Making Light Work Lighter
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Wavelength Swept Laser Product Application Notes

1) Overview

The WSL-001 is an OEM high-speed, polarization stabilized tunable laser for fiber sensor and OCT applications. The laser's wavelength can be swept at a frequency of up to 16 kHz across a tuning range of up to 150 nm, with an output optical power of up to 20 mW. The device outputs two λ-trigger (TTL) signals to indicate the exact starting and ending wavelengths of each wavelength sweep. It also outputs an optical frequency clock (TTL) signal with a spacing as low as 25 GHz as the laser is swept to give users instantaneous relative optical frequency marks. In combination with the λ-triggers, this allows the absolute frequency or wavelength of the laser to be known at each instant during each wavelength sweep. A VOA (Variable Optical Attenuator) is equipped for user to easily control the output power level. In addition, a power monitoring output is included to indicate the instantaneous laser output power at each wavelength. Other laser health parameters, such as laser average power, driving current, and chip temperature, are also provided via a digital interface. Finally, the laser incorporates automatic polarization optimization to guarantee long term stability. The WSL-001 is available with either a linearly polarized output (aligned to the slow axis of a PM fiber) or a depolarized output. This combination of features makes it easy to integrate the tunable laser into sensor interrogators, optical coherence tomography (OCT) equipment, spectrum analysis equipment, and general purpose test and measurement instruments.

The WSL-1000 is a bench-top version of WSL-100 but it enhances the function such as communication interface (RS-232, Ethernet, USB and GPIB), signal interface (All signals are BNC) and power supply (Universal power supply). On front panel there is a 20-lines LCD display for instrument information. Per laser safety consideration, a laser key is installed on front panel. With these enhanced features, WSL-1000 is convenient for lab use in OCT, fiber sensing and other applications.

Since the principle of WSL-001 and WSL-1000 is the same, below discussion will be based on WSL-001.

