Low-Loss, High-Uniformity 1x2, 1x4 and 1x8 Polymer Multimode Y-Splitters Enabling Radio-over-Fibre Multicasting Applications

N. Bamiedakis, J. Beals, F. Yang, A. Wonfor, R. V. Penty, I. H. White (1) J. V. DeGroot Jr., T. V. Clapp (2)
(1) Electrical Engineering Division, University of Cambridge, 9 JJ Thomson Avenue, Cambridge, CB3 0FA, UK,
nb301@cam.ac.uk
(2) Dow Corning Corporation, 2200 W. Salzburg Rd, Midland, Michigan 48686, USA

Abstract: *Novel low-loss, high-uniformity polymer multimode Y-splitters/combiners are presented. Excess losses of 2 dB and a splitting uniformity as good as 1.2 dB are obtained for an eight-way Y-splitter. The multimode aspect of the devices allows signal combining without the fundamental loss of 3 dB per split associated with the reciprocal use of single mode devices. A total insertion loss of 4 dB for an 8x1 combiner is recorded. By way of example, the asymmetrical behaviour of the device, when used for splitting as opposed to combining, is shown to, provide system advantage in a radio-over-fibre network. Here radio-over-fibre multicasting is demonstrated achieving a 2% EVM for IEEE 802.11g transmission in an 8-way 150 m range MMF network.*

1. Introduction

Polymer multimode waveguides that can be integrated on printed circuit boards (PCBs) have been of particular interest recently as they offer a low cost and highly efficient solution for high speed interconnects [1,2]. Siloxane materials have been studied for such applications as they have high-reliability with excellent mechanical and thermal properties, so that they can withstand temperatures in excess of 250°C needed for soldering [3]. Due to their relaxed alignment tolerances, multimode waveguides allow for reduced cost connectorisation. Yet further cost advantages could be achieved if added functionality is attained by forming components in the polymer guides. In this paper therefore we report the fabrication and characterisation of novel low-loss high-uniformity multimode polymer 1x2, 1x4 and 1x8 Y-shaped splitters and combiners. Despite their low potential cost, good performance is achieved, while the multimode aspect of the devices additionally allows signal combining without the 3 dB penalty/split normally observed in single mode devices. This gives enhanced performance for optical systems requiring such combining and hence this paper demonstrates the use of the devices in enabling multicasting in radio-over-fibre systems.

2. Device design and fabrication

The siloxane polymers, used for the proof-of-principle demonstration of the devices, are spun in resin form directly onto a silicon substrate and patterned by conventional photolithographic techniques. All devices have a waveguide cross-section of 50x20 μm. The splitter output arms are separated by 250 μm to match conventional ribbon fibre, VCSEL and photodiode array spacing (Fig. 1). The 1x2 Y-splitters consist of the input arm, a broadening taper region and two s-bends to achieve the required pitch for the output arms. The taper angle and s-bend length are chosen so as to create an adiabatic change of the structure [4]. The 1x4 and 1x8 splitters consist of cascaded 1x2 splitters with s-bend lengths modified to yield a similar minimum radius of curvature for the curved sections. The total device length, including a 1mm long input arm, is approximately 8.5 mm, 16 mm and 30 mm for the 1x2, 1x4 and 1x8 devices respectively (Fig. 2). Sets of devices are separated using a Disco 321 dicing saw. As control samples, straight waveguides are fabricated which exhibit intrinsic losses of 0.03-0.05 dB/cm at 850 nm. Samples fabricated on FR4 substrates yield identical results, indicating that the cladding material sufficiently masks the roughness of the FR4 substrate.

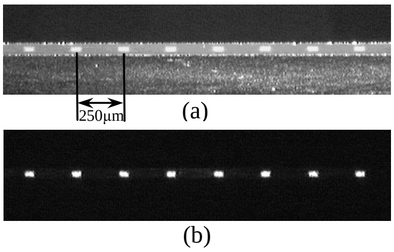


Fig. 1: Output facet of a 1x8 splitter (a) photograph (b) IR image with an 850 nm input.

