Design and Simulation of Polymer-based 1x4 Asymmetric Waveguide Coupler

Mohd Shafiq Mat Ghazali
Faculty of Mechanical Engineering,
Universiti Malaysia Pahang
26600 Pekan, Pahang, Malaysia
mohdshafiq89@ymail.com

Dr. Fadhlur Rahman Mohd Romlay
Faculty of Mechanical Engineering,
Universiti Malaysia Pahang
26600 Pekan, Pahang, Malaysia
fadhlur@ump.edu.my

***Abstract* — The design and modelling of a 1x4 asymmetric waveguide couplers based on optical glue Epoxy OG142 is presented. The 1x4 asymmetric coupler is based on a cascaded design of a 1x2 Y-branch with two 1x2 asymmetric couplers. The design of the asymmetric coupler is based on asymmetric Y-junction splitter using tap-off ratio (TOFR) technique. This asymmetric design was achieved by varying the size of the tap line while the bus line was fixed at 1 mm size. A Y-branch and the 1x2 asymmetric couplers with different taper sizes have been designed using CAD tool and ray traced using non-sequential ray tracing. The designed TOFR for the 1x2 asymmetric coupler varies from 23% to 50% for tap line width of 300 um to 1000 um. Ray tracing models of various coupler design showed a linear relationship between the tap-off ratio (TOFR) and the waveguide tap width. The simulated ray tracing result shows TOFR values for the 1x4 asymmetric waveguide coupler varies from 23.1 to 50% for tap width of 300 um to 1000 um.**

Keywords— asymmetric, plastic optical fiber, POF, Tap-off-ratio, TOFR, waveguide coupler, Y-branch.

I. INTRODUCTION

The use of plastic optical fiber (POF) as a medium for optical data communication is well known due to its highly large-core size, multimode properties, low cost and robust characteristics. Waveguide-based POF devices research are limited due to the fact that highly multimode devices have a smaller market especially for data communication application due to the high attenuation of POF compare to that of glass optical fiber [1]. Compare to the single mode glass fiber with an attenuation of 0.2 dB/km at 1550 nm, POF attenuation reaches 100 dB/km at 520 nm [2]. In sensor applications, POF has established wide use in multimode intensity-based sensor [3]. Some application examples of the intensity-based measurements POF sensors are detection of variation in liquid level, detection of liquid nitrogen level, temperature sensing [3], crack monitoring [4], monitoring dynamic response of fiber composite beam [5], and automobile sensor [6].

Optical sensing sometimes will require the passive optical devices to be designed with non-symmetrical branching arm. An asymmetric POF waveguide coupler has been widely ventured and used, recently by UKM researchers for a generating a unique series of optical power for code generation in an optical access-card system. The device is based on the 1x4 asymmetric waveguide coupler with hollow structure [7]. The design of the metallic hollow waveguide structure is based on the concept of light propagation along the waveguide solely by reflection on the metallic inner-surface.

In this paper, we report the design and simulation of polymer-based 1x4 asymmetric waveguide coupler to be used as an optical code generating device in an optical access-card system. The design is based on plastic PMMA or acrylic substrate with an optically clear polymer used as the waveguide core. The design of the device is based on the cascaded combination of a 1x2 Y-branch coupler and two asymmetric couplers. The waveguide core material will be based on epoxy resin Epotek OG142 material. The device design and simulation using ray tracing will be presented.

II. MATERIALS AND METHOD

The 1x4 asymmetric waveguide coupler is designed as an optical code generating device for a newly developed optical access-card system. Splitting ratio from 0% to 100% of the input power can be obtained using this 1x4 asymmetric waveguide design. Using a simple arrangement of the output power of the waveguide coupler, a simple optical code can be generated. Fig. 1 shows the concept how the output power of the 1x4 asymmetric waveguide coupler are utilized for generating the optical codes.

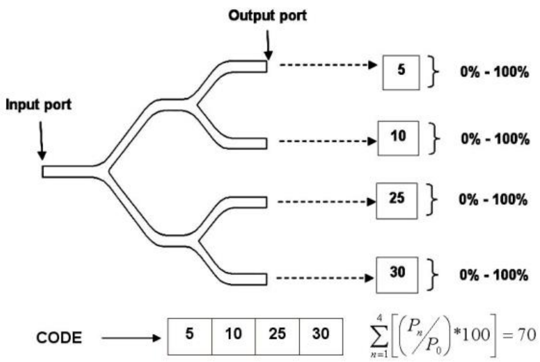


Figure 1. 1x4 optical code generation generating device

Fig. 1 illustrate an example of the 1x4 asymmetric waveguide couplers which can generate a simple code as shown. The number in the square box is the power ratio (in percentages). As can be seen, the 1x4 coupler provides a unique number 5:10:25:30, when arrange in series. Based on a simple arrangement of the output power, a series of optical codes can be produced. Each output port provides a distinctive power value which is achieved by a unique design of the waveguide coupler. The value for the output power can be easily controlled by using this asymmetric coupler design.

