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773

# Synchronous, ultrahigh repetition-rate bright/dark pulse train generation using nonlinear beat-signal conversion techniques

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## Abstract

We describe a simple, all-fiber, synchronous source of 110 GHz, 800fs bright solitons and 2.4ps dark pulses based on nonlinear beat-signal transformation techniques. Dark train modulation depths in excess of 80% are confirmed by cross-correlation of the two ouputs.

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The generation and propagation of bright and dark soliton pulses is an area of great scientific interest with relevance to many futuristic telecommunication and optical-processing applications. Bright solitons have been the subject of intense experimental investigation; however, the experimental study of dark pulse behaviour has been limited. This situation is in no small part due to the difficulty of generating and measuring such pulse forms (See e.g. Ref[1] and references within).

In this work we describe a simple, all-fiber, synchronous source of both bright and dark pulses at 110 GHz based on nonlinear beat-signal transformation techniques. The bright and dark trains are formed by simultaneous parallel nonlinear propagation of a high-intensity beat-signal in separate sections of dispersion-decreasing fibre (DDF) [1] and low positive GVD dispersion-shifted fibre (DSF) [2] respectively. The principle motivation behind developing such synchronous sources is that cross-correlation measurements between the dark/bright trains can easily be made, enabling detailed studies of high-frequency dark pulse behaviour to be performed.

The experimental configuration is illustrated in Fig.1. Two single frequency DFB lasers operating around 1551 nm were combined using a 50:50 coupler. The resulting beat-signal (tuned to 110 GHz) was then passed through a two stage 1064nm pumped $Er^{3+}/Yb^{3+}$-doped fibre amplifier. Upto 350 mW of average signal power was available at the amplifier output. The signal was then split via a coupler, 50% into the DDF (channel #1) for bright soliton generation and 50% into the +GVD fibre (channel #2) for dark-pulse formation. Independent variation of the intensity in each channel could be effected by controlled bending of the fibre at the separate channel inputs.

Channel #1 consisted of 1100 m of low -GVD DSF (D=0.5 ps/nm/km) followed by 1250m of dispersion-decreasing fibre (DDF) with dispersion varying between 7 ps/nm/km at the fibre input to ≈0.5 ps/nm/km at the output. A typical autocorrelation trace and optical spectra for the 110 GHz train of 800 fs pulses is shown in Fig.2a. The time-bandwidth product of the pulses was estimated to lie between 0.34-0.4 depending on the pump power and was thus close to that expected for transform-limited $sech^2$ pulses.

Channel #2 consisted of 2350m of -0.5 ps/nm/km (positively dispersive)

DSF. An autocorrelation trace and spectrum of a dark pulse train is shown in Fig.2b and clearly demonstrates the periodicity of the pulses (110 GHz). It is impossible however to make any further comments as to the temporal pulse quality from the autocorrelation alone due to the large background level between dark pulses.

The synchronous generation of both bright and dark pulses however permits cross-correlation measurements to be made. The well-defined ultrashort bright solitons (Fig.2a) can thus be used to probe the dark train (Fig.2b). The results are shown in Fig.3 where it is seen that a cross-correlation modulation depth of >80% is observed. The dark pulses are seen to have a width of approximately 2.4 ps (assuming a sech$^2$ form). At higher pump powers more complex pulse evolution was observed. Note that this particular dark pulse train is unstable and would decay on further propagation, as observed in Ref[3]. The use of alternative nonlinear beat-signal conversion techniques such as propagation in + GVD DDF should result in the generation of stable, dark soliton pulses.

The measurements presented illustrate the great potential of this simple, synchronous, dual-output source for the generation and study of high-frequency dark pulse propagation and interaction.

**References**

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2. S.V. Chernikov, D.J. Richardson, R.I. Laming, D.N. Payne, E.Dianov: Electron. Lett 28, p1210-1212 (1992).