2) Unique Feature Introduction

a) Basic operation scheme

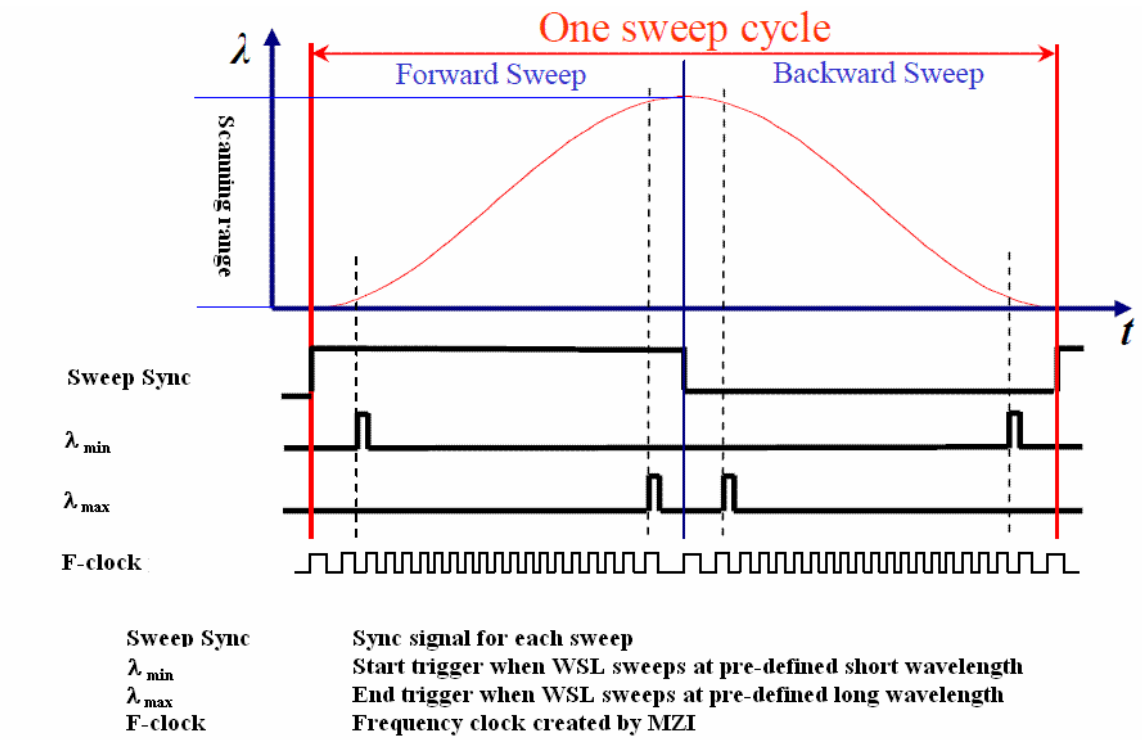


Fig. 1 Sweeping wavelength, Sweep sync, λ_{min} trigger, λ_{max} trigger and F-clock timing relationship

The operation scheme of WSL-001 in one sweep cycle is sweeping from short wavelength to long wavelength (Forward Sweep), and then sweeping back from long wavelength to short wavelength (Backward Sweep). WSL-001 is driven by sinusoidal signal.

There are 3 TTL signals in WSL-001 which could be used as timing reference:

1. Sweep Sync (Start at each sweep)
2. λ_{min} (Trigger when laser sweeps to certain pre-defined short wavelength)
3. $\lambda_{max,}$ (Trigger when laser sweeps to certain pre-defined long wavelength)

λ_{min} and λ_{max} are designed for user to know exact wavelength position during operation, they could also be used as the start point for data sampling. For example, in Forward Sweep, user can start sampling at λ_{min} and stop at λ_{max} ; in Backward Sweep, since sweeping is inverse to Forward

Sweep, user can start from λ_{max} and stop at λ_{min}. If both Forward Sweep and Backward Sweep are used, the actual repetition speed will be double.

b) Frequency clock

WSL-001 is a rapidly swept laser source for OCT imaging application and is driven by sinusoidal signal. In order to achieve the data sampling point equidistant in optical frequency, a reliable and accurate recalibration signal (Frequency-clock or F-clock) is required.

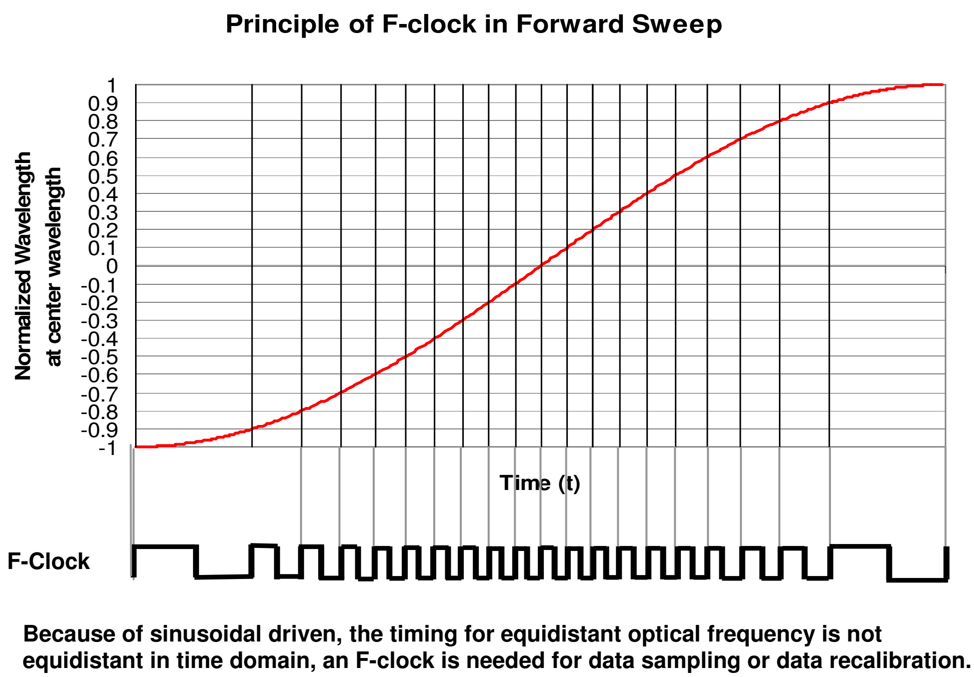


Fig. 2 Principle of F-clock

F-clock could be realized by Mach-Zehnder Interferometer (MZI). WSL-001 is equipped with one free-space MZI and necessary electrical. It can give user a TTL trigger (rising edge) as the zero-crossing of MZI output which detects the change of input optical frequency. The spacing of optical frequency could be selected when ordering. By using F-clock, user can take the data exactly by equidistant optical frequency even the timing may not be equidistant; this approach also relaxes the worry about laser stability and repeatability.

