This finding would be analogous to the central limit theorem in probability theory. Such research would uncover new techniques for reducing noise in electronic devices.

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References

3 Arnold, N. J.: 'Simulation of noisy, real-time thermal images', PhD dissertation, University of California, Santa Barbara, October, 1990

RAMAN AMPLIFICATION OF GAIN SWITCHED LASER DIODE SIGNAL AT 1.35 μm TO SOLITON POWER LEVELS

Indexing terms: Semiconductor lasers, Lasers, Diodes

Raman amplification to soliton powers of picosecond pulses from a distributed feedback laser diode signal emitting at 1.35 μm, with a maximum gain of approximately 30 dB is reported. The pump laser was a CW ML Nd: YAG laser operating at 132 μm.

Introduction: The generation and amplification of solitons in singlemode optical fibres has been investigated extensively, specifically for their potential in optical communication systems. Laser diodes provide the most promising source of Raman amplification to soliton powers of picosecond pulses from a distributed feedback laser diode signal emitting at 1.35 μm, with a maximum gain of approximately 30 dB is reported. The pump laser was a CW ML Nd: YAG laser operating at 132 μm.

Experimental: Fig. 1 shows the experimental setup for the amplification of the laser diode pulses. The pump laser was a CW ML Nd: YAG laser with a pulse repetition rate of 100 MHz. Typical pulse durations were 90 ps with a maximum peak power of ~200 W. The signal laser was gain switched at 100 MHz to coincide with the pump. An optical delay was used at the output of the signal to ensure optimum synchronisation between the pump and signal. Because the pulses coming from the gain switched DBR were chirped, a Fabry-Perot (FP) was put at the output of this signal to restrict the bandwidth and shorten the pulses. The signal was then launched through a Faraday isolator (FI) and into the optical fibre. A half-wave plate was used in the signal path to ensure its input polarisation would coincide with that of the pump. A copropagating geometry was used with the pump radiation coupled into the fibre via the same lens system as the signal. The fibre was 2 km long, singlemode at 1.32 μm, with a core diameter of 8 μm and with a minimum dispersion at 1.34 μm. This ensured that the signal radiation was in the anomalous dispersion region while keeping the pump radiation in the normal dispersion region, allowing maximum overlap of pump and signal. The value of the dispersion at 1.35 μm was approximately 3 ps/km nm. A polarisation controller (PC) was used at the input of the fibre to optimise overlap of the polarisations between signal and pump. The output from the fibre was directed to a spectrophotograph and autocorrelator. A Hamamatsu scanning oscilloscope was used to measure the input pulses. Power measurements to determine the gain were taken from the output of a monochromator where the average power at the signal wavelength was taken for various pump powers.

Results: The input signal pulses measured about 40 ps on the sampling oscilloscope. After amplification, the signal pulses had high enough intensity to be autocorrelated. Fig. 2 shows a typical autocorrelation of the amplified pulse. This had a duration of ~20 ps and was achieved with 440 mW average power of pump radiation (~44 W peak power), and 10 μW of signal radiation, ~5 mW peak power. The fundamental soliton power for a 20 ps pulse in an optical fibre with the parameters used in this experiment is ~7.5 mW peak power, so a gain of only 2 dB is necessary to reach soliton power levels assuming unchirped input pulses. The corresponding soliton length is 69 km.

Fig. 1 Schematic diagram of experimental arrangement

Fig. 2 Background free autocorrelation of amplified pulse from DBR laser

Although gains substantially greater than 2 dB were achieved in this experiment, spectral measurements revealed time-bandwidth products of up to 9.2, indicating the amplified pulses were highly chirped. This is not particularly surprising because in addition to the signal pulse having a residual chirp, the Raman gain process will also produce a chirp on the pulse due to velocity mismatch between the pump and signal radiation. Therefore, although the amplified pulses have powers in excess of the fundamental soliton power, the gain was experienced over an amplification length much less than the soliton period. Compression and the evolution of 'true' solitons would only be possible through relaunch in an additional fibre.
Fig. 3 shows the relationship between the gain and the pump power. The logarithm of the gain is approximately proportional to the pump power at the lower powers, as expected from a Raman gain process. At the higher powers this starts to approach saturation. The Raman gain coefficient can be calculated from the slope of the linear part of the graph. This gave a value of $0.19 \times 10^{-13}$ m/W which is somewhat lower than the theoretically calculated value of $0.37 \times 10^{-13}$ m/W. The major contribution to the discrepancy is most probably due to a reduced interaction length in the fibre due to phase mismatch between the pump and signal.

Fig. 3 Variation of gain as function of average pump power

Conclusion: We have demonstrated amplification of a DFB laser diode pumped by stimulated Raman scattering in a single-mode optical fibre at 1.35 µm. Gains as high as 28 dB were achieved at a repetition rate of 100 MHz using a CW ML Nd:YAG as the pump. Because gains of only 2 dB are required to produce soliton powers, the moderate pump powers necessary could be achieved using the more compact YAG laser systems.

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References

CHAOTIC BEHAVIOUR IN CURRENT-MODE CONTROLLED DC-DC CONVERTOR

Indexing terms: Convertors, Stability, Chaos

An approximate mapping is derived for a current-mode controlled buck converter, leading to a stability criterion. Conditions are derived under which chaos can occur, e.g. if $\Delta I_{R} < \Delta I_{S}$ for longer than a single clock cycle.

Introduction: It is well known that many current-mode controlled DC–DC convertors are prone to instability, often the usual criterion being that the switch duty factor exceeds 50%. It is shown, in a particular case, that what has up to now been referred to as instability is in fact chaos.

Current-mode controlled buck converter: Consider the circuit of Fig. 1 and the waveforms of Fig. 2. The circuit is employed to convert an input voltage $V_{i}$ into an output voltage $v = V_{ref}$. Switch $S$ is controlled by an R-S latch that is set by clock pulses of period $T$ with the latch set, $S$ is closed. The current $i$ in $L$ is converted by transresistance $R_{e}$ (a current-sensing amplifier) into a sawtooth voltage $\theta(t)R_{e}$. The error signal $v_{e}(t) = V_{ref} - v$ is amplified with gain $A$. A comparator produces a pulse if $\theta(t) > \Delta I_{S}$, resetting the latch and opening $S$. (Reset dominates over set.) In the periodic state all waveforms have period $T$, but under certain conditions subharmonics and chaos can occur, e.g. if $\Delta I_{R} < \Delta I_{S}$ for longer than a single clock cycle.

In the following analysis, operation of the buck converter is confined to the continuous conduction mode, i.e. $i > 0$ at all times.

Mapping: A mapping $F$ describes the behaviour of the inductor current by relating the current $i_{n+1}$ as $S$ closes to the current $i_{n}$ at the previous closing of $S$; i.e. $i_{n+1} = F(i_{n})$, $n = 0, 1, 2, \ldots$

The mapping is now derived with the following assumptions:

1. Capacitor $C$ is large enough that the ripple in the load voltage $v$ can be neglected ($RC \gg T$)

Fig. 1 Circuit diagram of current-mode controlled buck convertor

Fig. 2 Waveforms appearing in circuit of Fig. 1

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