

APPLICATION OF VARIOUS TOOLS TO DESIGN, SIMULATE AND EVALUATE OPTICAL DEMULTIPLEXERS BASED ON AWG

Dana Seyringer and Johannes Edlinger

Research Centre for Microtechnology, Vorarlberg University of Applied Sciences, Hochschulstr. 1, 6850 Dornbirn, Austria,

E-mail: dana.seyringer@fhv.at

Received 17 March 2015; accepted 15 April 2015

1. Introduction

Wavelength division multiplexing (WDM) is the uncontested candidate for increasing capacity throughput of optical networks. Arrayed waveguide gratings (AWGs) are the most promising devices for filters or multi/demultiplexers in such WDM systems because of their low insertion loss, high stability, and low cost [1].

2. AWG Functionality

The AWG consists of input/output waveguides, two couplers and an array of waveguides (also called phased array, PA) with constant path-length difference dL as shown in Fig. 1. One of the input waveguides carries an optical signal consisting of multiple wavelengths, $\lambda_1 - \lambda_n$. The input coupler distributes the light among the array of waveguides. Then the light propagates through the waveguides to the output coupler. The length of arrayed waveguides is chosen so that the optical path-length difference between adjacent waveguides, dL equals an integer multiple of AWG central wavelength λ_c of the demultiplexer. For this wavelength the fields in the individual arrayed waveguides will arrive at the input of the output coupler with equal phase and the field distribution at the output of the input coupler will be reproduced at the input of the output coupler. Linearly increasing length of arrayed waveguides will cause interference and diffraction when light mixes in the output coupler. As a result, each of the wavelengths $\lambda_1 - \lambda_n$ is focused into only one of the N output waveguides [2].

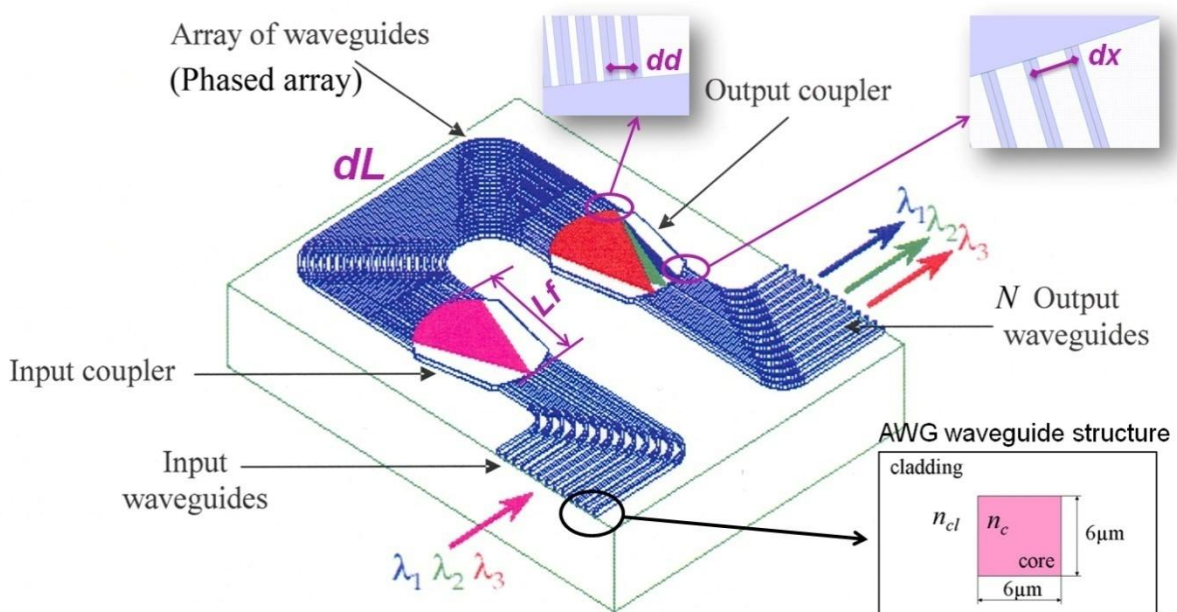


Fig.1: Principle of AWG with used waveguide structure.

