

# Tutorial

## **MAX Layout System**

**Micro Magic, Inc.**

*Version 5.1*



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## About this Document

This chapter provides an overview of the *Micro Magic, Inc. MAX Layout Editor Tutorial*:

- Objectives on this page.
- Getting set up on page 3.

## Objectives

This tutorial is intended to be a step-by-step introductory training in the use of the Micro Magic Tools (TM) MAX Layout Editor. By following the steps in this tutorial, you will learn how to run MAX, and how to use MAX to optimize your designs. Once you are familiar with MAX, refer to the Micro Magic Tools MAX User Guide for more detailed information about the tool and its options.

## Audience - MAX

This document is designed for chip designers and layout designers. It assumes that you have a strong foundation in IC design and development, and layout editing. This document also assumes that you are familiar with the following programming languages and operating systems: Tcl/Tk, and UNIX or Linux.

## Organization

This tutorial is divided into parts. Each part leads you through a different aspect of the Micro Magic Tools MAX Layout Editor.

This document contains the following parts:

- Preface, “About This Document” (this chapter), provides a brief description of the content and organization of this document.
- Part 1, “Introduction”, gives a brief overview of what you can accomplish using MAX, and the requirements necessary for running the program.
- Part 2, “Simple Layout”, provides instructions on using the basics of MAX to draw layouts utilizing paint and wires. In addition, this section provides details about the MAX window and user environment.
- Part 3, “Bigger Designs And Hierarchy”, builds on the fundamental procedures from the preceding sections, and illustrates how to use MAX for very large layouts.
- Part 4, “MAX-LS”, introduces interactive cross-probing with SUE, including automatic layout generation from schematics, and flylines.

## Chapter Organization

Each part contains descriptions of the commands and methodology necessary to create layout using MAX, with step-by-step, illustrative examples describing the usage of commands and procedures.

## Documentation Conventions

### General Conventions

This guide uses the following text conventions:

- Statements, commands, command output, filenames, directory names, and configurations are shown in a boldface, fixed-width font. The following example shows a full path name:

```
~/mmi_private/max/.maxrc
```

- In examples, text that you type literally is shown in bold. In the following example, you type the word *max*:

```
To launch max, type max
```

- Menus, menu options, and pop-up menus are generally shown in a boldface, sans serif font. For example:

```
Select Save As from the File Menu.
```

### Conventions for Software Commands and Statements

When describing the Micro Magic Tools (TM) software, this guide uses the following type and presentation conventions:

- Statement or command names that you type literally are shown nonitalicized. In the following example, the statement name is *set MC(default\_generator)*:

```
set MC(default_generator) sram
```

- Variables for which you substitute appropriate values, are shown in italics. Optional commands within a string of code are often enclosed within square brackets ([ ]). Variables are enclosed within angle brackets (<>). When you type the **setMACRO** statement, you substitute a value for *name*, *row1* and *row2*. *CELL* is an optional command.

```
set MACRO(<name>){[CELL]<row1><row2>...}
```

### Conventions for Mousing

Throughout this document, we assume you are using a 3-button mouse. When we refer to using the mouse, the following settings apply:

- Mouse-Button-1, or Button-1, refers to the left-most button (index finger) when you are using a right-handed mouse.

- Mouse-Button-2, or Button-2, refers to the middle, or center button (middle finger). This is generally a scroll wheel on most mice. When the scroll wheel is used in the max window, it zooms in and out on the layout. There are very few places where the middle mouse button or scroll wheel are used as a mouse button in MAX.

- Mouse-Button-3, or Button-3, refers to the right-most button (ring finger) when using a right-handed mouse.

Reverse these settings if you are using a left-handed mouse, using your mouse control program, so that you click Button-1 with your index finger, Button-2 with your middle finger, and Button-3 with your ring finger.

- “Click” means to depress the designated mouse button once.
- “Double-click” means to depress the designated mouse button twice, quickly.
- “Drag” means to depress and hold down the designated mouse button while moving the mouse.

## Documentation Feedback

We are always interested in hearing from our users. Please let us know what you like and do not like about the Micro Magic Tools documentation, and let us know of any suggestions you have for improving the documentation. If you find any mistakes or out of date information, please send email to [support@micromagic.com](mailto:support@micromagic.com)

## Support

For product problems or technical support issues, contact Micro Magic Tools at [support@micromagic.com](mailto:support@micromagic.com).

## Getting set up

MAX runs independently from the other Micro Magic tools.

First, ensure that the Micro Magic Tools software has been installed, and that you have a valid MAX License.

To run some parts of the tutorial you will need to have a MAX-LS license. If you do not have MAX-LS, simply skip that section.





# Part 1

## Introduction

Welcome to MAX, the full-custom layout editor from Micro Magic, Inc. MAX is more than just a simple layout editor. It is a complete layout environment.

### MAX Features

- Interactive viewing and editing of hierarchical layout
- Continuous DRC feedback during layout
- Hierarchical and incremental DRC
- Built in netlisting
- Interactive connectivity tracing
- Interactive wiring tool with flylines to show connections not yet completed
- Layout generator for gates (using MAX-LS)
- Generators for large regular structures such as SRAMS, ROMs, PLA's, and DRAM's (with the optional MegaCell Compiler)
- Interfaces to other tools, including schematic capture (for example SUE), and batch DRC and LVS (for example *Dracula* or *Calibre*).
- Smart palette for easy control and feedback on layers
- Full customization and extension via Tcl/Tk scripting language and API
- Technology independence via technology description files
- Optimized for large databases
- Very Fast Redisplay for Whole Chip Viewing and Inspection
- Reads/writes GDSII
- Runs on Linux operating systems.

This tutorial will introduce you to many of these features. Consult the Micro Magic, Inc. *MAX User Manual* and on-line documentation for further information.

## Starting up MAX

Before we get started make sure someone has already installed MAX at your site.

To run the tutorials, you need to make a personal copy of the MAX tutorial example files using `mmi_tutorial`.

- Step 1 ■ To install the MAX tutorial, type the following at the UNIX prompt:

```
mmi_tutorial
```

Make sure that the appropriate tool (MAX) is selected and then click on Install Tutorial.

The default installation directory is “`mmi_private/tutorial`” in your home directory. You can also select a different directory for installation. Don't worry if the directory doesn't exist, the `mmi_tutorial` script will make it if it can. You can also use this to reinstall a clean copy of the tutorial.

- Step 2 ■ To start the tutorial, you must first “`cd`” (change directory) to the directory that you installed the tutorial into. If you used the default directory, type:

```
cd ~/mmi_private/tutorial/max
```

Otherwise, replace the above directory with the directory you selected. This directory contains files that you will need to run the tutorial.

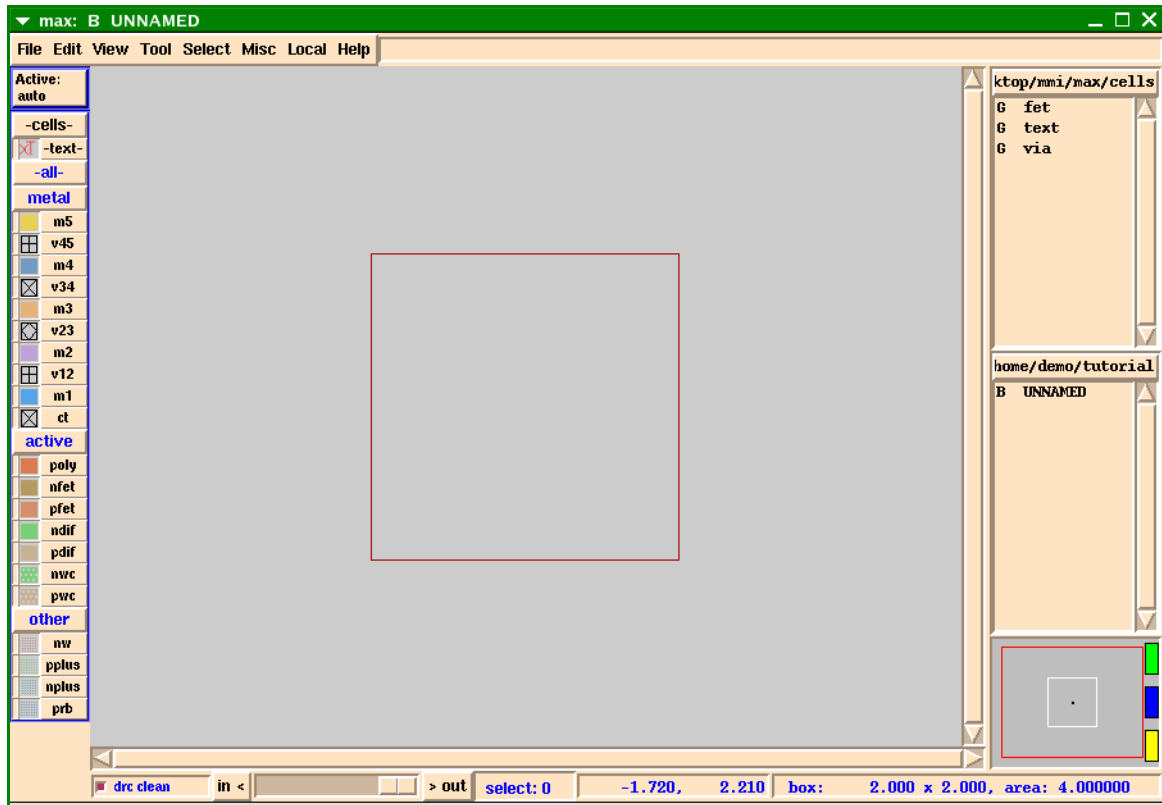
- Step 3 ■ Then to start MAX, simply type:

```
max
```

A window should come up that looks something like Figure 1. The rest of this portion of the tutorial will go over each section of the MAX windows.

- Step 4 ■ If you have two monitors, it is a good idea to have the window from which you started MAX (command window) visible on one monitor and MAX on the other monitor. At points during this tutorial you can look at results in the command window (the window from which you started MAX). If you have only one monitor, then it would be helpful to move the command window (the window from which MAX was started) to the bottom of the screen and size the MAX window such that you can see a few lines of the command window.

Figure 1: MAX Window



## MAX Screen Layout

On the very top of the window the title bar should say “max: UNNAMED”.

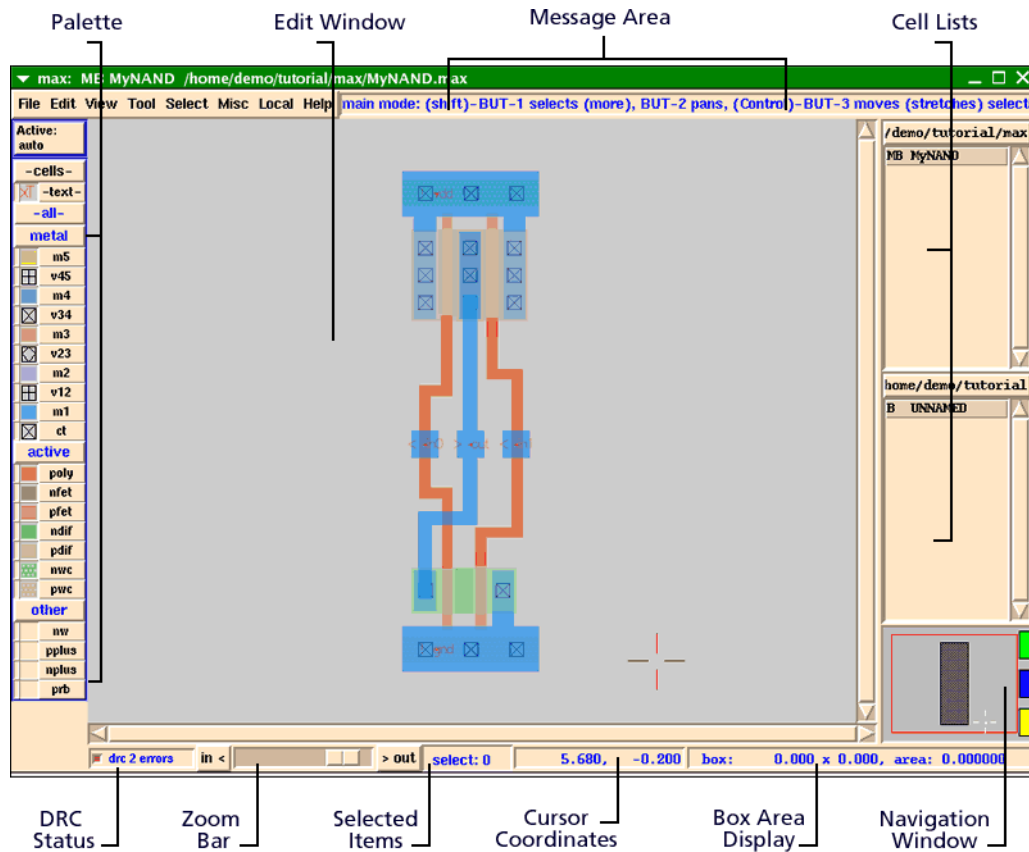
“UNNAMED” means that you have *not specified the file (cell)* you wish to edit.

Next, across the top you should see the menu bar which contains the following menu items: File, Edit, View, Tool, Select, Misc, Local, and Help. These are pull down menus much like any other application.

Directly to the right of the Help menu is the MAX Message Area. Depending on the location of the cursor, it currently says something like “main mode, (shift)-BUT-1 selects (more), BUT-2 pans, (Control)-BUT-3 moves (stretches) selection”. The MAX Message Area is a sort of mini-help feature. It tells you what each mouse button does, and when you have pulled down one of the menus from the menu bar, the message area will give you a short explanation of what the highlighted menu item does.

The remainder of this section of the tutorial goes over each area of the MAX window. Refer to the MAX User Manual for a more detailed description of the MAX window. Figure 2 points out the different attributes of the MAX window.

**Figure 2: Things in MAX Window:**



## Cell List Boxes

Down the right side of the window are several small List Boxes.

Each List Box contains cells in a given directory. That directory can be the user's "working directory" or a library.

Additional List Boxes can be added (or boxes deleted) by

- Clicking the left mouse button (Button-1) over the List Box header (the horizontal bar saying: `users/tutorial/max` in Figure 1), then,
- Clicking the left mouse button (Button-1) on either Make new list box, or Close this list box.

The directory the list box points to can also be changed by clicking on the desired directory. The directory list includes the directories of all cells that are currently loaded into MAX.

Your `max.rc` file can specify library directories to be autoloaded at startup time.

The `max.rc` file contains several other useful pieces of information. (See the Micro Magic, Inc. *MAX User Manual* for more details.)

You can also adjust the width of the list boxes by:

- Moving the mouse pointer over the vertical bar just to the left of the text. The bar will change to a small horizontal line with arrows on both ends.
- When the arrows appear you can adjust the list box width by clicking and dragging with Button-1 to the left or right.

## Navigation window

Below the list boxes is the Navigation Window. For large designs, you can use the Navigation Window to control the view you see in the main MAX window.



Holding down the left mouse button (Button-1) and dragging out a region in the Navigation Window will cause the main window to zoom to that region.

The small colored (green, blue, yellow) rectangular buttons on the right of the Navigation Window allow you to do several things.

- The topmost button (green by default) steps through the view stack. BUT-1 zooms backwards in the view stack, BUT-3 zooms forward in view stack.
- The other two buttons allow you to save (remember) and return to views - a different view for each. Position the mouse cursor over the buttons, and read their function descriptions in the Message Area.

For example, if you were at a view you knew you wanted to return to, simply click the right mouse button (Button-3) on the middle (blue) button to remember that location and zoom factor.

If you later wish to return to that view you simply click the left mouse button (Button-1) on that blue button to recall your view.

- The top button always zooms back and forth in the view stack. If you desire, you can add additional buttons to save more views. Both the number of view-save buttons, and their colors, can be changed in your `max.rc` file.

## Scroll and Zoom bars

**Scroll Bars** are laid across the bottom and right side of the Layout Window (and on the right side of the List boxes). These work like the scroll bars in most other applications.

Below the bottom scroll bar is the **Zoom Bar**. Pulling the slider button to the left zooms in, and to the right zooms out.

In addition, the mouse scroll wheel can be used to zoom in and out. Scroll wheel zooming is centered around the cursor position.

### **Mouse Coordinates and Box Size Location**

In the lower right hand corner the **Box Size** (in microns) is displayed. (More about the Box later.) This is useful when you wish to make an object a precise size. It is also useful for when you select an object and want to know how big it is.

Just to the left of the Box Size is the **Mouse Coordinates display**. Mouse coordinates are oriented with respect to the top level cell.

### **Number of Items Selected**

This box shows the number of items selected. The default is to display “>100” if more than 100 items are selected. By default any item (gcells, instances, rectangles, etc.) selected is displayed. This can be changed in your max.rc file.

### **DRC Control and Status**

In the lower left corner is the **DRC Status Box**. It tells you the current status of the continuous interactive DRC which runs in MAX. The DRC Status Box also has a small radio button where you can click to turn the interactive DRC on or off.

## **The Palette**

Down the left side of the window is the **Smart Palette**. The Smart Palette provides many features:

- It controls which layers are visible, and lets you choose layers for ‘painting’ (drawing rectangles).
- It gives feedback on what is currently under the cursor, and what is currently selected.
- It allows you to control which layers can be selected.
- And finally, it allows you change the color or stipple patterns of any of the layers.

Refer to the MAX User Manual for more details.

## **Layers**

Just above the palette are buttons labelled **Active:**, **-cells-**, and **-all-**.

**Active** lets you select the *active* layer. If you start a wire, it starts in the current Active layer. If Active is set to **auto**, the wire starts on the layer the cursor is currently over, or the default layer (usually set to M1).

**Cells** controls whether or not sub-cells and gcells can be selected.

**All** allows you to make all of the layers visible or invisible at the same time.

## **Getting Help**

Before we go any further, here is how to get help if you ever need it.

There are several levels of help available on-line to MAX users. You already know about the quick Help listed in the MAX Message Area.

In addition, you can access the complete on-line manual, the complete list of active hotkeys, and complete documentation of the text commands at any time.

- Step 1
- Assuming you have MAX running, click and hold down the left mouse button (Button-1) on the Help menu. This should pop up a sub menu as shown in Figure 3.
- About MAX** tells you the version of MAX you are running, the technology you are using, etc. You should make sure that you are running the **mmi18** technology for this tutorial. If you have not set it up otherwise in a setup file, then MAX by default will come up with the **mmi25** technology.