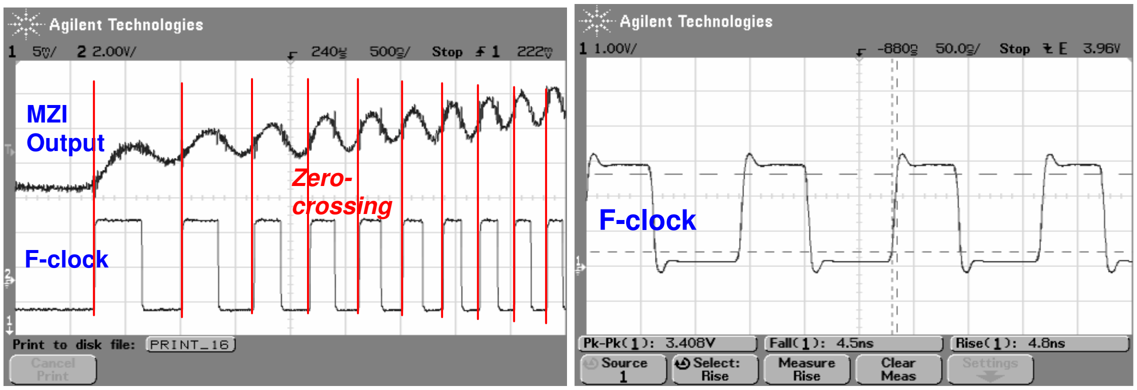


Fig. 3 A close view of F-clock

Below are the simple formulas to estimate the spacing of MZI for the F-clock and its data rate.

$$SP = \frac{c * \Delta\lambda}{\lambda_0^{\ 2} * N} \qquad (1)$$

SP	MZI frequency spacing
c	Light speed
$\Delta\lambda$	WSL spectral range (10 dB cutoff point)
λ_0	Center wavelength
N	Sample number in forward sweep

Since GP's WSL sweeps in both directions (forward & backward), a multiplication of 2 is necessary.

$$F_{avg} = N * R * 2 \qquad (2)$$

F_{avg}	F-clock average data rate
R	WSL repetition rate

The peak data rate could be estimated as

$$F_{peak} = F_{avg} * \frac{\pi}{2} = 1.57 F_{avg} \qquad (3)$$

F_{peak} could be used as a reference to choose your DAQ (Data Acquisition) card sampling rate.

c) Instantaneous power monitor

The instantaneous power monitor (0-5V, analog) is an analog signal which delivers an output voltage proportional to WSL-001 optical output power intensity. With Sweep Sync and triggers, user can always have a whole picture of WSL operation. User can also use this information to fine-tune the sampled data.

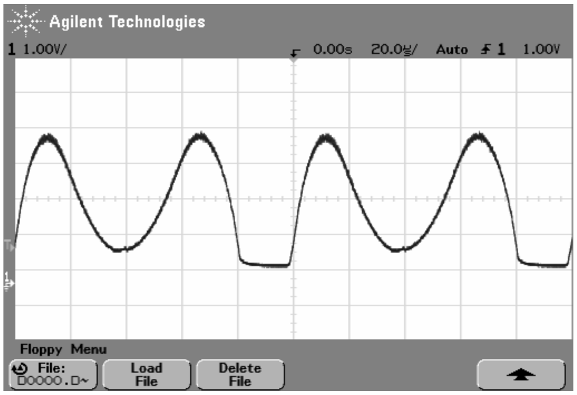


Fig. 4 Instantaneous power monitor signal

d) Built-in VOA

A VOA with a range of 20dB is built in WSL-001 so it is convenient for user to adjust the output power to the expected range.

e) Polarized consideration for lone time stability

In our design we incorporated the automatic polarization optimization to guarantee long term stability. Our WSL is available with either a linearly polarized output (aligned to the slow axis of a PM fiber) or a depolarized output.

f) Laser shut-down function per laser safety consideration

Since WSL-001 could reach 50 mW at static mode and belongs to Class 3B laser, many laser safety considerations were taken into account during design. One of these is "Laser Shut-Down" function. Below is the definition:

1) When instant optical power goes beyond +/- 20% of average, W_S pin at 26 pin communication connector will become '1'.
2) When instant optical power goes beyond +/- 50% of average, A_S pin at 26 pin communication connector will become '1', and WSL-001 could be shut-down in 100 ms if customer expected.

