present severe radiation losses both in the vertex and during propagation in the tilted waveguide. Moreover, alignment of the input fiber optical is essential. As far as power transmitted to the propagating mode is concerned, an inappropriate alignment could cause much higher losses or even asymmetrical power splitting in the Y-junctions. This latter fact would be of extreme importance if Mach-Zehnder interferometers were done, since it would cause an important contrast reduction.

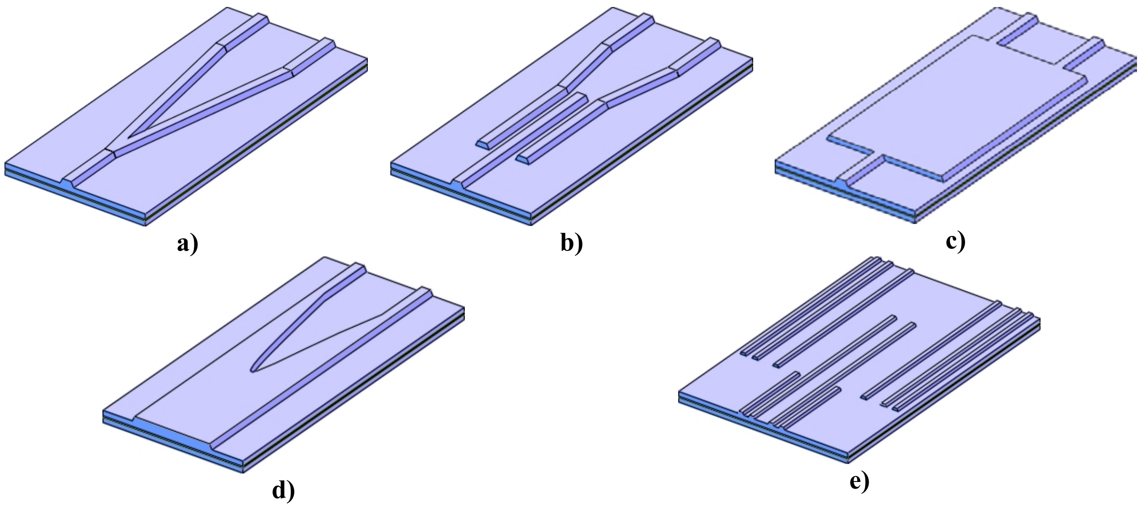

Fig 4.22. Different power splitters in integrated optics: a) Standard Y-junction b) 1x2 rib-directional coupler, c) 1x2 MMI, d) Parabolic-shaped structure, e) 1x2 ARROW-2D directional coupler.

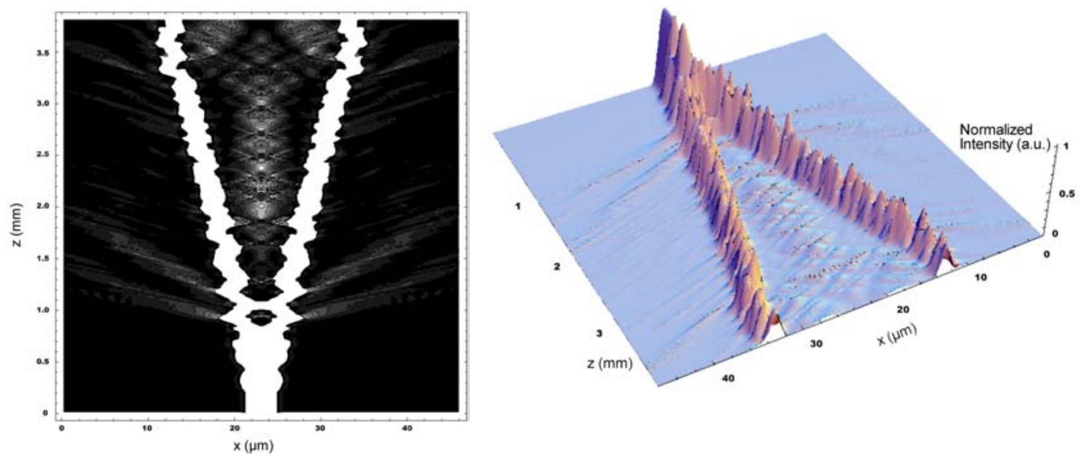

Fig 4.23. BPM simulation of a straight Y-Junction with 5º aperture angle between monomode waveguides and considering a 2μm blunted vertex.

