AN138

The PCS PDSP16510 Simulator (Version V.17)

Application Note

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PCS is a standalone program, running under DOS on PC platforms, which will perform a functional simulation of Mitel Semiconductor's PDSP16510 FFT Processor. The model in the simulator is bit-accurate which means that it is accurate down to the least significant bit in replicating the function of the FFT processor.

The C language device model, which forms the heart of the PCS simulator, is supplied in source code format. This allows a system incorporating the PDSP16510 to be simulated, in software, such that its performance may be characterised and optimised prior to the prototyping stage.

The PDSP16510 FFT Processor

The PDSP16510 calculates Fast Fourier Transforms of up to 1024 points at sampling rates of up to 40MHz. It uses a decimation in time radix four algorithm to calculate both forward and inverse transforms. The device contains its own RAM, which allows new data to be loaded whilst transforming the last data block. The PDSP16510 is also able to dump transformed data whilst simultaneously loading and transforming other data blocks. These three operations: data load, data transform and data dump may all be performed concurrently, if required.

The PDSP16510 also provides built-in data windowing functions: both Blackman-Harris and Hamming windows are supported without the need for any external components, and without adversely affecting the data throughput rate of the device.

The PCS Simulator

For a device as complex as the PDSP16510, the need to be able to predict whether a given level of performance can be met, prior to system design and implementation, is great. It may prove to be difficult to realise this need if published performance data is the sole source of information. The principle of the PCS simulator is that it allows users to predict the in-system performance of this device with user-defined input data. The simulator also allows the user to ask "what if" questions by varying transform size and window operators to gauge their effect without the disadvantages of committing any design to hardware.

PCS offers five options from the master menu:

1. Edit Input Data File
2. Edit Control File
3. Run Single Pass Simulator
4. Run Batch Simulator
5. Return To DOS

1. EDIT INPUT DATA FILE

PCS provides a simple file editor which allows the entry of hexadecimal complex data points in a form suitable for entry to the PDSP16510 simulator. The editor offers block copy and block delete functions to ease the entry and correction of large data sets. The editor also incorporates a generate option which may be used to generate signals composed by the addition of a number of complex or real sinusoids of varying frequency and amplitude.

Upon selecting option 1 from the master menu, a two digit filename should be entered. All PCS filenames take the form

PCS##.EXT

##	=	a user-defined two figure decimal number
EXT	=	one of a series of extensions used to denote the file type: input data file, control file, output data file etc.

The menu, displayed at the bottom of the screen, offers the following options:

Fetch
Scroll
Copy
Insert
Delete
Generate
ESCape

An option is chosen by pressing the key shown in parentheses in the menu. This is normally the first letter of the option, e.g. F for Fetch.

The upper part of the screen is dedicated to displaying the input data entered in the selected file. The column headings in this area are Cyc, RIN and IIN. These are cycle number, real data component and imaginary data component respectively.

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1. Fetch

Allows the user to move the display to a given cycle number.

2. Scroll

Scrolls the display upwards by one cycle each time it is invoked.

3. Copy

Allows a block of data to be copied from one part of the file and appended to the end of the file.

4. Insert

Used to insert data at a given point in a file. To insert the first data point in a new file, press carriage return when prompted for the cycle number.

5. Delete

Deletes all input data between two given points in the file.

6. Generate

This option is used to generate a signal consisting of a number of sinusoids of varying frequency and amplitude. For complex transforms, a maximum of four different sinusoids may be combined. For real transforms, each of the two real input signals may be composed of two different sinusoidal components.

Generate also offers the ability to load an externally generated tabular data file as an input data file. The file should have two columns, separated by at least one space character. The name should be of the standard PCS## format with the extension .DAT. Each column should hold 16 bit hexadecimal data; the first column representing real values and the second column imaginary values. An extract from such a file is shown below.

```
00FA 65B2
ABA3 562E
0000 34A2
12D2 8F02
```

For both internally and externally generated input data files, it should be noted that for an n point transform, the file should contain at least 3n data points. This is required such that the simulator has sufficient data to perform one complete load-transform-dump sequence. If a sufficient number of data points are not supplied, the data will be padded with zeros when loaded into the simulator. When Generate is used to create sinusoidal inputs, a file of the correct length is created automatically by the software.

