Application of Angular Method to Correct Channel Spacing Between AWG Demultiplexed Channels

D. Seyringer

Research Centre for Microtechnology, Vorarlberg University of Applied Sciences, Dornbirn, Austria,
dana.seyringer@fhv.at

ABSTRACT

We present the angular method to correct the channel spacing between transmitted output channels of an AWG. The developed method was applied to 40-channel, 100 GHz AWG and the achieved results confirm excelent correlation between designed channel spacing (100 GHz) and the channel spacing calculated from simulated and measured transmission characteristics.

Keywords: arrayed waveguide gratings, AWG, AWG channel spacing, AWG transmission parameters

1 INTRODUCTION

The key components in WDM systems, especially for powerful WDM applications, are pasive optical devices based on arrayed waveguide gratings (AWG). This is because AWG based devices have been proven capable of precisely demultiplexing a high number of optical signals with relative low loss [1].

Depending on the application, the AWGs are usually designed for a particular central wavelength, λ_c and for a particular number of transmitting channels, *Num* which are separated by a channel spacing, *df*. According to ITU-Grid the channel spacing is constant over all the transmitted channels in the frequency domain; it means it is not constant in the wavelength domain. This is due to the nonlinear dependency between wavelength and frequency. However, the channel spacing between transmitted optical signals is, in opposite to this, constant in wavelength domain but not in the frequency domain. To solve this problem, an angular method was developed and applied to 40-channel, 100 GHz AWG design and technologically verified. The achieved results show that the proposed method can be used for any AWG channel spacing adjustment.

2 AWG FUNTIONALITY

Based on a substrate, AWG consists of an array of waveguides (also called phased array, PA) and two star couplers (also called Free Propagation Region, FPR) as shown in Fig. 1. One of the input waveguides carries an optical signal consisting of multiple wavelengths, $\lambda_1 - \lambda_n$ into the first (input) star coupler, which then distributes the light amongst an array of waveguides. The light subsequently propagates through the waveguides to the second (output) star coupler. The length of the PA waveguides is chosen so that the optical path length difference between adjacent waveguides, *dL* equals an integer multiple of the 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. Consequently, the light beam interferes constructively in the output star coupler and converges at one single point on the focal line. For the central wavelength λ_c, the input field at the object plane of the input star coupler is transferred to the center of the image plane of the output star coupler. For all other wavelengths, there will be a phase shift in the PA waveguides. As a result, the phase front at the input of the output star coupler will be slightly tilted, so the beam is focused to a different point on the focal line. Placing of the waveguides at the focal points in the image plane allows the spatial separation of the transmitted wavelengths [2].
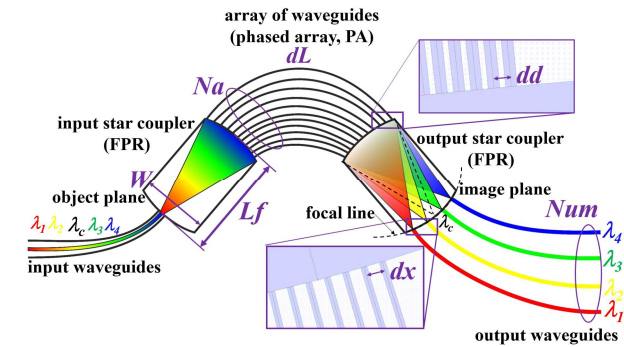

Figure 1: Topological structure and principle of AWG.

3 40-CH, 100 GHZ AWG DESIGN, SIMULATION AND TECHNOLOGICAL VERIFICATION

The AWG design begins with the calculation of the geometrical parameters determining the dimensions of the AWG structure. These parameters are essential to create the AWG layout [2, 3]. They are shown in Fig. 1: the minimum waveguide separation between input/output waveguides, *dx*; the minimum waveguide separation in the phased array, *dd*; the length of coupler, *Lf* and the PA waveguide length

increment, *dL*. Each AWG is designed for a particular number of transmitting channels, *Num* with a channel spacing, *df*.

