Summary

The PicoBlaze™ module is a fully embedded 8-bit microcontroller macro for the Virtex™-II series. Although it could be used for processing of data, the PicoBlaze macro is most likely to be employed in applications requiring a complex, but non-time-critical state machine.

This revised version of the popular Constant (k) Coded Programmable State Machine (KCPSM) macro (PicoBlaze) has also been developed with one dominant factor being held above all others—its size. The result is a microcontroller that occupies just 84 Virtex-II slices, which is 33% of the smallest XC2V40 device and incredibly less than 0.25% of the XC2V6000 device. Together with this small amount of logic, a single block RAM is used to form a ROM store for a program of up to 1024 instructions. Even with such size constraints, the performance is respectable in the 40 to 70 MIPS range, depending on device speed grade.

The PicoBlaze module is totally embedded into the Virtex-II device and requires no external support. Any logic can be connected to the module inside the Virtex-II device, meaning that any additional features can be added to provide ultimate flexibility. It is not so much what is inside the PicoBlaze module that makes it useful, but the environment in which it lives.

Notes:
1. For Virtex-E and Spartan™-II/IIE designs, see XAPP213.

Introduction

Figure 1 is a block diagram of a Virtex-II PicoBlaze module. The Virtex PicoBlaze module requires no external support and provides a flexible environment for other logic connections into the PicoBlaze module.
The PicoBlaze module is supplied as VHDL and as a precompiled soft macro that is handled by the place and route tools to merge with the logic of a design. This plot (Figure 2) from the FPGA Editor viewer shows the macro in isolation within the smallest Virtex-II device.

Figure 2: FPGA Editor View of a PicoBlaze Macro in an XC2V40 Virtex-II Device

In the larger devices, the PicoBlaze module is virtually free (Figure 3). The potential to place multiple PicoBlaze modules within a single design is obvious. Whenever a non-time-critical complex state machine is required, this macro is easy to insert and greatly simplifies the design.
PicoBlaze Resource Information

The following device resource information (Figure 4) is taken from the ISE reports for the PicoBlaze macro in an XC2V40 device. The reports reveal the features that are utilized and the efficiency of the macro. The 84 “slices” reported by the map process in this case can reduce to the minimum of 77 “slices” when greater packing is used to fit a complete design into a device.

XST Report

<table>
<thead>
<tr>
<th>LUT1</th>
<th>LUT2</th>
<th>LUT3</th>
<th>LUT4</th>
<th>muxcy</th>
<th>muxf5</th>
<th>xorcy</th>
<th>FD</th>
<th>FDE</th>
<th>FDR</th>
<th>FDRE</th>
<th>FDRE</th>
<th>FDS</th>
<th>RAM 32X1D</th>
<th>RAM 32X1S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>68</td>
<td>28</td>
<td>32</td>
<td>9</td>
<td>33</td>
<td>39</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>2</td>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

102 LUTs (51 slices)

TRACE Report

102 LUTs

Carry and MUX logic (Free with LUTs)

66 Flip_flops (Free with LUTs)

Register bank (16 slices)

Call/Return Stack (10 slices)

Total = 77 Slices

TRACE Report

Device,speed: xc2v40,-6 (ADVANCED 1.113 2002-08-21)

Minimum period: 8.966 ns
(Maximum frequency: 111.53 MHz)

55.8 MIPS

Figure 3: FPGA Editor View of a PicoBlaze Macro in an XC2V6000 Virtex-II Device

Figure 4: Device Resource Information
Figure 5 shows the PicoBlaze architecture.

**PicoBlaze Architecture**

### General-Purpose Registers
The feature set includes 32 general-purpose 8-bit registers, specified as s00 to s1F (can be renamed in the assembler). All register operations are completely flexible, with no registers reserved for special tasks or given any priority over any other register. No accumulator exists as any register can be adopted for use as an accumulator.

### Arithmetic Logic Unit
The Arithmetic Logic Unit (ALU) provides all the simple operations expected in an 8-bit processing unit.
All operations are performed using an operand provided by any register. The result is returned to the same register. For operations requiring a second operand, a second register can be specified or a constant 8-bit value can be supplied. The ability to specify any constant value with no penalty to the program size or performance enhances the simple instruction set. To clarify, the ability to “ADD 1” is the equivalent of a dedicated INCREMENT operation. For operations requiring more than 8 bits, addition and subtraction operations have an option to include CARRY. Bit-wise operators (LOAD, AND, OR, XOR) provide the ability to manipulate and test values. There is also a comprehensive Shift and Rotate group.

**Flags Program Flow Control**

The ALU operation results affect the ZERO and CARRY flags. This information determines the execution sequence of the program using conditional and non-conditional program flow control instructions. JUMP commands specify absolute addresses within the program space.

CALL and RETURN commands provide subroutine facilities for commonly used sections of code. A CALL command is made to a specified absolute address, while a program counter stack preserves the return address. The stack provides for a nested CALL with a depth of up to 31 levels, which should be more than adequate for the program size supported.

**Reset**

The RESET input forces the processor back into the initial state. The program executes from address 000 and interrupts are disabled. The status flags and CALL/RETURN stack are also reset. Note that the register contents are not affected.

**Input/Output**

The PicoBlaze module has 256 input ports and 256 output ports. An 8-bit address value provided on the PORT_ID bus together with READ_STROBE or WRITE_STROBE signals indicates the accessed port. The port address can be either supplied in the program as an absolute value, or specified indirectly as the contents of any of the 32 registers. Indirect addressing is ideal when accessing a block of memory either constructed from block or distributed RAM within or external to the Virtex-II device.

During an INPUT operation, the value provided at the input port is transferred into any of the 32 registers. An input operation is indicated by a READ_STROBE output pulse. Although using this signal in the design input interface logic is not always vital, it indicates that data has been acquired by the PicoBlaze module.

During an OUTPUT operation, the contents of any of the 32 registers are transferred to the output port. A WRITE_STROBE output pulse indicates an output operation. This strobe signal is used in the design output interface logic to ensure that only valid data is passed to external systems. Typically, WRITE_STROBE is used as a clock enable or write enable signal.

**Interrupt**

The processor provides a single interrupt input signal. Using simple logic, multiple signals can be combined and applied to this one input signal. By default, the effect of the interrupt signal is disabled and is then under program control to be enabled and disabled as required.

An active interrupt forces the PicoBlaze macro to initiate a “CALL 3FF” (i.e., a subroutine call to the last program memory location) for the user to define a suitable course of action. Automatically, the interrupt process preserves the current ZERO and CARRY flag contents and disables any further interrupts. A special RETURNI command ensures that the end of an interrupt service routine restores the status of the flags and controls the enable of future interrupts.
Constant (k) Coded Values

The PicoBlaze module is in many ways a state machine based on constants. Constant values are specified for use in the following aspects of a program:

- Constant data value for use in an ALU operation
- Constant port address to access a specific piece of information or control logic external to the PicoBlaze module
- Constant address values for controlling the execution sequence of the program

The PicoBlaze instruction set coding is designed to allow constants to be specified within any instruction word. Hence, the use of a constant carries no additional overhead to the program size or its execution. This effectively extends the simple instruction set with a whole range of virtual instructions.