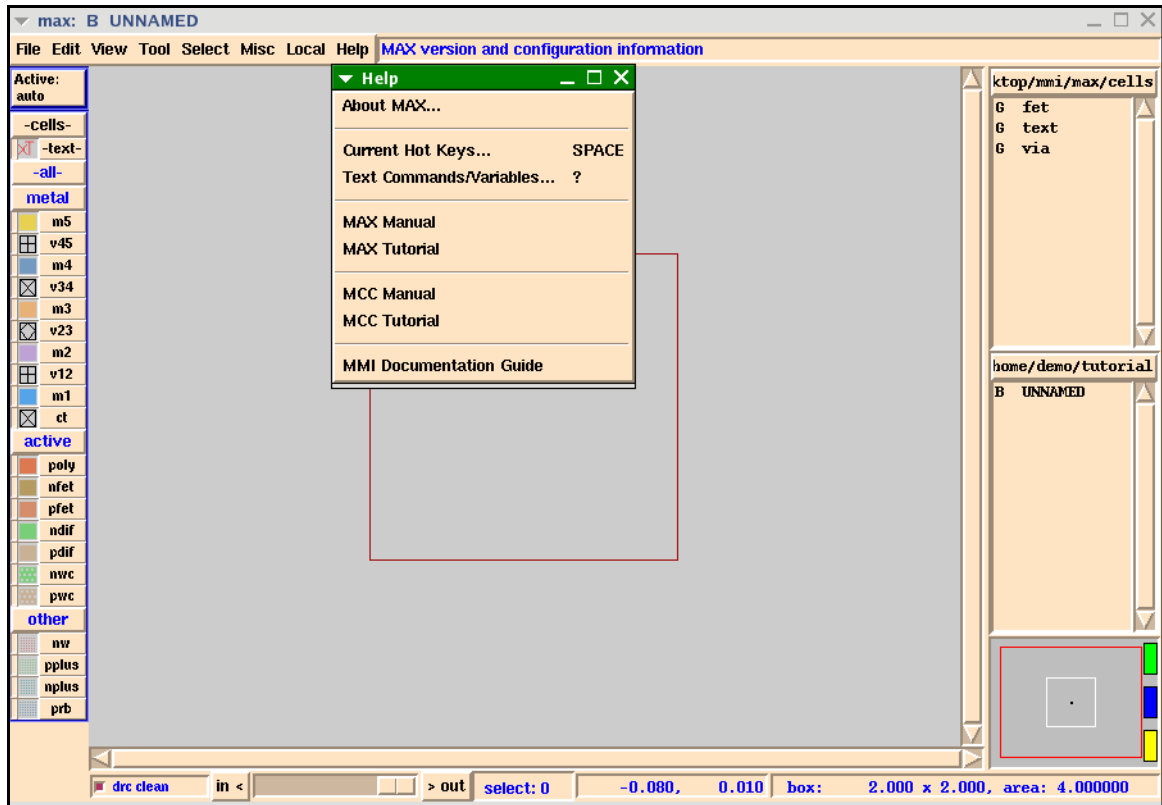
- Step 2
- If the technology is NOT set to **mmi18** then quit out of MAX (Hotkey: **Ctrl-d**) and restart it by typing:

```
max -tech mmi18
```

**mmi18** is a generic 0.18um CMOS technology provided by Micro Magic, Inc. It is similar (although not exactly the same) to many current 0.18um technologies and is a good place to start if you need to generate your own technology file.

**About MAX** will also tell you where the **MMI\_TOOLS** environment variable points. (This is the directory at your site where the MMI tools are installed.)

Figure 3: MAX Help Menu



Current Hot Keys gives you a list of all available hot keys. You can also hit the Space bar to bring up this list.

Text Commands/Variables brings up documentation for the MAX text commands and variables. Text commands are useful for writing scripts, generators, and other helpful programs. Text commands and the Tcl/Tk interface are the MAX API. They allow the user to add their own features to the Local and Tool menus.

MAX Manual brings up the MAX manual in your browser. The default browser is **Firefox**. This can be changed in your `max.rc` file.

MAX Tutorial brings up this tutorial.

MMI Documentation Guide brings up all of the documentation for all of the Micro Magic, Inc. software. This document has links to items like the Micro Magic, Inc. *SUE User Manual*, the Micro Magic, Inc *MAX User Manual*, other Micro Magic, Inc. software programs, and even to this tutorial.

Before proceeding you should bring up the Micro Magic, Inc *MAX User Manual* and see what's there. The User Manual is the reference manual to MAX and contains lots of information that you will not find in this simple tutorial.

You might also want to look at the menu items just to familiarize yourself with what's there.



## ***Tear Off Menus***

Sometimes it is convenient to make a menu its own window.

For example:

- Step 1     ■ Going back to the Help menu: when you hold down the left mouse button (Button-1) over the Help menu notice that there is a dotted line just before the About MAX menu item (not shown in the above figure).
  
- Step 2     ■ If you release the button while over the dotted line the menu will “tear off”. The menu then becomes a full-fledged window, like any other window on your desktop. The exact behavior will depend upon which OS and window environment you are running.

If you are running another window manager, your windows might behave a little differently. Consult your window system documentation for more details.

The chosen menu will stay pulled-down until you select either a menu item, or another menu.



# Part 2

## Simple Layout

OK, let's get started on some layout.

For this section, we will be using the mmi18 technology.

- Step 1
- To make sure you are using the correct technology, go to the **Help** menu and select **About MAX...** If the technology is not mmi18, exit MAX (**ctrl-d**) and restart MAX with the command:

```
max -tech mmi18
```

- Go to the File menu and select **New...** This will bring up the File Select box.

- Step 2
- Type in the cell name **foo** where it says **Filename:.** Then click **OK**, or hit **Return**.

The **UNNAMED** at the top of your MAX window should now say **foo**. This means that you are now editing the cell **foo**. When you save it out it will be saved as **foo.max**. Also, notice that **foo** now appears in the **Cell List Box** on the right side of the MAX window. The **B** to the left of **foo** means that this cell only exists in memory (buffer) and has never been saved.

### Using Gcells

While MAX can do very low level full custom layout, it also has a complete Tcl/Tk interpreter built in. Tcl is a language developed by John K. Ousterhout at UC Berkeley. Tk is the windowing tool kit. Books on both can be found at your local bookstore. The Tcl/Tk interface in MAX allows full access to MAX layout functionality, providing unprecedented power and flexibility.

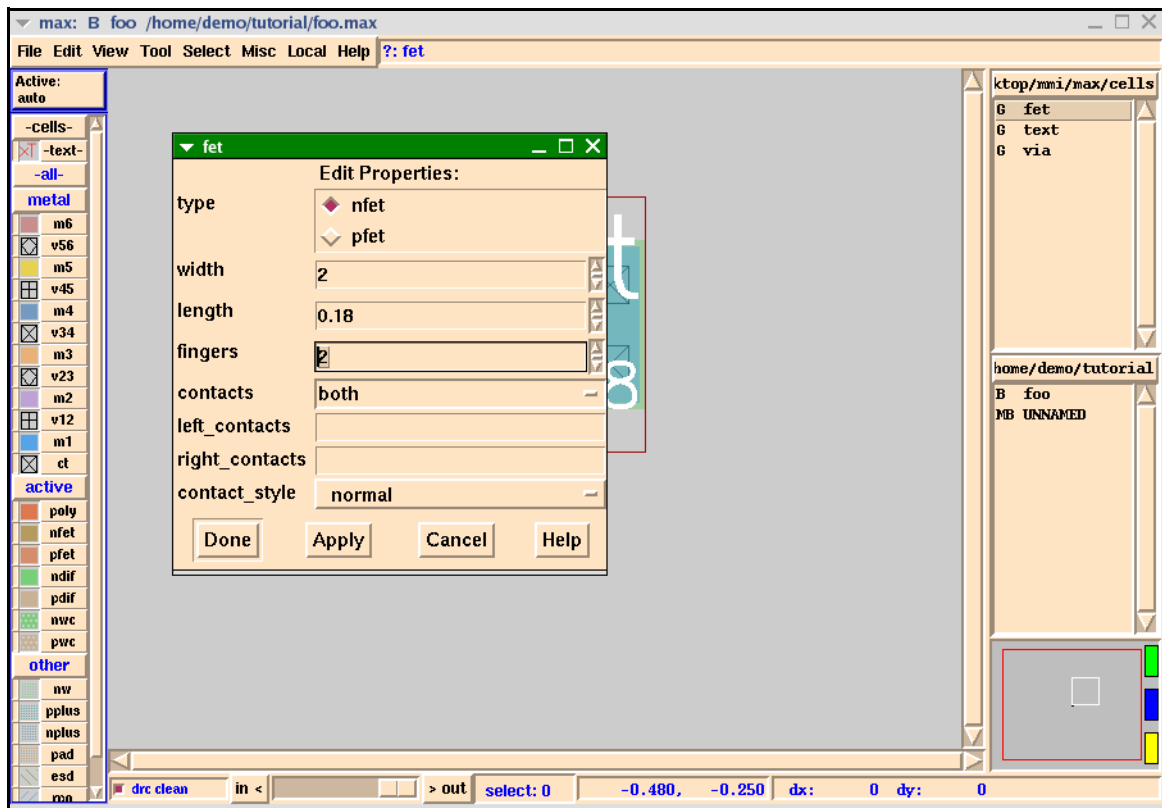
A **gcell** is a *cell generator* written in the Tcl/Tk language. The gcell generates layout for a cell automatically from “properties” that you specify using a simple menu interface. MAX comes with gcells to generate FETs and Vias.

- Step 1
- Go to the **List Box** down the right side and select **fet** from the list by clicking on it with **Button-1**. The **G** next to the **fet** indicates that this cell is a **gcell**, or generator.



If you do not see **fet** in the List box, click and hold the left mouse button (Button-1) over the List box header to display the directory list, then select the directory ending in **cells**. This is the directory that contains the **fet** and **via** gcells provided with the Micro Magic, Inc. software.

Figure 4: FET Gcell



When you click the left mouse button (Button-1) on **fet** in the List Box, the fet generator window will pop up. It should look something like Figure 4.

- Step 2 ■ Now, change the **width** to 2.0. This will make the nfet 2.0 $\mu$ m wide.
- Step 3 ■ Since we eventually want to use this device to make a 2 input NAND gate, change **fingers** to 2, and **contacts** to *both*.

Contacts allows you to put contacts on the left side, the right side, both sides, between the devices (all), or no contacts at all. Click on Help or refer to the Micro Magic, Inc. *MAX User Manual* for more details.

Clicking and holding the left mouse button (Button-1) on the little bar to the right of this option will bring up all of the possible options From this list you select *both*.

Step 4 ■ Now click Done.

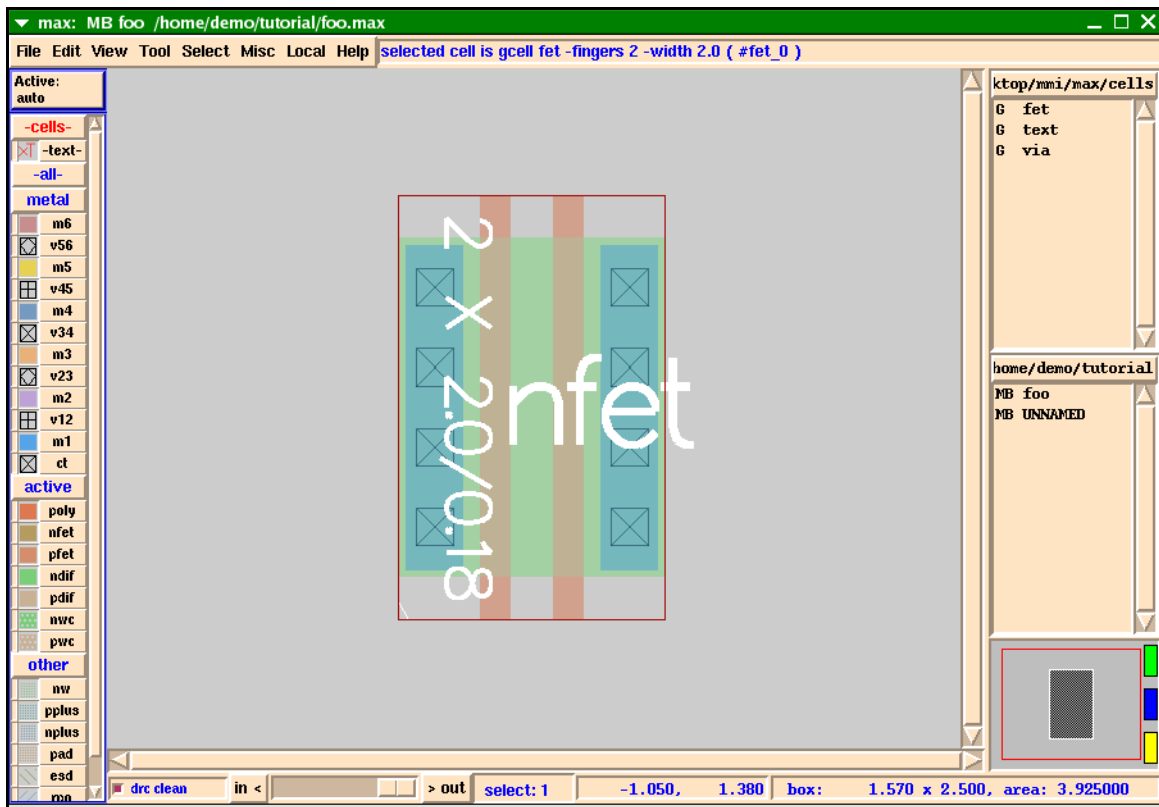
Two nfets merged (stacked) together should appear, attached to the upper-right corner of the cursor.

Step 5 ■ Click Button-1 to place the nfets in the window.

Step 6 ■ Type v (the hotkey for Zoom To Fit Edit Cell under the View menu) and the layout will be centered in the window.

Your screen should now look like Figure 5.

Figure 5: Generated nfet Gcell



The white text on the cell tells you that you are editing a fet (label at top), and that it is 2 gates x 2 microns wide, at a .18 micron channel length.

Notice that the letter **M** appears to the left of **foo** in the *Cell List Box*. This tells you that **foo** has been *Modified*.



You can undo whatever you have just done in MAX. Use the **u** hot key or select Undo from the Edit menu. You can also Redo what you have just undone using the **Shift-u** hotkey. There are 99 levels of undo in MAX. If you can remember back more than 99 items please call us, we would love to meet you!

## Zooming

- Step 7 ■ Now zoom out by typing **Shift-z**, or use Zoom Out in the View menu, or use the **scroll wheel** on your mouse (if you have one). You can also use the *Zoom Bar* at the bottom just below the scroll bars.

There are several methods for zooming found in the View menu.

Use the zoom hotkey to zoom to an exact region.

- Step 8 ■ Type **z**. This puts you in *zoom mode*. Note that the cursor has changed. Next hold down the left mouse button (Button-1) and “drag” out a box which surrounds the region you wish to zoom to. When you release the mouse the screen will zoom to where your box was.
- Step 9 ■ If you mess up don't panic. Remember, **u** will *undo* any edits you have made, and **v** will always *zoom to fit*.

One often-used technique for zooming is to use the **j** hotkey to *zoom in* by a factor of two centered on the mouse. The hotkey **Shift-z** can be used to *zoom out* by a factor of two.

If you are using a scroll wheel mouse, you can zoom in/out by pushing forward or backward on the scroll wheel while in the MAX window. Zooming will be centered around the point of the cursor.

## Selecting and Moving Layout

There are two types of layout you can select and move in MAX: **objects** and **paint**.

**Objects** may be *sub-cells* (cells), *generated cells* (gcells) or *polygons*.

**Paint** is basically *flat layout*. Think of paint as if you were painting something with a paintbrush. You can apply paint, remove paint, you can even stretch and drag paint. Paint is similar to flattened objects in other layout editors, but more flexible.

There are many methods for selecting objects and paint.

When MAX is in main mode (the default), if you simply drag out a region while holding down the left mouse button (Button-1), whatever is within the box will be selected when you release the button and will be highlighted in white.

- Step 1 ■ Drag a box over the stacked nfets we just drew. When you release the mouse button, whatever is “selected”, in this case the fet gcell, will be highlighted.

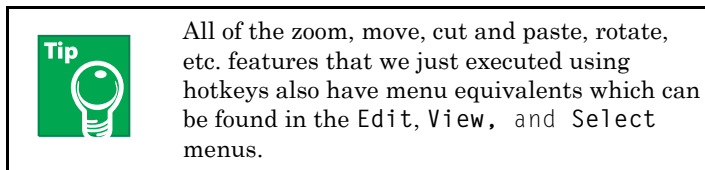
Once you have selected an object or paint you can do lots of things with it.

- Step 2 ■ For example, you can *rotate clockwise* it by typing the `r` hotkey. The **R** (shift-r) hotkey will *rotate counter-clockwise*. Try it.
- Step 3 ■ Type `r` three more times to rotate the object back to its original position.
- Step 4 ■ You can *move* layout up/down/left/right one grid at a time by using the arrow keys.
- Step 5 ■ You can also *move* any layout by first selecting it, then clicking and holding down the right mouse button (Button-3) and dragging it around the screen.

You can select objects or paint by clicking on them.

- Clicking the left mouse button on a piece of paint selects that particular rectangle of paint.
- Clicking on a cell, gcell or polygon will select the object.
- When there are multiple layers under the mouse cursor, clicking more than once will select each thing in turn. You can keep clicking until the one you want is selected. The **Cursor Probe** command (`l` - lower case L) opens a popup window showing everything underneath the cursor.

MAX also supports Cut, Copy, and Paste in the same format you would see on any good Mac- or PC-based drawing or painting program



## Duplicating gcells

We now wish to create a couple of pfets. We could go back to the List box and select the fet generator again, but there is another way.

- Step 1 ■ Simply select your nfet by either clicking the left mouse button (Button- 1) over it, or by dragging a box around it using Button-1.
- Step 2 ■ Now select `Duplicate` from the `Edit` menu, or type `d`. This creates a duplicate of the selected objects (or paint) slightly offset from the original.
- Step 3 ■ Hold down the right mouse button (Button-3) and move the new nfet above the existing nfet.

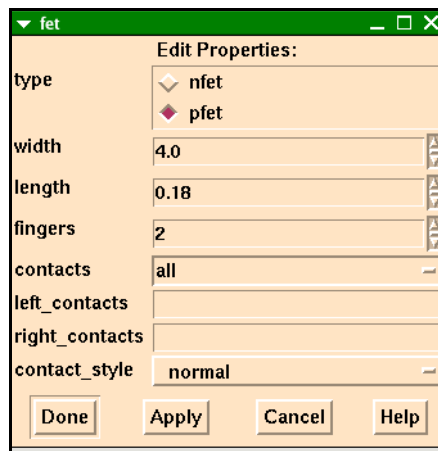
Notice that when you selected the fet and held down the middle mouse button (Button-2) the cursor changed to a 4-way arrow. This change in the cursor tells you that you are in a mode other than main mode. In this case you are in move mode.

Now you will begin to see the true power of gcells.

- Step 4 ■ Select the top nfets and then type `e`, or select `Push Into Cell` from the `View` menu. The popup menu shown in Figure 6 appears.
- Step 5 ■ Click on **pfet** to change it to a **pfet**.

- Step 6 ■ Change the **width** to 4, to make the pfet 4µm wide.
- Step 7 ■ Change **contacts** to *all* by clicking and holding Button-1 on the little bar on the right side of the box next to **contacts** and then click Button-1 on “*all*”.
- Step 8 ■ Once you are finished click Button-1 on Done to invoke the generator. This will change the old nfets to magically become new 4µm wide pfets with contacts in the middle and on both sides.

**Figure 6: Edit Properties Form For fet Gcell**



## Stretching gcells

As you have seen, gcells can be used to create fets and vias. The wiring tool can also automatically drop gcell vias. You can change the size of a gcell fet by:

- Using the e hotkey, and accessing the Edit Properties box, or
- Doing an Stretch Selected from the Edit menu (hotkey: **Control-BUT-3**). The cursor will change into a pointing finger. Place the mouse near the bottom (or top) of the fets and hold down the left mouse button (Button-1) (Notice the cursor changes to a ‘stretch arrow’) and drag up or down to stretch the fet. As explained below, using the Control-BUT-3 hotkey works slightly different than selecting it from the menu.

