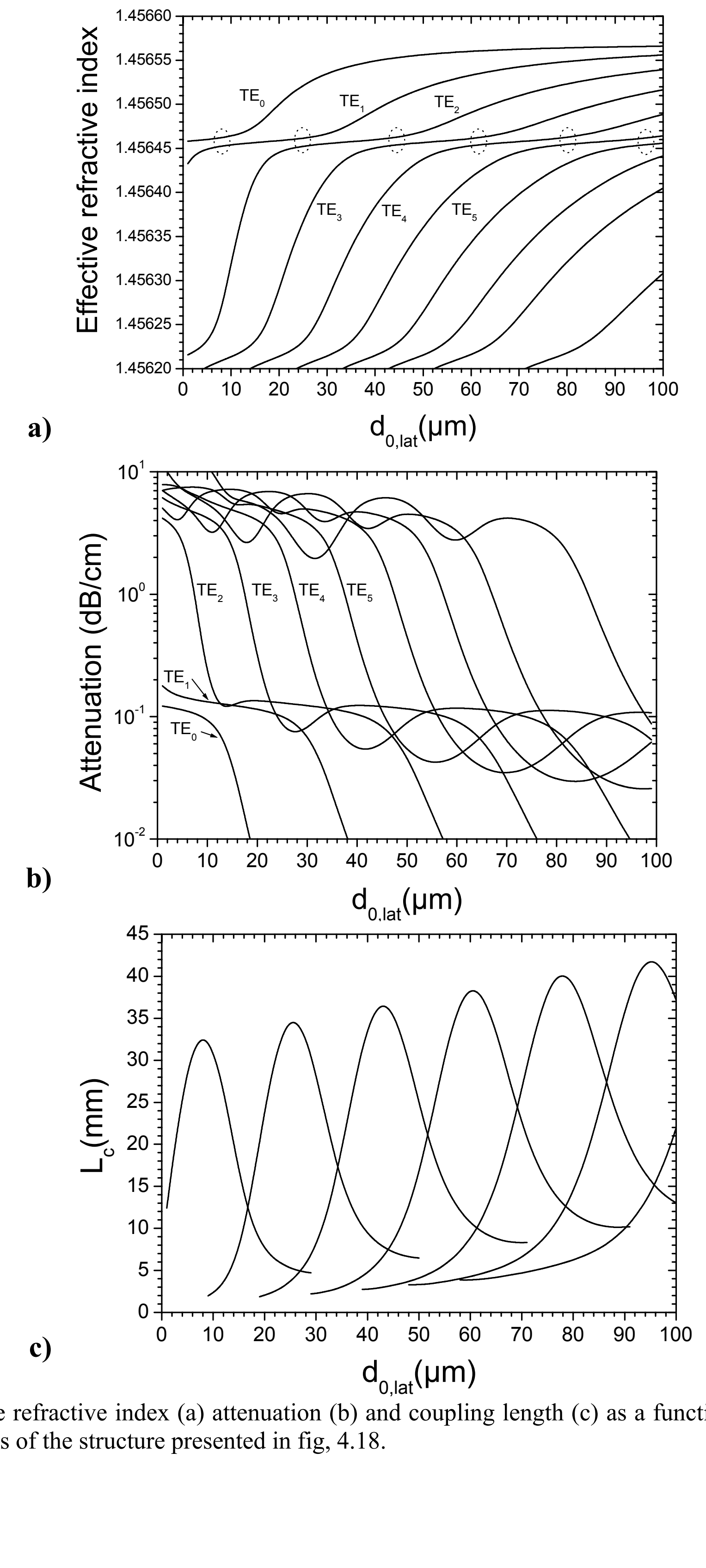
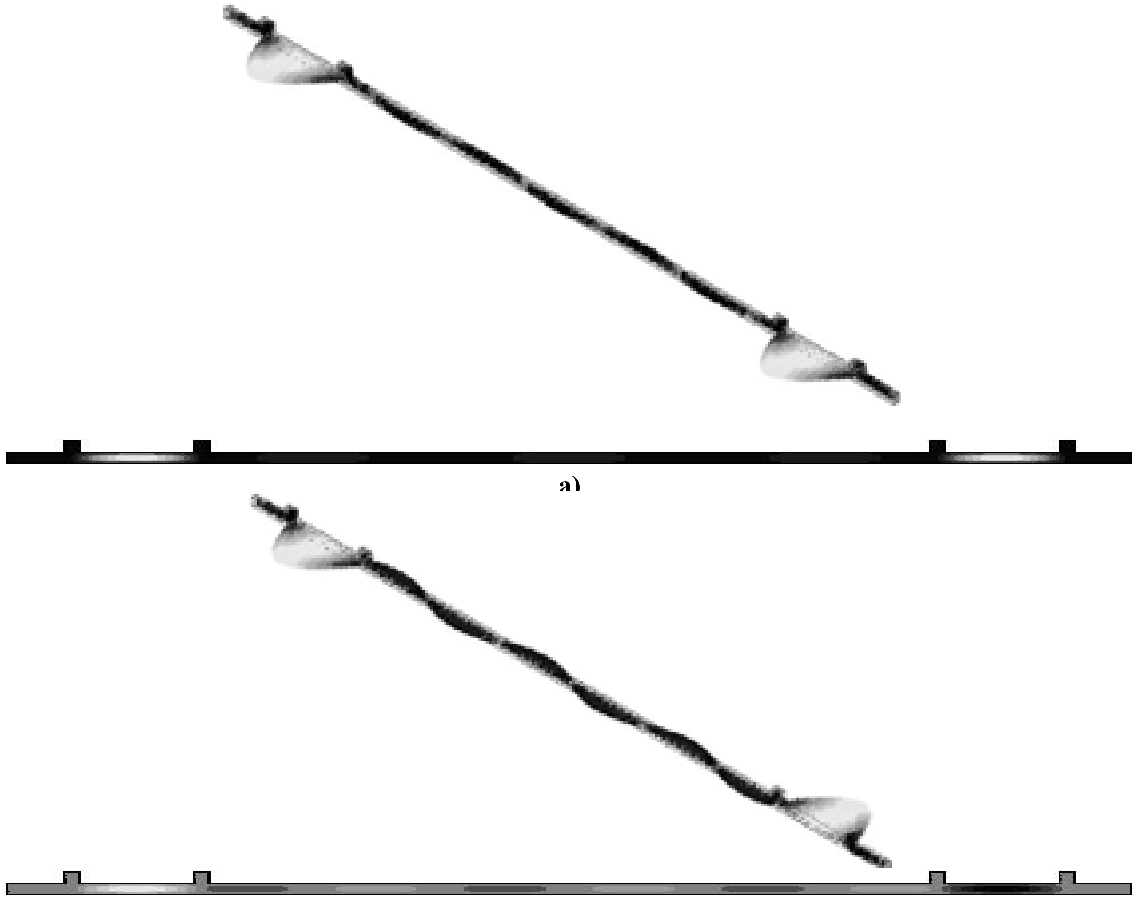


