BOWERS GROUP
(X 4235)

CALMAR
OPTCOM

Picosecond Pulsed Fiber Laser Instruction Manual

Model: PSL-10-1T
S/N: 880436

Part No. Man-880436

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Preface

Please take time to read and understand this Instruction Manual and familiarize yourself with the operating and maintenance instructions that we have compiled for you before you use the product. We recommend that the operator read the safety instructions, prior to operating the product.
This Instruction Manual should stay with the product to provide you and all future users and owners of the product with important operating, safety and other information.

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Calmar's policy and business code is to comply strictly with the U .S. export control laws. Export and re-export of lasers manufactured by Calmar are subject to the US Export Administration Regulations administered by the Department of Commerce, Bureau of Industry and Security. The applicable restrictions vary depending on the specific product involved, intended application, the product destination and the intended user. In some cases, an individual validated export license is required from the U S Department of Commerce prior to resale or re-export of certain products. Please contact Calmar, if you are uncertain about the obligations imposed by US law.

Warranty

Calmar Optcom Inc. warrants this product to be free from defects in material and workmanship for a period of one year from the date of shipment. If found to be defective during the warranty period, the product will be either repaired or replaced at Calmar Optcom's option.

To exercise this warranty, write or call Calmar Optcom Inc. You will be given prompt assistance and return instructions. Send the instrument, transportation prepaid, to indicated service facility. Repaired products are warranted for the balance of the original warranty period, or at least 90 days.

Limitation of Warranty

This warranty does not apply to defects resulting from the modification or the misuse of any product or part. Calmar Optcom Inc. shall not be liable for any indirect, special, or consequential damages.

Table of Contents

Safety Operation of Laser

Safety Symbols and Terms

The following safety terms and signs are used in this manual to call your attention to hazards or important information. These include:

WARNING:

- The **Warning** heading in this manual explains dangers refer to a potential personal hazard that could result in personal injury or death. (*Electrical*) (*Laser radiation*) It requires a procedure that, if not correctly followed, may result in bodily harm to you and/or others. Do not proceed beyond the WARNING sign until you completely understand and meet the required conditions.

CAUTION:

- The **Caution** heading in this manual refers to a potential *product* hazard. It requires a procedure that, if not correctly followed, may result in damage or destruction to the product or components. Do not proceed beyond the CAUTION sign until you completely understand and meet the required conditions.

NOTE

- The Note refers to any information regarding the operation of the product. Please do not overlook this information. It provides the information that may be beneficial in the use of this instrument

Laser Classification IIIB (< 500mW @ 1550nm)

This device is classified as a high power Class IIIB laser instrument under 21 CFR 1040.10. This product emits invisible laser radiation at or around a wavelength of 1550 nm, and the total light energy radiated from the optical output is less than 500 mW. This level of light may cause damage to the eye and skin. Despite the radiation being invisible, the beam may cause irreversible damage to the cornea. Laser safety eyewear is not provided with this instrument, but must be worn at all times while the laser is operational.

WARNING:

Use appropriate laser safety eyewear when operating this device. The selection of appropriate laser safety eyewear requires the end user to accurately identify the range of wavelengths emitted from this product. If the device is a tunable laser or Raman product, it emits light over a range of wavelengths and the end user should confirm the laser safety eyewear used protects against light emitted by the device over its entire range of wavelengths.

WARNING:

Use of controls or adjustments or performance of procedures other than those set forth in this User's Guide may result in hazardous radiation exposure.

CAUTION:

Do not install or terminate fibers when laser is active.

Notes for a Safe Operation

In order to ensure the safe operation and optimal performance of the product, please follow these warnings and cautions in addition to the other information contained elsewhere in this document.

CAUTION:

- The product has been designed for an AC power of 110 V or 220 V +10%, -13%, 47-63 Hz. Before switching the product on, make sure that it has the proper AC-power supply.

WARNING:

- Make sure this instrument is properly grounded. Any interruption of the protective grounding conductor from the protective earth terminal can result in personal injury.

WARNING:

- This device and all parts or components thereof are not meant to be operator serviced, except for the replaceable fuse(s). Refer all servicing to qualified CALMAR personnel. To prevent electrical shock, do not remove covers or system components. Any tampering with or disassembly of the device or parts or components will void the warranty and possibly expose the operator to an electrical shock hazard.

WARNING:

- Laser radiation is emitted from all optical outputs simultaneously. Avoid exposure from all unused optical ports. The product encloses class IIIB laser (1480-nm laser diode with power less than 500 mW) which may cause permanent eye damages or skin burns. Under the normal operating condition, the laser light is contained in the optical fiber within the product. Any disassembly of the product may expose the laser, and is strongly discouraged. Keep the AC power supply disconnected in case of disassembling the product.

WARNING:

- Do not enable the laser when no fiber or equivalent is attached to the optical output connector.

CAUTION:

- Unauthorized opening of the PSL unit is strongly discouraged. The unit contains fragile fiber-optic components, which can be damaged if the unit is open. This unit does not contain any parts, which need service by an end user. Warranty will be voided if damage of the unit is caused by any unauthorized opening.

- If this instrument is used in a manner not specified in this document, the protection provided by the instrument may be impaired and the warranty will be voided. This product must be used only in normal conditions.

CAUTION:

- Avoid mechanical shock to the unit. Excess force may cause misalignment of the unit.

Connector Cleaning Guide

- The fiber connector is very sensitive to contamination. Any contamination may severely reduce the output power. All fiber connectors should be cleaned before being connected to the output of the product. Caps should be left on connectors whenever they are not in use. Do not touch the connector end. Damage to connector end faces caused by improper care is not covered by the warranty.

WARNING:

- After making sure that the light source is off, check the connector ferrule end using the connector inspection microscope. If no dirt, grease or small particles are visible no further cleaning is necessary.
- Use canned air to remove loose particles.
- Either use automatic connector cleaner such as "Cletop". Wipe the connector as directed on the box. Be careful with angled connectors (connectors with green boots) to make sure the full surface contacts the cloth. You will need to tilt the connector slightly. Using an automatic cleaner is our preferred technique. Note that some low cost cleaners may leave small particles on the fiber surface.
- Or moisten a clean optical wipe with alcohol and wipe connector. Finish by wiping the connector with a dry part of the wipe. Be careful not to allow oil from fingers to contact connector. Allow the connector to dry for 1 minute. Inadequate drying can result in the alcohol residue burning into the connector end when the fiber is lit.
- Inspect the connector ferule under the microscope. Clean again if necessary.
- If a connector is to be used to transmit high powers (>50mW in average or >500mW in peak), great care should be taken in cleaning. Mating of these connectors should be kept to a minimum.

Bulkhead cleaning

- Fiber bulkhead adapters contain a zirconia or phosphor-bronze sleeve. After removing the connectors, these can be cleaned with a pipe cleaner moistened with isopropyl alcohol, and dried with canned air.

Connector Trouble Shooting

- A small black area appears in the middle of the connector, which cannot be removed by cleaning.

Some material (typically oil from skin contact, residue alcohol or particles from connector cleaning devices) has burnt on the connector surface. Do not use your device and contact CALMAR for assistance.

- A small circle of dried droplets are visible on the end of the connector.

The connectors were mated when one was still wet (typically from water/alcohol). Repeat cleaning procedure.

- The connector is clean but the loss on mating varies by 10dB or more.

Check to see if the bulkhead adapter sleeve is cracked. Be careful not to over-tighten connectors.

- A gray powdery grime continues to appear on the connectors after repeated matings.

If the bulkhead adapter sleeve is made from phosphor-bronze, some of the metal is probably rubbing off on the connectors.

Environment and Precautions

WARNING:

- Always use your device in conjunction with properly grounded power source.

CAUTION:

- Do not expose the device to a high moisture environment.

CAUTION:

- The device may or may not have a fan for active cooling. Make sure there is sufficient air-flow to cool the device, any objects that cover the ventilation holes must be removed.

CAUTION:

- Always clean optical connectors before connecting them to the amplifier. Use only the type of connectors noted in your specification. Use special high precision adapters for connecting the amplifier to an input source; otherwise maximum polarization extinction ratio may not be achieved. Calmar will not be responsible for the damage sustained by the device as result of using dirty or incompatible connectors.

Service and Repairs

There are no operator serviceable parts inside. Please refer all servicing to qualified CALMAR personnel.

Many issues and questions regarding the safety, set-up, operation and maintenance of the Calmar products can be resolved by reading this User's Guide carefully. If you have questions regarding the safety, set-up, operation or maintenance of your Calmar product, please call +1 (408) 733-7800.

If you cannot resolve the issues through the use of this manual or over the telephone with our technical support group, you may need to return the product to Calmar.

