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2×2 SINGLE-MODE FIBRE ROUTING SWITCH

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Abstract

An all-fibre 2×2 acousto-optic routing switch is described that has an insertion loss of 0.11 dB, a drive power of 1.5 mW and a switching time of 80 μs. The switch has a very simple construction and so has the potential to be low in cost.

Optical fibre switches connect input and output fibres together in a controllable way, and so perform a very basic function in telecommunications networks. The state of the device is determined by an electrical addressing signal. As well as being fast, a good switch will have small values for the insertion loss, crosstalk and electrical drive power, and will be of simple construction to minimise cost. This is particularly important when switches with many fibre ports are built up from arrays of elementary 1×2 or 2×2 elements. Routing switches are used to reconfigure a network, for example to establish a communications link along a certain path, or to bypass a segment due to failure or for maintenance. They can also be used in testing, to insert a succession of sources or test objects into a single measurement system.

There are three main technologies in use. Opto-mechanical switches[1] are complex and have long switching times of 20 ms or so, despite the maturity of the technology. The insertion loss of 0.5 dB or more, though the best available, is still large compared to other fibre components. Over a watt of electrical power is required while changing state, with a stand-by power of 50 mW. Typical thermo-optic switches[2] are faster (2 ms) and have no moving parts, but they suffer from greater losses (1.5 dB), worse crosstalk (15 dB) and higher continuous drive powers (600 mW). Electro-optic switches, based on $LiNbO_3$ for example, are fast and require little power; the penalty is a very large insertion loss, 4 dB or more.

There is therefore a need for a low-cost, low-loss and low-power fibre routing switch. To this end, it makes sense to consider all-fibre components, in which the light never leaves the medium of the fibre. Simplicity of construction reduces the cost, while the absence of breaks and collimation optics minimises the loss. We have recently developed an acousto-optic (AO) device that is based on one such all-fibre component, the single-mode fused taper coupler.

The properties of the device as a 633 nm frequency-shifter and electrically-tuned coupler with dissimilar ports have been described elsewhere[3]; here we describe its performance as a 1550 nm optical switch.

The coupler is a special type called the null coupler. It is made from two fibres with diameters mismatched to the extent that the resultant coupler does not actually couple any light. It is the extreme wavelength-flattened coupler[4]. Like the wavelength-flattened coupler, it can be made by pre-tapering one of two identical fibres along a short length before both fibres are fused and elongated together to form the coupler. This gives a device with identical single-mode ports. Light in one input fibre excites just the fundamental mode in the narrow waist of the coupler. Light in the other input fibre excites just the second mode in the waist. In both cases, the light propagates along the waist without further interactions, and returns to the original fibre at the output end of the coupler, Fig. 1(a).

A flexural acoustic wave propagating along the coupler causes a periodic refractive index perturbation in the waist. If a resonance condition is met - the acoustic wavelength matches the optical beatlength between the two modes - light can couple between the modes. Furthermore, if the amplitude of the acoustic wave is suitably adjusted, complete coupling is possible: light enters one fibre, excites one mode in the waist, is acousto-optically coupled to the other mode, and emerges from the other fibre at the output, Fig. 1(b). The acoustic wave is in turn generated in a transducer by an electrical signal. Thus the coupler and transducer together act as an electrically-driven 2×2 switch.

This switch has the advantages expected from an all-fibre device. Optically, it is a fused taper coupler, and so can have the ultra-low losses (<0.05 dB) associated with such couplers. The construction is simple, requiring no additional optical components, collimation or connections, with the potential for low cost. Furthermore, the power requirement is very small: because the light waves at the waist of a fused coupler fill the whole of the waist, the acoustic and optical waves share the same volume. This means that all of the acoustic energy contributes to the interaction.

The wavelength of operation λ is determined by the diameter $2R$ of the waist, which is easily controlled when the coupler is made. A simple analytical expression for the AO resonance condition gives R in terms of λ and the acoustic frequency f, under approximations that are valid for the devices we have constructed[5]:

$$R^3 = A\frac{\lambda^2}{f} \ . \tag{1}$$

The constant A is equal to 109.4 ms^{-1} for silica fibre. The switch changes state in the time taken for the acoustic wavefront to travel along the coupler waist. For a waist of length L, with R chosen to satisfy eq. (1), this time τ is given by

$$\tau^3 = B\frac{L^3}{\lambda f} \ , \tag{2}$$

where B is equal to 3.144×10^{-7} $\mathrm{m}^{-2}\mathrm{s}^2$ for silica fibre.

An AO switch was made as shown in Fig. 2. Standard single-mode fibre, with a diameter of 125 μm and an operating wavelength of 1550 nm, was used. The coupler was made by stretching a pair of fibres together in an oxy-butane flame. One fibre had been pre-tapered to a diameter of 90 μm beforehand. For the chosen acoustic frequency of around 10 MHz, eq. (1) indicates that the required waist diameter should be about 6 μm. For the interaction to be on resonance along the whole of the coupler, the waist must be uniform in diameter.

