The Timing Diagrammer Tutorial

This is a short tutorial that demonstrates how The Timing Diagrammer can help detect timing errors in digital designs. It teaches you how to draw timing diagrams using The Timing Diagrammer's delays, setups, clocks and part libraries. It also covers the waveform editing features, measurement and quick access buttons.

Introduction

You will draw the timing diagram for the circuit shown in Figure 1. This circuit divides the clock frequency in half. Both the flip-flop and the inverter have propagation times that delay the arrival of the Dinput signal. If the Dinput is delayed too long it will violate the data-to-clock setup time. This increases the risk of the flip-flop failing to clock in the data and can potentially lead to the flip-flop entering a metastable state.

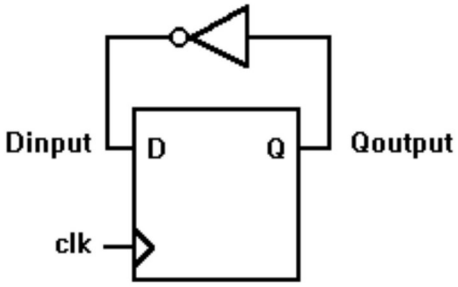

Figure 1: Tutorial circuit

Circuit Parameters:

clk = 20MHz(50ns period)

D flip-flop (74ALS74):

tpCKtoQ = Clock to Q propagation time = 5-18ns

tsDtoCK = D to rising edge Clock setup time = 15ns minimum

Inverter (74ALS04):

tpINV = inverter propagation time = 3-11ns

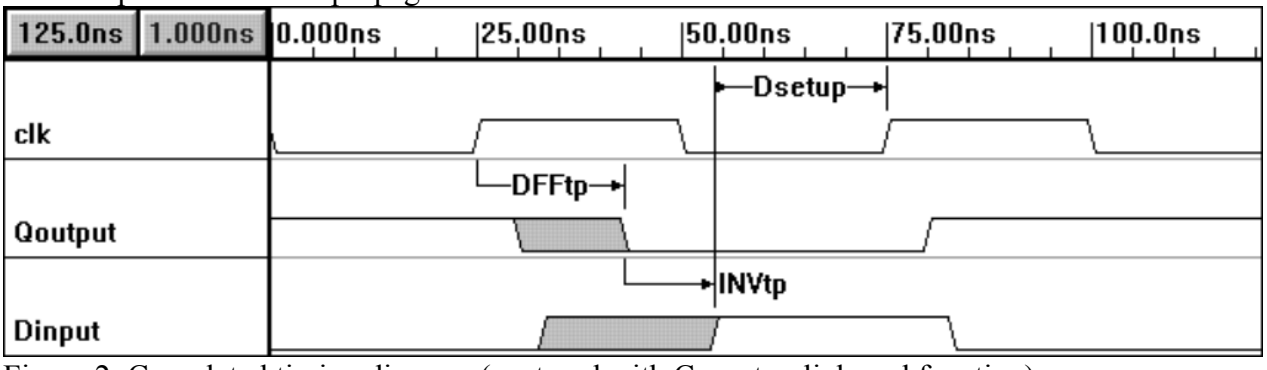

Figure 2: Completed timing diagram (captured with Copy-to-clipboard function).

Figure 2 is the completed timing diagram. The first thing you may notice is the gray signal transitions caused by the min/max values of the component delays. The gray areas of the signal transitions are uncertainty regions, which indicate that the signal may transition any time during that period. This is a little disconcerting especially if you have been using a low-end simulator that cannot compute both min and max at the same time. This representation shows the entire

range of possible circuit performance. With The Timing Diagrammer, there won't be any surprises during production when you get components at extreme ends of their tolerance range.

Set the Base Time Unit

At the beginning of each project, you will set the base time unit. The base time unit is the smallest representable amount of time that The Timing Diagrammer will be able to display. The base time unit determines the range of times that can be represented in your timing diagram.