Specifications

OPTICAL CHARACTERISTICS		
Peak Wavelength	1545 – 1560 nm	
Pulse Width	1.2 at one λ 1.5 across λ range	
Repetition Rate	5 ~ 11 GHz	
Output Power at 10GHz	> 20 mW	
OPTICAL COMPONENTS		
Gain Medium	Er-doped fiber	
Pump Source	1480 nm diode laser	
Connectors	FC/UPC PM fiber connector on main port (A) FC/UPC SM fiber connector on monitor port (B)	
OPERATING REQUIREMENTS		
Operating Voltage	85-264 V/AC 47 – 63 Hz, < 300 Watts	
RF Drive Frequency	5 – 11 GHz	
RF Drive Level	-5 to 1 dBm	
Operating Temperature	15 to 30 °C	
PHYSICAL CHARACTERISTICS		
Size	48 cm × 42 cm × 9 cm	
Weight	15 lbs	

Section 1 – Principle of Operation

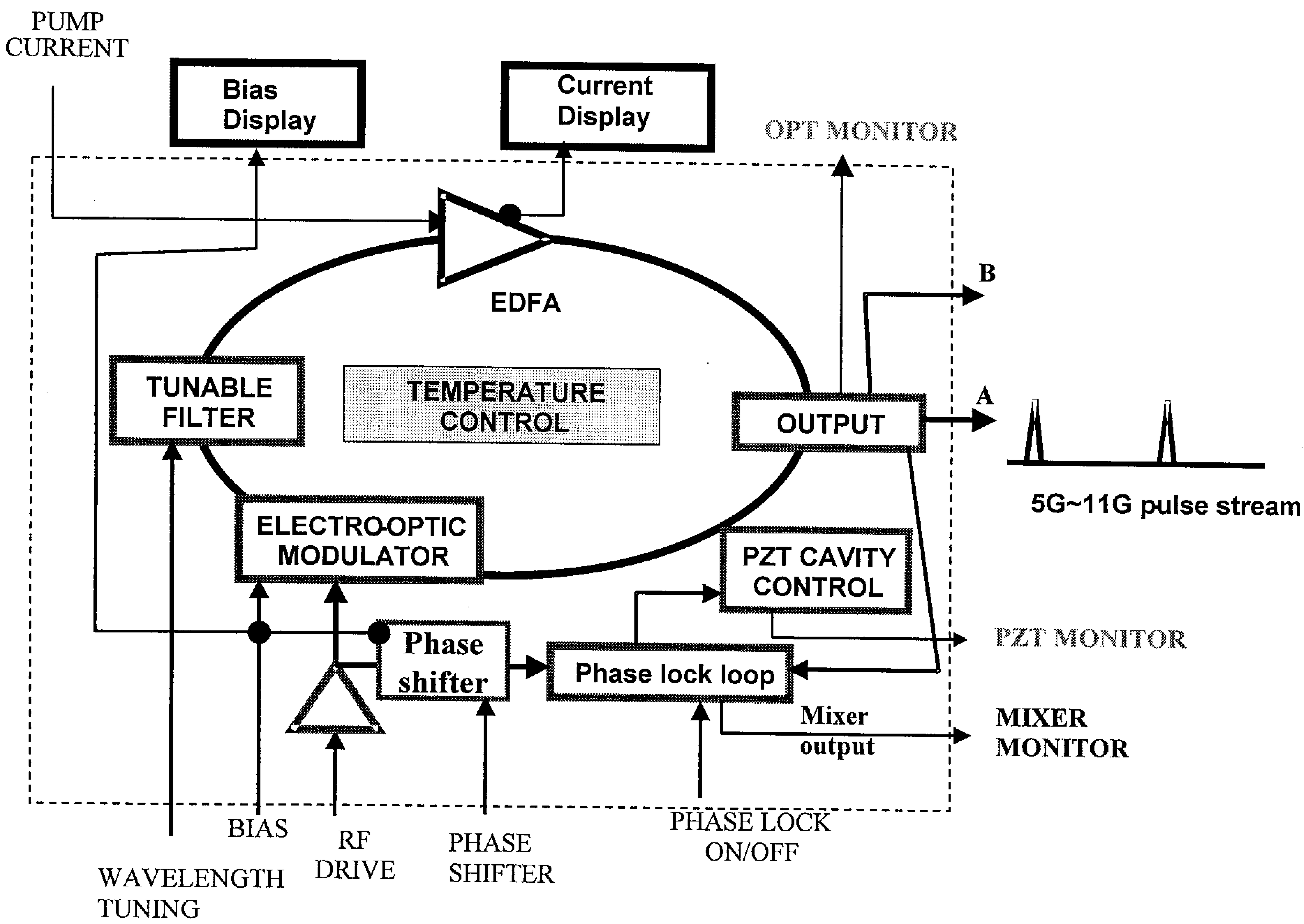


Figure 1. Functional diagram of PSL

The PSL is an optical pulse source. It produces an optical pulse train at repetition rates of 5 -11 Gb/s. The optical pulse train has pulse width of about 1.2 ~ 1.5ps. The optical pulse has wavelengths in the range of 1545 nm to 1560 nm.

The PSL laser is based on an actively mode-locked fiber laser. The laser cavity consists of **EDFA**, **OUTPUT** coupler, **ELECTRO-OPTICS MODULATOR**, **TUNABLE FILTER** and fiber that connect these devices together. The **PZT CAVITY CONTROL** adjusts the cavity length to achieve stable mode-locking. The base rate of the PSL is a 10 GHz pulse source.

WAVELENGTH TUNING controls the center wavelength of the tunable filter. **WAVELENGTH TUNING** determines the laser output wavelength.

The gain medium in the **EDFA** is Erbium-doped fiber. The pump laser in the **EDFA** provides optical pump to excite the gain medium. The pump laser is a 1480 nm diode laser. The diode laser is driven by an electrical current source. The current is displayed in the front panel and can be adjusted by tuning the **PUMP CURRENT** control knob. Adjustment of the pump laser current changes the output power.

The **ELECTRO-OPTIC MODULATOR** modulates the loss in the laser cavity to support the active mode-locking. The user supplied **RF DRIVE** is first amplified by an internal RF amplifier, and then drives the **ELECTRO-OPTIC MODULATOR**. The laser repetition rate equals the **RF DRIVE** frequency. The

ELECTRO-OPTIC MODULATOR is also controlled by externally supplied bias voltage. The modulator bias (**MOD BIAS**) voltage needs to be adjusted to a proper DC value to ensure proper mode-locking. Since the modulator bias point can drift over time, the modulator bias voltage may need to be adjusted from time to time.

The **PHASE LOCK LOOP** circuit provides a control voltage to **PZT CAVITY CONTROL**. The **PZT CAVITY CONTROL** fine-tunes the laser cavity length to ensure stable operation. The laser cavity has a round trip frequency of f_R ($f_R \sim 1.68$ MHz) that depends on the cavity length. To satisfy the condition of stable mode-locking, f_R of the laser multiplied by an integer M (M ~ 5,000) must be matched by the RF drive frequency AUTO **mode** ($f_D \sim 10$GHz) precisely.

$$f_D = M \times f_R \text{ (M is an integer)}$$

The laser repetition rate equals f_D. The laser can have multiple repetition rates according to the above formula, since M can be an arbitrary integer.

Since the laser cavity optical length may change according to temperature changes, **TEMPERATURE CONTROL** is used to ensure constant laser cavity length. The cavity length changes about 1.09E-5 per degree C. The temperature control gives a coarse tuning of f_R.

$$\Delta f_D = -1.09\text{e-}5\ \Delta T\ f_D \quad (\Delta T = T - T_o)$$

$$\Delta f_R = -1.09\text{e-}5\ \Delta T\ f_R$$

At a constant temperature, stable mode-locking can be achieved over a set of discrete microwave driving frequency points (f_D). These discrete points are separated by f_R (~ 1.68MHz). Varying the operating temperature can change the f_D. An ~ 15 degree C change of the temperature can lead to 1.68 MHz variations near 10 GHz which will enable the laser to operate at any frequency point.

