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(56) Documents Cited
GB 2191597 A **GB 2170920 A** **EP 0418872 A**
US 4307933 A **US 4301543 A**

(58) Field of Search
UK CL (Edition L) **G2J JGEC**
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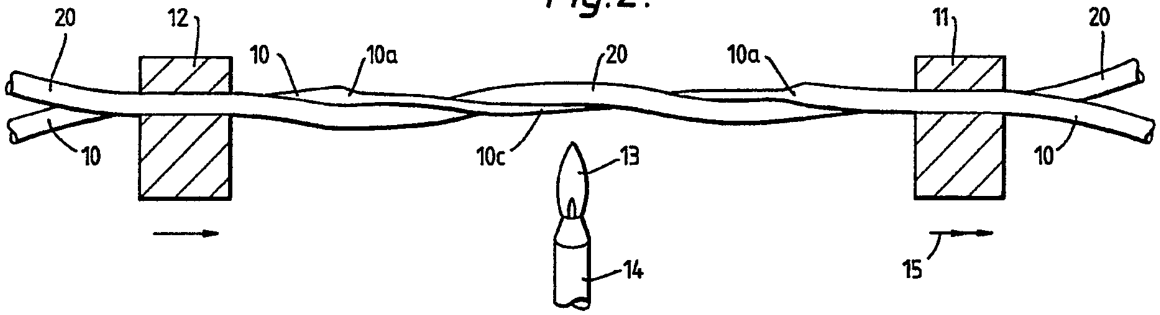
(54) Multiplexing optical waveguide couplers

(57) A wavelength multiplexing tapered fused fibre coupler is constructed from a pair of fibres (10, 20) which have unmatched propagation constants in their coupling region. The mismatch in a coupler can result from the choice of fibres with different index profile from which to construct it and/or from pre-tapering a portion of one of the fibres prior to constructing the coupler.

Fig.2.



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig.1.

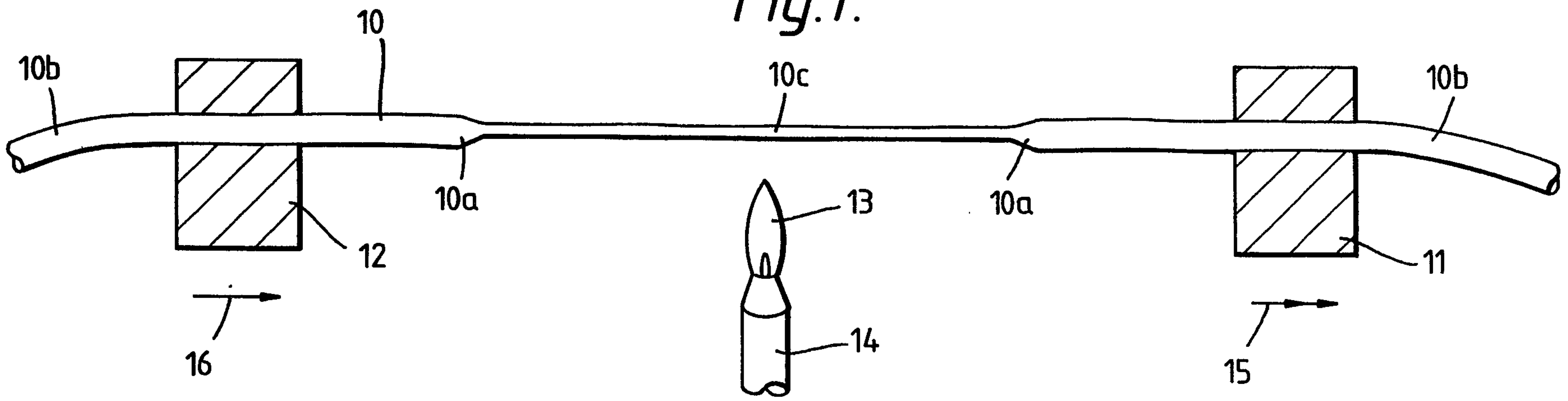
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Fig.2.

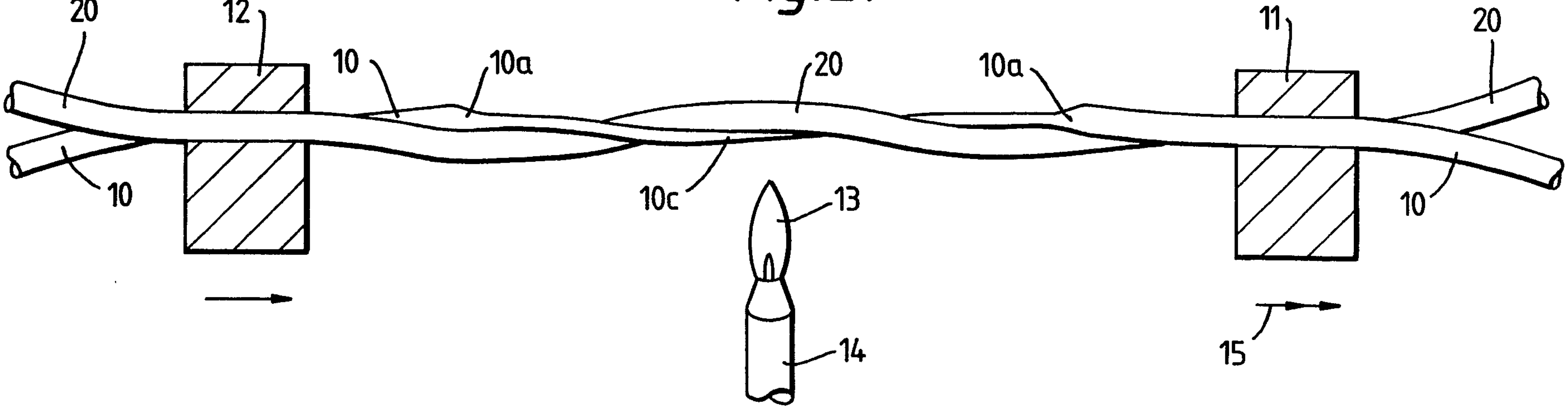
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Fig.3.