An alternative approach that overcomes the effect of the radiation losses and the blunted vertex is the replacement of the Y-junction by 1x2 rib directional couplers (fig. 4.24). If the two output waveguides are equal and the distance between the input and the output waveguides is the same, a 3dB power splitting will always be obtained. There exists, however, some drawbacks on this structure. Firstly, it requires quite long distance so as to completely transfer light to the output waveguides. Secondly, since coupling between rib waveguides can only be done at short distances (<10μm), it is necessary to use tilted or bent waveguides after the directional coupler, that causes an increase of the losses. Misalignment in the input waveguide will cause a minor power transferred to the outer waveguides and a small unbalance between the transmitted power. Moreover, as opposite to the Y-branch, it only acts as a 3dB splitter for a given wavelength.

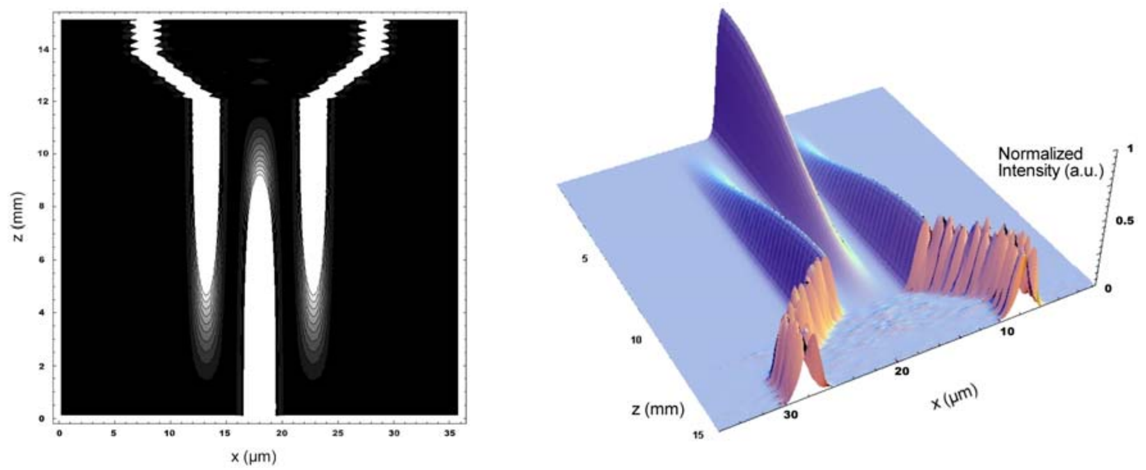

Fig 4.24. BPM simulation of a 1x2 directional coupler 3dB splitter device.

Multimode interference couplers can also be used as power splitters, as shown in fig. 4.25. Under a 1x2 configuration, it is relatively easy to obtain 3dB splitting with relatively short distances and with nearly no losses. On the other hand, it only has 3dB properties for a given wavelength and MMI properties are critical both in dimensions and in light injection positioning. Moreover, as the distance between the output waveguides increases, the MMI width should increase accordingly, being its fabrication parameters more restrictive. Maybe the optimum configuration would consist in a relatively narrow MMI and tilted outer waveguides that split them until the required distance.

