Optical Switches Based on The Generalized Mach-Zehnder Interferometer

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Multimode interference (MMI) couplers have found wide application in integrated optical circuits. These couplers are based on self-imaging multimode waveguides and have been shown to be very effective in splitting and combining optical beams. Their advantages include compact size, ease of fabrication, low excess loss, good crosstalk performance and accurate splitting ratios.

Good power balance and stable relative phases of the MMI couplers make them ideal for incorporation into generalized Mach-Zehnder interferometer (GMZI) structures. GMZI wavelength-selective switches, variable-ratio power splitters and optimized switches have been reported [1]. However, the switching capability of these devices has been very limited so far. The purpose of this paper is to further investigate the switching possibilities of the GMZI and to propose a novel design for an optical GMZI switch.

The general layout of an NxN GMZI is illustrated in Fig. 1. Identical 4x4 MMI couplers are used as splitter and combiner. They are linked by N arms, each containing a phase shifter, either electro-optic or thermo-optic in nature.

The transfer matrix $T$ for the NxN coupler ideally is given by

$$t_{mn} = a_{mn} \exp(j\phi_{mn})$$

where $a_{mn}$ is the (field) amplitude transfer coefficient, and the phase $\phi_{mn}$ is associated with imaging an input $m$ to an output $n$ [1].

The overall transfer matrix $S$ of the generalized Mach-Zehnder interferometer can be written as follows.
\[ S = \Lambda \mathbf{T} \mathbf{T}^{-1} \]  \hspace{1cm} (2)

where \( \Lambda \) is the diagonal matrix representing the phase shifts in the arms, and \( \mathbf{T} \) is the transfer matrix for the \( N \times N \) couplers.

Since the phase shifting arms provide only \( N \) degrees of freedom, then only \( N \) of the total \( N! \) number of switching states can be produced by such a structure. The phase shifts required in the arms for each state, are given by

\[ \Lambda = \mathbf{T}^{-1} S_s \mathbf{T}^{-1} \]  \hspace{1cm} (3)

where \( S_s \) is one of the \( N \) allowable switching states.

However, for a switch to be useful, it needs to provide all possible switching states. For the case of the \( 4 \times 4 \) switch, there are \( 4! = 24 \) separate states. The \( 4 \times 4 \) GMZI can be modified, by adding some additional logic, to enable it to provide the complete range of switching states. A complete switch is shown in Fig 2.

Thus by the addition of only four \( 2 \times 2 \) switches (which could be \( 2 \times 2 \) GMZI switches) all the switching states are achieved. The major advantages of this design are that the losses are uniform across the paths and that the switching states are achieved using only a very small number of phase shifters. External crossovers are avoided. The switch is rearrangeably non-blocking. However, it is possible to allocate the connections of the switch in such a way as to reduce the probability of rearrangement. The switch also has some fault-tolerant properties.

In summary, a brief outline of the switching capabilities of the GMZI has been given. This study has led to the design of a novel \( 4 \times 4 \) switch. This type of switch has good loss uniformity and requires only a relatively small number of phase-shifting or switching elements.

REFERENCE