WaveShaper Fourier Processor
User Manual

FINISAR®

Part Number 1238987
Revision B00

Important note: This guide covers operation of the Fourier Processor for WaveShaper S Series and M Series hardware.

It is not valid for other hardware or software releases.

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Section 1: Manual Overview

1.1 Introduction

The WaveShaper Fourier Processor Application is an addition to the WaveManager Suite of applications for the WaveShaper 4000 family. It provides tools for rapid prototyping optical circuits, enabling functions such as power sharing at each wavelength across multiple ports with attenuation and phase control to impose different delays on the different signal parts. This allows the user to program arbitrary types of single-input, multi-output interferometers, e.g. Mach-Zehnder Interferometers (MZI), Differential Quadrature Phase-Shift Keying DPSK demodulators, etc. Other applications could be crosstalk emulation/suppression and broadcasting.

1.2 About this manual

Section 2: Getting Started covers the WaveShaper Fourier Processor Application Installation and guidelines.

Section 3: WaveShaper Fourier Processor Overview describes each of the graphical interface controls and software response.

Section 4: Using the Fourier Processor briefly describes how to use the Fourier Processor application.

Section 5: WaveShaper Fourier Processor File Formats explains a little bit more about the two different file formats used by the software package.

Section 2: Getting Started

2.1 Safety Considerations

All safety considerations as described in the WaveShaper User Manual should be observed when working with WaveShaper equipment, in particular please observe the Laser Safety Guidelines also described in 2.2.

2.2 Laser Safety

The WaveShaper family of Programmable Optical Processors are designed for use with various classes of laser up to, and including, Class 3B lasers. Whilst the WaveShaper module does not generate laser light, laser light may be present on one or more output ports depending on the configuration of WaveShaper selected and the type of laser connected to the input port(s).

Warning

Please pay attention to the following laser safety warnings:

- **Under no circumstances look into the end of an optical output cable/connector(s) when the device is operational. If there is any laser radiation it could seriously damage your eyesight.**
- **Do not operate the WaveShaper without attaching the optical output connector(s) to a safely terminated mating connector(s).**
- **Refer servicing only to qualified and authorized Finisar personnel.**

2.3 Control Computer Requirements

The computer must have the WaveManager Application Suite used to control the WaveShaper already installed. The Fourier Processor application requires an additional:

- 400 MB of hard disk space
- 1GB of RAM

2.4 Windows Installation

! **The installation requires administrator rights on the target computer, but subsequent operation will require only standard user rights.**

! **The latest WaveManager package will automatically install the WaveShaper Fourier Processor software. Please refer to WaveManager and the WaveManager User Manual for further information on how to install the packages.**

2.5 Linux Installation

The WaveShaper Fourier Processor graphical interface is not available for Linux platforms. To implement power splitting functions on Linux platforms, please refer to the Application Programming Interface (API) documentation.

2.6 Connecting the WaveShaper to other equipment

The WaveShaper has optical connectors for input and output. Care should be taken with optical interface cleanliness. Connector ends should be cleaned using isopropyl alcohol and a lint-free tissue, or proprietary connector cleaning cassette, before mating.

2.7 Start-up and Initialization

To start the WaveShaper, connect power to the WaveShaper, turn on the WaveShaper and ensure the front panel LED is lit (WaveShaper S-series only). At start-up, the WaveShaper will initially be set to a blocked state, where the output optical power is minimized.

Ensure the WaveShaper is connected to the computer using a USB cable and wait for operating system to recognize the USB devices. Start the WaveShaper Fourier Processor application.

It should be noted that the WaveShaper has a warm-up time of up to 10 minutes following start-up, during which time it will function correctly, but the performance is not guaranteed to meet all specifications.

When the WaveShaper Fourier Processor Application Suite is started it will first configure all necessary drivers and communication ports, then identify and connect to the first detected WaveShaper device attached to the computer. Attempting to connect to a WaveShaper 100, 120 or 1000 would generate an error message as this family does not have multiple output ports. The process of identification and connection to a WaveShaper does not change the current settings of that device.

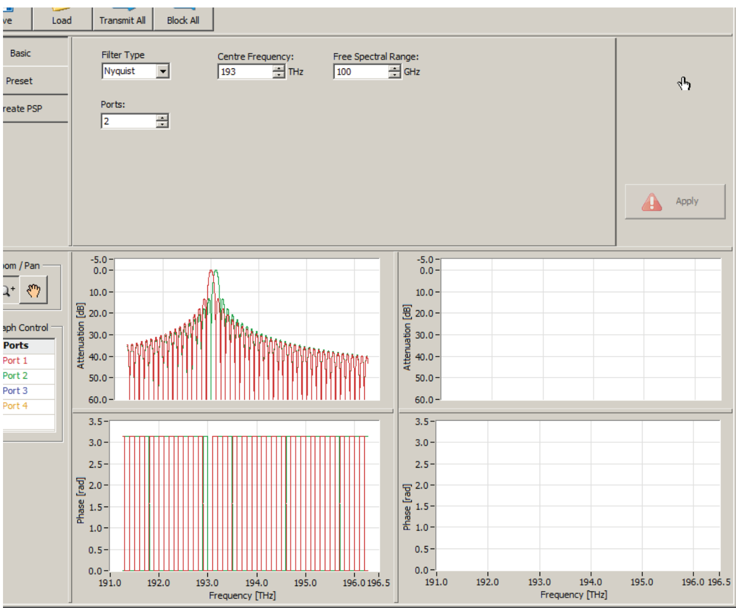


Figure 2.1 WaveShaper Fourier Processor in action

Section 3: WaveShaper Fourier Processor Overview

The WaveShaper Fourier Processor Application provides a powerful and intuitive graphical user interface for controlling a WaveShaper's attenuation and phase levels on multiple ports simultaneously across its frequency spectrum. The Fourier Processor makes it possible to share power in a single wavelength across multiple output ports, with arbitrary splitting ratios. Combined with spectral phase modulation, this leads to a powerful tool to create complex functions emulating optical circuits.