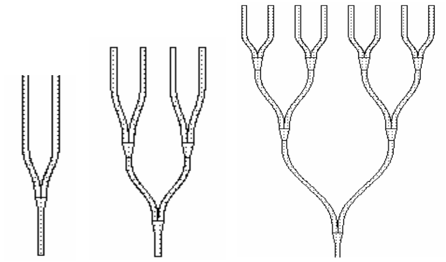


Fig. 2: Schematic of polymer Y-splitters.

3. Characterisation studies

The power transmission characteristics of the devices used as both splitters and combiners are investigated for different input conditions. An 850 nm VCSEL source is used as a transmitter. Two forms of launch have been studied. Firstly fibre launch has been employed where the input fibre can be offset in the horizontal direction to investigate the impact of input misalignment on overall power transmission as well as power imbalance between the output arms of the device. Secondly a free space launch utilising two 10x objective lenses and an unpackaged VCSEL source is also examined as this gives higher coupling efficiency. In both cases, a 62.5/125 µm cleaved multimode fibre (MMF) collects the light at each output arm of the device and delivers it to an optical power meter.

With a SMF, 50 µm MMF and 62.5 µm MMF input the excess losses recorded for the 1x2 Y-splitters are as low as 0.5 dB, 2 dB and 2.7 dB, and for the 1x8 splitter 1 dB, 2 dB and 3.5 dB, respectively, indicating the relative coupling efficiency of the different launches. It should be noted that the MM fibre cores are larger than the device guides leading to imperfect coupling efficiencies. This is expected to be removed following waveguide redesign.

Owing to the multimode aspect of the devices, splitting uniformity strongly depends on the mode power distribution at the input of the device. Figure 3 shows the maximum recorded power imbalance for the various input conditions and devices. The power difference between the output arms is below 0.5 dB, 1 dB and 1.2 dB for the 1x2, 1x4 and 1x8 Y-splitters for an MMF input. Multimode launches typically allow lower power imbalances as more modes are excited and power is more uniformly distributed within the devices (Fig. 4).

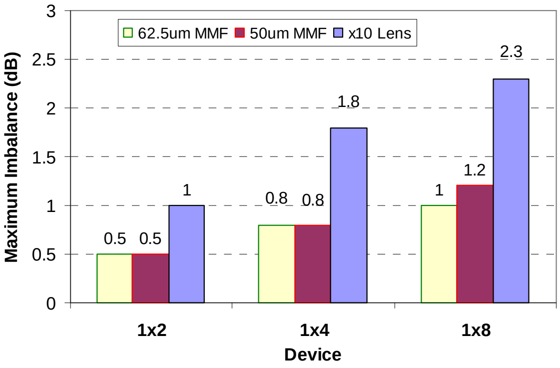
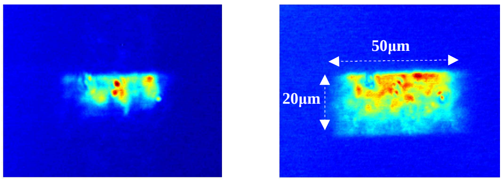


Fig. 3: Maximum imbalance between output arms of the 1x2, 1x4 and 1x8 Y-splitter for the various input conditions.



(a) (b)

Fig. 4: Near field images of an output arm of a 1x2 Y-splitter for a (a) restricted launch (SMF) (b) overfilled launch (MMF).

Figure 5 shows the variation of the maximum power imbalance between the output arms for a 1x8 Y-splitter with two different MMF launches as the input fibre is offset in the lateral direction. High splitting uniformity is achieved for all input fibre positions.

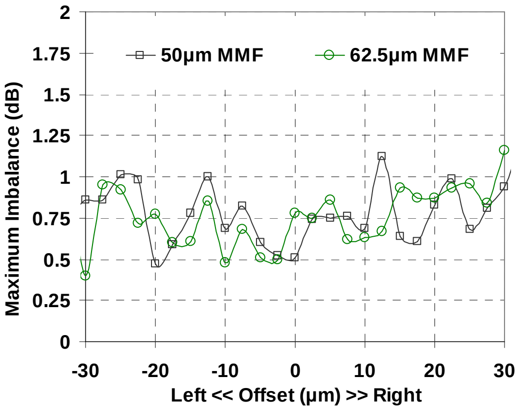


Fig. 5: Maximum imbalance between output arms of 1x8 Y-splitter for MMF inputs (waveguide core within ±25µm).

