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Transmission and modulation of 30-40 GHz pulses generated by a diode-driven, low-jitter, beat-signal to soliton train conversion source.

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Abstract

We report on the performance of a low timing-jitter, diode-driven, Nd:YLF pumped 5ps, 30-40 GHz soliton source based on beat signal conversion in a dispersion decreasing fibre. We demonstrate for the first time data encoding at 40 Gbit/s and transmission of the pulse trains over 205 km.

There has been considerable recent interest in the development of optical techniques for the generation of high frequency soliton trains based on nonlinear beat signal to soliton train conversion in dispersion profiled fibre circuits (see e.g. Refs.[1-4]). The techniques offer advantages of ultra-high repetition rates, high pulse quality, and broad wavelength and repetition rate tunability. However, although impressive source demonstrations have been made, their practical applications to date has been limited due primarily to issues relating to timing jitter [3,4], Stimulated Brillouin Scattering [2,3] and difficulties in applying the techniques to repetition rate ranges <40 GHz [1] to allow compatibility with state of the art, high data rate, electronics for data encoding. In this letter we report on the development and performance of a diode-driven, ultra-low jitter, 30-40 GHz soliton source with potential for telecommunication applications. In addition, we report the results of pulse propagation measurements of 35 GHz repetition rate, 5ps pulses over a 205 km dispersion shifted fibre (DSF) transmission line [5,9]. The experiments show that pulse trains from such sources can be transmitted with low distortion over terrestrial distances and can be controlled and detected electronically. Finally we demonstrate for the first time that pulse trains from such sources can be modulated using an all-optical modulator and a synchronised optical data stream.

The source configuration (Fig.1.) consists of three principle components: an optical beat-signal source, an Er^{3+}/Yb^{3+} optical power amplifier and a dispersion varying fibre section. In order to obtain a low timing jitter beat signal the output of a 1557 nm cw DFB laser was externally modulated using a 20 GHz amplitude modulator tuned to a transmission null and driven at 17.5 GHz to obtain 35 GHz sinusoidal modulation. The output from the beat signal source as measured on a scanning Fabry-Perot interferometer (1 GHz resolution) is shown in Fig.2. Two equal amplitude frequency components separated by 35 GHz are obtained with almost no component at the carrier wavelength. The dispersion decreasing fibre section consisted of 2 km of DSF to spectrally enrich the input beat signal [2], and an 8 km Dispersion Decreasing Fibre (DDF). The DDF dispersion followed a hyperbolic profile at 1550 nm tapering along the 8 km length from 13.75 to 2.75 ps/(nm.km). The profile and output dispersion were chosen so as to reduce the absolute physical length of fibre required to obtain high quality, adiabatic 40 GHz pulse generation at a mark to space ratio suitable for soliton transmission of 5:1, whilst maintaining a practical optical power requirement on the input beat signal (80 mW).

The source was tested under a wide range of input powers and beat frequencies in the range 32-40 GHz. Transform-limited, soliton pulses of durations 4.5-6.5 ps were obtained for input beat signal powers <20 dBm within the wavelength range of the available diodes 1547-1563nm. A typical autocorrelation function (ACF) and spectrum of a 35 GHz pulse train at the source output are shown in Fig.3a.

Pulse propagation experiments using the source (Tuned to 35 GHz) were performed over a transmission line incorporating four ~50 km spans of dispersion shifted fibre and 3 EDFAs [5]. At 1557 nm the dispersion in the first and last two spans was D=0.07 ps/(nm.km) and D=0.21 ps/(nm.km) respectively. Consequently the ratio of soliton period to amplifier spacing was 3 over the first two DSF sections and 1 in the final two DSF spans. We therefore anticipate a strong departure from average soliton dynamics in the second half of the link resulting in the generation of significant dispersive wave radiation [6,7]. As expected the pulses were found to propagate with negligible distortion either temporally, or spectrally, over the first 100 km (see Figs.3b). Marked changes were observed during propagation in the final two higher dispersion spans (Figs. 3c). In the time domain the pulses are found to propagate with reasonable stability, with little distortion other than a slight temporal narrowing and the appearance of a low-level, flat background (<5%) on the ACF at 205 km. However a modulation of the train spectral envelope is observed due to the constructive interference of dispersive wave radiation shed from the pulses within the final two DSF spans [7]. The depth and position of the spectral modulation and the appearance of the low-level ACF background component at 205 km is in good agreement with our numerical simulations of the system.

