mitter and receiver. Note that for the gating operation, we do not require phase coherence.

In Fig. 3, we propose an alternate scheme. We encode the spread signal into a PSK waveform, which is bipolar. The ASK to PSK conversion is done optically. At the receiver, we generate a PSK encoded chip sequence, which we mix with the received signal. The resultant signal is passed through a photodiode, which is a square-law device. Since the product of two bipolar signals is isomorphic to the logical XOR operation of their corresponding binary (0, 1) signals, we have achieved the same function as in the previous configuration.

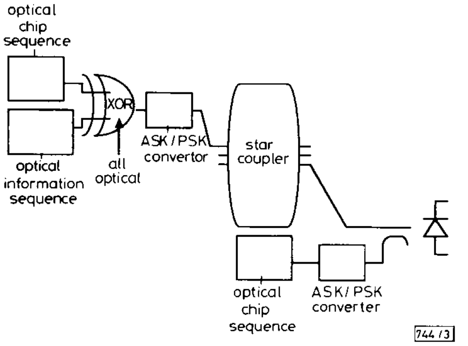

Fig. 3 *All-optical CDMA, configuration 2*

We will now compare the two configurations. For the first system, we required a received optical power of about 0·5 W. Since the received signal has propagated through the network, we will not receive the required signal power. However, a high power optical amplifier could be used to recover the necessary signal power level. For example, amplification up to 12 W is reported in Reference 9 with a fibre amplifier. As for the second configuration, we do not need such high power levels at the receiver, but since we are detecting coherently, we must maintain phase stability.

Conclusion: We have proposed two new configurations that overcome the speed limitations of electronic processing and the performance degradation associated with positive systems. They rely heavily on the availability of nonlinear optical devices.

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References

1 SALEHI, J. A.: 'Emerging optical code-division multiple access communication systems', *IEEE Network*, 1989, **3**, pp. 31–39
2 JACKSON, K. P. *et al.*: 'Optical fibre delay-line signal processing', *IEEE Trans.*, 1985, **MTT-33**, pp. 193–210
3 CHUNG, F. *et al.*: 'Optical orthogonal codes: Design, analysis, and applications', *IEEE Trans.*, 1989, **IT-35**, pp. 595–604
4 SARWATE, D. *et al.*: 'Crosscorrelation properties of pseudorandom and related sequences', *Proc. IEEE*, 1980, **68**, pp. 593–618
5 KAWAGUCHI, H.: 'Proposal for a new all-optical waveguide functional device', *Opt. Lett.*, 1985, **10**, pp. 411–413
6 FRIBERG, S. F. *et al.*: 'Nonlinear optical glasses for ultrafast optical switches', *IEEE J. Quantum Electron.*, 1987, **QE-23**, pp. 2089–2094
7 LATTES, A. *et al.*: 'An ultrafast all-optical gate', *IEEE J. Quantum Electron.*, 1983, **QE-19**, pp. 1718–1723
8 JACKSON, K. P. *et al.*: '1-Gbit/s code generator and matched filter using an optical fiber tapped delay line', *Appl. Phys. Lett.*, 1983, **42**, pp. 556–558
9 TAKADA, A. *et al.*: 'Picosecond laser diode pulse amplification up to 12 W by laser diode pumped erbium-doped fibre', *IEEE Photon. Technol. Lett.*, 1990, **2**, pp. 122–124

OPTIMUM TRANSMISSION CONDITIONS OF SOLITONS BY PRE-EMPHASIS TECHNIQUE

Indexing terms: Optical solitons, Optical communication

By using the 'pre-emphasis technique', under certain loss-limit and dispersion-limit constraints, there always exists an optimum combination of input pulse-width and pre-emphasis factor for a specific carrier wavelength to maximise the bitrate-length product.

