Frequency Counter
for
Spartan-3E Starter Kit

(with test oscillators)

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Xilinx Ltd
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Rev.1

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Any problems or items felt of value in the continued improvement of KCPSM3 or this reference design would be gratefully received by the author.

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The author would also be pleased to hear from anyone using KCPSM3 or the UART macros with information about your application and how these macros have been useful.

Design Overview

This design converts the Spartan-3E Starter Kit into a reasonably accurate frequency counter measuring frequencies up to 200MHz (and possibly more) as well as providing two different types of on-chip oscillator for test and evaluation. The design can be used 'as is' as a piece of test equipment but it is hoped that the design may form the basis for future PicoBlaze designs as well as provide a general introduction to the board. Some exercises are suggested to encourage further self study.

As well as providing the basic instructions to use the frequency counter, this document provides details of the design which is a good illustration of how a PicoBlaze processor can be used in conjunction with hardware to provide a solution. Hardware is used to provide the high speed support for the actual frequency measurement whilst PicoBlaze performs the overall control of the system, numerical conversions and direct drive of the LCD display which are all relatively slow, if complex, tasks.

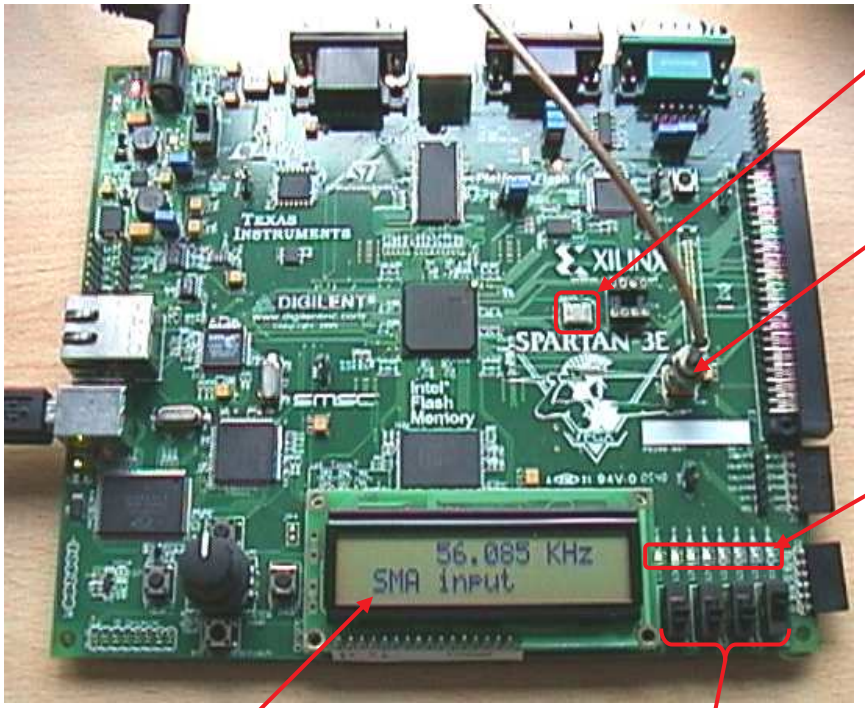
Load it now – it only takes 30 seconds!

It is recommended that you try this to become familiar with what the design does (operating instructions on the next page).