Try this on your pfet:

- Step 1 ■ Select the pfet by clicking on it with Button-1.
- Step 2 ■ Hold down the **Control-BUT-3** hotkey at the top border of the pfet and drag the mouse up.
- Step 3 ■ Undo the new width with the u hotkey.

This trick also works on vias, except the outcome is placing multiple vias!





You can stretch a well contact to help you with things like quickly building guard rings.

## Aligning objects

It would be nice if our new fets were lined up. One way to align objects is to draw a ruler (hotkey: **Control-r**), zoom way in, and carefully move the objects until they are aligned with the ruler. But a much easier way is to use the `Align Objects` command.

First, select all the objects to be aligned. One easy way to select multiple objects is to hold down the Shift key while clicking on them with the left mouse button (`Shift-Button-1`). The `Shift-Button-1` means “add or subtract something under the mouse to/from the selection”. If the gcell is selected, it will be deselected, and vice versa. You can tell when the gcell is selected because its outline is highlighted, and its name and size are also displayed in white.

- Step 1** ■ Press **Shift-Button-1** over the two gcells until they are both selected.

Second, you must place the box. By selecting the gcells with `Shift-Button-1`, the box has already automatically been placed over the last gcell you selected. The gcells will be moved so they align with the box, which, in this case, means that the first gcell you selected will be moved so it aligns with the second gcell you selected.

Finally, use the `Align Objects` command.

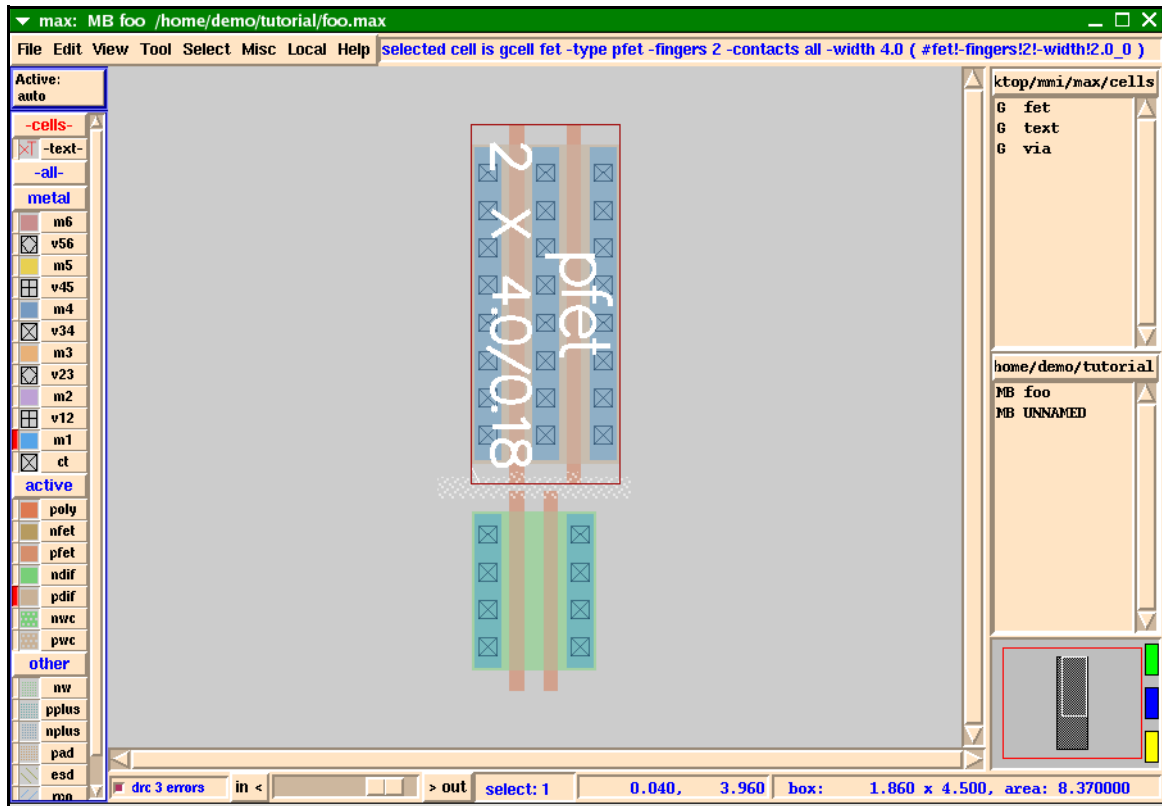
- Step 2** ■ Choose `Align Objects` from the `Edit` menu (hotkey: **Control-a**).
- Step 3** ■ Make sure that `left sides` (the default) is selected (has a red dot next to it.)
- Step 4** ■ Click `Done`. The gcells are now aligned vertically on their left sides.

## Continuous DRC

We are now going to see a really powerful feature in MAX, real-time DRC.

- Step 1** ■ With the new pfets on top of the nfets, select the pfets.
- Step 2** ■ Now, either using the arrow keys (best for precise placement) or by holding down the right mouse button (`Button-3`) and dragging, move the pfet just above the nfet as shown in Figure 7.

Figure 7: Real-time DRC



If you move the pfet too close to the nfet, little white dots will appear. These little white dots tell you that there is a **Design Rule Check error** (DRC error).

Notice that as you move the pfet closer or further away the DRC errors show up in “real” time! This is one of the powerful features in MAX.

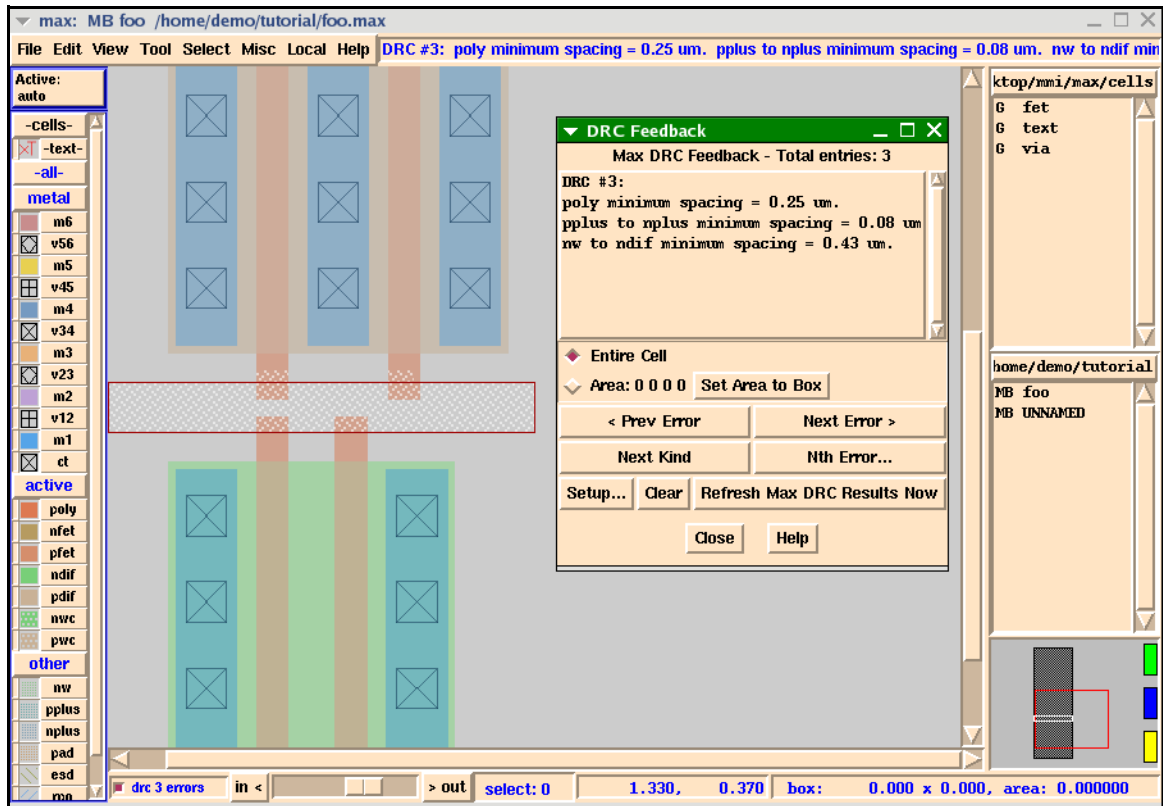
The Continuous DRC means you don't even have to learn the DRC rules, or count grids. Just move things closer together until you see the white dots, and then back off a little. The small DRC error box, to the left of the zoom bar, displays the number of errors.

If you are curious about what the error represented by the white dots is, then you can draw a box around the white dots, type **Shift-y** or choose **Explain DRC** under **Box** from the **Misc** menu. If the box is over only one DRC error, that DRC error will be displayed in the Message Area. If more than one DRC error is under the box, the number of DRC errors is listed in the Message Area. To see the list of all DRC errors under the box, look at the MAX command window (the window from which you started MAX). Another method of viewing DRC errors is shown below.

We are going to use the DRC Results form to view the DRC errors.

- Step 3     ■ Move the pfet close to the nfet, as shown in Figure 7, so that DRC errors occur.
- Step 4     ■ Select DRC Results from the Misc menu. You should see a popup window similar to Figure 8 .

Figure 8: DRC Results Popup Window



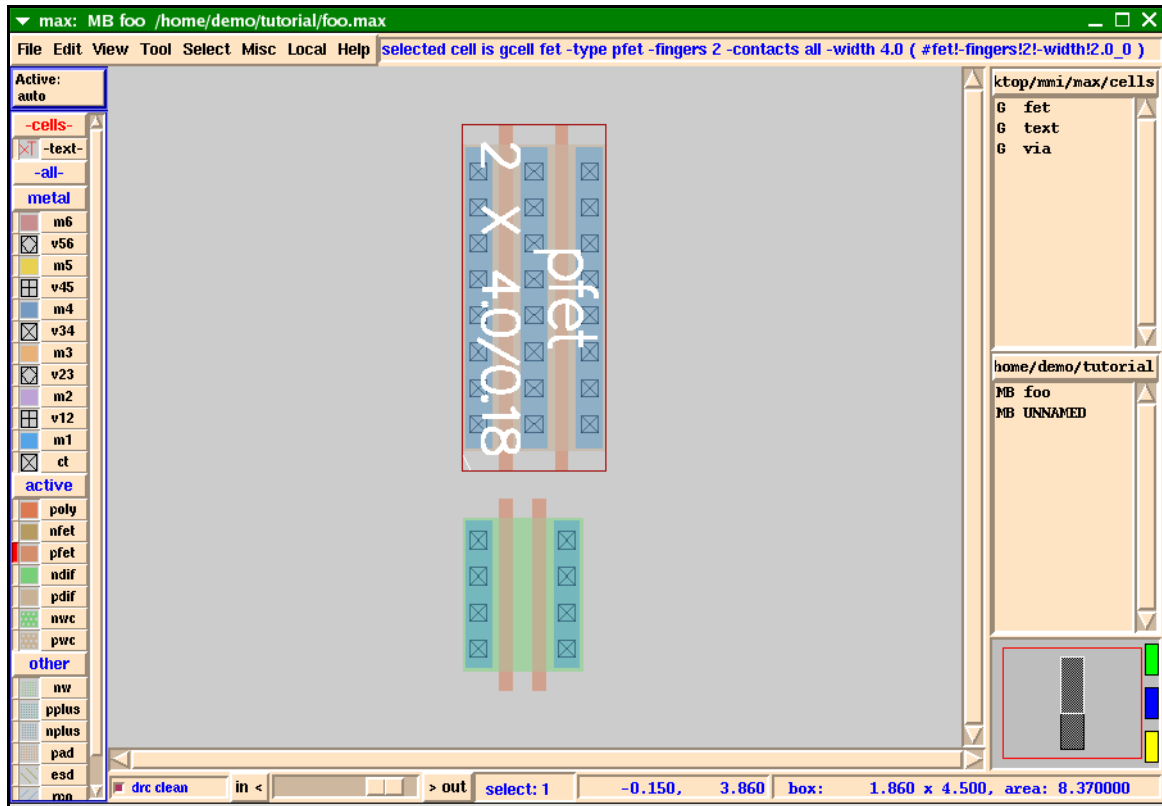
Step 5 ■ Click on Next Error to step through all of the DRC errors. Notice that each DRC error is highlighted in the layout, and the text of that DRC error is displayed in the DRC Feedback window as well as the MAX Message Area.

Step 6 ■ When you are finished looking at the DRC errors, click on Close in the DRC Feedback popup window.

Refer to the MAX User Manual for more details on the DRC Results popup window. This window can also be used to view results of DRC runs with other tools, such as Mentor Graphics Calibre.

Step 7 ■ For now, place the pfet above the left nfet so that the gates of the pfet and left nfet line up (this should be the case already after you aligned them). Then move the pfet up until it is DRC correct (no white dots) as shown in Figure 9.

Figure 9: FETs Lined Up



The Continuous DRC feature uses design rules defined in the **MAX technology file**. This single plain text file defines all the design rules needed by MAX's extensive DRC. The technology file uses a simple table format for most rules, resulting in a compact, easy to understand file format that can be as short as a single page.

Micro Magic, Inc. provides common CMOS technology files as a starting point to build your own, or you can build a prototype technology file automatically from an existing GDS file by choosing Import File from the File menu. For further information, refer to **Chapter 6: "MAX Technology Targeting"** in the Micro Magic, Inc. *MAX User Manual*.

## Wiring Mode

Now you will route up the poly. You could route the poly by drawing rectangles and then filling them with poly (red) paint, but that's a lot of work. There's a much easier way — use MAX's built-in wiring tool.

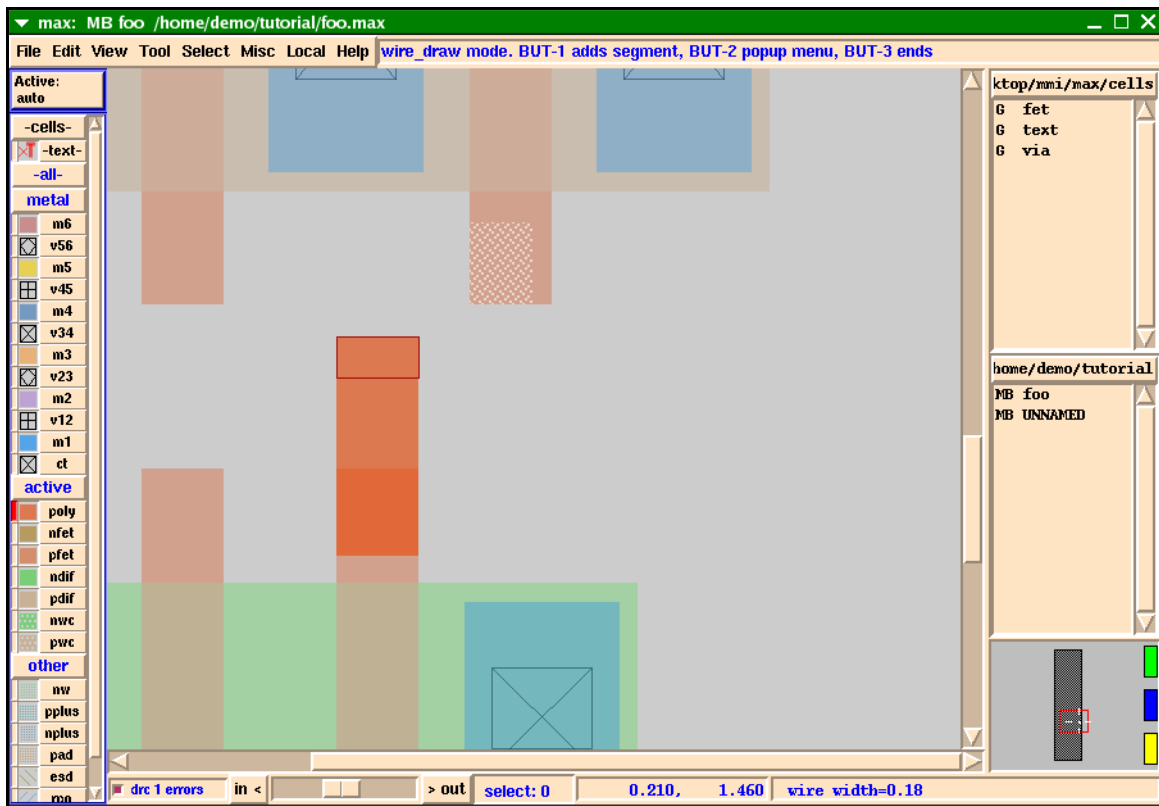
- Step 1 ■ To use the wiring tool type **w**, or select add wire from the Edit menu.

Notice the cursor has changed. Remember, that's to let you know you are in a different mode. In this case, you are in **wire** mode.


- Step 2 ■ Place the cursor over the poly on the right hand nfet (fet on the bottom) and click the left mouse button (Button-1).

- Step 3
- Now move the cursor up. A poly wire should follow the cursor, as shown in Figure 10. If the wire doesn't start in poly, check and make sure the **Active** layer is set to **auto** (the upper left corner of the MAX window).

Figure 10: Drawing A Wire



- Step 4
- If at any time when in wire mode you wish to bail out and start over, you can do so by typing **Ctrl-c**.



**Tip** **Ctrl-c** always aborts any sub-mode and returns you to main mode.

As the pfet is not directly above the nfet we need a “kink” in the wire. You do this by simply clicking the left mouse button (Button-1) where you want the kink.

- Step 5
- Move the cursor up and then click with the left mouse button to add a kink.
- Step 6
- Now move the cursor to the right until it's directly under the pfet poly and click the left mouse button again to add another kink.

### Step 7

- Finally, move the mouse up until it's over the pfet poly. If you glance up at the MAX Info Bar, notice that it says “**BUT-1 adds new segment BUT-3 ends**”. This means that when you click Button-3 it ends the wire.

In fact, MAX does even better than that. If you click the right mouse button over the poly but are not exactly in the middle of the wire, MAX will actually snap the wire into place for you and end it. How about that?

If you didn't put the wire exactly where you wanted it don't worry. You can always undo. While in wire mode, undo (**u**) will back up one segment at a time.

You might have noticed that the little piece of poly you just added is a brighter color than the poly that was part of the gcell fets. This is a feature in MAX that is designed to help you know what you are editing. Paint or objects that you draw in the cell you are currently editing show up brighter than the cells you are not editing. This includes gcells. Thus, since you are not editing the gcell fets, they show up dimmer than the cell that you are editing.

If you wish to have all of the layers show up the same brightness (even in the gcells or subcells) then go to the File, select User Preferences, select Display Options..., then select Dim Non-Edit Cells and click Done. The radio button should go “off” with the non-edit cells no longer dimmed.

## Editing a Placed Wire

Once a wire has been placed, you can edit the wire. The Edit menu contains commands to Move, Stretch, and Fill any painted layout, including wires.

You may find that it is sometimes even faster to simply redo a wire if you need to make a number of edits.

