Control of wavelength alignment in a wavelength division multiple access passive optical network

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In a wavelength division multiple access passive optical network based on spectral slicing, the wavelength drift of a multiplexer/demultiplexer due to varying ambient temperature in the passive outside plant, is compensated by controlling the temperature of the other device at central office location to wavelength alignment.

Introduction: In wavelength division multiple access (WDMA) passive optical networks (PONs), temperature dependence of wavelength selective components needs to be solved. One of the most potential technologies to be used for wavelength division multiplexing (WDM) in WDMA PONs is arrayed waveguide gratings (AWGs), which provide excellent performance and have the potential to achieve, in volume production, low cost per channel for a large number of wavelength channels. Temperature sensitivity of AWGs is typically solved by keeping them at a constant temperature, with active temperature control elements such as thermoelectric cooler/heater (TEC) or resistive heater. Electricity for such element is not available at the fully passive curbside location of WDMA PON. Athermal solutions for AWGs have been presented [1-3], but these are likely to have increased manufacturing complexity, adding cost and decreasing reliability and performance values. Also, ambient temperature at curbside location in a PON may vary over quite wider range than in the typical office environment of a WDM system, and then even athermal components may still have unacceptable wavelength drift.

This temperature dependence issue of WDMA PON concerns the downstream demultiplexing and upstream multiplexing functionality located in the passive fiber-optic plant. The downstream multiplexing and upstream demultiplexing functionality is located in the network hub, that is in the office environment with access to electricity. This makes it possible to have another approach to solution of the thermal wavelength drift problem: if the system can allow wavelength bands to drift to some extent, as long as these bands maintain alignment through the system, temperature control at the hub location can be used to keep the AWG there aligned with that on the passive curbside location. In spectral slicing WDM PONs, for example, the multiplexer/demultiplexer filters define the used wavelength bands, so no other wavelength control is needed in the system.

Principle: We have realized a prototype of spectral slicing WDMA PON network, providing up to 32 end users [4]. Conventional 32-channel silica-on-silicon AWGs were used. In field trial, AWGs were at two separate locations both having office environment. Also, difference of nominal temperatures at which AWG passband would be aligned with ITU-T WDM grid was about 4^{o}C. No wavelength alignment problems were encountered during the field trial, proving that AWG temperatures need to managed only within a few degrees, due to their low temperature dependences of about 0.013nm/ ^{o}C. Separate tests have shown that 0.1 nm wavelength misalignment, corresponding to more than 7 ^{o}C shift in temperature, caused about 1 dB penalty, from increased crosstalk.

To align wavelengths of two similar AWGs, the curbside AWG has an optical broadband source connected to one input port and transmits a spectral slice corresponding to its bandpass, and accurate alignment is achieved by setting the temperature of the hub AWG so that it demultiplexes this wavelength slice at maximum output power from corresponding output port. Constant small modulation of hub AWG temperature is needed to maintain alignment, contributing an additional penalty to the system. Availability of two signals, the ratio of which indicates directly the wavelength misalignment of AWGs, will make feedback temperature control of hub AWG simpler. Monitoring of output signals of two hub demultiplexer outputs corresponding to two neighboring passbands can be used to achieve this. Equalising these signals will align the curbside AWG passband center wavelength to be in the midpoint between the center wavelengths of the two used hub AWG passbands, so the center wavelengths of the two AWGs would be interleaved with an offset of half a wavelength grid separation. Therefore, for actual WDMA PON use, it is straightforward to design a custom AWG component to be used in the curbside, having an additional channel with offset of half wavelength grid separation at the edge of the used wavelength window. This additional channel would be used only for this wavelength alignment control purpose. Actual signals in the PON cannot be utilized for this purpose, since the presence of any particular signal in the network cannot be quaranteed.

Experiment and results: We demonstrated this principle of wavelength alignment using two regular AWGs in our system. The setup for testing the wavelength alignment control is shown in Figure 1. A similar LED that was used as a signal source in our WDMA PON was also used as the control channel optical source. With a variable optical attenuator set before erbium-doped fiber optical amplifier (OA) and AWG at hub, the attenuation level in the system was varied within the same range as in actual PON. AWGs were 100 GHz spaced 2x32 channel devices, having two ports at the multiplexed side – this was utilized to launch light from an amplified spontaneous emission (ASE) source through selected passbands of the two AWGs, in direction opposite to the actual signal and control channel. This light was combined to an optical spectrum analyzer (OSA) to monitor the spectra of these two AWG passbands in order to evaluate the achieved passband alignment. Both AWGs had TEC elements. Curbside AWG temperature could be set using a laboratory instrument TEC controller. Software implemented in a Linux control PC, controlled the hub AWG TEC, using feedback from the two measured optical control outputs. Minimum temperatures achieved in the laboratory environment with TEC were a few degrees below zero centigrade. Maximum temperature was limited to 85 ^{o}C to avoid damage to AWG components. In the setup, the target alignment corresponded to one and a half channel spacing (150 GHz) difference between the center wavelengths of the two passbands monitored at the OSA. The optical control input ratio to achieve this differs from unity due to loss differences of AWG outputs, and was calibrated once before testing. Due to the temperature limitations mentioned, curb AWG temperature could be varied roughly between 0 and 50 ^{o}C (hub AWG temperature at alignment is then more than 30^{o}C above this). For any set temperature within this range, the control system was always able to find and maintain alignment, as is shown in Figure 2.