In the tutorial circuit, the propagation times for the gates are in units of nanoseconds and the clock has a period of 20ns. Generally it is a good idea to set the base time unit for your project 1 unit below the units you are working in for best rounding performance during division operations (clock frequencies are inverted and stored internally as clock periods). To set the base time unit:

- Choose the "Options/Set Base Time Unit" menu in the timing window. This will display a dialog box with radio buttons that set the base time unit. The other options control how any currently existing parameters or signals are changed when the base time unit is changed and have no effect on an empty timing diagram. See the online help if you want to know more about these options.
- Click on "ps", to make picoseconds the base time unit if it is not already selected.

Set the Display Time Unit

Next you need to set the display time unit. The display time unit sets the units for times which you enter and for times displayed in the The Timing Diagrammer. Set the display time unit to the units you most commonly use in the design. To set the display time unit:

-Choose the "Options/Set Display Time Unit" menu in the parameter window. This will display a sub menu of display time units. The checked time is the current base time unit (Default is ns = nanoseconds).
-Click on "ns", to make nanoseconds the display time unit if it is not already checked.

Add the Clock

Start by adding the clock. The clock is named "clk", has a period of 50ns (20MHz), and starts with a low segment. To add the clock do the following:

- Left mouse click on the Add Clock button, in the top left hand corner of the screen. The "Edit Clock Parameters" dialog box will appear.
- Enter the name "clk" in the Label edit box.
- Enter 50 in the period box. Make sure the MHz/ns radio button is selected. Note that the frequency will change to match the new period value, when you move the selection to another edit box.
- Click the invert check box. Clocks are normally displayed high at time zero, so "invert" makes the clock start low at time zero.
- Left mouse click on the OK button to close the edit box.

For more information on clocks read the on-line help "Design Function Index / Clocks" entry. If you made a mistake designing the clock, then double left click on the waveform to reopen the "Edit Clock Parameters" dialog box.

Add Signals

Next add two signals and name them "Qoutput" and "Dinput".

- Left click twice on the Add Signal button to add two signals.
- Double left click on the top signal name to open up an edit box. Type in the name "Qoutput".
- Press the down arrow to open up an edit box on the second signal and type "Dinput".
- Press the Enter key to close the edit box.

Draw Signal Waveforms

Draw some random waveforms to become familiar with the drawing environment.

- Put the mouse cursor inside the drawing window at the same level as the signal name.
- Left click down to draw the waveform that is on the activated State Button from the end of the signal to the mouse cursor. State Buttons are the buttons with the waveforms drawn on them.
- Notice that a different state button is now activated. The State Buttons automatically toggle between the two most recently activated states. The next State Button that will become activated is marked with a red T above the name. (If you have a 3 button mouse, click the middle mouse button to toggle between the two most recently activated state buttons.)
- Left click on the "Tri" button to activate the tristate State Button.
- Draw more segments, using all the states. Just play around.

Your drawing should be a mess, or at least look nothing like figure 2.

Edit signal waveforms

There are 4 main editing techniques used to modify existing signals (Note: these techniques will not work on clocks). The most commonly used technique is the dragging of signal transitions to adjust their location. The other 3 techniques all act on signal segments, the waveforms between any two consecutive signal transitions. The segment waveform can be changed, deleted, or a new segment can be inserted within another segment. Use each of the following techniques:

- **Move a signal transition**: Left click down on a signal transition and drag it to the desired location. A green bar will appear that follows the mouse cursor. Release the mouse button when the green bar is at the location where you wish to place the transition.
- **Change the level of a segment**: A segment is the waveform between two consecutive signal transitions. Left click on the segment to select it. A selected segment will have a dotted black box drawn around it. If you try to select a narrow segment and one of the transitions gets selected, widen the segment by clicking the Zoom In button in the bottom left hand corner before attempting to select the segment. Then left click the State Button of the new level desired.
- **Delete a segment**: Select a segment (see above) and then press the delete key on the keyboard.
- **Insert a segment**: Double left click in the middle of a segment to insert two signal transitions that are 1 base time unit apart. Then drag one of the new transitions to make the segment the proper size. For this operation to work the original segment must be wide enough to be selected.

These techniques will not work on clocks. This is because clocks have fixed edges and segments. To edit a clock, double click on a segment of the clock waveform in the drawing window. This causes the "Edit Clock parameters" dialog box to appear. All clock parameters can be changed in

this dialog box. If you cannot double click on a segment without selecting a transition, zoom in until the segment is large enough.

