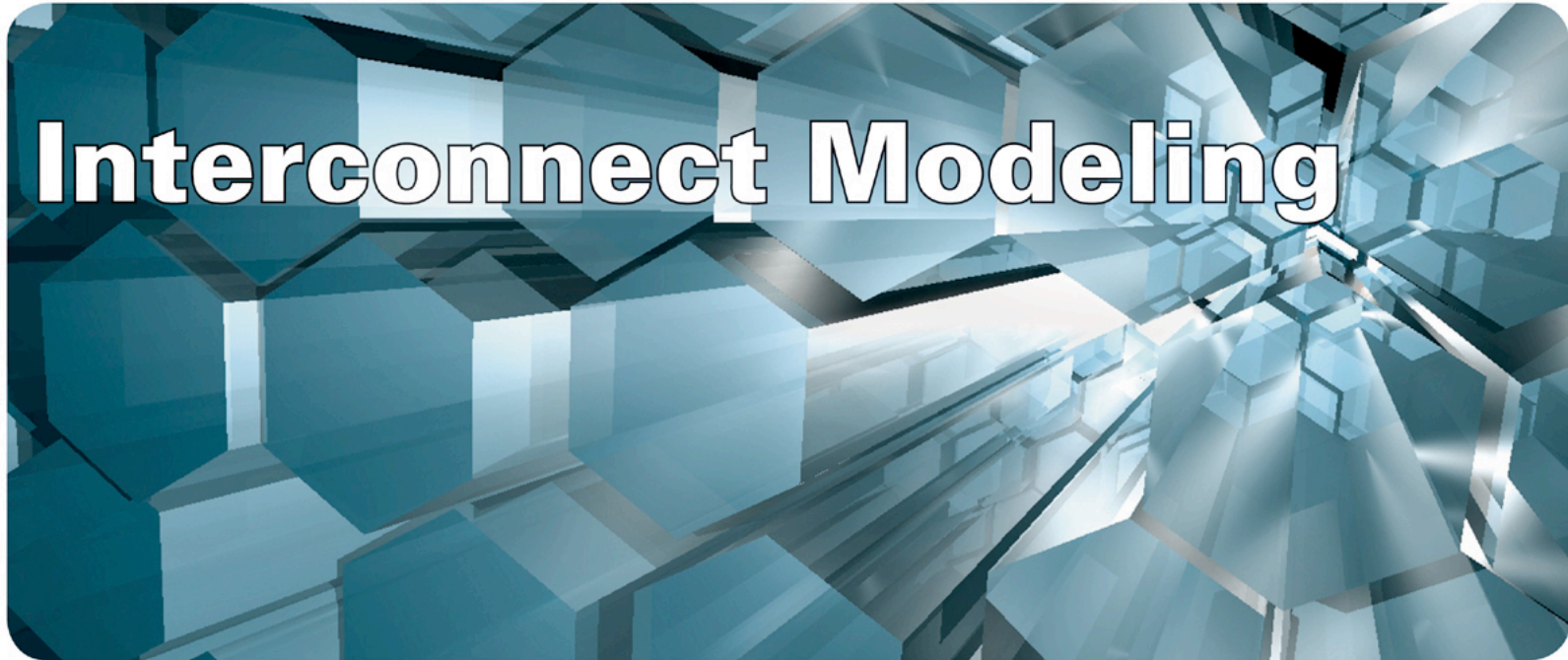


**QUEST:** High Frequency Parasitic Extraction



Application Examples



**SIMUCAD**



## Process and Inductance Modeling of a Square, Spiral, Six Turn Inductor, Fabricated on a Silicon Substrate

- This example is based on an IBM paper by Rob Groves et al. "Temperature Dependence of Q in Spiral Inductors Fabricated in a Silicon Germanium BiCMOS Technology" IEEE BCTM 9.3 pp. 153-156 1996
- The example shows the modeling of a 10nH square spiral inductor
- The simulation results obtained can be compared to measured results from the reference
- The files used in this example are from quest03 located in the quest/examples folder created when QUEST is installed



## Before Starting QUEST

- Before starting with QUEST lets examine the layout file that is used in this example, for the device fabrication. This will enable us to get a feel for what it is we are going to simulate
  - To do this we need a GDSII viewer; either Expert or MaskViews can be used
  - Open up MaskViews and click on Files, then import, then GDS2 stream import
    - This opens up the GDS2 stream format interface box
  - You will now see a GDS2 file called square\_ind.gds in the viewer
  - Click on structures, then on load, to load the cell into MaskViews



## Before Starting QUEST

- The entire GDS2 cell representing the square spiral inductor is shown in Figure 1a (less L#0)
- As we can see the GDS2 layers are numbered L#0 to L#4

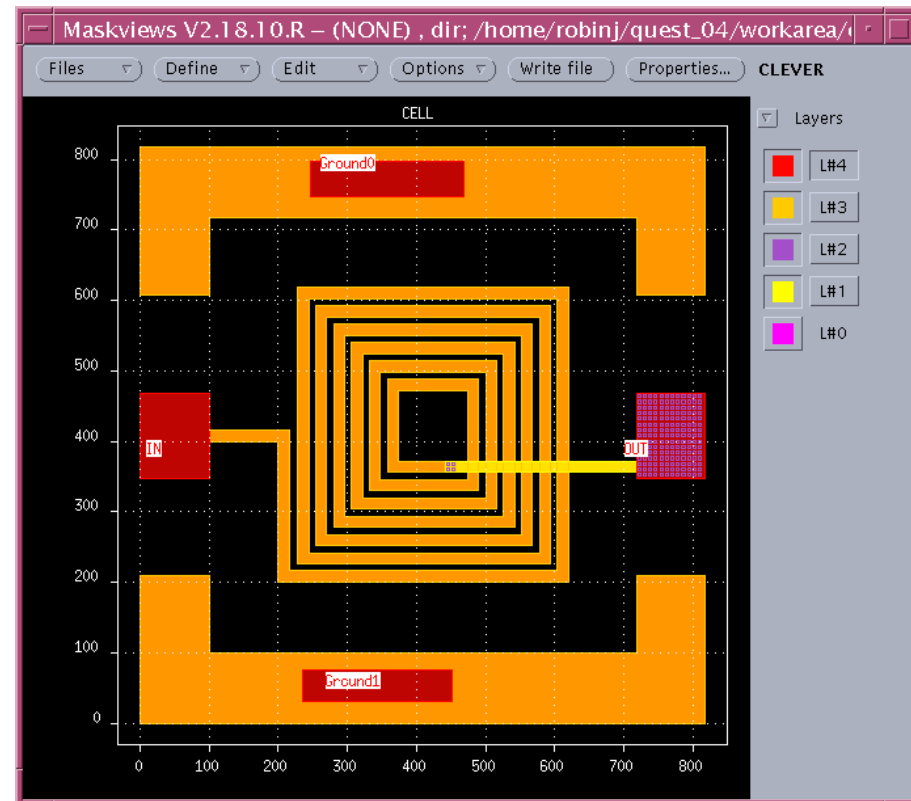
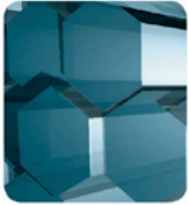


Figure 1a.



# Before Starting QUEST

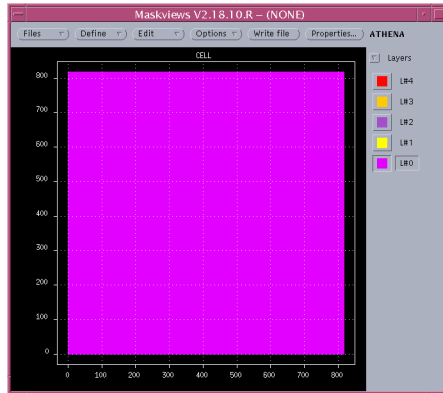


Figure 1b:L#0

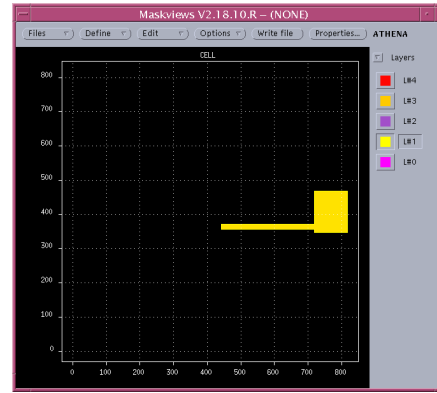


Figure 1b:L#1

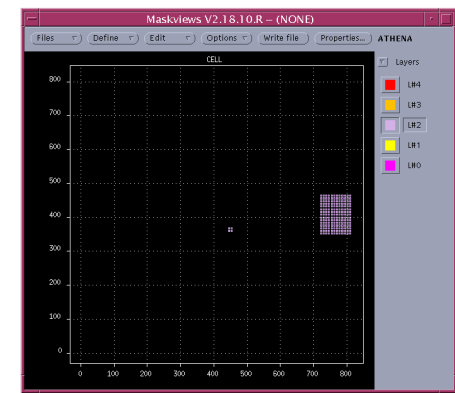


Figure 1b:L#2

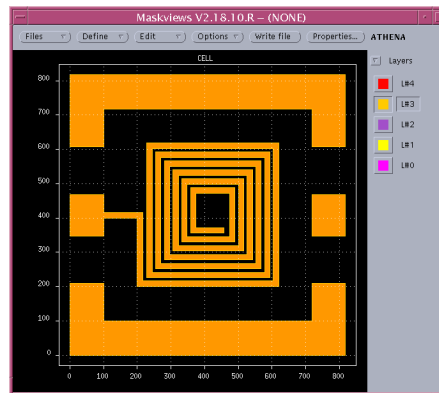


Figure 1b:L#3

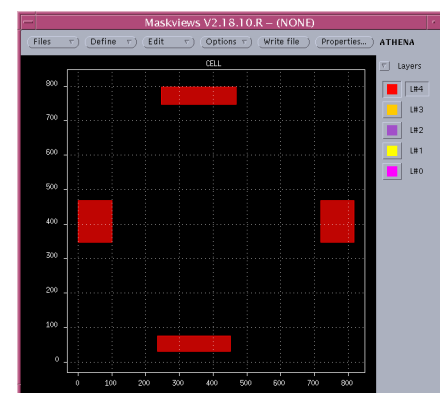


Figure 1b:L#4

Figure 1(b) shows each layer separately for clarification purposes. L#0 is used as the substrate layer, L#1 as metal2 (m2), layer 3 as metal3 (m3), layer 2 as a via connecting m2 to m3, L#4 as the electrode definition.