Generate also has the added benefit of automatically generating a control file of the correct length. This is true for all three generate options: sinusoidal inputs, inverse transforms and externally supplied tabular data.

When Generate is selected, the following prompts will be displayed:

Forward or Inverse transform *	Transform type
Size	Size of transform
Real or Complex	Type R or C to select real or complex transform
Overlap	Percentage by which data is overlapped. Valid responses are 0%, 50% and 75%
External data supplied	Load data held in an external file ?

If external data is not supplied, then the subsequent prompts will request the frequencies and amplitudes of the sinusoids which comprise the input data stream.

Window Operator	You may choose a Rectangular, Hamming or Blackman-Harris window operator.
Overflow Detection (Y/N)	If the response to this question is Y, then the simulator will assume that bit 3 of the mode control word is set. See data sheet for further information.

* See example 3 for further details on inverse transforms

Once all the parameters have been entered, the samples will be generated and stored in the required file.

Pressing Escape returns control to the master menu.

2. EDIT CONTROL FILE

The control file defines the state of the INEN (Input Enable) and DEF (Reset) signals for each cycle of the input data file. If the Generate option is used to create the input data file, the control file will be generated automatically. The control file should contain three cycles for every data point in the data input file.

If the control file is longer than the input data file (.DIN) then the input file will be recycled until the end of the control file is reached. Conversely, if the control file is shorter than the input data file, the simulation will terminate at the last cycle defined in the control file.

If the control file is to be generated manually, the editing options available are similar to those for input data file creation; namely Fetch, Scroll, Copy, Insert and Delete.

Automatically generated control files contain nine preamble cycles, which are used to reset the device and, thereafter, the three cycles per data point required by the simulator. This means that for a 256 point transform, for example, the input data file will contain 768 points and the control file 2313 cycles.

3. RUN SINGLE PASS SIMULATOR

The simulator takes the control and data files specified by the user as the basis of the simulation run. The options offered by the simulator are described below:

1. Halt

This is used to temporarily or permanently halt a simulation run. A record is kept of how many cycles had been simulated and the simulator may be restarted from that point by using the Run option.

2. Run

Starts the simulator from the cycle shown in the status display.

Once the simulation run has been completed, interrupted by reaching a breakpoint or paused by the user, a new menu is displayed which offers the following options:

Scroll
Fetch
Extract
Escape

Scroll and Fetch are used to view the data in the same way as when editing an input data file. Extract generates a file, called PCS##.RES, which contains two columns of data; the first being the real component and the second the imaginary component of each frequency bin of the transform.

3. Breakpoint

Allows the user to define the cycle at which the simulator will pause prior to starting the simulation run, thereby allowing the results generated up to the breakpoint to be viewed.

4. Plot

Presents a graphical view of either the input or the output waveform. It also displays the magnitude of the complex output.

5. Initialise

Resets the cycle number to 1.

6. Variables

This option is used to define the variable watchlist, i.e. which variables will be displayed after each cycle when the simulation is completed or paused. Placing an ‘X’ next to a variable name adds that variable to the watchlist, pressing carriage return advances to the next variable. The variables that may be added to the watchlist are:

Input Variables:	RIN	Real input data
	IIN	Imaginary input data
Control Variables:	INEN	Active low signal which starts load process
	DEF	Active low signal which resets model
Output Variables:	ROUT	Real output data
	IOUT	Imaginary output data
	S3_0	Accumulated block floating point (BFP) shift value
	DAV	Data available signal
State Variables:	DUMP	Output data memory pointer
	LOAD	Input data memory pointer
	STAGE	Number of FFT pass
	GROUP	Number of butterfly group
	SAMPL	Number of butterfly
	WKSP	Beginning of work space address
	OPSP	Beginning of output space address
	MODE *	FFT mode word (Auxilliary Data Input)
	IPSHF	Butterfly input data BFP shift value
	OPSHF	Butterfly output data BFP shift value
	DLSHF	Delayed output data BFP shift value
	OVFLW	BFP overflow flag
Memory Variables:	MEM0-7	Memory word 0-7 x (offset + 1)

* Bit 15 of the MODE variable indicates the end of a valid load process and the start of the butterfly processing. This is not used in the real device. Refer to the data sheet for mode word format.

