APSS Apollo Application Note on

Power Splitter Circuit

Design, simulation and layout

APN-APSS-PowerSplitter

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Abstract

This application note provides an overview example of how to create, simulate, and analyze a power splitter circuit using a Y-junction device, and compares the results with an identical splitter that uses an MMI device. The main focus of this document is to demonstrate how optical circuit designers can use a previously-designed device in a circuit and determine an optimal design. Apollo Photonics Solutions Suite (APSS) is a platform that can be used to perform all steps of the optical circuit design from waveguide selection, through designing a device, and creating or simulating the circuit.

This application note:

- describes the process of designing the circuit from one of the pre-defined devices available in APSS
- discusses some of the challenges and considerations in circuit design
- presents comments and suggestions for designing a photonic integrated circuit (PIC)
- provides simulation results for two examples

Keywords

photonic integrated circuit (PIC), power splitter, connectors, bending loss, Y-junction device, MMI device

Table of Contents

1 INTRODUCTION 5

2 ANALYSIS 5

3 DESIGN CRITERIA 7

4 STRUCTURES 8

4.1 ANALYSIS FOR POWER SPLITTER USING A Y-JUNCTION DEVICE 8

4.2 ANALYSIS FOR POWER SPLITTER USING AN MMI DEVICE 11

5 RESULTS 12

5.1 RESULTS FOR POWER COMBINER/SPLITTER USING A Y-JUNCTION DEVICE 12

5.2 RESULTS FOR POWER COMBINER/SPLITTER USING AN MMI DEVICE 15

6 CONCLUSION 17

7 REFERENCES 18

1 Introduction

Power splitter circuits perform some of the basic operation in optical systems. These circuits can be used in switching, filters, or multiplexers. A power splitter circuit can be created by combining a few basic components, such as Y-junction or MMI devices.

Y-junction and MMI are two basic components, which perform power splitting. A few of these devices can be combined to design a better circuit with more outputs. The focus of this application note is on the usage of a Y-junction and creating a 1x8 power splitter circuit. In this process unique advantages of APSS are also reviewed.

After a brief review of analysis method, design criteria of splitter circuit are pointed out. Then the circuit structure is studied. At the end by presenting some simulation result, and comparing two circuits (MMI and Y-junction based circuits), the application notes is concluded.

> ***Note:*** This document focuses on creating a power splitter circuit using a Y-junction, and does not discuss how to design or optimize circuits.

2 Analysis

Designing a PIC is more complex than a regular optical device. Due to the complexity and large size of a PIC structure, regular analytical and numerical methods in photonics cannot be used. For instance, Beam Propagation Method (BPM), which is one of the most powerful numerical methods, is a one-way method and does not consider reflection, and therefore cannot be used in circuit analysis. Reflection must be considered for correct circuit analysis because, in a circuit, several devices are connected to each other and reflection from any of them can affect the performance of the circuit. Regular BPM has other limitations. For example, it is possible that two devices are connected by half-circle connector, as shown in Figure 1. Using regular BPM, it is impossible to simulate a circuit with this type of connector.

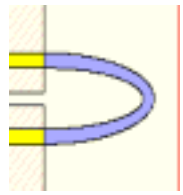

Figure 1 Half a ring connector

Another method for photonic device simulation is Finite Difference Time Domain (FDTD) method, which does incorporate reflection in its calculations. However, this method is also inadequate for most circuits, due to circuit size.

As two practical examples of PICs, two types of multiplexer were designed in [see references 1 and 2]. To analyze these structures, BPM or FDTD cannot be used. A different method is required.

Similar to microwave devices, we can define S-parameters for photonic devices. The S-parameter is defined as:

$$S_{ij} = \frac{Bi}{Aj}$$

where Aj and Bi are the coefficients of input and output waveguide modes at port j and i, respectively. In general, Sij is a complex number. The matrix containing the S-parameters is called the S-matrix. For each photonic device the S-matrix can be calculated. This allows each component of the circuit to be analyzed by different methods, for example, one component with FDTD, and one component with BPM.

After the topology of the circuit is defined using the network method [3], the overall S-matrix of the circuit can be calculated. To do the calculation, the connectors must be analyzed and the S-matrix for each connector must be determined. The best method to use to analyze connectors is the Cylindrical-BPM [4]. As mentioned, regular BPM or FDTD methods cannot be used effectively for this type of component.