Uniformity and diameter control are achieved by using a travelling flame as the heat source. The final coupler had a waist 25 mm long, and short taper transitions. The excess loss of the passive coupler was 0.08 dB, and the maximum splitting ratio was very small, 1:17000, indicating that it was a good null coupler. Thus, in the OFF state, the switch had a crosstalk of 42 dB and an insertion loss of 0.08 dB.

The acoustic wave was generated using a PZT disc driven by an RF electrical supply. The disc was linked to the fibres by a conical aluminium horn, which concentrates the acoustic wave at the apex. The horn was fixed to the fibres at some distance from the coupler. This allows the taper transition to concentrate the acoustic energy further, and avoids the scattering loss that would result from attaching the horn at the coupler itself, where the light is guided at the glass-air boundary.

With light of controlled polarisation and a wavelength of 1550 nm in one fibre, AO coupling was observed at the frequency of 10.6 MHz. By adjusting the acoustic amplitude, over 99.3 % of the light was coupled, corresponding to a crosstalk of 21.5 dB and an insertion loss of 0.11 dB for the switch in the ON state. The RF power supplied to the device was 1.5 mW.

The time response of the switch was measured by modulating the RF drive with a slow square wave. The resulting curves for the OFF to ON transition are given in Fig. 3 (similar curves were obtained for the other transition). The switch changes state in about 50 μs, which compares well with the 68 μs predicted by eq. (2). The time lag between the RF signal and the start of switching is the time the acoustic wave takes to travel from the transducer through the horn and along the fibres to the coupler. The net effect is a delay of about 80 μs between the electrical signal and the completion of optical switching. This switching time is over an order of magnitude less than that of any established switch technology, with the exception of electro-optics.

These results were obtained for acoustic frequencies around 10 MHz. As a consequence, the switched light is frequency-shifted by 10 MHz. In a succession of switching elements, the net frequency shift could be noticable. However, we have obtained similar results for devices driven at around 1 MHz; the net shift for a series of these switches is insignificant.

Our all-fibre switch outperforms all other designs regarding the insertion loss of 0.11 dB. The drive power of 1.5 mW and switching time of 80 μs also compare very favourably with the best commercially available switches. The construction is simple and monolithic, the optical element being just a particular type of fused coupler; although the waist is very thin, couplers as narrow as 1 μm can survive shock testing[7]. There are no gross moving parts. The coupler has four identical standard single-mode fibre ports by default, so there is no need for collimating optics and no pigtailing problems. The device should therefore yield a competitive low cost routing switch.

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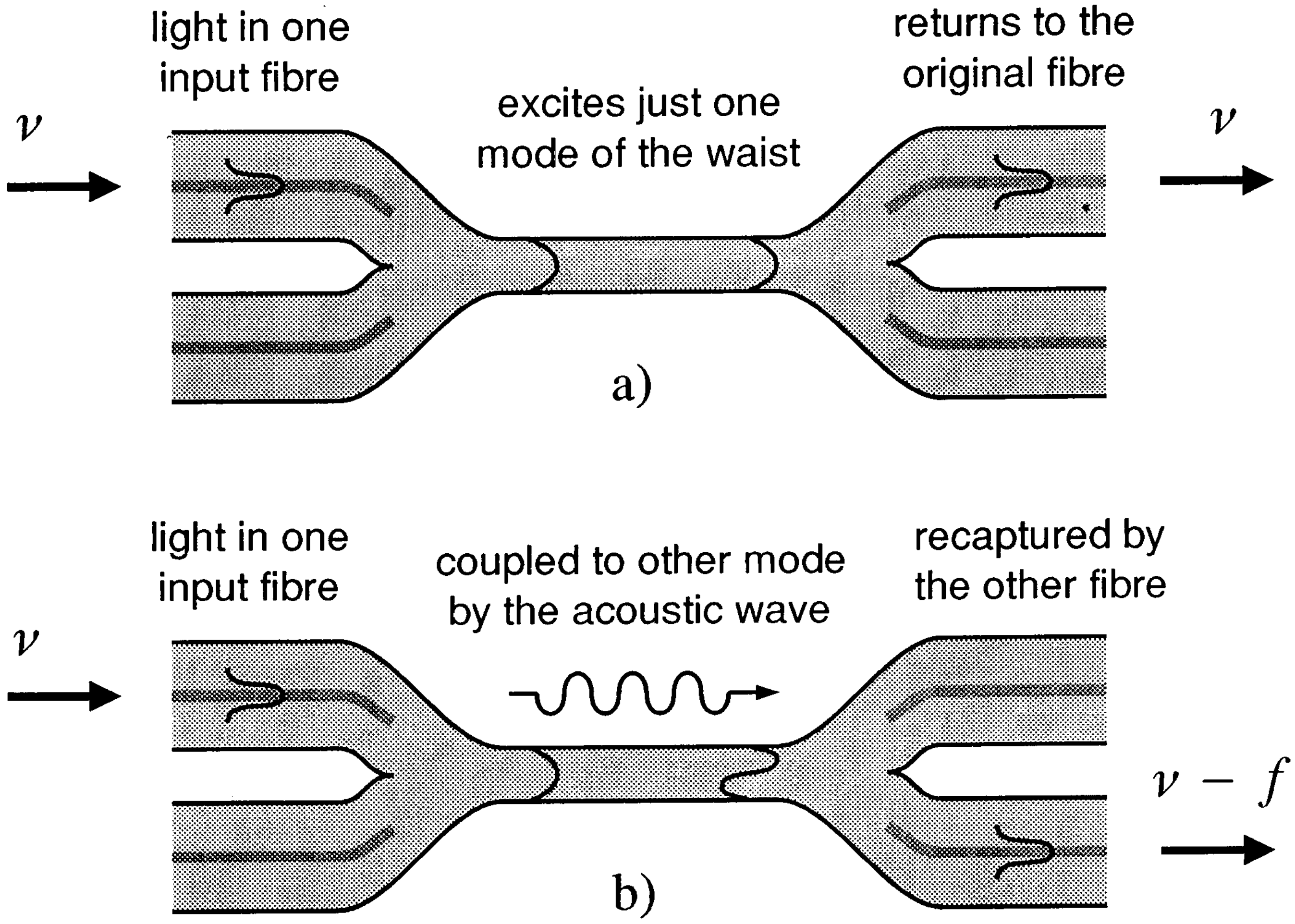
Figure captions