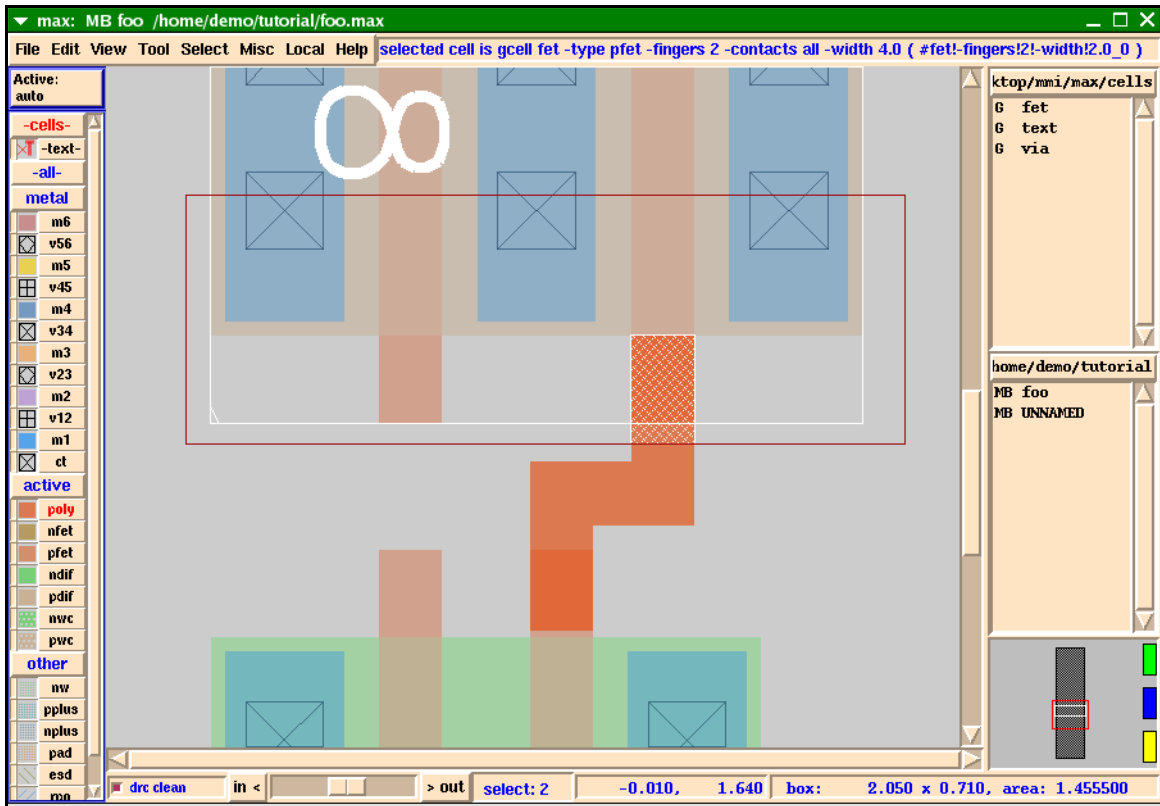
If you just want to move the wire a little you can select the wire segment you wish to move and then move it using the arrow keys. The arrow keys will do a “stretchy” move.

Let's try a stretchy move with our connected fets.

### Step 1

- Draw a box by holding down and dragging Button-1 so that it encloses part or all of the pfet, and part of the vertical section of the poly wire, as shown in Figure 11.

Figure 11: Stretchy Move



Step 2 ■ Press the up arrow key a few times and notice that the poly wire stays connected.

Step 3 ■ Undo your stretchy move with the **u** hotkey.

Now let's move the middle segment of the poly wire.

Step 4 ■ Select the horizontal section of the poly wire by clicking on it with BUT-1, as shown in Figure 12.

Figure 12: Moving Wire Segment



- Step 5
- Use the up and down arrow keys to move the segment. Notice that the wire stays connected.



If you want to move (and keep the net connected) the segment a long distance, you can use Ctrl-Button-3. Using Button-3 without the Ctrl will move the segment but will not maintain connectivity.

If you are using the arrow keys for the move and do NOT want the wires to stretch, hold down the Shift key when moving the selected layout.

- Step 6
- Finish wiring up the fet's gates by drawing the second poly wire as shown in Figure 13 using the wire (hotkey: **w**) command.

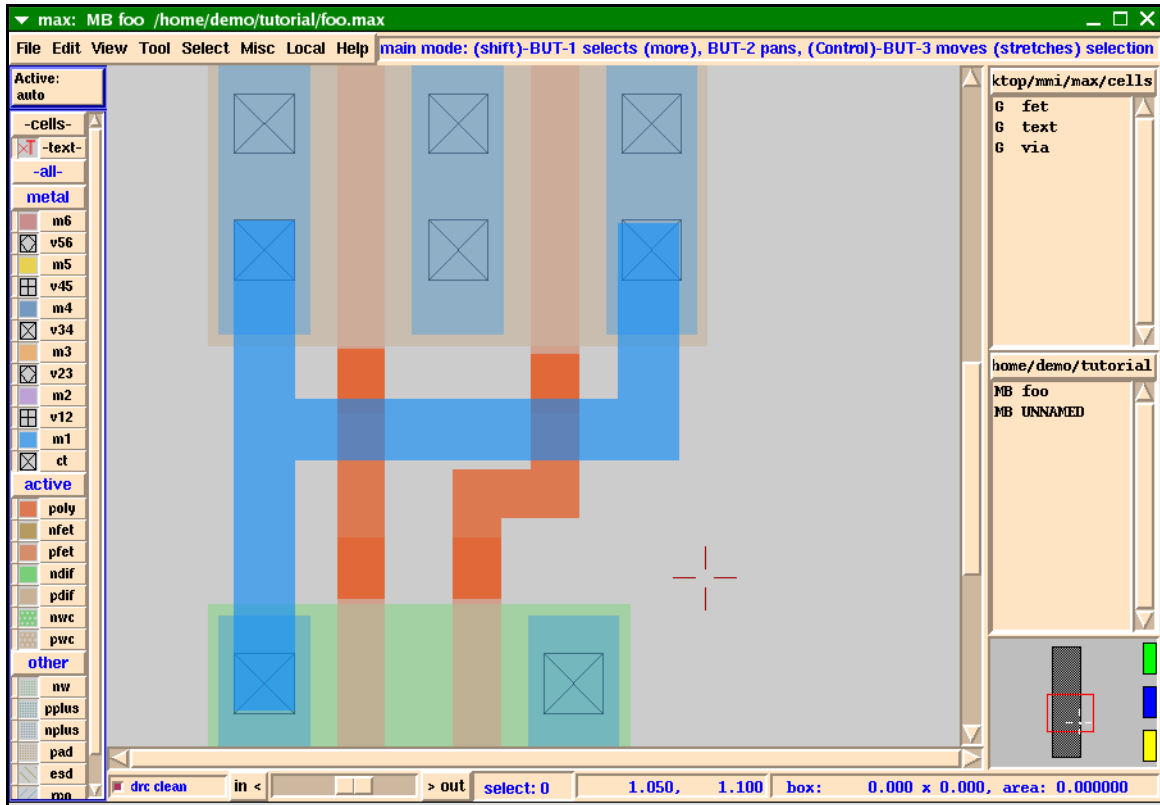
Now wire up the metal just as you did the poly.

- Step 7
- Get into wire mode (hotkey: **w**) and then click on one of the contacts and draw the metal so it looks like Figure 13.



- Step 8 ■ First wire the two left contact regions and then add the connection to the right pft contacts.

Figure 13: Wired 2 Left Poly Gates



When starting a new wire, the Active Layer box (remember it's on the top left just under the File menu) tells you what layer the wire (or circle or polygon) is going to be drawn in. If it is set to *auto* it picks the layer under the mouse.

If you want to tell it exactly which layer to start drawing on, then hold down the left mouse button (Button-1) over the Active Layer box. When the popup appears simply place the mouse over the layer you want and then release the button.

Since you have done a fair amount of work you should now save your layout.

- Step 9 ■ Type **Ctrl-s**, or select Save from the File menu. Notice that the **M** next to the **foo** in the Cell List went away. There is now a **W** next to **foo** which means that the cell has been written.

## Adding the Power Rails

We are ready to put in the power rails. Let's say we were laying out this NAND gate for a standard cell library. Furthermore, assume that the power and ground rails are run in Metal 1 (M1) and that they are 2µm wide.

Before adding the power rails, you need some more information about the wire mode, the box and the palette.

We could use the wire tool to draw the power rails, by drawing wires with width set to 2um. To do this, you would start drawing a normal wire (hotkey: **w**) in layer M1, positioned above or below the fets. Then, press and hold the right mouse button (Button-3) to access a popup menu for wiring options, including the current wire width. Here you can set the wire width of the current wire segment(s) to 2um, or whatever width you want.

You can also set the default width, spacing, and snap grid for each wire layer in the **Wiring Parameters** menu. It is found under **User Preferences** in the **File** menu, then choose **Wire Setup...** (or just use the **Shift-w** hotkey), then choose **Wiring Parameters**.

But this is a good opportunity to use paint directly. MAX has excellent capabilities for low-level layout “rectangle hacking”, and this is an ideal way to put in the power rails. To use paint effectively in MAX, we will first have to learn to manipulate the Box and use the Palette.

## The Box

The Box is important in MAX because it is used by many commands to determine where you are going to place, or do, something. For painting, the Box marks the region where paint is going to be drawn or erased. We have already seen the Box on the screen while doing the commands above; for example, the **Align Objects** command.

You can create a box by simply holding down the left mouse button (Button-1) and dragging the outline about a region.



Drawing a box by holding down Button-1 also automatically selects what is under the box, so don't drag a box around an entire chip! Use Box Mode (below) for that.

Assuming you were in **main** mode (the default), any paint within the box is selected. This is the way we have done things thus far.

You can also position the box exactly by typing **Shift-b**, or selecting **Box Dimensions** from the **Misc** menu, or by clicking on the **Box Size** window in the lower right corner of the display. Any of these will show a menu that allows you to precisely set the box size.

## Box Mode

Box Mode is useful when you need to do detailed layout. You can resize the box to the exact size you want, and place it exactly where you want it, without having to worry about corrupting any existing paint that you might have inadvertently selected.



Dragging out a box in this mode does NOT select anything.

After typing **b**, (or Make Box in the Misc menu) you can do any of the following:

- You can specify a new box position by holding down the left mouse button (Button-1) as you drag out a region, then release Button-1.
- Resize the existing box by moving the mouse over the sides or corners of the existing box until the cursor icon changes (to either a 'stretch-arrow' or a 'corner'), then drag that side or corner by pressing and holding the left mouse button (Button-1).
- Move the box by holding down the right mouse button (Button-3) and moving the mouse (a four-cornered arrow cursor appears).

## The Palette

A few more words about the *Smart Palette*. Remember, down the left side of the window is the Smart Palette.

The Smart Palette provides many features. It allows you to control what you can see, what you can select, what's under the cursor, what you can paint, and what the layers look like. Remember the MAX Message Area (directly to the right of the Help menu) will tell you what the available options are if you place the mouse over the palette.

- To control which layers are *visible*, click the left mouse button (Button-1) over the little colored square (to the left of the layer labels m5...v45...m4, etc.).
- To control *visibility by group*, click the left mouse button (Button-1) on the group button: **metal**, **active**, or **other**. This is a very useful feature for reducing clutter when you are working on a subset of the layers.
- To control which layers are *selectable*, click the left mouse button (Button-1) on the **layer name** (such as m2, v12, pfet, and so on). The layer name button will turn grey, and that layer will be disabled (NOT selectable). Or click the right mouse button (Button-3) over the group button to toggle selectability for the entire group.
- Layers which are *under the mouse* are indicated by a small rectangular red LED just to the left of the colored boxes.
- Layers which are *currently selected* are indicated by the layer name(s) changing from black to red.
- Finally, you can *change the color or stipple patterns* of any of the layers by clicking the middle mouse button (Button-2) over either the colored box or the layer name. This brings up the MAX Color/Stipple Editor. Using the editor, you can even change the colors of things like the background (for example, make it black), the grid, labels, etc.

While the grid color is changed in the MAX Color/Stipple Editor, the grid size and style are changed in Grid Setup... under User Preferences in the File menu, or by typing the **Shift-g** hotkey.

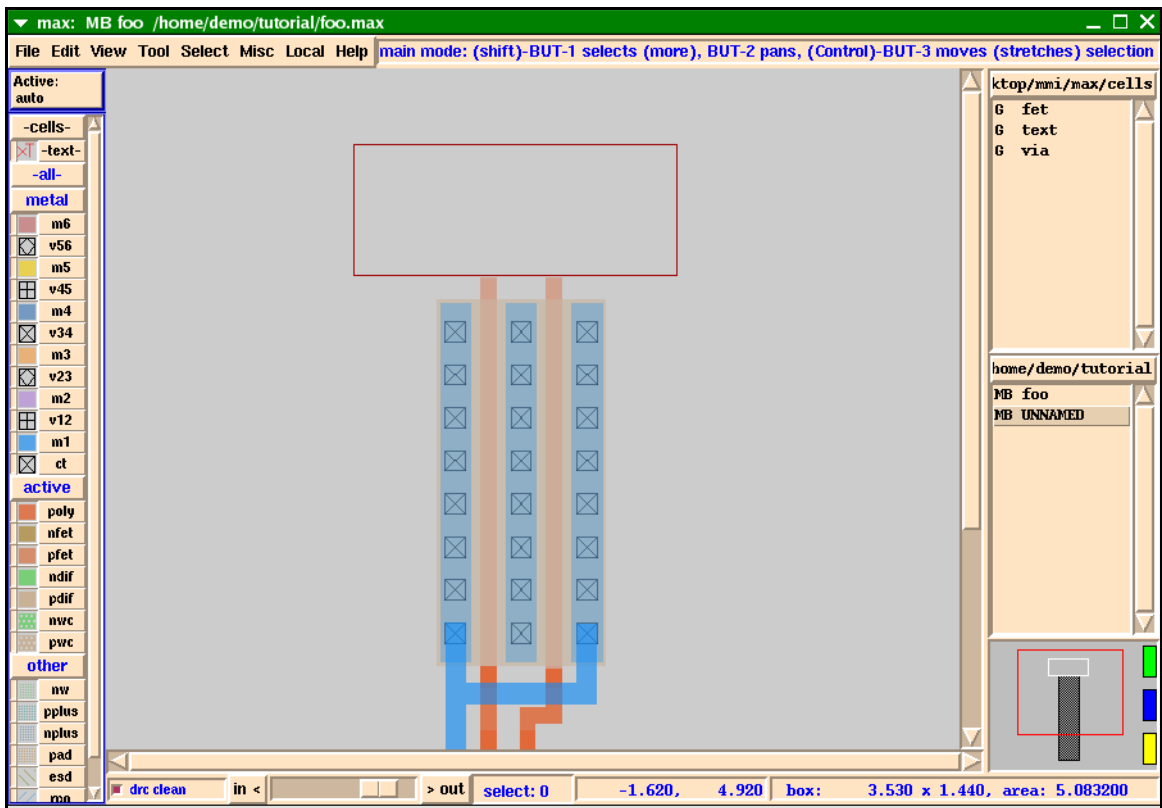
Remember, Undo (hotkey: **u**) can recover from this.

## Painting the Power Rails

Now we are ready to add the power rails as paint rectangles.

- Step 1 ■ Hold down the left mouse button (Button-1) and drag out a region where you want to paint the new Vdd power rail as shown in Figure 14.

Figure 14: Drawing a Box for Painting Power Rails



- Step 2 ■ Place the cursor over the M1 button in the palette (on the left), then click the paint hotkey **p** on either the text 'M1' or the little blue square (palette box) immediately to the left of the word 'M1'.

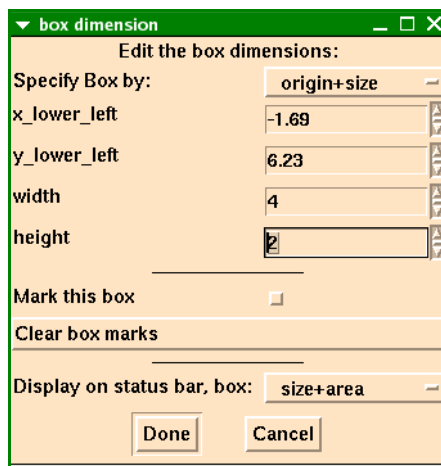


If you click the **p** hotkey over a place with NO layout, then the paint in the area under the box will be *erased*.

If the box isn't the size you want it (see the lower right corner for the box size) you can make the box exactly 2 $\mu$ m tall.

- Step 3 ■ Undo (**u**) the M1 paint before we resize the box.
- Step 4 ■ To make the box an exact size type **Shift-b**, or select Box Dimensions from the Misc menu. A popup menu as shown in Figure 15 appears.

**Figure 15: Box Dimensions Popup Form**



- Step 5 ■ Make sure the Specify Box by: is set to origin+size. Then type in 4.0 for the width and 2.0 for the height, then click Done.
- Step 6 ■ Fill the box with M1 by clicking **p** (paint) on the 'M1' paint square in the palette or any M1 in the layout.

Remember you can always resize or move the box as previously described in the section on The Box.

You can change the size of a paint region by stretching an edge of any width using the Edit Rectangle Edge command found in the Edit menu (hotkey: **a**).

- Simply type **a**. The cursor changes to let you know you are in Edit Edge mode. Now move the finger over the edge you wish to stretch. A little select box will show you which edge you are over.

- Once you have the edge you want, hold down the left mouse button (Button-1) and move the mouse in the direction you wish to stretch the edge. Release the button when the edge is where you want it.
- You can also change the size of a paint rectangle by first selecting it, and then selecting Edit Properties from the Edit menu (Hotkey: **Ctrl-p**).

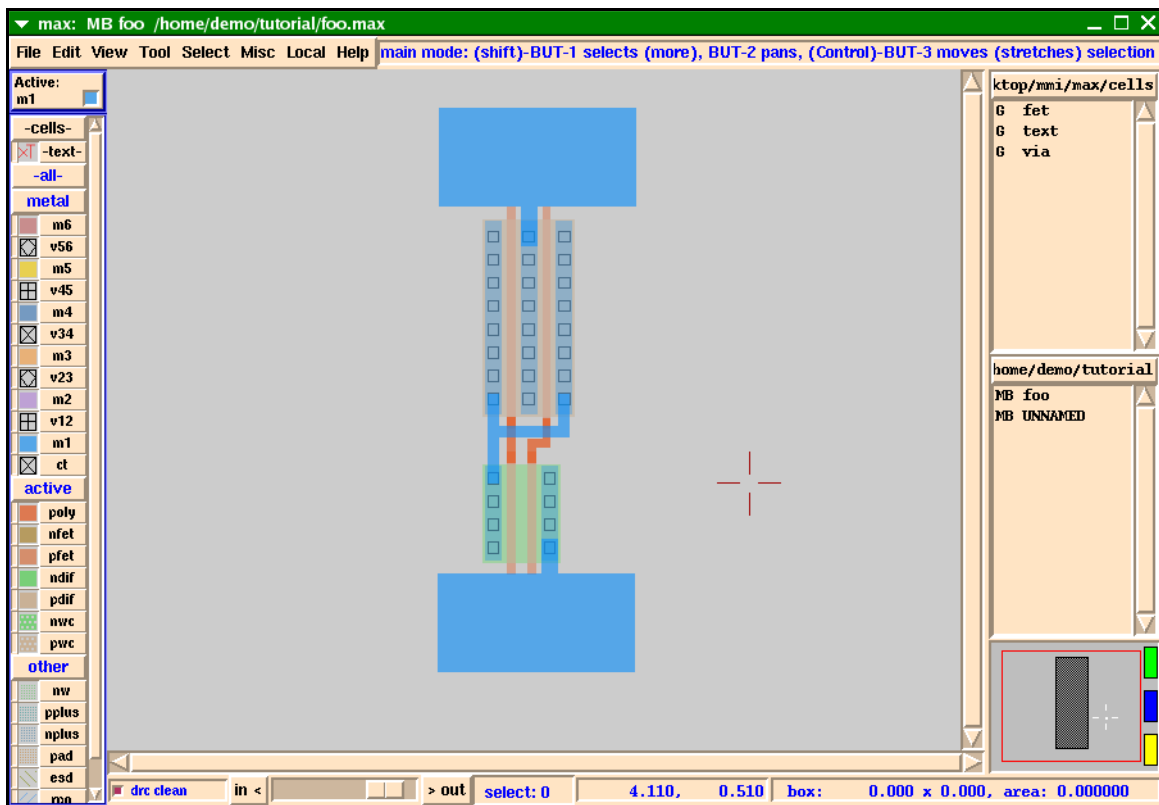
Once you have painted the top power line you can simply duplicate the top power line and move it down.

