Active synchronisation of 10GHz pulse-generating lasers

Active synchronisation of erbium glass pulse generated lasers (PGLs) to an external clock – using phase-locked loop circuitry – results in very low-phase noise. The passively mode-locked design requires no active electrical drive signal to produce pulses at rates of 10GHz and above. This combination of active clock synchronisation and passive mode-locking makes the erbium glass PGL both a simple and high-performance source.

Figure 1 shows a block diagram of the active synchronisation design. The external clock is injected into the phase locked loop (PLL) and a fast photodiode converts the laser's optical pulses into electronic pulses. The two signals are mixed in the phase comparator and an error signal is created. The loop filter defines the frequency bandwidth of the PLL and is chosen based on the characteristics of the source and the requirements of the application.

An actuator is used to physically lock the PGL by controlling the length of the laser cavity. Repetition frequency is inversely proportional to cavity

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Some of the key challenges in high-speed communications are the minimisation of jitter in data transmission, clock extraction from the data stream, and cost-effective high-speed system development. These demands require low-jitter sources for transmission and clock recovery and precision reference sources for development and testing. The author discusses how erbium glass pulse generating lasers (PGLs) can provide solutions to these problems in cost-effective platforms that migrate both to test instrumentation and network-deployed applications

length and the actuator synchronises the PGL to the external clock based on the error signal. The PGL is the voltage-controlled oscillator in the PLL and the timing jitter of the laser's output pulses is determined by the electronic circuit design, the clock's jitter, and the inherent phase noise in the PGL itself.

The erbium glass PGL requires a 980nm pump diode source to produce high-frequency pulses at the 1.5μm output wavelength. The pump is focused into the erbium glass gain medium, which generates the 1.5μm photons. One of the reflective interfaces in the laser cavity is a saturable absorber mirror which passively mode-locks the laser. This approach requires no external drive signal for mode-locking. This is in contrast to actively mode-locked systems in which cavity losses are externally modulated, thereby increasing the number of parts and complexity.

A mode-locked laser has multiple longitudinal modes running which are phase locked. This results in an operating condition that produces a stable and constant amplitude train of high repetition rate pulses. A saturable absorber is an ultra-fast optical switch that has a reflectivity dependent on
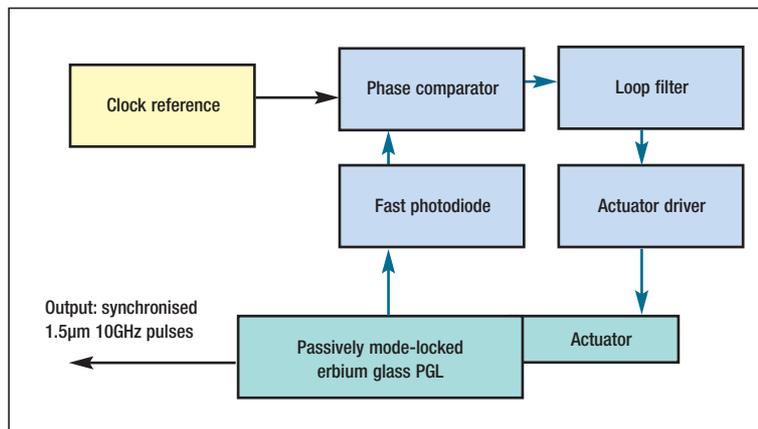
Figure 1. Block diagram of the phase-locked loop circuit for locking the passively mode-locked erbium glass PGL to an external clock reference

incident intensity. This has the effect of accumulating all the lasing photons inside the cavity in a very short time with a very high optical fluence. This unique device is fabricated using standard semiconductor processes. The passive mode-locking approach used in the erbium glass oscillator generates pulses all optically and has inherently low jitter on the order of 100fs.

Jitter in digital communications is the offset between the expected position of a transition to a one or zero and the actual position. This displacement in time has both spectral and power content. The noise that causes jitter is not uniform over all frequencies. Jitter is expressed in the time domain and phase noise is the frequency domain representation, where there is a mathematical relationship between the integrated phase noise and the rms jitter. Frequency limits are used to define the range of spectral power measurements used in the phase noise calculation.

CAUSES AND COMPONENTS

Jitter has numerous causes and components that are both deterministic and random. The SONET standard specs jitter in three modes: jitter generation, jitter transfer, and jitter tolerance. Jitter generation specifies the amount of jitter at the output of a component in the absence of applied input jitter. Jitter transfer is the ratio of the jitter output to input and assumes the transmit clock is derived from the incoming bit stream, which often contains significant jitter components. The jitter transfer spec limits how much of this jitter can be passed to a new or repeated data stream. Jitter tolerance identifies how much jitter an interface must be able to accept while still recovering data within the bit error rate (BER) limits of the link. The SONET standard limits the BER to 1×10^{-12}.