User can choose if they want this function or not while ordering.

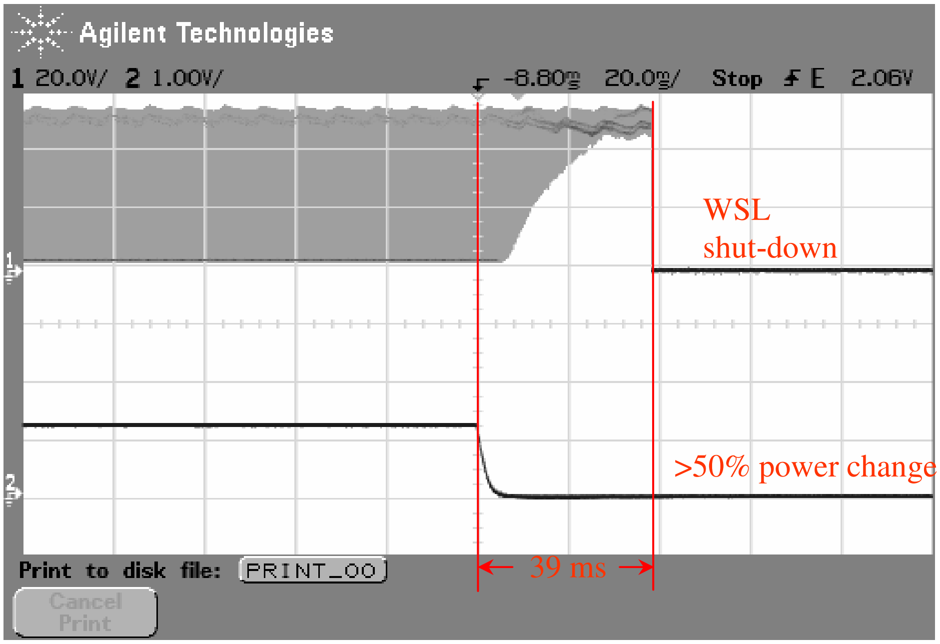


Fig. 5 Laser shut-down in 100 ms

g) Remote Control Toolkit

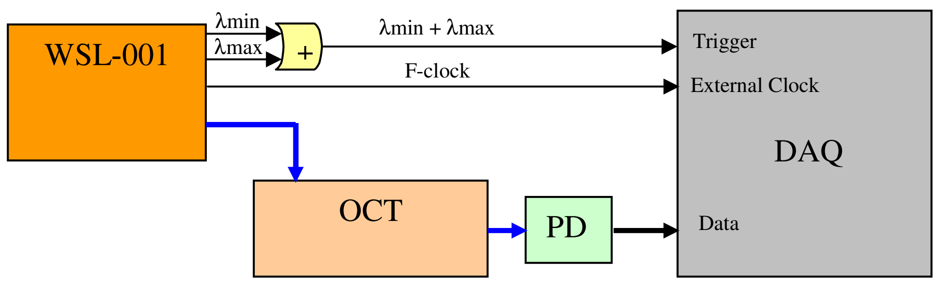
Since WSL-001 is designed for OEM application, usually it is controlled through RS-232. Unfortunately it is not so convenient for evaluation and stand-alone use. In order to make WSL-001 more convenient for users, a “Remote Control Toolkit” (RCT) is developed which is a GUI (Graphical User Interface) and could be installed in a PC. From PC with RS-232 or a USB-RS232 adaptor, user can easily control WSL-001 and get the necessary information.