3. AWG design

AWG design begins with the calculation of its geometrical parameters, which are essential to create the AWG layout. There are a couple of commercially available photonics software tools like Apollo Photonics, R-Soft, Optiwave or Photon that can be used to simulate created AWG layout (Fig. 2 shows the AWG layout created by Apollo Photonics tool). The output of the simulation is an AWG spectral response, so called transmission characteristics. They are the basis for the calculation of AWG transmission parameters.

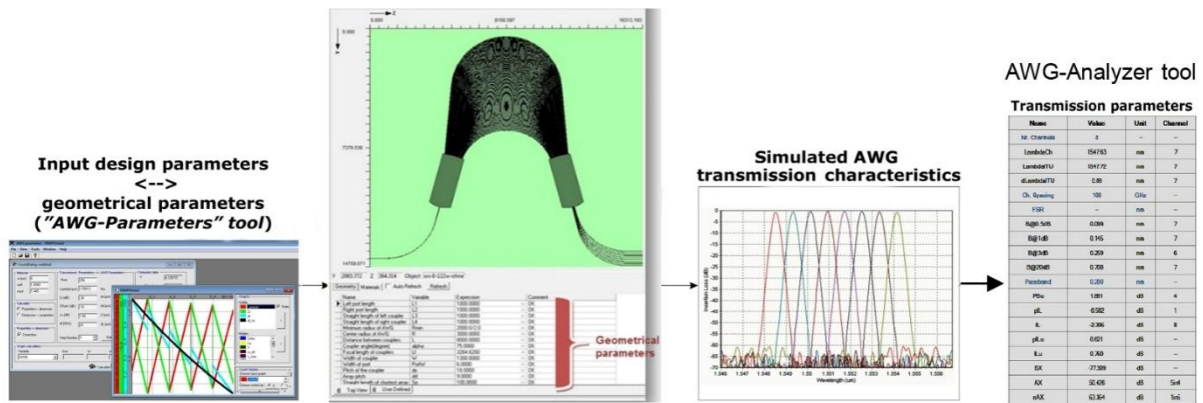


Fig. 2: Software tools used to design, simulate and evaluate AWGs.

Since there is a strong relation between the size of the AWG structure (i.e. its geometrical parameters) and its performance, the AWG geometrical parameters have to be calculated very precisely. Many published papers describing this relationship can be found in the literature. For our calculations, we used the well-known paper of Smit [2]. First calculations were done manually and were time consuming. Therefore, we developed a stand-alone software tool called “AWG-Parameters” based on this paper [3].

AWG-Parameters Tool

When designing AWGs three different sets of input parameters have to be considered:

Technological parameters are taken to design AWG waveguide structure (see “Material” window in Fig. 3-left):

- Waveguide structure: waveguide width $w = 6 \mu\text{m}$.
- Refractive indices: n_{eff} (effective index) = 1.455003, n_{out} is the refractive index of the cladding ($n_{cl} = 1.445$).

AWG type parameters (“Transmission Parameters ↔ AWG Parameters” window in Fig. 3-left):

- Number of output waveguides (channels): $Num = 8$.
- AWG central wavelength (λ_c): $Lambda (\mu\text{m}) = 1.55012 \mu\text{m}$.
- Channel spacing: $df (\text{GHz}) = 100 \text{ GHz}$.

Transmission parameters (“Transmission Parameters ↔ AWG Parameters” window in Fig. 3-left):

- Adjacent channel crosstalk between output waveguides (channels): $Cr (\text{dB}) = -30 \text{ dB}$.
- Adjacent channel crosstalk between arrayed waveguides: $CRaW (\text{dB}) = -10 \text{ dB}$.
- Uniformity over all the output channels (also called non-uniformity): $Lu (\text{dB}) = 0.7 \text{ dB}$.

Pressing “Calculate” the tool calculates all necessary geometrical parameters (dd , dx , Lf and dL , see Fig. 1) in “Transmission Parameters ↔ AWG Parameters” window (see Fig. 3-left):

- Number of arrayed waveguides: $Na = 100.951257$.
- Minimum waveguide separation between I/O waveguides: $dx (\mu\text{m}) = 19.328944 \mu\text{m}$.

- Minimum waveguide separation between PA waveguides: dd (μm) = 8.97488 μm .
- Coupler length: L_f (μm) = 3007.77618 μm .
- Length increment: dL (μm) = 111.621329 μm .