The devices are also studied under operation as combiners. The advantage of multimode combiners over single mode devices lies in the fact that there is no fundamental power loss associated with reciprocal use of the device (3 dB for a 1x2 device). Using a SMF or a lens input system to maximise coupling efficiency and achieve a restricted launch into the waveguides, the total insertion loss for a 1x2 combiner is 1.3 dB and for a 1x8 combiner is as low as 4 dB. Hence, the power difference between the two configurations (splitter and combiner) is 2 dB and 6 dB respectively for the 1x2 and 1x8 devices (Fig. 6). This asymmetric behaviour is particularly important in multicast antenna remoting or MMF PON applications where uplinks are limited by noise and hence power combining losses should be minimised. All arms of the combiner display high uniformity as well, exhibiting a power loss variation of less than 0.3 dB.

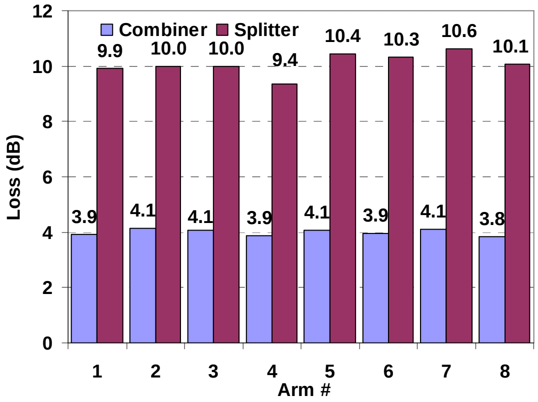


Fig. 6: Insertion loss of a 1x8 device used as a splitter and a combiner with a free space input.

A study of the causes of excess loss in the devices is currently in progress. The multimode launches that are used are overfilled and hence introduce additional loss, particularly in the combiners owing to the down-tapered region where higher order modes are susceptible to coupling to radiation modes. Optimisation of the launch is thus expected to lead to improved performance. Table 1 summarises the results obtained for the 1x2, 1x4 and 1x8 devices when operating as a splitter and a combiner for the various input configurations. Total insertion losses include coupling, splitting and propagation losses.

Table 1: Total insertion loss (including splitting losses) (dB) for the 1x2, 1x4 and 1x8 devices with different inputs when used as a (a) splitter (b) combiner.

(a)

Input	**Splitter**		
	1x2	**1x4**	**1x8**
SMF	3.4	6.6	10
50µm MMF	5	7.8	11
62.5µm MMF	5.7	9	12.5

(b)

Input	**Combiner**		
	1x2	**1x4**	**1x8**
SMF	0.9	1.5	4
50µm MMF	4	5.1	7
62.5µm MMF	4.7	6	9

4. Radio-over-fibre multicasting

To demonstrate the potential of these low cost devices, multicasting is studied in a radio-over-fibre system (RoF). The 1x2 and 1x8 devices are used both in a splitter and a combiner configuration to account for the downlink and uplink components of the system thus exploiting the devices' asymmetrical splitter/combiner performance.

A wireless LAN IEEE-802.11g signal (64-QAM, 54Mbps) at a carrier frequency of 2.412GHz (channel 1) is generated by a Rohde & Schwarz SMIQ vector signal generator and directly modulates the VCSEL source. The optical signal is transmitted though the 1x2 or 1x8 devices and a 62.5/125 µm multimode fibre link with lengths of 150 m and 300 m. A photodiode converts the received optical signal to an electrical one which is then demodulated by a Rohde & Schwarz vector signal analyser (Fig. 7).