To calculate the AWG geometrical parameters we used the design tool, called AWG-Parameters [3]. The tool was already applied in various AWG designs and experimentally well proven [4]. The user interface of this tool is presented in Fig. 2.
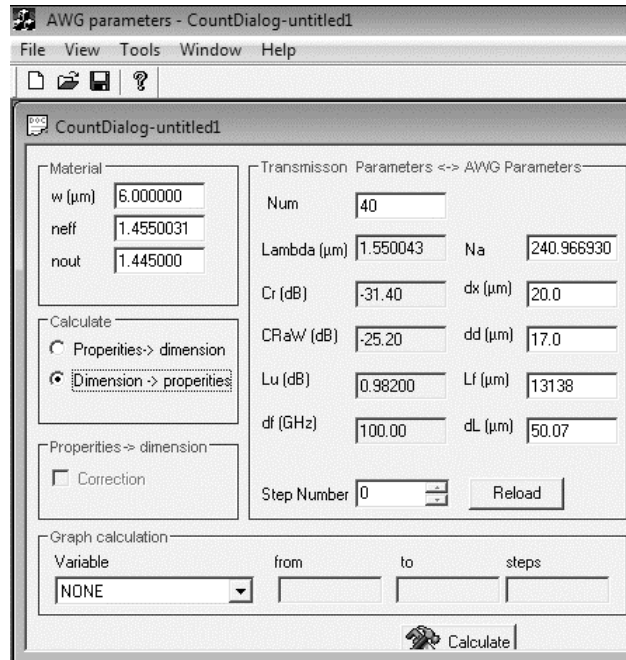

Figure 2: Design of 40-channel, 100 GHz AWG using AWG-Parameters tool.

The input for the calculation is a set of input parameters:

Technological parameters are taken to design AWG waveguide structure (see "Material" window in Fig. 2):
- Waveguide structure: waveguide width $w = 6$ µm.
- Refractive indices: n_{eff} (effective index) = 1.455003, n_{out} is the refractive index of the cladding ($n_{cl} = 1.445$).

AWG type parameters (see "Transmission Parameters $\leftarrow\rightarrow$ AWG Parameters" window in Fig. 2):
- Number of output waveguides (channels): *Num* = 40.
- AWG central wavelength (λ_c): *Lambda* = 1.55012 µm.
- Channel spacing: *df* = 100 GHz.

Transmission parameters (see "Transmission Parameters $\leftarrow\rightarrow$ AWG Parameters" window in Fig. 2):
- Adjacent channel crosstalk between output waveguides (channels): *Cr* = -31.4 dB.
- Adjacent channel crosstalk between arrayed waveguides: *CRaW* = -25.20 dB.
- Uniformity over all the output channels (also called non-uniformity): *Lu* = 0.982 dB.

Pressing "Calculate" the tool calculates all necessary geometrical parameters in "Transmission Parameters $\leftarrow\rightarrow$ AWG Parameters" window (see Fig. 1 and Fig. 2):
- Number of arrayed waveguides: *Na* ~ 241.
- Minimum waveguide separation between input/output waveguides: *dx* = 20 µm.
- Minimum waveguide separation between waveguides in phased array: *dd* = 17 µm.
- Coupler length: *Lf* = 13138 µm.
- Length increment: *dL* = 50.07 µm.

The calculated geometrical parameters (i.e. *dx, dd, Lf, dL*) were then used as an input in the commercial photonics tool Apollo Photonics, to create and to simulate the AWG structure.