# Before Starting QUEST

- Figure1c shows only layer4 selected from the main GDS2 file
- The text IN, Ground0, OUT and Ground1 are text boxes representing the electrode names of the device

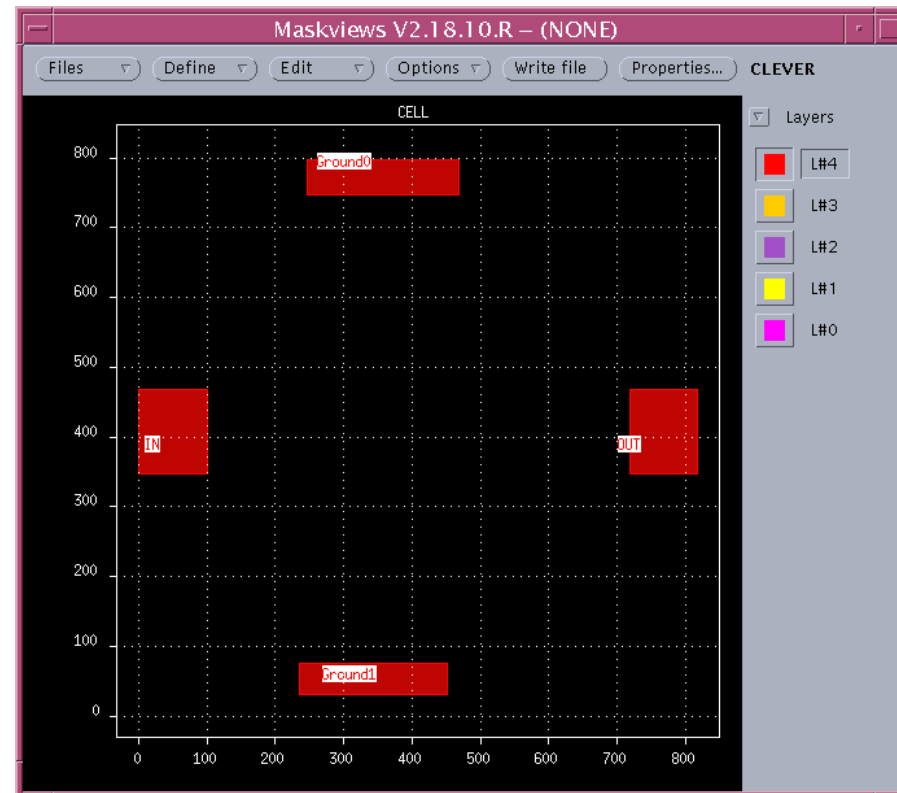


Figure1c.

# Using QUEST

- We now have a feel for the device structure, it is now time to start QUEST
- To start QUEST type **Quest&** in a terminal window
  - QUEST should appear as in Figure 2
- From Figure 2 we see that there are several square buttons running down the left hand side of the GUI
  - These represent the stages of a QUEST experiment that are to be completed

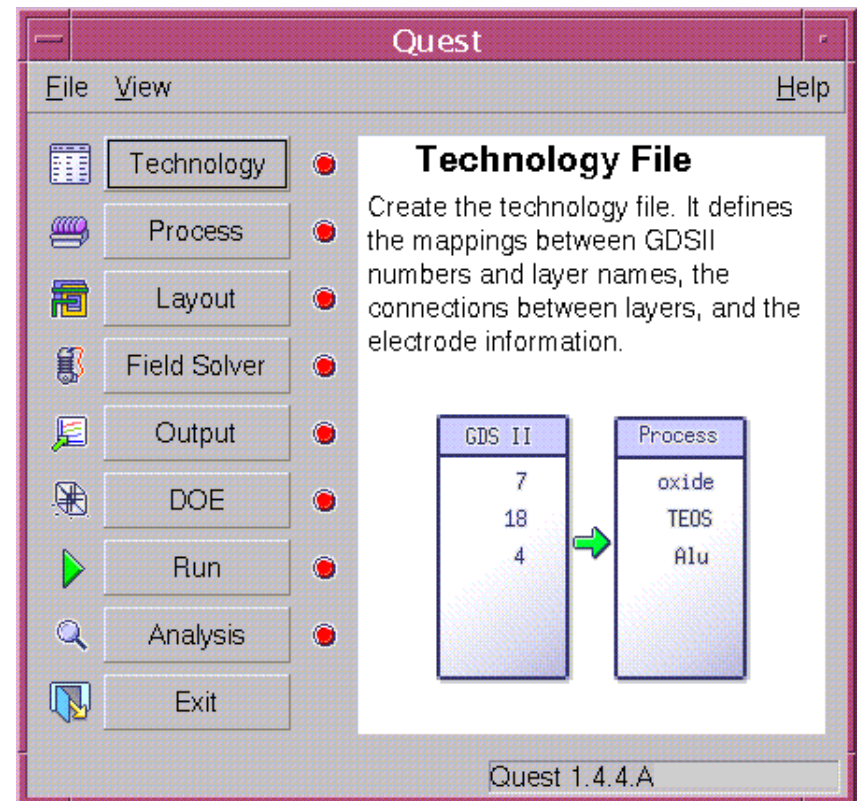
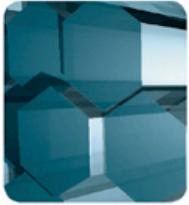


Figure 2.



## Using QUEST

- Firstly then we must address the technology stage. An understanding of what this stage does can be quickly obtained from the description given in the right hand side of the QUEST GUI
- We read the following:
  - "Create the technology file. It defines the mappings between the GDSII numbers and the layer names, the connections between layers, and the electrode information"
- Each one of the QUEST stages will have their own descriptive passages displayed in the right hand side of the QUEST GUI when selected



## Using QUEST

- To enter the technology stage click on the technology button
- We are met with the GUI shown in Figure 3

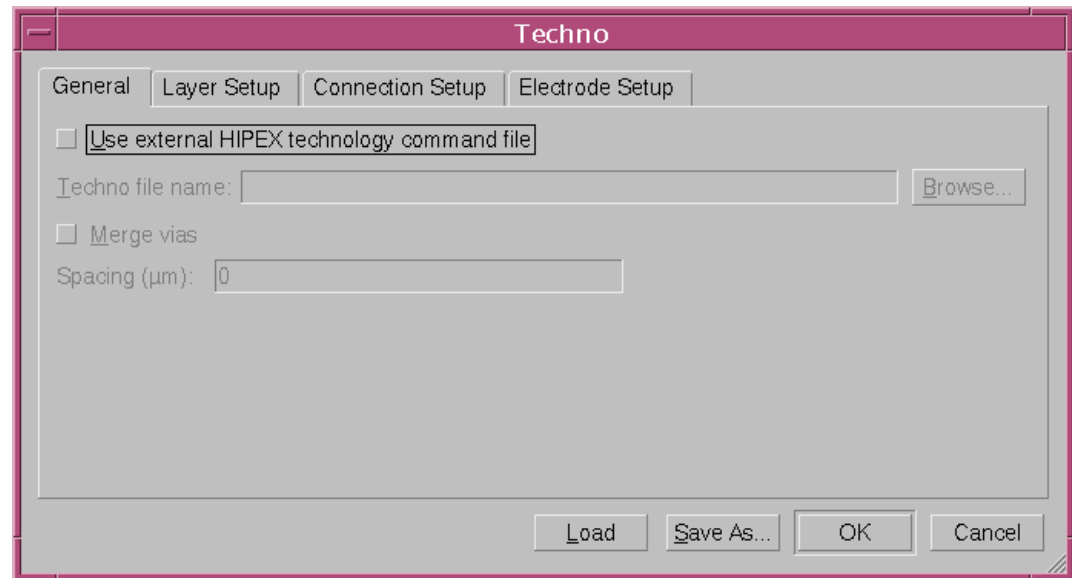
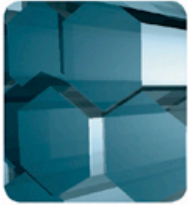


Figure 3.



# Layer Setup

- We see running along the top of the GUI four distinct section titles:
  - General
  - Layer Setup
  - Connection Setup
  - Electrode Setup
- Click on Layer Setup, the GUI should appear as Figure 4

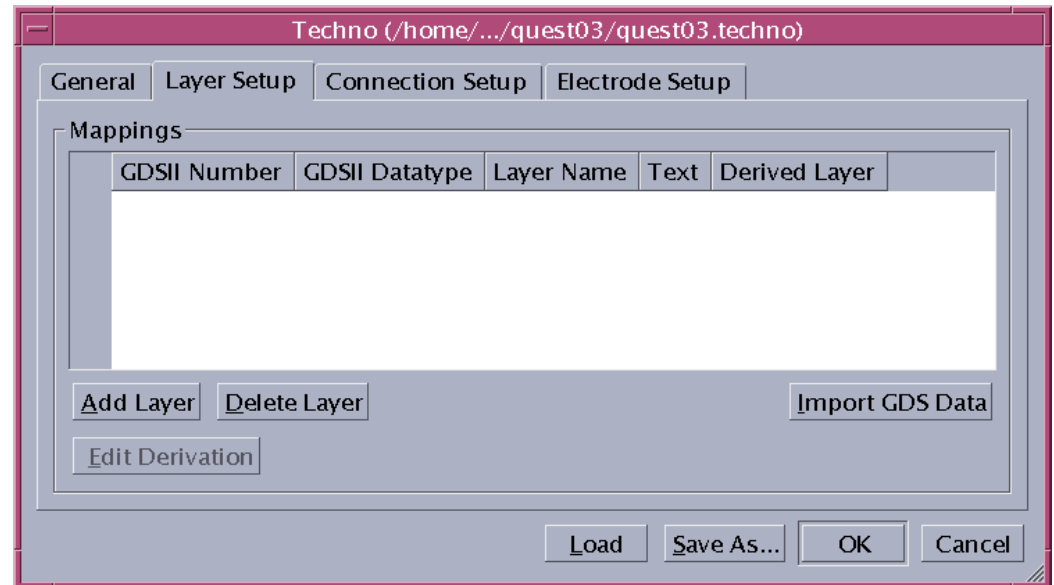
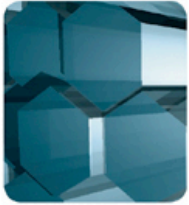


Figure 4.