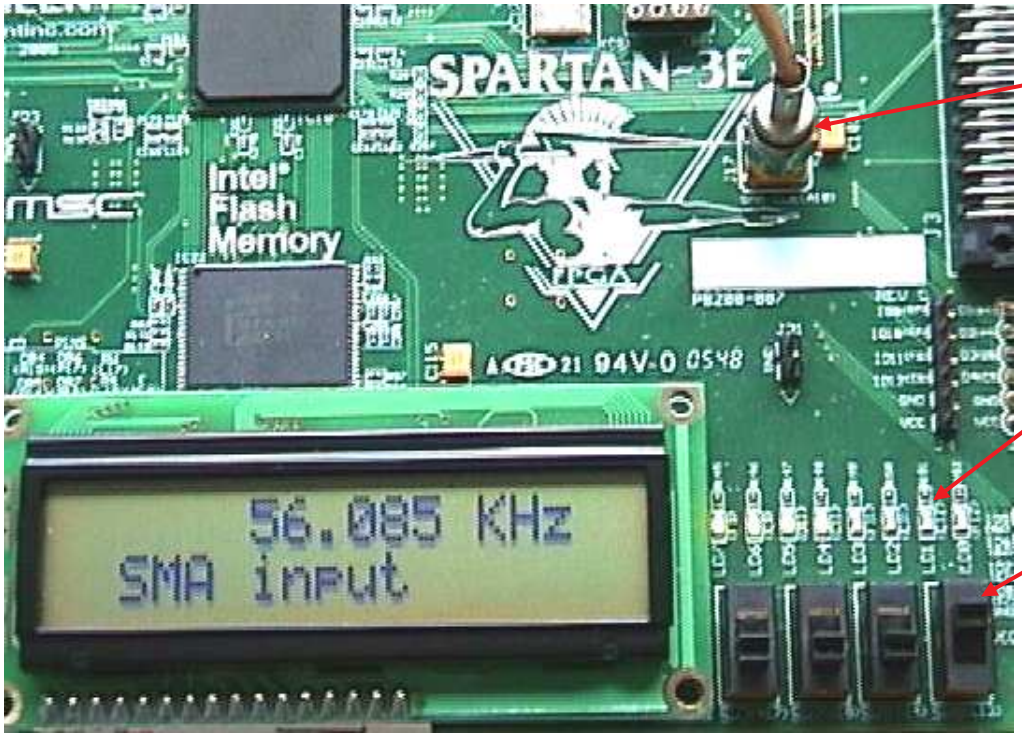
As well as the source design files, a compiled configuration bit file is provided which you can immediately download into the Spartan XC3S500E device on your board. To make this task really easy the first time, unzip all the files provided into a directory and then….

double click on 'install_frequency_counter.bat'.

Assuming you have the Xilinx software installed, your board connected with the USB cable and the board powered (don't forget the switch), then this should open a DOS window and run iMPACT in batch mode to configure the Spartan-3E with the design.



Operating Instructions



Apply external signal to be measured to the SMA connector (J17).

This is a direct input to the Spartan-3E device and is currently defined as having the LVTTL standard. This could be modified in the User Constraints File (UCF) if an alternative standard is required.

LEDs toggle at 1 second intervals to indicate measurement intervals

Raise one of the four slide switches to select the signal for measurement. If no switches are raised or more than one switch is raised at the same time a simple menu is provided.

The 50MHz signal is the on board 50MHz crystal oscillator (IC17). Since this is used to form the 1 second time base for all frequency measurements, selecting this as the input means that the system is measuring itself and therefore must produce the perfect result (even if the 50MHz is not 100% accurate).

This oscillator is implemented inside the Spartan-3E using a mode of the DCM normally reserved for test purposes. May be you will find such a ‘free’ oscillator useful in one of your designs.

A ring oscillator is one implemented using a combinatorial loop in the design. Normally something to be avoided and why processing this design will yield some warning messages. This design is an ideal way to experiment with these interesting beasts!

PicoBlaze Design Size

The images and statistics on this page show that the design occupies just 190 slices and 1 BRAM. This is only 4.1% of the slices and 5% of the BRAMs available in an XC3S500E device and would still be less than 20% of the slices in the smallest XC3S100E device.

