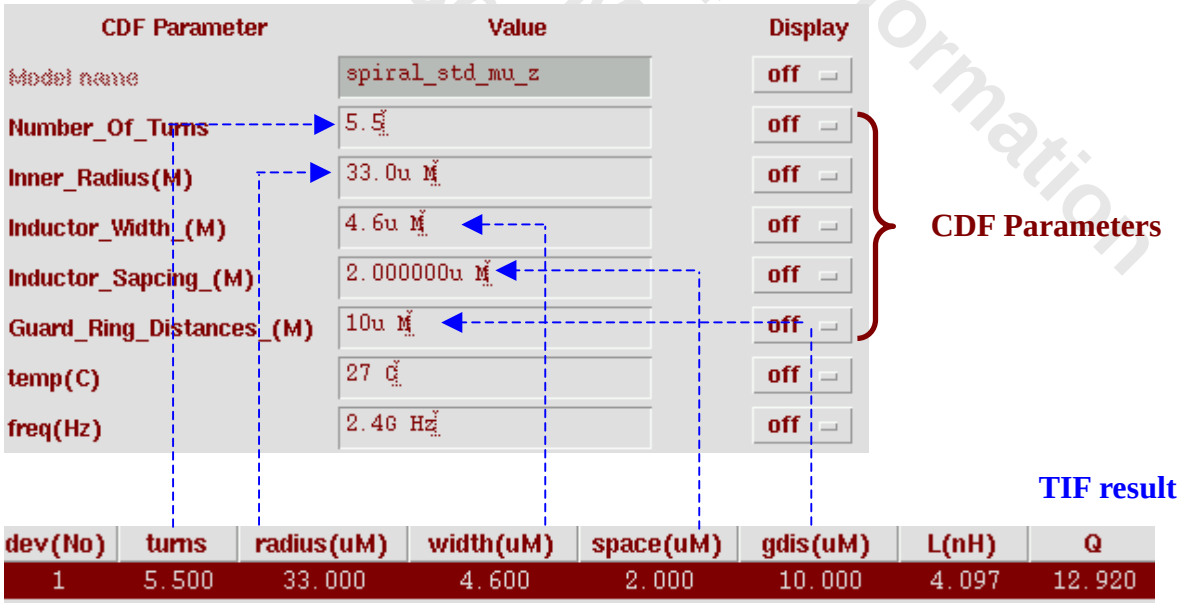
area_W(uM)	area_L(uM)
183.600	180.300
183.760	180.420
183.920	180.500
183.920	180.540
184.000	180.680
184.080	180.660
184.160	180.800
184.160	180.800
184.320	180.880

Result Plot and send to CDF

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

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

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



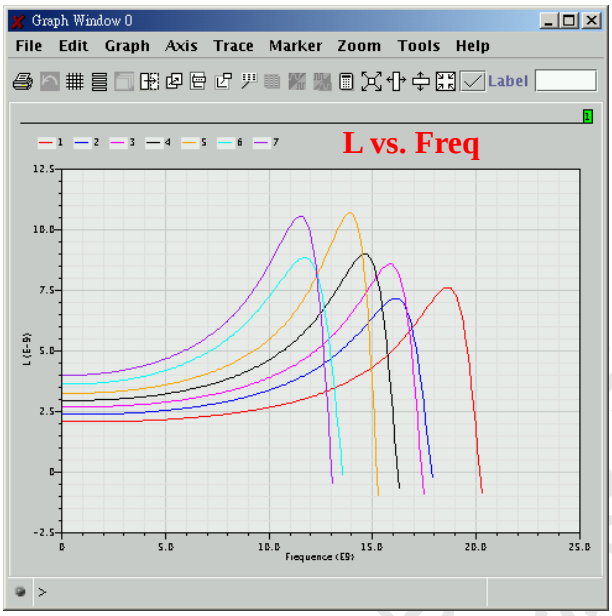
4. Press **Sweep Plotter (L_Q)** button in CDF form. **TSMC PDK Inductor Sweep Plotter** form appears. Select **turn** in Sweep Variable section. Make **min.** number of turn **4**, **max.** number of turn **5.5** and **step 0.25**. Press **Plot** button. Sweep plots of L and Q for number of

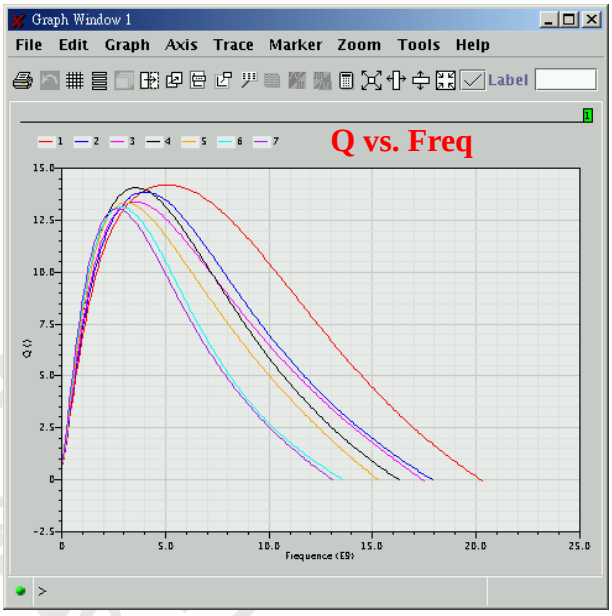
turn appear.

