data source. Each equaliser had 15 forward taps and 3 feedback taps.

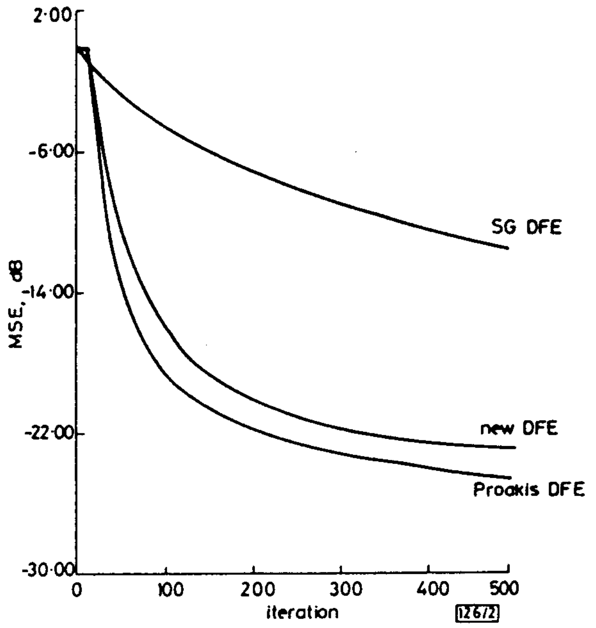

Fig. 2 *Speed of convergence on a time-invariant channel*

Speed of convergence: The new algorithm converges slightly less quickly than those in Reference 1. The improvement over the SG algorithm is substantial (Fig. 2). The sensitivity of the new algorithm to synchronisation errors was found to be lowest.

Steady-state behaviour: Its error-rate/SNR characteristics measured on a fading channel are comparable to the exact LS algorithm and superior to the SG algorithm (Fig. 3).

Conclusions: In spite of a slight degradation in performance, the new algorithm is very worthwhile, owing to the substantial reduction in algorithm complexity.

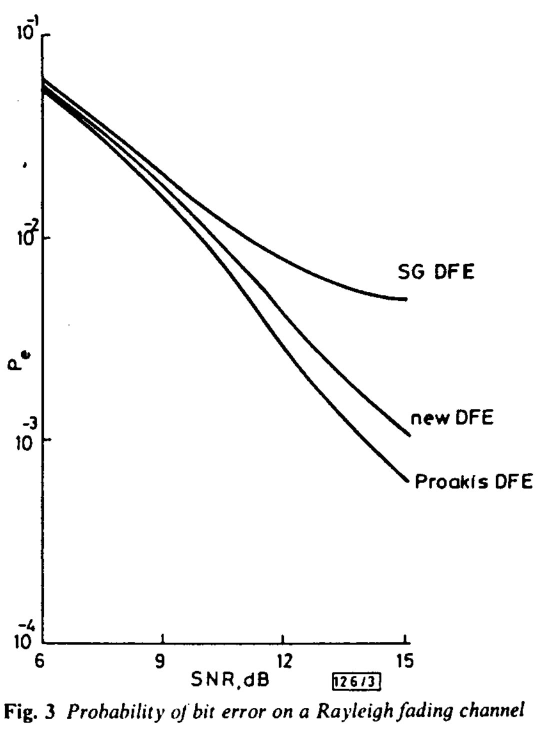

Fig. 3 *Probability of bit error on a Rayleigh fading channel*

Acknowledgment: This work is sponsored by Digital Equipment International B.V. (Clonmel).

A. D. FAGAN
N. M. O'HIGGINS

Department of Electronic Engineering
University College Dublin
Dublin 2, Republic of Ireland

21st November 1985

References

1 PROAKIS, J. G., and LING, F.: 'Lattice decision feedback equalisers and their application to fading dispersive channels'. Proceedings of international conference on communication, Boston, 1983, pp. C8.2.1–5

2 TAMBURELLI, G.: 'Digital receiver with distributed and integrated decision feedback and feedforward (to overcome the Nyquist barrier)', *CSELT Rapp. Tec.*, 1976, **4**, pp. 199–209

Q-SWITCHED OPERATION OF A NEODYMIUM-DOPED MONOMODE FIBRE LASER

Indexing terms: Lasers and laser applications, Doping

Q-switched operation of a neodymium-doped monomode fibre laser at 1·08 μm has been demonstrated. An intracavity acousto-optic modulator was used to switch pulses of 200 ns duration and 8·8 W peak power at a repetition rate of 100 Hz.