In comparison to regular electronic or microwave circuits, photonic circuits have different characteristics and limitations. These limitations affect circuit performance and must be considered in the design process. In regular electronic circuits, the only concern about connectors is the layout and how to avoid crossing connectors. In a PIC design, crossing the connectors is not an issue, but bending and radiation loss must be considered. If the connector design results in bending/radiation loss (due to, for example, too sharp a bend), the optical power can enter another device through an unintended path, instead of through its intended port and connector. If this loss is not incorporated in the network analysis, the analysis will be incorrect.

3 Design Criteria

The issues discussed above are applicable to the design of any PIC. For power splitter circuits more specifically, there are some additional criteria that must be considered. These criteria include the following:

- Broadband – Power splitters should have very small wavelength sensitivity. The ideal device is has no wavelength dependency.
- Uniform Distribution – Except for special applications, power splitters should equally distribute power, and all the outputs should be similar. In the ideal case all outputs are identical.
- Low Insertion Loss – Insertion loss reduces the performance of splitters, and the lower the insertion loss, the better the performance. In general, the return loss and radiation loss should also be minimal, so that almost all the power is transferred to output ports
- Compactness – If a several devices are used to make a power splitter, the circuit can be very bulky. It is important to use compact devices, or make the circuit as compact as possible. It reduces the manufacturing cost, and makes the circuit easier to combine with other components of the system.

Several devices can be used in power splitter applications, including Y-junctions, MMIs, and Star couplers. Depending on the requirements of the splitter application, a designer can use any of these devices or a combination of them. Among these devices, Y-junction

has better performance considering its insertion loss, size, and similar outputs. However, it has only two outputs.

In contrast, MMI or Star couplers can have several outputs. However, the Star coupler is relatively large, and does not provide uniform outputs. To get uniform outputs, all output ports must be located at the center of the device, which increases the width of the device. In a power splitter, the output ports are located at the edge of circuit and can be coupled outside using a standard fiber. For this reason, and due to its non-uniform outputs, the Star coupler is not further discussed in this document, and the focus will be on comparing Y-junction and MMI devices.

4 Structures

A simple topology is considered for a 1x8 splitter. The splitting is done in three stages. For this design we can use a Y-junction, or 1x2 MMI.

One of the main advantages of circuit analysis is to make use of the results of individual device analysis results. Once a Y-junction or MMI device is designed and analyzed, it can be used in several places in a circuit without introducing any extra work to the total circuit analysis.

4.1 Analysis for power splitter using a Y-junction device

The circuit is designed based on a silica-on-silicon channel waveguide, as shown in Figure 2. The channel is a square, and its width is 5 µm. All the index values shown are for wavelength=1.5 µm, and Temperature=25˚C. These values will be changed later, during the simulation when the wavelength is changed for purposes of comparison.