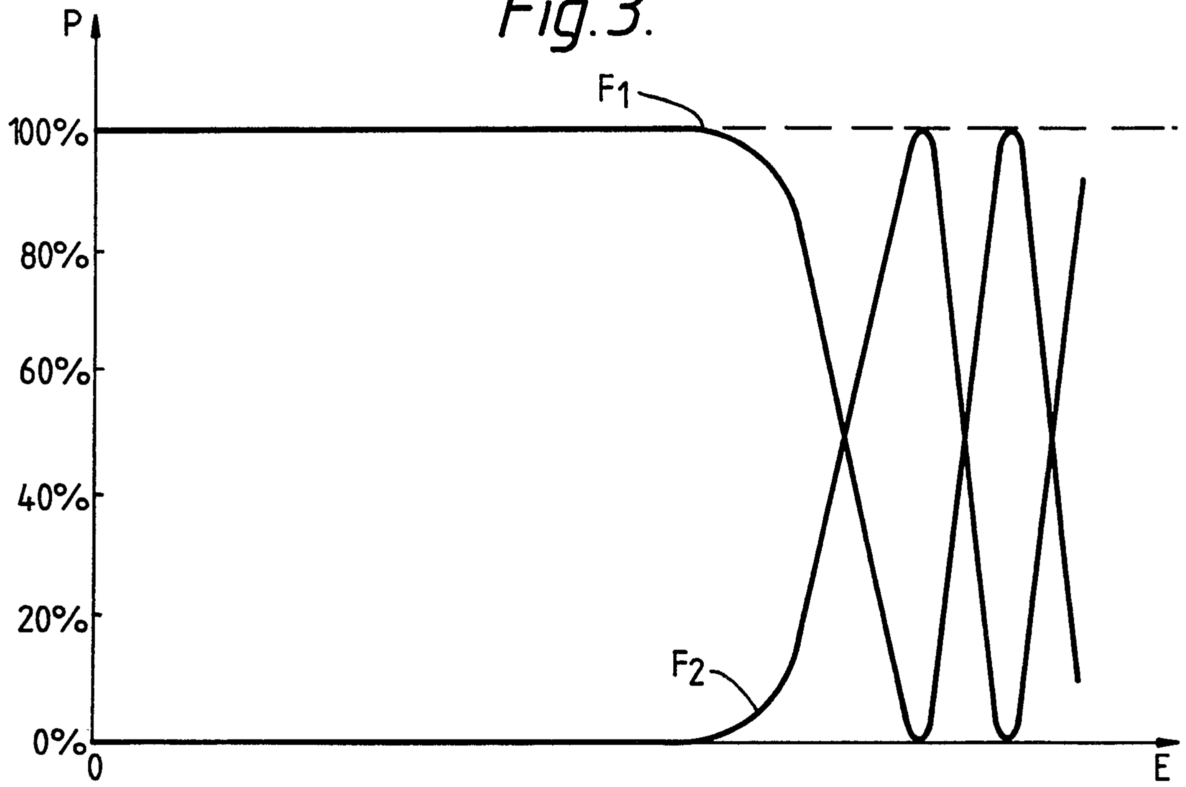

Fig.6.

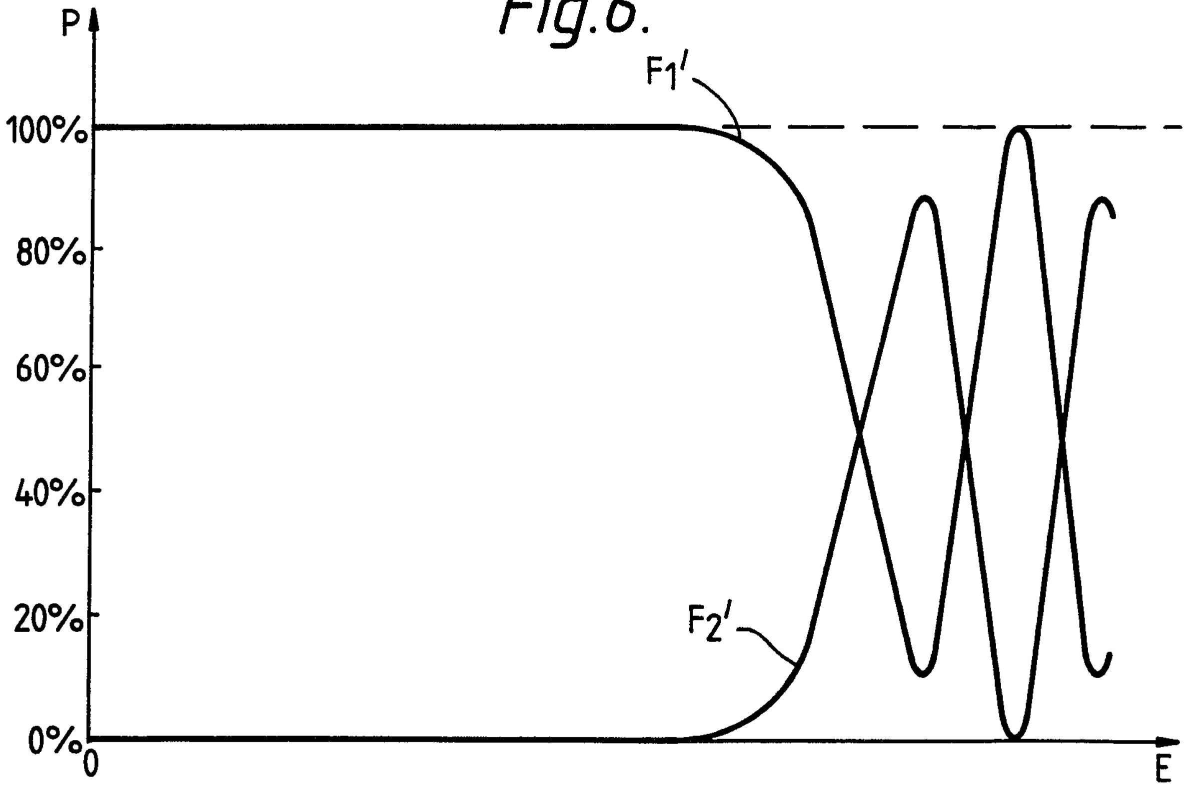

Fig.4.

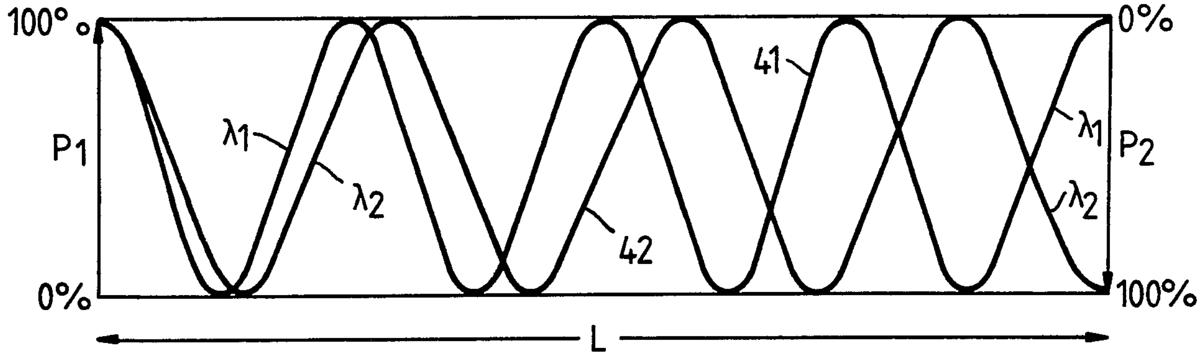

Fig.5.