Clock recovery derives the clock from the incoming data signal. This function must accept the incoming jitter tolerance and perform within the jitter generation and transfer requirements. A narrow
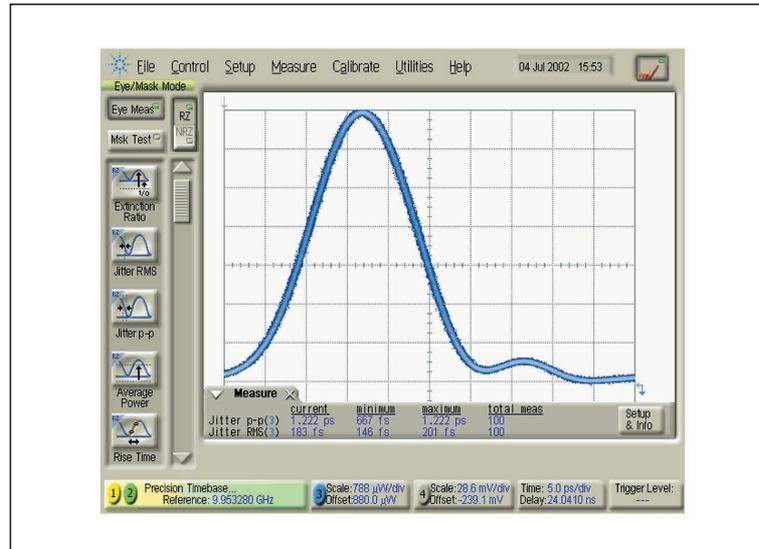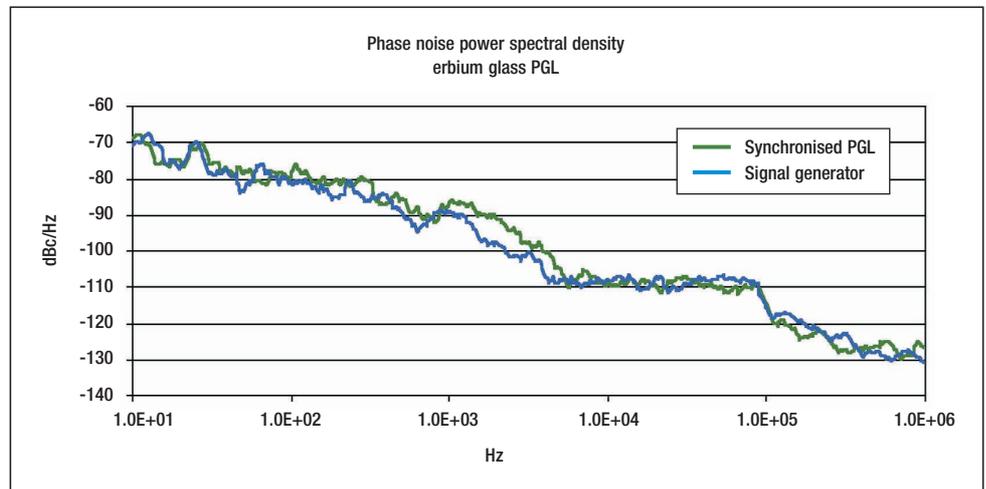

Figure 2.
a) 10GHz erbium glass PGL output pulse measurement showing 183fs rms jitter using the Agilent synthesiser as the reference clock. The instrument time base has a jitter spec of 200fs

b) Phase noise measurements of the erbium glass PGL and the Agilent synthesiser used as the clock

bandwidth PLL is best for implementing this function because it would attenuate most of the jitter that would be transferred through the system. A wide bandwidth PLL would transmit this jitter.

Figure 2 presents measurement results of jitter and phase noise for the erbium glass PGL. The top of the figure shows a screen shot of a timing jitter measurement made with the Agilent 86100A DCA and a 86107A precision time base module. This data shows the timing fluctuations of the PGL output pulses versus one period of the reference clock, which in this case was an Agilent E8251A signal generator. The measurement results in a rms timing jitter of 183fs. The precision time base has a jitter specification of 200fs, so this measurement is limited by the instrument

and indicates that the jitter of the PGL and signal generator are better than what was measured. A phase noise measurement will provide a better picture of the PGL's actual rms jitter.

The bottom of the figure shows a comparison of the measured phase noise between the PGL and the signal generator used as the reference clock. An Agilent E8241A signal generator with the low noise option was used as the clock. Spectral measurements were made using an Agilent 8565EC 50GHz microwave spectrum analyser with a phase noise module. The measurement range was from 10Hz up to 1MHz and the results show clearly that the PGL phase noise is very low and comparable to the phase noise of the signal generator.