Constant Cycles

All instructions under all conditions execute over two clock cycles. A constant execution rate is of great value, when determining the execution time of a program, particularly when embedded into a real-time situation.

Constant Program Length

The program length is 1024 instructions, conforming to the 1024 x 18 format of a single Virtex-II block RAM. All address values are specified as 10-bits contained within the instruction coding. The fixed memory size promotes a consistent level of performance from the module.

Using the PicoBlaze Macro

The PicoBlaze macro is used principally in a VHDL design flow. It is provided as source VHDL (kcpsm2.vhd), which has been written for optimum and predictable implementation in a Virtex-II device. The code is suitable for implementation and simulation of the macro and has been developed and tested using XST for implementation and ModelSim™ for simulation. See Figure 6 and Figure 7. The code should not be modified in any way.

```vhdl
component kcpsm2
    Port (      address : out std_logic_vector(9 downto 0);
                instruction : in std_logic_vector(17 downto 0);
                port_id : out std_logic_vector(7 downto 0);
                write_strobe : out std_logic;
                out_port : out std_logic_vector(7 downto 0);
                read_strobe : out std_logic;
                in_port : in std_logic_vector(7 downto 0);
                interrupt : in std_logic;
                reset : in std_logic;
                clk : in std_logic);
end component;
```

Figure 6: VHDL Component Declaration of KCPSM2
Connecting the Program ROM

The principal method by which the PicoBlaze program ROM is used is in a VHDL design flow. The PicoBlaze assembler generates a VHDL file in which a block RAM and its initial contents are defined (see Assembler Directives). This VHDL file can be used for implementation and simulation of the processor. It has been developed and tested using XST for implementation and Modelsim for simulation. See Figure 8 and Figure 9.

Figure 7: VHDL Component Instantiation of the KCPSM2

```
processor: kcpsm2
   port map(
      address => address_signal,
      instruction => instruction_signal,
      port_id => port_id_signal,
      write_strobe => write_strobe_signal,
      out_port => out_port_signal,
      read_strobe => read_strobe_signal,
      in_port => in_port_signal,
      interrupt => interrupt_signal,
      reset => reset_signal,
      clk => clk_signal);
```

Notes:
1. The name of the program ROM (shown as "prog_rom" in the above examples) depends on the name of the user's program. For example, if the user's program file was called "phone.psm," then the assembler generates a program ROM definition file called "phone.vhd."

Figure 8: VHDL Component Declaration of Program ROM

```
component prog_rom
   Port (      address : in std_logic_vector(9 downto 0);
               instruction : out std_logic_vector(17 downto 0);
               clk : in std_logic);
end component;
```

Figure 9: VHDL Component Instantiation of Program ROM

```
program: prog_rom
   port map(
      address => address_signal,
      instruction => instruction_signal,
      clk => clk_signal);
```
Alternative Design Flows

Although the primary design flow is VHDL, the PicoBlaze module can be used in any design flow supported by Xilinx using the following files:

**kcpsm2.ngc**

The NGC file provided was made by synthesizing the `kcpsm2.vhd` file with XST (without inserting I/O buffers).

This file can be used as a “black box” in a Virtex-II design, and it will be merged with the rest of the user’s design during the translate phase (ngdbuild).

Note that buses are defined in the style `IN_PORT<7:0>` with individual signals from `in_port_0` through `in_port_7`.

**prog_rom.coe**

The COE file generated by the assembler is suitable for use with the Xilinx Core Generator.

The file defines the initial contents of a block ROM. The files generated by Core Generator can then be used as normal in the chosen design flow and connected to the PicoBlaze “black box” in the user’s design.

Notes:

1. It is recommended that "embedded_kcpsm2.vhd" be used for the generation of an ECS schematic symbol.

Simulation

If the NGC file is used in the design flow, then some form of back annotated net list needs to be used for simulation of the design to fill in the “black box” details required by the user’s simulator.

PicoBlaze Instruction Set

This section lists a complete instruction set representing all opcodes.

1. “XX” and “YY” refer to the definition of the storage registers “s” in range 00 to 1F.
2. “kk” represents a constant value in range 00 to FF.
3. “aaa” represents an address in range 000 to 3FF.
4. “pp” represents a port address in range 00 to FF.

Program Control Group

```
JUMP aaa
JUMP Z,aaa
JUMP NZ,aaa
JUMP C,aaa
JUMP NC,aaa

CALL aaa
CALL Z,aaa
CALL NZ,aaa
CALL C,aaa
CALL NC,aaa

RETURN
RETURN Z
RETURN NZ
RETURN C
RETURN NC
```

Notes:

1. Call and Return supports a stack depth of up to 31.
Logical Group
LOAD sXX,kk
AND sXX,kk
OR sXX,kk
XOR sXX,kk

LOAD sXX,sYY
AND sXX,sYY
OR sXX,sYY
XOR sXX,sYY

Arithmetic Group
ADD sXX,kk
ADDCY sXX,kk
SUB sXX,kk
SUBCY sXX,kk

ADD sXX,sYY
ADDCY sXX,sYY
SUB sXX,sYY
SUBCY sXX,sYY

Shift and Rotate Group
SR0 sXX
SR1 sXX
SRX sXX
SRA sXX
RR sXX

SL0 sXX
SL1 sXX
SLX sXX
SLA sXX
RL sXX

Input/Output Group
INPUT sXX,pp
INPUT sXX,(sYY)

OUTPUT sXX,pp
OUTPUT sXX,(sYY)

Interrupt Group
RETURNI ENABLE
RETURNI DISABLE

ENABLE INTERRUPT
DISABLE INTERRUPT
Under normal conditions, the program counter (PC) increments to point to the next instruction (Figure 10). The address space is fixed to 1024 locations (000 to 3FF hex), making the program counter 10-bits wide. The top of the memory is 3FF hex and increments to 000.

The JUMP instruction can be used to modify this sequence by specifying a new address. However, the JUMP instruction can be conditional. A conditional JUMP is only performed if a test performed on either the ZERO flag or CARRY flag is valid. The JUMP instruction has no effect on the status of the flags (Figure 11).

Each JUMP instruction must specify the 10-bit address as a three-digit hexadecimal value. The assembler supports labels to simplify programming (Figure 12).
CALL

The CALL instruction is similar in operation to the JUMP instruction. It modifies the normal program execution sequence by specifying a new address. The CALL instruction can also be conditional. In addition to supplying a new address, the CALL instruction also causes the current program counter (PC) value to be pushed onto the program counter stack. The CALL instruction has no effect on the status of the flags (Figure 13).

The program counter stack supports a depth of 31 address values, enabling nested CALL sequences to a depth of 31 levels to be performed. Since the stack is also used during an interrupt operation, at least one of these levels should be reserved when interrupts are enabled.