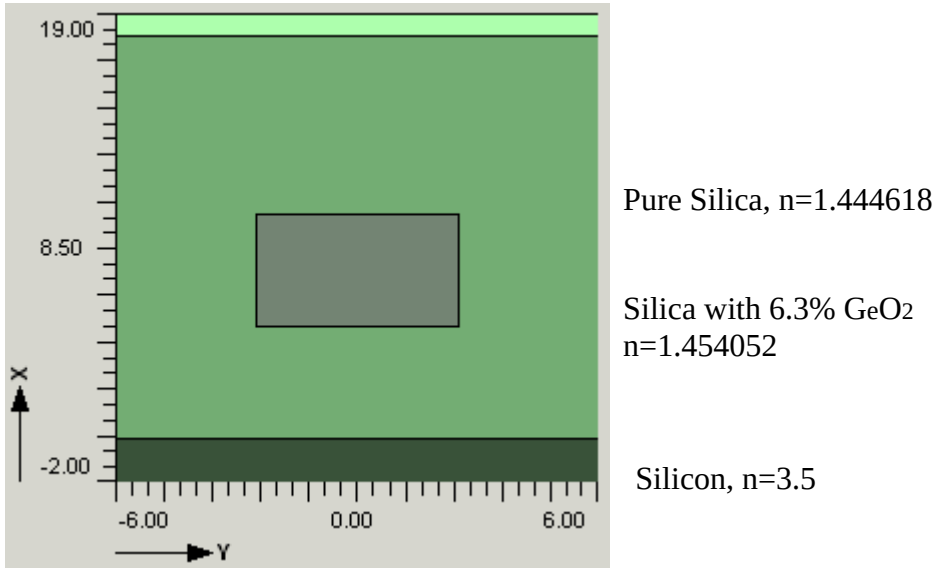

Figure 2 Waveguide cross section

The Y-junction is designed based on this waveguide. Note that y=0 is not the same in waveguide and device coordinates. The y=0 in waveguide coordinates, Figure 2, is at the center of device ports which is y=31 in Figure 3. The port width of the Y-junction is set to 5 µm. Each arm of the Y-junction is a double-arc bend and has a constant bending radius. The length of each arm is 900 µm, and its height is 20 µm. The top-view of the structure is shown in Figure 3. The Y-junction is a three-dimensional structure.

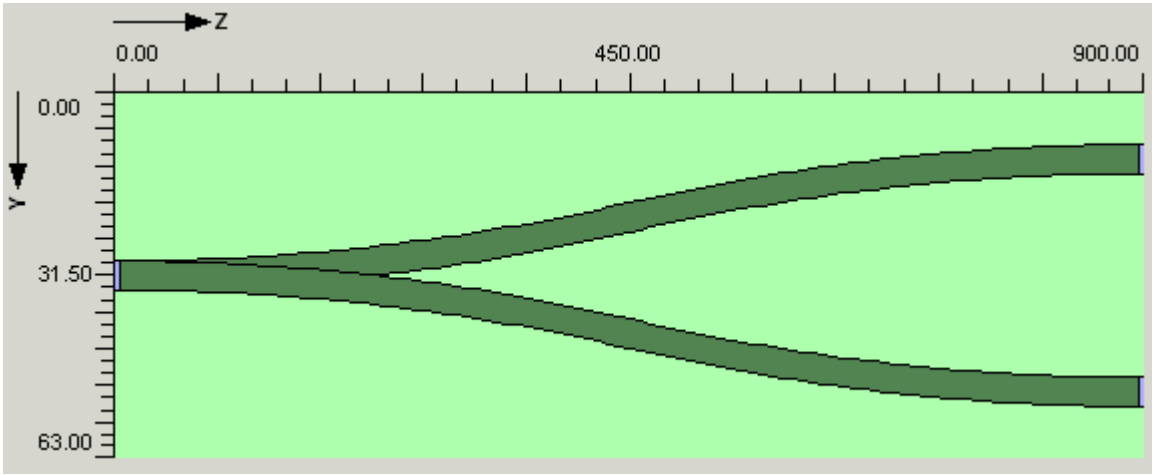

Figure 3 Y-junction device

Then the Y-junction as used to create the 1x8 combiner/splitter is shown in Figure 4.