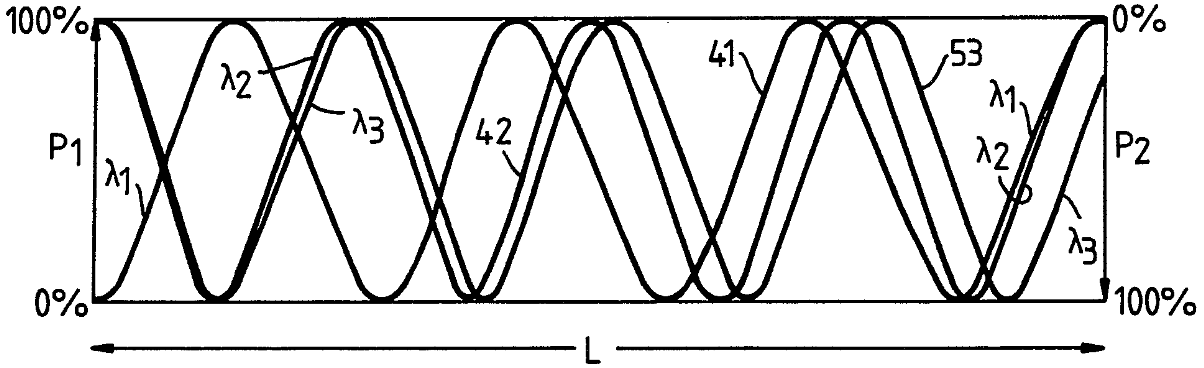

Fig.7.

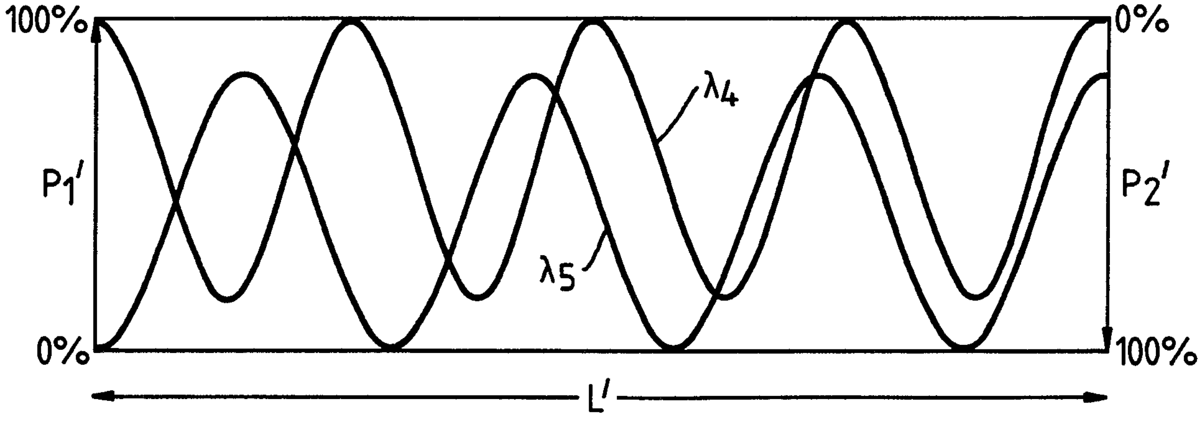

Fig. 8.

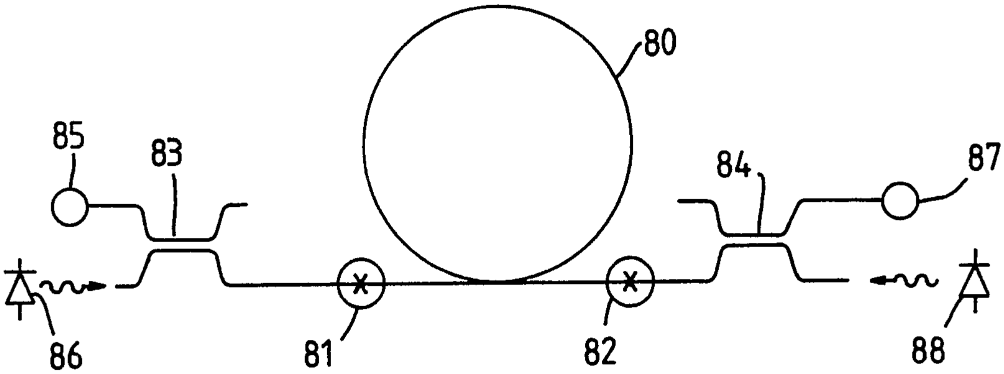

Fig. 9.

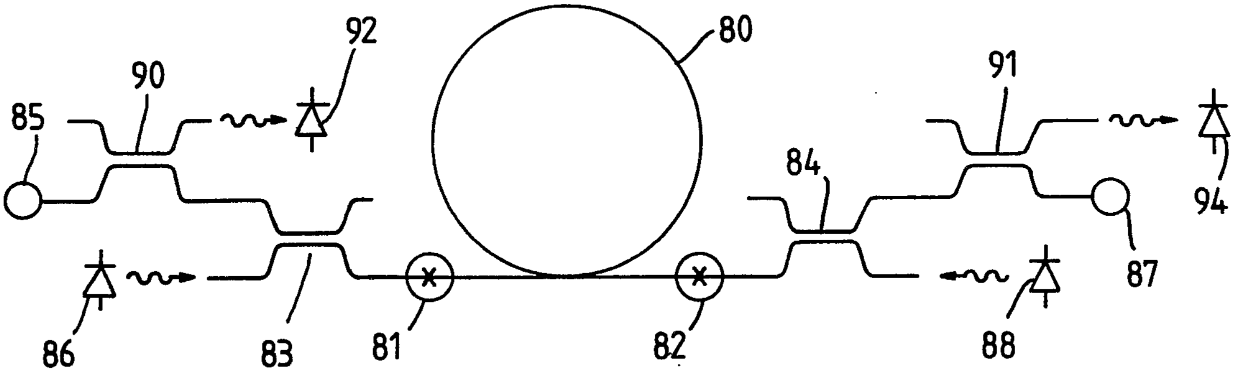

Fig.10.