It is not possible to run the Fourier Processor software on single output port units (i.e. 100, 120 and 1000 models).

3.1 User Interface Overview

The main functional sections of the WaveShaper Fourier Processor are described below (Figure 3.1).

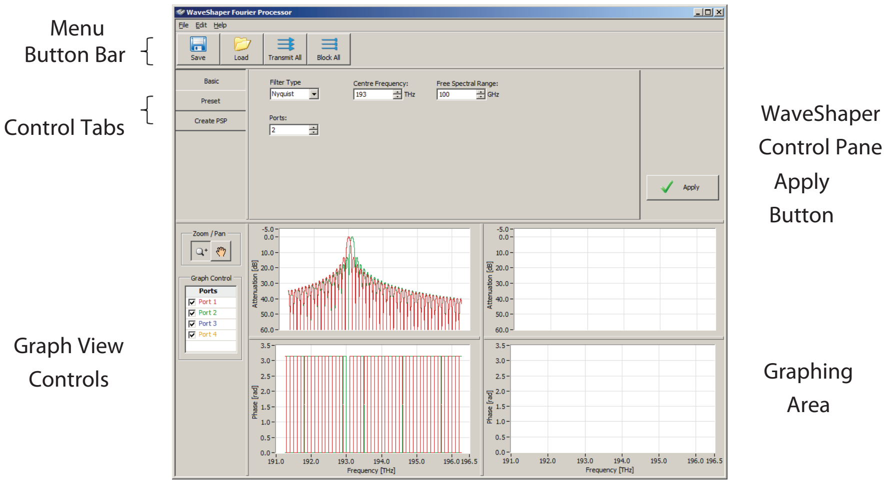


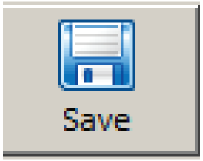
Figure 3.1 Fourier Procesor showing main controls

The main elements of the WaveShaper Fourier Processor application window are:

- Menu bar.
- Button Bar - buttons for commonly used actions.
- WaveShaper Control Pane: see Section 4: Using the Fourier Processor
- Graphing Area Controls.

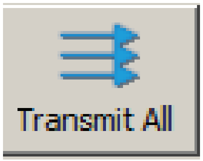
Button Bar

Provides short-cuts for frequently-used commands. The areas of the button bar and actions of the buttons are as follows:

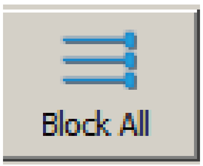


Save — Opens a Save As dialog box to allow user to save a Power Split Profile (*.psp*) file.

Load — Allows the user to browse, open and load a saved Power Split Profile (*.psp*) file.



Transmit All — “Transmit” operates on the currently selected port of the WaveShaper and sets all frequencies to be transmitted with no attenuation. When the “Transmit” button is pressed, the necessary commands are immediately sent to the WaveShaper and the user does not need to press <Apply> to force an upload.



Block All — “Block All” sets all frequencies to be blocked on the common port. When the “Block All” button is pressed, the necessary commands are immediately sent to the WaveShaper and the user does not need to press <Apply> to upload.

Graphing Area

The graphing area allows the user to view graphs which display the WaveShaper filter profile, in terms of relative power and phase, for those ports selected by the graph control "port" select check boxes.

The “Current” right hand side attenuation and phase graphs display the profile currently applied to the selected WaveShaper. The “Preview” graphs (left hand side) show the profile which will be generated on the selected WaveShaper when the <Apply> button is pressed.

Graphing Area View Controls

Zoom in — Left mouse button: drag to select zoom in area, release to zoom in.

Zoom out — Right click to restore graph area to full view.

Pan — Left mouse button: drag and release to pan to a different graph area. Multiple grab and release actions can be performed to reach the desired view area.

Restore — Right click to restore graph axes to full view.

Apply Button

Clicking the <Apply> button transfers the profile visible in the preview graphs to the

WaveShaper, with the progress bar indicating progress in uploading the new profile.

Menu Structure

The application provides access to many functions through drop-down menus as defined below.

File

Select WaveShaper Device Ctrl+W

Allows the user to select an attached WaveShaper from the active WaveShapers listed.

Save PSP Ctrl+S — Opens a dialog box to allow user to save the current Profile as a Power Split Profile (*.psp*) for later use.

Load PSP Ctrl+O — Opens a dialog box to allow user to load Profile as a Power Split Profile (*.psp*) for later use.

Exit Ctrl+Q — Exits the program in the same manner as clicking the window control "x" button

Edit

Insertion Loss Fine Adjustment

Allows the user to manually adjust the insertion loss for each port. This adjustment is to cater for connector path insertion loss variation. It is not saved in the Power Split Profile but is available to make fine adjustments across different WaveShapers, whilst keeping the *.psp* profile the same. See Figure 3.2.

