Pulse-generating lasers drive high-speed applications

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Pulse-generating lasers are becoming practical for network deployment and can provide engineers with cost-effective technical solutions to the challenges of RZ pulse generation at higher data rates. PGLs are also a key part of the development of advanced systems by enabling high-performance test and measurement instruments and laboratory tests.

PULSED-LASER TECHNOLOGY

Pulse-generating lasers appropriate for telecommunications applications are based on modelocking technology and include fiber lasers, semiconductor lasers, and a passively modelocked erbium glass oscillator. A modelocked laser has multiple modes running that are phase locked. This results in an operating condition that produces a stable and constant amplitude train of high-repetition-rate pulses. Modelocking of this sort can be achieved through active modulation of the losses in the laser cavity, or passively with a saturable absorber, which requires no external drive signal.

FIGURE 1. An erbium glass PGL is a passively modelocked laser that incorporates a saturable absorber, high reflector (HR), output coupler (OC), and gain element. The PGL is optically pumped with a 980-nm diode laser (top). A 10-Gbit/s pulse train from an erbium glass PGL with a pulse width of about 3 ps measured with a high-speed oscilloscope (bottom).

A saturable absorber is an ultrafast optical switch that has a reflectivity dependent on 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. There is a bitemporal response in the saturable absorber, which comprises a fast response on the order of femtoseconds and is responsible for pulse shortening and a longer time response-on the order of picoseconds to nanoseconds, which initiates self-starting of the laser.

An example of this approach is shown in Fig. 1. The gain in an erbium glass oscillator PGL is optically pumped by a 980-nm diode laser. The pulsed laser uses a semiconductor saturable absorber mirror fabricated with
fundamental semiconductor techniques. Pulse frequency is inversely proportional to cavity length, which is on the order of 10 to 15 mm for 10 GHz and 2.5 to 4 mm for 40 GHz.

Jitter is a critical requirement for RZ sources and fundamentally comes from perturbations to the laser cavity from mechanical, thermal, vibration, or pumping fluctuations. The passive modelocking approach used in the erbium glass oscillator generates pulses all optically and has inherently low jitter on the order of 70 fs. Measurement of high speed pulses and jitter can be performed through integration of the phase noise, by using precision time bases with high-speed detectors and a sampling oscilloscope, or with recent techniques involving optical sampling (see “PGLs enable optical sampling,” this page).

**RZ SYSTEM DESIGN**

Optical transmission systems are limited by dispersion, attenuation, and cost, all of which drive fundamental requirements. The performance of the pulse source is a primary factor in each case. High-power erbium glass PGLs offer many unique advantages to the system designer.

Compared to non-return-to-zero (NRZ) pulses, RZ pulses have a far greater tolerance to the effects of chromatic dispersion. They maintain practical residual tolerances at much higher launch powers. This key benefit allows low-cost unrepeated transmission over multiple segments of varying dispersion legacy fiber.

Increasing link speeds decreases the sensitivity of the receiver by reducing the power per bit received. Simply boosting transmitted power to compensate results in increased nonlinear effects in the fiber, which degrade performance. RZ pulses have a greater tolerance to these nonlinear effects and thereby reduce the transmission penalty. RZ pulses are also more tolerant to polarization-mode dispersion and give a 1- to 3-dB advantage at 10 GHz, and more at higher rates.

**FIGURE 2. The RZ eye diagram of a 40-GHz erbium glass PGL shows a clean, high performance signal.**

Fiber attenuation results in nominally 3 dB of loss for every 12 km of fiber. High-power RZ pulses like those produced by an erbium glass PGL provide both performance and cost advantages due to their high output power of between 5 and 20 dBm, and contrast ratio of typically >38 dB. Semiconductor modelocked lasers, in contrast, generally have very low powers around 200 µW with weaker contrast ratios and require amplifiers.

Historically, the economics of deploying higher bandwidth systems shows that implementation of new systems begins when four times the transmission speed is achieved at double the cost. Therefore, it is clear that driving down both system and component costs will be critical to widespread implementation.

Increasing bandwidth on a single channel is accomplished by increasing the speed using optical time-domain multiplexing (OTDM) techniques, while wavelength-division multiplexing (WDM) is used to increase bandwidth by adding additional channels. The lowest total bandwidth cost is achieved with the smallest number of the fastest channels practical. High-speed OTDM systems have been limited because of the absence of an appropriate pulsed source for cost-effective RZ applications. These fundamental applications include transmission, demultiplexing, gating, and clocking. Erbium glass PGLs are such a source and will enable high-speed OTMD applications and the move to higher bandwidth systems.