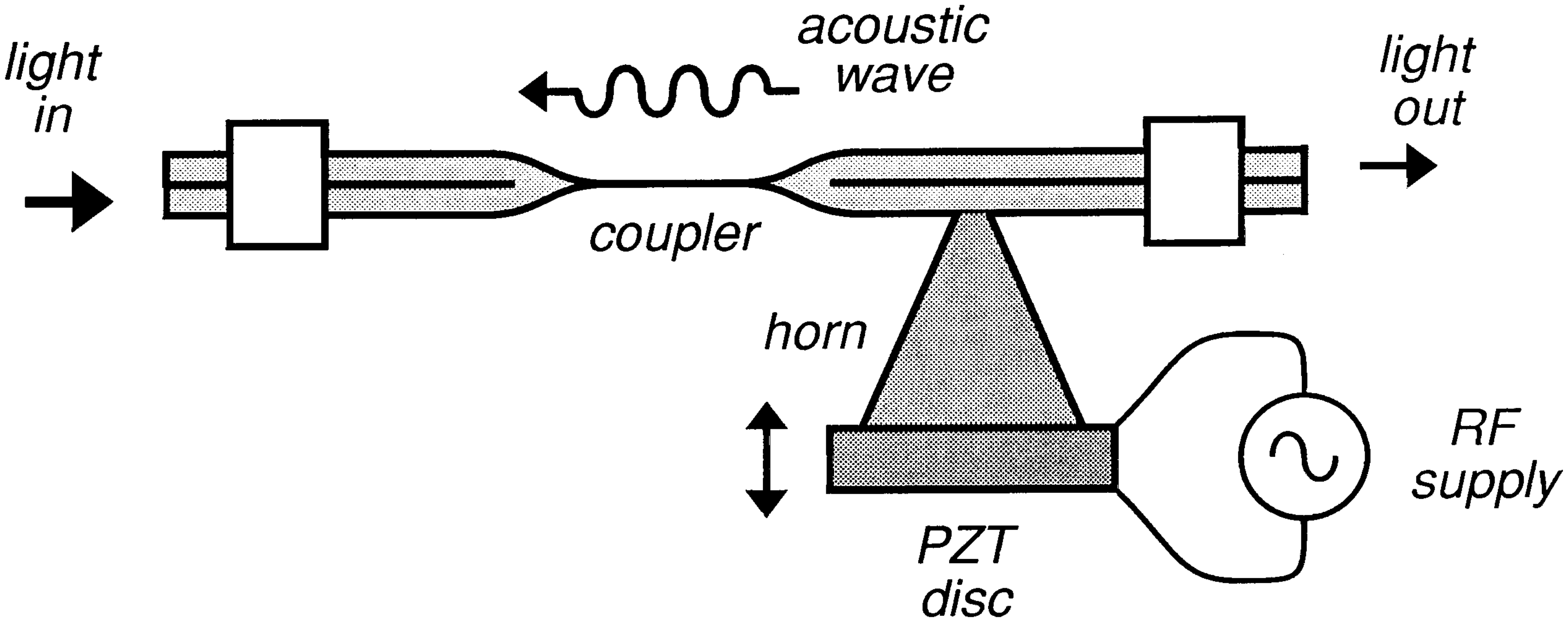
1. (a) The propagation of light through a passive null coupler.