MAP report

```
Number of occupied Slices:     190 out of    4,656     4%
Number of Block RAMs:            1 out of       20     5%

Total equivalent gate count for design:  85,032
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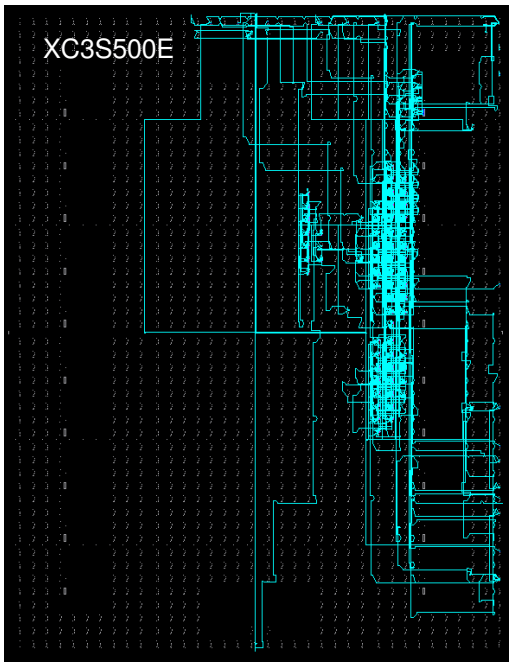
PicoBlaze makes extensive use of the distributed memory features of the Spartan-3E device leading to very high design efficiency. If this design was replicated to fill the XC3S500E device, it would represent the equivalent of over 1.5 million gates. Not bad for a device even marketing claims to be 500 thousand gates ☺

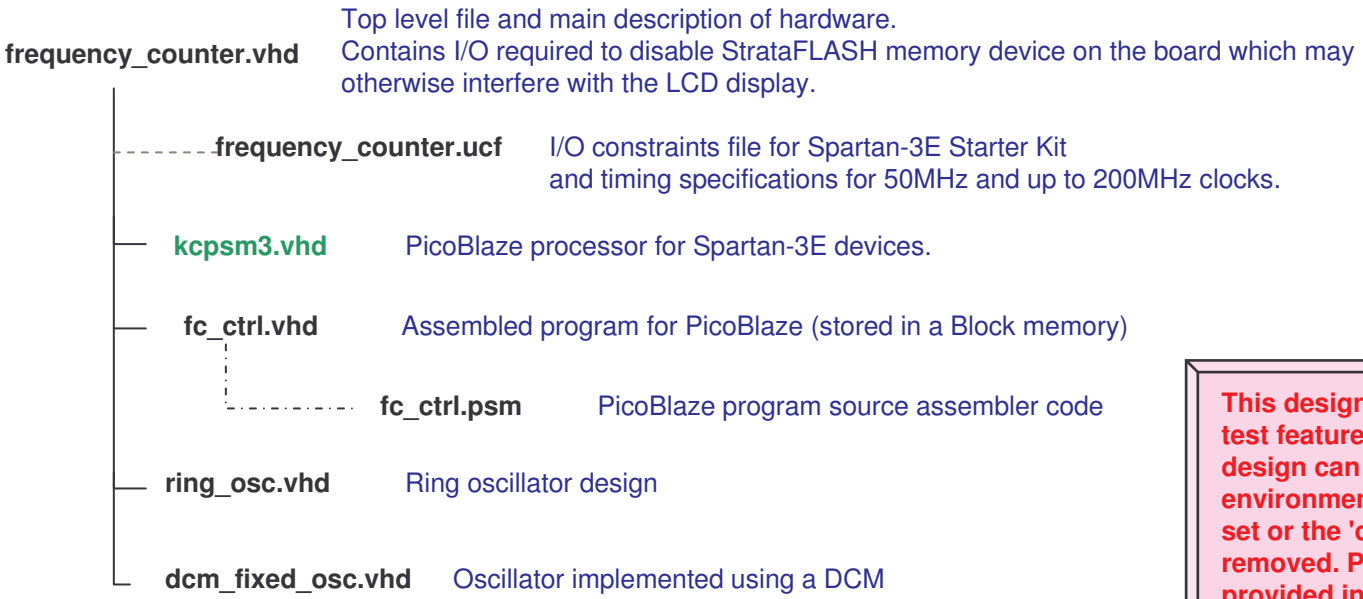
FPGA Editor view



Floorplanner view

Design Files

The source files provided for the reference design are…..



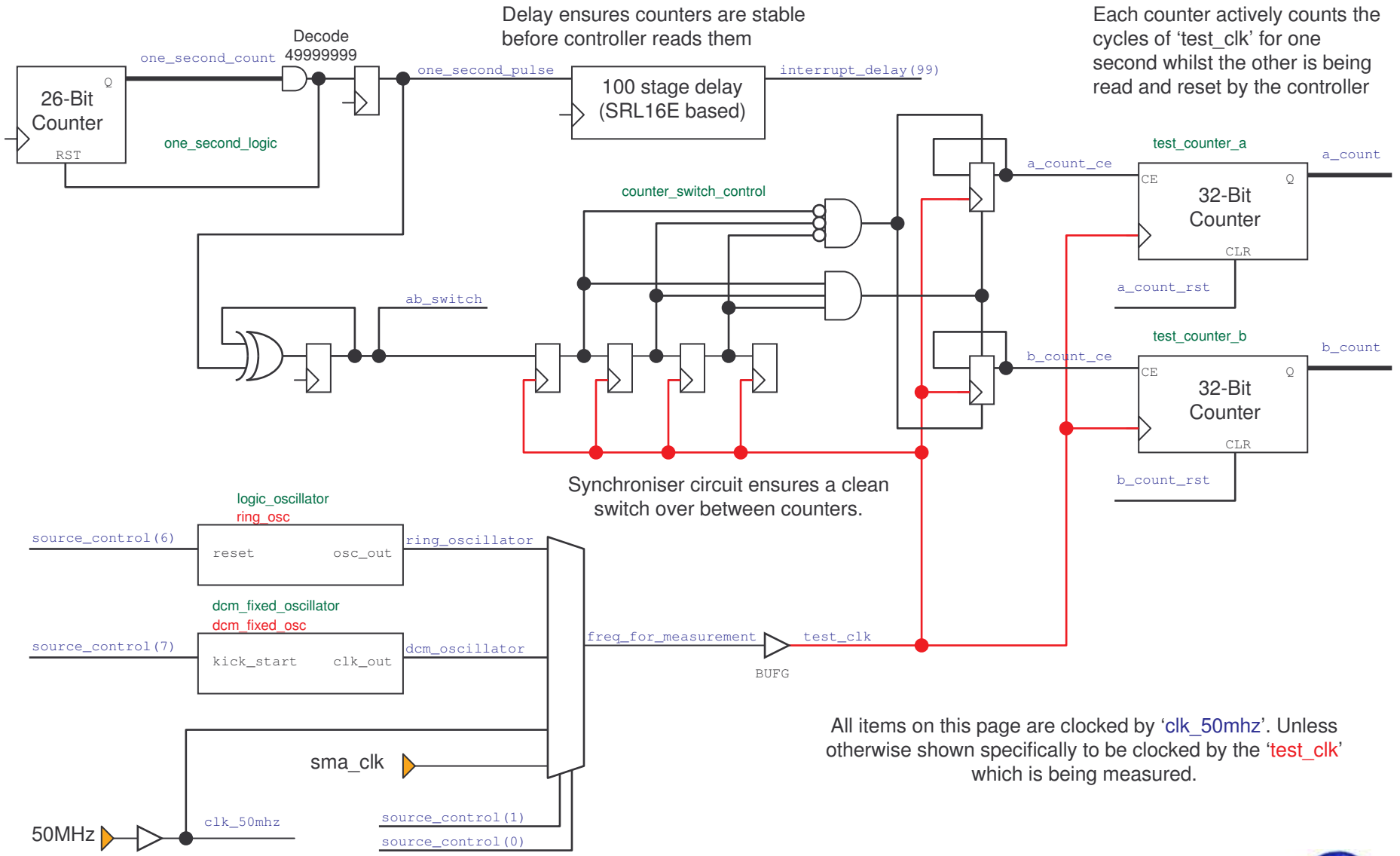
This design contains an evaluation test feature of the DCM. Before this design can be processed a special environment variable needs to be set or the 'dcm_fixed_osc' module removed. Please read the notes provided in 'dcm_fixed_osc.vhd' for details of this special requirement.

Note: The file shown in **green** is not included with the reference design as it is provided with PicoBlaze download. Please visit the PicoBlaze Web site for your free copy of PicoBlaze, assembler, JTAG_loader and documentation.

www.xilinx.com/picoblaze

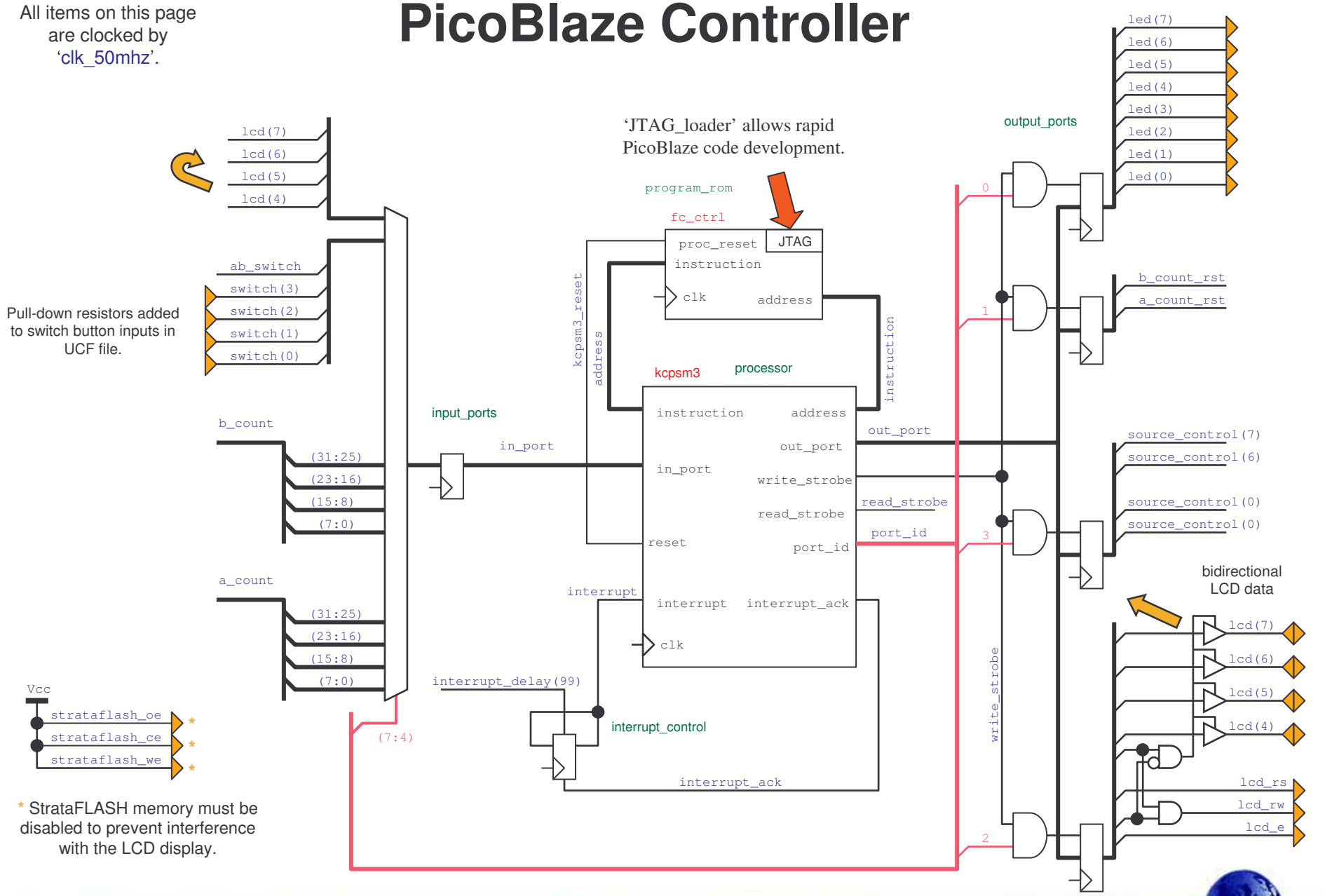