The display allows a total of twelve variables to be displayed simultaneously.

7. Escape

Returns to the master menu.

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4. RUN BATCH SIMULATOR

This option has been included to speed up those simulation runs where a trace file, listing the values of a number of variables for each cycle, is unnecessary. In batch mode, up to six simulations may be performed serially, with each taking only two thirds of the time required in single pass mode, on average. The output of the simulator is a PCS##.RES file for each input file listing real and imaginary frequency bin data. The options offered by the batch simulator are:

1. Queue

The input data filenames are specified using this option. Up to six filenames may be entered, each separated by a carriage return.

2. Run

Initiates a simulation run for all the files selected via the Queue option.

3. Abort

This option will abort the simulation of the current input file and start the simulation of the next input file in the queue.

4. Halt

Aborts the current simulation and returns control to the user. Selecting Run at this stage will start the simulation process once more from the first file in the queue.

5. Escape

Returns to the master menu.

SIIMULATION EXAMPLES

Example 1 - Square wave using external data file

This example demonstrates how an external data file may be used to supply the data points for a simulation run.

The first task is to generate a text file, using a text editor, describing the square wave. The filename should be of the form PCS##.DAT, where ## is a two figure number between 00 and 99. The contents of the file will describe a square wave where the real component varies between zero and positive full scale values with the imaginary component always set to zero. Hence, the file should look like this:

```
0000 0000
(30 lines as above)
0000 0000
7FFF 0000
(30 lines as above)
7FFF 0000
```

This basic 64 line block should be repeated 12 times to yield a file 768 lines long. This is three times the required transform size, namely 256 points, in order to feed the simulator enough data points to perform a complete load-transform-dump cycle.

Now, invoke the PCS program and follow the steps listed below:

`<CR>`	Displays the master menu (note: <CR> = Carriage Return)
`1`	Selects Edit Input Data File option
`## <CR>`	Where ## is the name of the PCS##.DAT file containing the square wave data
`G`	Selects Generate option
`F`	Selects forward transform
`256 <CR>`	Selects 256 point transform
`C`	Complex transform
`0 <CR>`	0% overlap
`Y`	Signifies that an external .DAT file is the source of the input data
`R`	Use a rectangular window function
`N`	No overflow detection

The software will now start generating the .DIN file and displays the current sample number near the bottom of the screen. In total, 767 samples will be generated. When sample generation is complete, the prompt “View Data Y/N” will be displayed. Press N at this point to continue to the next phase.

Now type the following:

`3`	Selects single pass simulator option
`## <CR>`	Define input data file name
`P`	Select Plot
`I`	Select input signal
`R`	Selects real part of input signal
`1`	Zoom factor 1

The amplitude-time plot of the input signal is displayed. It can seen that it varies between zero and positive full scale with three cycles in total. To run the simulation type the following:

`ESCAPE`	Returns to the simulator menu
`V`	Select variables option. Select the following variables only: RIN IIN INEN DEF ROUT IOUT S3_0 DAV For the remainder, press <CR> when prompted
`0 <CR>`	To specify zero memory offset.
`R`	Starts the simulation run.

The simulator will run till cycle number 2313. When the simulation is complete, the trace file will be displayed. It lists the cycle number in the first column and the values of each of the watchlist variables after each cycle. Fetch and Scroll may be used to inspect this file. Extract creates an output file, named PCS##.RES, which lists the real and complex components of each of the frequency bins in tabular hexadecimal form. Pressing ESCAPE returns to the simulator menu.

When the simulator menu is displayed, type the following:

`P`	Select Plot
`M`	Magnitude of output data
`2`	Zoom factor 2

This will display the magnitude of the forward fast Fourier transform of the square wave. As expected, harmonics of the fundamental frequency can be seen with their amplitude decreasing as frequency increases.