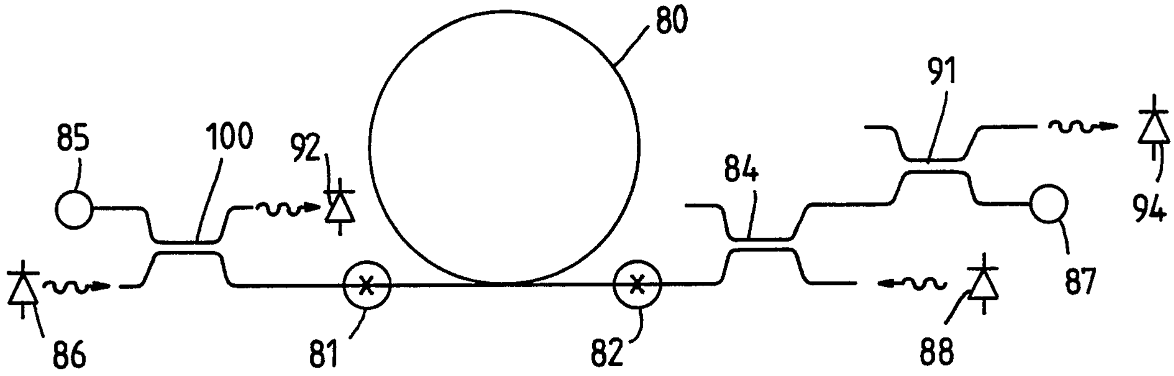
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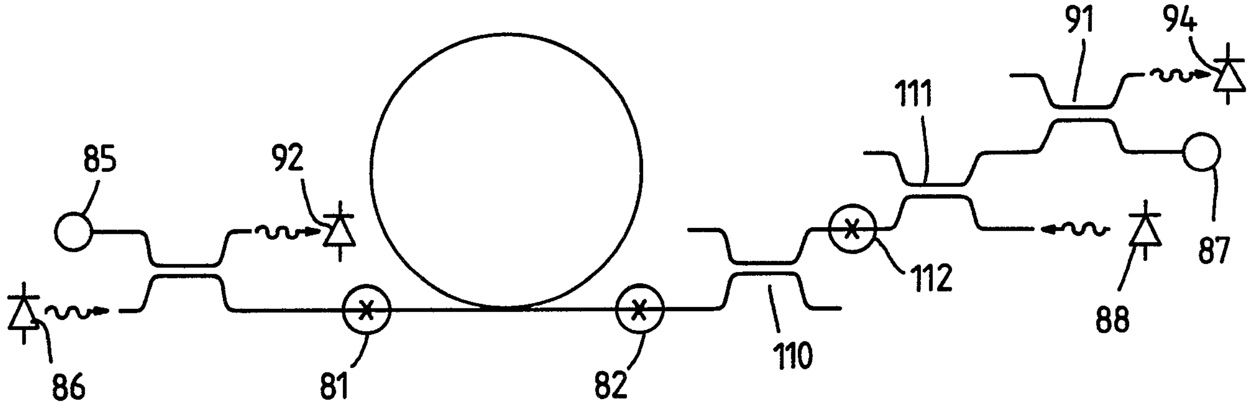
Fig.11.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MULTIPLEXING OPTICAL WAVEGUIDE COUPLERS

This invention relates to multiplexing optical waveguide couplers, and particularly, though not necessarily exclusively to 2 x 2 fused tapered optical fibre versions of such couplers. These couplers find particular but not necessarily exclusive application in the construction of optical fibre amplifiers.

Relatively close control over the optical coupling exhibited by a tapered fused fibre coupler can be provided by making such a coupler by the progressive stretching method of manufacture described in GB-B 2,150,703, to which attention is directed. In particular this progressive stretching method can be used to make, from pairs of lengths of optical fibre having matching propagation constants, frequency multiplexing 2 x 2 tapered fused fibre couplers with a high measure of reproduceability.

For many applications a wavelength multiplexing 2 x 2 coupler is required to have the property that power launched into a particular one of its two input ports at a particular first wavelength will emerge substantially exclusively from a particular one of its two output ports, while power launched into the other input port at a particular second wavelength will emerge similarly substantially exclusively from the same particular one of the two output ports. In this way two signals, respectively at the first and second wavelengths, can be applied to the coupler on separate ports to emerge with minimum loss from a common port, or alternatively, can be applied on a common port so as to emerge from separate ports. Such couplers will be termed 'total power' wavelength multiplexing couplers in order to distinguish them from certain other types of 2 x 2 wavelength multiplexing couplers to be described later.

Such 'total power' wavelength multiplexing couplers are, by their very nature, inherently wavelength sensitive devices, by which is meant that power that is launched into one input port of such a coupler will emerge from its two output ports in relative proportions that are functionally dependent upon the wavelength of that input power. An important additional characteristic of such 'total power' wavelength multiplexing couplers is that this wavelength sensitivity passes through zero at those wavelengths for which the optical power launched into one input port is transferred between the fibres an integral number of times to emerge substantially exclusively from either one of the two output ports.

For certain applications it is desirable to have a kind of 2 x 2 wavelength multiplexing coupler having the property that, if first and second signals of different wavelength are applied respectively to its two input ports, then substantially all of the first signal will emerge from one of its output ports together with the majority, but not all, of the second signal, thereby leaving the small residue of the second signal to emerge from the second output port. This small residue, which may for instance be required for monitoring purposes, is usually not much greater than 10%, is typically about 5%, but may be 2% or less. Such a function can be performed for signals of wavelengths λ_1, and λ_3 by a 'total power' wavelength multiplexing coupler designed for multiplexing wavelengths λ_1 and λ_2, where λ_3 is not too far removed in wavelength from λ_2, but is sufficiently far removed to be significantly beyond the region of zero wavelength sensitivity. The penalty of this approach is that the residual signal of wavelength λ_3 emerging from the second output will only exist if the wavelength sensitivity of the coupler at wavelength λ_3 is itself significant. This wavelength sensitivity is generally undesirable because it means that the proportion of the power tapped off into the second output is wavelength dependent.

The present invention is directed, in one aspect thereof, to a kind of wavelength multiplexing 2 x 2 tapered fused fibre coupler having the property that power launched into a particular one of its two input ports at a particular first wavelength will emerge substantially exclusively from a particular one of its two output ports, while the majority of power launched into the other input port at a particular second wavelength will similarly emerge from the same particular one of the two output ports, leaving the residual portion to emerge from the other output port. In addition the coupler shall have the property that its wavelength sensitivity at both the first and second wavelengths shall be substantially zero. Such couplers will be termed 'non-total power' wavelength multiplexing couplers in order to distinguish them from the 'total-power' ones referred to earlier. It will later be shown that the 'non-total power' couplers also have the property that the propagation constants of their two constituent fibres are unmatched in the coupling region, whereas in the case of the 'total-power' couplers these constants are matched.