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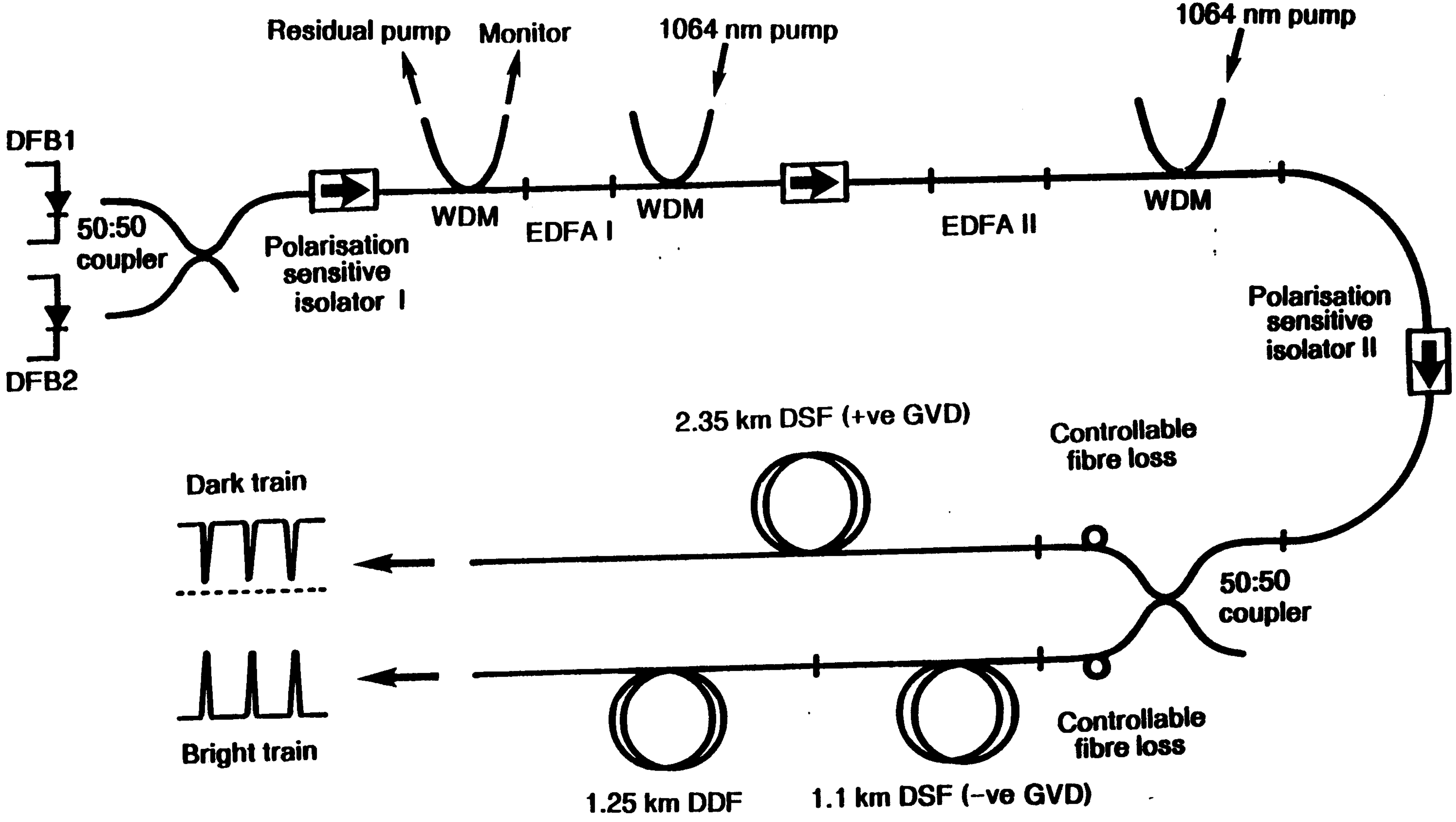