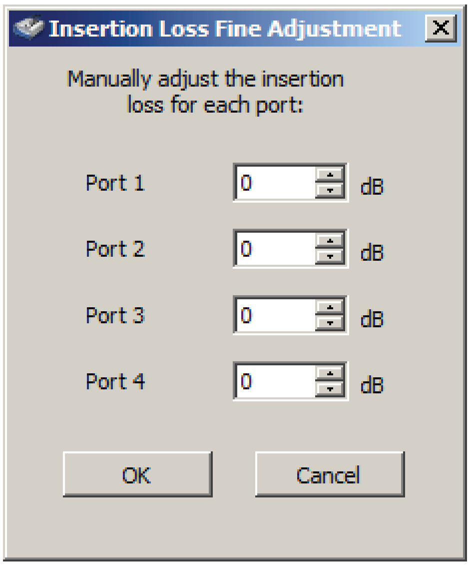


Figure 3.2 Port Setup Insertion Loss Adjustment

Help

User Manual... — Opens the Fourier Processor User Manual.

3.2 Adding a WaveShaper during program operation

The WaveShaper Fourier Processor Application automatically registers active WaveShaper devices at start up and connects to the first available device. Once Windows has successfully recognised and installed the USB driver, select the device to connect the Fourier Processor application to using:

File-> Select WaveShaper Device

The popup window is populated with attached WaveShaper devices, other than the one already in use by the application.

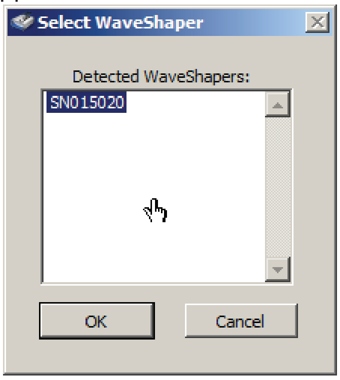


Figure 3.3 WaveShaper Device Selection

If a WaveShaper is attached that has not been previously installed on this machine, it will be necessary to close the Fourier Processor application and run WaveManager with the new device powered up and connected. Please refer to the WaveManager User Manual for more information on how to configure a new WaveShaper device. Once the WaveShaper is configured with WaveManager, please close WaveManager, and start the Fourier Processor application.

Section 4: Using the Fourier Processor

4.1 Overview

The WaveShaper power splitting profile is generated by the WaveShaper Fourier Processor Application and uploaded to the currently selected WaveShaper when the <Apply> button is pressed. This section describes the different ways in which the profile on the WaveShaper can be modified.

For ease of use, the different ways of modifying the optical spectrum are addressed using different sub-tabs, located at the left hand side of the main WaveShaper Control Pane. The sub-tabs available are summarized in Table 4.1.

Name	Description	Section
Basic	Allows user to select pre-defined filter types, and provides appropriate controls for adjustments. These customised profiles can be saved as psp files for future loading.	4.2
Preset	Allows the user to load preset WaveShaper Power Splitting Profiles (*.psp*).	4.3
Create PSP	Allows the user to allocate pre-defined *.ucf* files to individual ports with adjusted centre frequency and specify the ports which will equally power share the input signal.	4.4

Table 4.1 Summary of Fourier Processor sub-tabs

In all cases, the changes which are made on the sub-tab are reflected in real-time on the "Preview" pane but are only uploaded to the WaveShaper when the <Apply> button is pressed.

4.2 Basic sub-tab

The Basic sub-tab provides an easy-to-use interface to control the profile of a WaveShaper using basic filter types (Figure 4.1).

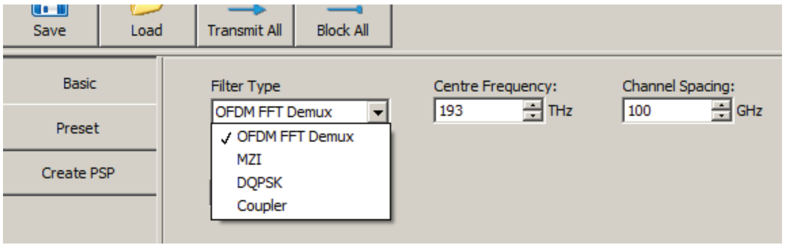


Figure 4.1 Filter type selection drop down list

4.2.1 Filter Type

This allows the user to select the filter shape from a drop-down list. The control Pane displays controls appropriate to the filter type selected. The Nyquist, MZI and DQPSK filters effectively demodulate the incoming signal to port 1 and successive ports as required.

The coupler filter is a power sharing filter and further described in Section 4.2.8.

4.2.2 Centre Frequency Control - OFDM FFT Demux, MZI and DQPSK

This allows the user to set the centre frequency of the filter output to port 1 and is programmable in 1 GHz steps. Adjustment of the centre frequency is through direct editing in the entry box or through the use of the up/down arrows associated with the entry box. The filter output to port 2 has the centre frequency range of the first port plus the channel spacing or free spectral range.

4.2.3 Channel Spacing/Free Spectral Range - OFDM FFT Demux, MZI and DQPSK

This allows the user to change the channel spacing/free spectral range of the filter selected in 0.1 GHz increments.

Adjustment of the channel spacing or free spectral range is through direct editing in the entry box or through the use of the up/down arrows associated with the entry box.