Hint - If you only want to write new programs for PicoBlaze using the existing hardware design, then simply use the JTAG_Loader utility supplied with PicoBlaze. The design supplied is already equipped with the JTAG loading circuit (see schematic on page 8).

Frequency Counter Logic



PicoBlaze Controller

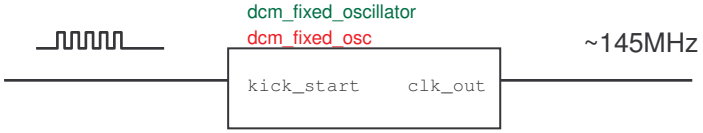
All items on this page are clocked by 'clk_50mhz'.



Oscillators

DCM Oscillator

This reference design introduces a test and evaluation mode of the DCM for you to investigate. To achieve this, a special test primitive called 'DCM_SPAR3.TEST' is used. For further details of connectivity and other special ISE set up requirements please read the notes provided in the design file 'dcm_fixed_osc.vhd' .



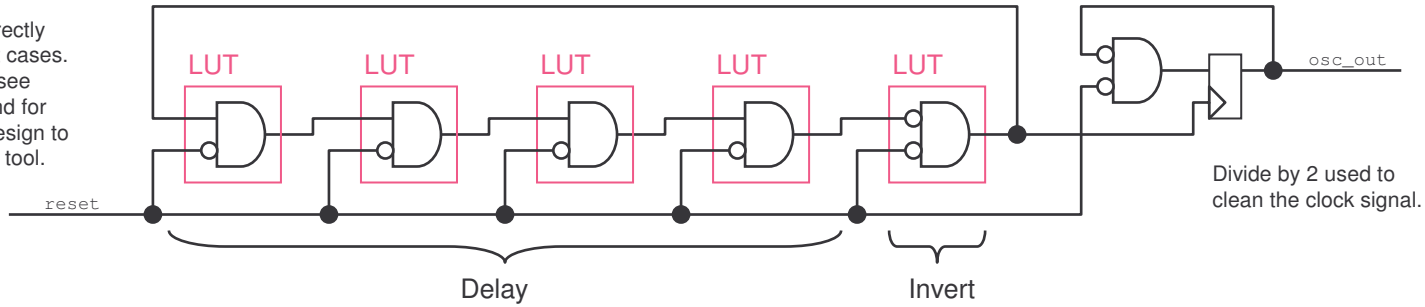
Using the DCM oscillator is simple. All you need to start it are a few transitions on the input to give it a 'kick start'. In this design PicoBlaze generates a short burst of pulses, but really any signal with a few transitions would be enough. The output frequency is independent of the stimulus used, and once started, no further stimulation is required. Since there is no definitive timing reference within the Spartan-3E device, the frequency of oscillation will depend on the fabrication process of the device itself as well as temperature, voltage and aging effects during operation.