III. Device Design

The 1x4 asymmetric coupler is based on two optical device designs: 1x2 Y-branch and the 1x2 asymmetric coupler designs. The 1x2 Y-branch coupler will enable the input optical power to be divided at 50% of the input power. Figure 2 shows the 2D layout of the Y-branch coupler designs used..

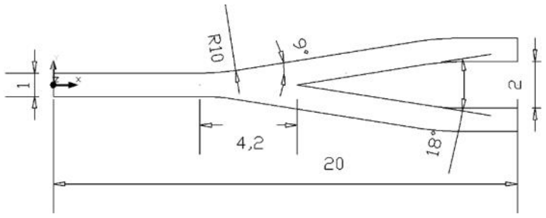


Figure 2. 1x2 POF coupler designs with 18º splitting angle and branching radius of 10 mm [8]

The second component of the 1x4 asymmetric coupler is the 1x2 asymmetric couplers. Two of these couplers will be used. The design of 1x2 asymmetric coupler is based on a simple Tap Off Ratio (TOFR) technique to tap off power from the main bus line [8,9]. Fig. 3 shows a 1x2 asymmetric Y-junction splitter with bus and tap lines and a splitting angle of 18° [8]. In order for the tap line with smaller core size to be coupled to a larger core POF cable, a linear taper structure has been included at the end of the tap line.

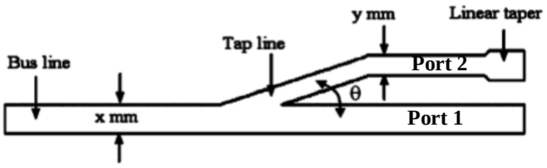


Figure 3. 1x2 polymer waveguide coupler design with different tap line (y) and bus line (x) [8].

The 1x2 asymmetric coupler utilized the concept of TOFR where a simple power tap can be achieved. The concept of TOFR is based on the asymmetric Y-junction splitter shown in Fig. 3 where the optical power in the bus line will be larger than that of the tap line. This is achieved by having the size of the tap line (port 2) to be smaller compare to the bus line (port 1). The TOFR or the ratio of the power exiting through port 2 to the total power incident in the bus line (port 1) is given by equation below [9]. By changing the taper line width, several combinations of the output power can be generated. The size of the bus line is set at 1 mm.

$$TOFR = \frac{y}{y+x} \qquad (1)$$

The 1x4 asymmetric waveguide coupler can be easily constructed by utilizing the preceding 1x2 Y-branch and two 1x2 asymmetric waveguide couplers. A 1x2 Y-branch coupler is cascaded with two 1x2 asymmetric couplers. The Y-branch coupler will provide a 50% power splitting at the output port. In order to complete the 1x4 coupler structure, two asymmetric 1x2 couplers are inserted. The concept of cascading the designs is shown in in Fig. 4.

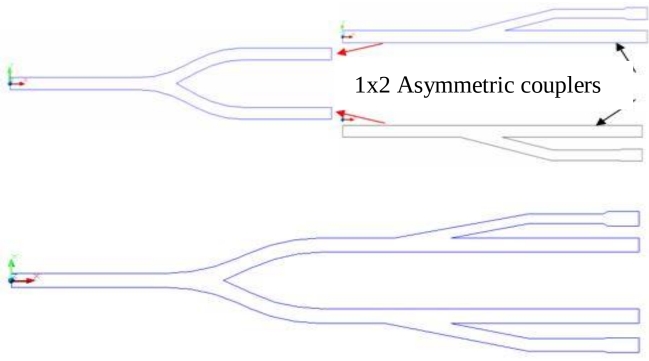


Figure 4. Higher-level waveguide design (a) 1x2 Y-branch coupler before joining with two asymmetric 1x2 couplers; (b) 1x4 coupler with asymmetric branches

IV. Result and Discussion

In this paper, the design and simulation of the 1x2 and 1x4 asymmetric waveguide couplers with different TOFR are shown. Simulation of the waveguide coupler has been performed using non-sequential ray tracing technique. The wavelength used in this simulation is 650 nm, with an input power of 1.0 mW. In the ray tracing, the core of the waveguide is based on Epotek's OG142 optical polymer with an index of refraction of 1.58. The cladding for the waveguide is PMMA material with an index refraction of 1.49. Fig. 5 shows the cross section of the waveguide coupler showing proposed materials for the core and cladding. Fig. 6 shows the ray tracing diagram a 1x2 asymmetric waveguide coupler with a TOFR of 30%.

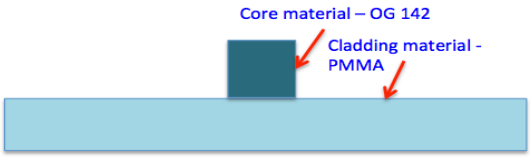
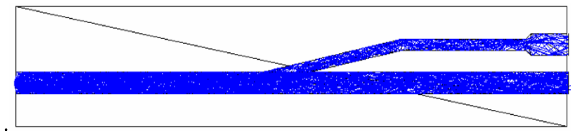


Figure 5. Cross section view of the waveguide coupler with the core and cladding properties



(a)

Figure 6. 2D ray tracing diagram for 1x2 asymmetric waveguide coupler: 30% TOFR.