- Step 7     ■ Select the power line with the left mouse button.
- Step 8     ■ Duplicate the top power line (hotkey: **d**) and move it down as shown in Figure 16.



**Tip** If you duplicate something and hold the Shift key down while moving it, the duplicated item will remain lined up with the original.

**Figure 16: Nand Wired to Power Rail**



Now that you have painted in your power and ground rails you want to wire them up using the Wiring Mode as before.

- Step 9 ■ After you have entered the Wire Mode (**w**), hold down the Shift key and click the left mouse button (Button-1) over the middle of the pfet contact region. This will start a M1 wire with the width of the M1 under the cursor.

By holding down the Shift key you are telling the wire tool to use the width of the wire under the cursor and NOT the minimum wire width. Connect it to the power rail.

- Step 10 ■ Now connect the right nfet contact region to the ground rail.

Your cell should now look like Figure 16.

### **Wiring Mode - Changing Layers**

Notice that the inputs and outputs are all found within the power straps. What if they need to be brought out so a router can get to them?

Let's assume the router requires all signals to be at the top of the cell and in M1. You need to route the poly wires over the M1 power straps and then change to M1.

Wire Mode in MAX can make this job easier since it can change layers for you.

- Step 1 ■ To route the wire, type **w** (Wire Mode) and click the left mouse button (Button-1) over one of the poly wires.

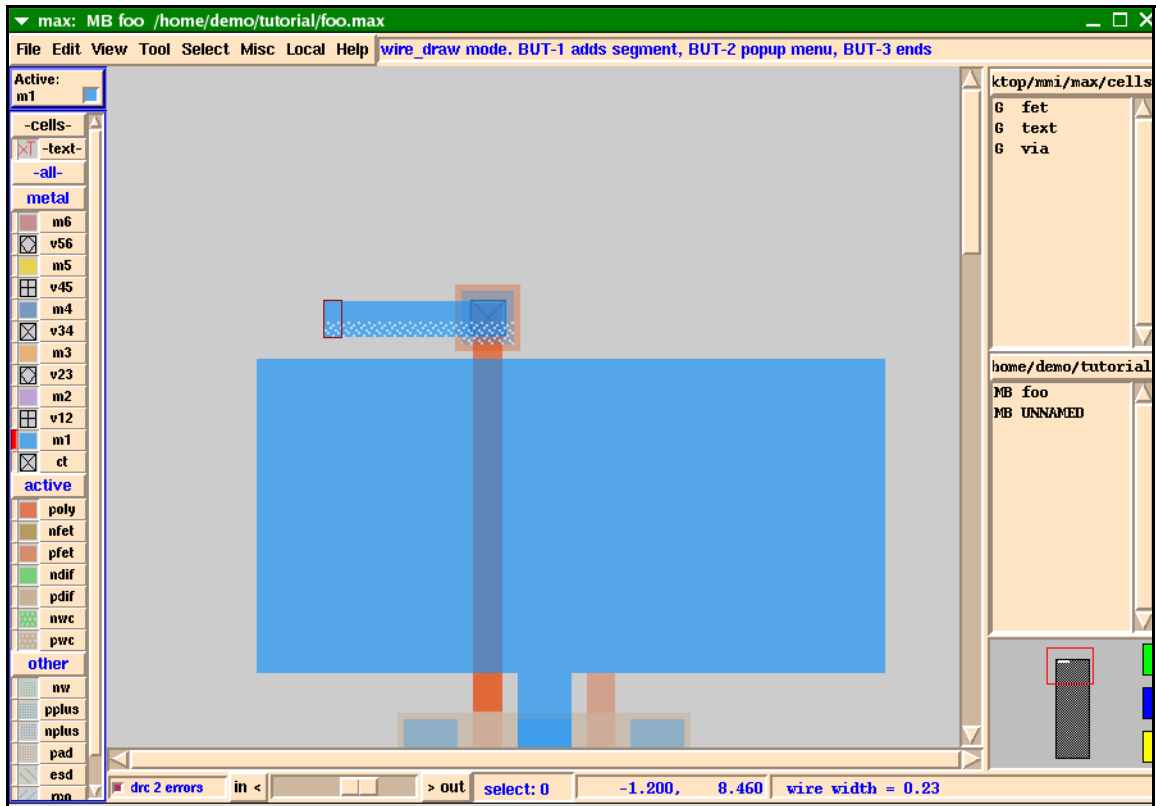
- Step 2 ■ Drag the mouse up and over the M1 power rail, drawing the poly wire.

- Step 3 ■ Type **d**. This will **drop a poly to M1 contact** for you, which you can move around.

- Step 4 ■ Now try moving the mouse to the left. This will draw a M1 line left of the contact. While holding the mouse to the left try moving it up and down (north and south).

Notice that the contact tracks the vertical location of the mouse for you. Also notice that the DRC is working while you are moving the contact. Whenever you get too close to the M1 Vdd line, the little white DRC dots appear, as you can see in Figure 17.

Figure 17: Active DRC Showing Errors As Wire Is Drawn.



- Step 5
- Move the mouse around to get the contact where you want it (no DRC errors), press and hold the middle mouse button (Button-2), and select `anchor vertex` from the popup menu or simply type the hotkey `a` to 'freeze' or anchor the contact in place. Then drag the mouse upward.

As you continue dragging the mouse upward notice that you are now in M1. If you hit `d` (***drop a contact***) again, you will add a via1 and automatically change to M2. This will continue until your technology runs out of metal layers.

The generic technology file we have included (mmi18) has six layers of metal.

Tip

You can zoom in on an area while in wire mode. Click the hotkey `z` and zoom in on the desired area with Button-1. You are then returned to wire mode. You can also zoom out (**Shift-z**) or zoom to fit (**v**) while in wire mode.

- Step 6
- End the wire by clicking the right mouse button (Button-3) at the desired location, as shown in Figure 18.





Typing **d** in wire mode drops a contact and brings you up to the next higher layer. If you want to go down a layer simply type **Shift-d** and the wiring tool will drop a contact or via, and bring you down to the next lower layer.

There are LOTS of other options in the wiring tool, such as snap to grid, wire in 45's, change wire layer, and more.

- To see the Wire Mode menu simply hold down the middle mouse button (Button-2) when in wire mode. This will bring up the Wire Mode pop-up menu.
- One of the options is **Shift-w** which brings up a more extensive Wire menu (also found as Wire Setup... in User Preferences under the File menu). This menu gives you such options as Active Layer (which can also be set via the Active Layer Box in the upper left corner of MAX), the Default Layer, Snap options, and you can even override any or all of the wiring parameters.

Remember, for a list of all the options (hotkeys) while in wiring mode, hit the Space bar, or select hotkeys in the Help menu.

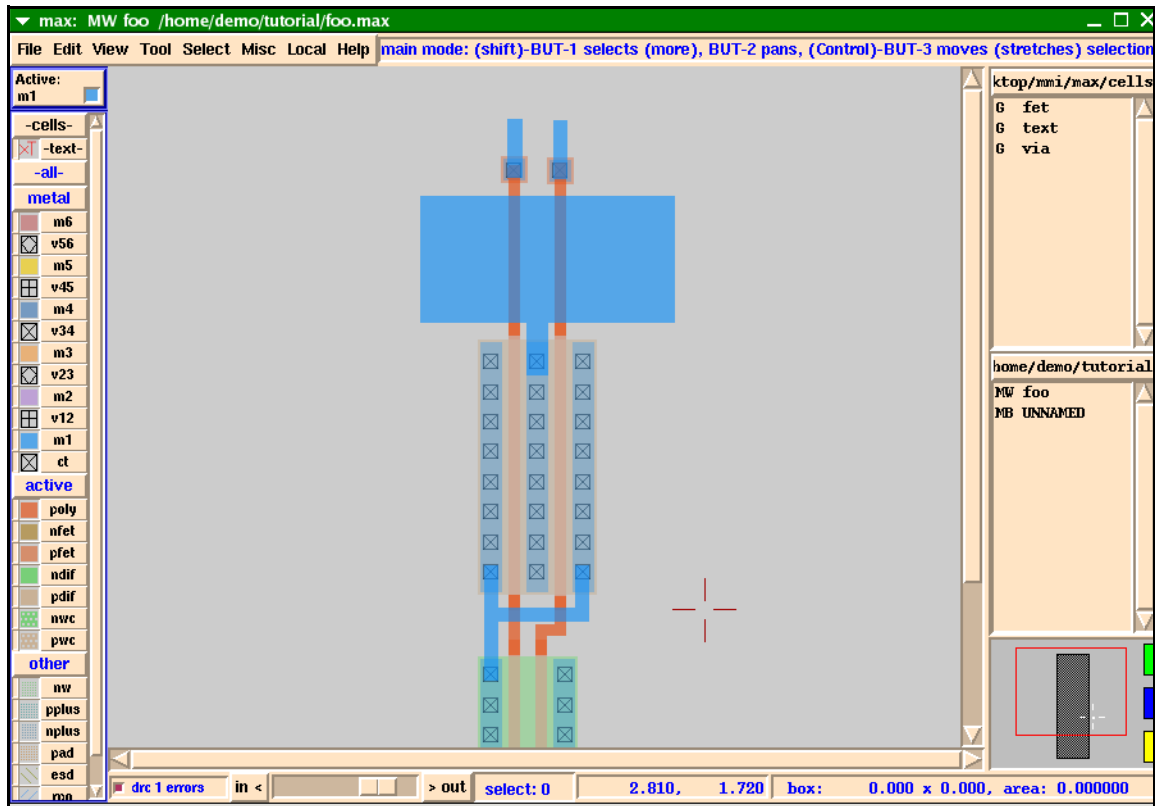
Space bar hotkeys option works for ALL modes in MAX.

#### Step 7

- Wire up the other poly input.

Your cell should now look like Figure 18.

Figure 18: Inputs of Nand Brought Outside



If the top of the M1 wires are not aligned as shown in Figure 18, there are a number of ways to align them.

- Step 8
- The easiest way is to draw a box and select the top edges of both wires. Then click the erase hotkey **o** over empty space (any area where there is no layout) and the selected paint will be erased.

You can also use the **F**ill command in the **E**d*i*t menu to extend both top edges of the M1 wires up. (Refer to the Micro Magic, Inc. *MAX User Manual* for more details.)

## Erasing Layers

We are getting ready to finish this cell and your boss has just informed you that the power rails have been changed from M1 to M2.

- Step 1
- To change them simply hold down the left mouse button (Button-1) and drag a box around the upper (Vdd) rail to select it.
- Step 2
- Now if you type the Erase command (hotkey: **o**) over blank space on the screen it will erase everything within the box. But wait! You also have some poly within the box. If you erase everything inside the box your poly will also go away.
- Step 3
- Undo (**u**) your last change.

MAX allows you to selectively erase layers.

Step 4 ■ To do this select the M1 power rail by drawing a box enclosing the M1 power rail.

Step 5 ■ Then, select the Erase command (hotkey: **o**) over a piece of M1 in the layer, or 'M1' in the palette. The Erase command (**o**) tells MAX to erase the layer under the cursor.

Like the painting function, erasing works from both the palette and by clicking on the layer in the actual layout.

You will notice that the box is not the correct size.

We're now going to erase the M1 a third way.

Step 6 ■ Undo (**u**) your last change.

Step 7 ■ Click with Button-1 on the M1 power rail. You may need to click a second time to select the entire power rail.

Step 8 ■ Now, to selectively erase M1, click the **o** hotkey over a piece of M1.

Once you have erased the M1 layer, notice that your box is exactly the size it needs to be for the M2.

Step 9 ■ Simply click the **p** hotkey over 'M2' in the palette.

There are several ways to accomplish what you just did. For example, rather than drawing a box around the M1 power lines - which also selects the poly crossing over it - you could click the left mouse button (Button-1) over the M1 power line to select it. Once selected, hit the **Delete** key to delete the selected item.



**Delete** will delete everything you currently have selected, including paint, polygons, gcells, and sub-cells.

There are several options for mouse selection.

- Clicking button-1 will select the object or rectangle of paint under the cursor.
- Holding down the Shift key while clicking button-1 will add to the selection.
- Holding down Button-1 while dragging out a region will select objects and paint within that region.

Once you have selected the layer, instead of deleting it and then replacing it with another layer, you can also use the nifty little Change Layer feature found in *Edit Properties...* under the *Edit* menu.

Change the lower (GND) M1 and replace it with M2.

Step 10 ■ To do this simply select the M1 rectangle, then choose *Edit Properties...* from the *Edit* menu, or type the **Ctrl-p** hotkey. Change the layer to **M2** and click **Done**.

Now go ahead and attach the power and ground lines to the new M2 straps.

To do this, use the wire mode.

- Step 1     ■ Start the wire (**w**) from the M1 wires using Shift-Button-1, so that the wire width will match.
- Step 2     ■ When you are over the M2 straps type **d** to add a via to M2
- Step 3     ■ Click the right mouse button (Button-3) to end the wire.
- Step 4     ■ Next route the output to the top over the M2 next to the inputs so the router can get to it as well.



This will introduce a DRC error if you followed the layout instructions as stated.

- Step 5     ■ Select the two **ct\_poly** gcells and the two pieces of M1 using Shift-Button-1 to add to the selection, as shown in Figure 19.
- Step 6     ■ Use the right arrow key to move the selection to the right until there are no more DRC errors.

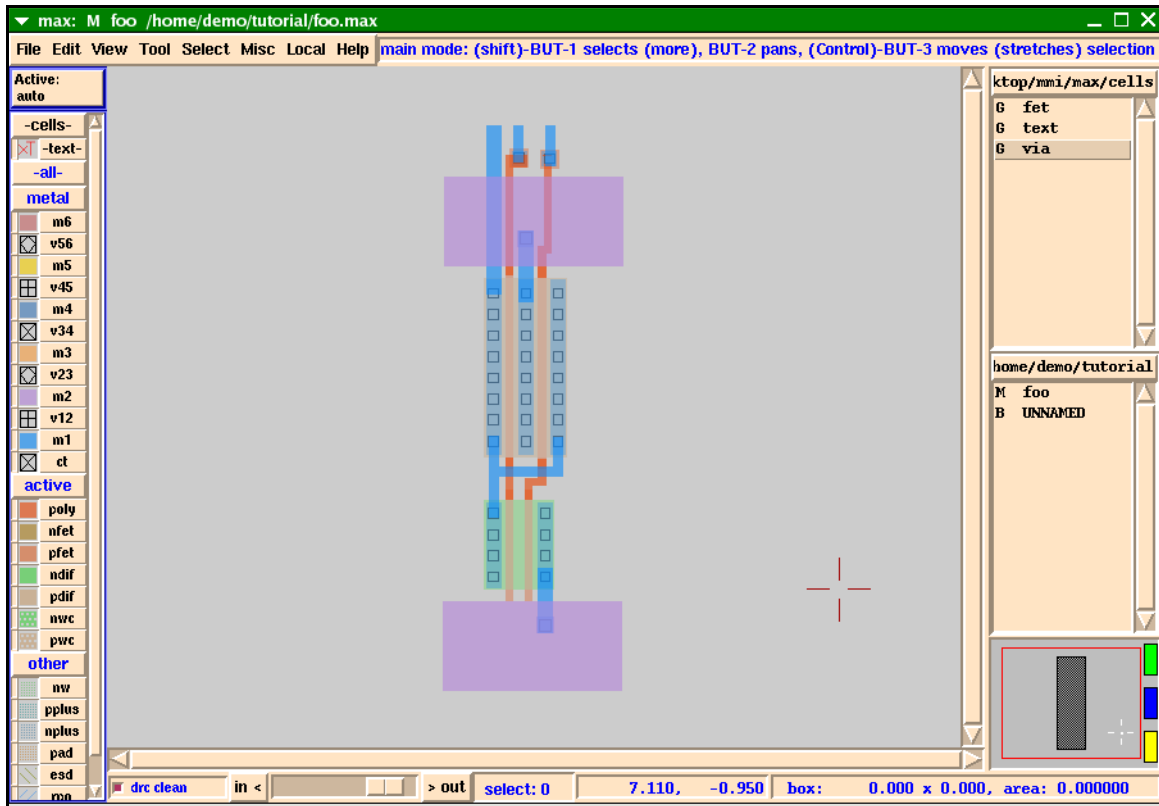
Figure 19: Selected Poly Gcells And M1 Wires



You could also jog the M1 output, or the poly lines going under the M2 as well. It's up to you.

However you do it, your design should now be DRC correct and look similar to Figure 20.

Figure 20: Nand Gate Wired Up



## Text

There is one last thing before we are finished with our Nand gate.

The input and output nets of the Nand gate should be marked with unique names. This is accomplished by adding **Text** to the nets.

- To add Text, you first select the paint rectangle where you want to put Text. Simply click the left mouse button (Button-1) on the piece of paint, which will select the paint rectangle and place the Box around it.
- The new Text will be positioned in the center of the paint rectangle. To position the Text elsewhere, use the left mouse button (Button-1) to drag a small box over the paint at the location where you want the Text.
- To edit text that has been placed, first select the text (it will turn white) and press **Shift-t** to bring up the MAX Text Edit dialog box.

Step 1 ■ Select the ground (lower) rail (click with Button-1)

Step 2 ■ Then type **t** for **Text**, or choose Add Text from the Edit menu. The MAX Text Edit dialog box will appear.

- Step 3 ■ Enter the name **GND** into the Text field.

The MAX Text Edit dialog box permits you to set the type of Text label: **input**, **output**, and so forth. Marking labels as inputs, outputs, global, etc. can be useful for use with other extraction or routing tools.

You can also specify the Text “position”, such as **n** for north, or **s** for south. Specifying the orientation of the Text, relative to the crosshair that marks the Text location, places it on one side or another for easier viewing.



North and south orient vertically, above or below the crosshair. All other directions orient horizontally, to the left (nw, w, sw) or right (ne, e, se) sides of the crosshair.

The Text “type” can be a **point** (the default) or a **box**. The ‘box’ option produces text which marks a specified area, but is rarely used.

- Step 4 ■ Specify the GND text direction to be **e** (*east*) and specify that it is a *global* signal.

- Step 5 ■ Now move the mouse to the point on the layout you wish the text to be and click the left mouse button (Button-1).