Now use the above techniques to edit the signals so they have the same transitions as the signals in figure 2. This is not the normal way to make a timing diagram, but it will teach you how to use the editing features of The Timing Diagrammer. Make sure you try all the editing techniques. Do not draw the gray uncertainty regions, they will automatically get drawn when the delays are added. If you want more instruction read the on-line help "Design Functions Index / Drawing Waveforms".

Make sure your drawing approximately matches figure 2

Your drawing should consist of the one clock and two signals. If you added more signals or other things delete them now. Almost everything can be deleted by selecting its name then typing the delete key. See the on-line help for any specific information.

The waveform transitions should be in approximately the same positions as figure 2. If not, then use the editing techniques of the previous section to adjust the waveforms.

Tile the parameter and timing windows so that you will be able to see the interaction between the two windows.

- Choose one of the "Window/Tile" menu options in the timing window.

Adjust the zoom level of the drawing so that only 3 whole clock periods are shown on the screen.

- Left mouse click the "Zoom In" or "Zoom Out" buttons, in the bottom left side of the window to show less or more of the waveform.

The right mouse button (mode buttons):

In the next sections we will be adding delays, setups, and comments to the timing diagram. These objects are all added using the right mouse button. Which function the right mouse button performs is determined by the second group of buttons on the button bar marked DELAY, HOLD, SETUP, TEXT and DELETE. The red or activated mode button indicates the current functionality of the right mouse button. To activate a different mode button left click on it.

Statements like "Activate the Delay mode" mean: if the button of that name is not already activated (red), then left click on the button.

Add the D flip-flop propagation delay

Add the delay that represents the propagation time from the positive edge of the clock to the Qoutput of the D flip-flop. To add the delay do the following:

- Activate the DELAY mode.
- Left mouse click on the first rising edge of the clock.
- Right mouse click on the first falling edge of the Qoutput signal.

This will draw the D flip-flop delay, and creates a blank delay in the parameter window.

When delays are added they are blank and do not enforce any timing restraints. You can still drag the falling edge of the Qoutput signal. Now fix the delay values, by editing the parameter in the parameter window.

- Left mouse click on the parameter cell in the "min" column. This will highlight the cell and open an edit box at the top of the screen.
- Type 5 and press the Enter key to close the edit box. This enters 5 base time units, or 5ns for this project.

Two things happened when you pressed enter:

1) The value was automatically copied to the max column. This is because delays must have both min and max values.
2) Next the falling edge of the Qoutput signal adjusted itself so that it was 5ns from the clock edge. Measure this for yourself using the time readouts above the signal name window. Left click on the first transition and then move the cursor to the second transition. Notice the blue readout says 5ns.

Next, finish editing the rest of the parameter. The parameter is named "DFFtp", has a max time of 18ns, and a comment of "CK to Q propagation time". To edit do the following:

- Left mouse click on the parameter cell in the "name" column.
- Type "DFFtp".
- Tab twice so that the max cell is highlighted.
- Type 18. This means 18 base time units, or in this project 18ns.
- Tab once so that the comment cell is highlighted.
- Type "Ck to Q propagation time" and press the Enter key.

Notice the falling edge of Qoutput now has a gray uncertainty region. Use the time measure readouts to verify that the edges of the region are 5ns and 18ns from the clock edge (13ns of uncertainty).

Add the Inverter propagation delay

Add the delay that represents the propagation time of the inverter from its input Q to its output D. To add the delay do the following:

- Activate the DELAY mode.
- Left mouse click on the first falling edge of the Qoutput signal (the same edge that ends the "DFFtp" delay).
- Right mouse click on the first rising edge of the Dinput signal.

This will draw the inverter delay, and create a blank delay in the parameter window. Now lets edit the parameters from the inside the drawing window instead of going to the parameter window. Double click with the left mouse button on the new delay in the drawing window and enter the following values in the dialog box that appears:

- Name is "INVtp".
- Min time is 3ns.
- Max time is 11ns.
- Comment is "Inverter(Q to D) delay".