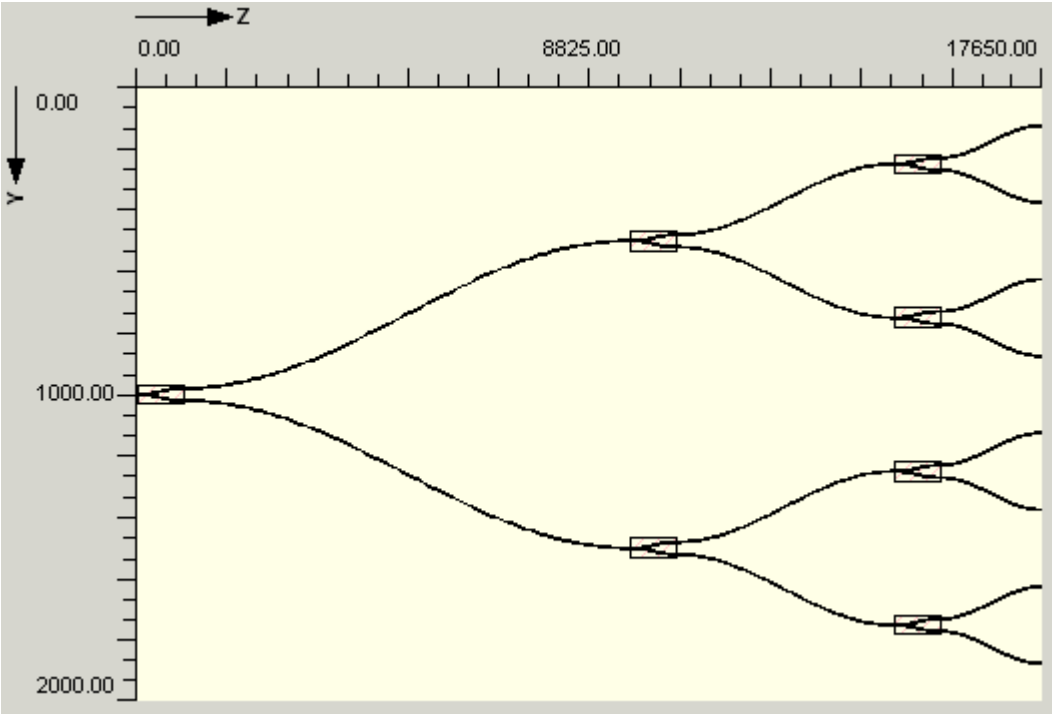

Figure 4 The 1x8 power splitter

In this circuit, only one type of device, Y-junction, is used. This device can be optimized and used in the circuit. There are a few points that should be considered when designing this circuit. This circuit is built on the silica-on-silicon waveguide structure. This waveguide has a good match with standard optical fiber. Therefore the output port separations should be at least 250 µm. All the circuit terminals are located at the edge of the circuit layout.

To avoid any losses to the connector, losses in the S-bend connectors should also be checked. This can be investigated in two ways; either as a S-bend device or as connector in the circuit. As an S-bend device with the chosen waveguide, the loss will be less than 0.001 for any length/height ratio higher than 17 (at wavelength=1.5 µm). In consideration of all the above conditions, the layout of the 1x8 splitter was created as shown in Figure

4. Because the Y-junction is a broadband device, the resulting power splitter is also broadband.

4.2 Analysis for power splitter using an MMI device

A similar configuration is used with a 1x2 MMI, Figure 5. This device is also built on the same waveguide as shown in Figure 2.

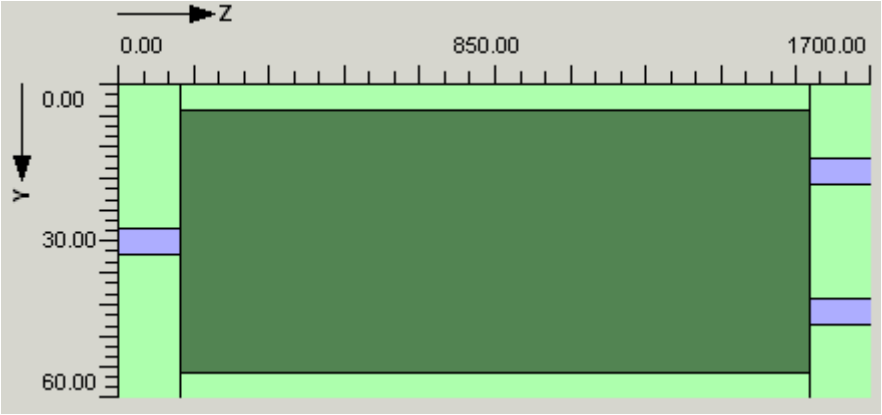

Figure 5 MMI device

To achieve the required splitting effect, the length of MMI device must be longer than the Y-junction device. MMI devices also typically have higher insertion loss. The splitter with MMI is shown in Figure 6. This circuit has similar connectors as the circuit with Y-junction, Figure 4.

> ***Note:*** This document does not discuss how to design MMI circuits. For more information about MMI circuit design, please see APN-APSS-MMI.