Figure 3. Optical clock recovery using an erbium glass PGL in a high data rate optical demultiplexing application
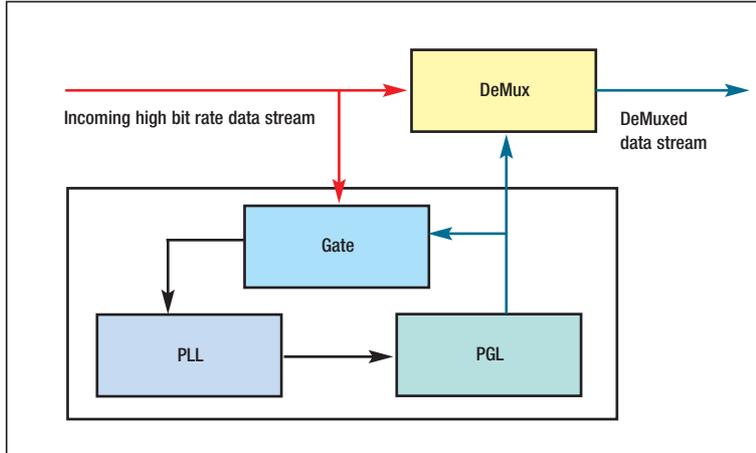
HIGH DATA RATE SYSTEMS REQUIRE THE RECEIVER TO RECOVER A BIT CLOCK FROM THE INCOMING DATA. THE RECOVERED CLOCK IS THEN USED TO RETIME THE RETRANSMITTED DATA

Calculations for rms timing jitter from this data result in about 70fs for PLL loop bandwidths tested from 3.5kHz to 10kHz. The results from the time domain and frequency domain measurements are comparable and differences can be attributed to differences in measurement instruments and techniques.

Phase noise is measured against the reference oscillator in the microwave spectrum analyser. The microwave spectrum analyser uses a reference sine wave to sweep across the frequency range of interest. Power measurements are made at successive intervals in frequency, which are then integrated into a phase noise power spectral density curve.

The resolution bandwidth (RBW) of the microwave spectrum analyser defines how narrow a frequency window is used for the measurement and has the effect of averaging out fluctuations within each measurement window. A 10Hz offset is a practical low-end frequency, but measurements can be made down to the milli-hertz level with special equipment and long measurement periods.

TIMING JITTER

Timing jitter is a more intuitive measurement since it detects actual timing fluctuations. Jitter is typically measured using a sampling oscilloscope where an external clock signal is used as a reference. Each sampled data point is acquired based on the trigger, so trigger instability and instrument noise also contribute to the overall measurement. Wander is a term that describes jitter at low frequencies due to factors such as temperature drift, and is another component to jitter measurements and system performance.

High data rate systems require the receiver to recover a bit clock from the incoming data. The recovered clock is then used to retime the retransmitted data or to perform other critical timing operations. Also, measuring key parameters like BER or the chromatic dispersion power penalty requires a stable phase relationship between the clock and data inputs of the error detector and measurement system. These development and test applications require that the error detector's clock must be recovered from the incoming data signal.

Figure 3 shows a block diagram of one application of optical clock recovery in a high-speed optical demultiplexer. The low timing jitter of the erbium glass PGL allows precision synchronisation of the PGL reference pulses with the incoming optical pulse data stream. The optical demux can be set up to use clock recovery at a sub harmonic of the incoming data stream, for example at a 16:1 ratio to demultiplex a 10Gbit/s bit stream from a 160Gbit/s or at 16:4 ratio to demux a 40Gbit/s bit stream. The demux is an optical gate, which is triggered by the recovered clock using the PGL. Electrical demultiplexing is impractical at high data rates.

Development of high-speed systems also requires precision pulses for laboratory tests, validation of critical test results, and for development of both engineering and manufacturing test capabilities. Having a compact, low-jitter, high-power pulsed source can allow the designer to repeatedly check the validity of set-ups and results with a known reference and allow accurate conclusions to be drawn from the time-consuming and costly testing that is required to develop high-speed systems.

The erbium glass PGL can also be used to evaluate new system capabilities and architectures, such as the example in Figure 3, with a source that has the proper characteristics in terms of pulse width, jitter, power, and repetition rate. Also, this type of PGL can migrate into test equipment and network applications in a straightforward way so designers can have confidence that their results transfer from the lab into the product and the field.

Jitter performance is critical for optimisation of the link design for low cost and high performance. Active synchronisation of the passively mode-locked erbium glass PGL to an external clock results in a very low jitter source which is also cost-effective both in the lab and the field. ●