PERFORMANCE OF AN 8 × 8 $LiNbO_3$ SWITCH MATRIX AS A GIGAHERTZ SELF-ROUTING SWITCHING NODE

Indexing terms: Integrated optics, Optical switching

The performance of an $LiNbO_3$ integrated-optic crossbar switch as a node in a gigahertz self-routing network is measured. Switch throughput supports 12·5 Gbit/s signals with a measured switching speed of 1·33 GHz. Crosstalk due to RF/acousto-optic coupling and modulation depth are reported at 1·33 GHz. Optical self-routing of 100 Mbit/s information using the 8 × 8 switch is demonstrated.

Introduction: Requirements of the physical layer in a photonic switching network include a high channel bandwidth for the throughput of ultra-high bandwidth signals, fast switching speeds and optical processing of switching control algorithms to remove the speed bottleneck imposed by electronic processing.[1] Integrated-optic waveguide switches offer a channel bandwidth comparable to that of the fibre itself. Recently, complex integrated-optic switching structures, such as Ti : $LiNbO_3$ 8 × 8 crossbar switch matrices, have been fabricated.[2–4] Optical decoding of a self-routing protocol has also recently been reported and discussed.[5] With these advances in channel transparency, switching speed and control processing speed, the bandwidth of the photonic switching network will be comparable to the bandwidth of the fibre-optic network. Understanding the high-speed switching characteristics of integrated-optic switch matrices is necessary to optimise performance of the network.

The first demonstration of high-bandwidth transmission (80 ps pulses) through a complex switching structure is reported in this letter. The switching characteristics of an 8 × 8 integrated-optic crossbar switch (Ti : $LiNbO_3$) at gigahertz speed are measured. These characteristics include switching rise and fall times, RF/acousto-optic crosstalk and modulation depth. The performance of the switch matrix as an ultrawide-bandwidth switching medium is demonstrated by routing 80 ps pulses at a rate of 100 Mbit/s. Routing decisions are based on destination information encoded in the data using 12·5 Gbit/s optical spread-spectrum code sequences. The encoding and decoding of optical CDMA (code division multiple access) chip sequences using all-optical techniques is reported.

Optical switch matrix: The switching structure used is the strictly nonblocking 8 × 8 $LiNbO_3$ integrated-optic switch matrix previously reported.[3] Switching crosspoints are of the stepped delta-beta reversal type. Direction couplers are changed from the bar to cross stage with 64 V and 28 V (peak to peak with 1 ns risetime) pulses, respectively, level-shifted by 46 V at a bias network. Electrical crosstalk isolation is provided by guard electrodes located between directional coupler electrodes. The control signal is applied to the switch through a butterfly-style interconnection board.[3] Single-mode optical fibres are coupled using silicon V-grooves and mechanical positioners. The optical input is linearly polarised using a three-turn optomechanical polariser.

High-frequency measurements: The layout of the lower vertex of the 8 × 8 crossbar is shown in Fig. 1. Switching parameters were measured for switch 2. An optical signal is injected at input port 1, with switches 1 and 3 biased in the cross and bar states, respectively. Outputs 2 and 3 were monitored by analogue receivers with a frequency response of 400 MHz and sensitivity of −34 dBm.

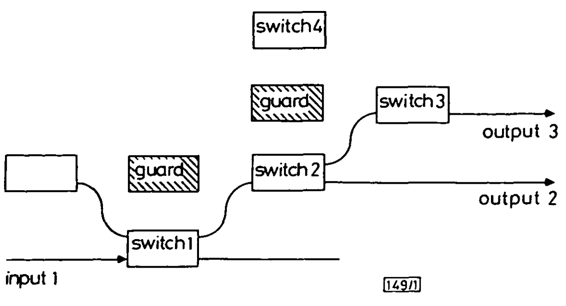

Fig. 1 *Schematic layout: lower vertex of 8 × 8 $LiNbO_3$ integrated-optic crossbar switch*

The switching speed is measured by switching out 2 ns of a 10 MHz optical square wave injected at port 1. Fig. 2 shows 2 ns of the input waveform switched from output 2 (upper trace) to 3 (lower trace). Switching rise and fall times are measured to be 750 ps. The improvement from a 1 ns rise-time drive voltage to 750 ps switching rise time is due to a nonlinearity in the voltage/switching characteristics. The switching speed is believed to be limited by the capacitance of the electronic interconnection. Modulation depth is measured to be 15 dB. This figure may be improved by using polarisation-preserving fibres.