## Layer SetUp

- In this GUI we need to rename the GDS2 layer numbers, that exist in the GDS2 layout, into layer names that QUEST requires
- To do this we can:
  - go back and look at the GDS2 numbers in Maskviews and then manually enter each one into the GUI, then rename them
  - -or-
  - we can make use of the Import GDS Data capability of QUEST (which we shall use in this example)
- Click on the Import GDS Data button; a drop down load menu appears
- Locate the GDS2 file and click on open



# Layer SetUp

- The Layer Setup GUI now looks like Figure 5a
- At this point we now have all of the layer number information in QUEST
  - it is now much easier for us to make the name changes required
- Simply click on the Layer Name text and modify as you wish
- The renaming of the layer numbers to layer names follows directly from the structure information

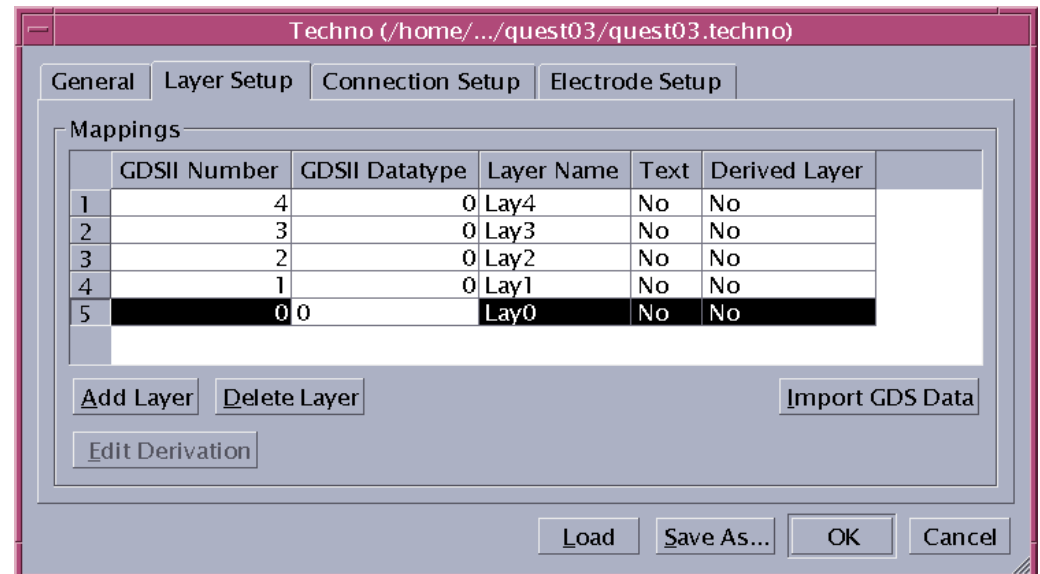
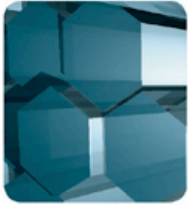


Figure 5a.



# Layer Setup

- Labeling the layers intuitively we have:
  - L#0 to sub
  - L#1 to m2
  - L#2 to via
  - L#3 to m3
  - L#4 to electrode
- The Layer Setup GUI now looks like Figure 5b

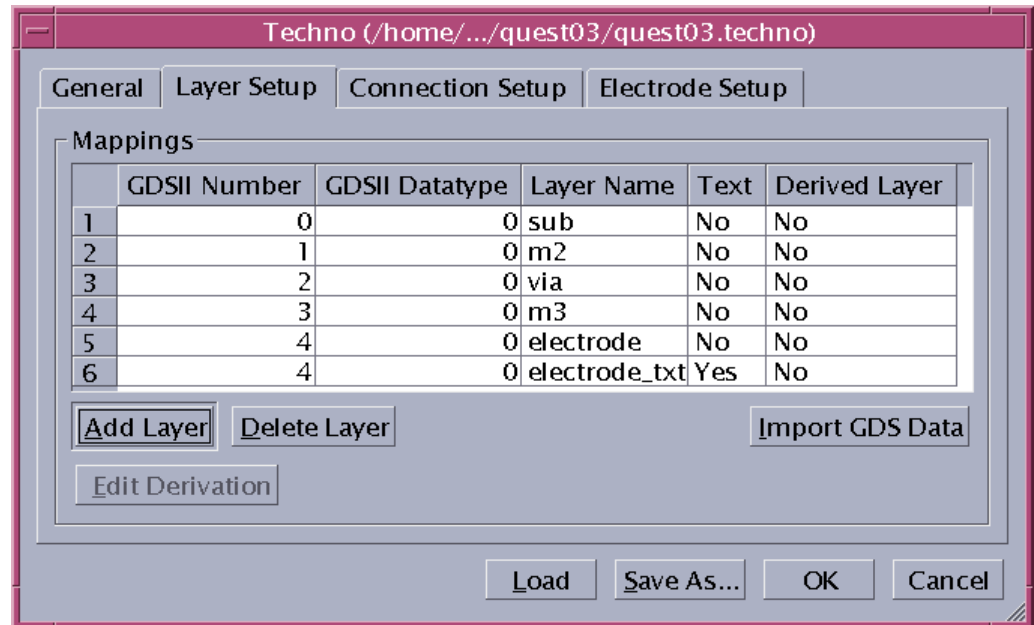
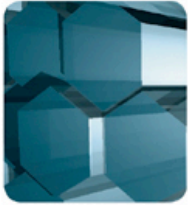


Figure 5b.



## Layer Setup

- Of note in the Layer Setup GUI is the addition of a sixth layer; an explanation for this is given as follows:
  - As we have seen the GDS2 layout has text boxes for the electrode identification
  - This text has to be input into QUEST as a separate text layer
  - We therefore add another layer, call it electrode\_txt for our own identification purposes, define its type as text, and map it to the layer that contains the electrode pads/bonds in the GDS2 layout i.e. in this case layer4
    - To add this extra layer click on Add Layer and fill in the appropriate fields making sure to put Yes in its text field box



## Connection SetUp

- We are now finished with the Layer setup, we must now examine the connection setup
- Click on the Connection Setup GUI, it appears as in Figure 6
- The connection setup is used to define which layer is connected to which layer

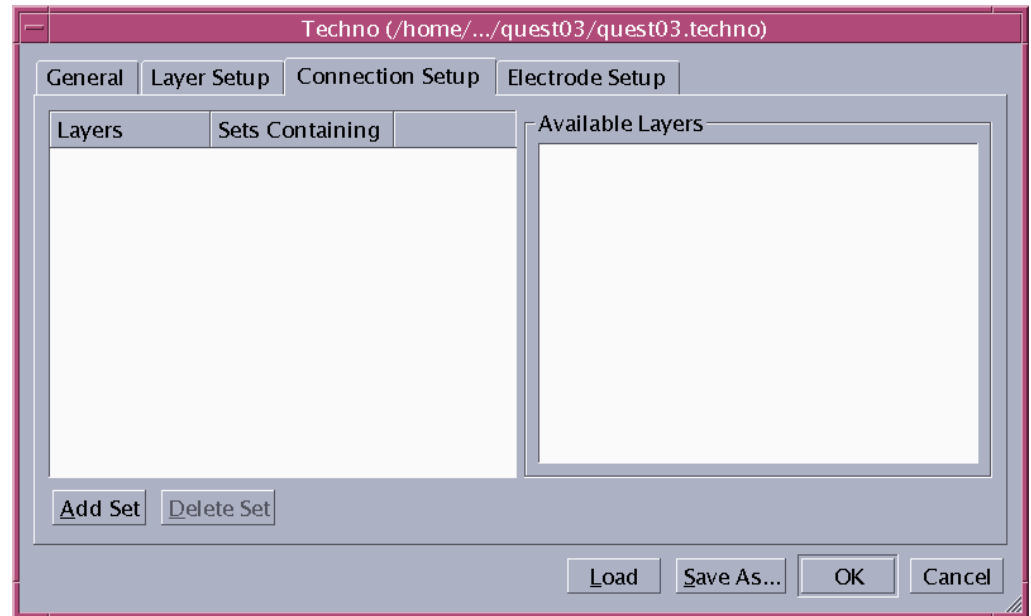
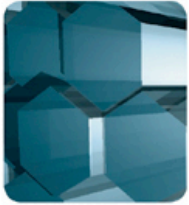


Figure 6.