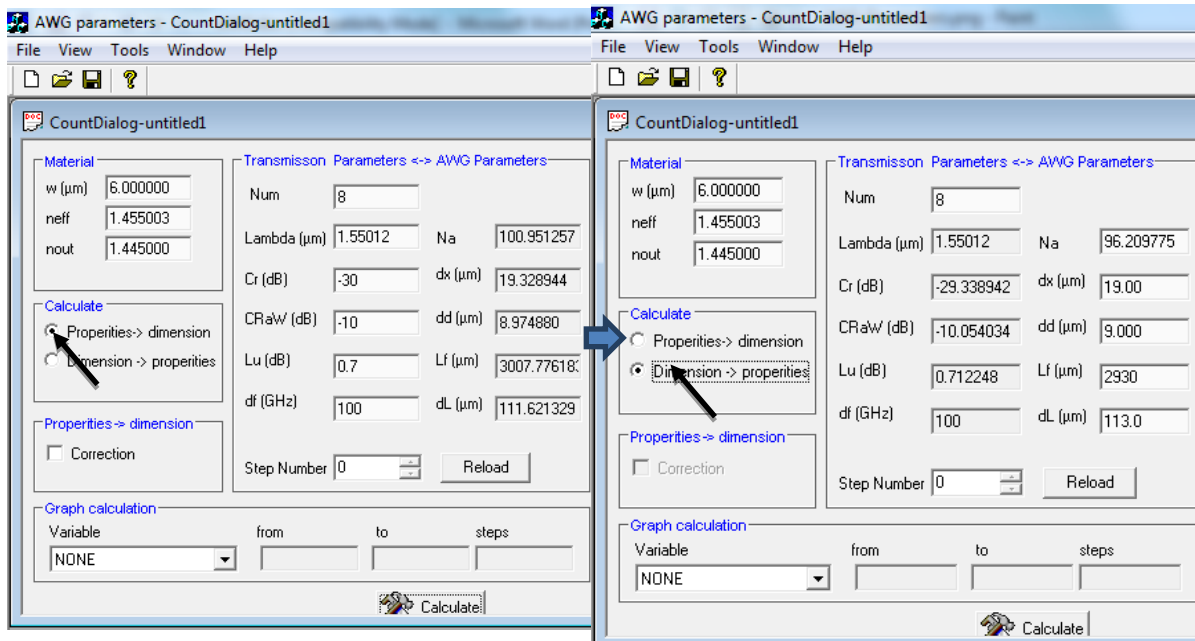


Fig.3: Geometrical parameters calculated using AWG-Parameters tool.

The tool also offers the function “Calculate” (see “Calculate” window in Fig. 3). This is a very important function allowing us to calculate the geometrical parameters from the transmission parameters (“Properties→dimension”) and vice versa (“Dimension→properties”). This function is used to easily adjust calculated geometrical parameters to the technological requirements. For example the calculated minimum waveguide separation in the phased array: dd (μm) = 8.974880 μm (see Fig. 3-left) is very difficult to reach technologically in comparison to $dd = 9$ μm achieved using the function “Dimension→properties” (see Fig. 3-right).

4. AWG simulation and evaluation

The calculated geometrical parameters of 8-channel, 100 GHz AWG (i.e. dx , dd , L_f , dL taken from Fig. 3-right), were used as an input in the Apollo Photonics tool to create AWG layout and to do the BPM simulation. The output of the simulation is an AWG spectral response for both the transverse electric- (TE) and the transverse magnetic (TM) polarization states so called transmission characteristics shown in Fig. 4-left. They are the basis for the calculation of AWG transmission parameters defining the performance of AWG and determining its suitability for a particular application. These parameters were calculated using our in-house developed software tool AWG-Analyzer [4] shown in Fig. 3-right.

AWG-Analyzer tool

User interface of AWG-Analyzer tool is shown in Fig. 4-right. It is divided into three windows:

Raw Data (textual representation of raw data): the content of the original input file (consisting simulated or measured data) is displayed in the “Raw Data” window.

Diagram (graphical representation of raw data): is displayed in the “Diagram” window.