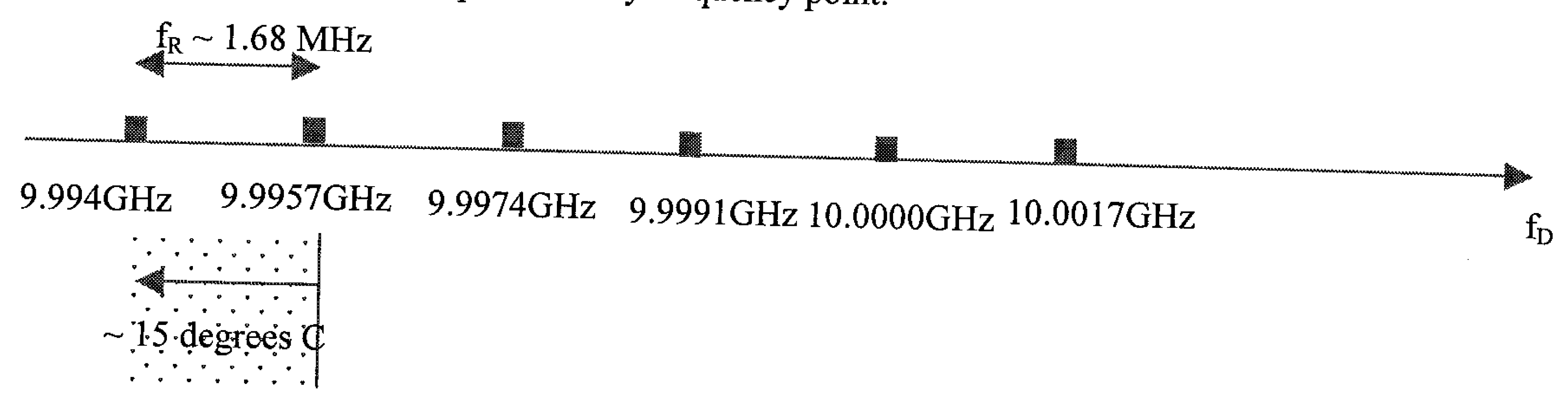


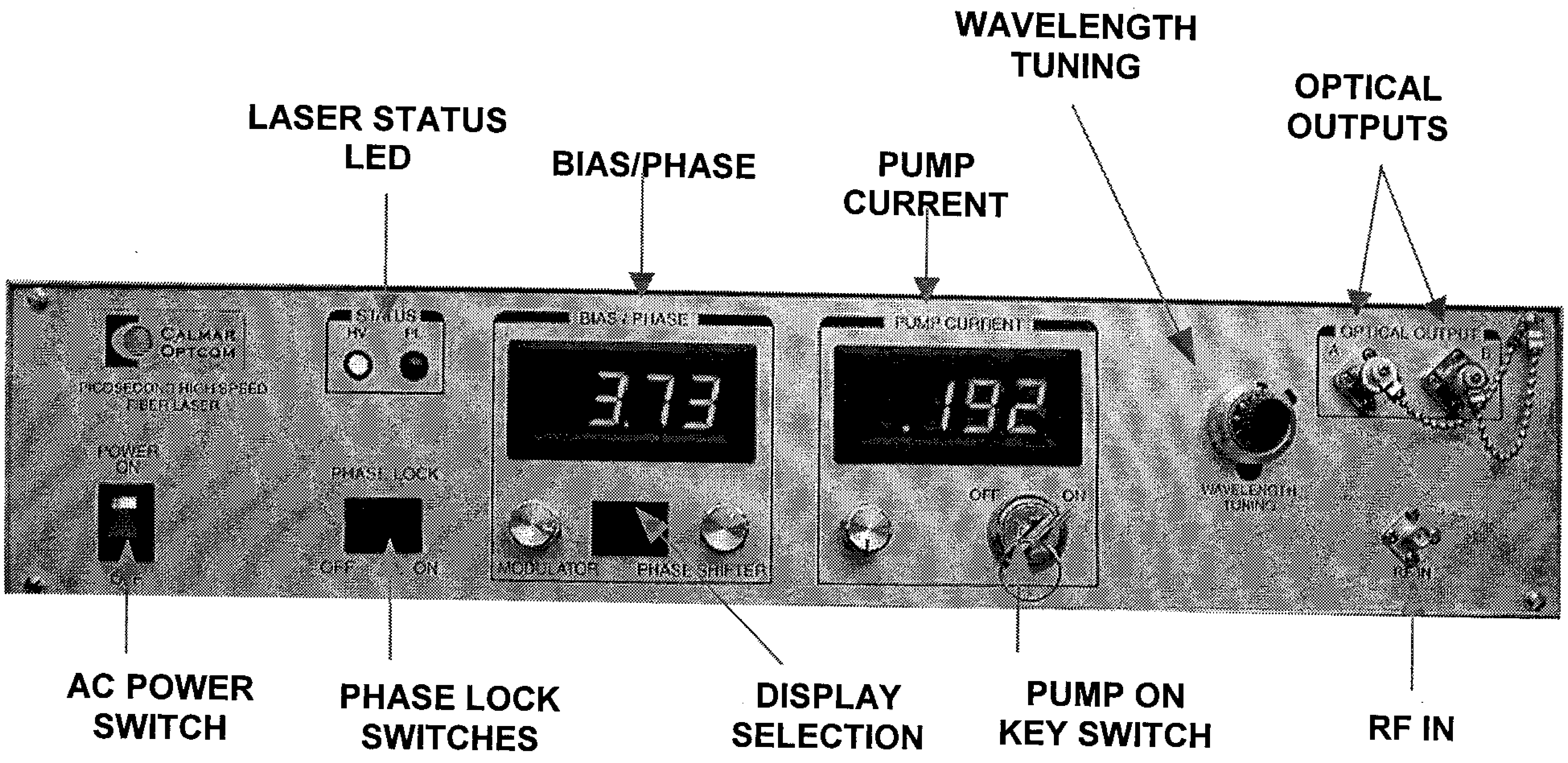
Figure 2. Illustration of discrete repetition rate points

Figure 2 shows the discrete repetition rate points for which the fiber laser can produce stable output at a certain temperature. The spacing between discrete points is about 1.68 MHz. By varying temperature in the range of 15 degree C, the discrete frequency points will shift by 1.68 MHz, thereby covering all the frequencies (near 10GHz).

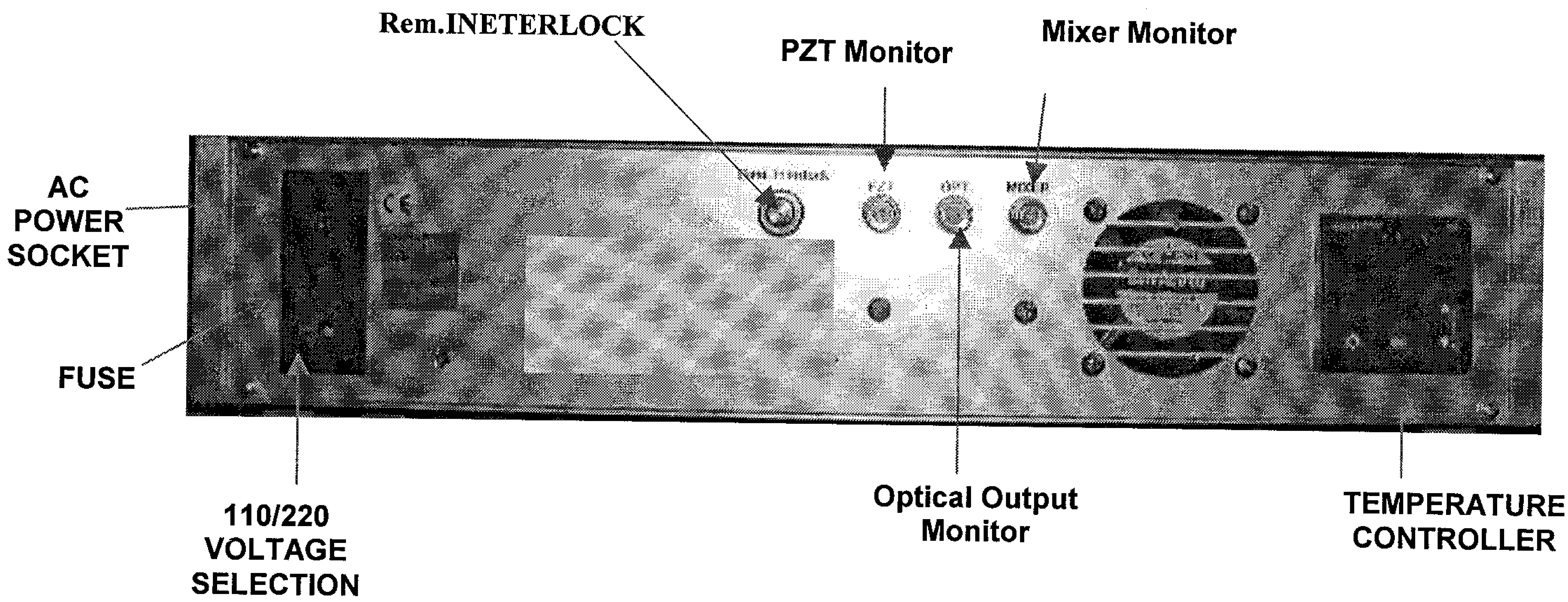
Note: For repetition rate much lower than 10 GHz (such as 5 GHz), it may not be possible to have laser work exactly at some repetition rate. The required temperature for the repetition rate may be outside the 30 –48 degree C. User could then find laser to work at a repetition rate which is less than round trip frequency (1.68MHz) away from the desired repletion rate.

PZT CAVITY CONTROL gives a fine-tuned f_R all the time. The range of PZT control is about several hundred kilohertz.

PHASE SHIFTER controls the phase of the **RF DRIVE** signal into the **PHASE LOCK LOOP.** The **PHASE SHIFTER** must be adjusted precisely so that the **PHASE LOCK LOOP** can function properly. There is a mixer inside the **PHASE LOCK LOOP**. The mixer output voltage should be close to zero when the PSL is mode-locked properly. The **LP MONITOR** produces the mixer output.



Front Panel



Rear Panel

Figure 3 Panel illustrations

Section 2 – System Operation

2.1 - Front and Rear Panels

Operation controls are on the front panel. Power supply inlet, temperature control and computer control input/output are on the rear panel.