## Connection SetUp

- For this example, we know that the layer labeled as via connects m2 to m3 so we must identify this to be the case in the connection setup
  - To do this we make use of sets
- To create a set connecting the via to m3 and m2 we just click on a particular layer in the available layers section of the connection GUI, and whilst holding the mouse button down, drag the layer to the layer we wish to connect it to in the layers section of the connection GUI



## Connection SetUp

- Following this methodology, Figure 7 shows an expanded set#0 under the via layer, containing m3 and m2 layers, thus identifying to QUEST that m3, m2 and the via are connected
  - The number 1 to the right of m2 and m3 in the layer section of the connection GUI indicates that m2 and m3 belong to one set
- Figure 7 also serves another purpose
  - In Figure 7 it is also seen that the layer electrode\_txt is connected to the layer electrode, these two layers being connected following the same method previously discussed. In this way these two layers are used to give the structure its electrode names

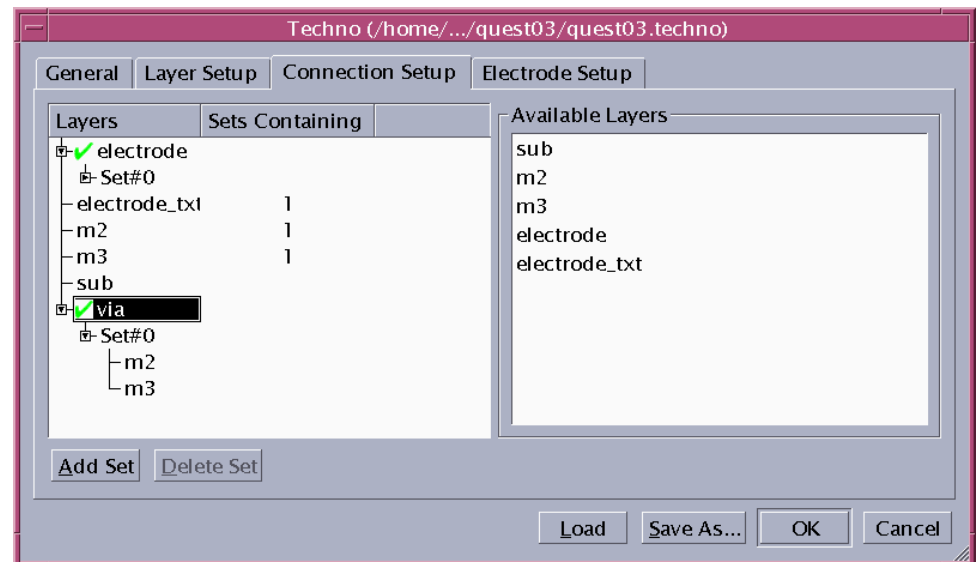


Figure 7.



# Electrode Setup

- The connection setup is now complete. There is still however a requirement for us to identify what metal layer the electrodes are to be attached to. The electrode setup GUI allows us to do this
- Figure 8 shows that the electrode layer is attached to the process layer metal 3
- We have now completed the technology setup
  - click on OK and save the file

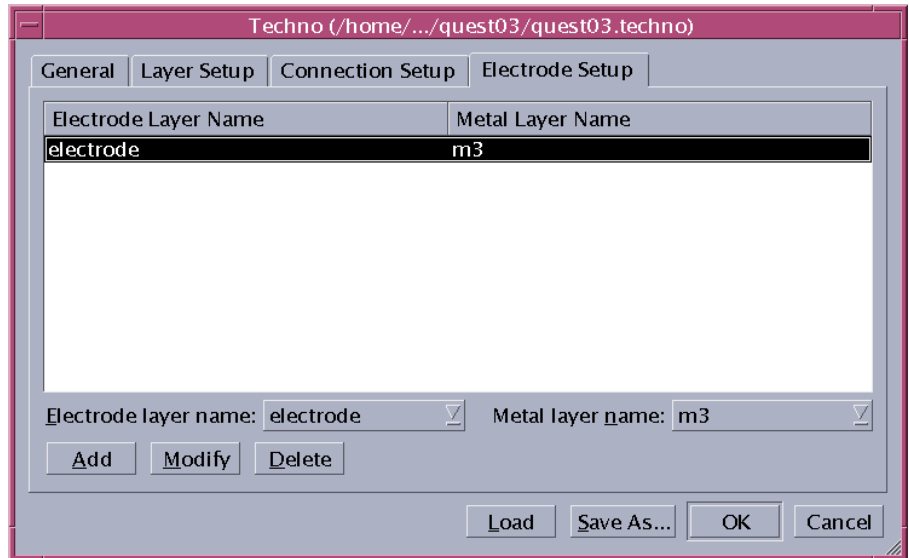


Figure 8.



# Process Description

- Now we move onto describing the process that is to be used
- Figure 9 details the process used for this example

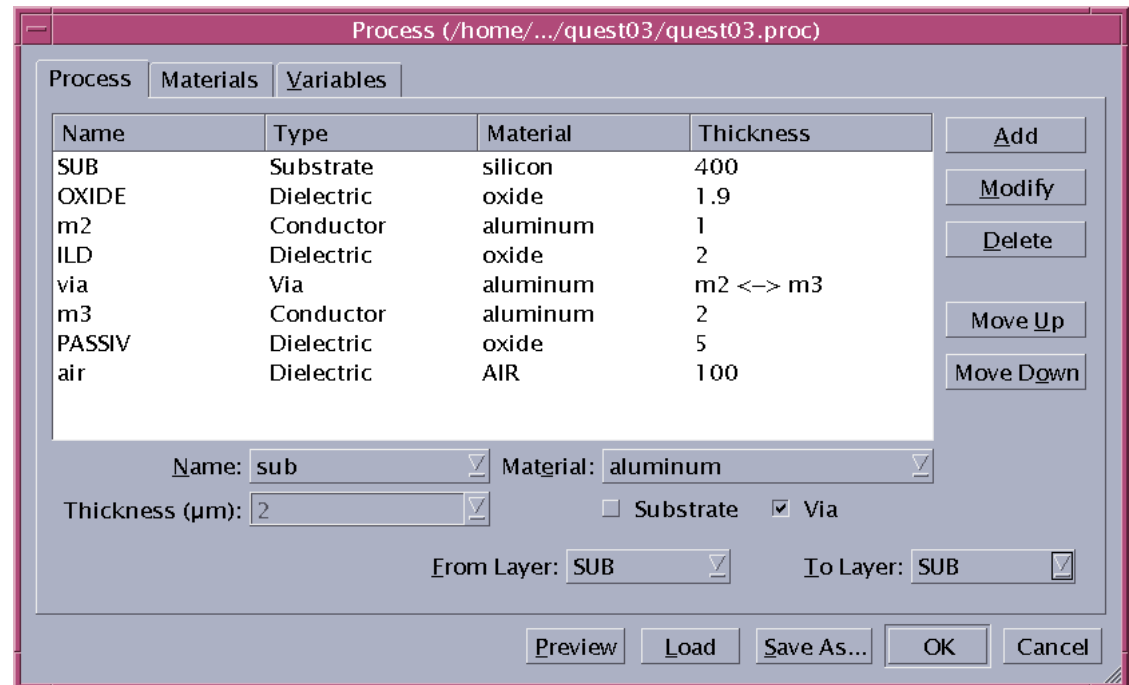


Figure 9.



## Process Description

- As seen in Figure 9 we have several layers starting with the substrate and ending with air
  - The substrate has been given a thickness of 400 microns and the air a thickness of 100 microns
  - These values of thickness for the substrate and air have been chosen so that the full volume of inductive flux lines are included in the calculation, which is vital for accurate inductance calculations
- As a general rule, a safe substrate depth and air height would be the diameter of the inductor being simulated
  - Since in this example the inductor has a diameter of approximately 400microns, the substrate has been given a depth of 400 microns



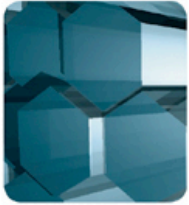
## Process Description - Choosing Layer Name

- Each process layer was entered into the process GUI by first clicking on the material type from the material drop down GUI
- After selecting a material the name of the layer must be identified
  - The names to choose from will be in the Name drop down menu if the material type is a conductor, since these names are the masks that are available i.e. those that were defined in the layout



## Process Description - Adding the Via

- When adding the via, it is important to remember that the metal layers associated with the via must be defined before the via
- The via is added by:
  1. adding the "via from" process layer into the process stack
  2. then adding the inter layer dielectric
  3. then adding the "via to" process layer into the process stack
  4. then adding the actual via layer specifying the "via to", "via from" layer and select its name as via



## Process Description

- The process stage also allows you to enter process variables that can then be used in the subsequent design of experiments (DOE) stage
- User defined process materials are also readily entered using the materials page of the process GUI
  - It is important to define both the conductivity and permittivity of the substrate for accurate modeling of the quality factor,  $Q$ , versus frequency
  - The Materials page of the process GUI allows this to be done