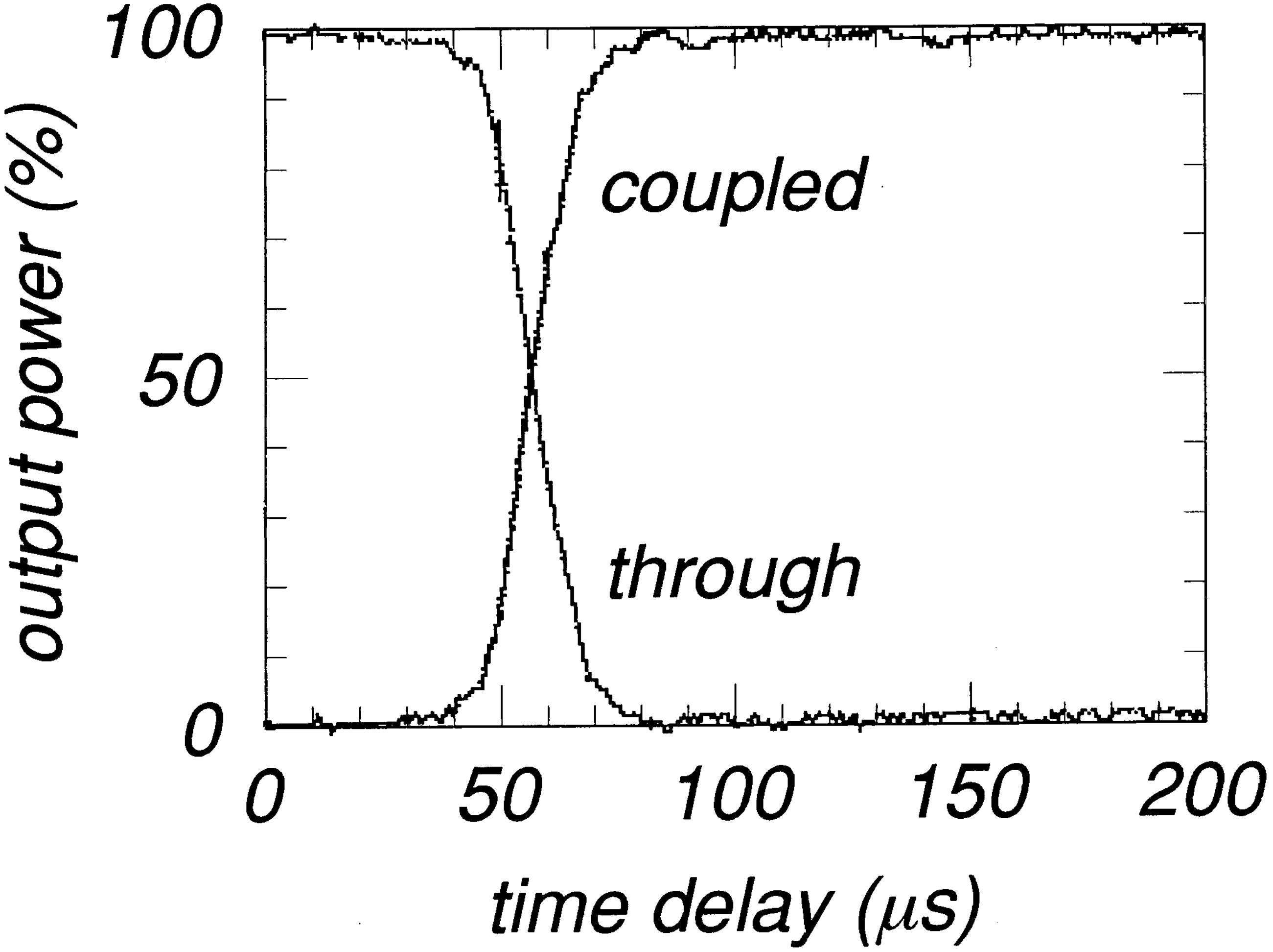
   (b) Acousto-optic switching in the coupler.

2. The construction of the all-fibre switch.

3. The time variation of the optical power in each output of the switch. The RF drive is turned on at $t=0$.


light in one input fibre
ν
excites just one mode of the waist
returns to the original fibre
ν
a)
light in one input fibre
ν
coupled to other mode by the acoustic wave
recaptured by the other fibre
$\nu - f$
b)


light
in
acoustic
wave
light
out
coupler
horn
RF
supply
PZT
disc


100
50
0
output power (%)
coupled
through
0
50
100
150
200
time delay (μs)