Notice the large uncertainty region for the Dinput transition. Click on the first rising edge of Dinput, then use the blue delta readout to verify that the uncertainty region lasts for 21ns (13ns from DFFtp + 8ns from INVtp = 21ns). Next click on the first edge of clk and measure to the end of the uncertainty region of Dinput. If both the inverter and the D flip-flop are slow Dinput may not transition until 29ns after the clock edge.

Add the setup for the Dinput to clock

Next add the setup for the D input to clock transition.

- Activate the SETUP mode.
- Left mouse click on the first rising edge of the Dinput signal (the same edge that ends "INVtp" delay).
- Right mouse click on the second rising edge of the clock.

This will draw the setup parameter. Notice that the arrows of the setup are pointing to the control signal. This means that you added the setup correctly.

Like delays, setups also are created with blank min/max values. They must be have a min value before they start to monitor the data signals position. Edit the setup so that the name is "Dsetup", the min time is 15ns, max time is blank, and comment says "check for metastable condition". Do the following:

- Left click on the name cell of the setup. This will cause the cell to highlight and an edit box to open at the top of the screen.
- Type "Dsetup".
- Tab once so that the min cell is highlighted.
- Type 15 (=15ns since display time unit is nanoseconds).
- Tab twice so that the comment cell is highlighted.
- Type "Ensure setup time for DFF is met".
- Press Enter to close the edit box.

Notice the margin column says that there is a 6ns safety region before the setup is violated. Measure this by clicking on the second rising edge of the clock and placing the cursor on top of the maximum edge of the Dinput signal. The blue time readout should say -21ns (setup time 15ns - measured 21ns = 6ns margin).

Next let's demonstrate what happens when a setup is violated. Increase the inverter's delay so that the maximum delay is 18ns instead of 11ns. Do the following:

- Left click on the INVtp delay's max cell in the parameter window.
- Type 18 and press the Enter key.

Notice that the setup has turned red in both the drawing and parameter windows. Now change the inverter delay back to 11ns.

Add a free parameter

So far we have always directly edited a parameter's values. This is inefficient and error prone if the circuit is large. It would be better to define one variable that held the value and make everything that needed that value reference this variable. Then if the time needs to be changed, you only have to edit one variable.

Free parameters act as variables that can be referenced by other parameters. They are called "free" because these parameters are not attached to any signal transitions in the drawing window. Let's add a free parameter to hold the propagation times for the inverter. To add a free parameter:

- Select the "Edit/Add free parameter" menu option in the parameter window. A blank free parameter will be added to the parameter window.
- Enter ("tpFreeInv", 3ns, 11ns, "74ALS04 inverter delay") for the (name, min, max, and comment cells) of the free parameter.
- Enter blanks for the INVtp min and max cells. Left click on the min cell. Backspace until there is nothing in the edit box. Press Enter. Answer Yes to the dialog box.
- Type "tpFreeInv" in the min or max cell of INVtp to make INVtp reference this free parameter.

You can also save free parameters to special library files which can later be merged into other projects. For more information on free parameters read the on-line help "Design Function Index/Parameter Window".

Using formulas and constants

Parameters can contain mathematical formulas as well as numeric time values. Legal operations are multiplication(*), division(/), addition(+), and subtraction(-). For example, the inverter in this circuit could in reality be 3 cascaded inverters used to generate a minimum delay of 9ns. To represent this in your timing diagram:

-Click in the min cell of INVtp and enter: '3 * tpFreeInv

Note: '3 is a constant value that will not change if you change the base time units.

Summary

In this tutorial we have covered three main topics. The first is how to start a project. Next we covered signals, which includes clocks, signals, and drawing the waveforms of the signals. And finally we covered parameters, which includes delays, setups, and free parameters. Below is a review of the concepts covered in the tutorial.

1) Starting a project

- Always set the Base Time Unit at the beginning of a project by selecting a time in the "Options/Set Base Time Unit" menu.
- Also set the Display TIme Unit to a convenient level for entering time values.

2) Signals

Clocks

- Clock are special periodic signals that draw themselves. Clock edges are fixed and cannot be edited with normal mouse techniques.
- Add a clock by clicking on the Add Clock button.
- Edit a clock by double clicking on the clocks waveform.