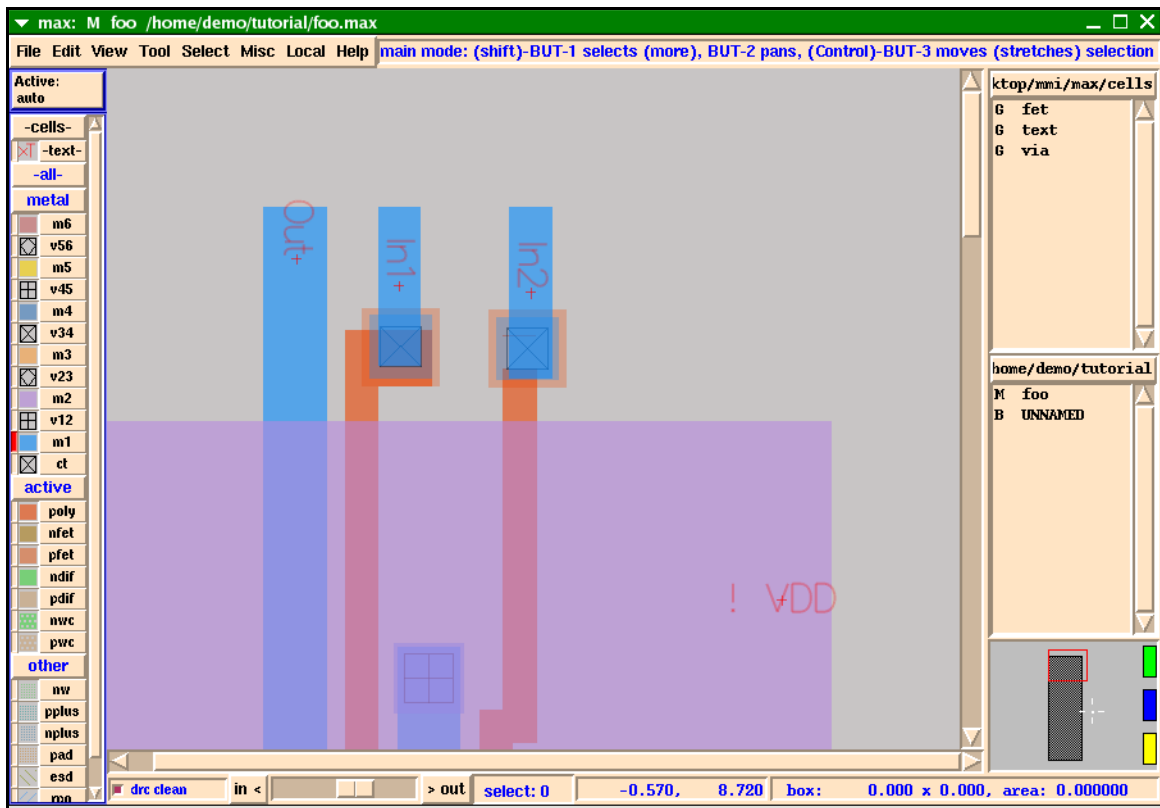
- Step 6 ■ Then click Done or hit Return.

In this tutorial:

- **VDD** and **GND** were marked as *global*, and are positioned east (**e**). Text was positioned at the far right side by first dragging out a small box close to the edge before typing the **t** hotkey.
- The inputs (**In1**, **In2**), and output (**Out**), were marked as *local*, and are positioned north (**n**). A small selection box was used to position the **Out** label at the very edge. The **In1** and **In2** labels are positioned by default in the center of their paint areas.

- Step 7 ■ Add labels for VDD, In1, In2 and Out, as shown in Figure 21.

Figure 21: Adding Text

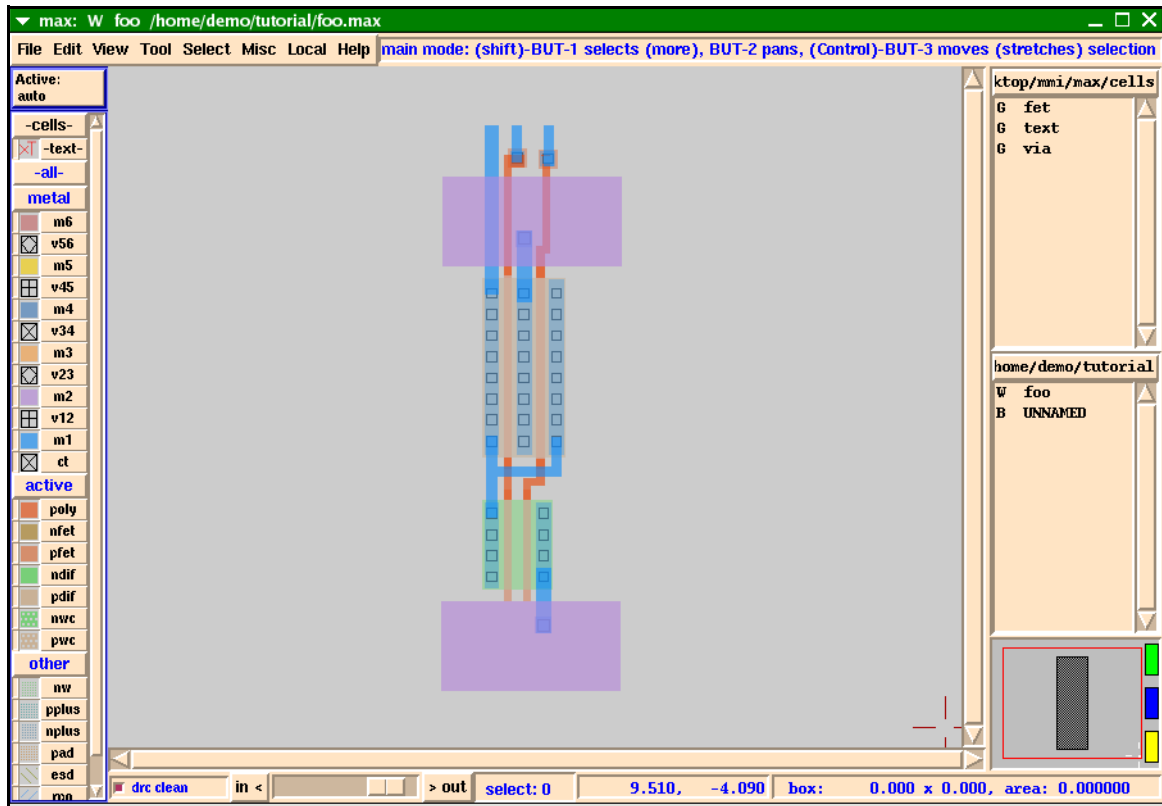


Step 8 ■ Remember to save your cell (Hotkey: **Ctrl-s**).

At this point our little NAND gate example should be done, and yours should look something like Figure 22.



Figure 22: Finished Nand Gate



You can copy the cell into a new name. Let's call it **my\_nand**.

- Step 9      ■ Select Save As... from the File menu.
- Step 10     ■ Type in "**my\_nand**" in the Filename field and click on OK.

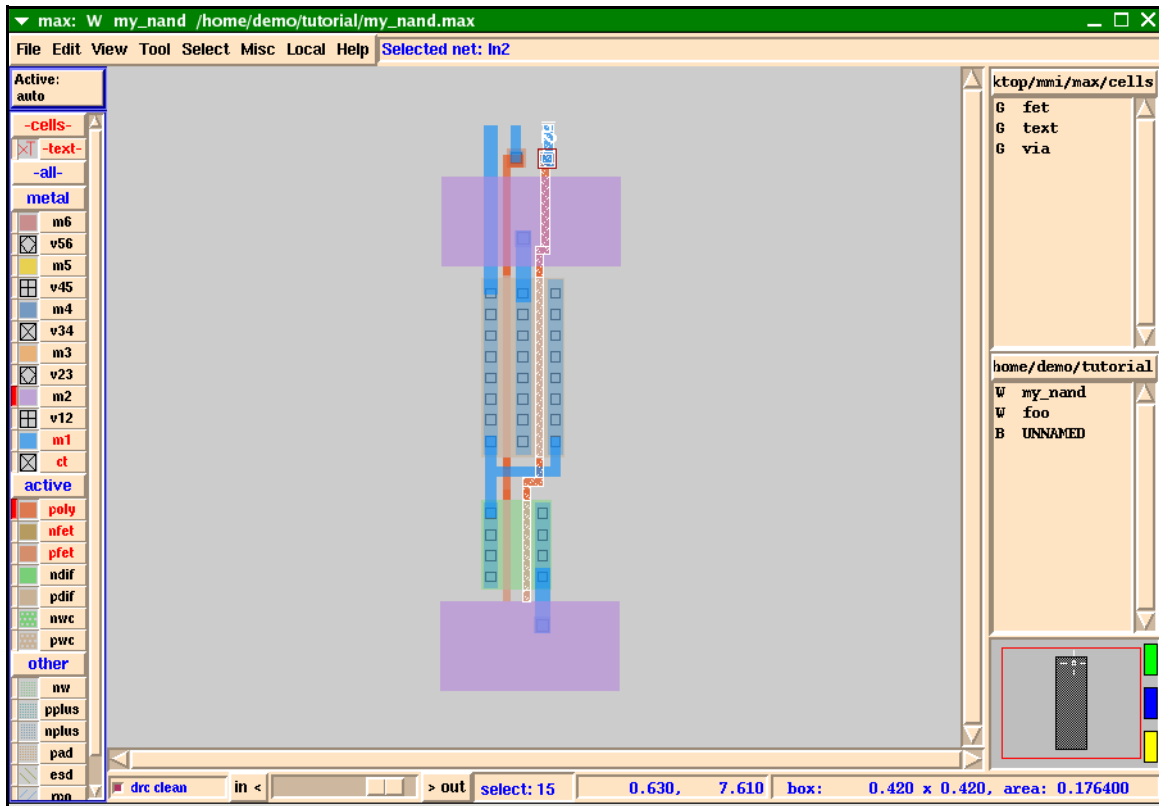
You will now see both **foo** and **my\_nand** in the List box. You are currently editing **my\_nand**.

### Selecting Nets

MAX can trace connectivity through vias and contacts to interactively show everything connected to a net. Place the mouse over any piece of metal, poly or diffusion and type **s**, or choose Select Net from the Select menu. MAX will automatically select the entire net that is connected to that piece of paint, and will also display the net name, if known, in the MAX Message Area. The net name(s) are taken from any Text (labels) attached to the net.

- Step 1      ■ Move the mouse over the M1 rectangle for 'In2' in the upper right corner.
- Step 2      ■ Type the **s** hotkey. You should now see the net highlighted as in Figure 23.

Figure 23: Highlighted Net



If there are multiple layers under the mouse cursor, you type **s** multiple times to cycle through the nets.



Tip

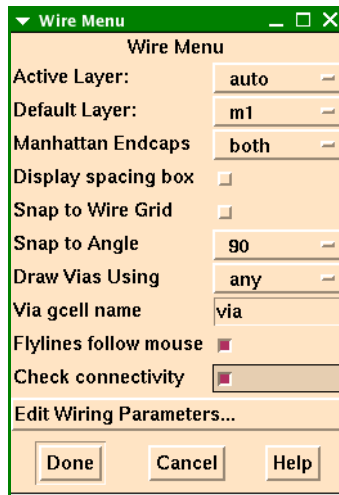
One nice feature often used for debugging is that, when MAX selects a net, the name of all of the text labels on that net are displayed in the MAX Message Area (at the top, just to the right of the menus) as well as the Command window. For example, if you select **VDD** and the names **VDD** and **GND** both appear, you know you have a problem.

MAX can also check to make sure you don't accidentally connect two nets with the wire tool which have different net names. If your nets have text on them at the level of hierarchy you're editing, you will get a warning when connecting them.

Step 3

- To use this feature, it needs to first be turned on. To bring the Wire Setup form, select **User Preferences** and then **Wire Setup** under the **File** menu. You should see the popup menu shown in Figure 24.

**Figure 24: Wire Menu Warning Popup**



- Step 4 ■ Click on the Check Connectivity toggle button to turn the feature on, and then click on Done.
- Step 5 ■ Now use the wire tool (Hotkey: **w**) to connect the **VDD** and **GND** power rails.
- Step 6 ■ When you end the wire on the other power rail, you get a warning in the Command window (the window from which you started MAX) telling you that you are connecting two different nets.

Notice that the wire does get drawn, even though it creates a short. The MAX methodology is to warn you if you're creating DRC or LVS errors, but still allow you to create that layout.

- Step 7 ■ Undo (**u**) the wire.

### **Advanced Selecting, Duplicating, And Renaming**

Let's look at a few more advanced selection techniques before we go on.

- We already know that we can *select pieces of layout* by:
  - Dragging the select box around them, or
  - Clicking on them.

Here are a few interesting things we can do with our layout.

- Select Menu ■ To *select a cell* rather than some paint or an object:
  - Position the mouse cursor over the cell and type **f** (Select Cell from the Misc menu). Type **f** repeatedly to cycle the selection through overlaid cells.
  - After all cells under the cursor have been displayed, the **f** key places a box around the entire cell.

- It's easier to use the **f** hotkey instead of the menu item for the `Select Cell` command because it uses the mouse cursor location to select cells.

#### Select Menu

- The `Cursor Probe` command is another way to see which layers and objects are under a particular point.
  - To **Probe**, put the mouse over some layout geometry in your cell and select the `Cursor Probe` hotkey: **l** (lower case L).
  - You could also choose `Cursor` from the `Select` menu, then point at the location you want to probe. The `Cursor Probe` menu that appears contains a list of all the layers and objects under that point.
  - To **select a paint rectangle** or other object, click on it in the popup with mouse Button-1. To deselect it, click again.
  - By default, only items in the current edit cell are displayed, since those are the only ones you can effectively manipulate. But if you choose the `All Expanded Cells` radio-button, the list will contain everything in any cell under the point where you probed.
  - You can also **clear the selection** by choosing `Clear Selection` from the **Select** menu.

#### File Menu

- Another way of duplicating layout is by using the `Copy Cell Buffer` command in the `File` menu. This command will copy the current cell buffer to a new cell buffer in memory. The new cell will be saved to disk when you `Save` the cell (from the `File` menu.)

#### File Menu

- The `Save As` command (also in the `File` menu) is similar to `Copy Cell Buffer`, but also immediately saves the cell to disk. In fact, the `Copy Cell Buffer` command was used to create an Inverter cell (**INV.max**) from the **Nand** cell we just finished, and the `Save As` command was used to save cell **foo** as **Nand.max**.

#### File Menu

- If you are working on a cell and want to discard its contents, perhaps to completely replace it with another cell, you can use the `Delete Cell Buffer` command (under the `File` menu) to delete the in-memory copy of a cell. This command does not affect the file on disk.

Now would be a good time to save your work (Ctrl-s).



For the next section, the examples provided in the tutorial were created using **mmi25** technology, and will not load if the technology is set to **mmi18**.

Close this copy of MAX using **Ctrl-d** or `Exit` from the `File` menu, and start a new one from a shell window using the command `max -tech mmi25`.

# Part 3

## Bigger Designs and Hierarchy

Now let's use our NAND gate and an inverter cell to build something a little bigger.

- Make sure that you are running the **mmi25** technology for this section.

If the technology is NOT set to **mmi25** then quit out of MAX (Hotkey: **Ctrl-d**) and restart it by typing:

```
max -tech mmi25
```

- Step 1
- Go to the File menu and select New... Name the new cell “row”.

You should now be editing **row.max**.

Look up at the title bar. It should say **max: B row**.

Max does not automatically load all the cells in a library. To auto load the cells you can do it from the cell list of add it to you max.rc file.

- Step 2
- Hold down the left mouse button (BUT-1) over the name of the lower cell list. It will say something like “private/tutorial/max” Select **Autoload Directory**.

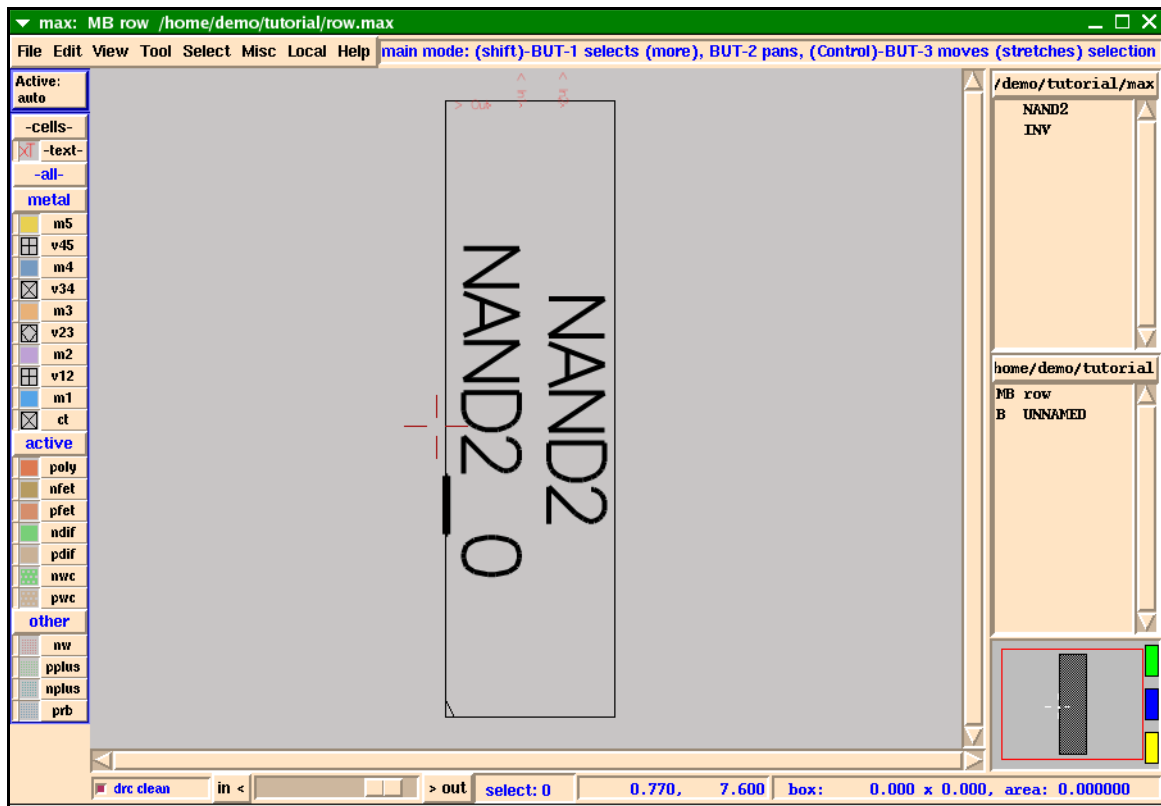
You should now see INV and NAND2 listed in the cell list box.

- Step 3
- Go over to the Cell List box and click on **NAND2** with the left mouse button (Button-1).

This drops an instance of NAND2 into your row cell. Now you should see something like Figure 25.

You only see the instantiation of the NAND2 cell and not the internals. We'll cover that later.

Figure 25: Instantiation of NAND2 cell




- Step 4 ■ The new cell should already be selected. If not, select it now by clicking on it with the left mouse button (Button-1.)
- Step 5 ■ Select **Array Cell...** from the **Edit** menu.
- Step 6 ■ Enter **4** for the **columns** field, select **cells** for the **type**, and click on **Done**.

You could also have used the text command:

```
:array 4 1
```

Text commands are typed in the MAX Command Window (the Xterm window from which you launched MAX).