Introduction: There has recently been considerable interest in the use of rare-earth-doped single-mode fibres in high-gain laser systems.[1,2] The devices reported so far have been continuous-wave, typically producing a few milliwatts of continuous-wave laser light. For many applications, such as frequency conversion of the output light by nonlinear optical processes, this power level is insufficient. In this letter we report the first demonstration of Q-switching of a fibre laser, and have shown that an enhancement of some[3–4] orders of magnitude in the peak power output can be readily obtained.

Design: The laser system was designed to allow the insertion of a Q-switched into the cavity while maintaining low cavity losses and efficient pumping. This resulted in the arrangement shown in Fig. 1.

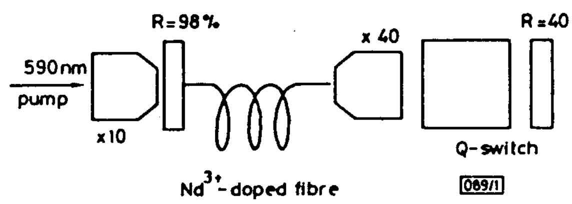

Fig. 1 *Experimental arrangement used to demonstrate Q-switched operation of an Nd^{3+}-doped fibre laser*

The active medium was an Nd^{3+}-doped single-mode optical fibre of length 2·3 m over which the continuous-wave dye laser pump light at 590 nm was totally absorbed. The high reflector ($R \simeq 98\%$) was butted against the cleaved fibre end, and launching of the pump laser into the fibre was achieved through this reflector using a $\times 10$ microscope objective. The very low optical losses incurred with this configuration allowed an output coupler of 40% transmission to be used with an intracavity microscope objective ($\times 40$) to provide a collimated beam at the output mirror. The Q-switch, an Isomet 1205C-1 acousto-optic modulator, was inserted into the cavity between the microscope objective and output coupler, an arrangement in which the pumping rate is not affected by the Q-switch losses. The monomode fibre ensured that the output beam was a pure TEM_{00} mode.

Performance: The RF power was applied to the modulator in the form of a square wave, producing an estimated 40% modulation in the single-pass transmission. The laser output in each low-loss half-cycle consisted of a large spike followed by several smaller spikes and then continuous-wave action. During the low Q cycle of the modulator the laser was below threshold. By altering the duty cycle to shorten the high Q period relative to the low Q period, all laser output after the initial large spike in each cycle could be suppressed, with a corresponding increase in peak power. Fig. 2 shows a typical output pulse obtained for a 100 Hz repetition rate and a high Q period of 5 μs. A peak power of approximately 8·8 W was achieved in a pulse of 200 ns duration. This pulse duration is in good agreement with the calculated value. The fibre laser

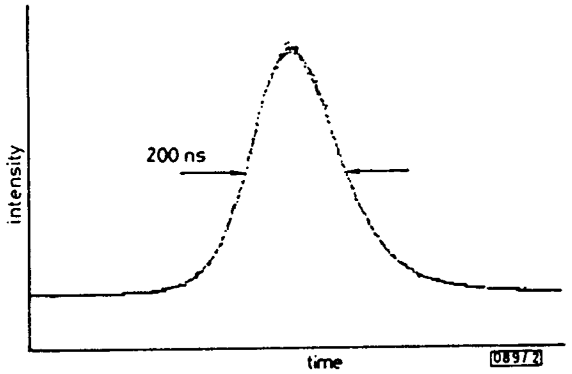

Fig. 2 *Profile of 1·08 μm pulse obtained in Q-switched operation*

operated in Q-switched mode for a day or more continuously with negligible long-term variation of the pulse shape.

We also investigated the effect of replacing the modulator in the cavity by an ordinary optical chopper wheel. Remarkably, we found that, in spite of the slow switch-on time of the chopper, which was 10 μs or a few hundred cavity round-trip times, peak powers approaching half those given by the acousto-optic modulator, whose switch-on time was a few nanoseconds, could be achieved. Fig. 3 shows a typical pulse

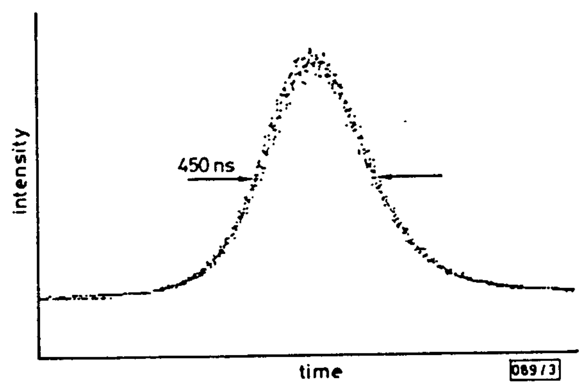

Fig. 3 *Profile of 1·08 μm pulse obtained by Q-switching with optical chopper*

of 4 W peak power and 450 ns duration obtained in this way. Multiple subsidiary pulses followed the initial pulse and could not readily be eliminated, but the experimental simplicity of this technique, which has no associated problems of alignment and cavity loss, makes it attractive.