Introduction: Optical solitons in a monomode fibre are formed through the balance between intrinsic self-phase modulation (SPM) and chromatic dispersion in the anomalous dispersion region. Fibre loss gradually weakens the SPM effect and then broadens the pulse. By pre-emphasising the fundamental soliton at the fibre input end, the soliton feature is expected to persist longer along the fibre. The 'pre-emphasis technique'[1] has the input

$$q(\xi = 0, \tau) = A \operatorname{sech}(\tau)$$

where A is the pre-emphasis factor, and $A > 1$. $A > 1$ has two advantages: larger loss-limited distance and initial pulse narrowing. But too large a value of A will induce pulse splitting because of the second-order soliton under the influence of the fibre loss. Therefore, a proper value of A, (A) *max*, for the maximum bitrate-length product, (BL) *max*, can be expected for certain loss-limit and dispersion-limit constraints. The following simulation uses the propagation beam method to solve the nonlinear Schrodinger equation with the loss term[2]:

$$i\frac{\partial q}{\partial \xi} + \frac{1}{2}\frac{\partial^2 q}{\partial \tau^2} + |q|^2 q = -i\Gamma q$$

where q, ξ, τ, and Γ represent normalised electrical field, propagation distance, time and fibre loss, respectively. A dispersion-shifted fibre has been used, and the dispersion curve[3] is moved parallel with zero-dispersion wavelength, λz, from 1·273 μm to 1·55 μm. The fibre loss and the effective core area are 0·2 dB/km and 25 μm^2, respectively. For the direct intensity modulation and demodulation scheme, we take a detection sensitivity of 10^4 photons per bit as the loss-limit. Ten times the pulsewidth is used as the time slot for one bit to avoid soliton interaction, so the bit-rate is calculated by $B = 1/(10 \times Tw)$, where Tw is the pulsewidth. By considering the finite pulse-width and detector response, the central seven pulse-widths of the time slot is taken as the detection window.[4] The intensity-weighted RMS width is used to measure the pulse width, and a pulse-width broadened factor of two is used as the dispersion-limit.

Results and discussion: Fig. 1 shows the pulsewidth normalised to the initial pulse as a function of propagation distance for various As. The input pulse-width is 7·9 ps and the carrier wavelength is 10 nm larger than λz. All curves have been stopped by the loss-limit. For $A = 1$, from the beginning of

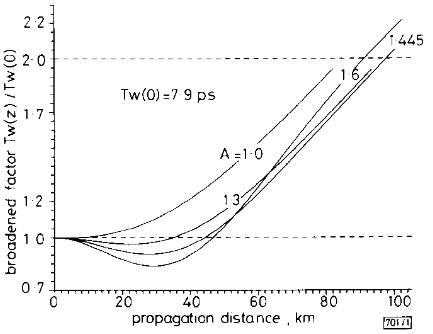

Fig. 1 *Pulse-width against propagation distance*

propagation, the balance between the SPM effect and chromatic dispersion has been destroyed, so the broadened factor is always larger than unity. When $Z > 30\,\mathrm{km}$, the dependence of the pulse-width on distance becomes linear. For $A > 1$, the SPM effect is initially stronger than chromatic dispersion, the pulse-width is reduced to a minimum value at $Z = Z_{min}$. When $Z > Z_{min}$, the SPM effect becomes weaker than chromatic dispersion, the pulse-width again increases and eventually reaches the linear evolution region. But for too large a value of A, the splitting of the second-order soliton into two peaks contributes to the rapid growth of the pulse-width. We should be able to find a pre-emphasis factor (A) *max* to obtain a maximum bitrate-length product (BL) *max* for a given constraint of dispersion-limiting. In Fig. 1, (A) *max* equals 1·445 under a dispersion-limit of broadened factor 2. Fig. 2 shows BL as a function of A for various Tw's. We notice that for a certain pulse-width, there exists a (BL) *max* for a corresponding (A) *max*. For $Tw = 7{\cdot}5\,\mathrm{ps}$, all points on the curve are obtained by dispersion-limiting. For the cases of larger pulse-widths, parts of the curves are obtained by loss-limit and the other parts by dispersion-limit. Fig. 3 shows the (A) *max* and (BL) *max* as functions of the pulse-width. The curve of (A) *max* against Tw contains a turning corner. Right at the corner, i.e., $Tw = 7{\cdot}84\,\mathrm{ps}$, ($A$) *max* occurs at the point which the loss-limited curve intersects with dispersion-limited curve at the maximum point of the latter. To the left of the turning corner, the system is dispersion-limited and (A) *max* increases linearly with Tw. To the right of the turning corner, (A) *max* increases with a higher growth rate. The highest value of (BL) *max*, 1237·7 Gbit/s km, occurs just right of the turning corner, where $Tw = 7{\cdot}9\,\mathrm{ps}$ and (A) *max* = 1·445. Fig. 4 shows the temporal profile of output pulse at $z = 97{\cdot}8\,\mathrm{km}$ under the optimum transmission condition. The detected pulse intensity in the detection window still holds 99% of the total pulse energy.