# Process Description – Process Preview

- The process entered can be previewed, Figure 10a, using the preview button

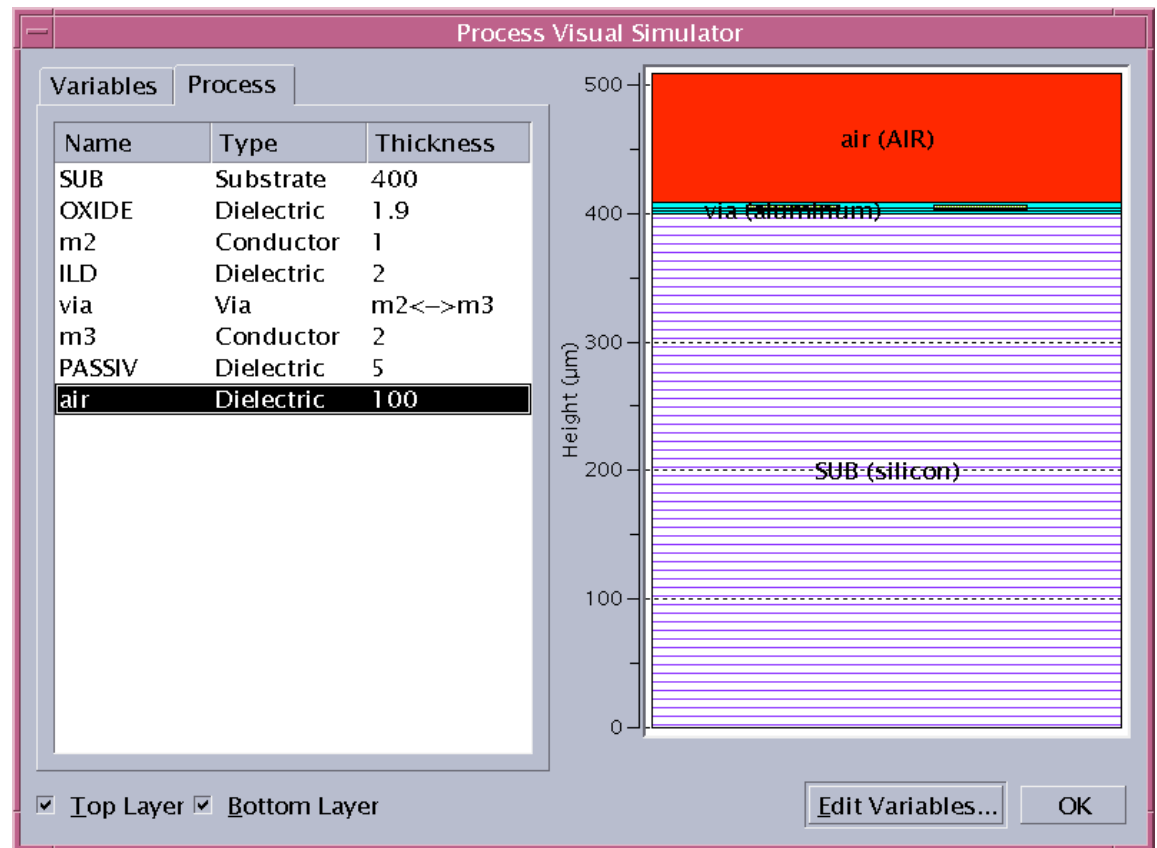


Figure 10a.

## Process Description – Process Preview

- Figure 10b shows the preview of the process with the bottom and top layers omitted, here more detail of the metal layers and the via together with the ILDs is seen
  - The pattern of m2, the via and m3 in figure 10b is not indicative of the mask information at this point. The pattern is there to identify that layer as a masked layer

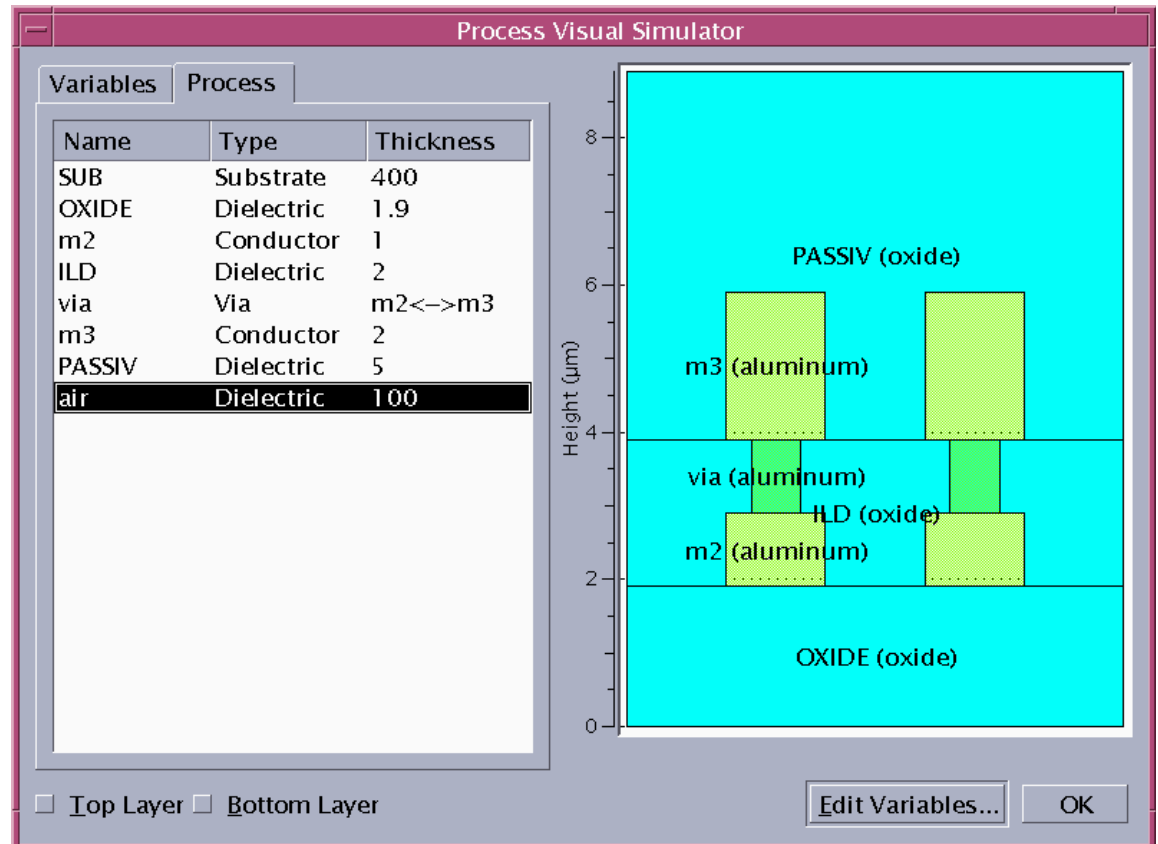
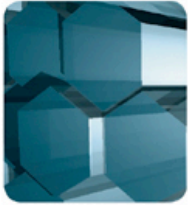


Figure 10b.



## Loading the GDS2

- We have now finished the process definition
  - Click on OK and save the file
- Next we need to load in the GDS2 layout
  - Click on the Layout section and the layout GUI appears as in Figure 11a
  - Then click on load within the GUI and locate the file called square\_ind.gds and click on open

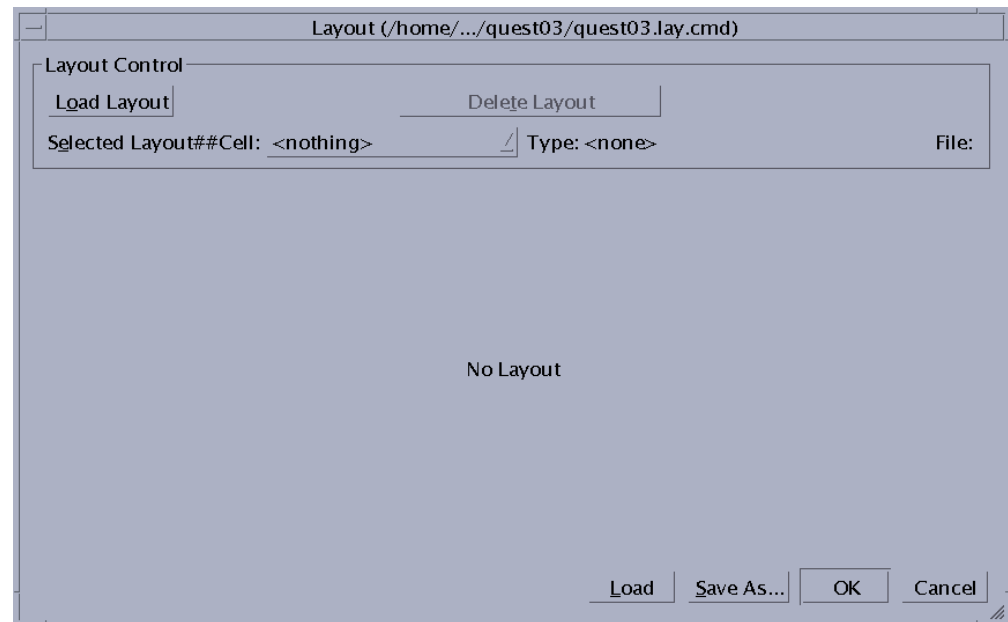
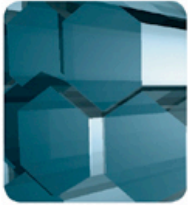


Figure 11a.



## Loading the GDS2

- A GDS2 file can contain many cells, therefore a cell loader, shown in Figure 11b, automatically opens up enabling you to select the particular cell you wish to load
- In the case of this example there is only one cell entitled CELL
  - Highlight this in the cell loader and click on OK, the GDS2 cell is now loaded into QUEST

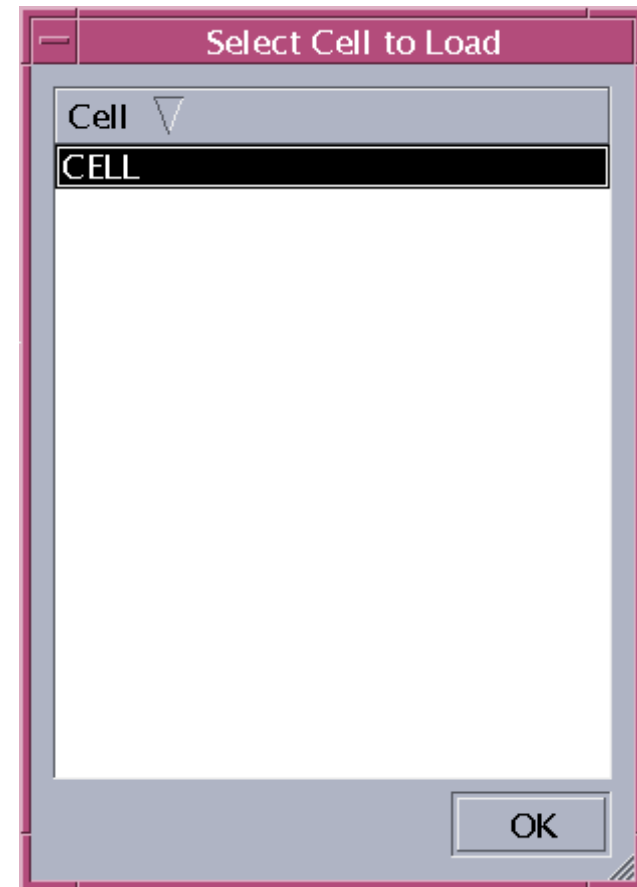
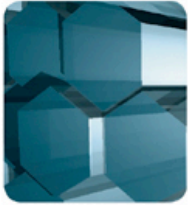


Figure 11b.