In the 1x2 asymmetric waveguide coupler design and simulation, the values for the tap width are set from 300 um up to 1 mm which provide TOFR of 23% until 50%. The design TOFR values with the tap line width of 300 um to 1 mm is obtained using equation (1) where the tap width are varied while the bus line is set at 1 mm. Fig. 7 shows the plot of the TOFR against the tap width for both the designed and simulated devices. The result of TOFR for the designed device are based on equation (1), for y= 300 um until y=1000 um with a fixed bus line width, x of 1000 um. The simulated waveguide coupler shows the same linear characteristics as that of the designed. The simulated TOFR obtained for the 1x2 asymmetric waveguide coupler is from 21.0 to 49.9%.

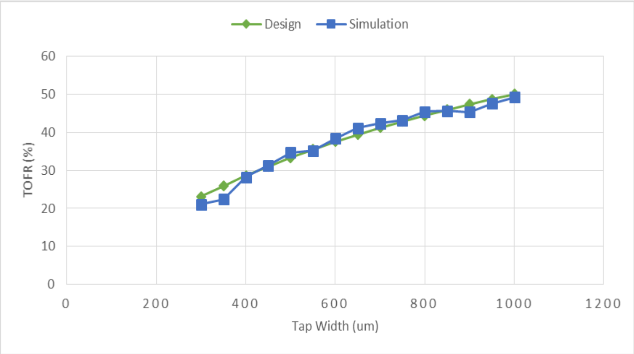


Figure 7. TOFR vs Tap width for 1x2 asymmetric coupler (design and simulation)

The results for the 1x2 asymmetric waveguide couplers will be used to design and model the 1x4 asymmetric couplers. Fig. 8 show the ray tracing of 1x4 asymmetric waveguide coupler and how it is partitioned into six sub-sections. If the input power is set at Po, then the section A and B would have output powers of 0.5Po. After the 3 dB split, the asymmetric coupler design in section C, D, E and F will split the 0.5Po into smaller fractions of optical power.

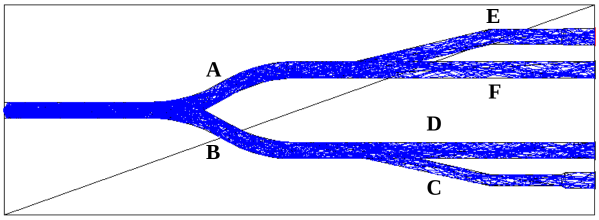


Figure 8. Ray tracing and partitioning the 1x4 asymmetric waveguide coupler

Table 1 shows five designs of the 1x4 asymmetric coupler showing the branches C, D, E and F with their respective tap line and bus line widths. Table 2 shows the output power at each output branch C, D, E and F for the device design. The simulation results for the 1x4 asymmetric waveguide coupler are shown in Table 3. Based on these results, each of simulated output corresponds close to the require design value.

TABLE 1 1X4 ASYMMETRIC COUPLER DESIGNS: OUTPUT BRANCH WIDTH SIZES

Design No.	Branch C-D		Branch E-F	
	C Tap Width (um)	D Bus Line (um)	E Tap Width (um)	F Bus Line (um)
1	900	1000	700	1000
2	500	1000	500	1000
3	1000	1000	700	1000
4	600	1000	800	1000
5	1000	1000	500	1000

TABLE 2 OUTPUT POWER FOR 1X4 ASYMMETRIC WAVEGUIDE COUPLER (DESIGN)

Design No.	Output Power (mW)			
	C	D	E	F
1	0.20	0.28	0.15	0.32
2	0.08	0.38	0.08	0.38
3	0.25	0.25	0.15	0.32
4	0.11	0.37	0.18	0.31
5	0.25	0.25	0.08	0.38

TABLE 3 OUTPUT POWER FOR 1X4 ASYMMETRIC WAVEGUIDE COUPLER (SIMULATION)

Design No.	Output power (mW)			
	C	D	E	F
1	0.22	0.27	0.15	0.32
2	0.08	0.39	0.08	0.39
3	0.30	0.20	0.15	0.32
4	0.12	0.39	0.17	0.28
5	0.26	0.22	0.08	0.40

V. CONCLUSIONS

The design and simulation of 1x2 and 1x4 polymer-based asymmetric waveguide couplers for an optical access-card system are presented. The 1x4 asymmetric coupler has been proposed to function as an optical code generating device where it uses a cascaded combination of 1x2 Y-branch and two 1x2 asymmetric couplers. The waveguide devices are based on optical epoxy OG142 glue as the core material and PMMA material as the cladding/substrate. Non sequential ray tracing of the polymer waveguide coupler has been performed to characterize the optical performance of the device. The results shows there is a linear relationship between the output TOFR and the waveguide tap line width.

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