Table 1 - Front Panel

Labels		Description	Function
POWER ON/OFF		Rocker switch	Turn AC power on and off to control AC power supply to the whole system
PUMP CURRENT		ON/OFF key switch	Enable/Disable pump laser
		10-turn potentiometer	Set current of pump laser
		Digital panel meter	Display current of pump laser in Amperes
LASER STATUS	**PL**	Phase lock ON/OFF indicator	On: indicates phase is locked.
	HV	PZT voltage status	On: indicates PZT voltage in normal range.
PHASE LOCK	**ON/OFF**	Rocker switch	ON: Enable Phase Lock Loop to Supply Control Voltage to PZT Cavity Control OFF: Disable Phase Lock Loop
BIAS/PHASE		Rocker switch	Switch Display to BIAS or PHASE
		Digital panel meter	Displays bias voltage or phase shifter voltage
		MODULATOR knob	Adjusts bias voltage
		PHASE SHIFTER knob	Adjusts phase voltage
OPTICAL OUTPUT	A	FC/UPC PM fiber receptacle	Optical pulse output; PM fiber; key to the slow mode axis
	B	FC/UPC SM fiber receptacle	Auxiliary optical pulse output; SM fiber
WAVELENGTH TUNING		Knob	Tunes wavelength
RF IN		SMA F connector	RF drive signal, 5.0 – 11 GHz

Table 2 - Rear Panel

LABELS	Description	Function
POWER	AC Power Inlet	Connect to AC Power Supply 85-132 or 170-264 VAC
TEMPERATURE CONTROL	Temperature Controller	Adjust Laser Temperature using the up and down arrow key (30~48 °C)
REM.INETERLOCK	Remote Interlock	Laser enable/disable by remote interlock
PZT Monitor	BNC Connector	Monitors PZT Voltage. Range 0~2.5 V
MIXER Monitor	BNC Connector	Monitors phase lock loop mixer output level
OPT Monitor	BNC Connector	Photo detector monitor output (0 ~ 5 V, DC ~ 10 MHz)
FUSE	Fuse Holder	3 A Fuse
Voltage Selector	Power supply Voltage selector	Switch power supply voltage between 110V and 220V
FAN	Fan Blocks	Provide Cooling for Proper Operation

Caution: To avoid overheating to the laser unit, do not set the temperature of the laser more than 48 degree C

2.2 – Operating Parameters

There are seven operating parameters that need to be set in order to obtain the desired optical pulses from the PSL laser. Two of the parameters are for the external RF drive source that has to be set by the user. The other five parameters can be set by the PSL front or rear panel adjustments.

Table 3 – Operating Parameters

Parameters	Location	Adjustment Method	Comments
RF DRIVE FREQUENCY f_D	External	Manual	5.0 GHz to 11GHz
RF DRIVE POWER LEVEL	External	Manual	-5 dBm to 1 dBm
LASER TEMPERATURE	PSL Back Panel	Manual temperature controller adjustment	35 – 48 degrees C, needs to be set to match the RF drive frequency (see Table 5, and Page 6 for f_D calculation)
WAVELENGTH	PSL Front Panel	Manual wavelength tuning knob	1545 nm – 1560 nm
MODULATOR BIAS	PSL Front Panel	Manual	Need to be optimized to achieve low noise operation
PHASE SHIFTER	PSL Front Panel	Manual	Need to be optimized to achieve low noise operation
PUMP CURRENT	PSL Front Panel	Manual	Control output power, need to be in a stable range for stable operation

From **Section 1 – Principle of Operation,** assuming the laser cavity has a round trip frequency of f_R and the RF driving frequency to satisfy the condition of stable mode-locking is f_D, we have:

$$f_D = f_T \pm N \times f_R \text{ (N is a integer, 0, 1, 2, ...)}$$

$\mathbf{f_R}$**:** laser cavity round trip frequency

$\mathbf{f_D}$**:** RF frequency satisfying the condition of stable mode-locking

$\mathbf{f_T}$**:** test point frequency

Table 4 - Operating Driving Frequency

Name	Range		Initial Test Frequency	Notes
f_D	max	11 GHz	9.95328 GHz	Optimal value may change depending on the above formula. At each frequency point, the tolerance is 2E-5 or 200 kHz. Laser temperature is set at 37.2degrees C.
	min	5.0 GHz		
f_R	N/A		1.68 MHz	

The laser temperature must be set to match the RF drive frequency f_D. Table 5 provides the parameters for the laser to operate at frequency of 5GHz, 10GHz and 11GHz.

Table 5 – Laser Operating Parameters when RF Drive Frequency is 5GHz, 10 GHz and 11GHz

Drive Frequency (GHz)	4.9924	9.95328	11.0012
Drive Level (dBm)	-5	0	0
Laser Temperature (C)	37.2		
Wavelength (nm)	1550		
Wavelength Indicator	2.32		
Modulator Bias (V)	3.65	3.70	3.70
Phase Shifter (V)	13.16	6.97	8.79
Pump Current (mA)	180	600	620

Table 6 – Initial Operating Parameters when RF Drive Frequency is 10 GHz

Name	Range		Initial Optimum Value	Note
RF DRIVE FREQUENCY			9.95328 GHz	
RF DRIVE POWER			0 dBm	Occasionally varying RF power by 0± 2 dB may help to achieve low noise
LASER TEMPERATURE			37.2 degree C	Relates to RF drive frequency
WAVELENGTH			1550 nm	
PUMP CURRENT	Max	950 mA	600 mA	Pump current influences output power, output pulse width, and output stability.
	Min	0 mA		
MODULATOR BIAS	Max	8.9 V	3.70 V	Modulator bias voltage influences stability. Optimal bias voltage usually drifts quickly during initial operation.
	Min	0 V		
PHASE SHIFTER	Max	19 V	6.97 V	The phase shifter voltage influences the stability of the laser. The optimal phase shifter value strongly depends on the RF drive frequency, pump current and modulator bias.
	Min	0		

2.3 – PSL Initialization

INITIAL STATE

Before turning on the **POWER** switch, the **PUMP CURRENT ON/OFF** switch should be in the **OFF** position. The **PUMP CURRENT** control knob should be set to minimum (turned counter-clockwise all the way).

Turn the **POWER** switch on. After about 20 minutes, the laser can now be operated.

The **PHASE LOCK ON/OFF** switch should be in the **OFF** position. Turn the **PUMP CURRENT ON/OFF** switch in the **ON** position.

WARM UP

The laser cavity is in a temperature-controlled chamber. It requires 20 minutes to warm up the laser cavity. The temperature will achieve its stable condition in another 20 minutes to one hour. The laser can operate after it reaches its operating temperature; however, the laser will be most stable when the laser cavity temperature reaches its stable condition.

The operating temperature needs to be set to a certain value depending on the RF drive frequency. Refer to Table 5 for special temperature settings for three RF drive frequencies. For other frequencies, it is recommended adjusting the temperature in the range of 30 - 48 degree C. The temperature coefficient of the laser drive frequency is –1.09E-5 per degree C. Please refer to Section 1 for appropriate temperature and repetition rate settings.

Note: The room temperature needs to be at least 5 degrees C below the laser temperature. Otherwise the laser temperature may not reach the set temperature.

The power switch should be left **ON** to keep the laser cavity temperature stable for quick startup operation, when the laser is not in use temporarily.

EXTERNAL RF SOURCE SETUP

The following is the minimum equipment needed to be able to adjust the PSL to its operating state:
(1) **RF SOURCE,** 5.0 ~ 11 GHz with frequency tuning resolution better than 10 KHz, maximum output power more than 2 dBm, and low phase noise.
(2) A high speed digital sampling scope (bandwidth > 20 GHz) with optical input, trigger frequency range > 10 GHz. A high-speed (< 20 ps) photodetector can be used as the optical front end with the digital sampling scope.

The setup is as shown in Figure 4. The **RF SOURCE** output is split into two parts. One part goes to the PSL **RF IN**. The other part goes to the **DCA** (digital high speed sampling scope) trigger input. The **OUTPUT A** of the PSL should be attenuated to below 1 mW and then fed through the optical input of the plug-in module of the **DCA**.