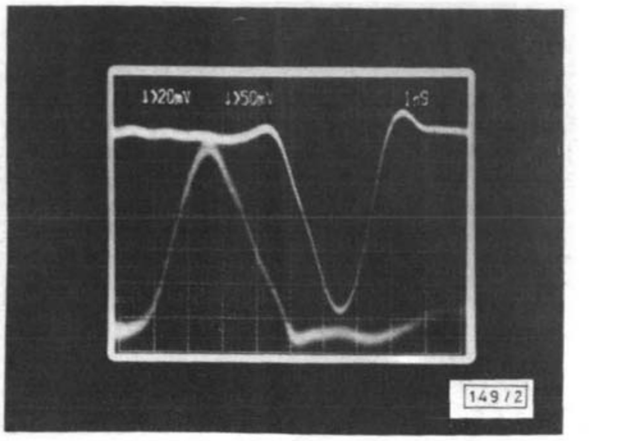

Fig. 2 *Switching rise-time measurement: optical signal switched from output 2 (top trace) to output 3 (lower trace)*

Crosstalk due to acousto-optic and/or RF interaction between adjacent switches has been studied.[6] This effect will be predominant during switch transitions due to nonlinearities in the voltage/switching transfer characteristics. We measure low-level crosstalk by biasing switch 2 between the cross and bar states. With electronic switching pulses applied to the adjacent switch (4), a −12·3 dB signal fluctuation was measured on top of a low frequency optical square wave applied to the input of switch 2. The guard electrode is grounded to reduce electrical crosstalk.

Optical self-routing: The 8 × 8 switch is used as the switching element in an optical self-routing experiment[5] to observe its performance as a self-routing switching node. In self-routing switching networks, data are tagged with destination information which is processed at a switching node for routing control. Recently it has been shown that fibre-optic delay-line signal processing techniques may be used to decode self-routed optical information.[5] Here we demonstrate that data can also be encoded using optically generated spread-spectrum codes[7] and then decoded at the switching node to produce a real-time routing decision.

Optical generation of the code sequence is performed as shown in Fig. 3. An 80 ps optical pulse (wavelength = 1·3 μm),

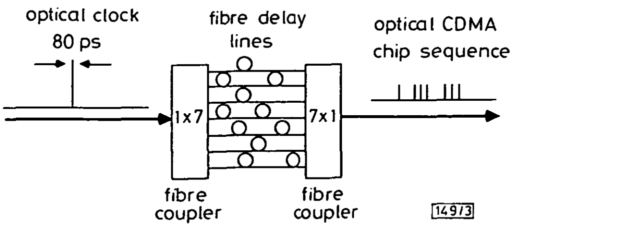

Fig. 3 *Optical encoding of CDMA chip sequence using tapped fibre-optic delay-line processor*

generated from a mode-locked laser, is passed through a tapped fibre-optic delay-line transversal filter to produce the chip sequence: 1(11)1(4)1(4)1(11)1(4)1(4)1 (see Fig. 4; numbers in parentheses are number of consecutive zeros between ones). When this sequence is passed through a matched delay-line filter, an autocorrelation function is generated (Fig. 5). The delay-line encoder is constructed using single-mode fibre and couplers (7 ports of a 1 × 8) for transmission compatibility to the high-speed network. However, at the routing controller,

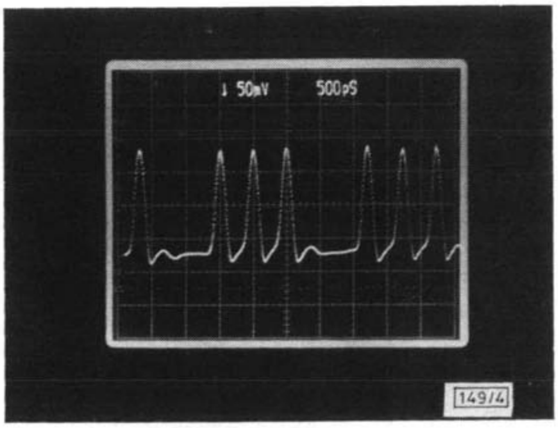

Fig. 4 *Optical CDMA chip sequence*
Chip widths are 80 ps

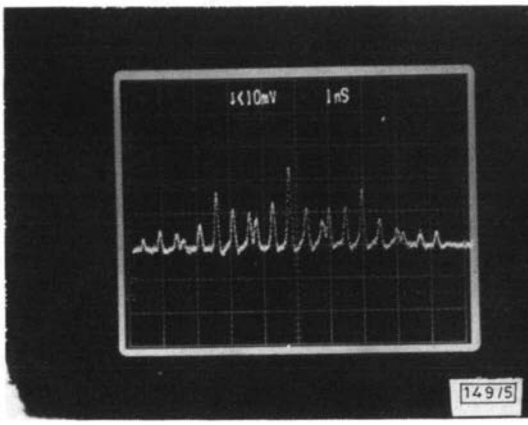

Fig. 5 *Autocorrelation function produced by shifting chip sequence (Fig. 4) through a matched fibre-optic tapped delay-line transversal filter*