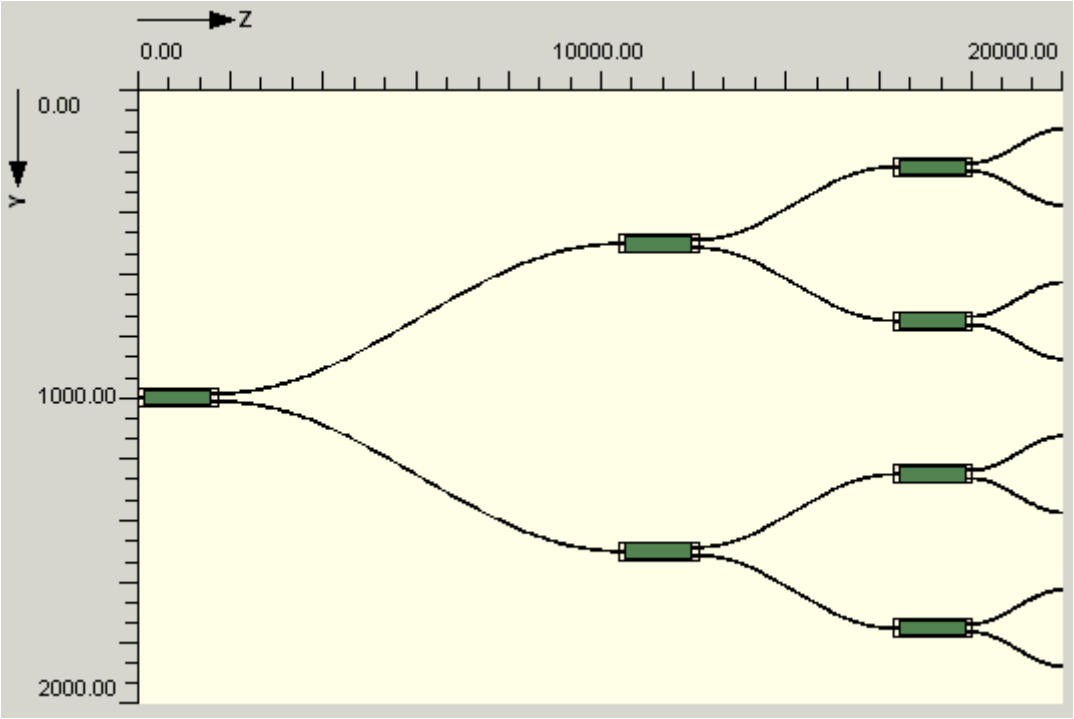

Figure 6 Power splitter using MMI

5 Results

This section provides a summary of the performance analysis of both of the splitters; one made with the Y-junction device, and one made with the MMI device.

5.1 Results for power splitter using a Y-junction device

This device is simulated by PBM. The field distribution is shown in Figure 7. This is the field distribution at the center of Silica channel as shown in Figure 2, where x= 7.75µm.

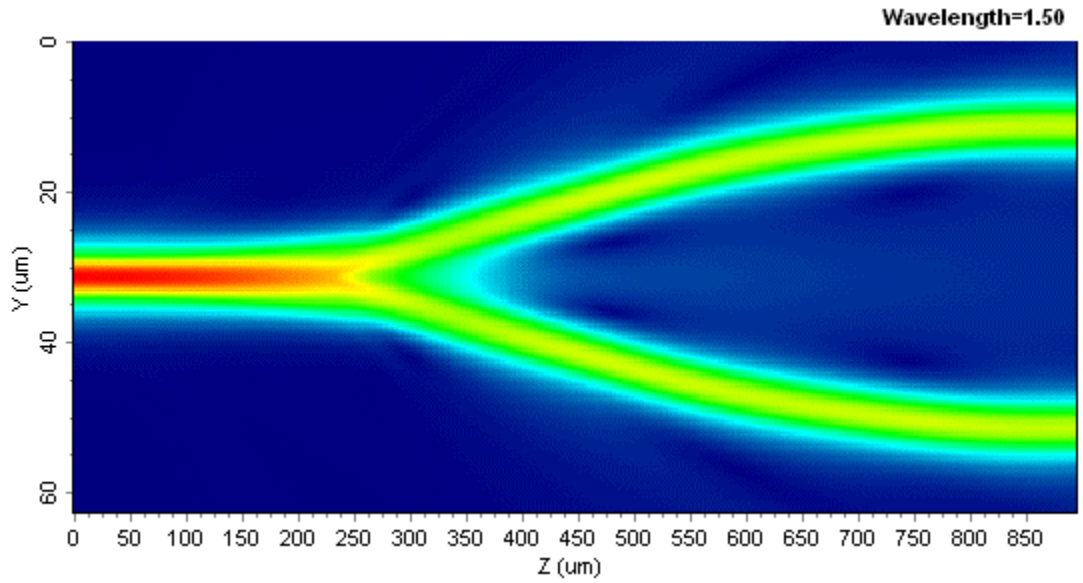

Figure 7 Field distribution in the Y-junction

Figure 8 shows the insertion loss at two output ports of the Y-junction. They are exactly the same, and, as expected, the power is equally divided into two ports at all wavelengths.