The stack is implemented as a separate cyclic buffer. When the stack is full, it overwrites the oldest value. Hence, it is not necessary to reset the stack pointer when performing a software reset. This also explains why there are no instructions to control the stack and why no program memory needs to be reserved for the stack.

Each CALL instruction must specify the 10-bit address as a three-digit hexadecimal value. To simplify programming, labels are supported in the assembler (Figure 14).

![Figure 13: CALL Instruction](image)

![Figure 14: CALL Instruction Specification](image)
**RETURN**

The RETURN instruction is the complement to the CALL instruction. The RETURN instruction is also conditional. In Figure 15, the new program counter (PC) value is formed internally by incrementing the last value on the program address stack, ensuring that the program executes the instruction following the CALL instruction which resulted in the subroutine. The RETURN instruction has no effect on the status of the flags.

![Figure 15: RETURN Instruction](image)

The programmer must ensure that a RETURN is only performed in response to a previous CALL instruction, so that the program counter stack contains a valid address (Figure 16). The cyclic implementation of the stack continues to provide values for RETURN instructions which cannot be defined. Each RETURN only specifies the condition for flag tests.

![Figure 16: RETURN Instruction Specification](image)
Interrupt Group

RETURNI

The RETURNI instruction (Figure 17) is a special variation of the RETURN instruction. It concludes an interrupt service routine. The RETURNI is unconditional and always loads the program counter (PC) with the last address on the program counter stack. The address does not increment in this case, because the instruction at the address stored needs to be executed. The RETURNI instruction restores the flags to the point of interrupt condition. It also determines the future ability of interrupts using ENABLE and DISABLE as an operand.

The programmer must ensure that a RETURNI (Figure 18) is only performed in response to an interrupt. Each RETURNI must specify if a further interrupt is enabled or disabled.

\[
\begin{array}{cccccccccccccccccccc}
17 & 16 & 15 & 14 & 13 & 12 & 11 & 10 & 9 & 8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
\end{array}
\]

RETURNI ENABLE

\[
\begin{array}{cccccccccccccccccccc}
17 & 16 & 15 & 14 & 13 & 12 & 11 & 10 & 9 & 8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{array}
\]

RETURNI DISABLE

Figure 17: RETURNI Instruction

Figure 18: RETURNI Instruction Specification

ENABLE INTERRUPT and DISABLE INTERRUPT

These instructions are used to set and reset the INTERRUPT ENABLE flag (Figure 19). Before using ENABLE INTERRUPT (Figure 20), a suitable interrupt routine must be associated with the interrupt address vector (3FF). Never enable interrupts while performing an interrupt service.

\[
\begin{array}{cccccccccccccccccccc}
17 & 16 & 15 & 14 & 13 & 12 & 11 & 10 & 9 & 8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
\end{array}
\]

ENABLE INTERRUPT

\[
\begin{array}{cccccccccccccccccccc}
17 & 16 & 15 & 14 & 13 & 12 & 11 & 10 & 9 & 8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \\
\hline
1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{array}
\]

DISABLE INTERRUPT

Figure 19: ENABLE/DISABLE INTERRUPT Instruction

Figure 20: ENABLE/DISABLE INTERRUPT Instruction Specification
**Logical Group**  

**LOAD**

The LOAD instruction specifies the contents of any register. The new value is either a constant or the contents of any other register. The LOAD instruction has no effect on the status of the flags (Figure 21).

![Figure 21: LOAD Instruction](x627_20_120402)

Since the LOAD instruction does not affect the flags, it is used to reorder and assign register contents at any stage of the program execution. Because the load instruction is able to assign a constant with no impact to the program size or performance, the load instruction is the most obvious way to assign a value or clear a register.

Each LOAD instruction (Figure 22) must specify the first operand register as "s" followed by two hexadecimal digits. The register also forms a destination for the result. The second operand must then specify a second register value in a similar way or specify an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.

![Figure 22: LOAD Instruction Specification](x627_21_111102)
AND

The AND instruction performs a bit-wise logical AND operation between two operands. For example, 00001111 and 00110011 produces the result 00000011. The first operand is any register, and it is the register assigned the result of the operation. A second operand is also any register, or an 8-bit constant value (Figure 23). Flags are affected by this operation. The AND operation can be used to perform tests on the contents of a register. The status of the ZERO flag then controls the flow of the program.

Each AND instruction (Figure 24) must specify the first operand register as “s” followed by two hexadecimal digits. This register also forms the destination for the result. The second operand specifies a second register value in a similar way, or specifies an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.

Figure 23: AND Instruction

Figure 24: AND Instruction Specification
OR

The OR instruction performs a bit-wise logical OR operation between two operands. For example, 00001111 OR 00110011 produces the result 00111111. The first operand is any register. This register is assigned the result of this operation. A second operand is also any register, or an 8-bit constant value (Figure 25). Flags are affected by the OR operation. The OR instruction provides a way to force setting any bit of the specified register, which can be used to form control signals.

```
<table>
<thead>
<tr>
<th>Register</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>sXX</td>
<td>OR</td>
</tr>
<tr>
<td></td>
<td>k k k k k k k k</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>Register</th>
<th>sYY</th>
</tr>
</thead>
</table>
```

Figure 25: OR Instruction

Each OR instruction (Figure 26) must specify the first operand register as "s" followed by two hexadecimal digits. This register also forms the destination for the result. The second operand must then specify a second register value in a similar way, or specify an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.

```
<table>
<thead>
<tr>
<th>OR sXX,kk</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0 1 0 0 1 x x x k k k k k k k k</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>OR sXX, sYY</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 0 1 0 0 0 0 0 x x x x y y y y y y y y 0 0 0</td>
</tr>
</tbody>
</table>
```

Figure 26: OR Instruction Specification
XOR

The XOR instruction performs a bit-wise logical XOR operation between two operands. For example, 00001111 XOR 00110011 produces the result 00111100. The first operand is any register, and this register is assigned the result of the operation. A second operand is also any register, or an 8-bit constant value. Flags are affected by this operation (Figure 27). The XOR operation inverts bits contained in a register, which is used in forming control signals.

Each XOR instruction (Figure 28) must specify the first operand register as “s” followed by two hexadecimal digits. This register also forms the destination for the result. The second operand must then specify a second register value in a similar way, or specify an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.

Figure 27: XOR Instruction

Figure 28: XOR Instruction Specification
The ADD instruction performs an 8-bit addition of two operands. The first operand is any register, and it is this register that is assigned the result of the operation. A second operand is also any register, or an 8-bit constant value (Figure 29). Flags are affected by this operation. Note that this instruction does not use the CARRY as an input, and hence, there is no need to condition the flags before use. The ability to specify any constant is useful in forming control sequences or counters.