4.2.4 Ports Selector - OFDM FFT Demux

This allows the user to select the number of ports to which adjacent channels will be directed. The default value is 2 ports.

4.2.5 OFDM FFT Demux Filter Type

The Nyquist filter is designed for demodulating neighbouring channels to adjacent output ports, creating spectrally overlapping *sinc* functions on up to 4 output ports. Port 1 receives the channel at the designated centre frequency, port 2 receives the next channel (i.e. at centre frequency plus the channel spacing). Ports 3 and 4 if required on adjacent channels.

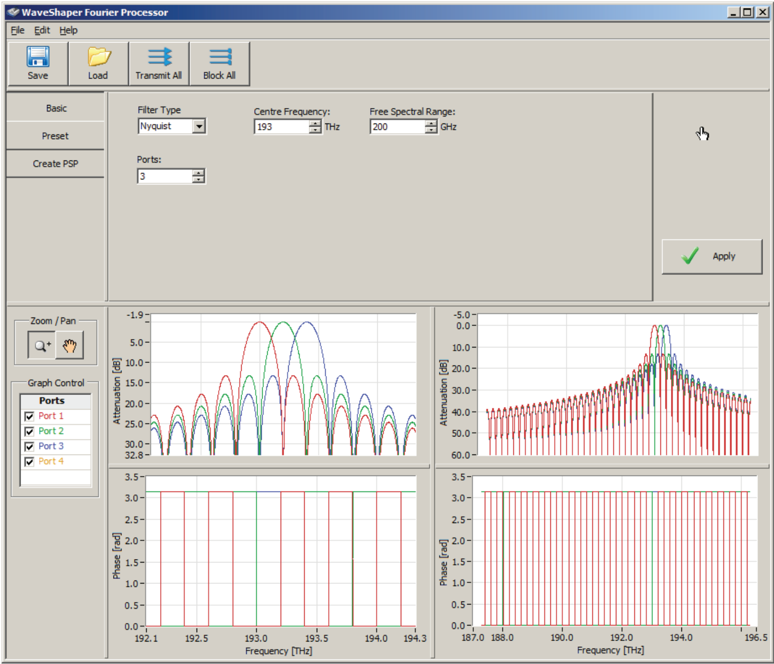


Figure 4.2 Nyquist Filter

4.2.6 MZI Filter Type

The Mach–Zehnder interferometer filter creates the spectral functions associated with a Mach–Zehnder interferometer, with a given free spectral range. The centre frequency determines where port 1 will see a constructive output, whilst port 2 will a constructive output at a distance specified by the free spectral range.

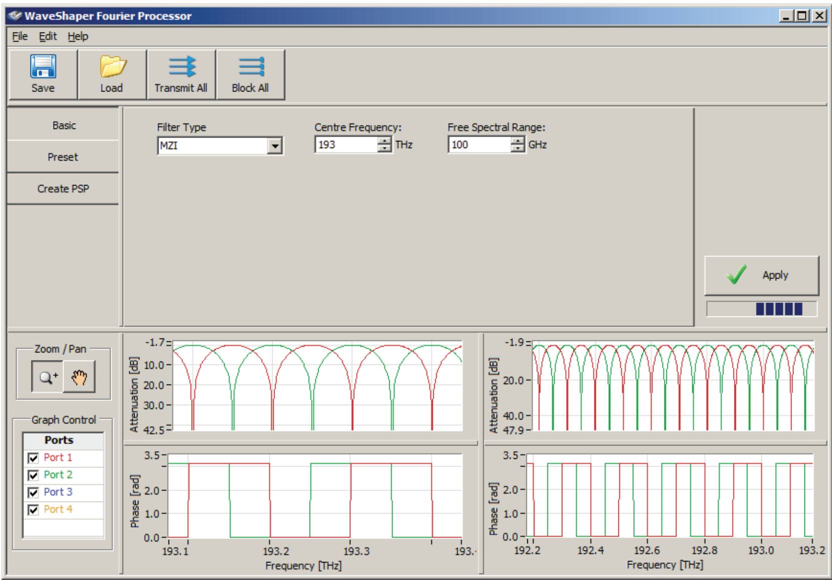


Figure 4.3 MZI filter

4.2.7 DPQSK Filter type

Similarly to the MZI filter, the DPQSK Filter (differential quadrature phase shift key) separates out each quadrature to ports 1, 2, 3 and 4 based on the centre frequency and free spectral range (see Figure 4.4).