phase coherence among the optical chips in the CDMA coded data caused random interference when recombined at the correlator. Use of a multimode correlator, with a multimode pigtail of several meters, appeared to reduce correlation peak fluctuations by scrambling the phase front. This autocorrelation function may be readily threshold-detected electro-optically to produce a switching control signal or perform data reconstruction.[5]

The self-routing experiment is shown in Fig. 6. CDMA chip sequences are modulated by electronic data using a Mach–Zehnder type integrated-optic modulator. The optical clock is injected into port 1 of the 8 × 8 switch. Normally the CDMA chip sequence would be sent to a switching node to be processed and switched. Instead, owing to power budget limitations, we routed the optical clock, which was available at

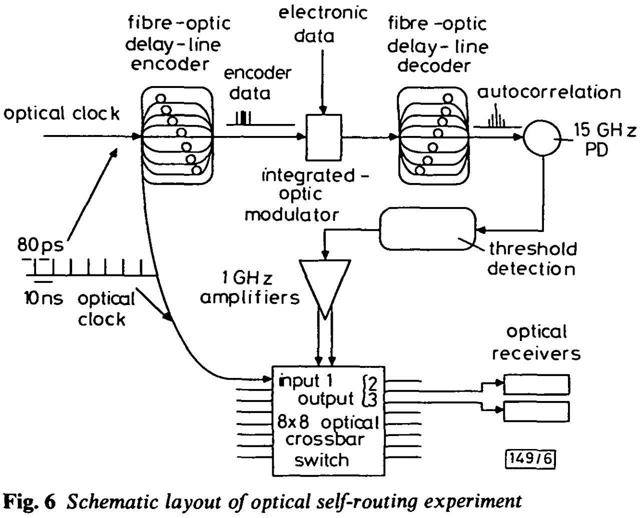

Fig. 6 *Schematic layout of optical self-routing experiment*

the free output of the 1 × 8 coupler at the optical encoder. Fig. 7 shows the self-routing of 100 Mbit/s optical data. Electronic data (top trace) modulate the CDMA sequence

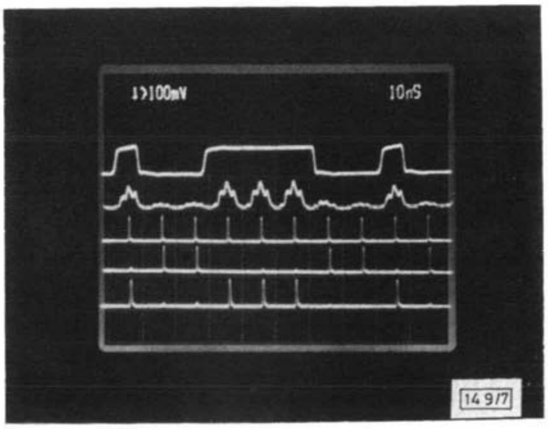

Fig. 7 *Results of optical self-routing experiment*
Input electrical data (upper trace); modulated autocorrelation function for routing control (2nd trace); 80 ps at 100 MHz repetition rate input to switch matrix (3rd trace); outputs 2 and 3 of switch matrix (lower 2 traces)

producing a modulated correlation function (2nd trace). If the sequence produces an autocorrelation peak (which in this case it does), a threshold detector and switching pulse amplifier activate the switch to route the optical clock (third trace) from output 2 to 3 (lower two traces).

Summary: The transmission of 80 ps pulses through an 8 × 8 integrated-optic crossbar switch is reported. The switching speed of the directional coupler switching element is measured to be 1·33 GHz. This rise time may be shortened with lower capacitance interconnection techniques. Crosstalk due to RF and/or acousto-optic coupling is measured at −12·3 dB at 1 GHz. The switching speed and modulation depth of the switch are acceptable for use in fast photonic switching networks. The demonstration of 100 Mbit/s optical self-routing of 12·5 Gbit/s signals shows promise for ultra-high-speed packet or bit switching systems.[1]

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1st October 1987

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