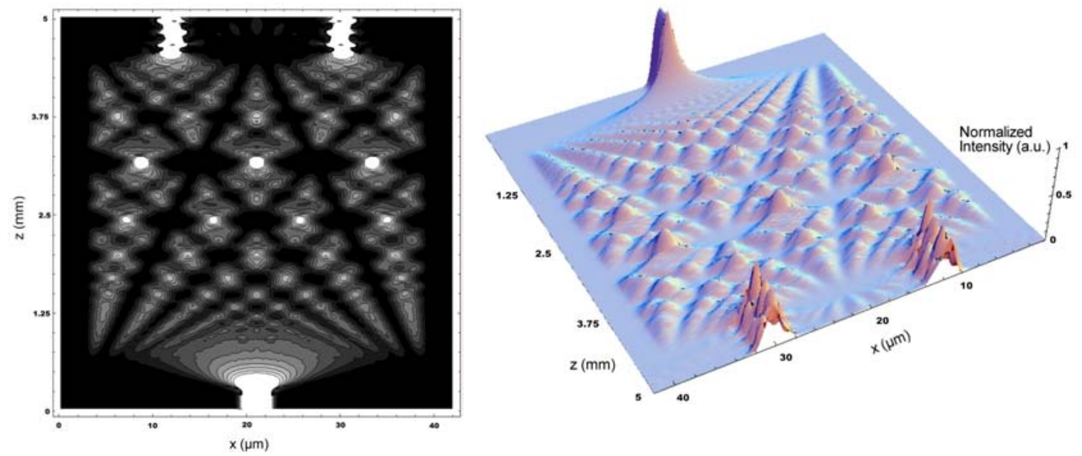

Fig 4.25. BPM simulation of a 1x2 MMI for power splitting purposes.

All the previously described configurations require a very precise alignment between the fiber optics and the input monomode waveguide. This problem can be overcome using a highly multimode waveguide for the input waveguide. As can be observed in fig. 4.26, power injected is decomposed as a function of the waveguide modes. If the input Gaussian beam is width enough, multimode interferences are significantly distorted and homogeneous wavefront is obtained. Thus, aligning becomes less critical, since small displacements does not cause significant variations on the wavefront.

It has been reported that elliptic **[14]** and parabolic **[15]** shaped multimode regions are able to provide with flat spectral response and minor losses as compared to straight tilted waveguides. Concerning parabolic structures, the standard device presented in the literature consists on a single mode waveguide that injects light on the edge of a parabolically-shaped multimode region. This configuration can also be reversed, that is, light could be injected from a broad region and the guiding structure could get progressively thinner, following a parabola. This configuration, which we have labeled as U-junction, could also be understood as a tapered waveguide or, more properly, a parabolically-shaped MMI. It can be observed in. 4.26 how, in each parabolic horn, there exist lengths where asymmetrical 1x3 and 1x2 splitting could be obtained, confirming its MMI behavior. As far as power splitting is concerned, it can be seen that the losses are significantly minimized as compared to straight waveguides. The previously mentioned easy aligning and the extremely small distance required for power splitting makes of this configuration one of the most promising structures in integrated optics.

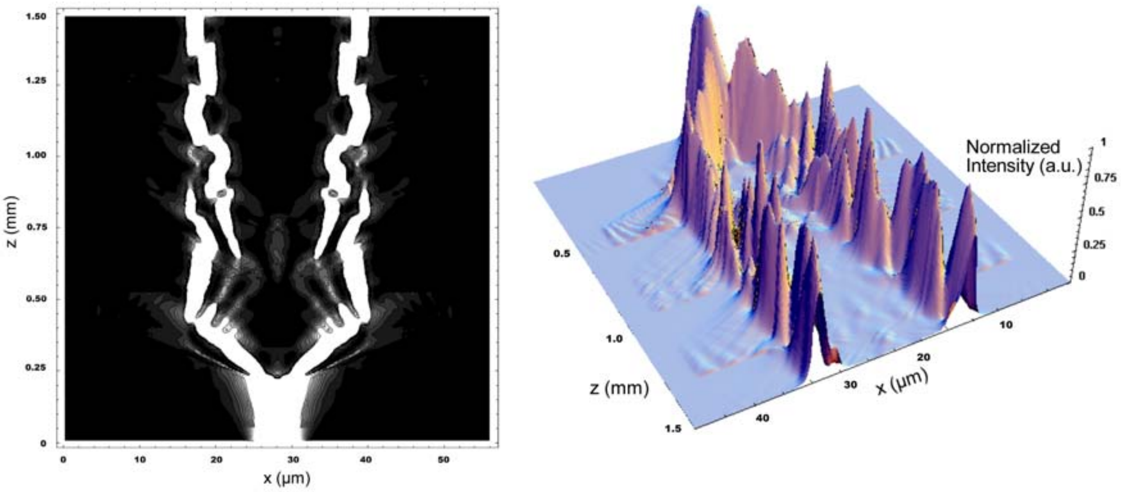

Fig 4.26. BPM simulation of a parabolic U-junction.