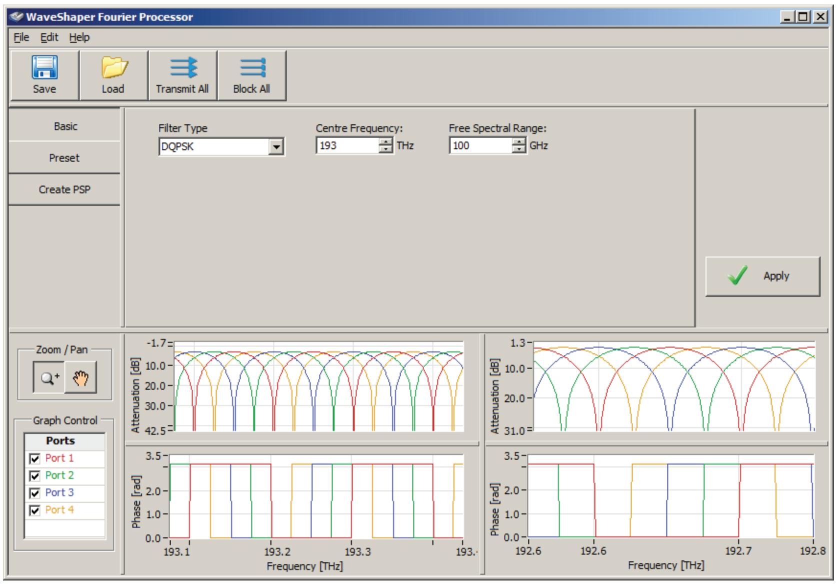


Figure 4.4 DPQSK Filter

4.2.8 Coupler

The coupler allows the user to power share the input to directed output ports. The user may wish to take advantage of the ability to fine tune the output port insertion loss variations into the power sharing algorithm through use of the Edit -> Insertion Loss Fine Adjustment menu capability (See Figure 3.2 , Section 3.1).

It has two modes of operation for setting the power sharing: normalized and absolute.

Normalized

In normalized mode, the power sharing algorithm determines the power attenuation levels based on the ratios provided for the active outputs. For example, if 3 ports are selected, ports 1 and 2 set to 50% , port 4 set to 100%, ports 1 and 2 would each see an additional 6 dB of loss whilst, port 4 would see an additional 3 dB loss, on top of the insertion loss of the unit. See another example in Figure 4.5

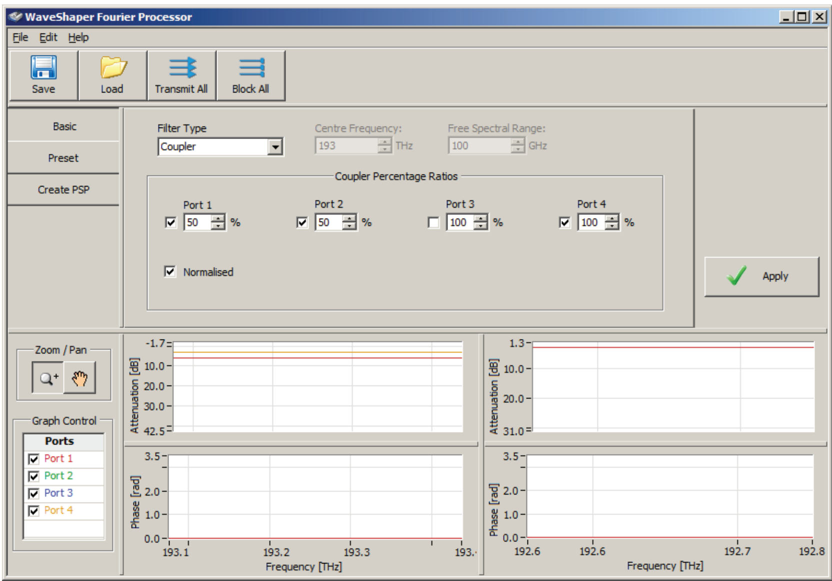


Figure 4.5 Normalized coupler

Absolute ("Normalized" is unticked)

In absolute mode the available power is shared between the active output ports according to the percentage set. The sum of active port percentages must be ≤ 100%.

See example in Figure 4.6.

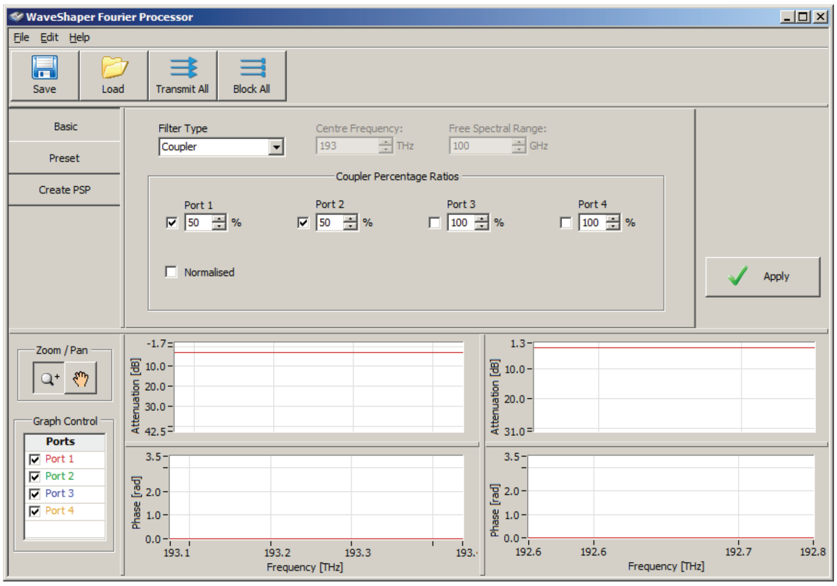


Figure 4.6 Absolute 50/50 coupler

If the sum of active port percentages is larger than 100%, the example in Figure 4.5 would generate a warning that clipping would occur (See Figure 4.7).