Fig 4.19. Effective refractive index (a) attenuation (b) and coupling length (c) as a function of d_0 for the lowest order modes of the structure presented in fig, 4.18.



a)

b)

Fig 4.20. Symmetrical (a) and asymmetrical (b) modes of a remotely-coupled ARROW-2D structures, forming a directional coupler.

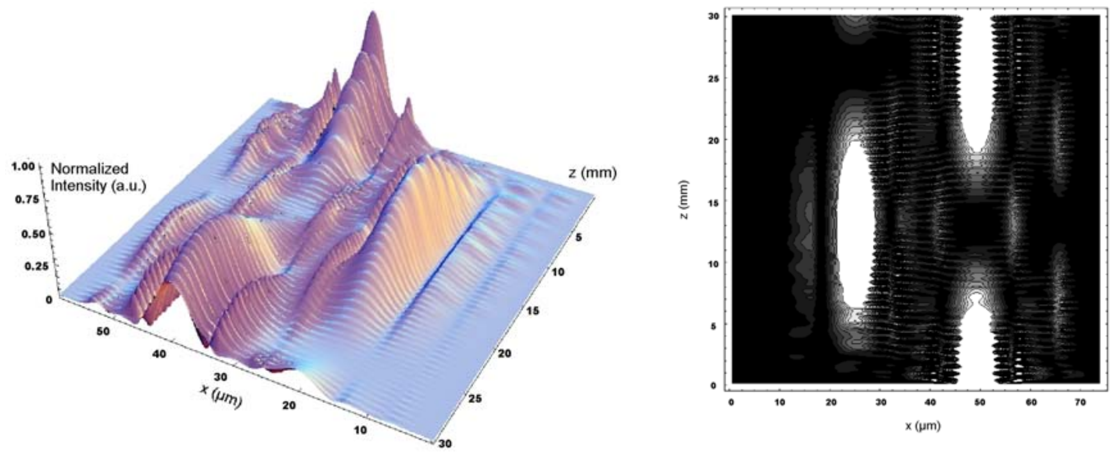
The major advantage of these kind of directional couplers is the possibility of power interchange between two waveguides that would be considered as non-coupled if the confinement were done by ways of a rib. As presented in table 4.3, although the coupling length is quite high, it allows coupling between remote waveguides that can be distanced up to some hundred microns.