Signals

- Add a signal by clicking on the Add Signal button.
- Edit a signal's name by double clicking on the name.

Drawing waveforms

- State buttons are the buttons with the waveforms drawn on them. The activated state button (red) indicates which type of waveform will be drawn next.
- State buttons toggle between the last two activated states. The toggle state button is indicated with a red T above the name.
- Place cursor in drawing window, at the same level as the signal name. Left click to draw the waveform from the end of the signal to the mouse cursor.

Editing waveforms

- Move a signal transition: Left click down on the transition and drag it. Release the mouse button when the green bar has been moved to the desired location.
- Change the level of a segment: A segment is the waveform between two consecutive signal transitions. Left click on the segment to select it. Then left click the State Button of the new level.
- Delete a segment: Select a segment (see above) and then press the delete key on the keyboard.
- Insert a segment: Double left click in the middle of a segment to insert two signal transitions. The segment must be wide enough to select in order for this operation to be successful.

3) Parameters

Mode Buttons

The mode buttons are the five buttons named DELAY, SETUP, HOLD, TEXT, and DELETE. They determine the functionality of the right mouse button. The red mode button indicates the current functionality of the right mouse button.

Delays

- Delays with defined values force two signal transitions to be a fixed distance apart.
- Activate the DELAY mode to make the right mouse button add delays.
- Add a delay by left mouse clicking on the first signal edge then right mouse clicking on the delayed edge.
- Delay values are edited in the parameter window or by double clicking on the delay in the drawing window.
- Delays must have both minimum and maximum values defined. They can be the same value.

Setups

- Setups monitor the position of a data signal with respect to a control signal.
- When a setup is violated the setup turns red in both the timing and parameter windows.
- Activate the SETUP mode to make the right mouse button add setups.
- Add a setup by left mouse clicking on the data signal to be monitored. Then right mouse click on the control signal.
- Edit setup values in the parameter window (can also double click in drawing window).
- The "max" column is optional for setups, and is rarely used. If a "max" constraint is specified, then the signal transition has to occur between the min and max times.

Free parameters

- Free parameters are variables that other parameters reference. To make a parameter reference a free parameter, type the name of the free parameter in the min or max column.
- Free parameters are not attached to signals in the timing window.
- To add a free parameter choose the "Edit/Add free parameter" menu option in the parameter window.

What the tutorial did not cover

We have not covered several features and most of our menu functions. The on-line help and our manual should give you more information on these functions.

Major features not covered:

- Text objects: Lets you put comments anywhere in the timing window. The text objects can either be fixed to a time or to a signal transition.
- Hold parameters: Similar to setups but work the other way.
- Moving signals: Select one or several signal names. Left click when cursor turns to a double arrow and drag to a new location.
- Moving Parameters: Just like signals except that they must be moved one at a time.
- Copy to clipboard: Takes a snapshot of the timing window and puts it in the clipboard. Good for documentation and copying to word processors (disabled in the Evaluation version). Figure 2 was created using this feature.
- Edge Placement: Double left click on a signal transition to open up the Edge Placement dialog box which allows you to place an edge at an exact time and optionally lock it there.
- Printing: Either the timing window or the parameter window can be printed (disabled in the Evaluation version).
- Reconvergent fanout: Automatically handles distance and margin calculation adjustments to properly account for delays common to multiple timing paths.

Menu based functions not covered:

- File\Merge: Two different projects can be merged into one.
- Edit\Undo: Undeletes an object.
- Draw Menu: Duplicates several of the buttons on the button bar.
- View\Show xxx: Toggle switches for showing/hiding parameters and text objects.
- View\Hide signals: After selecting signal names you can hide the signals.
- View\Hide parameters: Hides a parameter selected in the drawing window.

Options sub menu:

- Sloped or Straight edges: Controls the appearance of signal transitions.
- Black signals or Black with separators: Determine whether or not there will be signal dividing lines.
- Middle mouse function: Determines how the middle mouse button works.
- Status Bar: Toggles the status bar on/off.
- Text & Color preferences: Controls all the windows background colors and default fonts.
- Parameter Display preferences: Allows parameters to be displayed by name, value, margin, or comment in the drawing window.