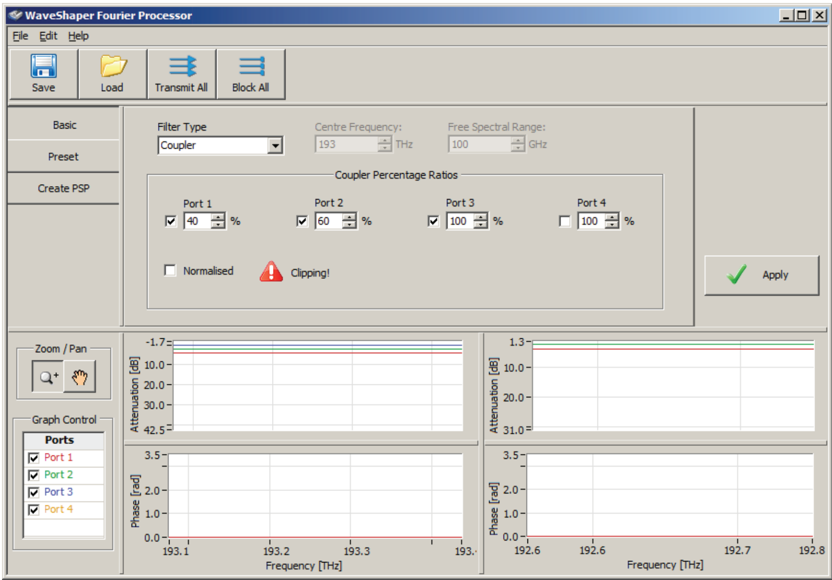


Figure 4.7 Coupler Clipping example: 40%+60%+100%>100%

4.3 Preset sub-tab

The Preset sub-tab allows the user to select an existing **.psp* file. Click on file name and the highlighted profile is displayed in the preview window.

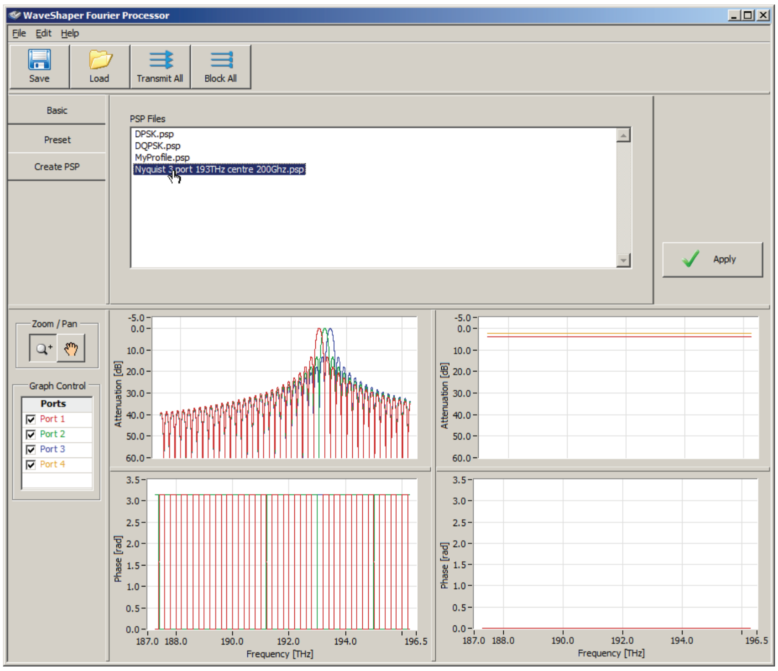


Figure 4.8 Preset sub-tab

4.4 Create PSP sub-tab

This sub-tab allows the user to select individual ports as active, the filter (**.ucf*) and the centre frequency of the filter for each port. The power is shared equally between each active port.

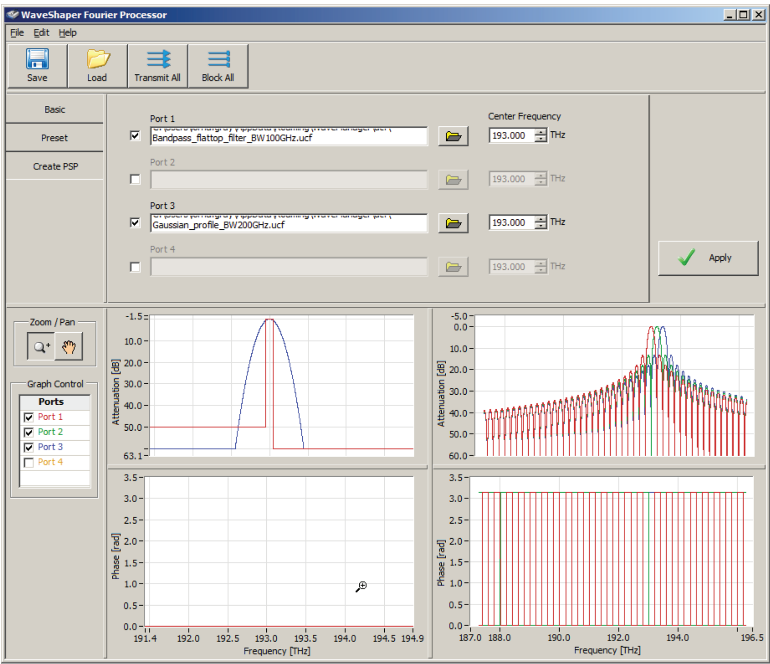


Figure 4.9 Create PSP sub-tab

Section 5: WaveShaper Fourier Processor File Formats

5.1 Overview

The Fourier Processor software supports two different input file formats: **.ucf* and **.psp*. These have different applications as outlined in Table 5.1.