So far, all presented structures have been tested for 30µm-separation between output waveguides. In a practical situation, however, they would be distanced some hundred microns, that would cause a significant increase of the device total size. It has been previously shown that ARROW-2D directional couplers do not depend on the distance between waveguides, since coupling is produced by ways of leaky waves. Thus, using exactly the same configuration of 1x2 directional couplers, but adapted to ARROW-2D structures, a long-distance 3dB power splitter can be obtained. As can be seen in fig. 4.27, there exists some drawbacks on this structure. Firstly, not all the power is transmitted to the outer waveguides, since a certain amount is confined on the lateral antiresonant structures. Moreover, It should be taken into account that even if the lateral antiresonant structures of the input waveguide were removed, there could still be remote coupling between the output waveguides. Generally, power interchange is only desired at concrete zones. In order to avoid uncontrolled remote coupling, a shielding structure, as could be a trench, should be placed between the two output waveguides, but it will require a second mask level.

During all this subsection, Several new and well-known 3dB power-splitting structures that overcome the problems of the standard Y-junctions have been presented. Some of their most significant properties can be seen and compared in table 4.4.

Reasons why choosing a certain configuration will depend on the concrete application in which the 3dB splitter will be applied. As a rule, when small distances between the output waveguides are to be obtained, it is more desirable to work with directional couplers or MMI. For large splitting distance, a Y-junction or a parabolic (U-) junction will presumably provide with more satisfactory results.

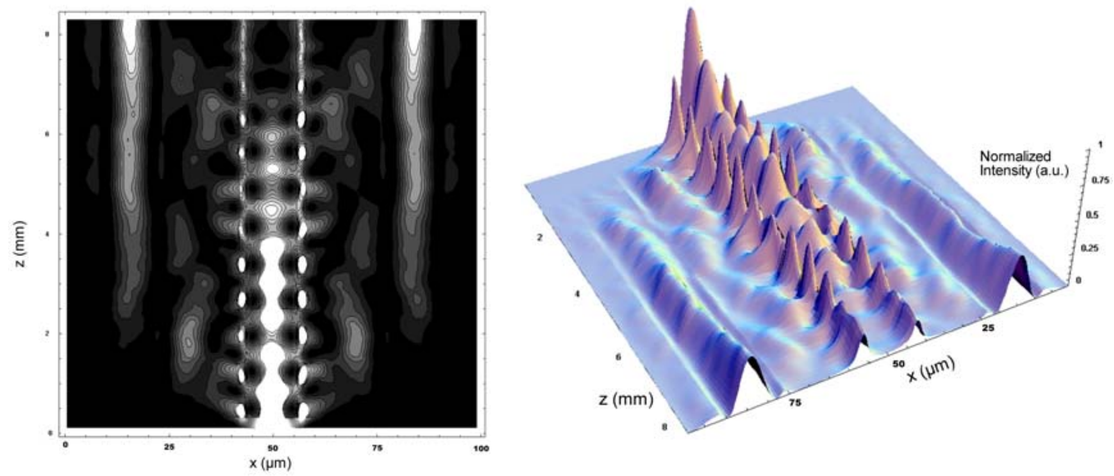

Fig 4.27. BPM simulation of a ARROW-2D 3dB power splitter.

	Straight Y-Junction	**Rib 1x2 Directional Coupler**	**1x2 MMI**	**Parabolic 3dB Splitter (U-Junction)**	**ARROW-2D Directional Coupler**
Total Length (mm)	3	15	4	1.5	8
Losses (dB)	3.3	1.2	0.2	1.6	3.0
Unbalance	Uncontrolled	No	No	No	No
Required alignment precision	High	High	High	Low	High
Blunted vertex	Yes	No vertex	No vertex	No	No vertex
Main drawbacks	Blunted vertex	Small distance between waveguides	Critical dimensions	Not observed	Large distances required
Wavelength-selective	No	Yes	Yes	No	Yes

Table 4.4: Comparison between the different power splitters presented in this subsection.