The output of the simulation is a spectral response for both, transverse electric- (TE) and transverse magnetic (TM) polarization states: transmission characteristics (Fig. 3a). The AWG was also fabricated and Fig. 3b presents the measured transmission characteristics. As shown, the characteristics are rather similar to each other, confirming excelent agreement between the design and fabrication.
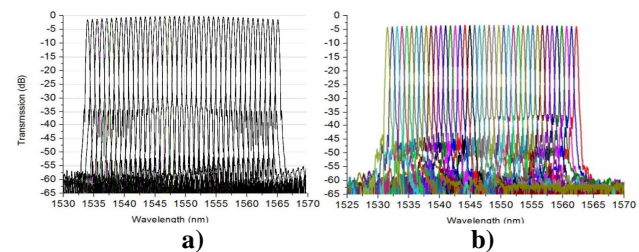

Figure 3: 40-channel, 100 GHz AWG: (a) simulation, (b) measurement.

Transmission characteristics create a basis for the calculation of AWG transmission parameters [5]. The most important parameters are listed in Table 1 and they confirm the excellent correlation between the design, simulation and fabrication, too. One of these parameters is channel spacing parameter, *df* and it is defined as a separation between the channel center frequencies (or wavelengths) of two adjacent transmitting channels (*df/dLambda*). According to the ITU-Grid this parameter is constant over the all channels in the frequency domain; it means it is not constant in the wavelength domain. This is due to the nonlinear dependency between wavelength and frequency. However, the channel spacing between AWG demultiplexed optical signals is, in opposite to this, constant in wavelength domain but not in frequency domain. The graphical representation of this frequency channel spacing tendency, *df (GHz)* is shown in Fig. 4a. Figure 4b shows the wavelength channel spacing tendency, *dLambda* that is nearly constant having the value of 0.8 nm.

40-channel, 100 GHz AWG	Input design parameters from Fig.2	Simulation	Measurement	Measurement (after correction)
AWG central wavelength, λ_c	1550.12 nm	1550.12 nm	1548.35 nm	1548.35 nm
Channel Spacing, df	100 GHz	~ 100 GHz	~ 100 GHz	100 GHz
Peak insertion loss, pIL		-1.502 dB	-4.15 dB	-4.17 dB
Peak insertion loss uniformity, $pILu$	Lu = 0.982 dB	0.87 dB	0.73 dB	0.74 dB
Adjacent channel crosstalk, AX	Cr = -31.4 dB	-30.39 dB	-30.28 dB	-31.15 dB
Non-adjacent channel crosstalk, nAX		-37.70 dB	-40.66 dB	-40.7 dB
Background crosstalk, BX		-65.2 dB	-67.65 dB	-67.72 dB

Table 1: 40-channel, 100 GHz AWG: transmission parameters calculated from simulated and measured characteristics.
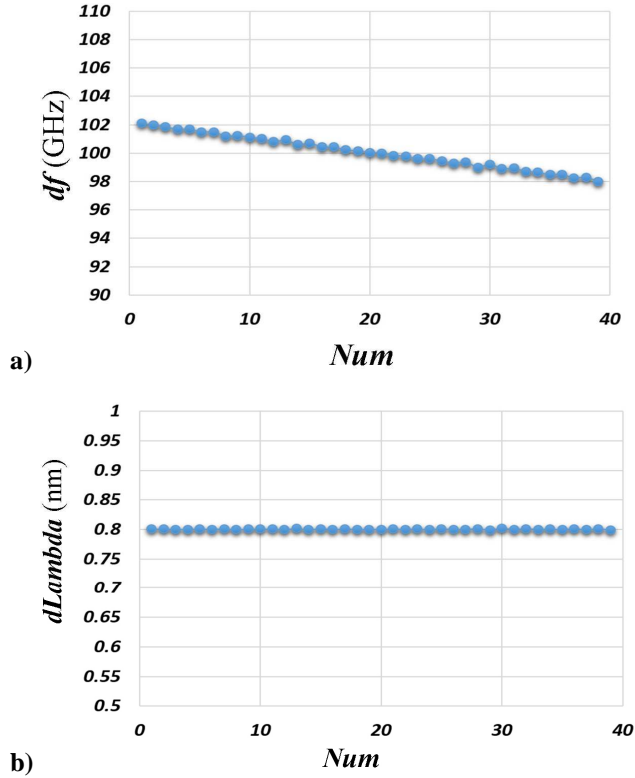

a)

b)

Figure 4: 40-channel, 100 GHz AWG measurement: (a) channel spacing in frequency, df, (b) channel spacing in wavelength, $dLambda$.