Example 2 - 1024 Point With Sinusoidal Data

In this example, the Generate function will be used to create a waveform composed of two sine waves of different frequency and amplitude. To do this, follow the instructions below:

Invoke the PCS program and type the following:

`<CR>`	Displays master menu
`1`	Select Edit Input Data File
`## <CR>`	Where ## is the name to be given to the new data file
`G`	Invokes Generate function
`F`	Forward transform
`1024 <CR>`	Size of transform
`C`	Complex
`0 <CR>`	0% overlap
`N`	No external data file
`10 <CR>`	Frequency of first signal
`0.8 <CR>`	Amplitude of first signal
`Y`	Signifies that another signal is to be added to the input signal
`20 <CR>`	Frequency of second signal
`0.4 <CR>`	Amplitude of second signal
`N`	Signifies that no more sinusoids are to be added to the input signal
`H`	Hamming window
`N`	No overflow detection

The software now generates the required input waveform, which is 3071 cycles in length. The hexadecimal input data may be viewed at this stage. To continue to the next stage press N at the “View Data Y/N” prompt.

To simulate the device with the input defined above:

`3`	Selects single pass simulator
`## <CR>`	Specify input file name
`P`	Plot
`I`	Input waveform
`R`	Real component
`1`	Zoom factor

This displays the form of the input wave.

`ESCAPE`	Returns control to the simulator menu
`V`	Define watchlist. Select the first eight variables (as in example 1)
`0 <CR>`	Memory offset
`R`	Runs the simulation

The simulation runs to 6150 cycles. When complete, the trace file may be viewed. Pressing ESCAPE returns to the simulator menu. Now type:

`P`	Plot
`M`	Magnitude
`3`	Zoom factor

This will display the magnitude of the fast Fourier transform calculated by the simulator. The two peaks generated by the two sinusoids are clearly visible.

Note that higher frequency components peak is 6dB lower than that of the lower frequency peak. This is as predicted by theory.

Example 3 - Generating Inverse Transforms

Inverse transforms may be generated using output data files produced by PCS or by employing a user generated data file containing frequency data. The procedure employed to generate an inverse transform from both file formats is essentially the same.

1. User Generated Data Files

As with forward transforms, the PCS simulator accepts data files containing two columns of data, seperated by at least one space character, where the first column represents the real component of the data and the second column the imaginary component. For inverse transforms, each row of the data file represents a particular frequency bin; the first row being the D.C. bin and so on.

The inverse transformation of a pure sinusoid will be performed. This will illustrate clearly the link between the input data file containing frequency information and the output signal calculated by the simulator. The first step is to create a file 256 lines long, called PCS##.DAT. The contents of this file should be as shown below. This file may be easily generated using a line editor with block cut and paste facilities.

```
0000 0000
0000 0000
0000 0000
0000 0000
0000 0000
7FFF 0000
0000 0000
(248 lines of zero data)
0000 0000
```

Invoke PCS and type the following when the master menu is displayed:

`1`	Edit Input Data File
`## <CR>`	Enter name of .DAT file
`G`	Select Generate option
`I`	Inverse transform
`256 <CR>`	Selects 256 point transform
`C`	Complex data
`0 <CR>`	0% overlap
`Y`	Signifies that an external file holds the data
`N`	No overflow detection

The software will now start generating data samples. After the 255th sample, the warning “Insufficient data: padding with zero” will be displayed. This is due to the fact that the simulator always expects sufficient data to carry out a complete load transform dump cycle, whereas the data file contains only one third of the data required for such a cycle. However, padding the data with zeros gives the same end result. When the prompt “View Data Y/N” is displayed, press N to continue to the next phase:

`3`	Selects single pass simulator
`## <CR>`	Define input data filename
`R`	Run simulation

The simulation will run for 2313 cycles. Now type:

`<ESCAPE>`	Returns to simulator menu
`P`	Select plot option
`O`	Output signal
`R`	Real component
`2`	Zoom factor

The display will show a sinusoid whose first peak is at the left hand edge of the graph. Now type the following:

`<CR>`	To select a further plot
`O`	Output signal
`I`	Imaginary component
`2`	Zoom factor

The display shows another sinusoid of equal amplitude and frequency to the first, but lagging in phase by 90°.