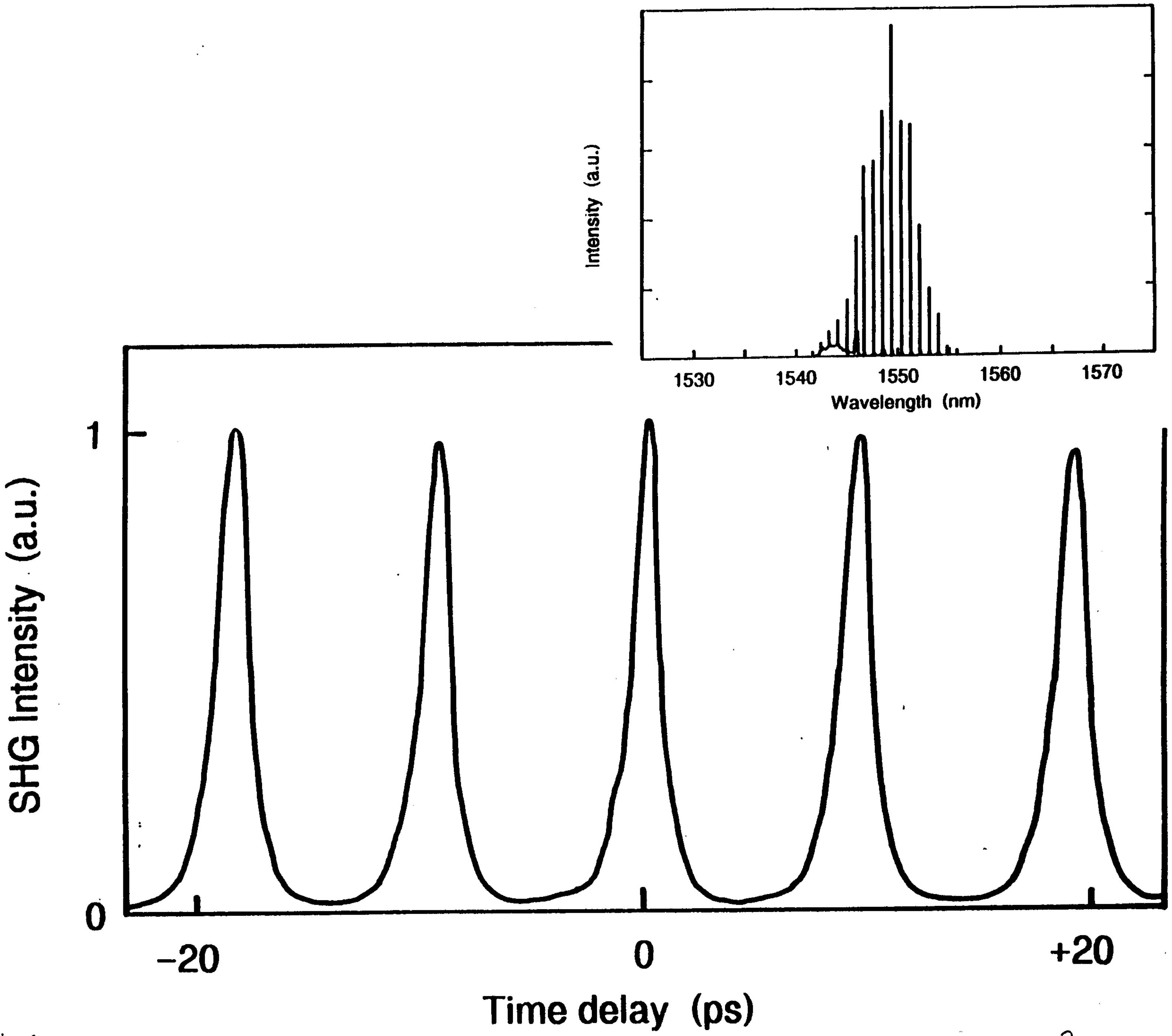
Fig.1 Experimental configuration.