According to the present invention there is provided a wavelength multiplexing 2 x 2 tapered fused fibre coupler constructed from first and second single mode fibres laterally optically coupled together in a coupling region of reduced cross-section, in which coupling region the propagation constant of one fibre is significantly different from that of the other such that power launched into the first fibre at a first frequency is transferred between the fibres zero or an even number of times in the coupling region to emerge substantially exclusively from the first fibre, while power launched into the second fibre at a second frequency is transferred between the fibres an odd number of times in the coupling region to provide a maximum power transfer to the first fibre while leaving a significant residual small portion of the second frequency power remaining in the second fibre.

The invention also provides an optical amplifier including a multiplexer for mixing optical signal power with optical pump power, which multiplexer includes a tapped signal power output, and includes two optical waveguides with mismatched propagation constants in a region where they are mutually coupled providing the multiplexer with the property that a proportion of any signal power launched into the multiplexer emerges from the tapped signal power output, and that a signal wavelength exits for which the proportion is a finite proportion, the wavelength sensitivity of which proportion is substantially zero at that signal wavelength.

There follows a description of the manufacture of wavelength 'non-total power' multiplexing couplers embodying the invention in preferred forms, and of the use of such couplers in optical fibre amplifiers. The description refers to the accompanying drawings, in which:-

Figures 1 and 2 schematically depict successive stages in the manufacture of a 'non-total power' wavelength multiplexing coupler,

Figure 3 depicts how, for a particular wavelength, power transfer in a coupler with matching propagation constants ('total power' coupler) varies as a function of extension in the course of manufacture,

Figures 4 and 5 depict how, for selected specific wavelengths, power transfer in the completed coupler of Figure 3 varies as a function of distance along the coupling region,

Figure 6 depicts how, for a particular wavelength, power transfer in the 'non-total power' coupler of Figures 1 and 2 varies as a function of extension in the course of manufacture,

Figure 7 depicts how for selected wavelengths, power transfer in the completed coupler of Figures 1, 2 and 6 varies as a function of distance along the coupling region,

Figure 8 is a diagram of a basic optical fibre amplifier,

Figure 9 is a diagram of the amplifier of Figure 8 modified to include a signal amplification monitoring facility, and

Figures 10 and 11 are diagrams depicting two ways in which the amplifier of Figure 9 can be implemented using couplers of Figures 1, 2, 6 and 7.

Using the method of GB-B 2,150,703, a single length 10 (Figure 1) of single mode optical fibre is subjected to a progressive stretching treatment in order to produce a pair of adiabatic of tapers 10a that link unstretched end portions 10b of the fibre with an intermediate stretched, and therefore reduced diameter, portion 10c. This is accomplished by tensioning the fibre between a pair of movable clamps 11 and 12 which are traversed at controlled rates in the axial direction of the fibre tensioned between them. A fine flame 13, issuing for instance from a length of hypodermic tubing 14, provides a relatively sharply localised hot zone in which the fibre is heat softened sufficiently to allow plastic flow. Both clamps are traversed at controlled rates in the same direction with respect to the flame 13, with the leading clamp being caused to move faster than the trailing clamp, as symbolised by arrows 15 and 16, so that the fibre is being continuously stretched by the differential movement of the traversal, this stretching being accommodated by the plastic flow localised in the region heat softened by the flame. The differential speed of the two clamps is typically no more than a few per cent of the speed of either one of them, and so several traverses are typically required to provide the requisite draw-down ratio. Successive stretching traverses may, as found convenient, either be performed in opposite directions, or be performed all in the same direction, but with a non-stretching traverse in the opposite direction, with the flame removed, interposed between each stretching traverse.

As a result of this stretching operation the propagation constant of the fibre in the reduced diameter portion 10c is significantly different from that in the unstretched end portions 10b. This stretching of fibre 10 may be referred to as the pre-tapering of fibre 10 in order to distinguish such tapering from any subsequent tapering of the fibre performed once it has been stranded with another fibre. Pre-tapering is only necessary when the two fibres from which the coupler is being made start out with identical propagation constants, but even they do not start out so, pre-tapering may still be required to adjust the amount of mismatch to a specific desired value.

The pre-tapered fibre 10 is stranded with a second length 20 (Figure 2) of single mode fibre whose propagation constant is unmatched with respect to that of the reduced diameter stretched portion 10c of fibre 10. Ths second length is typically identical in profile with the unstretched end portions 10a of fibre 10. The stranding together of the fibres 10 and 20 is preferably accomplished without twisting either fibre about its own axis since such twisting is liable to introduce unwanted birefringence into the completed coupler. The coupler is made by subjecting the twisted pair of fibres to a progressive stretching treatment substantially according to the method described in GB-B 2,150,703, and as described above with particular reference to Figure 1. The effects of this progressive stretching are first to introduce mutual optical coupling between the reduced diameter portion 10c of fibre 10 and fibre 20, and then to strengthen that coupling to form the device into a wavelength multiplexing coupler with the required optical properties.

The strengthening of the coupling between the fibres, as progressive stretching proceeds, can be monitored by injecting light of a chosen wavelength into one end of one of the fibres, and monitoring that which emerges from its far end, or that which emerges from the far end of the other fibre. For the case of a conventional coupler constructed from two fibres with matching propagation constants, trace 30 of Figure 3 depicts, as a function of extension, E, the percentage of light power, P, launched into one of the fibres, F_1, that reaches its far end, while trace 31 depicts the percentage transferred to emerge from the far end of the other fibre, F_2. It is seen from these two traces that the initial extension has no effect, with the two fibres remaining essentially uncoupled. Then as the extension proceeds further, mutual coupling commences and strengthens. The result is that power is progressively transferred to the other fibre, and then once total transfer has been effected, it is progressively transferred back again. (Total transfer of power from the first fibre to the second only occurs when the two fibres have matching propagation constants). This power transfer cycle is then repeated over and over again as the extension is progressively increased. The coupling is a function of wavelength, and so the total transfers of power will occur at different extensions for different wavelengths.