File Type	File Suffix	Description	Section
User Configured Filter	*.ucf*	Controls basic WaveShaper Functionality. Multiple *.ucf files can be merged into a *.psp file	5.2
Preset	*.psp*	Allows the user to load Preset WaveShaper Power Split Profiles	5.3

Table 5.1 Summary of WaveShaper Fourier Processor file types

5.2 User Configured Filters (*.ucf) files

The ability to load and then easily control user configured filters is key to the operation of the WaveShaper. To this end, the WaveManager supports the same **.ucf* file import format used in previous versions of the WaveShaper software.

To ensure data integrity, the software will parse, truncate and interpolate the **.ucf* file to ensure the requested filter shape is calculated to conform to the limits set by the WaveShaper capabilities. The following rules for preparing and interpreting the **.ucf* files therefore apply.

The number of frequency data points must be at least one. The interpolation in the WaveManager software chooses the attenuation and phase values corresponding to the frequency value that is nearest to the respective frequency in the WaveShaper. Hence, if there is only one point defined, all frequencies will be set to the same attenuation and phase values defined by that point. Any WaveShaper frequency outside of the defined frequency range of the input file will be set to the respective edge points of the input file definition, as that will be the nearest neighbour to these frequencies.

For optimal consistency and portability of **.ucf* files between different WaveShapers, it is recommended to specify the profiles down to a resolution of 1 GHz.

5.2.1 File Structure

The format of a **.ucf* file is a tab delimited text file with three columns: Frequency Offset (THz), Attenuation (dB) and Phase (rad). The file can be generated using a spreadsheet program, such as Microsoft Excel (saving the document as a **tab delimited text file**). The file extension must be "*.ucf*" for the file to appear in the File Open dialog box.

5.2.2 Frequency

The filter frequency is defined in THz as the detuning (positive and negative) from an arbitrary centre frequency. The frequencies do not have to be balanced around the centre frequency, but the frequency data set must contain one, and only one, value of zero, which the WaveShaper interprets as the centre frequency. The values in the frequency column must also be monotonically increasing. Each frequency data point must have a corresponding value of Attenuation and Phase. If no specific attenuation or phase value is required, values of 0 must be specified at these points.

5.2.3 Attenuation

The calibrated attenuation values available in the WaveShaper hardware are 0 to at least 30 dB, and also provides a 'Block' state with attenuation of typically >50 dB. To guarantee the portability of filter shapes between WaveShaper units, the **.ucf* attenuation range should be limited to 0-30 dB. The interpretation of the **.ucf* files provides access to the full range of attenuation controls as follows:

Requested Attenuation	**.ucf* interpretation
<0 dB	Truncated to 0 dB
0 - 30 dB (Note 0-10dB for 120)	Guaranteed accuracy according to the WaveShaper specification
30.1 - 40 dB	WaveShaper attempts to set attenuation to requested value. No guarantee of accuracy.
>40 dB	Signal set to 'Block'

Table 5.2 Summary of attenuation interpretation for user configured filter files

5.2.4 Phase

The phase control range available in the WaveShaper is $0\text{-}2\pi$. The User Configured Filter may specify a phase outside of this range, however, this will be re-calculated by the WaveShaper software as input phase mod 2π shown in Figure 5.1 below.

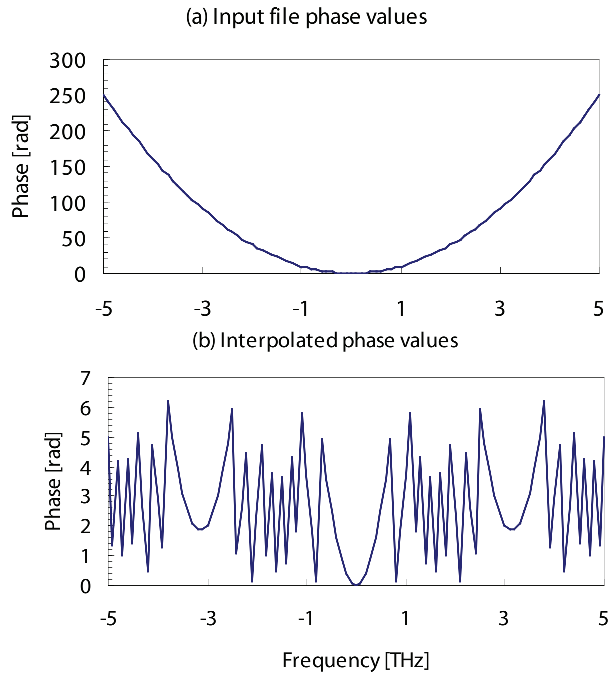


*Figure 5.1 Example of limits imposed by interpolation of phase values in the *.ucf file. The phase values are calculated as (input phase mod 2π).*

The mathematical operations performed by the WaveShaper software on the User Configured Filter data file are summarised in Table 5.3 below.

Parameter	Units	Interpretation
Frequency	THz	Interpolated to fit defined filter (channel) bandwidth
Attenuation	dB	Value dependent - see Table 5.2
Phase	Rad	Modulo 2π

Table 5.3 Summary of data interpretation for user configured filters

Examples of **.ucf* files are provided with the software and should be studied to understand the structure of the file.

*5.2.5 Using Microsoft Excel to generate *.ucf files*

When using Microsoft Excel to generate a **.ucf* file, the following points should be noted.