Applications which are not absolutely time critical or for which another timing reference is available (e.g. data strobes on a communication channel) may find this mode of the DCM useful and help save the cost of fitting an external crystal oscillator. Please use this frequency counter design to evaluate this feature.

Ring Oscillator

A ring oscillator is implemented using the look up tables of the CLBs and the general purpose interconnect. As with all oscillators, the rate of oscillation is determined by the length of a delay implemented in a loop. A single inverter in the loop implements a high gain inverting amplifier leading to the unstable condition required for oscillation. This is one of those interesting cases where digital logic is really being used in an analogue way.

Hint – A combinatorial loop is quite correctly considered bad design practice in most cases. It should not therefore be surprising to see warnings generated by the ISE tools and for 'keep' attributes to be required in the design to stop logic optimisation by the synthesis tool.



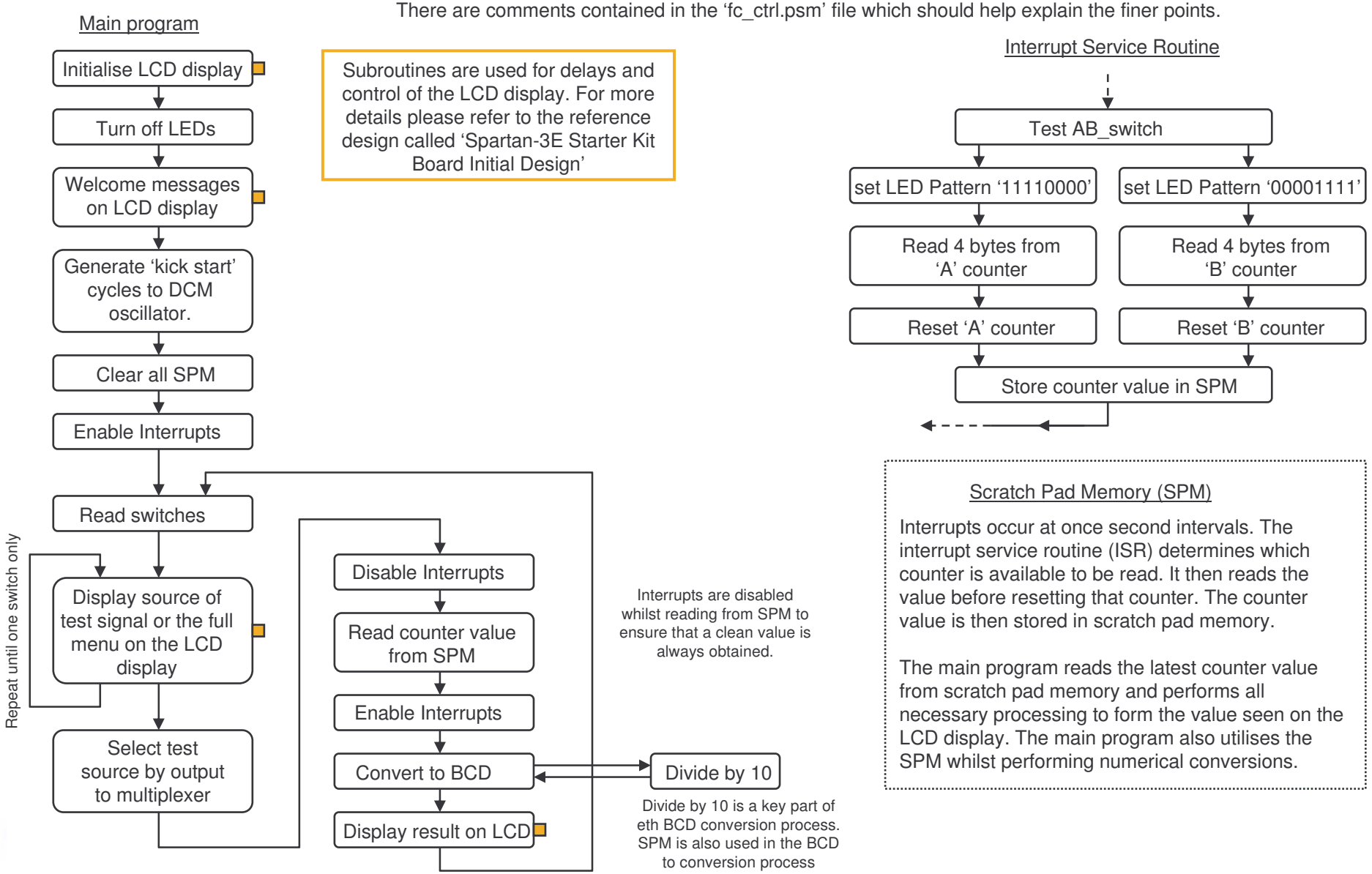
The output frequency will once again depend on the fabrication process of the device itself as well as temperature, voltage and aging effects during operation. However, the fact that this is a 'soft design' means that the initial amount of delay in the loop can be adjusted by changing the number of LUTs as well as by their relative placement and the interconnect used.

The frequency counter design provides a platform for experimentation with these low cost oscillators.