In the case of a coupler that has been made with an extension providing several power transfers the wavelength sensitivity is demonstrated in Figure 4 which depicts the power transfer as a function of distance along the coupling region, length L, of the coupler for a number of specific wavelengths. The plots of Figures 4, 5 and 7 assume their respective couplers to be lossless so that a single trace can at the same time represent the optical power, P_1, in one of its constituent two power, P_2, in its other fibre, as measured at the right hand scale. Trace 41 is in respect of a wavelength λ_1, for which there are eight complete transfers of power in proceeding the full coupling length of the coupler. Trace 42 is in respect of a shorter wavelength λ_2 which therefore is more tightly bound, and for which there are only seven complete transfers of power. From Figure 4 it is seen that optical power launched into either one of the fibres at the wavelength λ_1 emerges from the coupler substantially exclusively on the same fibre, whereas optical power launched into the same fibre at the wavelength λ_2 emerges substantially exclusively from the other fibre. Conversely, as depicted in Figure 5 (which is in respect of the same coupler as that of Figure 4), if a first signal at the wavelength λ_1 is launched into one of the fibres, while a second signal at the wavelength λ_2 is launched into the other, it is seen that the coupler acts to combine the two signals onto a common output fibre. Accordingly the coupler of Figures 4 and 5 is seen to function as a 'total power' wavelength multiplexing coupler for the wavelengths λ_1 and λ_2. Figure 5 includes an additional trace, trace 53 which is in respect of a wavelength λ_3 for which there are slightly less than eight power transfers in the full distance of the coupling length L of the coupler. From Figure 5 it is seen that with this coupler, if at one end of the coupler power at wavelength λ_1 is launched into one fibre, while power at wavelength λ_3 is launched into the other fibre then, at the other end of the coupler, substantially all the λ_1 wavelength power and most, but not all, of the λ_3 wavelength power emerge from the fibre into which the λ_3 wavelength power was launched, while the balance of the λ_3 wavelength power emerges from the fibre into which the λ_1 wavelength power was launched. The coupler is thus seen to act in some, but not all, ways like a 'non-total power' wavelength multiplexing coupler for wavelength λ_1, with wavelength λ_3. In particular the drawback of this type of coupler for achieving multiplexing at these two wavelengths is that the division of the wavelength λ_3 power between the two output ports of the coupler is relatively highly wavelength dependent (in contradistinction to a non-total power wavelength multiplexing coupler). This results from the fact that the gradient of the λ_3 wavelength trace 53 is not zero at the far end of the coupling region.

In the foregoing description relating specifically to Figures 3, 4 and 5, attention has been directed to couplers made from pairs of fibres having identical propagation constants in their coupling regions, but now attention will be reverted to the properties of couplers, such as the one described above with reference to Figures 1 and 2, whose fibres have unmatched propagation constants in their coupling regions. Like Figure 3, Figure 6 depicts how, in the making of a coupler, the transfer of power between the two fibres varies with extension, but in the case of Figure 6 the two fibres have non-matching propagation constants in the coupling region. In consequence the transfer of power from the transfer of power from the first fibre, F'_1 to the other, F'_2, never reaches totality, but instead passes through a series of maxima each of which is short of totality by an amount dependent upon the degree of mismatch. Between each pair of maxima there is a minimum at which the power is transferred substantially totally back to fibre F'_1. Figure 7 depicts how the completed coupler of Figures 1, 2 and 6, of coupling length L', responds to the launching of power of wavelength λ_4 and λ_5 respectively into its two fibre inputs. The coupling wavelengths λ_4 and λ_5 are at the specific wavelengths for which the coupling strength is such that for wavelength λ_4 there have been four complete cycles of transfer of power between the two fibres in the course of its passage down the full coupling length L' of the coupler, while for wavelength λ_5 there have been three and a half cycles. Figure 7 shows that this coupler acts as a 'non-total power' wavelength multiplexing coupler for the wavelength λ_4 with wavelength λ_5, and that in contradistinction to the coupler described with reference to Figures 3, 4 and 5 the wavelength sensitivity of the division of the wavelength λ_5 power between the two output ports of the coupler is at a minimum because the gradient of the λ_5 wavelength trace is zero at the far end of the coupling region.

In the making of a coupler, by the method described above with particular reference to Figures 1 and 2, to achieve a non-total power wavelength multiplexing coupler for multiplexing two specific wavelengths λ_A and λ_B, it will be clear that it is a straightforward matter to terminate the extension at a point where light of wavelength λ_A launched into one of its fibres will emerge substantially exclusively from the far end of that fibre. All that this requires is to launch light of that wavelength into the fibre, to monitor the resulting output from the other fibre as the coupler is being made, and then to halt the extension at one of the constants at which the monitored power drops substantially to zero. If for instance extension is halted at the fourth time the monitored power drops to zero, corresponding to the right hand edge of Figure 7 ($\lambda_A = \lambda_4$), then there is a specific wavelength, λ_5, for which the power transfer is not at the fourth minimum, but instead is at its maximum value between the third and fourth minima. It will however be quite by chance if this λ_5 registers with the required λ_B. On the other hand, when constructing the coupler it is found that, as extension proceeds, the difference in wavelength between that for which the power transfer is at the n^{th} minimum, and that for which the power transfer is at its maximum between the $(n-1)^{th}$ and the n^{th} minimum, is steadily reduced as the value of the integer n is increased. Therefore it is possible to select an appropriate value of n to provide a relatively close approximation to the desired wavelength separation, and then to modify the drawing conditions, for instance by changing the lengths of the traverses or the temperature produced by the flame 13, so as to fine-tune the coupling efficient to provide the required wavelength separation to the desired accuracy.

The foregoing specific description has been particularly directed to the construction of wavelength multiplexing couplers to multiplex power at a first wavelength with power at a second wavelength in the specific way that involves the first wavelength power making 2N transfers between the fibres while the second wavelength power makes (2N-1). This implies that the first wavelength power is less strongly bound than the second wavelength power, which in turn implies that the first wavelength is longer than the second wavelength. In the case of a 'non-total power' wavelength multiplexing coupler, it is specifically only the second wavelength power, the shorter wavelength power, that makes the odd number of transfers, that is divided between both outputs. However the multiplexer will also act as a non-total power wavelength multiplexing coupler for multiplexing power at the first wavelength (that makes 2N transfers) with power at a third wavelength that makes (2N = 1) transfers. This third wavelength is less strongly bound than the first wavelength, and hence is a longer wavelength, and since it is a wavelength that makes an odd number of transfers in a 'non-total power' coupler power at this third wavelength is divided between both outputs. Thus it is seen that a 'non-total power' wavelength multiplexing coupler can be constructed for division either of the longer, or of the shorter, wavelength. A special case of division of the longer wavelength is when 2N = 0. In this instance the coupling between the fibres at the third (longer) wavelength is just strong enough for the third wavelength power to make its single transfer, whereas the first (shorter) wavelength is so much shorter, and hence so much more tightly bound to the fibre into which it is launched, that it passes straight through the coupler without transfer.