Each ADD instruction (Figure 30) must specify the first operand register as “s” followed by two hexadecimal digits. This register forms the destination for the result. The second operand must then specify a second register value in a similar way, or specify an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.
ADDCY

The ADDCY instruction performs an addition of two 8-bit operands together with the contents of the CARRY flag. The first operand is any register, and this register is assigned the result of the operation. A second operand is also any register, or an 8-bit constant value (Figure 31). Flags are affected by this operation. The ADDCY operation is used in the formation of adder and counter processes exceeding eight bits.

```
<table>
<thead>
<tr>
<th>sXX</th>
<th>sXX</th>
<th>+</th>
<th>Constant</th>
<th>CARRY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>sXX</th>
<th>sXX</th>
<th>+</th>
<th>sYY</th>
<th>CARRY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

CARRY ? Set if result of addition exceeds FF. Reset in all other cases.
ZERO ? Set if all bits of result are zero. Reset in all other cases.

**Figure 31: ADDCY Instruction**

Each ADDCY instruction (Figure 32) must specify the first operand register as “s” followed by two hexadecimal digits. This register also forms the destination for the result. The second operand must then specify a second register value in a similar way, or specify an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.

```
<table>
<thead>
<tr>
<th>ADDCY sXX,kk</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 1 0 1 x x x x k k k k k k</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>ADDCY sXX, sYY</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 1 0 1 x x y y y y 0 0 0 0</td>
</tr>
</tbody>
</table>
```

**Figure 32: ADDCY Instruction Specification**
SUB

The SUB instruction performs an 8-bit subtraction of two operands. The first operand is any register, and this register is assigned the result of the operation. The second operand is also any register, or an 8-bit constant value (Figure 33). Flags are affected by this operation. Note that this instruction does not use the CARRY as an input and, hence, there is no need to condition the flags before use. The CARRY flag indicates when an underflow has occurred. For example, if “s05” contains 27 hex and the instruction SUB s05,35 is performed, then the stored result is F2 hex and the CARRY flag is set.

Each SUB instruction (Figure 34) must specify the first operand register as “s” followed by two hexadecimal digits. This register also forms the destination for the result. The second operand must then specify a second register value in a similar way, or specify an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.
SUBCY

The SUBCY instruction performs an 8-bit subtraction of two operands together with the contents of the CARRY flag. The first operand is any register, and this register is assigned the result of the operation. The second operand is also any register, or an 8-bit constant value (Figure 35). Flags are affected by this operation. The SUBCY operation is used in the formation of subtract and down-counter processes exceeding 8 bits.

Each SUBCY instruction (Figure 36) must specify the first operand register as “s” followed by two hexadecimal digits. This register also forms the destination for the result. The second operand must then specify a second register value in a similar way, or specify an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.
Shift and Rotate Group

SR0, SR1, SRX, SRA, RR

The shift and rotate right group all modify the contents of a single register (Figure 37). All instructions in the group have an effect on the flags.

- **SR0 sXX**
  - "0" instruction
  - CARRY
  - ZERO
  - Set if all bits of result are zero.
  - Reset in all other cases.

- **SR1 sXX**
  - "1" instruction
  - CARRY
  - ZERO
  - Set if all bits of result are zero.
  - Reset in all other cases.

- **SRX sXX**
  - CARRY
  - ZERO
  - Set if all bits of result are zero.
  - Reset in all other cases.

- **SRA sXX**
  - CARRY
  - ZERO
  - Set if all bits of result are zero.
  - Reset in all other cases.

- **RR sXX**
  - CARRY
  - ZERO
  - Set if all bits of result are zero.
  - Reset in all other cases.

**Figure 37: Right Shift Register Instructions**

Each instruction must specify the register as "s" followed by two hexadecimal digits (Figure 38). The assembler supports register naming to simplify programming.

**Figure 38: Right Shift Register Instruction Specification**
SL0, SL1, SLX, SLA, RL
The shift and rotate left group all modify the contents of a single register (Figure 39). All instructions in the group have an effect on the flags.

Each instruction must specify the register as "s" followed by two hexadecimal digits (Figure 40).

The assembler supports register naming to simplify programming.

Figure 39: Left SHIFT Register Instructions

Figure 40: Left SHIFT Register Instruction Specification
Input and Output Group

**INPUT**

The **INPUT** instruction enables data values external to the PicoBlaze module to be transferred into any one of the internal registers (Figure 41). The port address (in the range 00 to FF) is defined by a constant value, or indirectly as the contents of the any other register. The flags are not affected by this operation.

```
<table>
<thead>
<tr>
<th>sXX</th>
<th>Port Value</th>
<th>PORT_ID Address</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>p p p p p</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>sXX</th>
<th>Port Value</th>
<th>PORT_ID Address</th>
<th>sYY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

*Figure 41: INPUT Instruction*

The user interface logic is required to decode the PORT_ID port address value and supply the correct data to the IN_PORT. The READ_STROBE is set during an input operation (see **READ and WRITE STROBES**), but is not vital for the interface logic to decode this strobe in most applications. However, it can be useful for determining when data has been read, such as when reading a FIFO buffer.

Each **INPUT** instruction (Figure 42) must specify the destination register as “s” followed by two hexadecimal digits. It must then specify the input port address using a register value in a similar way, or specify an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.

```
<table>
<thead>
<tr>
<th>INPUT sXX,PP</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0</td>
</tr>
<tr>
<td>0 0 0 0 x x x x p p p p p p p p p p</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INPUT sXX,(sYY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0</td>
</tr>
<tr>
<td>1 1 0 0 0 x x x x y y y y y y y y y y</td>
</tr>
</tbody>
</table>

*Figure 42: INPUT Instruction Specification*


**OUTPUT**

The OUTPUT instruction enables the contents of any register to be transferred to logic external to the PicoBlaze module. The port address (in the range 00 to FF) is defined by a constant value, or indirectly as the contents of the any other register (Figure 43). The flags are not affected by this operation.

The user interface logic is required to decode the PORT_ID port address value and capture the data provided by the OUT_PORT. The WRITE_STROBE is set during an output operation (see READ and WRITE STROBES) and should be used to clock enable the capture register (or write enable a RAM).

Each OUTPUT instruction (Figure 44) must specify the source register as “s” followed by two hexadecimal digits. It must then specify the output port address using a register value in a similar way, or specify an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.

**Figure 43: OUTPUT Instruction**

The user interface logic is required to decode the PORT_ID port address value and capture the data provided by the OUT_PORT. The WRITE_STROBE is set during an output operation (see READ and WRITE STROBES) and should be used to clock enable the capture register (or write enable a RAM).

Each OUTPUT instruction (Figure 44) must specify the source register as “s” followed by two hexadecimal digits. It must then specify the output port address using a register value in a similar way, or specify an 8-bit constant using two hexadecimal digits. The assembler supports register naming and constant labels to simplify programming.

**Figure 44: OUTPUT Instruction Specification**
READ and WRITE STROBES

These pulses are used by external circuits to confirm input and output operations. In the waveforms (Figure 45), it is assumed that the content of register s1E is 47, and the content of register s1A is 42.

PORT_ID[7:0] is provided with the full two clock cycles to be decoded by external logic. The WRITE_STROBE is provided on the second clock cycle to confirm an active write by the PicoBlaze module. In most cases, the READ_STROBE is not utilized by the external decoding logic, but again occurs in the second cycle and indicates the actual clock edge on which data is read into the specified register.

Notes:
1. For timing critical designs, timing specifications can allow two clock cycles for PORT_ID and data paths, and only the strobes need to be constrained to a single clock cycle.
**RESET**

The PicoBlaze module contains an internal reset control circuit to ensure the correct start up of PicoBlaze following device configuration or global reset. This reset can also be activated within the user's design.

The PicoBlaze reset is sampled synchronous to the clock and used to form a controlled internal reset signal which is distributed locally as required. A small ‘filter’ circuit (Figure 46) ensures that the release of the internal reset is clean and controlled. The reset input can be tied to logic 0 if not required, and the filter is still used to ensure correct power-up sequence. See (Figure 47 and Figure 48)

![Figure 46: PicoBlaze Filter Circuit](image)

![Figure 47: Release of Reset after Configuration](image)

**PicoBlaze Assembler**

The PicoBlaze Assembler (Figure 49) is provided as a simple DOS executable file together with two template files. The files `KCPSM2.EXE`, `ROM_form.vhd`, and `ROM_form.coe` should be copied into the user's working directory.

Programs are best written with either the standard Notepad or Wordpad tools. The file is saved with a `.psm` file extension (8-character name limit).

Open a DOS box and navigate to the working directory. Then run the assembler `kcpsm2 <filename> [.psm]` to assemble the program. It all happens very fast.
Assembler Errors

The assembler stops as soon as an error is detected (Figure 50). A short message is displayed to help determine the reason for the error. The assembler also displays the line it was analyzing when the problem was detected. The user should fix each reported problem in turn and re-execute the assembler.

Since the execution of the assembler is very fast, the display appears to be immediate. The user can review everything that the assembler has written to the screen, by redirecting the DOS output to a text file using: `kcpsm2 <filename>.vhd <filename>.coe > screen_dump.txt`
Assembler Files

The PicoBlaze Assembler actually reads three input files and generates thirteen output files. See Figure 51 for a diagram of these files.