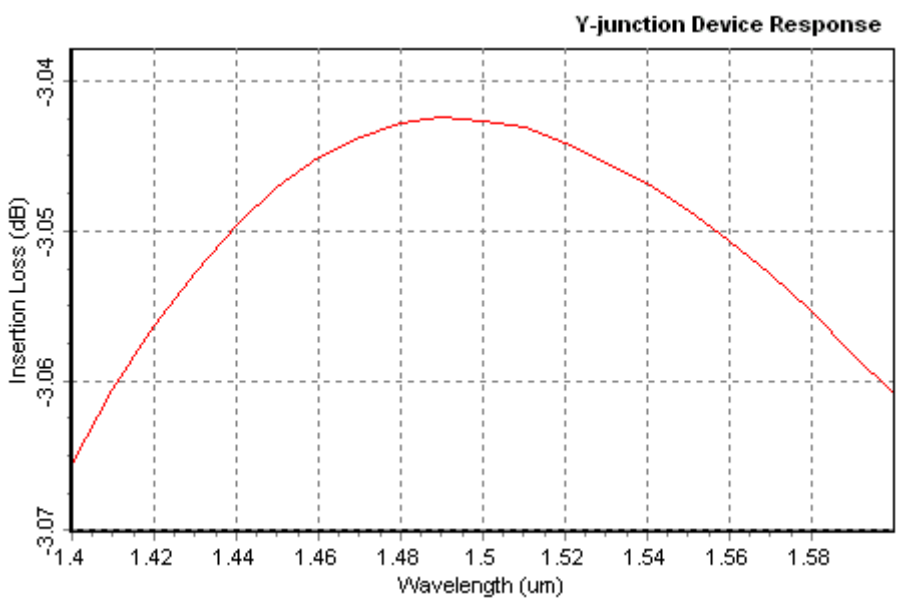

Figure 8 Insertion loss at output ports of the Y-junction

Figure 9 shows the insertion loss at all eight output ports after circuit simulation. Measured loss remained the same over a wide range of wavelengths. Since all Y-

junctions are the same and the connectors are known to deliver very little insertion loss, this result can be expected. Furthermore, the Y-junction device, and therefore the circuit itself, is broadband.

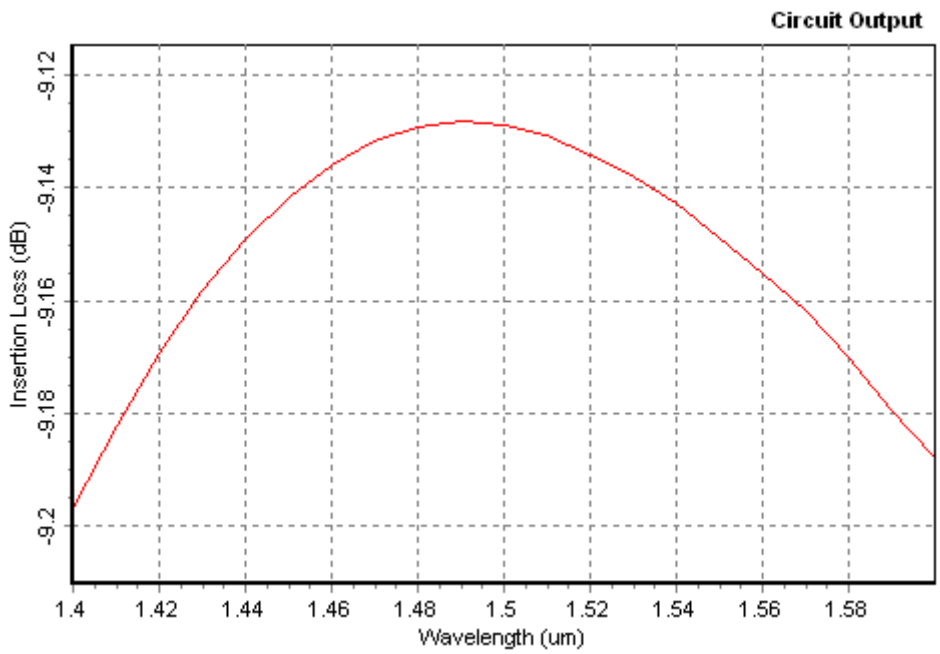

Figure 9 Insertion loss in the circuit outputs

During the circuit simulation, the S-parameters of all connectors were calculated by Cylindrical-BPM. The performance of one of the output connectors, at the last stage, is shown in Figure 10.