**Tip** A list of text commands can be found under the Help menu. Click on a command in this list to bring up detailed documentation on it.

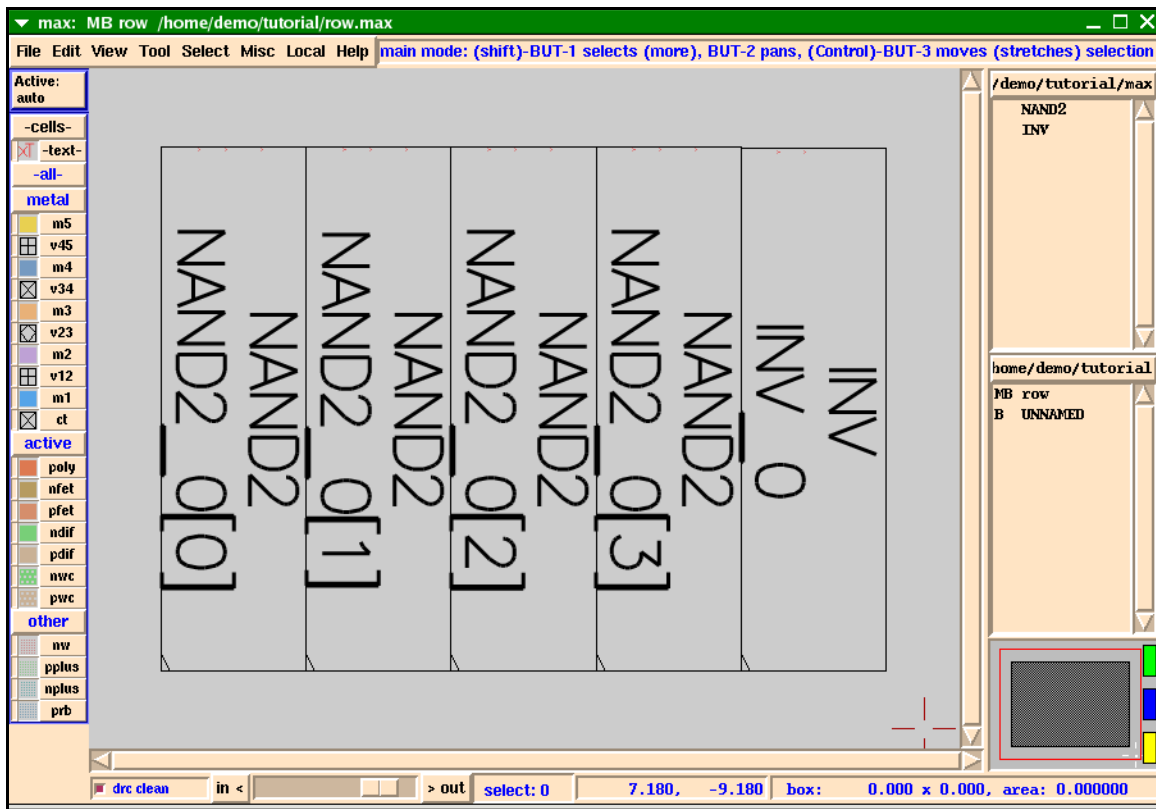
- Step 7 ■ Zoom out (hotkey: **Shift-z**) so that you can see all of the NAND2 instances.

- Step 8 ■ Return to the Cell List box and click on **INV** with Button-1.
- Step 9 ■ Place it to the right of NAND2 so that it abuts just as the array of NAND2 cells abut, as shown in Figure 26.

For easier visibility while placing objects, you can:

- Zoom in while you are moving an object using **z**, **Shift-Z** or **j**, or by using the scroll wheel on your mouse.
- Place the object and then zoom in and use the arrow keys for more precise positioning.
- Use the **Align** command to help align the bottom edges.

**Figure 26: MAX Hierarchy**



While placing the inverter, white dots may appear indicating that the DRC check is working. DRC checking runs automatically as you go, and the dots disappear once the inverter is correctly positioned. This works even though the lower level of hierarchy is not visible.

Your layout window should now look like Figure 26.

## Show/Hide Internals

You might want to see what's inside of the NAND2 cells or the inverter.

- Step 1 ■ To do this, select the **INV** cell by clicking on it using the left mouse button, or by typing the **f** hotkey, and then type **Shift-i**, or select **Internals, View Cell** from the **Internals, Misc.** menu under the **View** menu. (Typing **Shift-h** will Hide Internals for the cell.) This shows you the internals of just the INV cell.
- Step 2 ■ To view internals for the entire design, type **i (Internals, View All** from the **View** menu).

Note that the NAND2 cell looks a lot like the NAND cell you laid out earlier; however, to make life easier, we have made sure the power rails will line up with the other cells in the library.

## Push, Pop, and Edit in Place

OK, at this point let's say our boss comes over again and says: "Sorry, but you need to bring the outputs to the bottom of the cells".

There are two ways to do this. We will use one method on the **INV** cell and the other (just to be different) on the **NAND2** cell.

### First Method: Editing by Pushing Into Cell

- Step 1 ■ First, select the **INV** cell using **f** or **Select Cell** from the **Select** menu. If you get a fet or row selected, type the **f** hotkey multiple times until **INV** is selected.
- Step 2 ■ Now type **e** to edit the cell or select **Push into Cell** from the **View** menu.
- Step 3 ■ Once inside the cell, add the output wire as you did before using the wire mode. Refer to Figure 20.
- Step 4 ■ Now type **Ctrl-e** or **Pop out of Cell** from the **View** menu to "pop" up a level and return back to **row.max**.

You should now see that the change you made is in the **INV** cell within **row.max**.

### Second Method: Editing Cell or Object in Place

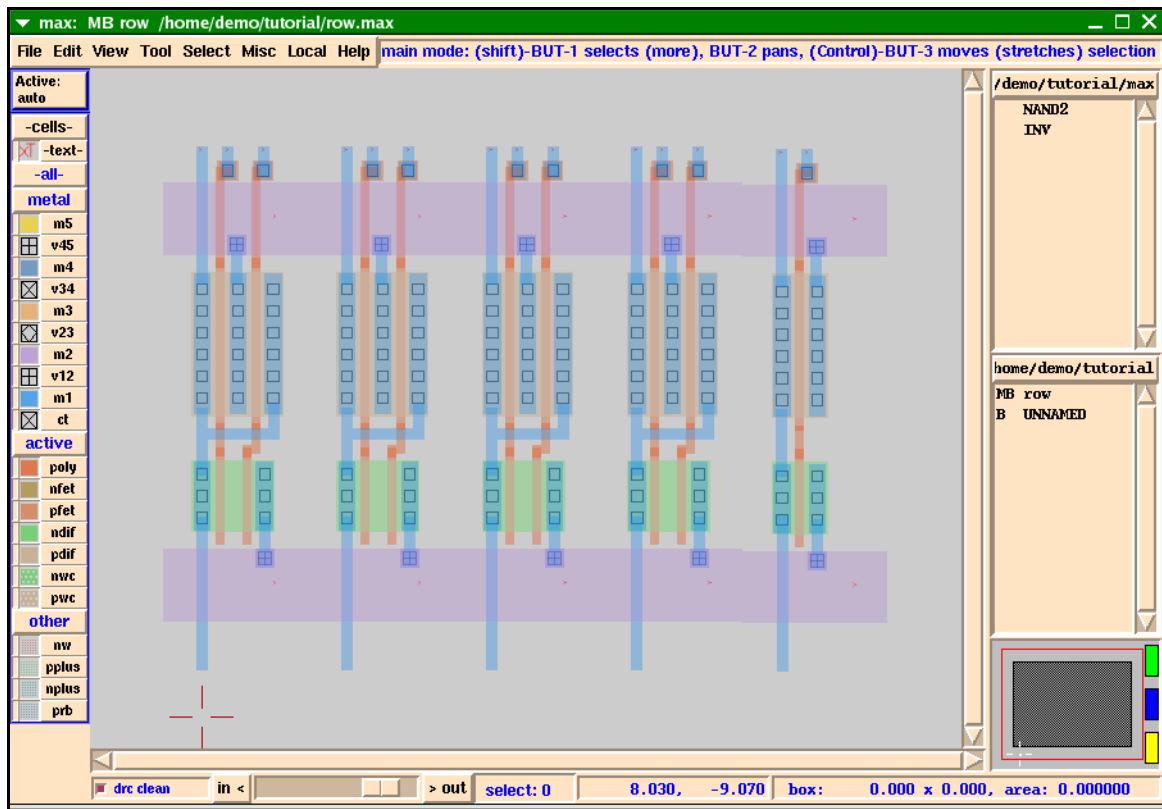
Now let's edit the **NAND2** cell. To do this one we are going to use the **Edit Cell or Object in Place** option from the **View** menu.

- Step 5 ■ Select the **NAND2** cell, then type **Shift-e** to **Edit in Place**.  
  
Notice that the **NAND2** cell you selected appears darker than the other cells. This tells you that you are now editing that cell.
- Step 6 ■ Go ahead and add your new wire. You will see that the wire appears in **ALL INSTANCES** of **NAND2**, not just the one you are editing.
- Step 7 ■ Type **Ctrl-e** to pop back up to the top level (row).



Your row cell should now look like Figure 27.

**Figure 27: Outputs Brought Out to Bottom**



Now, just for grins, let's wire up two of the gates.

Since we want to wire them up in `row.max` and NOT in `NAND2.max`, we must first make sure `row.max` is our *edit cell*.

NOTE: You can always tell which cell you are editing by looking at description in the MAX Title Bar.

To get back to `row.max` (if you're not there already) there are several methods:

- Type **Ctrl-e** a few times or until you are sure you have popped out of any cells you entered using **Shift-e** or Edit Cell or Object in Place from the View menu. Watch the MAX Title Bar.
- You can also click with Shift-Button-1 on `row` from the Cell List box.

In general, *push*, *pop*, and *edit in place* work well for cells in the same hierarchy, while using the Cell List boxes is the preferred method for traversing larger, less connected databases.

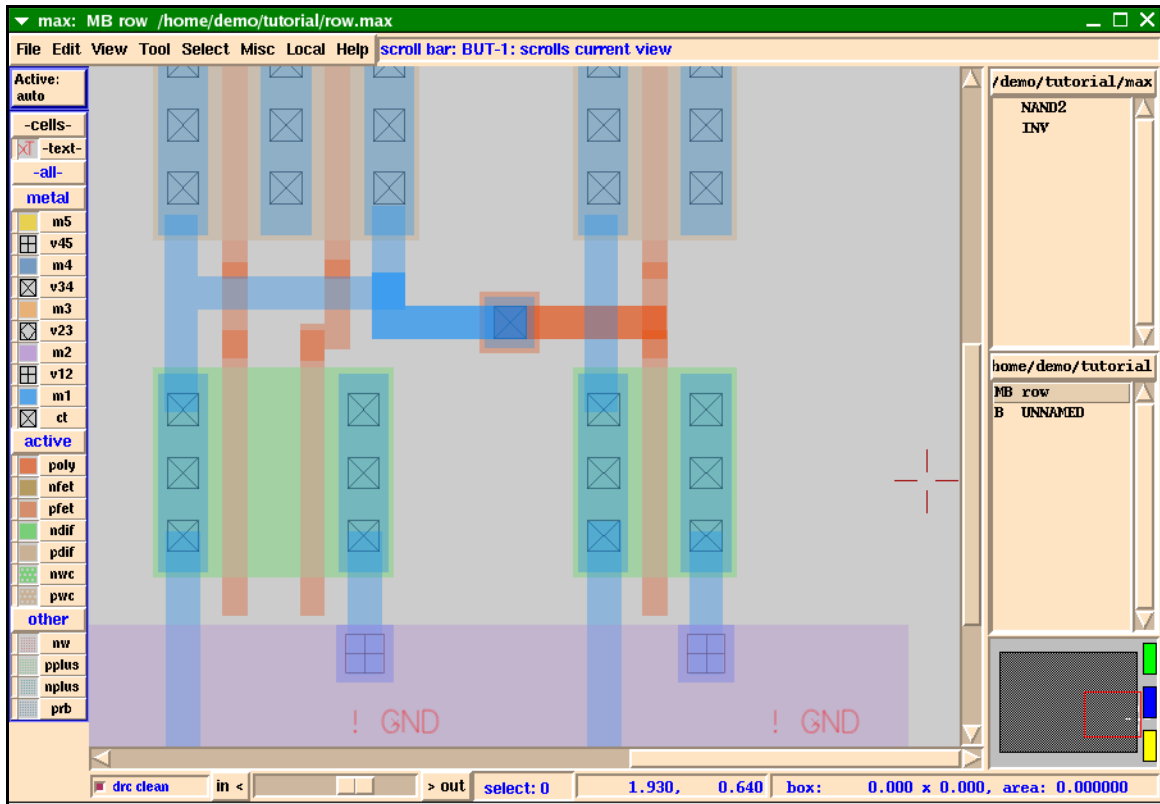
#### Step 8

- Now that `row.max` is your edit cell, use the wire mode to hook up a couple of wires.

Notice that these wires are once again darker than the wires in the cells.

Figure 28 shows a zoomed in view of a couple of gates wired up within `row.max`. You can see that the new wires in `row.max` (the current edit cell) are darker than the wires contained within `NAND2.max` and `INV.max`.

**Figure 28: Cells Wired Up**



Let's save our work.

- Step 9** ■ Select **Save Multiple** from the **File** menu, and then **Save Edit Cell and Descendents**. This saves the current edit cell `row`, as well as any modified cells that are instantiated in that row.
- Step 10** ■ Exit out of MAX by typing **Ctrl-d** or selecting **Exit** from the **File** menu.

If you have made changes to cells since your last save, you'll get a warning popup message. You can either **Exit and Lose Changes**, or **Cancel** and save the cells.

# Part 4

## MAX-LS

MAX-LS, an entry in the chip development suite from Micro Magic, Inc., includes ALL of the features included in regular MAX and several added powerful features.

### MAX-LS Features

MAX-LS includes all of the standard MAX features, as well as the following additional ones:

- SUE base version, without Netlisting and Simulator interfaces.
- Auto-layout Generation of SUE schematics into MAX.
- Interactive Cross-probing between SUE and MAX.

One reason for the power of MAX-LS is that both MAX and SUE have complete Tcl/Tk interfaces. This means that you can write and execute full Tcl programs in either tool. Tcl also provides a means for inter-program communication.

SUE and MAX use the notion of “send” commands to talk to each other. Cross-probing is one example of this inter-program communication. Automatic layout generation and fly-lines are also features gained by using both SUE and MAX.

We are going to use MAX-LS for this next example. Don't worry if you haven't used SUE before. SUE and MAX are both part of the Micro Magic, Inc. chip design suite, so they have similar interfaces. You can also launch the SUE tutorial if you wish to learn more about SUE.

### Automatic Layout Generation and Fly-lines

To see how SUE and MAX can work together we are going to bring up a simple NAND gate in SUE.

**Step 1** ■ First, if you haven't already done so, save your previous work in MAX and then quit out of MAX using `Exit` from the `File` menu.

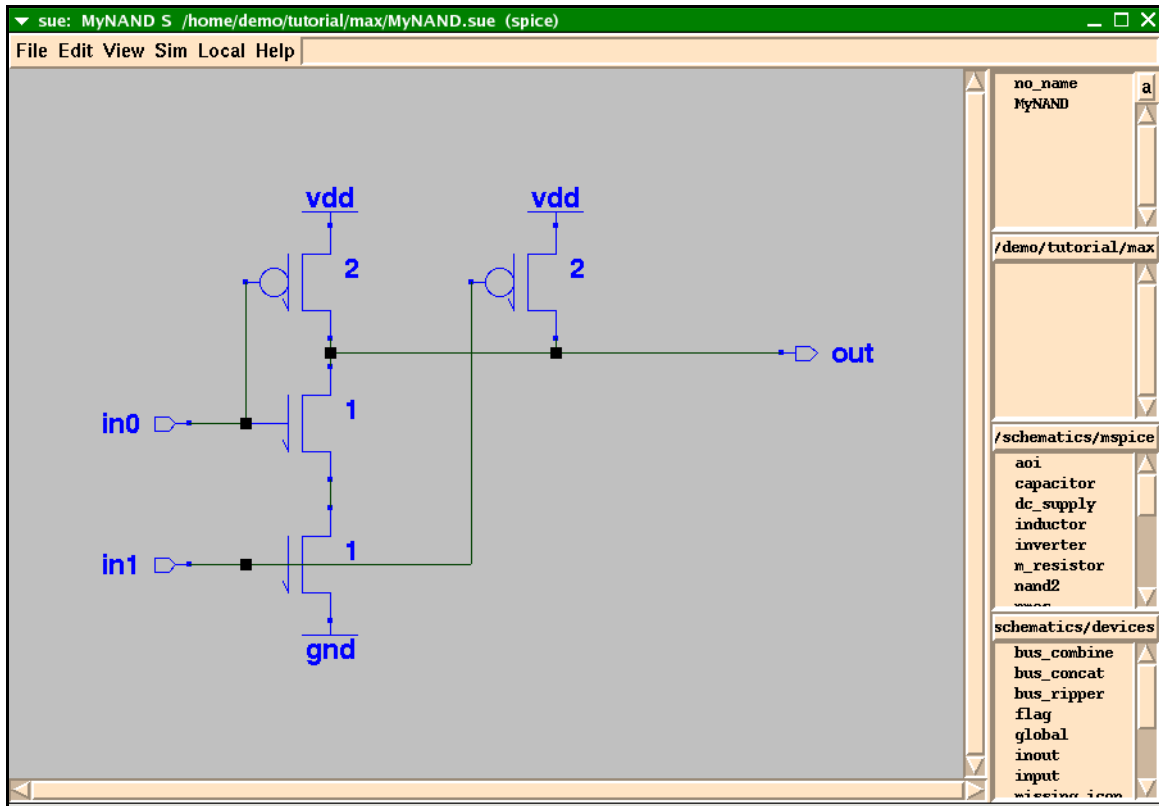
**Step 2** ■ Now bring up SUE by typing

```
sue MyNAND
```

This will launch SUE and automatically load in the `MyNAND.sue` circuit.

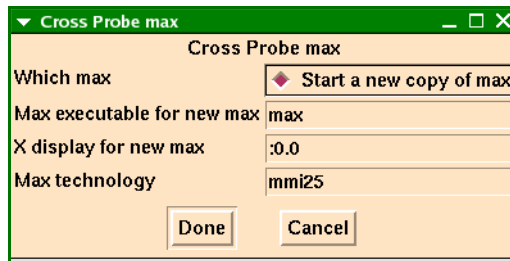
Your SUE window should look like Figure 29.

**Figure 29: SUE Schematic For "MyNAND"**



- Step 3
  - Go to the Sim menu and select `sim netlist`. It's the top choice.  
  
If the top choice is set to something else, like `spice netlist`, then select `Change Simulation Mode` from the Sim menu and click on the Sim box when the `Change Simulation Mode` dialog box comes up.
- Step 4
  - Now from the Sim menu select `MAX Cross Probe Init`.  
  
The `Cross Probe` popup menu will appear.
- Step 5
  - If you have other copies of MAX open (in our example, there is one other copy of MAX running), be sure and select `Start a New Copy of MAX`.
- Step 6
  - For MAX Technology, fill in `mmi25`, as shown in Figure 30. Then click Done.

Figure 30: Cross Probe Menu.