```
<filename>.psm  } Program file

ROM_form.vhd     KCPSM2.EXE     pass1.dat
ROM_form.coe

ROM definition files for design
{ <filename>.vhd  <filename>.log  Assembler report files
  <filename>.coe  constant.txt
  <filename>.hex  labels.txt
  <filename>.dec

ROM definition files for other utilities
{ <filename>.coe  <filename>.fmt  Formatted version of user input file
```

**Figure 51: Files Associated with Assembler**

Notes:

1. All output files are overwritten each time the assembler is executed.

The *hex* and *dec* files provide the program ROM contents in unformatted hexadecimal and decimal for conversion to other formats not supported directly by the assembler. There is no further description in this application note.

**ROM_form.vhd File**

This file provides the template for the VHDL file generated by the assembler and suitable for synthesis and simulation. This file is provided with the assembler and must be placed in the working directory.

The supplied *ROM_form.vhd* template file defines a single-port block RAM for Virtex-II devices configured as a ROM. The user can adjust this template to define the type of memory desired. The template supplied includes additional notes on how the template works.

The assembler reads the *ROM_form.vhd* template and simply copies the information into the output file *<filename>.vhd*. There is no checking of syntax, so any alterations are the responsibility of the user.

The template contains some special text strings surrounded by {} brackets. These are {begin template}, {name}, and a whole family of initialization identifiers, such as {INIT_01}. The assembler uses {begin template} to identify where the VHDL definition begins. It then intercepts and replaces all other special strings with the appropriate information. {name} is replaced with the name of the input program .psm file. See Figure 52.
ROM_form.coe File

This file provides the template for the coefficient file generated by the assembler and suitable for the Core Generator. This file is provided with the assembler and must be placed in the working directory.

The supplied ROM_form.coe template file defines a Dual Port Block RAM for a Virtex-II device in which the A-port is read only and the B-port is read/write. The user can adjust this template to define the type of memory for the Core Generator to implement.

The assembler reads the ROM_form.coe template and simply copies the information into the output file <filename>.coe. There is no checking of syntax, so any alterations are the responsibility of the user.

The template can contain the special text string (name) which the assembler intercepts and replaces with the name of the program file. In Figure 53, (name) has been replaced with “simple.”

```
entity {name} is
  Port (     address : in std_logic_vector(9 downto 0);
             instruction : out std_logic_vector(17 downto 0);
             clk : in std_logic);
  end {name};

architecture low_level_definition of {name} is

  --
  attribute INIT_00 of ram_1024_x_18 : label is "(INIT_00)";
  attribute INIT_01 of ram_1024_x_18 : label is "(INIT_01)";
  attribute INIT_02 of ram_1024_x_18 : label is "(INIT_02)";

Figure 52: ROM_form.vhd
```

```
ROM_form.coe
component_name={name};
width_a=18;
depth_a=1024;

memory_initialization_radix=16;
global_init_value=00000;
memory_initialization_vector=

<filename>.coe
component_name=simple;
width_a=18;
depth_a=1024;

memory_initialization_radix=16;
global_init_value=00000;
memory_initialization_vector=
01400, 23412, 09401, 100A0, 0C018, 35401, 34000, 00000, ...

Figure 53: ROM_form.coe File
```
Note: It is vital that the last line of the template contains the key words:

```
memory_initialization_vector=
```

These words are used by the Core Generator to identify the data values that follow. The assembler appends the 1024 values required. Indeed, the template could simply contain this one line provided the Core Generator GUI is used to set up all other parameters.

**<filename>.fmt File**

When a program passes through the assembler, additional files to the .vhd and .coe files are produced to assist the programmer. One of these files is called **<filename>.fmt**, which is the original program but in a formatted state. Looking at this file is an easy way for the programmer to see that everything has been interpreted correctly. The **<filename>.fmt** file:

- Formats labels and comments
- Puts all commands in upper case
- Correctly spaces operands
- Gives registers an ‘sXX’ format
- Converts hex constants to upper case

See Figure 54. The user can write a PSM program quickly and then use KCPSM2 to make a formatted version.