## Loading the GDS2

- The layout GUI now appears as shown in Figure 11c
- In the figure we see the layer mapping information that we entered in the technology section
  - Click on OK and save the file appropriately
  - We have now finished the layout section

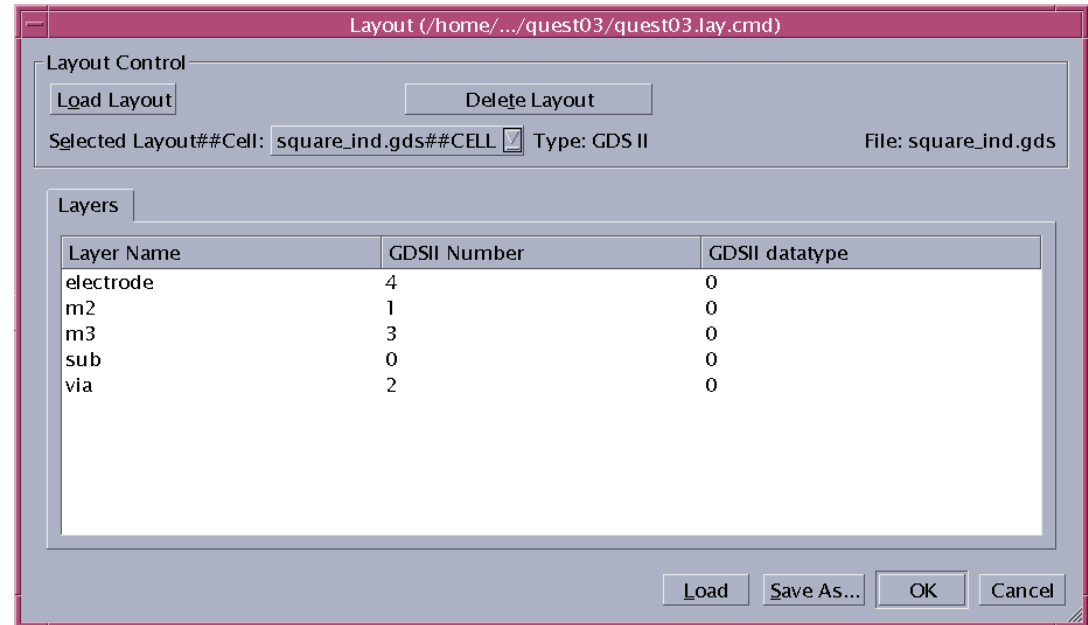
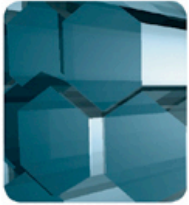


Figure 11c.



# Defining Elements

- Next we must define elements required by the field solver for calculating the capacitance (CG) and the inductance (RL)
- The field solver GUI is shown in Figure 12a
  - From the figure we see that there are several distinct sections that require our attention
  - Firstly we see that there are two different types of simulation that can be performed; this example as we know deals with an inductor, therefore we choose multi-ports as the simulation type

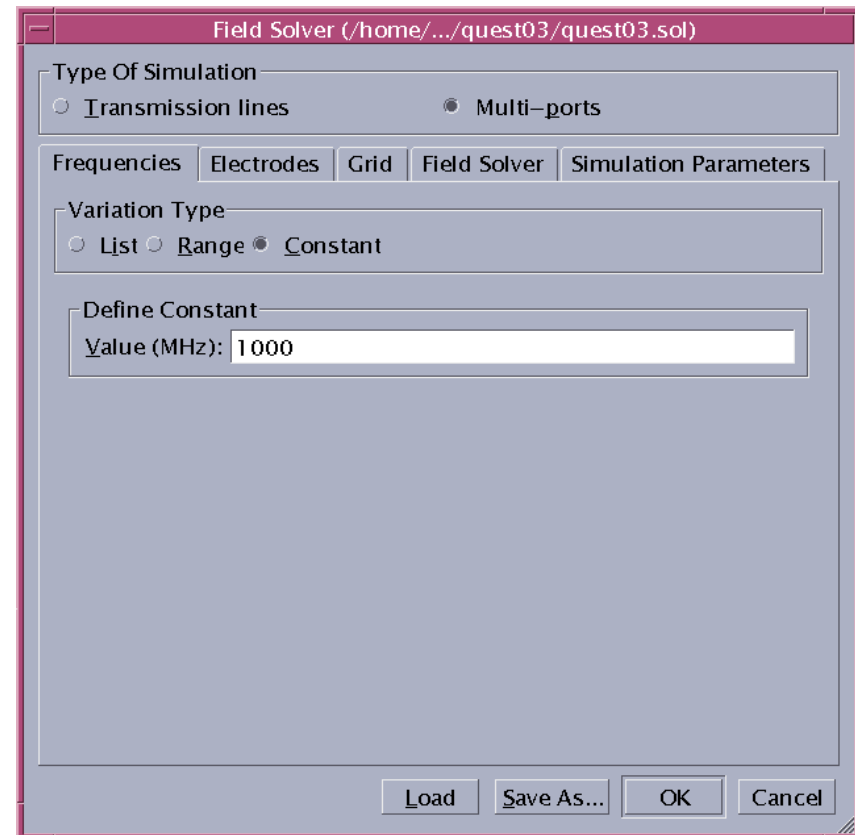
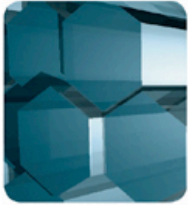


Figure 12a.



# Simulation Frequency

- The simulation frequency can either be constant, or it can vary
- The variation can be according to a user predefined list or over a range automatically generated by QUEST
- To enter a list of frequencies just click on the List button in the field solver GUI and a List definition box opens up, Figure 12b
  - Values for the frequency are entered into the Value section and the Add button is then clicked
  - As can be seen in figure 12b several values for the frequency appear constituting the list

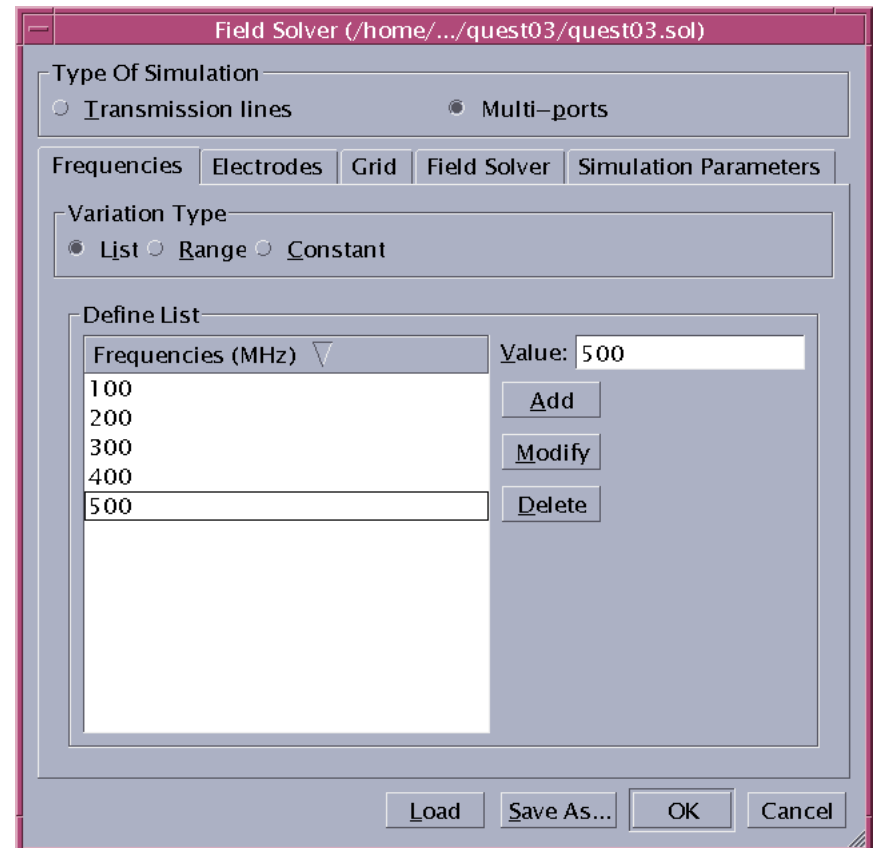
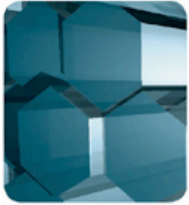


Figure 12b.