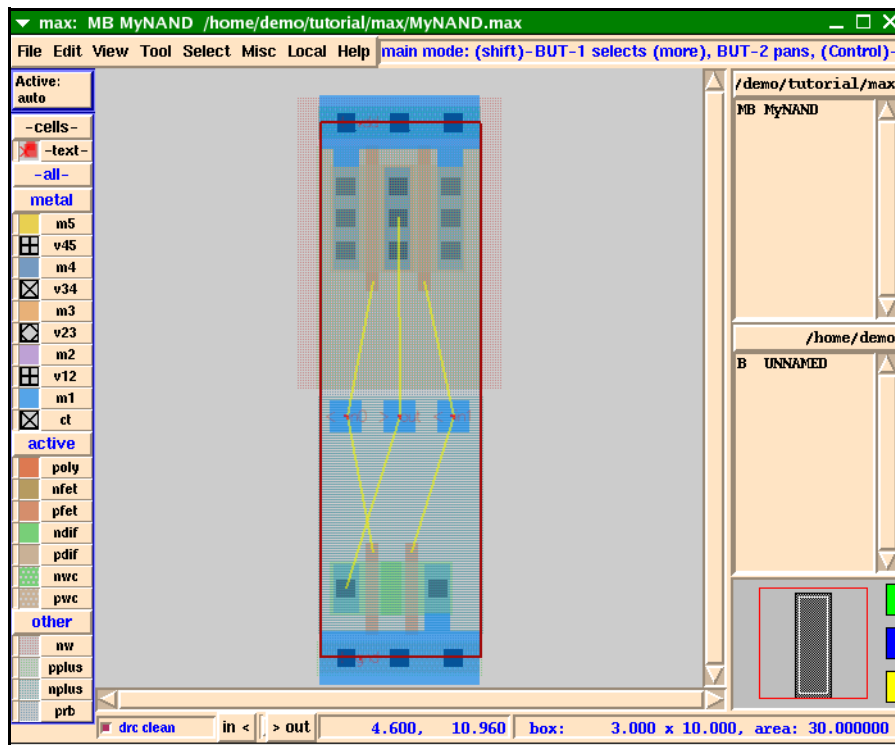
This will launch a new Xterm window, and start up MAX from that window.

- Step 7
- You'll see a message saying there is no existing MAX layout for **MyNAND**. Click on new to generate a new cell.
- Step 8
- Now go to the Tool menu in MAX and select Layout Generator.
- Step 9
- When the file select popup appears, select **MyNAND.sim** from the Cell List, and click on OK.

The Layout Generator window should now come up. This window has several options.

- Generate stdcell layers is a shorthand for either “just give me the devices with flylines” or “give me all of the wells, well contacts, power straps, etc. needed to make a standard cell-like layout”.
  - If you click on the Edit Per-Cell Options button you have various options like using gcells or paint for fets, enable flylines, and automatically folding fets larger than a specified size. If you turn share\_contacts on, the Layout Generator will automatically share contacts and diffusions for you. (For now we don't want to change anything so just hit Cancel.)
  - The Edit Stdcell Options box gives you several options for producing standard cell-like layout.
  - The Edit Layers to Generate box gives you control over which layers the Layout Generator will automatically generate for you. This gives YOU, the designer, the ability to control what the tool does for you and what you want total control over.
- Step 10
- Once you are done looking over the many options the Layout Generator has, simply click Done and the layout for **MyNAND** will be generated for you automatically. It should look like Figure 31.

Figure 31: Layout Generator Result



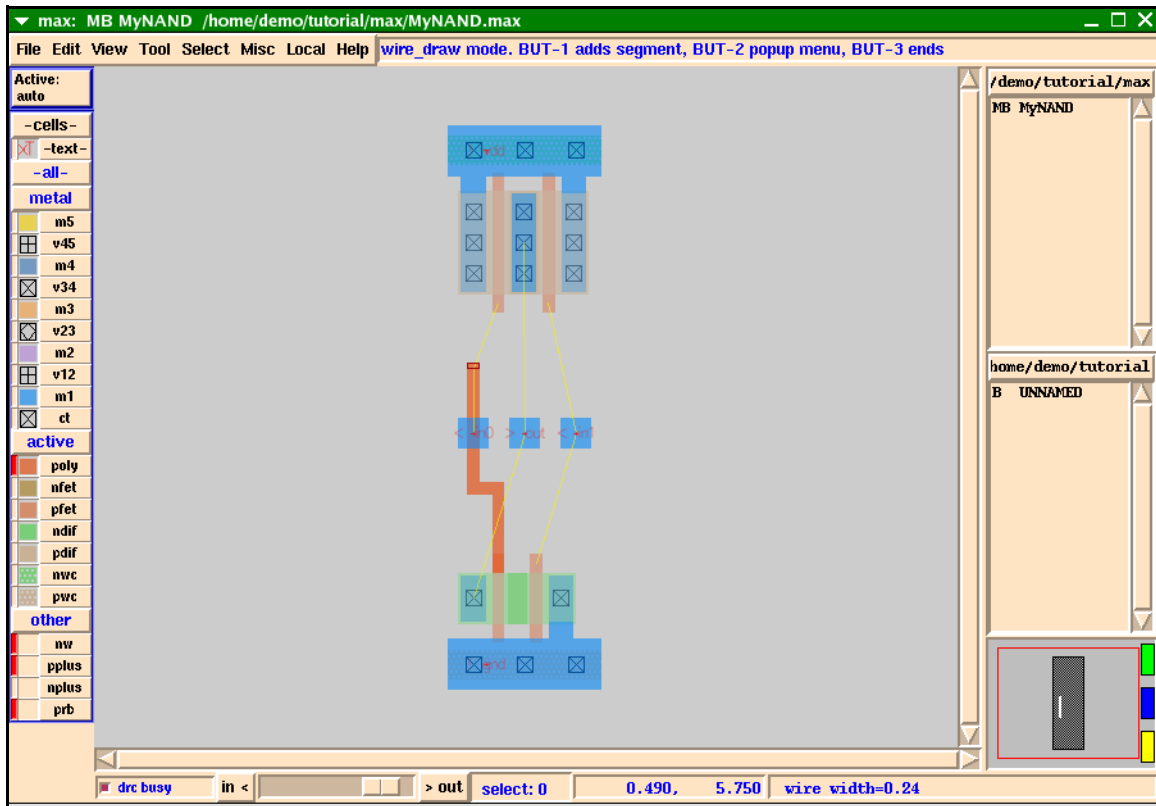
Notice that the devices have already been placed and sized correctly. Where possible, the Layout Generator has even shared contacts and diffusions for you. Also, notice there are fly-lines connecting the various nodes together. These fly-lines tell you how to wire things up correctly - so let's do it.

To begin, let's wire up the left-most poly gates.

- Step 1 ■ First, *turn off the visibility* of the other layers by clicking on other in the Palette with Button-1. This will make the layout less cluttered.
- Step 2 ■ To draw the wire, simply hit the **w** hotkey to get into wire mode, then click the left mouse button (Button-1) over the lower left poly gate and drag the mouse upwards.
- Step 3 ■ Use Button-1 to add corners where needed.
- Step 4 ■ End the wire by clicking with the right mouse button (Button-3) over the upper left fet.
- Step 5 ■ To complete this connection, you will need to start a wire on the M1 routing pad, drop a via down (**Shift-d**) to poly and end the wire with the right mouse button. This connects the M1 routing pad and text *in0* to the poly wire.

Did you notice that the fly-line tracked your wire as you drew it? See Figure 32.

Figure 32: Flylines Tracking



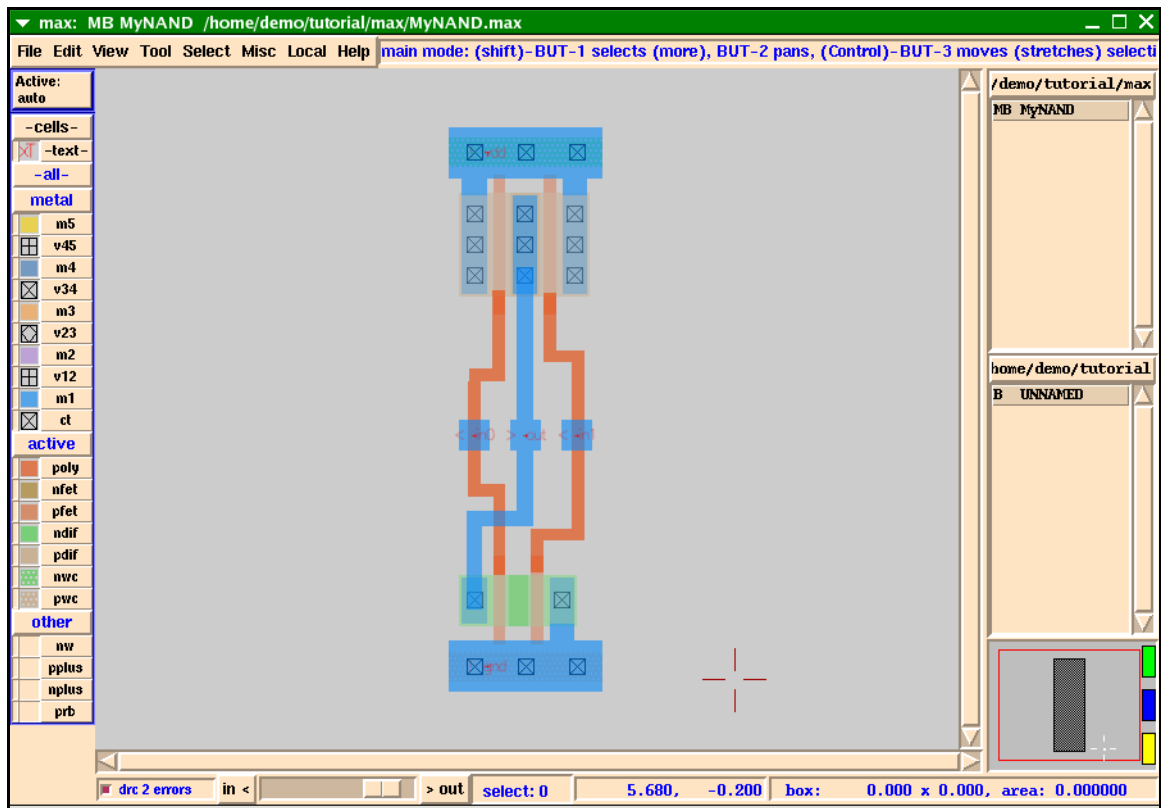
This feature makes it easy to hook up cells correctly. All you need to do is follow the fly-lines!

Step 6 ■ OK, now let's wire up the rest of the cell.

If you ever forget any of the wiring tool options, remember the status box next to the Help menu will tell you what the buttons do, and you can always hit the middle mouse button (Button-2) to get the Wire Tool pop-up menu.

Your circuit should now look something like Figure 33. Make sure there are vias on the two input routing pads connecting them to the poly wire.

Figure 33: Wired MyNAND Gate



## Cross-Probing with SUE

Making sure your circuit is wired up correctly is very important. MAX-LS provides flylines to help you accomplish this. But what if you import some layout from another tool, or create the layout without the flylines and you want to make sure it's correct?

MAX-LS has a powerful feature known as **cross-probing**. This allows you to select a piece of layout and highlight the corresponding object in the schematic, or vice versa. You can initiate cross-probing from either SUE or MAX.

To start the cross-probe from SUE you would select MAX Cross Probe Init from the Sim menu just as you did to start up MAX.

### Cross-Probing: SUE to MAX

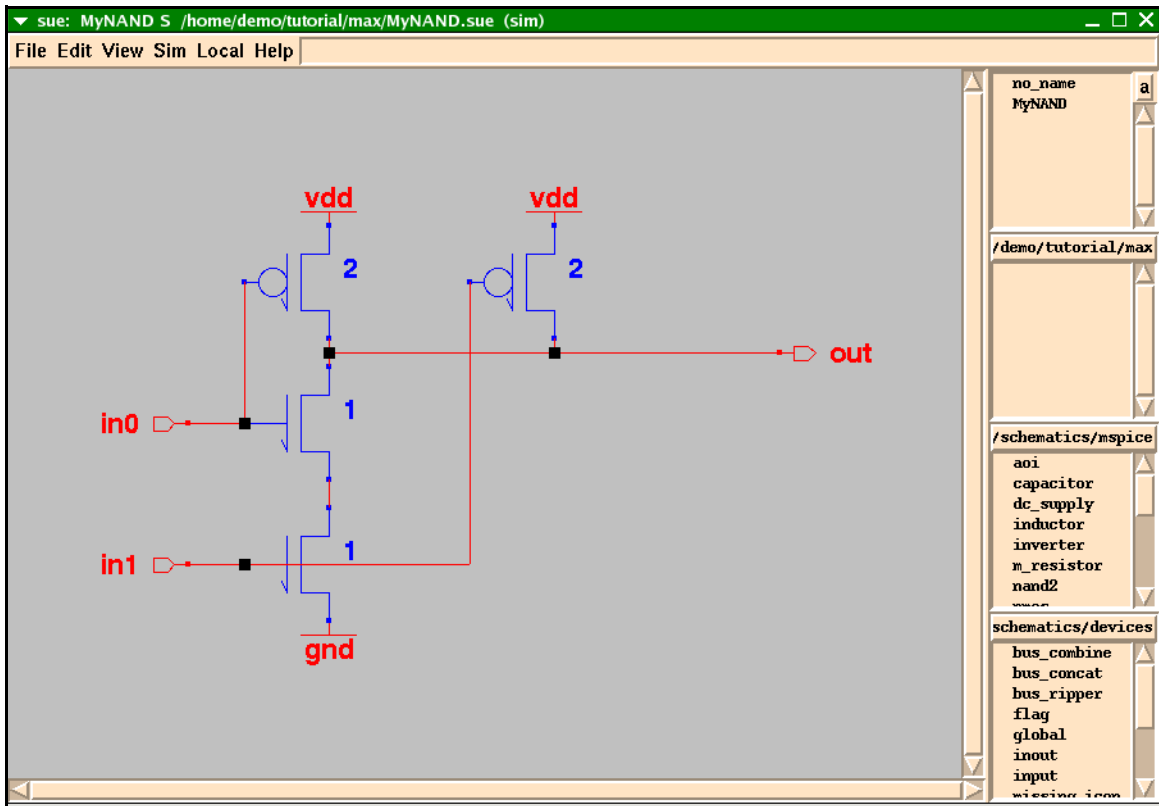
This time let's set up cross-probing from the MAX side.

- Step 1     ■ Select SUE Cross Probe Init from the Tool menu in MAX.
- Step 2     ■ Assuming you only have one copy of SUE running, select sue. Don't start a new copy. Click on Done.



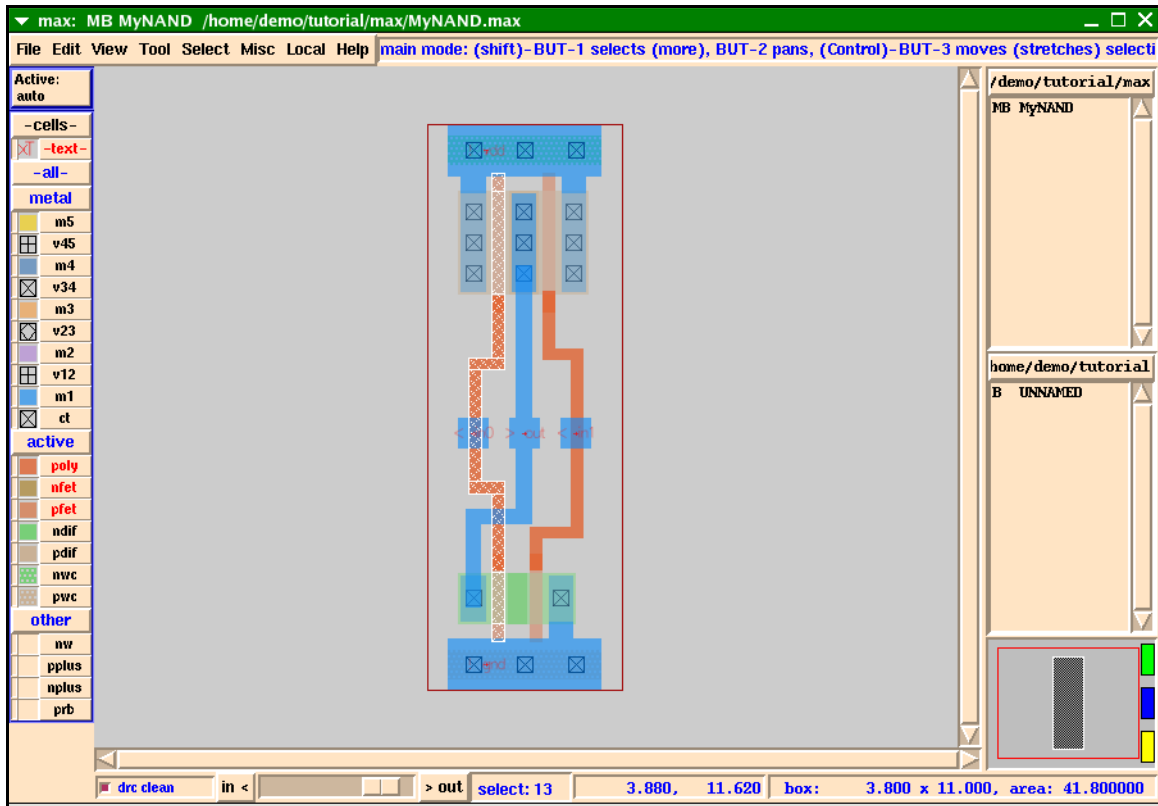
Once MAX and SUE are done communicating, SUE will highlight the nodes it and MAX agree upon in red, as shown in Figure 34, and MAX will highlight the same nodes in white.

**Figure 34: Matching Nets in SUE**



- Step 3**
- Now select the port labeled **in0** in the SUE schematic and type **k**, or select **Cross Probe** from the **Sim** menu. Notice that the wire labeled **in0** on the MAX layout is now highlighted in white! See Figure 35.

Figure 35: Corresponding Net "in0" In MAX



### Cross-Probing: MAX to SUE

You can also cross-probe from MAX to SUE.

- Step 1 ■ Select the wire labeled **out** in MAX and then or select SUE Cross Probe Init from the Tool menu.
- Step 2 ■ Type **k**, or select SUE Cross Probe from the Tool menu. Notice that the wire labeled **out** in the SUE schematic is highlighted in red.

This is yet another way SUE and MAX help you keep track of your design.

### Advanced Features

There are several advanced features found in MAX which were NOT covered in this tutorial.

For example, customization is possible over a wide range, from minor user preferences (controlled by the **.maxrc** file) to megacell generators. See MAX Manual under the Help menu for more details.

## To Learn More About MAX and SUE

To learn more about MAX go to *MAX Manual* under the *Help* menu, or refer to the Micro Magic, Inc. *MAX User Manual*.

To learn more about SUE, go to the *SUE Tutorial* or *SUE Manual* under *Help* for on-line information, or refer to the Micro Magic, Inc. *SUE Tutorial* and *SUE User Manual* documentation.

For additional documentation on any of the Micro Magic, Inc. chip design suite, use the on-line reference *MMI Documentation Guide* under the *Help* menu.

And, as always, the best way to really learn a program is to use it. We hope that the Micro Magic, Inc. programs SUE and MAX will help you do better designs in less time.