A particular application of 'non-total power' wavelength frequency multiplexing couplers is in the construction of optical fibre amplifiers. A configuration of prior art optical fibre amplifier is depicted in Figure 8, and consists of a length 80 of amplifying fibre spliced at 81 and 82 between a pair of 'total power' wavelength multiplexing couplers 83 and 84 which multiplex the signal wavelength with the pump wavelength. The input signal to be amplified is applied to port 85 of coupler 83, while pump power for the amplifier from a laser diode 86 is applied to the other input port for co-pumping of the fibre 80. Similarly the output of the amplifier is taken from port 87 of coupler 84, while optical power for counter-pumping is applied to it from a laser diode 88. The amplifier just described is both co-pumped and counter-pumped, but if pumping from only one end is desired one of the couplers and its associated laser diode is dispensed with. For many applications it is desirable to monitor the performance of the amplifier by extracting a portion of the signal input to the amplifier, and comparing it with an extracted portion of the amplified signal delivered to its output. This may be achieved, as depicted in

Figure 9, by the addition to the amplifier of Figure 8 of a pair of monitor couplers 90 and 91, and a pair of monitor photodiodes 92 and 93. The monitor implies 90 and 91 may be 2 x 2 tapered fused fibre couplers made by the progressive stretching method of GB-B 2,150,703, but in which the extension is halted shortly after mutual lateral coupling has just been established so that only a small proportion of any power coupling in either fibre is transferred to the other. As a consequence of the small amount of coupling, the wavelength sensitivity of the coupling is also correspondingly small, and is not significant in relation to the spectral width of the amplification band of the amplifier.

A single 'non-total power'wavelength multiplexing coupler 100, which is multiplexing at the signal and pump wavelengths, can be substituted, as depicted in Figure 10, for the tandem arrangement of the monitor coupler 90 and 'total power' wavelength coupler 83 to provide a saving in component count, together with the possibility of a reduced insertion loss.

For reasons of achieving good amplification efficiency, the amplifying typically fibre has the same size as, but an index profile significantly different from, that of the fibre used elsewhere for the transmission of the signal. Simple butt splices at 81 and 82 between amplifying index profile fibre and signal transmission index profile fibre are liable to produce excessive loss, but this loss can be reduced by heating of the fibres in the neighbourhood of such splices so as to promote diffusion of their cores, and hence a reduction of the effective mismatch. If this diffusion technique is employed, then each of the couplers of Figure 10 can be made from a pair of signal transmission index profile fibres having matching propagation constants, remembering that in the case of coupler 100, (which is a 'non-total power' wavelength multiplexing coupler), one of its two constituent fibres needs to have been pretapered so as to produce a pre-stretched region in which the propagation constant of this fibre is mismatched the requisite amount in relation to that of the other fibre.

An alternative approach to the profile mismatch problem, and one which is described in British Patent Application No. 9213713.2, involves the construction of couplers from pairs of dissimilar index profile fibres. Application No. 9213713.2 describes how a 2 x 2 coupler can be made from a length of signal transmission index profile fibre and a length of amplifying index profile fibre, the particular method of manufacture described being the progressive stretching method of GB-B 2,150,703 modified by the pre-tapering of the signal transmission type fibre so as to provide it with a propagation constant that, in the coupling region of the coupler in which it is optically coupled with the amplifying index profile fibre, matches that of that amplifying index profile fibre. It may be noted that in such a coupler the amplifying index profile fibre has to have substantially the same index profile as that of the actual amplifying fibre to which it is spliced, but does not itself need to incorporate any dopant that would actually render it capable of acting as amplifying fibre.

Applying this alternative approach to the profile mismatch problem of Application No. 9213713.2, with suitable modification, the amplifier of Figure 10 may have its monitor coupler 91 constructed from a pair of signal transmission index profile fibres with matching propagation constants, and its 'total power' wavelength multiplexing coupler 84 and its 'non-total power' wavelength multiplexing coupler 100 each constructed from a length of signal transmission index profile fibre and a length of amplifying index profile fibre. In the case of the 'total power' wavelength multiplexing coupler 84, the length of signal transmission index profile fibre, which is the fibre terminating in port 87, is pre-tapered so as to provide it with a pre-stretched region with a propagation constant that in the coupling region of the coupler in which it is optically coupled with the amplifying index profile fibre, matches that of that amplifying index profile fibre, which is spliced at 82 to the amplifying fibre 80. In the case of the 'non-total power' wavelength multiplexing coupler 100, the length of signal transmission index profile fibre, which is the fibre terminating in port 85, does not need to be pre-tapered in order to produce the propagation constant mismatch necessary for the construction of a 'non-total power' wavelength multiplexing coupler. On the other hand the amount of mismatch thereby provided may not be such as to provide the requisite division of the signal power between the amplifying fibre 80 and the monitor photodiode 92, in which case one or other of the two fibres will need pre-tapering to make the appropriate adjustment.

If the pump and signal wavelengths are widely separated, such as for instance using light at a wavelength of 980 nm to pump a signal at a wavelength of 1550 nm, the construction of the 2 x 2 couplers 84 and 100 from dissimilar index profile fibres is relatively simple because they can be made as couplers for which the number of power transfers at the pump and signal wavelengths are respectively 0 and 1. At this comparatively low strength of coupling the form birefringence is small enough to make the transfer of signal power between the fibres substantially independent of the state of polarisation of that signal power.

If the pump and signal wavelengths are much closer, for instance using light at a wavelength of 1480 nm to pump a signal at a wavelength of 1550 nm, then the construction of the couplers 84 and 100 needs to be rather more complicated because, if the coupling between the fibres is strong enough to transfer most or all of the signal power from the signal transmission index profile fibre to the amplifying index profile fibre, or vice versa, it will also be strong enough to effect significant transfer of power between the fibres at the only slightly shorter wavelength of the pump power. The required wavelength selectivity is achieved by choice of a larger value of N for the numbers, 2N and (2N + 1), of power transfers occurring in the coupler at the pump and signal wavelengths. The stronger mutual coupling between the fibres that is implied by this means that the effects of form birefringence can no longer be neglected if the amplifier is to operate independent of the state of polarisation of its signal input.

Significant birefringence in a progressively stretched fused fibre coupler normally arises because the stretching is normally performed at a high enough temperature to provide a substantial coalescence of the two fibres so as to convert the highly re-entrant initial figure eight configuration of cross-section to one in which the re-entrance is minimal or non-existant. If the amount of coupling between the two fibres is relatively weak, as for instance in the case of a coupler providing only a single transfer of power between the fibres, then the amount of form birefringence of a coupler made at a temperature producing substantial coalescence of the fibres is small enough to be neglected, but with stronger coupling involving multiple power transfers, the form birefringence assumes greater signficance. The result is that, if form birefringence is not compensated, the coupler can be constructed so as to transfer power efficiently for either one of the principal states of polarisation of that coupler, but not both states together. Our method of reducing the effect of form birefringence, and hence of obviating this problem, is described by I.J. Wilkinson and C.J. Rowe in an article entitled "Close Spaced Fused Fibre Wavelength Division Multiplexer with very low Polarisation Sensitivity", Journal Elec. Letters March 1990. Vol 26, No. 6 p382, and involves twisting of the fibres. Another method involves performing the progressive stretching operation at a significantly lower temperature, one in which the fibres become united over only a small proportion of their circumference, and thus retain a cross-sectional configuration more closely approximately to a figure eight. It is believed that this is effective in reducing the effect of form birefringence by matching it with an oppositely directed stress birefringence.