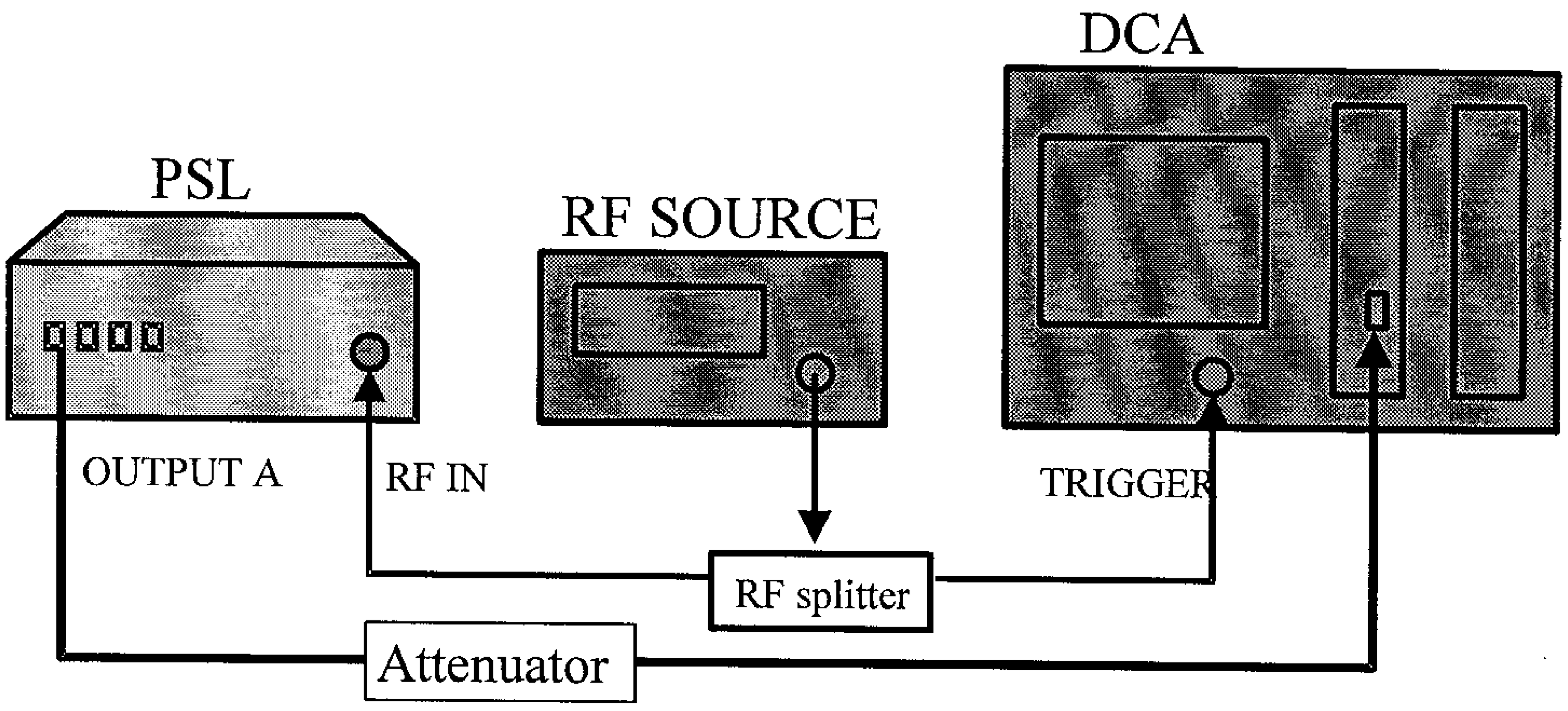


Figure 4. Setup for initializing the PSL driven by an external RF SOURCE

Set the **RF SOURCE** output level such that the PSL has **-5 dBm** to **1 dBm** (maximum RF level should be less than 5 dBm) input and the high speed **DCA** has and adequate trigger input. Set the **RF SOURCE** frequency to a point as stated in Table 3.

Set the **DCA** to *20 ps/div* and short persistence mode. Make sure the **DCA** is well triggered and its vertical scale and offset are set for optimal display.

• **Caution:** ⚠

Most high-speed optical detection systems are highly vulnerable to high power damage. It is recommended to attenuate the optical power to below 1 mW before feeding it into any high-speed optical detection setup.

• **Caution:** ⚠

Clean the fiber connector tip before connecting it to the OPTICAL OUTPUT. A dirty connector tip will increase connection loss significantly.

• **Note:** OUTPUT A has high optical output power around 50 mW. The fiber connector connection lifetime is usually short. It is very important to clean the fiber tip before any use. It is also highly recommended that any fiber connection should be done only when PUMP CURRENT is switched off.

WAVELENGTH SETUP

Turn the **PUMP CURRENT ON/OFF** key switch to the **ON** position. Turn the **PUMP CURRENT** knob clockwise to set the **PUMP CURRENT** to ***0.600 A***.

Wavelength turning knob has been equipped to indicate wavelength. Please refer **Table 7.**

If user wants to get accurate wavelength, he/she is advised to use an optical spectrum analyzer or a wavelength meter. Adjust WAVELENGTH TUNING to a desired wavelength. Also please note that the output wavelength is stable after the PSL is locked under its optimized condition.

Table 7 Wavelength Tuning

	Wavelength Selection			
	1545nm	1550nm	1555nm	1560nm
Reading (mm)	2.06	2.31	2.56	2.90

2.4 – PSL Locking

Before start, make sure that the laser working temperature is stable.

LOCK LASER

1)First, the PSL **PHASE LOCK ON/OFF** switch should be at **OFF** position.

2)Set **MODULATOR BIAS** and **PUMP CURRENT** to the recommend value on Table 6 (or Table 7 for wavelengths other than 1550 nm).

3)After setting the frequency of the **RF SOURCE** to f_T, fine-tune the frequency around the initial f_T to find the clear 10 G pulse train display on **DCA**. A typical trace is shown on Figure 5. It is normal at this moment that the trace on **DCA** is only clear for a short period of time and then drifts away.

Note: If the laser temperature and RF drive frequency are not matched, one cannot find a stable trace. Note: Figure 5 and Figure 6 used a limited bandwidth (~30GHz) system to characterize the output of the 10 GHz laser. The shape in figure 5 and 6 are distorted due to the bandwidth limitation.

4) Adjust the **Phase Shifter** to **5V~10V.** Set the **PHASE LOCK ON/OFF** switch to **ON** position. The trace on **DCA** should now stop drifting. The **LASER STATUS HV** LED (PZT voltage range) should be on.

(If the trace keeps drifting and **LASER STATUS HV** LED is off, refer to **TROUBLE SHOOT**).

5) To get laser exactly working at f_T, fine-tune(with step not more than 10 kHz) **RF SOURCE** frequency back to f_T. Then fine-tune **PHASE SHIFTER** around their set value to achieve a stable low noise trace on **DCA**. A typical trace is shown in Figure 5b. Sometimes, fine adjustments of PUMP CURRENT and MODULATOR BIAS are helpful to achieve low noise trace in the process.

NOTE: MODULATOR BIAS can drift over a range of several volts, and usually drifts fast at the beginning of laser operation and drifts slowly over time. The range for optimal **MODULATOR BIAS** is about 0.3 volts to 0.5 volts above the null point. See TROUBLE SHOOT section for finding optimal Modulator Bias.

TROUBLE SHOOT

Problem: If during the above stated process, **PHASE LOCK ON/OFF** switch is set to **ON,** but trace fails to stabilize and then **LASER STATUS HV** LED is off.

Answer: Repeat the above process from 1) to 4). If it fails after several tries, it means the initial **MODULATOR BIAS** and/or **PHASE SHIFTER** is too far away from the optimal points. Now the **PHASE LOCK ON/OFF** switch should be set to the **OFF** position. One should find optimal **MODULATOR BIAS** and **PHASE SHIFTER** points, and repeat the above process 1) to 4).

FINDING OPTIMAL MODULATOR BIAS: The optimal **MODULATOR BIAS** point is about 0.5 Volts above the modulator bias null point. The **RF SOURCE** frequency should be fine-tuned to show a clear trace near 10GHz. One can find the modulator bias null point by varying **MODULATOR BIAS** while observing the **DCA** display. When the **DCA** indicates that the laser produces an output pulse train at 20 GHz, **MODULATOR BIAS** is close to the null point. Record this **MODULATOR BIAS** voltage as modulator null point. The optimal **MODULATOR BIAS** voltage is 0.5 volts above the null point.

FINDING OPTIMUM PHASE SHIFTER: At the optimal **PHASE SHIFTER** value, the mixer output DC level is close to 0 volt and the slope of variation is negative. The **RF SOURCE** frequency should be fine-tuned so that the **DCA** shows nearly clear 10 GHz traces. One can observe the mixer output **LP MONITOR** on a 100 MHz scope (1 ms/div, 100mV/div) with DC input. By varying the **PHASE SHIFTER** knob, one can find the optimal **PHASE SHIFTER** value.