Select **Guard Ring Distance** as Sweep Variable. Make **min. step** and **max.** to be **10**, **10** and **50** respectively then press **Plot** button.

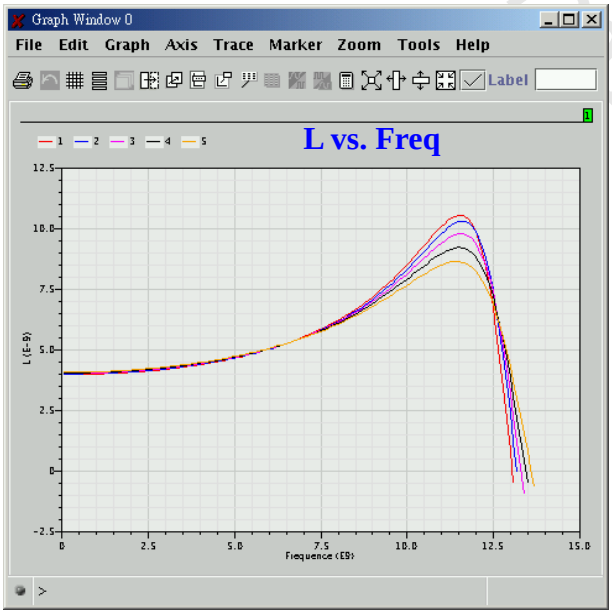
Comparing sweep plots for above two variables. Observe that L and Q are much more sensitive for **turn** then **Guard Ring Distance**.