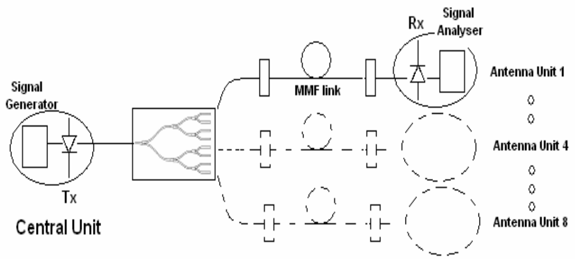


Fig. 7: Schematic of radio-over-fibre downlink.

The root-mean-square (rms) error-vector-magnitude (EVM) of the received electrical signal in all output channels is measured and plotted as a function of the fibre input misalignment and for the different link lengths of MMF. The received optical power in each arm is also recorded for every position of the input to verify uniform power splitting. Figure 8 shows the EVM and normalised received power in each output arm versus input offset for a downlink system with a 50 µm MM input fibre, a 1x8 splitter and a 150 m MMF link. EVM rms values are around 2% while the output power imbalance is less than 1.2 dB and the device excess loss is 1.5 dB. The additional 0.5 dB MM fibre link loss results in a total optical link loss of approximately 11 dB per channel. For the corresponding uplink a similar EVM value of 2% is recorded while the total loss is 7 dB, demonstrating the advantage of the splitter/combiner asymmetry. Using a SMF or free space input will yield a 4 dB total loss without any EVM degradation. Thus, the uplink noise performance is improved significantly. Table 2 summarises the results obtained for the RoF system under the conditions described above.

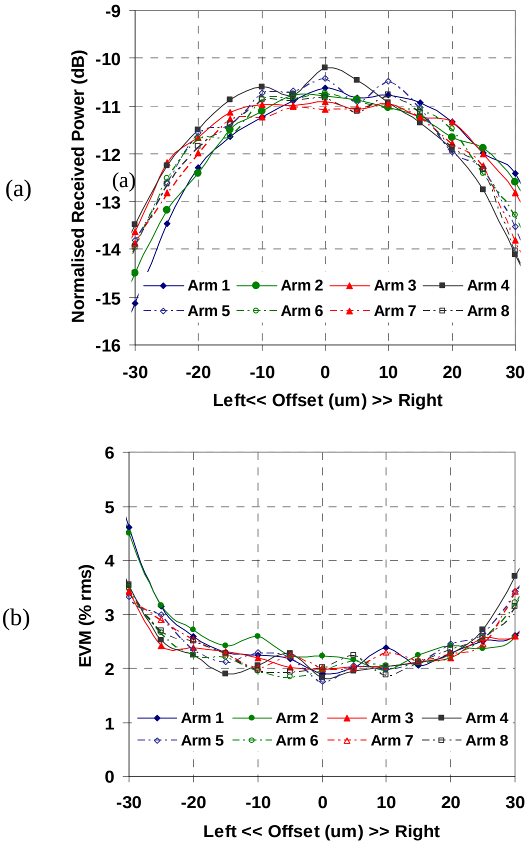


Fig. 8: 1x8 Y-Splitter performance for a 150 m MMF link: (a) Normalised received power (b) EVM versus input offset for all arms.

Table 2: EVM values of (a) 1x2 and (b) 1x8 devices for a 50 µm MMF input and different MMF link lengths.

(a)

Device	**Y 1x2 – EVM (% rms)**	
Link Length	**Splitter**	**Combiner**
0 m	1.3	1.2
150 m	1.5	1.5
300 m	2.3	2.3

(b)

Device	**Y 1x8 – EVM (% rms)**	
Link Length	**Splitter**	**Combiner**
0 m	1.5	1.5
150 m	2	2.2
300 m	3.2	3.5

5. Conclusions

Multimode polymer 1x2, 1x4 and 1x8 Y-splitters have been fabricated exhibiting high output uniformity and an excess loss as low as 2 dB for the 1x8 splitter. The devices exhibit differing behaviours when used as a splitter or as a combiner leading to a 6 dB power difference for the 1x8 device. Multicasting in a radio-over-fibre system is enabled for both the downlink and uplink directions. Exploiting the splitter/combiner asymmetry, a clear power advantage for the uplink is shown and similar EVM values as low as 2% are achieved for IEEE 802.11g transmission in both directions for an 8-way 150 m range MMF network.

6. References

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