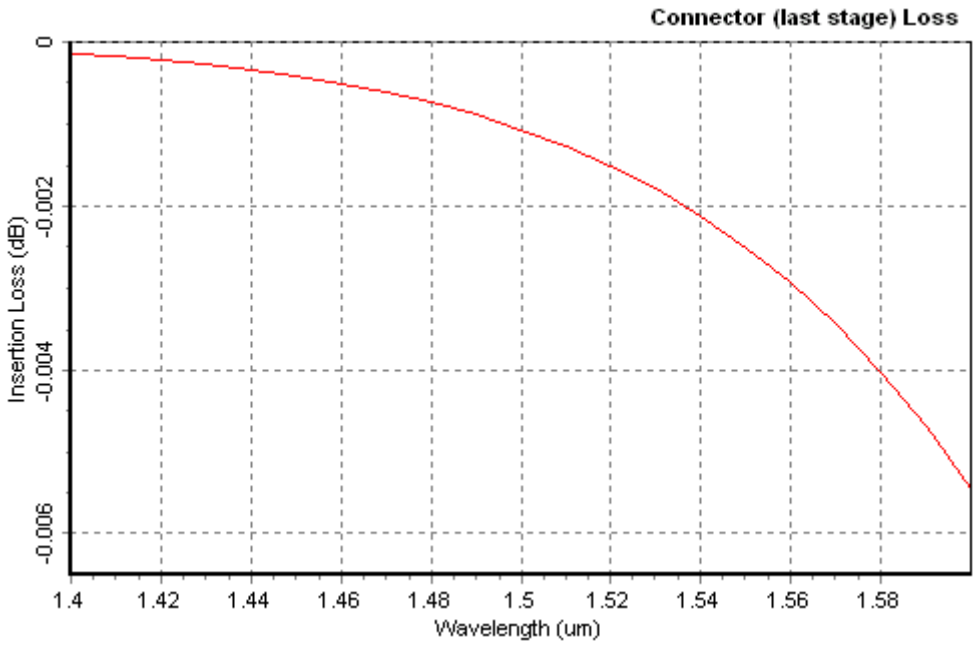

Figure 10 Performance of the output connector

5.2 Results for power splitter using an MMI device

Based on the waveguide shown in Figure 2, a 1x2 MMI splitter was created with the Width=50 µm. APSS has a built-in function to estimate the MMI length. This function is based on an analytical expression. For more information about MMI circuit design, please see APN-APSS-MMI. For this structure, the estimated length is as 1375 µm, at the center wavelength, 1.5 µm. However, to optimize the structure, the length of MMI was scanned from 1260 to 1560 µm, and the wavelength from 1.4 to 1.6 µm. Only three sets of simulation results are shown in Figure 11. The length of MMI is set to 1420 µm at the center wavelength.

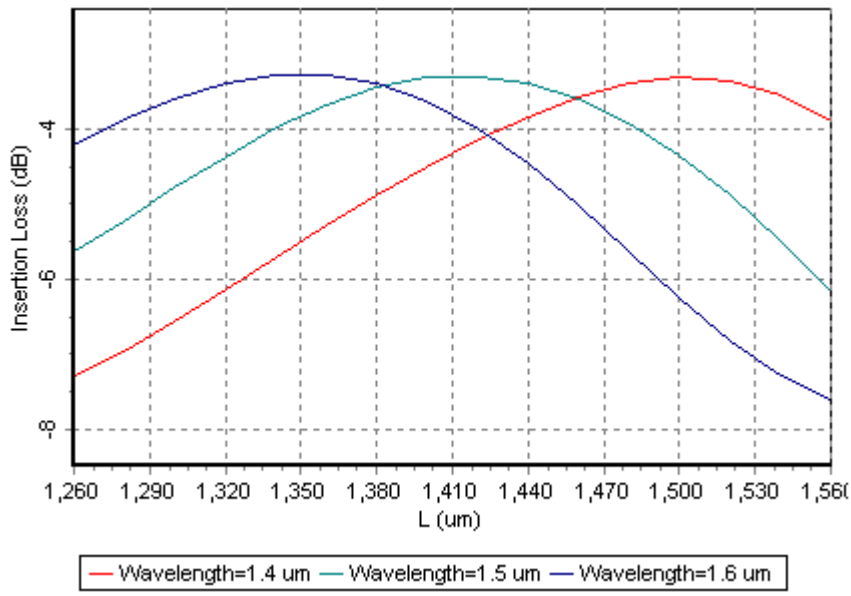

Figure 11 MMI response for different Wavelength and MMI length (L)

The insertion loss of MMI for L=1420µm is shown in Figure 12. By comparing Figure 12 and Figure 8, we can see that MMI has more loss than the Y-junction device. It is also not broadband.