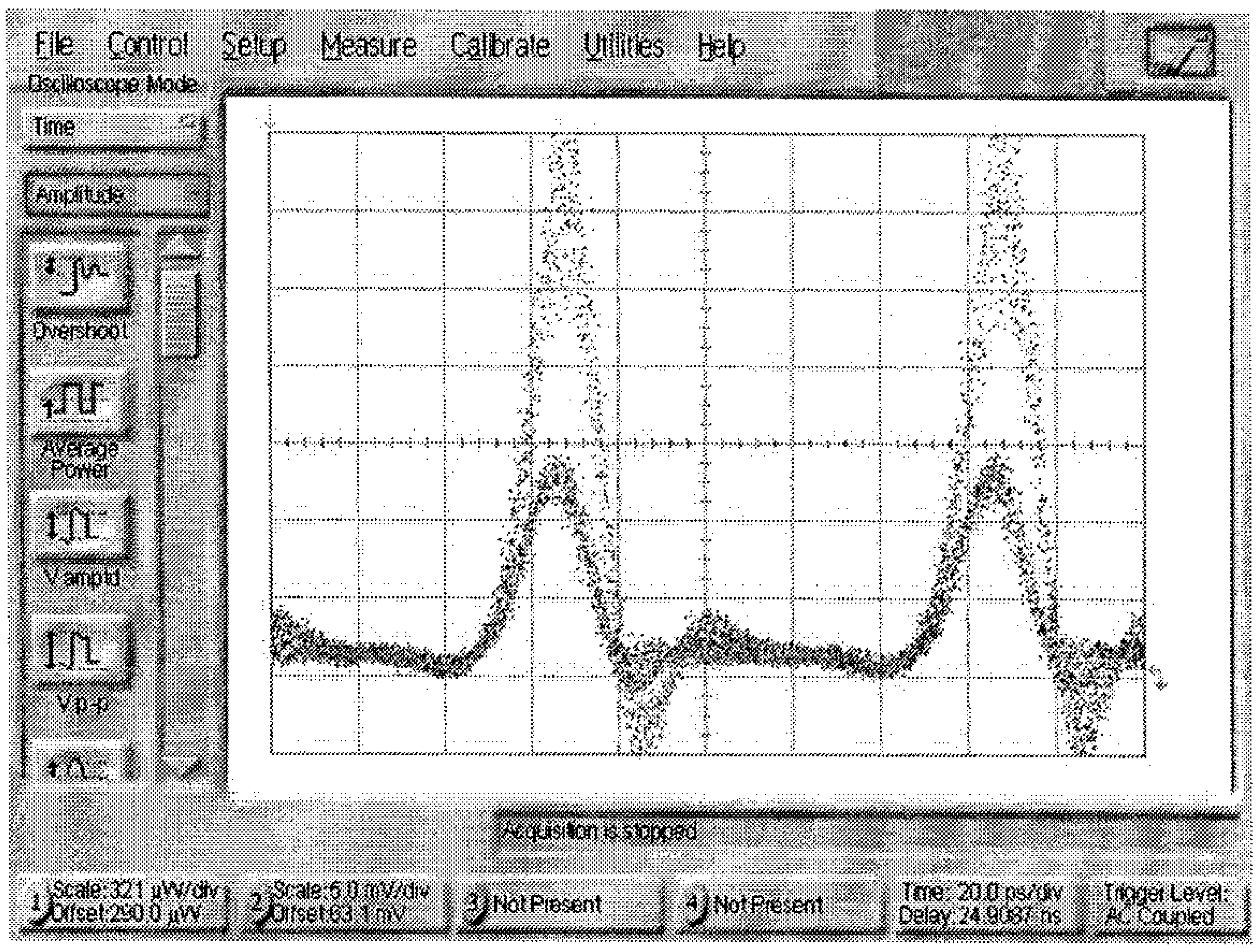


Figure 5 Pulse traces on a DCA scope show the laser is closed to mode-lock condition

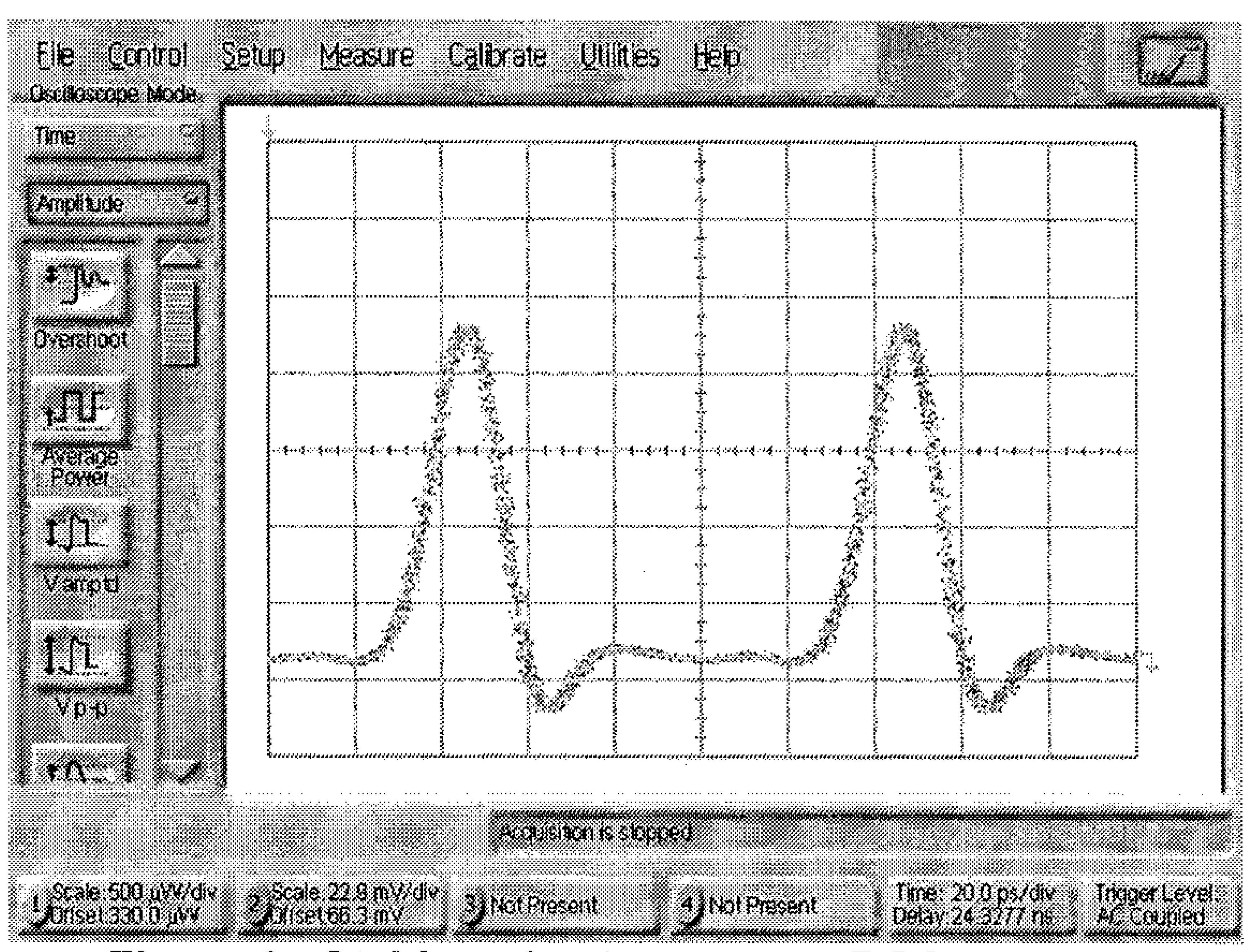


Figure 6 Stable pulse traces on a DCA scope

(Figure 5) the RF SOURCE frequency is close to a stable mode-locked frequency point. The phase lock switch is off; (Figure 6) the laser is phase-locked to the RF SOURCE with phase and bias optimized.

Section 3 – Output Characterization

3.1 – Output Characteristics

The characteristics of the PSL output (serial number S/N 880436) are shown in Table 8. The pulse width of the laser was measured by using a 1-meter PM fiber patch cord connecting the **OPTICAL OUTPUT** to an autocorrelator.

Note: *The pulse width and optical spectrum width can change significantly with different fiber patch cord length due to the dispersion and self phase modulation effects.*

Table 8. Characteristics of the PSL output (RF f = 9.95328 GHz, T = 37.2degrees C)

Wavelength (nm)	1545	1550	1555	1560
Pulse Width (ps)	1.37	1.23	1.18	1.20
Output Power (mW)	34	42	44	45
Pump Current (mA)	510	600	600	600
Phase Shifter (V)	7.36	6.97	6.88	6.70
MOD BIAS (V)	3.70	3.70	3.70	3.70

3.2 – Pulse Width Characterization

The pulse width of the PSL output was measured using an autocorrelator. Figure 7 shows the autocorrelation trace in a linear scale. Figure 8 shows the autocorrelation trace in a log scale. The pulse width is 1.18ps.