4 CHANNEL SPACING CORRECTION

To explain this problem we will concentrate on the process of focusing different signals (λ_1 - λ_n) at the focal line in the output star coupler (Fig. 1). As can be seen all wavelengths are focused each at one well-defined point lying on the focal line. All these points are spread linearly and the spacings between λ_1 - λ_n are constant. From this follows that the spacings between output waveguides, placed at these focus points, are also constant (the minimum waveguide separation parameter, dx). From equation $\lambda = c/f$ (where λ = wavelength, c = speed of light, f = frequency) is evident that constant $dLambda$ leads to not constant df. Shifting the positions of the output waveguides,

i.e. recalculating the parameter, dx the channel spacing, df can be corrected to a constant value very precisely.

4.1 Angular Method

The angular method is based on the fact that the output coupler, where the output waveguides are placed, is a circle of radius $Lf/2$ (see Fig. 5).
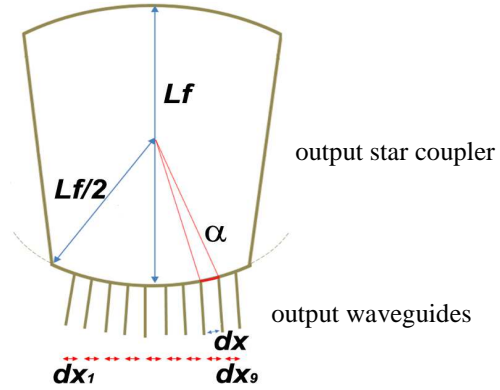

Figure 5: Graphical representation of the angular method.

Therefore, the designed dx value (in µm) is first converted into angles in radian, dx^o. Then the needed correction in radian dx^o_n is applied. Finally, this correction is converted back into µm, dx_n. After applying the angular method there are Num-1 dx_n values (Num – number of output waveguides), which are not constant anymore (see in Fig. 5 the arrows with $dx_1 – dx_9$). Mathematical description of the new output waveguide separations, dx_n is:

$$\alpha = \frac{dx}{\frac{Lf}{2}} = dx^o \tag{1}$$

$$dx^o_n = \frac{dx^o * df}{df_n} \tag{2}$$

$$dx_n = \frac{Lf}{2} * dx^o_n \tag{3}$$

where df_n are the channel spacings from Fig. 4a.

5 APPLICATION OF ANGULAR METHOD IN AWG DESIGN

The new calculated minimum waveguide separations, dx_n were applied to the 40-channel, 100 GHz AWG design. To this purpose, we used the same AWG layout with the same calculation conditions. In this layout, we just changed the dx parameter from its constant value to the dx_n values calculated using angular method. This AWG design was simulated, fabricated and measured (see Fig. 6b). As can be seen, since we changed only the dx parameter in the AWG layout, the transmission characteristics are nearly identical with the original measured characteristics presented in Fig. 6a. This is confirmed also by the calculated transmission parameters presented in Table 1, "measurement (after correction)" column. As can be seen, all channel crosstalk parameters, i.e. *AX, nAX and BX* feature slightly better value in optimized design (after applying channel spacing correction method). In opposite to this, the insertion loss, *pIL* and the insertion loss uniformity, *pILu* feature slight worsening of their values compared to the original parameters presented in column "measurement".

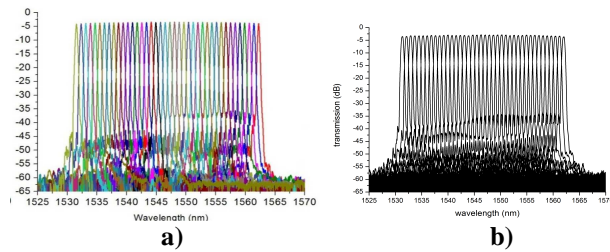**a)**   **b)**

Figure 6: 40-channel, 100 GHz AWG: measurement (a) and measurement after applying channel correction (b).