```
constant max_count, 18; count to 24 hours
namereg s14, counter_reg; define register for counter
constant count_port, 12
start: load counter_reg, 00; initialise counter
loop: output counter_reg, count_port
add counter_reg, 01; increment
load s00, counter_reg
sub s00, max_count; test for max value
jump nz, loop; next count
jump start; reset counter

<filename>.fmt

CONSTANT max_count, 18 ; count to 24 hours
NAMEREG s14, counter_reg ; define register for counter
CONSTANT count_port, 12
start: LOAD counter_reg, 00 ; initialise counter
loop: OUTPUT counter_reg, count_port
ADD counter_reg, 01 ; increment
LOAD s00, counter_reg
SUB s00, max_count ; test for max value
JUMP NZ, loop ; next count
JUMP start ; reset counter
```

Figure 54: **<filename>.fmt File**
The `.log` file (Figure 55) provides the user with the most detail about the assembly process which has been performed. This is where the user can observe how each instruction and directive has been used. Address and opcode values are associated with each line of the program and the actual values of addresses, registers, and constants defined by labels are specified.

<table>
<thead>
<tr>
<th>Address</th>
<th>Op-Code</th>
<th>Label</th>
<th>Instruction</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td></td>
<td></td>
<td>CONSTANT max_count, 18</td>
<td>;count to 24 hours</td>
</tr>
<tr>
<td>000</td>
<td></td>
<td></td>
<td>NAMEREG s14, counter_reg</td>
<td>;define register for counter</td>
</tr>
<tr>
<td>000</td>
<td>01400</td>
<td>start:</td>
<td>LOAD counter_reg[s14], 00</td>
<td>;initialise counter</td>
</tr>
<tr>
<td>001</td>
<td>23412</td>
<td>loop:</td>
<td>OUTPUT counter_reg[s14], count_port[12]</td>
<td></td>
</tr>
<tr>
<td>002</td>
<td>09401</td>
<td>ADD</td>
<td>counter_reg[s14], 01</td>
<td>;increment</td>
</tr>
<tr>
<td>003</td>
<td>100A0</td>
<td>LOAD</td>
<td>s00, counter_reg[s14]</td>
<td></td>
</tr>
<tr>
<td>004</td>
<td>0C018</td>
<td>SUB</td>
<td>s00, max_count[18]</td>
<td>;test for max value</td>
</tr>
<tr>
<td>005</td>
<td>35400</td>
<td>JUMP</td>
<td>NZ, loop[001]</td>
<td>;next count</td>
</tr>
<tr>
<td>006</td>
<td>34000</td>
<td>JUMP</td>
<td>start[000]</td>
<td>;reset counter</td>
</tr>
</tbody>
</table>

Values contained in [] brackets indicates the value associated with the label i.e., 'loop' is resolved to be address '001'.

Figure 55: `<filename>.log File`

**constant.txt and labels.txt Files**

These two files (Figure 56) provide a list of line labels and their associated addresses and a list of constants and their values as defined by constant directives in the program file. These are useful during the development of larger programs.
pass.dat Files

The pass.dat files (Figure 57) are internal files to the assembler and represent intermediate stages of the assembly process. These files are typically ignored, but can help in identifying how the assembler has interpreted the program file syntax. The files are automatically deleted at the start of the assembly process. If there is an error detected by the assembler, the .dat files are only complete until the point of the last successful processing.

The .dat files segment the information from each line into the different fields. Each pass resolves more information. The example shown here is related to the line:

```
ADD counter_reg, 01 ;increment
```
It can be seen that pass1.dat has purely segmented the fields of the line. In the final pass5.dat, the assembler has resolved all the relevant information.

```
Part of pass1.dat

    LABEL-
    INSTRUCTION-add
        OPERAND1-counter_reg
        OPERAND2-01
    COMMENT-;increment

Part of pass5.dat

    ADDRESS-002
    LABEL-
    FORMATTED-ADD counter_reg, 01
    LOGFORMAT-ADD counter_reg[sl4], 01
    INSTRUCTION-ADD
        OPERAND1-counter_reg
        OP1 VALUE-sl4
        OPERAND2-01
        OP2 VALUE-01
    COMMENT-;increment
```

Figure 57: pass.dat Files

Program Syntax

Probably the best way to understand what is and what is not valid syntax is to look at the examples and try the assembler. However, some simple rules are of assistance from the beginning. To ensure that the correct program syntax is used, the following suggestions are recommended:

**No blank lines.** A blank line is ignored by the assembler and removed from any formatted files. To keep a line, use a blank comment (a semicolon).

**Comments.** Any item on a line following a semi-colon (;) is ignored by the assembler. Concise comments should be used to keep the program manageable and make it easy to print out programs and log files.

**Registers.** All registers should be defined as the letter 's' immediately followed by two hexadecimal digits the range 00 to 1F. The assembler will accept any mixture of upper and lower case characters and automatically convert them to the 'sXX' format where 'XX' is one of 00,01,02,03,04,05,06,07,08,09,0A,0B,0C,0D,0E,0F,10,11,12,13,14,15,16,17,18,19,1A,1B,1C, 1D,1E,1F.

**Constants.** A constant is specified in the form of a two-digit hexadecimal value (range 00 to FF). The assembler accepts any mixture of upper and lower case characters and automatically converts them to upper case.

**Labels.** Labels are any user-defined text string and are case sensitive for additional flexibility. No spaces are allowed, but the underscore character is supported. Valid characters are 0 to 9, a to z, and A to Z. Labels should be reasonably concise to keep the program formatting clean. Labels which could be confused with hexadecimal addresses and constants or register specifications are rejected by the assembler.
**Line Labels.** A label used to identify a program line for reference in a JUMP or CALL instruction should be followed by a colon (:) Figure 58 shows the use of a label to identify a program line and its use later in a JUMP instruction.

![Figure 58: Line Label Example](image)

**Program Instructions**

The instructions should be as shown in PicoBlaze Instruction Set. The assembler is very forgiving over the use of spaces and <TAB> characters, but instructions and the first operand must be separated by at least one space. Instructions with two operands must ensure that a comma (,) separator is used.

The assembler accepts any mixture of upper and lower case characters for the instruction and automatically converts them to upper case. The following examples show acceptable instruction specifications, but the formatted output shows how it was expected.

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Assembler</th>
</tr>
</thead>
<tbody>
<tr>
<td>load s15, 7E</td>
<td>LOAD s15, 7E</td>
</tr>
<tr>
<td>AddCY s08, S1E</td>
<td>ADDCY s08, s1E</td>
</tr>
<tr>
<td>ENABLE interrupt</td>
<td>ENABLE INTERRUPT</td>
</tr>
<tr>
<td>Output S12, (S08)</td>
<td>OUTPUT s12, (s08)</td>
</tr>
<tr>
<td>jump Nz, 267</td>
<td>JUMP NZ, 267</td>
</tr>
<tr>
<td>ADD s1F, step_value</td>
<td>ADD s1F, step_value</td>
</tr>
<tr>
<td>INPUT S19, 28</td>
<td>INPUT s19, 28</td>
</tr>
<tr>
<td>sl1 s0e</td>
<td>SL1 s0E</td>
</tr>
<tr>
<td>RR S08</td>
<td>RR s08</td>
</tr>
</tbody>
</table>

Most other syntax problems are solved by reading the error messages provided by the assembler.

**Assembler Directives**

The assembler supports three assembler directives. These commands are used purely by the assembly process and do not correspond to instructions executed by PicoBlaze module.

**CONSTANT Directive**

This directive provides a way to assign an 8-bit constant value to a label. In this way, the program can declare constants such as port addresses and particular data values needed in the program. By defining constant values in this way, it is often easier to understand their meaning in the program rather than as actual hexadecimal constant values in the program lines. Figure 59 illustrates the directive syntax and its uses.
Figure 59: CONSTANT Directive

Notes:
1. A constant is global. Even if a constant is defined as the end of the program file, it can be used in instructions anywhere in the program.
2. Constant names must not contain any spaces although the underscore character is supported. Valid characters are 0 to 9, a to z, and A to Z.

In Figure 59, “max_count” is being used to specify a data constant of 18 hex. In the program, this is used to test the value of a counter. By using a constant directive, the code is more readable. It would also be possible to change the constant value and its effect would be applied to multiple places in the program.

“count_port” is being used to specify a port address. In the program, the OUTPUT instruction refers to the port by name rather than absolute value. By using a constant directive, the code is more readable. It would also be possible to change the constant value once in the directive and its effect would be applied to multiple places in the program. This is particularly useful when defining the hardware interface. Indeed, the program can be developed before the I/O addresses are defined.

NAMEREG Directive

This directive provides a way to assign a new name to any of the 32 registers. In this way, the program refers to “variables” by name rather than as absolute register specifications. By naming registers in this way, it is easier to understand the meaning in the program without so many comments. It also helps to prevent inadvertent reuse of a register with associated data corruption. See Figure 60.

Figure 60: NAMEREG Directive

Notes:
1. Register names must not contain any spaces although the underscore character is supported. Valid characters are 0 to 9, a to z, and A to Z.

In Figure 60, the register s14 has been renamed to be “counter_reg” and is then used in multiple instructions, making it clear what the meaning of the register contents actually are.
**Important:** The NAMEREG directive is applied in-line with the code by the assembler. Before the NAMEREG directive, the register is named in the ‘sXX’ style. Following the directive, only the new name applies.

It is also possible to rename a register again (i.e., NAMEREG counter_reg, hours) and only the new name applies in the subsequent program lines. This can be useful in making portable code and subroutines.

### ADDRESS Directive

ADDRESS directive (Figure 61) provides a way to force the assembly of the following instructions commencing at a new address value. This is useful for separating subroutines into specific locations and vital for handling interrupts. The address must be specified as a three-digit hexadecimal value in the range 000 to 3FF.