Complete PicoBlaze Program

This information is intended to give a guide to the way in which the PicoBlaze assembler code is organised. It is not intended to be a lesson in how to write assembler code or explain how PicoBlaze works. Please refer to the documentation for PicoBlaze (KCPSM3).

There are comments contained in the 'fc_ctrl.psm' file which should help explain the finer points.



Scratch Pad Memory (SPM)

Interrupts occur at once second intervals. The interrupt service routine (ISR) determines which counter is available to be read. It then reads the value before resetting that counter. The counter value is then stored in scratch pad memory.

The main program reads the latest counter value from scratch pad memory and performs all necessary processing to form the value seen on the LCD display. The main program also utilises the SPM whilst performing numerical conversions.

Exercises and Investigations

Improving accuracy

If you have access to a calibrated frequency counter or frequency source, use this to determine to actual frequency of the 50MHz crystal oscillator installed on your Starter Kit board. Then adjust the once second counter to improve the accuracy of your system.

How fast is yours?

To help evaluate the implementation of embedded oscillators, please observe the frequency of both your DCM and Ring oscillators on your board and send them to the author (ken.chapman@xilinx.com) so that the spread of values can be characterised over time. Please use the original configuration BIT file provided for this experiment and do state any special conditions (i.e. measurement taken outside at the South Pole!).

Ring Oscillator experiments

Evaluate the approximate changes in frequency achieved by increasing and decreasing the number of LUTs forming the loop delay.

Ideally create a design in which the loop delay is selectable using a byte written from PicoBlaze to a control port as this will allow one single placement to be used.

Modify the PicoBlaze code to record and display the maximum and minimum frequencies generated by the ring oscillator over time. Use this also to evaluate the effect on frequency due to temperature. Once evaluated, can you use a ring oscillator to determine the temperature of the silicon?

Long Term Stability Tests

The reference design provided includes two counters. This ensures that every cycle of the test source is recorded and this means PicoBlaze can determine the long term average number of cycles generated as well as short term fluctuations and peaks. Adapt the PicoBlaze code to display statistics for a long term tests of this kind.

Remote Control and Monitoring

Add an RS232 interface (UART) to the design and adapt the PicoBlaze program to allow remote control and monitoring from a PC. Use an application on the PC to graphically display the long term stability of the test clock or embedded oscillators.