Fig. 6 Control WSL-001 from PC by “Remote Control Toolkit”

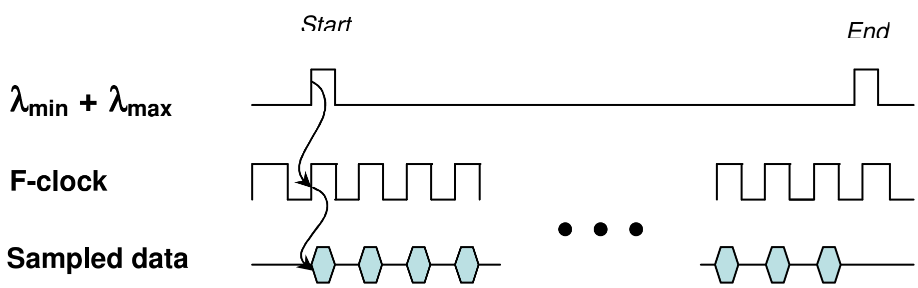
3) Typical Data Sampling for OCT Application

1. Using F-clock as external clock

Since our F-clock is a TTL digital signal, if user's DAQ card accepts "frequency-varying" external clock, F-clock could be used directly as external clock to take the data. This sampled data is equidistant in optical frequency (MZI spacing) so it can be conveniently processed by FFT (Fast Fourier Transform) to get the real time domain signal.



(a) Configuration



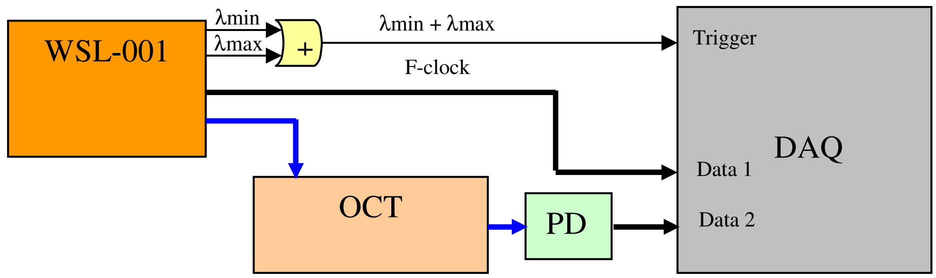
(b) Timing

Fig 7 F-clock as external clock directly

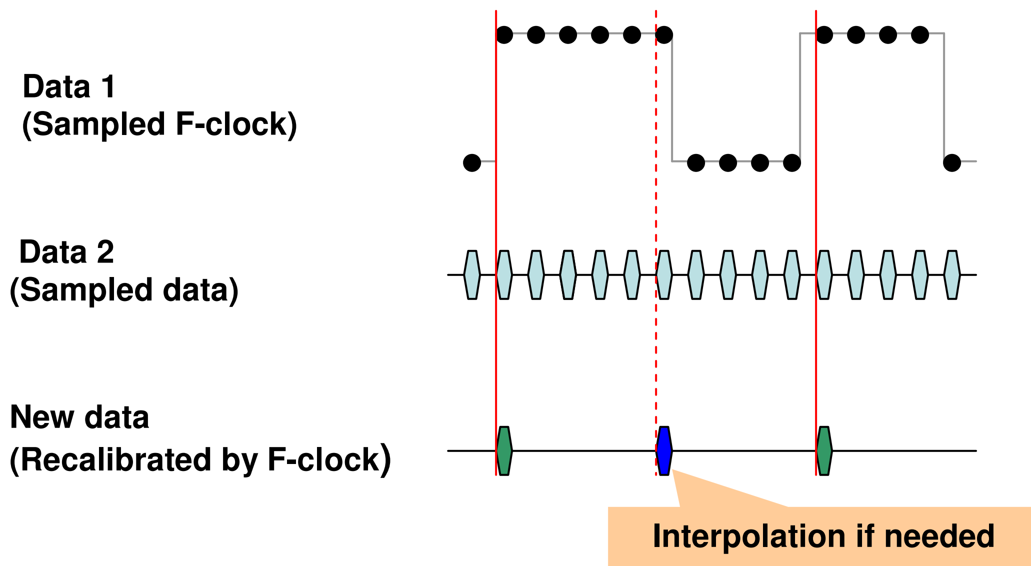
2. Take both F-clock and data for recalibration

If DAQ can not accept "varying-frequency" external clock and DAQ's internal clock is fast enough, user can sample both F-clock and data at same time by DAQ internal clock, and then recalibrate the data against F-clock. The recalibration could be done by picking up the data aligned with the rising edge of each F-clock pulse so a new data which is "sampled by F-clock" will be created.