```assembly
JUMP NZ, inner_long
RETURN
;Interrupt Service Routine
ISR: LOAD wait_light, 01 ;register press of switch
OUTPUT wait_light, wait_light_port ;turn on light
RETURNI DISABLE ;continue light sequence but no more interrupts
ADDRESS 3FF ;Interrupt vector
JUMP ISR
;end of program
```

*Figure 61: ADDRESS Directive*

In Figure 62, the log file shows that the ADDRESS directive is used to force the last instruction into the highest memory location in the program RAM. This is the address to which the program counter is forced during an active interrupt.

```assembly
246 35644 JUMP NZ, inner_long[244]
247 24000 RETURN
248 01201 ISR: LOAD wait_light[s12], 01 ;register press of switch
249 23210 OUTPUT wait_light[s12], wait_light_port[10] ;turn on light
24A 2C000 RETURNI DISABLE ;continue light sequence but no
3FF 34248 ADDRESS 3FF ;Interrupt vector
3FF 3248 JUMP ISR[248]
3FF ;end of program
```

*Figure 62: ADDRESS Directive Example*

### KCPSM Code Compatibility

KCPSM and KCPSM2 have many similarities. However, each has been tuned to specific device architecture so there are differences. KCPSM2 has more program space and more registers and, therefore, it can accommodate a program written for KCPSM. However, there are some details to be considered when moving programs.

**Registers**

The key difference from a user perspective is that there are 32 registers with names “sXX” rather than 16 registers with names “sX.” If existing code is to be used with KCPSM2, the NAMEREG directive can make the code compatible.
Simply add the following lines before any active instructions:

- namereg s00,s0
- namereg s01,s1
- name
- name
- namereg s0F,sF

Now the lower 16 registers have the same identifiers as that for KCPSM. However, the input code must use the “sX” format correctly and not an upper case “S” or lower case hexadecimal digit. Therefore, the "format.psm" output from KCPSM should be used where possible.

**Address Range**

Since the KCPSM2 module supports 1024 program instructions and the KCPSM module supports 256, it is always possible that the program will fit. However, the different address range does make a difference to ADDRESS directives.

Any address directives used in the program code need to be adjusted to specify the desired assembly address as three hexadecimal digits rather than two.

**Interrupt Vector**

During an active interrupt, the program counter of KCPSM is forced to the last memory location “FF.” In a similar way, the program counter of KCPSM2 is also forced to the last memory location, but this is now “3FF” due to the larger program space. Therefore, it is vital that programs using interrupts adjust the location of the interrupt vector. This typically involves adjusting the associated ADDRESS directive from address FF to 3FF.

**Label Validity**

The assembler has slightly different rules concerning which labels for lines, constants, and registers are acceptable. For example, a constant label cannot be “s1e” because this can be confused with a default register name of the KCPSM2 macro. Therefore, it may be necessary to adjust some of the user names in the program code. Typically, labels are descriptive so this issue should not be encountered.

---

**Interrupt Handling**

Effective interrupt handling requires skill, and this document does not explain how and when an interrupt should be used. The information supplied should be adequate for the user to assess the capability of the PicoBlaze module and to create interrupt-based systems.

**Default State**

By default, the interrupt input is disabled. This means that the entire 1024 words of program space are used without any regard to interrupt handling or use of the interrupt instructions.

**Enabling Interrupts**

For an interrupt to take place, the ENABLE INTERRUPT command must be used. At critical stages of program execution where an interrupt is unacceptable, a DISABLE INTERRUPT is used. Since an active interrupt automatically disables the interrupt input, the interrupt service routine ends with a RETURNI instruction, which also includes the option to ENABLE or DISABLE the interrupt input as it returns to the main program.

During an interrupt (Figure 63), the program counter is pushed onto the stack and the values of the CARRY and ZERO flags are preserved (for restoration by the RETURNI instruction). The
interrupt input is automatically disabled. Finally, the program counter is forced to address 3FF (last program memory location) from which the next instruction is executed.

**Basics of interrupt Handling**

Since the interrupt forces the program counter to address 3FF, it will generally be necessary to ensure that a jump vector to a suitable interrupt service routine is located at this address. Without a JUMP instruction, the program rolls over to address zero.

In typical cases, an interrupt service routine is provided. The routine can be located at any position in the program and jumped to by the interrupt vector located at the 3FF address. The service routine performs the required tasks and then ends in RETURNI with ENABLE or DISABLE.

**Figure 64** illustrates a very simple interrupt handling routine. The PicoBlaze module generates waveforms to an output by writing the values 55 and AA to the waveform_port (port address 02). It does this at regular intervals by decrementing a register (s00) based counter seven times in a loop.

When an interrupt is asserted, the PicoBlaze module stops generating waveforms and simply increments a separate counter register (s1A) and writes the counter value to the counter_port (port address 04).
Design VHDL Example

The following VHDL shows the addition of the data capture registers to the processor. Note the simplified port decoding logic through careful selection of port addresses. The complete VHDL file is supplied as `kcpsm2_int_test.vhd`.