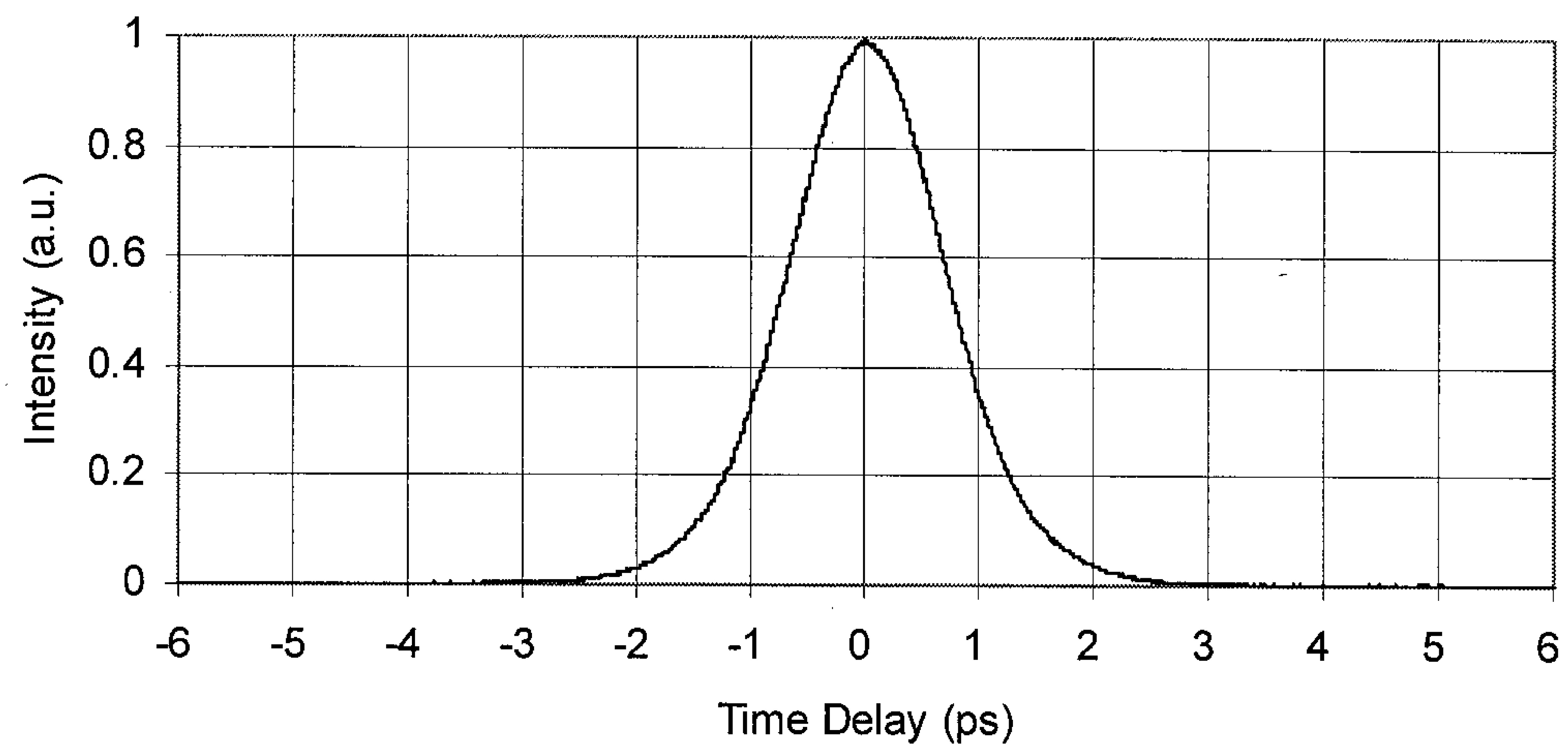


Figure 7. Autocorrelation trace in linear scale

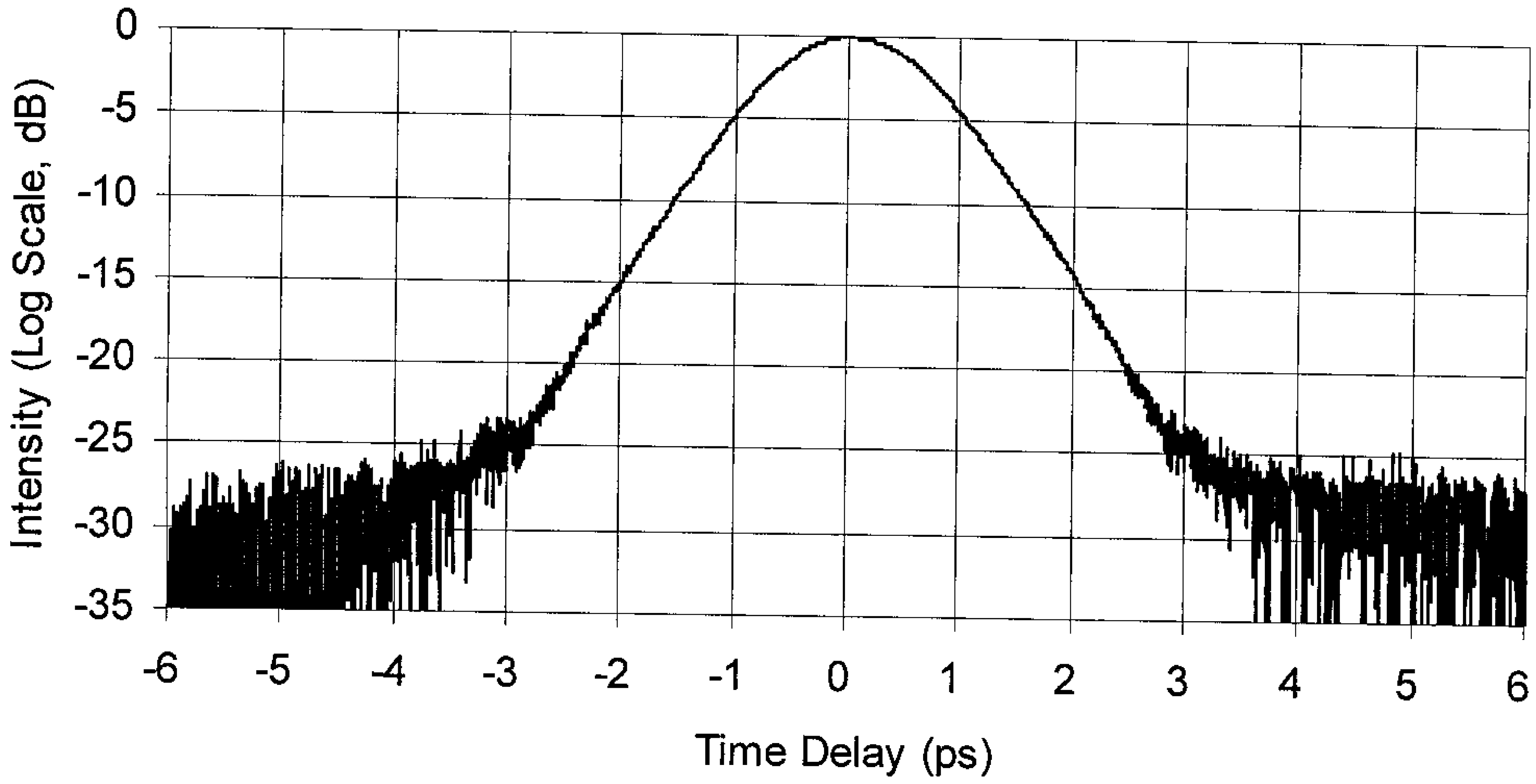


Figure 8. Autocorrelation trace in log scale

3.3 – Optical Spectral Characterization

Figure 9 shows an optical spectrum of the PSL output when stable mode-locking is achieved. The resolution is set at 0.01 nm. When the laser is stable, the 0.08 nm (10 GHz) modulation is clearly visible.

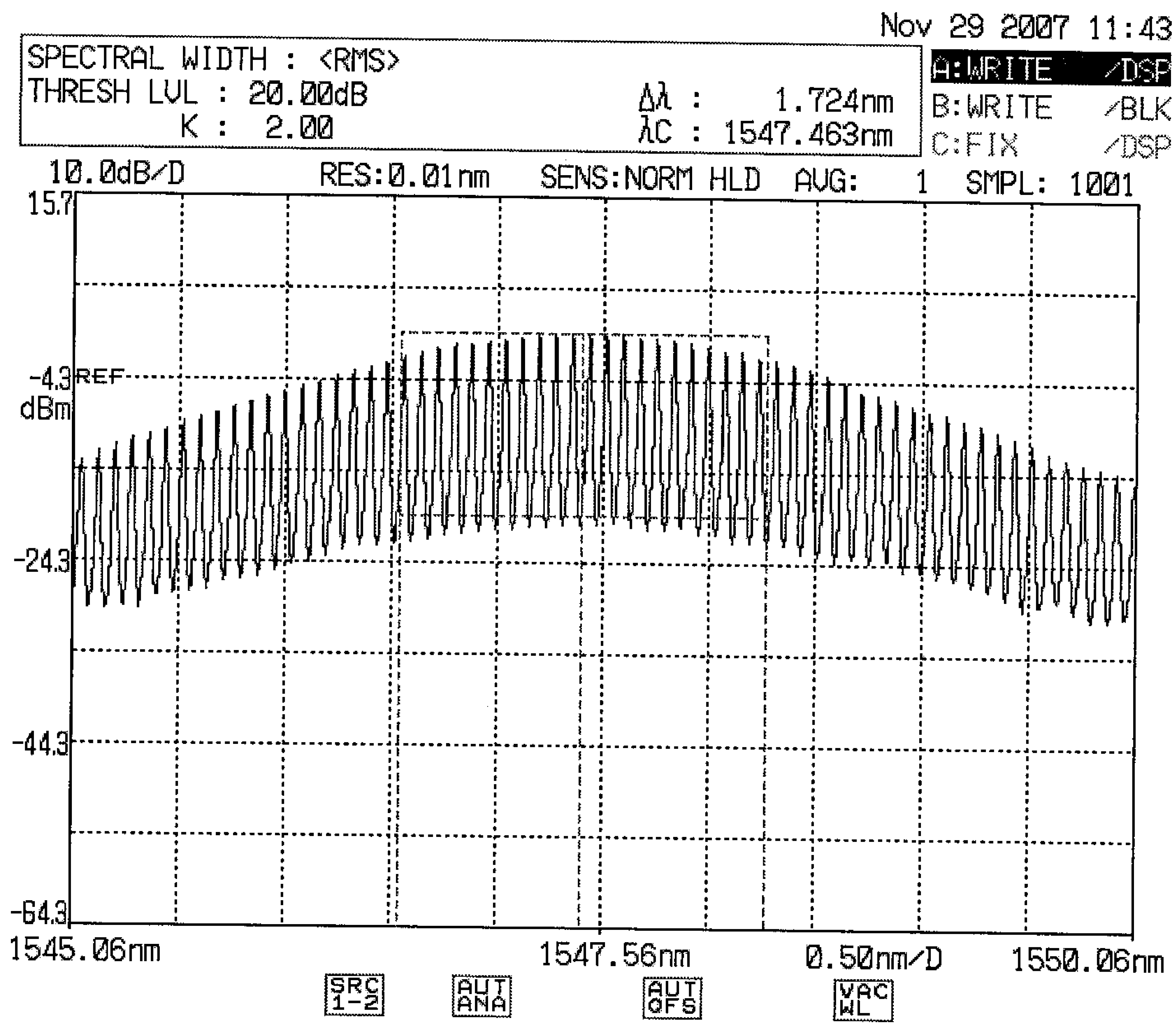


Figure 9. Optical spectrum of a 10 GHz output when the laser is in a stable mode-locking state

3.4 – Pulse Train Characterization

Using the setup as in Figure 4, one can characterize the pulse. Figure 10 shows the output of the 10 GHz pulse trains.