# Simulation Frequency

- In this example however we will let the frequency vary exponentially over a range of 20 frequencies from 100 to 10000MHz, we therefore enter this as such into the GUI, Figure 12c

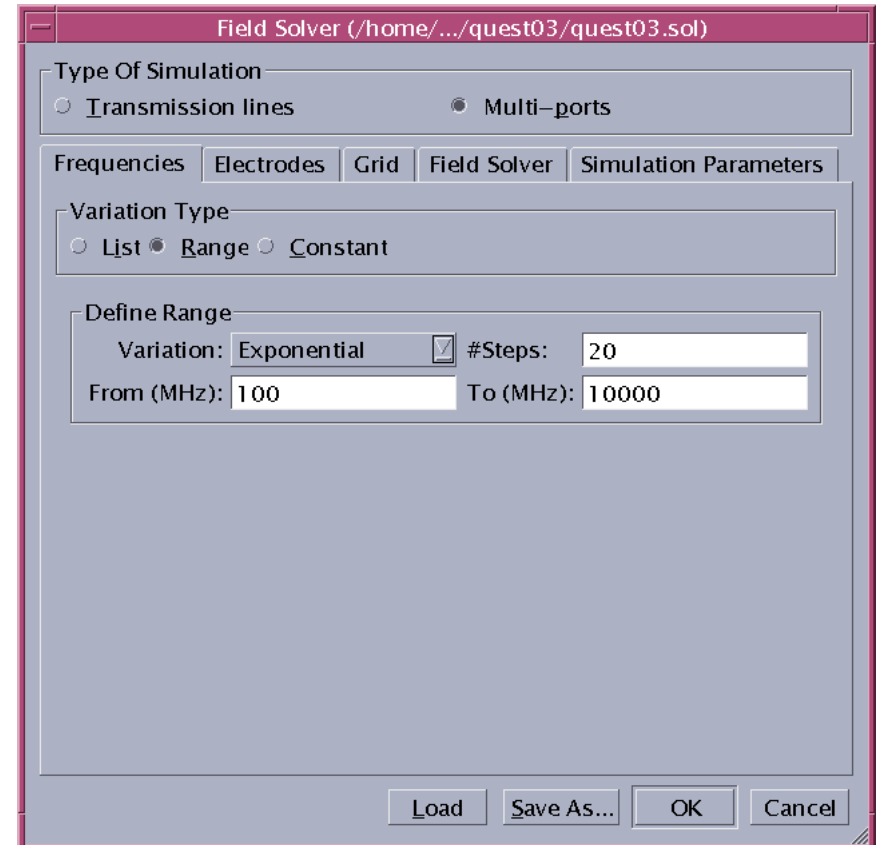


Figure 12c.



# Electrode Definition Interface

- The electrode definition interface, for a multi-port simulation, is used to set the electrodes for each port, Figure13 shows the complete electrode definition used in this example
- If electrodes in the structure are on floating conductors or on grounded conductors, then they must be identified as either a grounded node or floating node in the field solver GUI
- In this example the electrodes Ground0 and Ground1 are grounded nodes
- For a multi-port device, the port numbers must be defined together with which electrode is attached to them
- If the reference of a port is not an electrode, we make use of the reserved electrode name subs\_ground, this makes the substrate electrode the reference for the port. In this way we ground out the reference electrode for the two port network

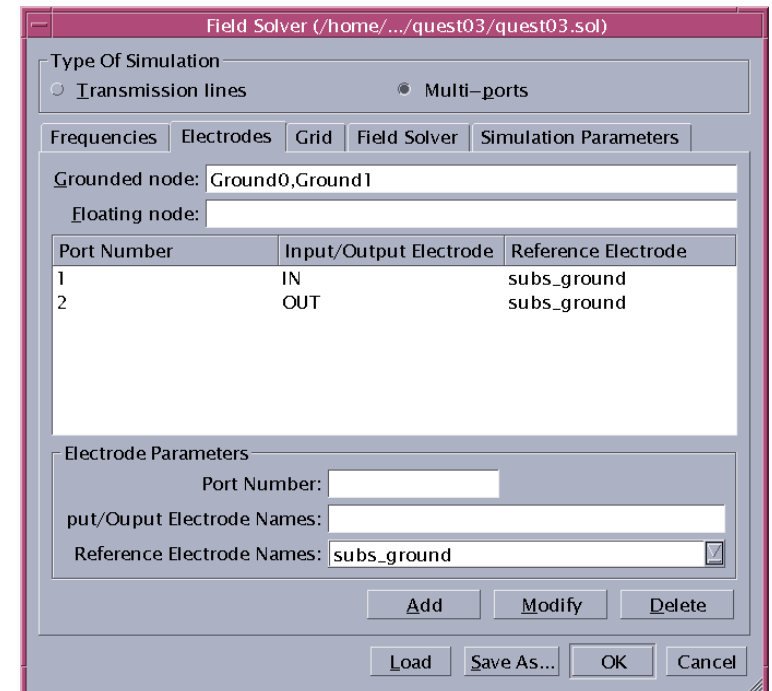


Figure 13.



## Grid Interface

- The Grid interface, Figure 14, is used to specify the grid spacing in the X, Y and Z directions
  - The units are in microns
  - in this example the spacing has been set to 5 microns in the X and Y direction and 0.5 microns in the Z direction

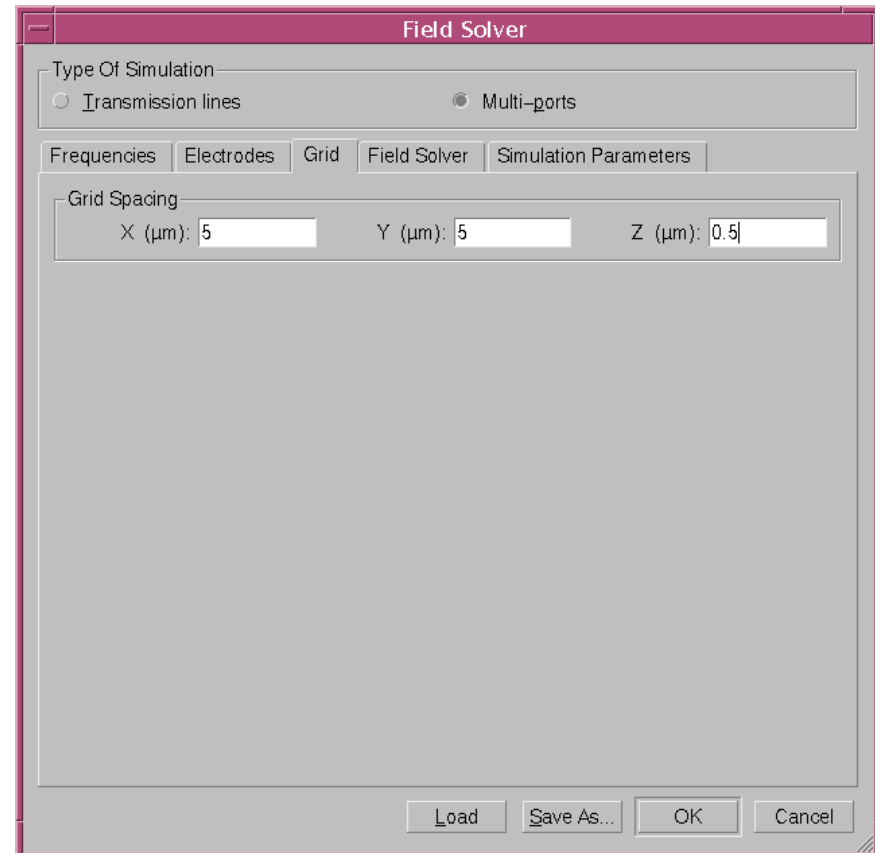


Figure 14.



## Field Solver Interface

- The field solver interface is seen in Figure 15. The maximum number of iterations and residue value to be set for the capacitance and inductance calculations are defined in this interface
  - The residue represents the overall speed of convergence in the simulation process
  - The residue value sets a limit for the minimum speed of convergence for a simulation
  - In this example the residue is set to 0.01
- The box definition corresponding to the computation window is also set in this GUI
  - The box definition must be greater than the size of the layout
  - The box definition is calculated automatically by QUEST, as is the case in this example, although users may specify it by checking the manual checkbox

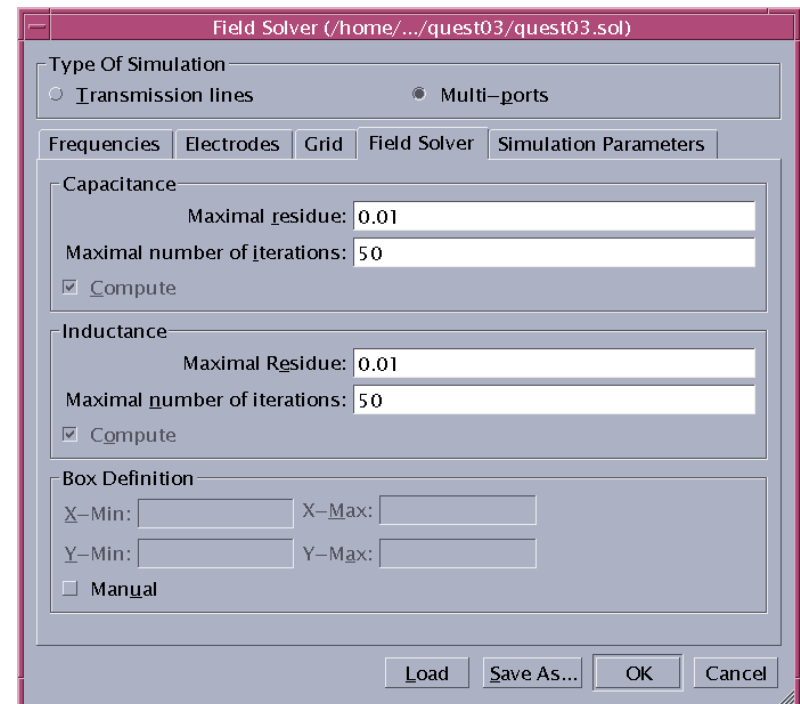
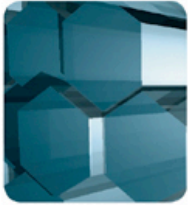


Figure 15.