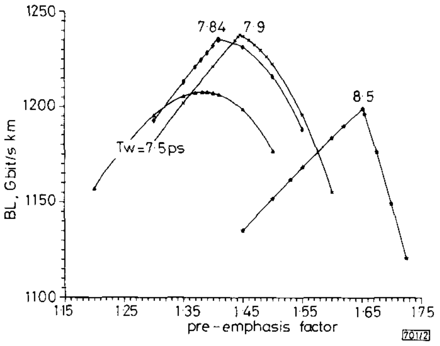

Fig. 2 *Bitrate-length product against pre-emphasis factor*

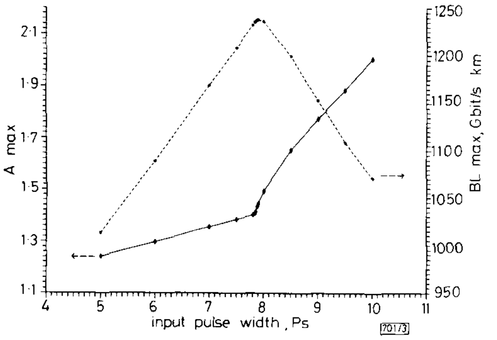

Fig. 3 *Maximum bitrate-length product optimum pre-emphasis factor against pulse-width*

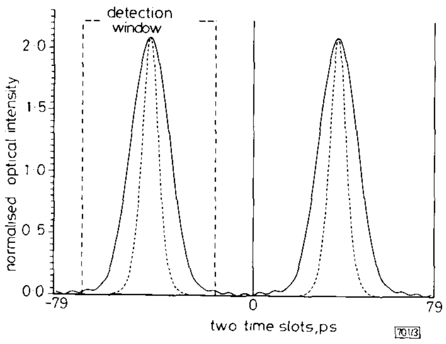

Fig. 4 *Initial pulse profile (dashed line) and output pulse profile (solid line) at Z = 97·8 km*

Conclusions: The numerical results show that, for a specific carrier wavelength, there always exists an optimum combination of input pulse-width and pre-emphasis factor to achieve the highest bitrate-length product. A BL value of 1237·7 Gbit/s km or higher can be achieved without any repeater.

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References

1 NAKAZAWA, M., KIMURA, Y., SUZUKI, K., and KUBOTA, H.: 'Wavelength multiple soliton amplification and transmission with an Er^{3+}-doped optical fibre', *J. Appl. Phys.*, 1989, **47**, pp. 2803–2812

2 HASEGAWA, A., and KODAMA, Y.: 'Signal transmission by optical solitons in monomode fiber', *Proc. IEEE*, 1981, **69**, pp. 1145–1150

3 MARCUSE, D.: 'Pulse distortion in single-mode fibers', *Appl. Opt.*, 1980, **19**, pp. 1653–1660

4 MOLLENAUER, L. F., and GORDON, J. P.: 'Soliton propagation in long fibers with periodically compensated loss', *IEEE J. Quantum Electron.*, 1986, **QE-22**, pp. 157–173

INTEGRATED STRUCTURE FOR GENERALISED CONNECTION NETWORKS EMPLOYING OPTICAL SWITCHES

Indexing terms: Optical switching, Network topology

A new integrated structure is proposed for generalised connection networks, which requires fewer optical crosspoints for 4 × 4 and 8 × 8 broadcast switching than previously known structures.

Introduction: Optical space switches can provide broadband switched connections in PBX and local network environments.[1] Generalised connection networks (GCNs) offer the additional facility of broadcasting from any one of N inputs to any number up to N of outputs, enabling any customer in a local network, for example, to become a broadcast service provider to other customers. The smallest GCNs published to date[2,3] operate by separating the broadcast function into two parts; an initial replication network (generaliser) to generate the required number of copies, followed by a one-to-one switching network (connector) to connect the copies to the appropriate outputs. This segregated approach requires more crosspoint switches than the $N \log_2 N$ theoretically required to provide all of the N^N possible permutations. GCNs using make/break contacts require $5{\cdot}8 \log_2 N$,[2] and when using optical changeover switches they would require $O(2N \log_2 N)$.[3]

A new structure of the generalised connection network has been found, which is better suited for use with optical crosspoint (changeover) switches, whether of the bulk-optic or waveguide type, than the previously known structures. The