Since the source was derived from a synthesised frequency generator, the excellent frequency stability (< 0.5 ps rms jitter) allowed temporal measurement of a beat frequency generated pulse stream to be carried out for the first time [9]. Furthermore, using a 40 GHz clock recovery circuit we have recently been able to synchronise an independently generated 40 Gbit/s optical data stream [5] (comprising 6ps switching pulses derived from a 1545 nm gain switched DFB) with a 40 GHz soliton train. The two signals were passed into an all-optical modulator based on nonlinear polarisation switching in an optical fibre [10] to encode the 1557 nm, 40 GHz continuous wave soliton stream with the data carried by the 1545 nm data stream. A typical modulated pulse stream is shown in Fig.4. The switched pulses (3-

4ps) were found to be slightly narrower than the input pulses (5-6 ps) and a switching contrast ratio of >19 dB was obtained. These results constitute the first demonstration of the modulation of the output of a beat signal soliton source. A full characterisation of the modulator operation will be reported at the conference.

In conclusion, we have demonstrated a practical low-timing jitter, diode-driven, soliton source capable of operating in the range 30-40 GHz. In addition, we have performed long distance, multi-amplifier stage pulse transmission experiments using a beat-signal source, and demonstrated high quality, transmission of 35 GHz, 5.2 ps pulses trains over a total distance of 205 km. Good pulse propagation characteristics were obtained despite the large amplifier spacing of 50 km and a strong violation of average soliton dynamics in the later half of the link. Transmission over considerably greater distances can be expected from an optimised system, with reduced dispersion variation and/or amplifier spacing. In addition, we have demonstrated for the first time 40 GBit/s data encoding of the output of a beat signal soliton source. This transmitter should enable a true appraisal of the suitability of such beat signal to soliton train conversion sources for future high frequency telecommunication applications to be made, and the use of all optical modulation demonstrates the suitability of such sources to higher capacity systems.

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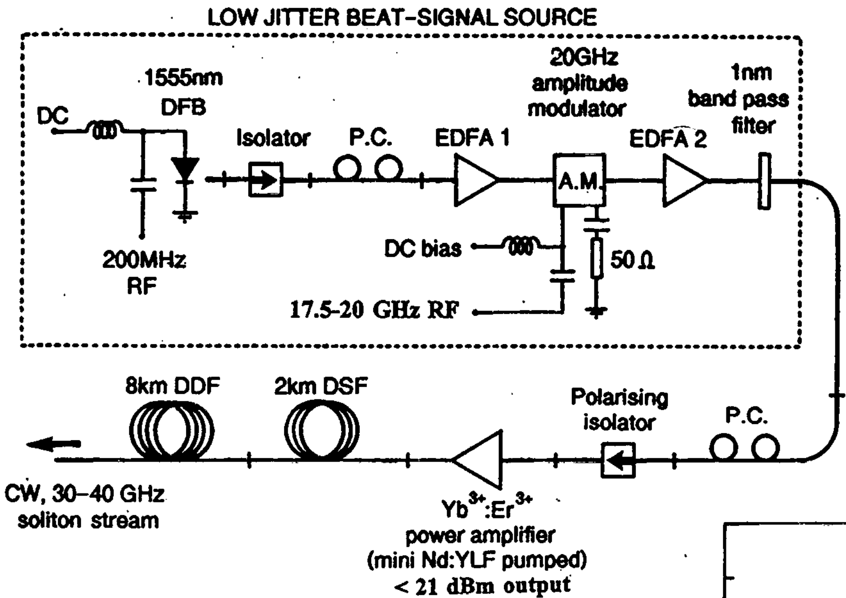