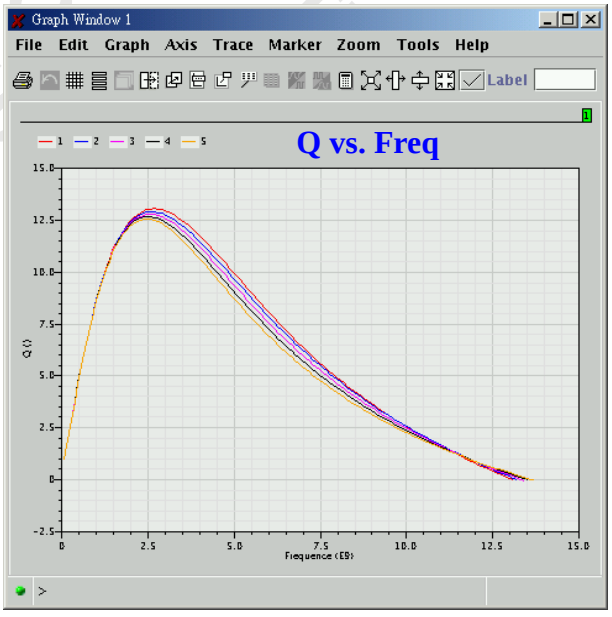
Sweep for turn





Sweep for Guard Ring Distance

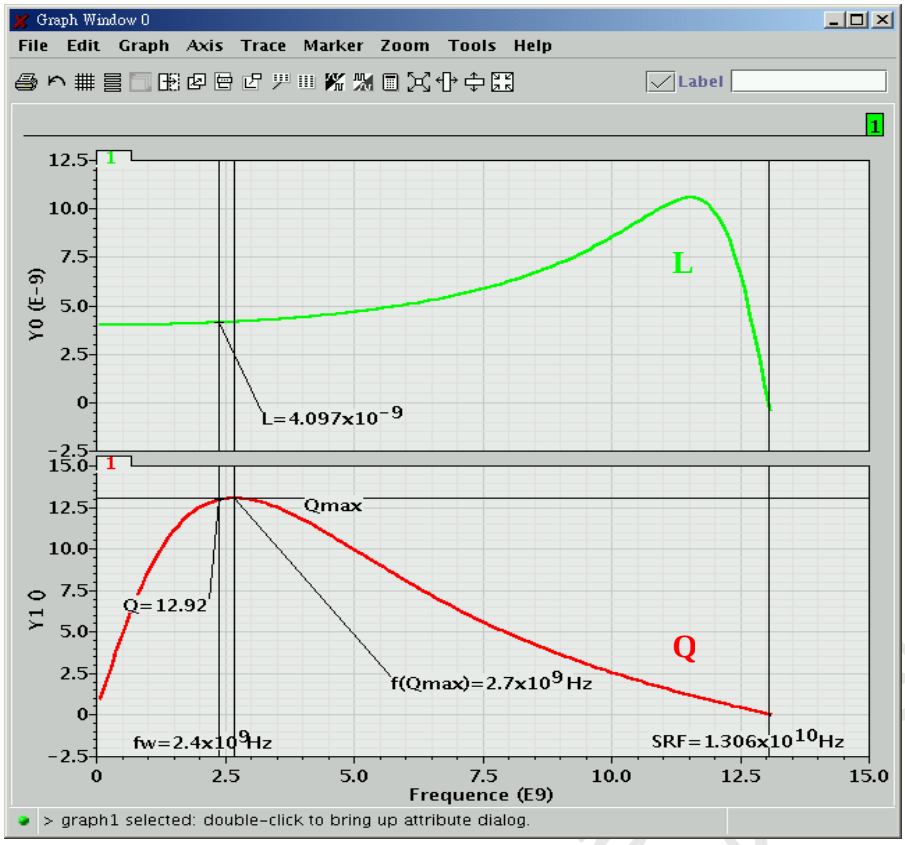




Result analysis

Below is the optimal device of refinement and its L Q plots. The inductance, Q value and SRF shown in result browser match those in plots.

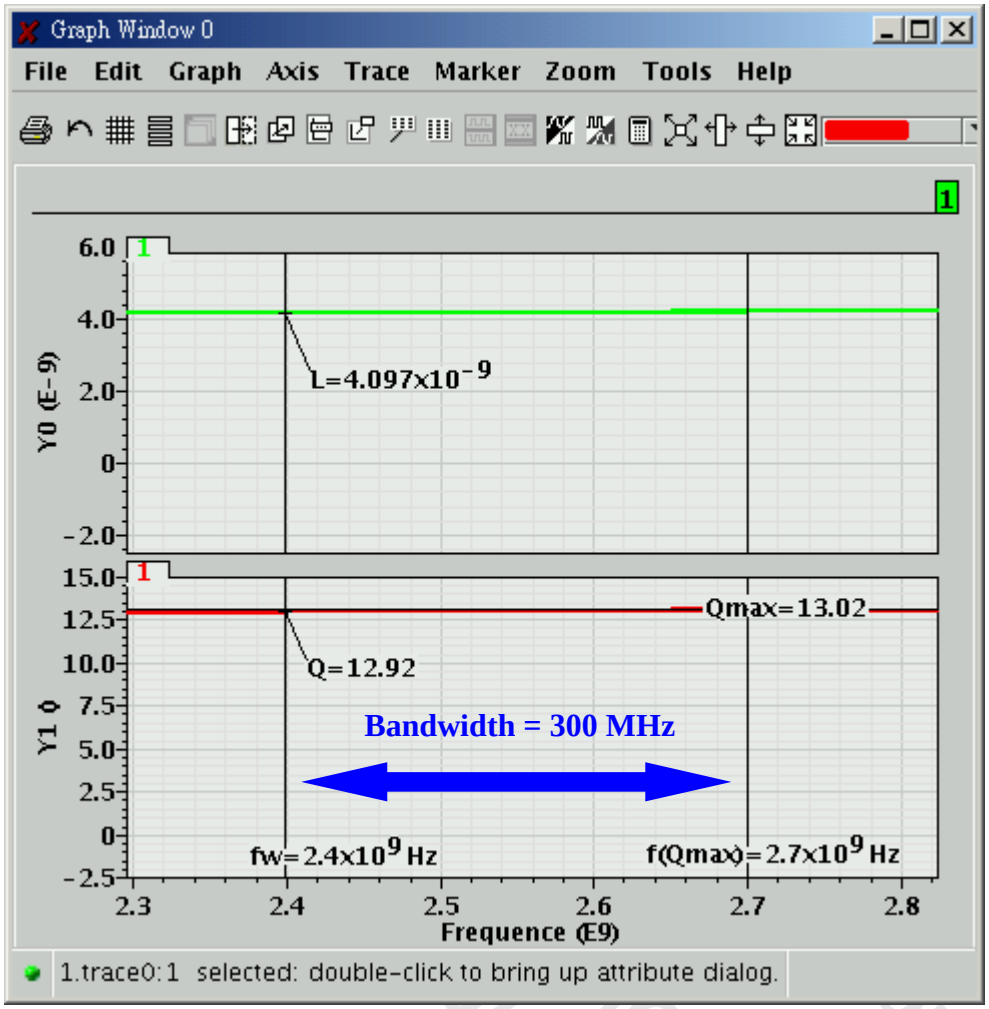
L(nH)	Q	L_slop(nH/GHz)	|F(Qmax)-F(w)|(GHz)	Freq(GHz)	SRF(GHz)
4.097	12.920	0.118	0.300	2.400	13.065



This device also satisfies design objectives.

	Objective	Result	Meet Requirement?
Working Freq.	2.4 GHz	2.4 GHz	yes
Inductance (L)	4 nH ± 3%	4.097 nH	yes
SRF	Min. 10 GHz	13.065 GHz	yes
Q	Min. 10	12.920	yes

Bandwidth objective above states “Working frequency falls on left hand side of F(Qmax) within **300 MHz** range”. Graph below is the zoom-in L Q plots between fw and f(Qmax). The bandwidth: f(Qmax) – fw = 2.7 GHz – 2.4 GHz = 300 MHz also meets objective.



Summary

In this tutorial, TIF successfully finds an inductor that meets design objectives with nearly optimize area size.

User should learn how to configure TIF 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 TIF efficiently.