```vhdl
-- adding the output registers to the processor

IO_registers: process(clk)
begin
    -- waveform register at address 02
    if clk'event and clk='1' then
        if port_id(1)='1' and write_strobe='1' then
            waveforms <= out_port;
        end if;
    end if;
    -- Interrupt Counter register at address 04
    if clk'event and clk='1' then
        if port_id(2)='1' and write_strobe='1' then
            counter <= out_port;
        end if;
    end if;
end process IO_registers;
```

*Figure 65: Design VHDL Example*

Interrupt Service Routine

In the assembler log file for the example, it can be seen that the interrupt service routine has been forced to compile at address 2B0, and that the waveform generation is based in the normal lower addresses. This makes it easier to observe the interrupt in action in the operation waveforms. This program is supplied as `int_test.psm` for the user to compile.
Interrupt Operation

The waveforms in Figure 67 taken from an actual ModelSim-XE simulation show the operation of PicoBlaze module when executing the example program at the time of an interrupt. The VHDL test bench used to generate these waveforms is supplied as testbench.vhd.

By observing the address bus, it is possible to see that the program is busy with generating the waveforms and even shows the port 02 being written the AA pattern value. Then while in the delay loop which repeats addresses 005 and 006, it receives an interrupt pulse.

It can be seen that PicoBlaze module took a few cycles to respond to this particular pulse (see timing of interrupt pulses) before forcing the address bus to 3FF. From 3FF, the obvious JUMP to the service routine located at 2B0 can be seen to follow and a resulting counter value (in this case 03) is written to the port 04.

Figure 66: Interrupt Service Routine

Figure 67: Interrupt Operation
The operation of an interrupt in PicoBlaze module is also visible. It can be seen that the last address active before the interrupt is 006. The JUMP NZ instruction obtained at this address (opcode 35405) is *not* executed. The flags preserved are those which were set at the end of the instruction at the previous address (SUB s00,01). The RETURNI has restored the flags and returned the program to address ‘006’ so that the JUMP NZ instruction can at last be executed.

**Timing Of Interrupt Pulses**

It is clear from the previous simulation waveforms that the constant two cycles per instruction is maintained at all times. Since this includes an interrupt, the use of single cycle pulses for interrupt can be risky. However, the waveform in Figure 68 can be used to determine the exact cycle on which the interrupt is observed and the true reaction rate of KCPSM2.

![Interrupt Timing](Figure 68: Interrupt Timing)

Therefore, it is advisable that an interrupt signal should be active for a minimum of two KCPSM2 rising clock cycle edges. An improvement would be for the interrupt service routine to acknowledge the interrupt to the external logic. There are three ways to achieve this:

- Service routine *writes* to a specific port to acknowledge interrupt and reset driving pulse (wasteful).
- *Read* a specific port to determine the reason for interrupt and use READ_STROBE as a register reset pulse.
- Decode the address bus to identify when the address 3FF has been forced by the active interrupt.

**CALL/RETURN Stack**

The PicoBlaze module contains an automatic embedded stack which is used to store the program counter value during a CALL instruction (or interrupt) and restore the program counter value during a RETURN (or RETURNI) instruction. The stack does not need to be initialized or require any control by the user. However, the stack can only support nested subroutine calls to a depth of 31.

This simple program can calculate the sum of all integers up to a certain value, i.e., ‘sum_of_value’ when value=5 is 1+2+3+4+5 = 15. In this case, the sum of integers up to the value 31 (1F hex) is calculated to be 496 (01F0 hex). This is achieved by using a recursive call of a subroutine and results in the full depth of the call/return stack being utilized. Obviously, this is not an efficient implementation of this algorithm, but it does fully test the stack.
Hints and Tips

Compare Operations

COMPARE Instruction

The PicoBlaze module does not directly support a compare instruction, so a combination of instructions based on a subtraction should be used. Here are three ideas:

**Case 1** - A subtract instruction is destructive, so if the value in the register to be tested is valuable, then copy it to a temporary register before performing the test. In this example, the operation jumps to a routine if the value in s0F is 27.

- LOAD s00, s0F
- SUB s00, 27
- JUMP Z, my_routine

**Case 2** - The use of a temporary register may not be ideal, and the additional instructions to perform the compare can seem wasteful. Sometimes, the compare operation can be usefully combined with the operation being performed. In this example, a counter is being formed in the s0F register and the next step is to jump to routine when the counter reaches the value 27.

- ADD s0F, 01
- ADDC Y s0F, 00
- SUB s0F, 01
- RETURN Z
- CALL sum_to_value
- RETURN

Note that the act of testing the counter value in s0F does destroy the value and when the compare value is not 27, it needed to be restored using addition. However, when the count value was 27, the effect was also to reset the counter value which is probably what would have been required anyway.
Case 3 - It is possible to test if a register is zero without destroying the contents and only using a single instruction. In this example, s0F reads the status of an input port and a test is made to see if any switches have been pressed (indicated by a 1).

```plaintext
INPUT s0F, switch_port
AND s0F,s0F       ; test for zero
JUMP NZ, switch_routine
```

Reference Design Files

All files described in this application note (plus some additional files) are available on the Xilinx Xilinx PicoBlaze Lounge site at:


Conclusion

A microprocessor module does not have to be large or expensive when implemented in a Virtex-II device. The Virtex-II architectural features (block memory, distributed memory, dedicated multiplexers, and carry logic) are ideal for the construction of fully embedded microprocessor modules.

The PicoBlaze module is a simple 8-bit processor with an instruction set for basic control functions and data manipulation. This is achieved with just 84 slices and one block RAM. Even with a silicon utilization over performance objective, over 50 MIPS of processing power shows the very high performance provided by Xilinx devices. Most typical applications do not exploit this performance, but simply benefit from the small size and the design methodology.

When a processor is completely embedded within an FPGA, no I/O resources are required to communicate with other modules in the same FPGA. Additionally, system design flexibility is included along with savings on PCB requirements, power consumption, and EMI. Whenever a special type of instruction is required, it can be created in hardware (other CLBs) and connected to the PicoBlaze solution as a kind of coprocessor. Indeed, there is nothing to prevent a coprocessor from being another PicoBlaze module. In this way, even the 1024-instruction program length is not a limitation.

PicoBlaze has been used successfully by thousands of Xilinx customers. Many references to its use and alternative software development tools can be found when searching the web (search for KCPSM and PicoBlaze). The author welcomes any feedback from PicoBlaze users.

Revision History

The following table shows the revision history for this document.

<table>
<thead>
<tr>
<th>Date</th>
<th>Version</th>
<th>Revision</th>
</tr>
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<tbody>
<tr>
<td>12/17/02</td>
<td>1.0</td>
<td>Initial Xilinx release.</td>
</tr>
<tr>
<td>02/04/03</td>
<td>1.2</td>
<td>Minor edits done.</td>
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