2. PCS Generated Data Files

All PCS simulation runs allow the user to produce a .RES file listing the contents of each of the frequency bins in tabular format (see section 3, paragraph 2 for information on the Extract option). The data contained in this file is in the correct format to be fed directly into PCS as a .DAT file.

In order to use the .RES file in this manner it must be renamed from PCS##.RES to PCS##.DAT via the DOS RENAME command. Ideally a new filename should also be chosen, e.g. rename PCS01.RES to PCS02.DAT. This reduces filename confusion as other files with the name PCS01 will already exist in addition to PCS01.RES. Once the file is renamed, the procedure for calculating an inverse transform is exactly the same as that described above for user generated .DAT files.

Additional Example Files

The PCS distribution disk contains three external data files comprised of test data taken from the silicon compiler used to design the PDSP16510. Multiple 64 point transform data is provided in the file FFT64.DAT which includes four different signal blocks of 64 points each. Thus the 256 output points show four different responses in sequence. Normal 256 point transform data is provided in the file FFT256.DAT and 1024 point transform data is provided in the file FFT1024.DAT. All files are run with a rectangular window function applied to the data. To use these files they must first be copied to files which PCS recognises as external data files, i.e. they should be copied to filenames of the form PCS##.DAT. See example 1 for further information on external data files.

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APPENDIX 1

PDSP16510 FFT Processor Model

Although the internal algorithms have been developed to mimic those in the device, the internal structure and method of processing are merely functional and not gate level equivalents. Pipeline effects on data values have been accounted for but the model does not provide an exact representation of device operation in real time.

The interface for this model has been rationalised for clarity and does not provide all the control signals used by the real device. The model incorporates complex data I/O paths which are controlled by INEN and DEF signals. These are considered sufficient to provide an accurate functional simulation of the device. Load and dump clocks are simulated internally and although load and dump rates are varied according to the active FFT process they are obviously tied to the system clock, represented by the simulator call.

The real device performs four butterflies in 12 system clock cycles. This model incorporates only one data path structure and is set to process one butterfly every three cycles, thus completing four butterflies in 12 cycles or calls from the simulator. This infers that for transform sizes with fewer or an equal number of butterflies (16, 64 or 256 point), each sample in the data file must be entered over three cycles. Output data will also be spread over three cycles. In order to fit 1024 point transform simulations into the maximum cycle count of 9999, the butterfly process rate has been increased to one per cycle. The data file need only repeat sample data over two cycles to allow one complete transform process (1280 cycles) to complete within the loading period (2048 cycles). This mechanism was developed to permit the model to handle the extended I/O periods required by overlapped transforms and does not represent any structure in the real device.

The GENERATE function in the input data editor allows for this pseudo clock structure. If you are using the INSERT function, this clock structure must be accounted for.

Internal state variables are used merely to monitor the state of the FFT process and do not represent any registers, storage or control structures in the real device. The memory area is defined as an 8x256 word array and the simulator will trace any column of 8 words by entering a memory offset value from 0 to 255 in the memory variable list. The memory is partitioned by each FFT process according to its particular needs. All FFT processes use a load space in which to deposit input data, a work space in which the butterfly processes are executed and an output space from which completed transforms are clocked out. This arrangement permits loading, processing and dumping of data to be simultaneous processes. The load space is normally twice the size of the selected transform to permit overlapped sampling modes. The work space and output space are equal to the size of the transform. Thus, for a 64 point transform the load space is 128 words long (offsets 0 to 15), the work space is 64 words long (offsets 16 to 23) and the output space is also 64 words long (offsets 24 to 31).

Model Limitations

Although the model was designed to be bit accurate, tests indicate that bit 0 of the result is not always the same as that produced by the PDSP16510 when processing identical data.

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