1. The file should be saved as Text (Tab delimited) (**.txt*) file and subsequently renamed to have the suffix “ucf”.

2. Before saving as a **.txt* file, the format of all columns should be set to ‘Number’ with at least three (3) decimal places. If the number format is set to less decimal places, Excel may misinterpret the data during the translation to a tab delimited file.

5.3 WaveShaper Preset Power Split Profile (**.psp*) files

Preset files provide a way to fully define the filter/power split profile of a WaveShaper across all Frequencies and Ports. It is the power splitting equivalent of the WaveShaper

Preset File (*.wsp) and provides frequency, attenuation and phase information for all ports undergoing power splitting.

As such it is a very powerful tool to easily configure the WaveShaper to a required complex, multiport spectrum.

To ensure data integrity, the WaveShaper Fourier Processor software parses the *.*psp* files to ensure the requested filter shape is calculated to conform to the limits set by the WaveShaper capabilities. The following rules for preparing and interpreting *.*psp* files therefore apply.

5.3.1 File Structure

The PSP file format can be broken up into two sections: the header and the body.

The file can be generated using a spreadsheet program, such as Microsoft Excel (saving the document as a tab delimited text file). The file extension must be "*.psp*" for the file to appear in the File Open dialog box.

5.3.2 PSP Body

The format of a *.psp* file is a tab delimited text file with up to 9 columns: **Absolute** Frequency (THz), Attenuation (dB), Phase (Rad) ... [Attenuation (dB), Phase (Rad)].

The PSP body is expected to have a total of 9 columns unless a port allocation vector is given (see "5.3.3 (Optional) Header" for more information).

	Port 1		Port 2		Port 3		Port 4	
Frequency [THz]	Att. [dB]	Phase [rad]	Att. [dB]	Phase [rad]	Att. [dB]	Phase [rad]	Att. [dB]	Phase [rad]
191.250	0.000	0.000	0.500	0.000	60.000	0.000	6.024	3.142
191.252	0.000	0.000	0.500	0.000	27.080	3.142	5.511	3.142
…	…	…	…	…	…	…	…	…
196.274	5.756	0.000	0.500	0.000	6.305	3.142	3.016	3.142
196.275	6.020	0.000	0.500	0.000	6.024	3.142	3.012	3.142

*Table 5.4 Sample PSP data. Note that the headings are for instruction only and are not part of the *.psp file.*

Number of Frequency Data Points

Unlike *.*ucf* files, every GHz must be specified for the whole available spectrum in every *.*psp* file. The first and last points in the file must be as per specification for the respective WaveShaper model. To avoid interpolation and rounding problems, it is recommended to check that the frequencies are specified to at least 3 decimal places in the *.*psp* file.

Frequency

Each frequency data point (specified in absolute terms for *.*psp* files) must have a corresponding value of Attenuation, Phase. If no specific attenuation or phase value is required, values of 0 must be specified at these points.

Attenuation

The calibrated attenuation values available in the WaveShaper hardware are 0 to 30 dB. The calculation of the attenuation levels in the Fourier Processor software requires an iterative method however. This method will try to find the closest attenuation and phase levels to the ones specified in the **.psp* file, hence there is no guarantee of accuracy when using the Fourier Processor software.

Phase

The phase control range available in the WaveShaper is 0-2π. The **.psp* file may specify a phase outside of this range, however, this will be re-calculated by the WaveShaper software on interpolation as (phase modulo 2π) as shown in Figure 5.1.

5.3.3 (Optional) Header

It is possible to include optional header items at the top of the PSP file. They provide additional information about the PSP. Each header item should have its own line, and be prefixed with a hash '#' character.

The Port Allocation Vector Header Item

The port allocation vector allows power splitting on less than 4 ports. It consists of a comma-delimited list of port numbers mapping the active ports to their associated attenuation and phase column pair in the body. I.e. the n^{th} port number in the vector maps attenuation and phase to columns $2n$ and $2n+1$ respectively in the PSP body. The number of columns expected in the PSP body is then $1+2N$ when there are N ports in the port allocation vector. Consider this example port allocation header line:

#4,2

This indicates the following information:

- Only Ports 2 and 4 are activated. The behaviour at Ports 1 and 3 is undefined.
- The attenuation and phase information for Port 4 is given by columns 2 and 3 respectively.
- The attenuation and phase information for Port 2 is given by columns 4 and 5 respectively.
- The main PSP body should only contain 5 columns.

When power splitting is performed on less than 4 ports, there are advantages to using the port allocation vector compared to using dummy values for the unused ports. These advantages include increased optical transmission, reduced *.psp file size, and increased profile generation speed.

Unscaled Mode Header Item

By default, a PSP profile is set to "scaled" mode. Use the following header item to switch to Unscaled mode:

#Unscaled

Scaled mode

All ports are allocated an equal share of optical power. An attenuation of zero corresponds to a port transmitting its entire share. It is not possible for a given port to transmit more power than its given share. E.g. it is not possible to transmit ALL of the optical power to a single port when power splitting with 4 active ports under scaled mode. Equivalently, "Scaled" mode introduces the following attenuation to each port:

Number of Active Ports	Additional Attenuation [dB]
1	0
2	3
3	4.8
4	6

Unscaled mode

The attenuation value specified for the port is the amount of the available input optical power transmitted to the port. Note: clipping can occur in this mode if total sum of requested power levels on any wavelength is larger than 100% of the incoming light.