Abstract Ladder networks, consisting of chains of 2×2 switches and delay lines, have many potential uses in future optical communications. These are discussed, and implementation via photonic crystal technology and advances in integrated optics is outlined.

Introduction
Over the last 15 years, many communications switching architectures have been proposed which are composed of optical switches, and also use optical delay-line memories for storage purposes. In the electronic domain, RAM technology is well developed, however fibre delay-line memories can be bulky and environmentally unstable, making them difficult to implement. The development of photonic crystal (PhC) technology amongst others means that these architectures may become realisable. PhC’s offer high density integration combined with strong light-matter interactions, to offer enhanced photonic functionalities. In particular, tuneable optical cavities may also be attractive in improving bandwidth-time products [1].

In this paper, we concentrate on so-called “ladder networks”, which consist of a chain of 2×2 optical switches and delay-lines (Figure 1), and can be used for a wide variety of applications, as detailed below. Integration of such repeating sub-system components is advantageous in integrated optical design, such that optical cross-points and delay devices of the type mentioned above fall well within current technology (e.g. [2]). While many other structures have been proposed, ladder networks serve as a good example of these techniques.

A ladder network has two inputs, although, for some applications, only one is used. Likewise, either one or two outputs may be used. The application that is chosen determines the delay line lengths \(d_1, d_2, d_3\) etc. Information may be switched in single-bits units – this has the advantage of requiring small delay-lines, which are more easily fabricated. However, the switches must be able to change state every bit-period. Larger units of information may be switched, for example a “block” which occupies a TDM timeslot, or a packet, in which case it is assumed that all packets are of equal length. This relaxes the requirements on switching time, but requires longer delay-lines since many bits are contained in each block or packet. There is also an electronic controller which determines the state that each optical switch takes on during each bit period, block period, or packet period.

\[\text{Figure 1: Ladder networks.}\]

Time division multiplexing
In time-division multiplexing, information is transmitted as “frames”, each composed of a number of equally-sized “timeslots”. The position within the frame of a block of information (i.e. its timeslot number) determines the channel to which it belongs, and hence its destination. The ladder networks shown above can accept one or two such information streams, and rearrange all these incoming streams (each defined by its physical input connection, and its timeslot number) so that they appear on the output connections, on any timeslot defined by the electronic controller. This is a fundamental and crucial function in telecommunications switching. For example, to switch 2 inputs/outputs and 4 timeslots, the sequence of delay-lines would be \(d_1 = 1\) timeslot, \(d_2 = 2\) timeslots, \(d_3 = 2\) timeslots, \(d_4 = 1\) timeslot [3]. Larger frame sizes require a longer ladder network.

Packet switching
In packet switching, each packet contains information (in its header) which defines its destination. Hence there is no “frame” structure, and the packet’s destination is not defined by its position within a frame. The ladder network of Figure 1 can be used as a simple packet switch [4]. With four delay-lines, for example, the sequence would be \(d_1 = 1\) packet, \(d_2\)
= 2 packets, $d_3 = 4$ packets, $d_4 = 8$ packets. Adding more delay lines provides more packet buffering.

**Synchronisation**

Synchronisation is a crucial function, and is required to ensure that packets or TDM frames are aligned when they enter the switch; otherwise it will not function correctly. In this case, by making each delay-line double the length of the previous one, the ladder network can be used with one input and output as a variable delay, which is adjusted by means of the optical switches to ensure that alignment takes place.

**Code generation and detection in OCDMA**

If each $2 \times 2$ optical switch in Figure 1 is replaced by a passive directional coupler, the ladder network can be used as an encoder or decoder for optical code division multiple access (OCDMA) networks [5]. Each user in a passive network is allocated a unique code, and each “1” bit it sends is encoded using a ladder network. Each different user has a different sequence of delay-lines, and thus a different code. By using the correct delay-line values in the ladder network decoder, information being sent by a particular user can be distinguished by a receiving user, from undesired signals sent by other users.

**Conclusions**

There are many structures that have been proposed which consist of optical switches and delay-lines. In this paper, we have concentrated on one such structure, namely the ladder network. Even the simple structure shown in Figure 1 has a wide variety of applications in communications switching. Other structures exist which have more than two inputs and outputs, or which can be used for high-speed multiplexing and demultiplexing of high-speed optical time-division multiplexed (OTDM) data. A major problem, limiting the practicality of these structures, has been the reliance on optical fibre delay-lines. Photonic crystal technology coupled with advances in integrated optics offer the prospect of switching modules which feature not only routing functions but the buffering essential to so many applications; all in a compact industry-standard package.

**References**

5. L. Tančevski et al. IEEE Photonics Technology Letters, 6 (1994), 309-