If the sample rate is high enough, user can also use F-clock as reference point to pick up the data in between to get more detail information (interpolation).



(a) Configuration

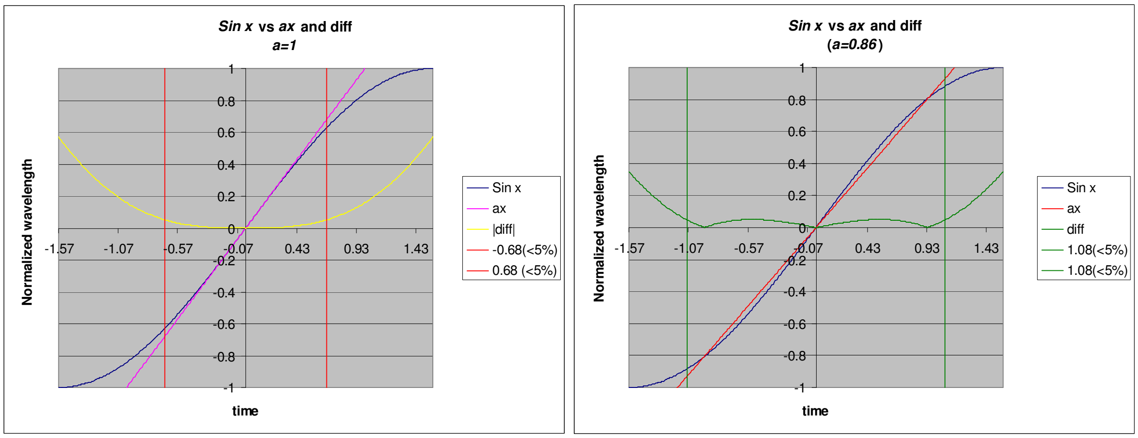


(b) New data

Fig 8 Take both F-clock and data for recalibration

3. Linear sampling

In many cases, people like linear sampling since the result can be easily converted to k-space. Fortunately, at certain region of one sweep cycle, the difference between $y=ax$ (a is 1 or close to 1) and $y = \sin x$ is very small. If we limit the difference less than ±5%, choose $a=1$, the duty cycle will be 43%; if we choose $a = 0.86$, the duty cycle will be 68.8% (Fig 9).



(a) *a=1*, *duty cycle=43%* (b) *a=0.86, duty cycle=68.8%*

Fig 9 Difference between $y = \sin x$ and $y = ax$

This analysis means that if we use the range up to 2/3 (duty cycle) of total WSL scanning range for a linear sampling, the error will be very small.

The formula (4) could be used to convert *N* time domain samples into wavelength:

$$\lambda(i) = \lambda_{\min} + \frac{\lambda_{\max} - \lambda_{\min}}{N} * i \qquad (4)$$

$$i = 1,2,\ldots,N$$

$\lambda(i)$ Wavelength corresponding to Sample *i*
N Sample number in forward sweep or backward sweep

By this way user can just use DAQ's internal clock do a quick sampling, and then convert the data to K-space without any post-recalibration.

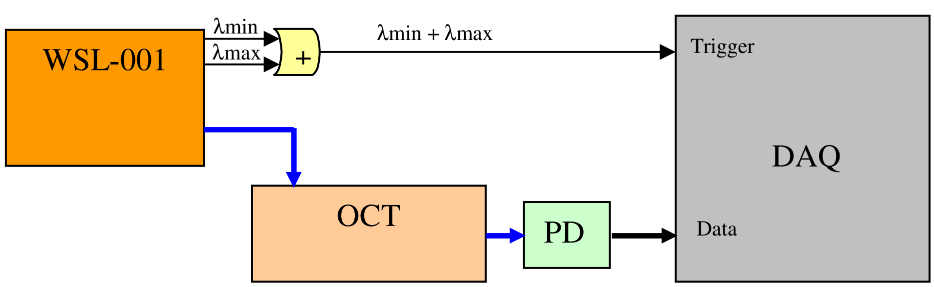


Fig 10 Linear sampling