Fig1 Source configuration

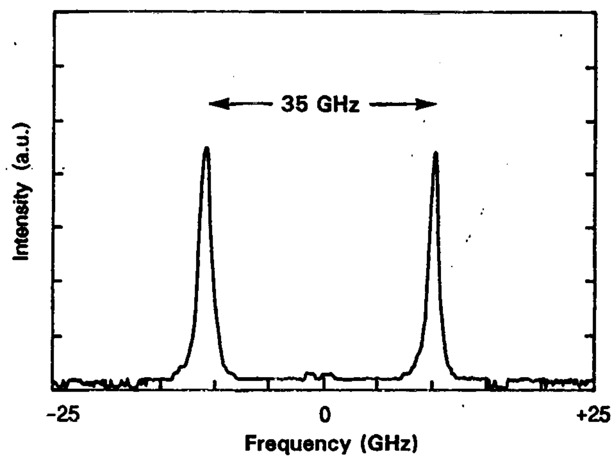

Fig2 Low, jitter input seed signal spectrum as generated by the amplitude modulator based, beat-signal seed source.

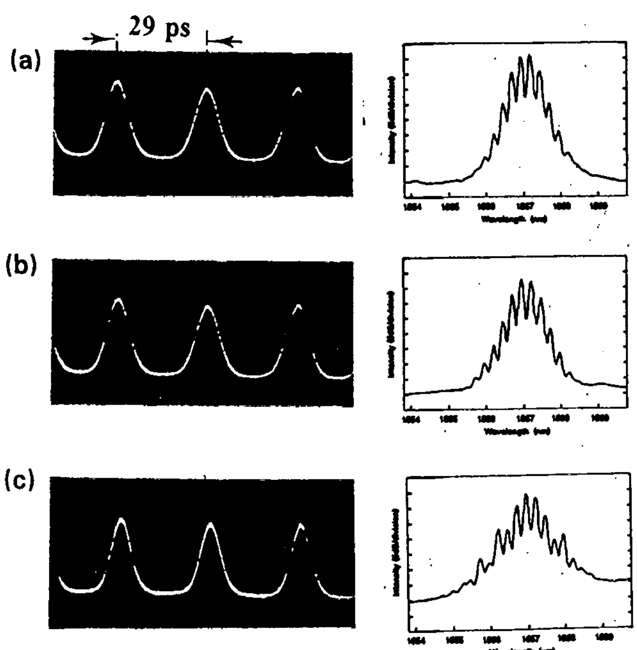

Fig3 Autocorrelation and optical spectrum of 35 GHz pulse trains (a) at system input, (b) after 100 km, (c) after 200 km.

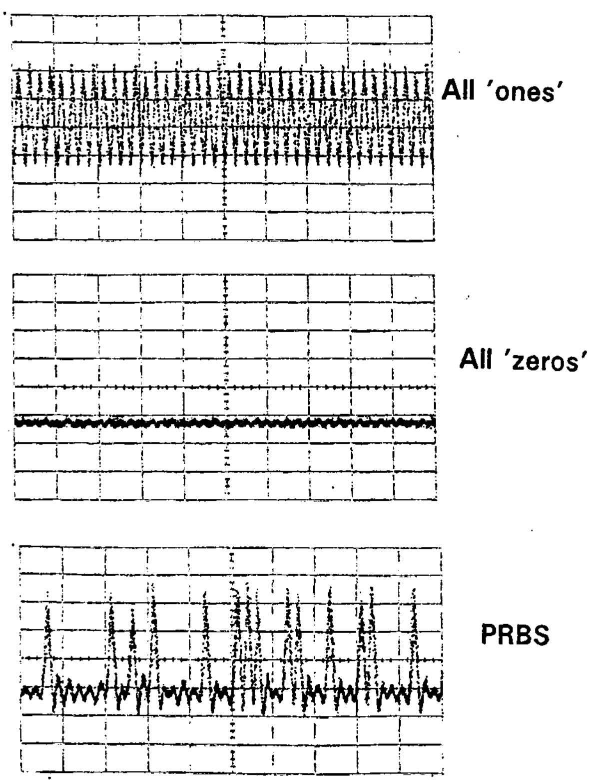

Fig4 40 Gbit/s modulated soliton stream at optical modulator output as measured on a 32 GHz detector/sampling scope system.