Fig.2a Autocorrelation trace and optical spectrum of 110 GHz, 800 fs bright soliton train.

Fig.2b Autocorrelation and spectrum of 110 GHz dark pulse train.

Fig.3 Cross-correlation of dark-bright pulse trains of Figs.2a&b.


Residual pump
Monitor
1064 nm pump
1064 nm pump
DFB1
DFB2
50:50 coupler
Polarisation sensitive isolator I
WDM
EDFA I
WDM
EDFA II
WDM
Polarisation sensitive isolator II
2.35 km DSF (+ve GVD)
Controllable fibre loss
Dark train
50:50 coupler
Bright train
Controllable fibre loss
1.25 km DDF
1.1 km DSF (–ve GVD)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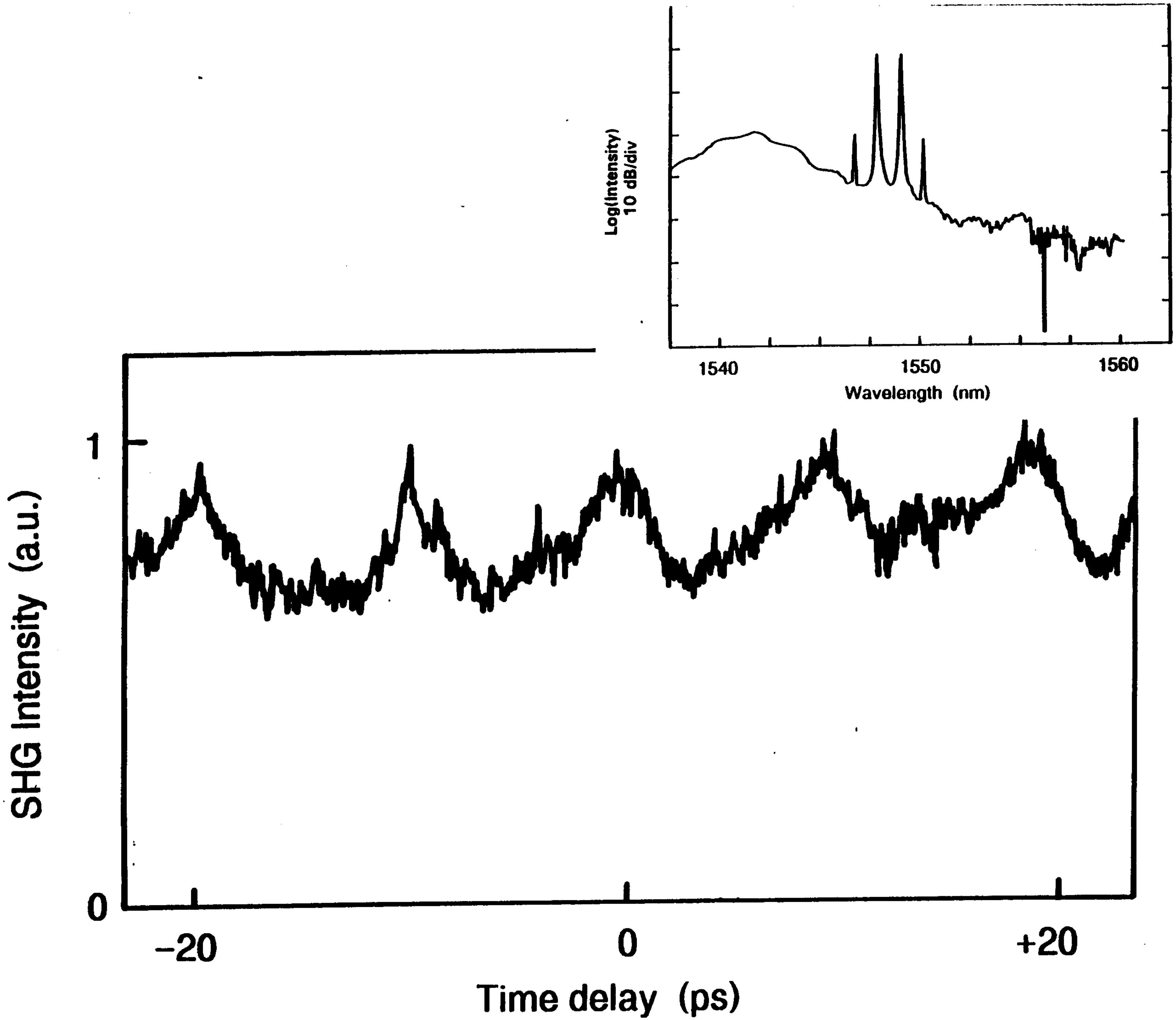
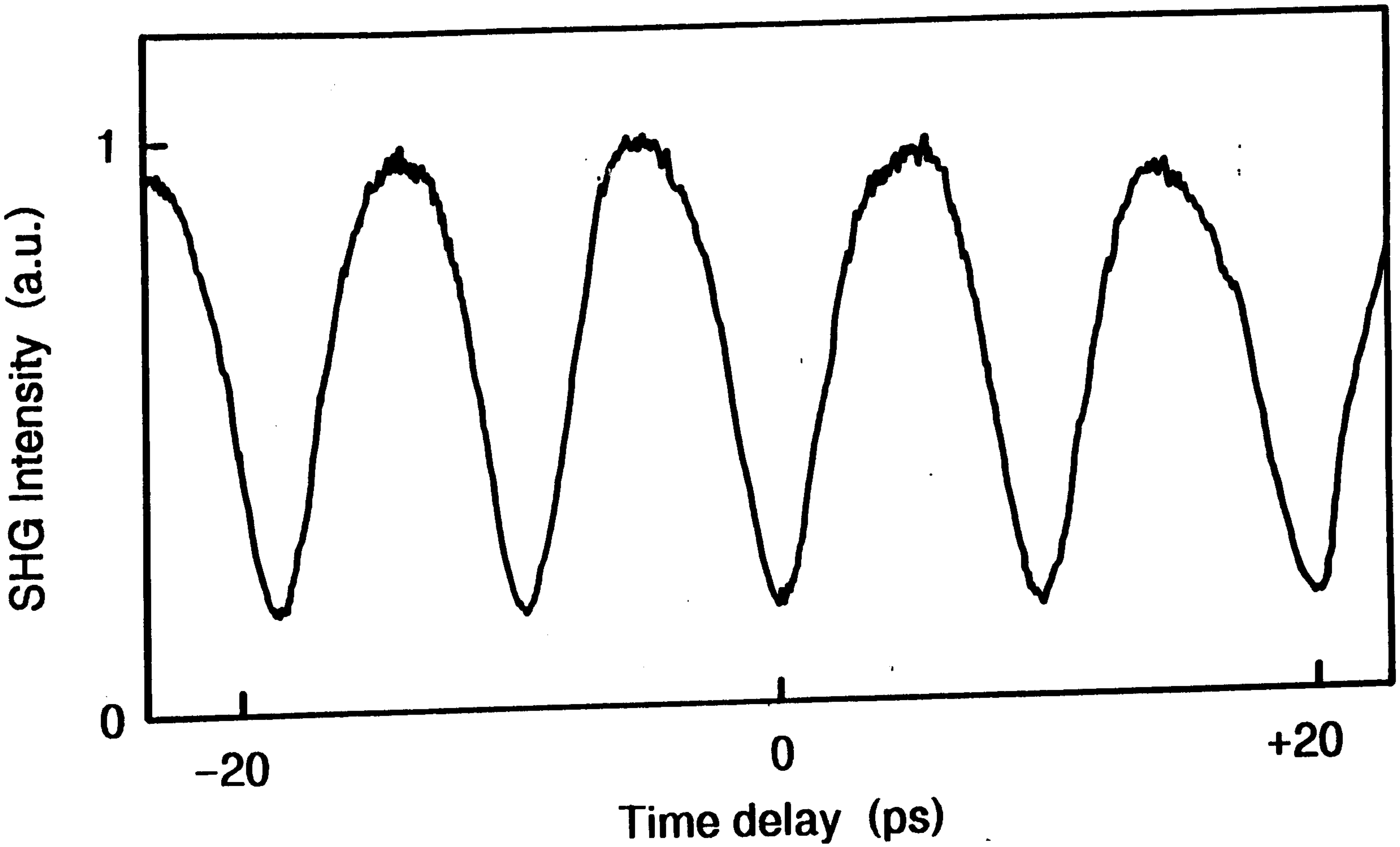
1540
1550
1560
1570
Wavelength (nm)
SHG Intensity (a.u.)
1
0
−20
0
+20
Time delay (ps)

2a


Log(Intensity)
10 dB/div
1540
1550
1560
Wavelength (nm)
SHG Intensity (a.u.)
1
0
−20
0
+20
Time delay (ps)

2b



3