Figure 7a shows the channel spacing, *df* calculated from transmission characteristics after applying the angular method. As shown, the parameter *df* is constant over all channels and correlates with the designed value 100 GHz. *dLambda* channel spacing parameter is no more constant but accordingly increases as can be seen in Fig. 7b.

6 CONCLUSION

We have shown that the transmission parameter, *df* (the frequency channel spacing parameter) calculated from simulated/measured AWG transmission characteristics, is not constant. However, according to ITU-Grid this channel spacing should be constant over all the channels in the frequency domain; it means it is not constant in the wavelength domain. This is due to the nonlinear dependency between wavelength and frequency. The problem is that the channel spacing between AWG demultiplexed optical signals is, in opposite to this, constant in wavelength domain but not in the frequency domain. Therefore a new method was developed to recalculate the positions of the output waveguides to get constant channel spacing in frequency domain. The results show that proposed method can be used for the AWG channel spacing adjustment.
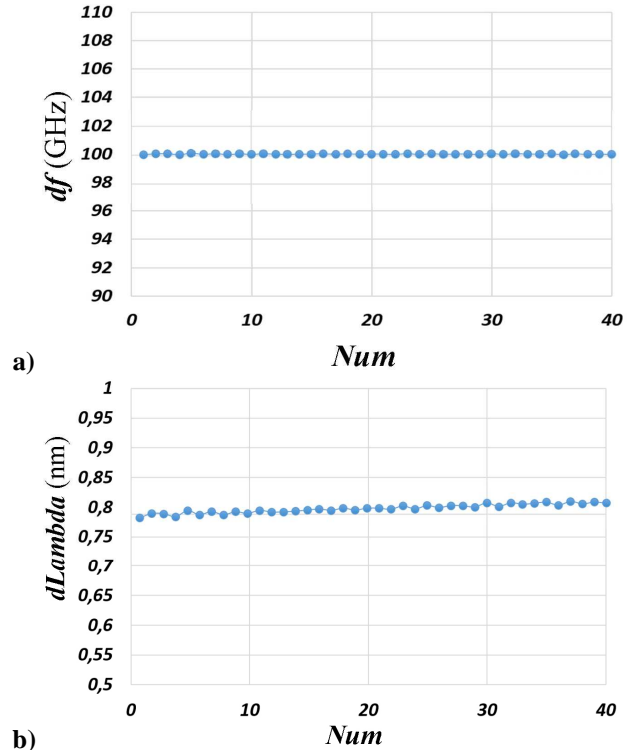

a)

b)

Figure 7: 40-channel, 100 GHz AWG measurement after applying angular method: (a) channel spacing in frequency, *df*, (b) channel spacing in wavelength, *dLambda*.

REFERENCES

[1] H. Takahashi, et al., "Arrayed-Waveguide Grating for Wavelength Division Multiplexing/Demultiplexing with Nanometer Resolution," Electronics Letters, vol. 26, 1990.

[2] M. K. Smit, Cor van Dam, "PHASAR-Based WDM-Devices: Principles, Design and Applications," IEEE Journal of select. topics in quantum electronics, vol. 2, 1996.

[3] D. Seyringer, M. Bielik, "AWG-Parameters: new software tool to design arrayed waveguide gratings," Proc. SPIE 8627, Integrated Optics: Devices, Materials, and Technologies XVII, 862716, 2013.

[4] D. Seyringer et al., "Design, simulation, evaluation, and technological verification of arrayed waveguide gratings", Opt. Eng., vol. 53, no. 7, p. 071803, 2014.

[5] D. Seyringer, P. Schmid, "A new software tool is developed to evaluate the measured/simulated transmission characteristics of optical multiplexers/demultiplexers," Proc. SPIE, 8167, id. 81671D, 2011.