At least in the case of reducing the effects of form birefringence through reducing the temperature at which the coupler is made, the reduction of the effect of form birefringence is brought about at the expense of introducing another factor, namely that the propagation constants of the two fibres in the coupling region are also effected. In the case of a 'total power' wavelength multiplexing coupler constructed from a pair of identical fibres with matching propagation constants in its coupling region, this is no particular problem because any such effects will apply equally to both fibres, and hence will not disturb a pre-existing match. This will not generally apply in respect of couplers constructed from dissimilar fibres. In the case of a 'non-total power' wavelength multiplexing coupler, such as the coupler 100 of Figure 10, any differential effect can usually be accommodated in the design because a match of propagation constants is specifically not required, whereas in the case of a 'total power' coupler, such as a coupler 84 of Figure 10 made from dissimilar fibres, any differential effect can be more difficult to accommodate. In this instance the change in propagation constants will not in general be the same for both fibres, with the result that a match is not preserved over the full range of possible temperatures for constructing the coupler. In other words, a double match has to be obtained, in that it is necessary not only to make this coupler at the temperature which cancels out the form birefringence, but also to pre-stretch one of the fibres so that its propagation constant is matched with the other. If it is desired not to go to the trouble of achieving this double match, the need for it can be avoided by making the splice 82 a diffused splice between amplifying index profile fibre on its amplifier 80 side and signal transmission index profile fibre on its coupler 84 side so as to be able to make the coupler 84 from a pair of signal transmission index profile fibres. An alternative method of avoidance is the same as that which is described with particular reference to Figure 2 of Application No. 9213713.2, and involves retaining the splice 82 as a simple splice between two lengths of amplifying index profile fibre, and replacing the single coupler 84 of Figure 10 with a concatenated pair of 2 x 2 couplers 110 and 111 as depicted in Figure 11.

Coupler 110 is a fibre coupler constructed from a length of amplifying index profile fibre, that is spliced at 82 with the amplifying fibre 80, and a length of signal transmission index profile fibre that is spliced at 112 with the coupler 111. The signal transmission index profile fibre of coupler 110 is pre-stretched in order that its propagation constant matches that of the amplifying index profile fibre in the coupling region so that all the power from the amplifying fibre 80 is transferred across to the signal transmission index profile fibre. Unlike the couplers 84 of Figures 9 and 10, it is not a wavelength multiplexing coupler designed to multiplex the signal and pump wavelengths, instead it is a 'splice' coupler in which only a single power transfer is made in the whole length of its coupling region. In consequence the coupling between the fibres in this coupler is relatively weak, and as a result the effects of form birefringence are too small to be significant. Coupler 111 is a conventional 'total power' wavelength multiplexing coupler made from two signal transmission index profile fibres with matching propagation constants.

CLAIMS.

1. A wavelength multiplexing 2 x 2 tapered fused fibre coupler constructed from first and second single mode fibres laterally optically coupled together in a coupling region of reduced cross-section, in which coupling region the propagation constant of one fibre is significantly different from that of the other such that power launched into the first fibre at a first frequency is transferred between the fibres zero or an even number of times in the coupling region to emerge substantially exclusively from the first fibre, while power launched into the second fibre at a second frequency is transferred between the fibres an odd number of times in the coupling region to provide a maximum power transfer to the first fibre while leaving a significant residual small portion of the second frequency power remaining in the second fibre.

2. A tapered fused fibre coupler as claimed in claim 1, wherein one of said first and second fibres is tapered more than the other.

3. A tapered fused fibre coupler as claimed in claim 2, wherein on the sides of the tapers remote from the coupling region said first and second fibre have substantially matching propagation constants.

4. A tapered fused fibre coupler substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

5. An optical fibre amplifier including a tapered fused fibre coupler as claimed in any preceding claim.

6. An optical amplifier including a multiplexer for mixing optical signal power with optical pump power, which multiplexer includes a tapped signal power output, and includes two optical waveguides with mismatched propagation constants in a region where they are mutually coupled providing the multiplexer with the property that a proportion of any signal power launched into the

multiplexer emerges from the tapped signal power output, and that a signal wavelength exits for which the proportion is a finite proportion, the wavelength sensitivity of which proportion is substantially zero at that signal wavelength.

7. An optical fibre amplifier substantially as hereinbefore described with reference to Figures 10 and 11 of the accompanying drawings.

Amendments to the claims have been filed as follows

1. A wavelength multiplexing 2 x 2 tapered fused fibre coupler constructed from first and second single mode fibres laterally optically coupled together in a coupling region of reduced cross-section, in which coupling region the propagation constant of one fibre is significantly different from that of the other such that power launched into the first fibre at a first frequency is transferred between the fibres zero or an even number of times in the coupling region to emerge substantially exclusively from the first fibre, while power launched into the second fibre at a second frequency is transferred between the fibres an odd number of times in the coupling region to provide a maximum power transfer to the first fibre while leaving a significant residual small portion of the second frequency power remaining in the second fibre.

2. A tapered fused fibre coupler as claimed in claim 1, wherein one of said first and second fibres is tapered more than the other.

3. A tapered fused fibre coupler as claimed in claim 2, wherein on the sides of the tapers remote from the coupling region said first and second fibre have substantially matching propagation constants.

4. A tapered fused fibre coupler substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

5. An optical fibre amplifier including a tapered fused fibre coupler as claimed in any preceding claim.

6. An optical amplifier including a multiplexer for mixing optical signal power with optical pump power, which multiplexer includes a tapped signal power output, and includes two optical waveguides with mismatched propagation constants in a region where they are mutually coupled providing the multiplexer with the property that a proportion of any signal power launched into the

multiplexer emerges from the tapped signal power output, and that a signal wavelength exists for which the proportion is a finite proportion, the wavelength sensitivity of which proportion is substantially zero at that signal wavelength.

7. An optical fibre amplifier substantially as hereinbefore described with reference to Figures 10 and 11 of the accompanying drawings.

Patents Act 1977

Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

GB 9225186.7

Relevant Technical fields

(i) UK Cl (Edition K) G2J - JGEC

(ii) Int Cl (Edition 5) G02B

Databases (see over)

(i) UK Patent Office

(ii)

Search Examiner

M J PRICE

Date of Search

16 FEBRUARY 1993

Documents considered relevant following a search in respect of claims 1 TO 5

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB A 2191597 (PLESSEY) see eg Figures 1-3	1 at least
X	GB A 2170920 (STC) see eg Figure 4	1 at least
X	EP 0418872 (JAPAN) see eg the Figures	1 at least
X	US 4307933 (GD) see eg Figure 8	1 at least
X	US 4301543 (GD) see eg Figure 3	1 at least

		to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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