Refractive indexes			Layer thicknesses			Directional coupler geometry				
n_c	n_1	n_2	d_c (μm)	d_1 (μm)	d_2 (μm)	$d_{c,lat}$ (μm)	$d_{1,lat}$ (μm)	$d_{2,lat}$ (μm)	$d_{0,lat}$ (μm) $d_{c,lat}$=16μm	L_c(mm) θ= 90º
1.46	2.00	1.46	3.00	0.38	1.50	10-18	2	$d_{1,lat}/2$	$\Omega\ d_{c,lat}$*	>40

* Ω =1,2,3...

Table 4.3: Optimal dimensions for the ARROW-2D based directional coupler.

Although this study has been restricted to single lateral antiresonant pairs, it is possible to design a directional coupler whose waveguides have several antiresonant structures. The most interesting configuration would consist on two antiresonant pairs at the outer sides of the waveguides and a single antiresonant pair at the inner sides. This structure will have a better lateral confinement, due to the double antiresonant pair, while keeping the high leakage (power transfer) between waveguides, causing the coupling length to be the same as calculated previously. BPM simulations have been done considering $d_{c,lat}$=12μm $d_{1,lat}$=2μm and d_0=24μm. Its results are presented in figure 4.21. As it can be seen, ARROW-2D waveguides are coupled by ways of the second order mode of the $d_{0,lat}$ zone. The main drawback of the ARROW-2D directional couplers is that power transference between waveguides is not complete, since coupling by leaky waves always causes a loss penalty. As can be observed in fig 4.21a, although undoubtedly there exists a power exchange, there is a residual power on the $d_{0,lat}$ region that does not reach the second waveguide since it bounces back on the inner lateral antiresonant structures. Finally, on the right hand side of the picture 4.21b it can be observed how there exists a standard coupling between the two outer lateral structures, as it was predicted in the previous subsection.



a) **b)**

Fig 4.21. 3D plot (a) and contour plot (b) modes of the optimized remotely-coupled ARROW-2D directional coupler.

4.4 3dB Splitters/Junctions

Y-junctions are frequently used in integrated optics. They can be used to form power dividers, junctions, Mach-Zehnder interferometers **[10]** and modulators **[11]**. The main problem of these structures is the radiation loss at and in the vicinity of the junction, which can be significant when the separation angle between the two branches is greater than 1º, as presented in **[12]**. In a symmetrical Y-splitter, loss increases slowly for low branching angles, increasing dramatically as the angle increases. To maintain low loss it would be necessary to work at small angles, which would mean excessively large structures. To overcome this problem, the most common design consists on the replacement of straight waveguides with bend waveguides. If bending is optimized, it assures a much faster power splitting with reasonable losses. However, all possible Y-junction modifications have the same technological parameter that is susceptible to cause variations of its performance. As it was mentioned in the previous chapter, the sharpness of the vertex in the taper region that joints both waveguides is extremely difficult to obtain due to limited lithographic resolution. Sharp vertices can be obtained by double masking **[13]**, but hardens the process and increases its complexity and price.

With single mask, a blunted vertex occurs in the waveguide junction that causes extra loss and uncontrolled modal conversion in the tapered region. Although modal properties could be controlled by ways of the appropriate rib height and waveguide width, it would also mean an increase of the total losses. As can be seen in fig. 4.22, there exists several alternatives to standard Y-junction (fig. 4.22a) that overcomes the blunted vertex problem, as can be 1x2 directional coupler-based power splitters (4.22b), 1x2 MMI (4.22c), parabolic-shaped structures (4.22d) or 1x2 ARROW-2D directional couplers (4.22e). In order to make a feasible comparison between them, two identical output monomode waveguides (w=5µm, h=2.5µm) were 30µm distanced and all configurations were tested. The basic requirement was to obtain maximum power transference at the output waveguides with a minimum length.

Firstly, a linear Y-Junction waveguide was simulated by BPM. In this case minimum distance will obviously depend on the angle between waveguides. As previously described, an agreement must be reached between the splitting angle and the device losses. For comparison purposes, a 5º angle has been chosen. By far, this value is much higher than the optimal angle, but our intention is to analyze where Y-junctions fail on its working principle. For that reason we also have considered a 2µm blunted vertex instead of a sharp edge. As can be seen in fig. 4.23, light injected in the device