## Simulation Parameter Page

- The final interface of the Field Solver GUI is the simulation parameters page, Figure 16
- QUEST will take into account the impedance and resistive properties of the actual measurement equipment
- In this way QUEST will enable users to compare simulated results with actual measured data
- The simulation parameters page allows users to set these measurement properties

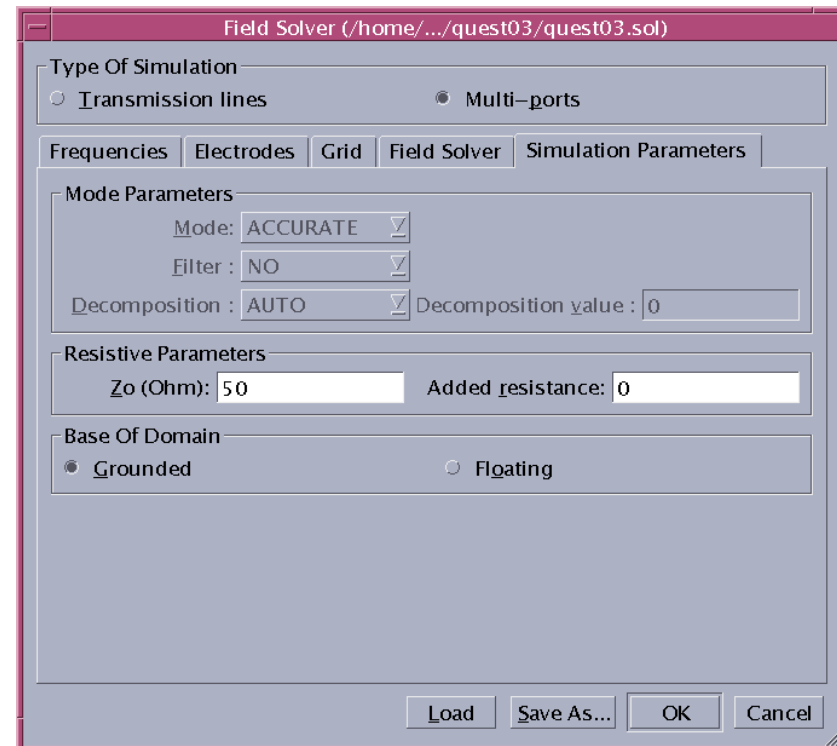
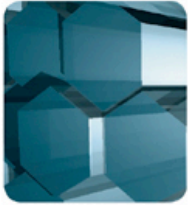


Figure 16.



## Output Interface

- QUEST allows the user to specify several output attributes via the output interface, Figure 17
- The output interface also allows the user to choose which type of results to save e.g. 3D structure files, spice netlist
- It is advisable to use meaningful prefixes as seen in the figure

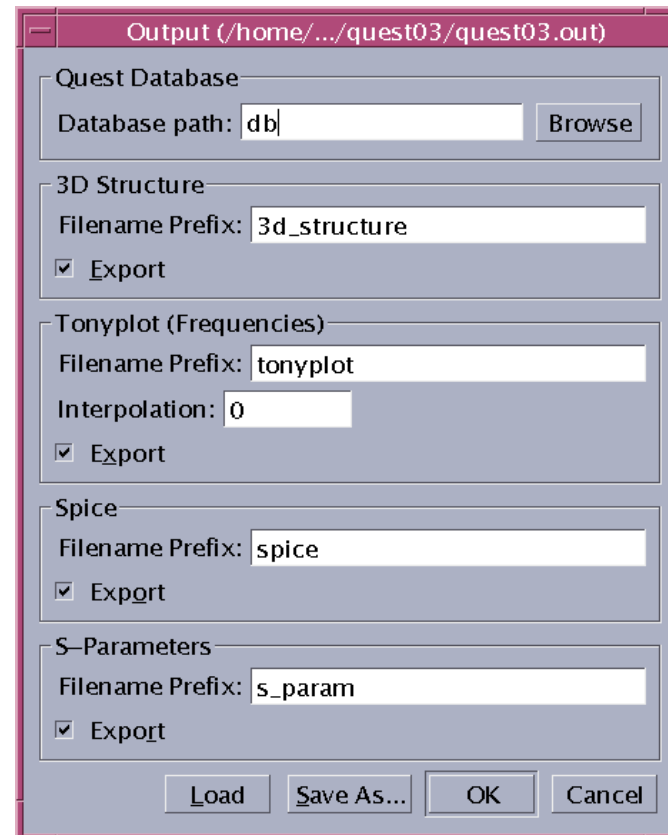
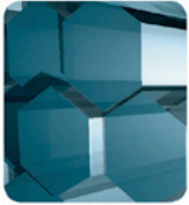


Figure 17.



## Design of Experiments Stage

- The Design of Experiments (DOE) stage completes the definition of any process or layout variables that have previously been created
- The DOE interface, Figure 18, allows the user to specify the values that the variables take and how the values that the variables take are adjusted
- Several design methods are available
- This example however does not have any process or layout variables, so this section is not filled out

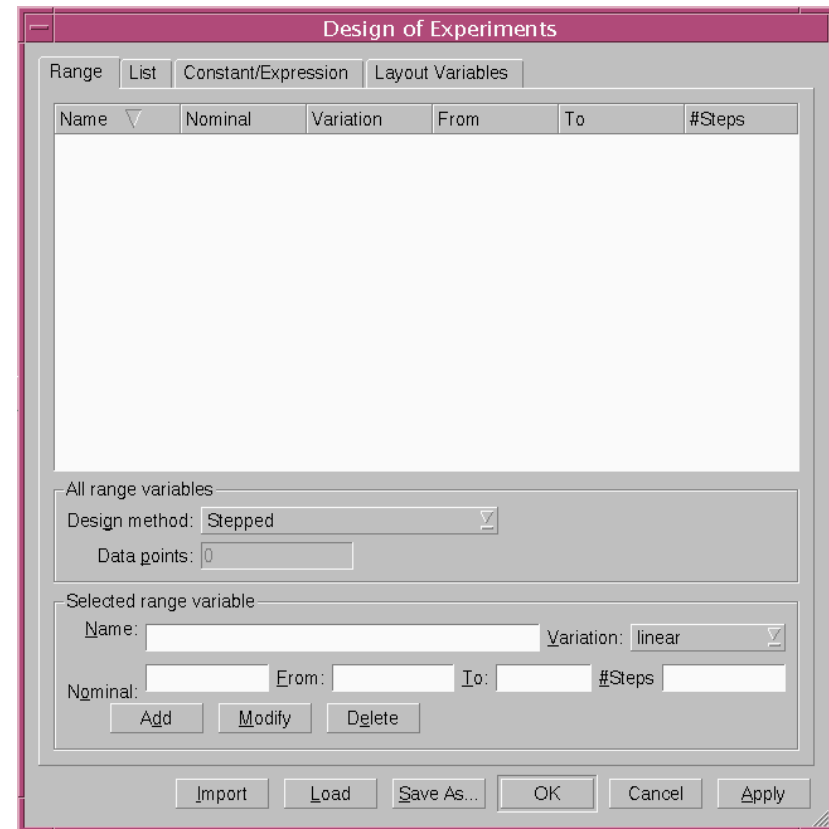
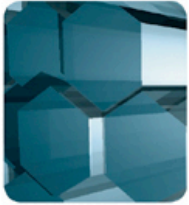


Figure 18.



# Running the Simulation

- Having now finished setting up the experiment we click on the run button to run the simulations
- Figure 19 shows the Q factor as a function of frequency for both port1 and port2
- Figure 20 shows the inductance as a function of frequency
- Both the figures can be compared to Figure 4 and Figure 5 of the reference

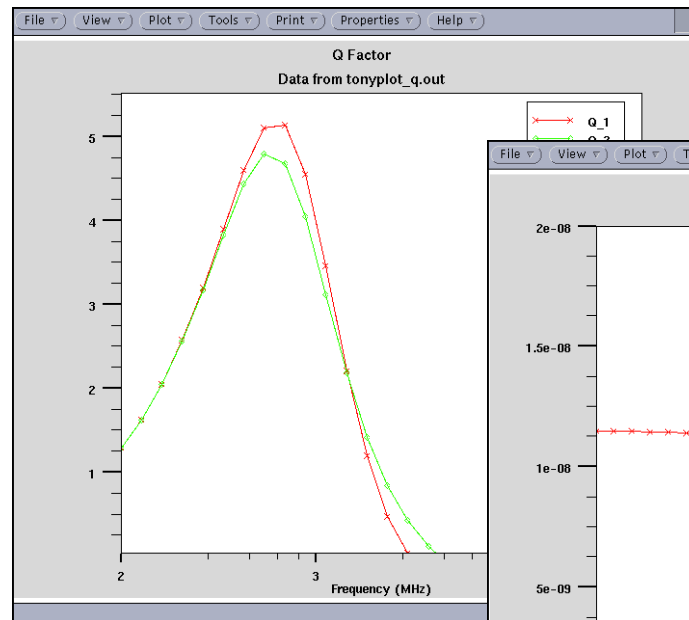


Figure 19.

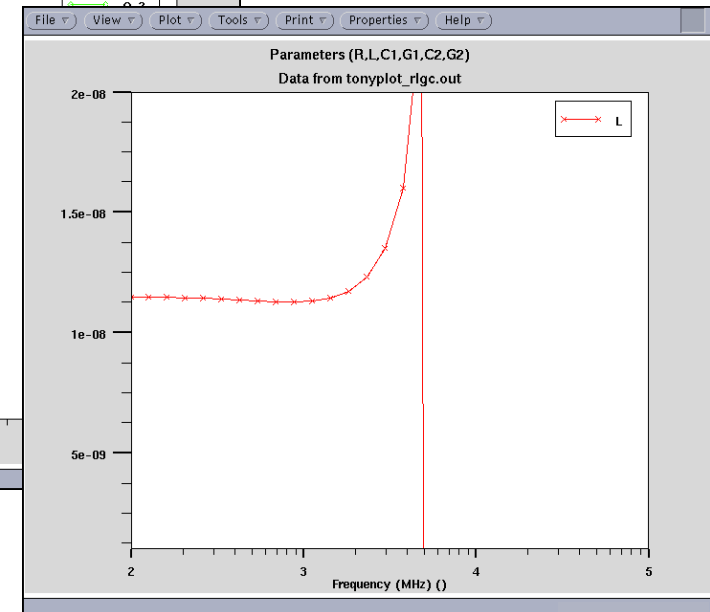
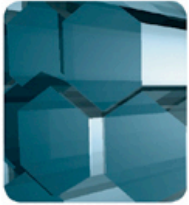


Figure 20.



## Conclusion

- We have gone through a complete engineering example in QUEST and have used QUEST to physically simulate a BiCMOS process used to create a square spiral inductor
- Pertinent characteristics have been shown to agree with actually measured data