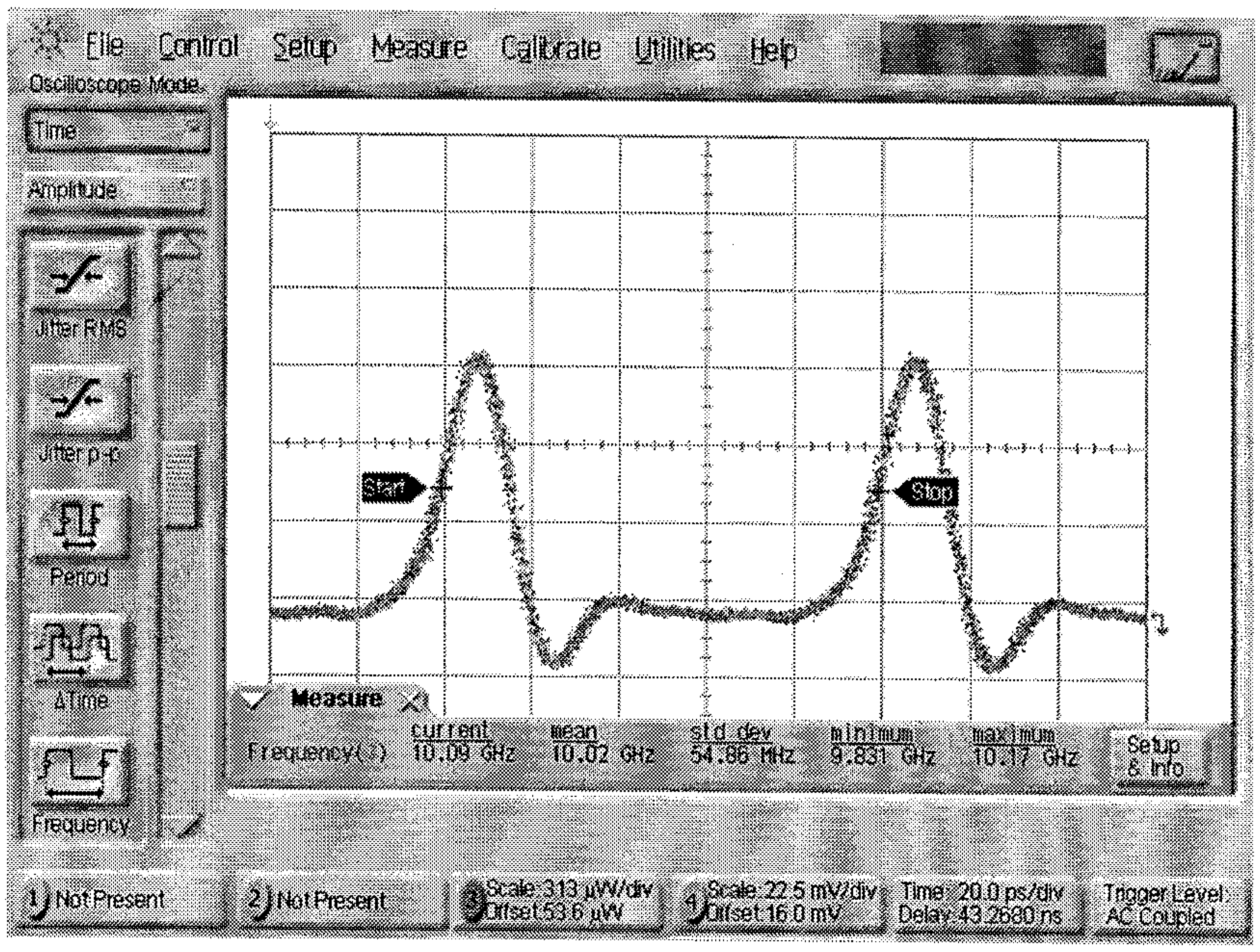


Figure 10. The scope trace of 10 GHz output of the PSL

3.5 – RF Spectrum Characterization

The PSL output is characterized by means of a high-speed photodetector (> 10GHz) followed by an RF spectrum analyzer. The RF spectrum around the modulation frequency (10 GHz) gives a good indication of laser stability. The lower the side mode, the better the stability of the laser. The PSL can achieve a side mode-suppression ratio better than 65 dB.

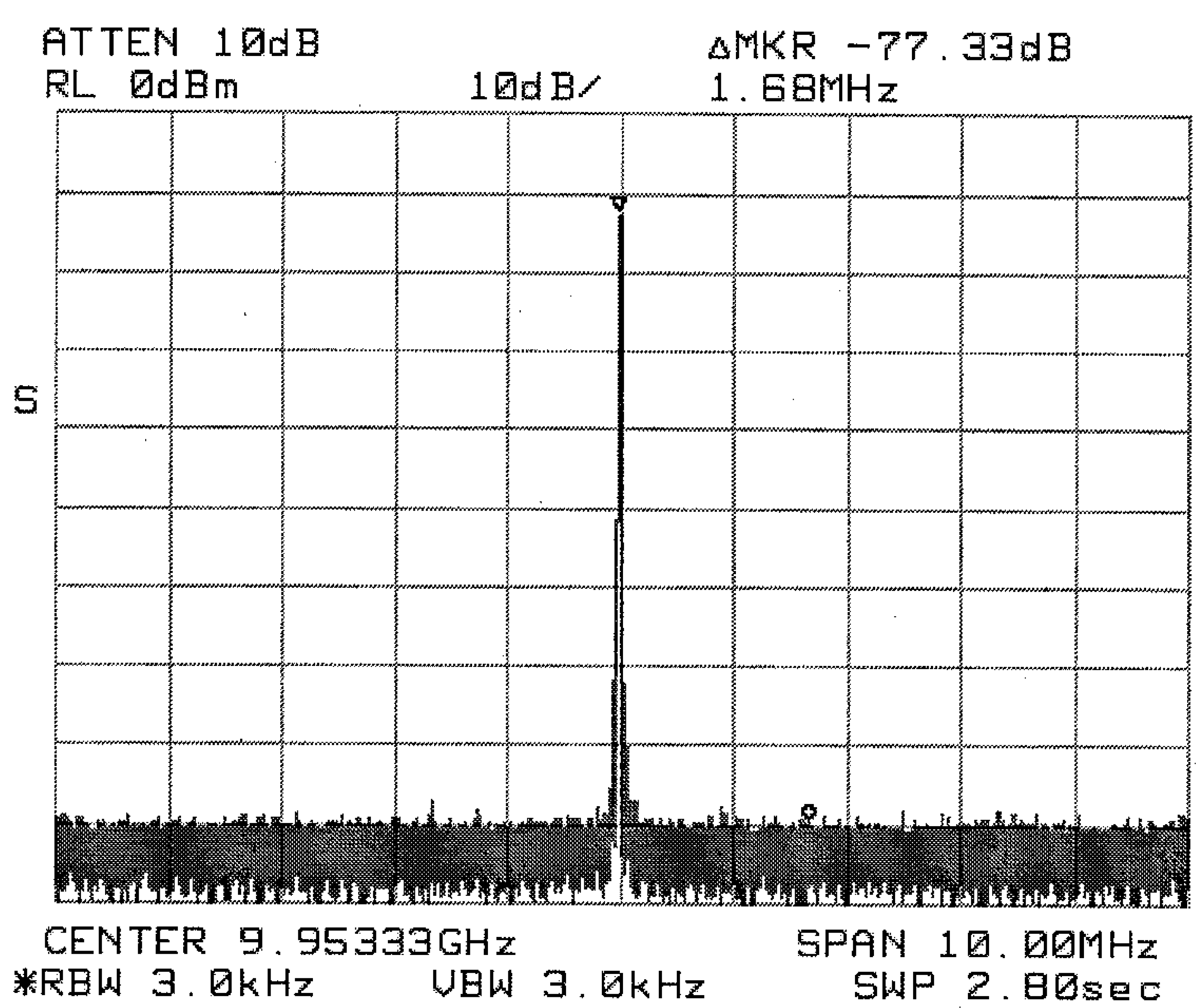


Figure 11. The RF spectrum of 10 GHz output of the PSL