Conclusion: We have demonstrated that Q-switching allows an Nd^{3+}-doped monomode fibre laser to produce high peak powers. If the dye laser pump source was replaced by a semiconductor diode laser as in Reference 1, then a compact high-power source could be envisaged. The same Q-switching techniques described here should also prove suitable for fibre lasers based on other dopant ions. In particular, the ability to use a simple mechanical chopper, with the advantage of low cost and ease of use, looks encouraging.

Acknowledgments: This work has been supported by a grant from the UK SERC and also in part under a JOERS programme. The authors are grateful to S. Poole and other members of the Fibre Optics Group in the Department of Electronics & Information Engineering, Southampton University, for kindly providing the doped fibre. One of us (I. P. Alcock) acknowledges the support of an SERC studentship.

I. P. ALCOCK
A. C. TROPPER
A. I. FERGUSON
D. C. HANNA

12th November 1985

Department of Physics
University of Southampton
Southampton SO9 5NH, United Kingdom

References

1 POOLE, S. B., PAYNE, D. N., and FERMANN, M. E.: 'Fabrication of low-loss optical fibres containing rare-earth ions', *Electron. Lett.*, 1985, **21**, pp. 737–738

2 MEARS, R. J., REEKIE, L., POOLE, S. B., PAYNE, D. N.: 'Neodymium-doped silica single-mode fibre lasers', *ibid.*, 1985, **21**, pp. 738–740

IMPROVED SYSTOLIC ARRAY FOR LINEAR DISCRIMINANT FUNCTION CLASSIFIER

Indexing term: Signal processing

A word-level systolic array with 100% efficiency is described for the linear discriminant function classifier. When compared with two previous word-level linear classifier arrays, it not only saves about C inner product step cells, where C is the number of weighted vectors used, but also simplifies the chip's I/O design.

Introduction: The linear discriminant function classifier is widely used in statistical pattern recognition, such as the Euclidean minimum distance classification[1] and voiced/unvoiced classification[2] etc. Let $X = [x^1x^2 \ldots x^n]$ be a feature vector and $W_i = [w_i^1 w_i^2 \ldots w_i^n w_i^{n+1}]$ be the ith weighted vector, where $i = 1, 2, \ldots, C$. Then the ith class linear discriminant function is defined as

$$g_i(X) = x^1w_i^1 + x^2w_i^2 + \cdots + x^nw_i^n + w_i^{n+1} \quad (1)$$

$$= X'W_i^T \quad (2)$$

$$= w_i^{n+1} + XW_i'^T \quad (3)$$

where $X' = [x^1x^2 \ldots x^n 1]$ and $W_i' = [w_i^1w_i^2 \ldots w_i^n]$. Following the method used by Urquhart,[3] operations of the linear discrimint function classifier can be partitioned into: (i) computing $g_i(X)$ for $i = 1, 2, \ldots, C$, and (ii) finding the class label l_i for which $g_i(X)$ is maximum.

To perform the above operations fast, several linear classifier arrays whose computations are based on eqn. 2 have been described in References 3 and 4. Those with contraflow possess only 50% efficiency and those with static weighted vectors possess 100% efficiency. However, updating the weighted vectors is much easier to achieve in the former than in the latter. Besides, using eqn. 2, which is an $(n + 1)$-dimensional inner product computation, to compute the linear discriminant function is not efficient enough in terms of both hardware and computation time, owing to the fact that the last multiplication operation in eqn. 2 is unnecessary. In this letter an improved word-level systolic array with both contraflow and 100% efficiency is proposed for the linear discriminant function classifier to remove the redundancy and the tradeoff. Moreover, for ease of both constructing a large array from smaller unit chips and interfacing with memory, a byte-serial grouped I/O scheme is described for the chip.

Systolic system: In the proposed array shown in Fig. 1, which is in fact a module for constructing larger arrays, each linear discriminant function is computed from eqn. 3 instead of eqn. 2, i.e. each $g_i(X)$ is obtained by performing one n-dimensional inner product initialised by some proper value. The leftmost column of C delay elements is used to properly provide the initial values. The subarray composed of $C \times n$ inner product step cells is used for the computations. The column of C classification cells is used for performing the classification. The rightmost column of C delay elements is used to properly provide the class labels for each current discriminant function. When compared with the two word-level arrays in Reference 3, the proposed one requires an additional