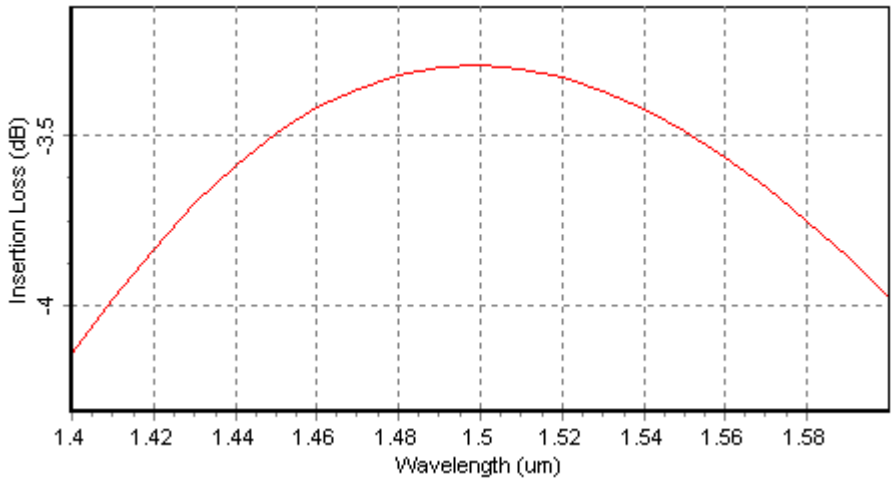

Figure 12 MMI response, L=1420 um

The MMI, as estimated by APSS, is put in the circuit shown in Figure 6. The insertion loss from this version of the power splitter circuit is shown in Figure 13.

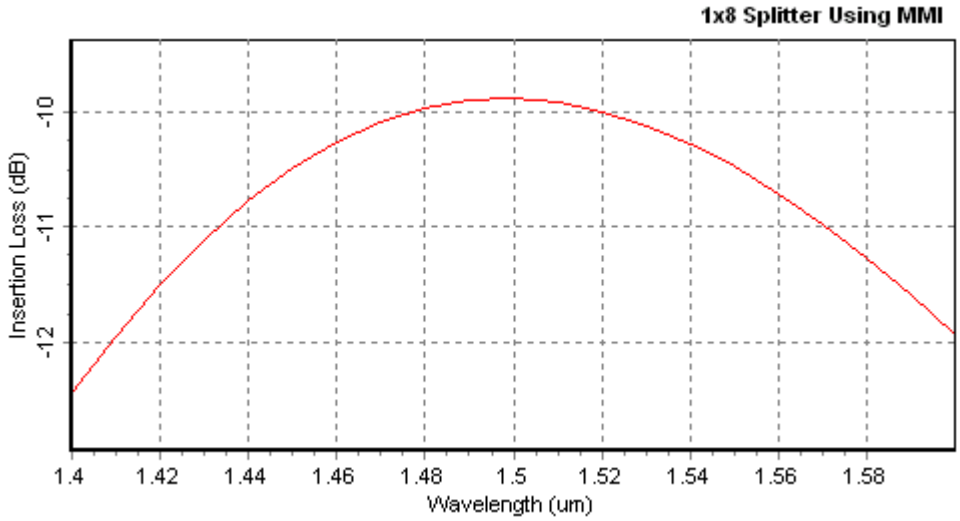

Figure 13 Simulation results of Splitter using MMI

Comparing the two power splitters, we can see that the splitter based on Y-junction is better since it is broadband, and the insertion loss is significantly less. The one with Y-junction is also more physically compact.

6 Conclusion

This document compared two versions of a simple power splitter circuit each constructed using different components. As discussed, connector type and corresponding losses are very important considerations when designing a PIC. Additionally, when individual sub-components are simulated by different methods (for example, one by FDTD and one by BPM), the final circuit analysis should be able to make use of those earlier simulation results. As a user-friendly graphical user interface, the APSS can help optical designers with all of these considerations — enabling them to quickly create, simulate, and compare both simple and complicated circuits — so that they can determine the optimal design for any specific application.

7 References

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