Transmission Parameters: table containing all evaluated transmission parameters:

- **Nr. Channels:** number of output channels
- **LambdaCh:** channel center wavelength
- **LambdaITU:** the nearest ITU wavelength to the channel center wavelength

- **$d\lambda_{ITU}$** : the nearest ITU wavelength to the channel center wavelength
- **Ch. Spacing**: channel center wavelength
- **FSR**: free spectral range
- **$B@0.5dB$** : bandwidth of optical signal at -0.5dB, -1dB, -3dB drop from the transmission peak
- **Passband**: symmetrical wavelength range around each channel center wavelength
- **Pbu**: passband uniformity
- **pIL**: peak insertion loss: the loss in power measured from peak to the 0 dB reference line
- **IL**: insertion loss of a channel measured within the passband to the 0 dB reference line
- **pILu**: peak insertion loss uniformity: the difference between maximum and minimum peak insertion loss over all the output channels
- **ILu**: insertion loss uniformity calculated within the passband of each channel over all the output channels
- **AX**: adjacent channel crosstalk (also called the channel isolation)
- **nAX**: non-adjacent channel crosstalk
- **BX**: background crosstalk

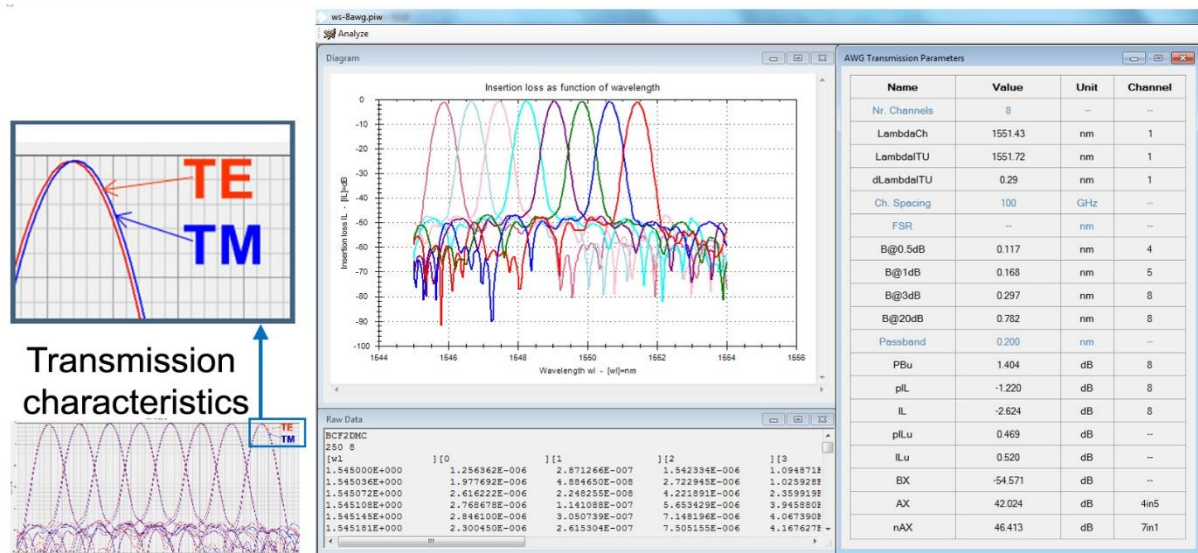


Fig. 4: AWG-Analyzer tool with simulated characteristics of 8-ch. 100 GHz AWG.

5. AWG design verification

This AWG design was also technologically verified and Fig.5 shows comparison of both transmission characteristics: simulation (Fig. 5-left) and measurement (Fig. 5-right). As can be seen, both characteristics feature good correlation. That is also confirmed by the transmission parameters calculated from both characteristics using our in-house developed AWG-Analyzer tool as presented in Table 1.

6. Discussion and conclusion

Table 1 shows the most important transmission parameters: input design parameters (input for AWG-Parameters tool, Fig. 3-right), parameters calculated from simulated- and from measured transmission characteristics (output from AWG-Analyzer tool). As can be seen the AWG central wavelengths, λ_c from simulated and measured transmission characteristics do not agree with the designed value, $\lambda_c = 1550.12$ nm. This deviation is a result of the effective refractive index, used in the waveguide structure simulation, which calculated value in Apollo photonics tool does not fit to the technology. Further, insertion loss calculated within the passband (= 25 % of channel spacing), $IL = -2.624$ dB.