**PERFORMANCE**

RZ pulse specifications have been defined for applications in systems operating at 10- and 40-Gbit/s advanced development, and for test instrumentation (see table). However, in meeting these specifications, the characteristics of different types of PGLs varies.
Semiconductor PGLs are small but have low output power so amplification is required. This degrades performance and is costly. The high pulse power and slew rate in the semiconductor gain region produces nonlinear effects such as chirp, which limit operation and reduce contrast ratio. Timing jitter is typically higher in semiconductor lasers than in other types of PGLs. Broad commercialization of these devices has not occurred because of these limitations.

Fiber lasers produce high output power, have large footprints, typically use active modelocking, consume significant power, and are expensive. They do offer broad wavelength tunability and other adjustments. These harmonically modelocked lasers also result in occasional pulse dropouts. For these reasons their use has been confined largely to research labs.

Erbium glass PGLs can enable new levels of RZ transmission system performance, which can be quantified using the Q factor. The Q factor is a measure of the quality of an eye diagram and is given by the signal difference between the one and zero levels divided by the sum of the r.m.s. noise levels (see Fig. 2). This directly relates to the bit-error rate (BER) when assuming reasonable statistics and white Gaussian noise. A $Q$ of 6...
corresponds to a BER of 10e-9 given these assumptions. Q values of greater than 8 or 9 correspond to BERs greater than 10e-12, which is at the practical limits of normal measurements. Systems tests using an ERGO PGL resulted in Q values of >9 for link spans of 120 km (see Fig. 3). The plot of log(BER) vs. received power is a typical way to determine if error-free transmission can be reached.

OTHER APPLICATIONS

Demultiplexing and data add/drop at rates higher than 40 Gbit/s requires a pulse-generating laser in the receiver or add/drop site to pick-off individual data pulses. Recent tests with an erbium glass PGL have demonstrated OTDM demuxing from 160 Gbit/s down to 10 Gbit/s. The PGL is used to clock the phase of the semiconductor optical amplifiers (SOA), which requires a very fast control edge, a short pulse, and low jitter (see Fig. 4).

Other important all-optical signal-processing applications that require simple, high-power RZ pulses include clock recovery, all-optical 3R and 2R, high-speed optical clocking, and all-optical switching. A compact, network-deployable PGL will be a key building block in these and other applications and will continue to drive the shift to high-speed RZ and OTDM systems.

In addition to system applications, PGL sources for laboratory instruments are needed. Test and measurement equipment leads network specifications technically and faster data rate performance will drive next-generation test and measurement instruments.

There are numerous time-domain applications of PGLs in test equipment. Stimulus and impulse response tests use the PGL as a reference pulse for performance validation and system characterization such as dispersion testing. Phase-locking the PGL to an incoming signal for optical clock recovery solves a critical need in digital communications analyzers at high data rates. Maturing RZ systems entering manufacturing will drive new instruments for compliance testing using PGLs as a source to achieve low-cost error-rate testing.

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Optical sampling oscilloscope measures fast laser pulses

Conventional electrical sampling oscilloscopes lack adequate bandwidth to accurately characterize 40-Gbit/s systems now being designed. Recent advances in optical sampling technology have enabled a fundamental leap in sampling bandwidth to attain over 500 GHz of optical bandwidth. This allows testing of high-speed RZ signals (typically 25-ps bit periods with 6- to 8-ps rise times) that provides clarity and enhances development. For example, viewing two distinct laser pulses that are separated in time by only 6 ps is straightforward.

A successful configuration for accomplishing this challenging measurement task is the free-space optical microbench (see figure). This architecture employs a nonlinear optical technique called sum frequency generation (SFG). The optical signal under test is connected to the test instrumentation via polarization-maintaining fiber (PMF). This signal is then mixed with a very short fiber-ring laser pulse (100 fs FWHM) by utilizing a dichroic beamsplitting optic.

The 100-fs laser pulse is frequency doubled to obtain a 780-nm wavelength for ease of spectrally isolating the sampling laser from the laser under test. This mixed optical beam contains both 780-nm photons and 1550-nm photons. These two different wavelength photons are both incident on a periodically poled lithium niobate (PPLN) nonlinear crystal, which is used to convert the two higher wavelength photons to a third wavelength. The third wavelength is then detected by a high-gain avalanche photodiode (APD).
An optical sampling oscilloscope incorporating a nonlinear crystal can achieve 500 GHz of optical bandwidth (left) as illustrated on an optical sampler displaying 160-GHz multiplexed PGL pulses (right). This optical sampling method is most beneficial when trying to resolve very narrow, temporally adjacent optical pulses—a common measurement need when designing 40-Gbit/s transmission systems that will transmit consecutive RZ pulses. A more challenging measurement is trying to resolve 160-Gbit/s RZ pulses (6-ps bit periods with 1- to 2-ps rise times), but this configuration can also handle the task (see www.agilent.com/comms/ost for further information).