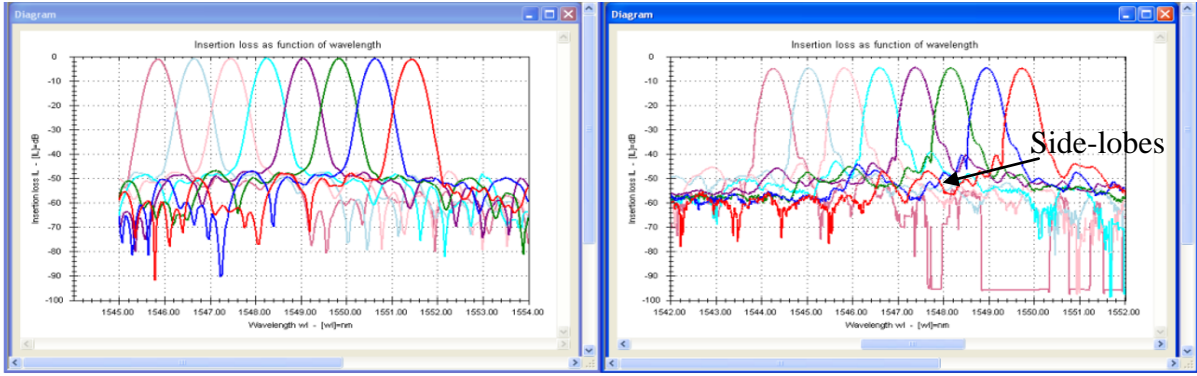


Fig. 5: Simulated (left) and measured (right) characteristics of 8-ch, 100 GHz AWG.

Measured insertion loss reached $IL = -6.438$ dB. This parameter is always higher than its simulated value since it includes also the coupling losses between the fibers and waveguides and propagation losses in the AWG structure. Insertion loss uniformity, Lu (design) and ILu (simulation and measurement) is similar for all three cases, because this parameter depends mainly on the AWG structure itself. Here, the small deviations result from the slightly different optical signal shapes. AWG-Parameters tool considers ideal Gaussian shape whilst the simulated- and measured non-uniformity depends also on the tapers used in AWG design. Adjacent channel crosstalk, Cr (design) and AX (simulation and measurement) (also calculated within the passband) feature very good agreement between the theoretical value ($Cr = -29.33894$ dB) and the measurement ($AX = -32.476$ dB). The simulated value ($AX = -42.024$ dB) is about 10 dB better than the channel crosstalk calculated from the measured characteristics. This difference is a result of the side lobes in the measured characteristics (shown in Fig. 5-right), originating from the fabrication imperfections. Non-adjacent channel crosstalk, nAX together with the background crosstalk, BX feature an excellent agreement between the simulated and measured values.

Tab 1: Input design parameters (AWG Parameters tool) together with parameters calculated from the simulated transmission characteristics (AWG-Analyzer tool: simulation) and from the measured transmission characteristics (AWG-Analyzer tool: measurement).

8-ch, 100 GHz AWG	AWG-Parameters tool: input design parameters	AWG-Analyzer tool: simulation	AWG-Analyzer tool: measurement
Number of channels	Num = 8	Nr. Channels = 8	Nr. Channels = 8
AWG central wavelength, λ_c	Lambda = 1550.012 nm	$\lambda_c = 1549.00$ nm	$\lambda_c = 1547.50$ nm
Channel spacing	df = 100 GHz	Ch. Spacing ~ 100GHz	Ch. Spacing ~ 100 GHz
Insertion loss	Depends on technology	IL = -2.624 dB	IL = -6.438 dB
Insertion loss uniformity	Lu = 0.712248 dB	ILu = 0.520 dB	ILu = 0.694 dB
Adjacent channel crosstalk	Cr = - 29.338942 dB	AX = -42.024 dB	AX = -32.476 dB
Non-adjacent ch. crosstalk	Depends on technology	nAX = -46.413 dB	nAX = -46.308 dB
Background crosstalk	Depends on technology	BX = -54.571 dB	BX = -54.793 dB

Acknowledgement

This work was carried out in the framework of FFG project COHESION, project no. 848588.

References:

- [1] K. Okamoto: Fundamentals of Optical Waveguides, Academic Press (2000).
- [2] M. K. Smit, et al.: *J. Select. Topic Quantum Electron.*, **2**, p. 236 (1996).
- [3] D. Seyringer and M. Bielik: In: *SPIE Photonics West*, Feb 2-7, San Francisco (2013).
- [4] D. Seyringer and P. Schmid: In: *SPIE OSD*, Sept5-8, Marseille, France, p. 8167 (2011).