In order to test the ability to track the temperature drift of curbside AWG, this temperature was ramped up from 0 to 50 ^{o}C in 45 minutes, and hub AWG temperature controlled by the system is shown in Figure 3. The simple control algorithm was always able to maintain alignment within one degree of temperature – the corresponding wavelength accuracy could not be directly measured with the resolution of OSA. Even though there was a considerable amount of ASE from the EDFA due to the low control channel optical power, alignment was kept within this accuracy when control signal power was changed within the range from –42.5 to –50.5 dBm specified for our WDMA PON system signal powers.

Conclusion: For actual system, the demonstrated principle requires a special curbside AWG design, having control channel passband at half a wavelength grid separation from signal channel grid. Alternatively, we have also trialed a temperature control based on monitoring a single channel of our regular AWGs, which allows their direct alignment without offset. This achieved same level of alignment accuracy and tracking capability as the principle described here, but required constant modulation of hub AWG temperature with modulation amplitude of about 1^{o}C. The final choice of temperature control method cannot be done here, as it depends on weighing allowed tolerance against simplicity of used hardware and software, but we have shown that quite sufficient temperature control can be realized without high complication. The signal passbands in WDMA PON can be aligned across wider temperature range such as –40 to +85°C by either having slightly athermal AWG at curbside or using a hub AWG based on silicon-on-insulator technology [5,6], which has an order of magnitude higher temperature dependence of wavelength. Both of these solutions would require hub AWG temperature to be changed only within substantially smaller temperature range, readily achieved using TEC or even heater element.

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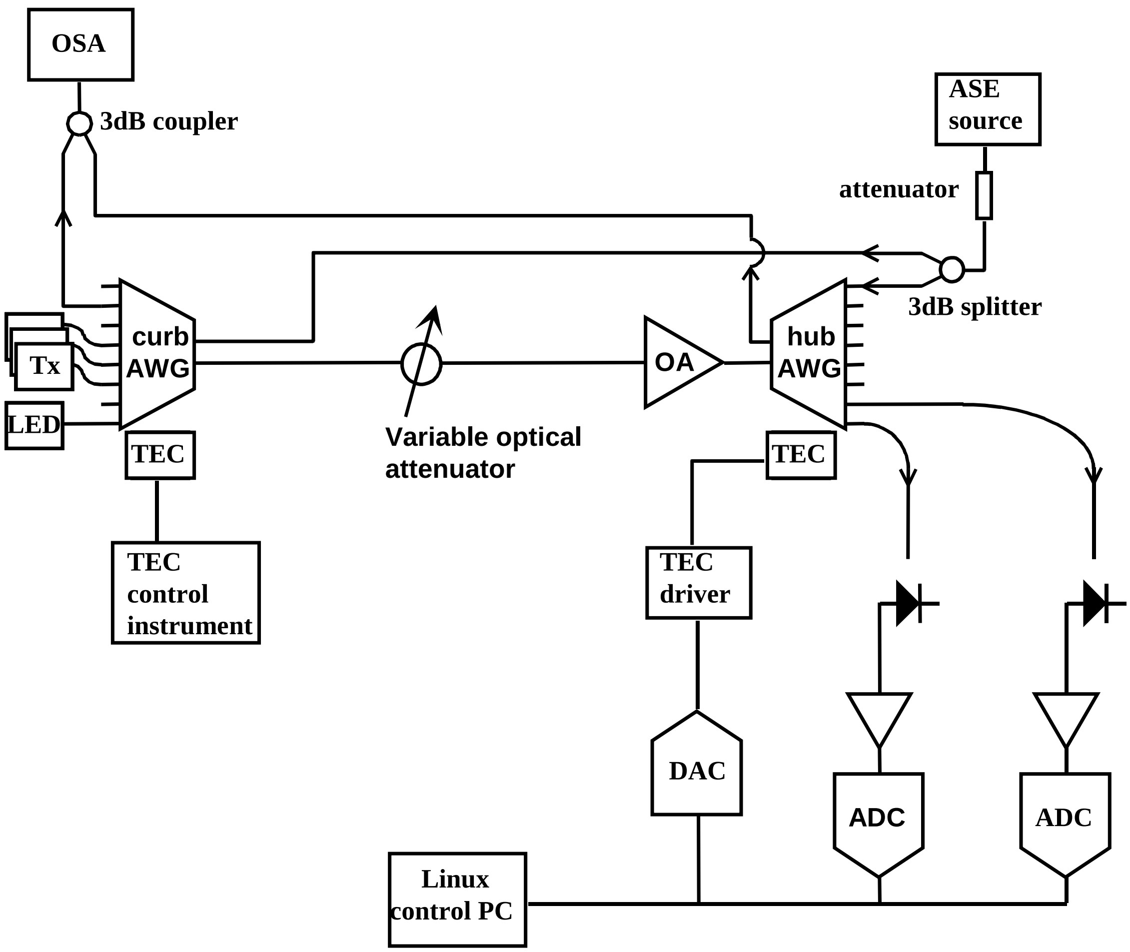
Figure captions:

Figure 1. The setup for testing wavelength alignment control.

Figure 2. Transmission from the ASE source through the curbside AWG passband (left side) and hub AWG passband (right side), at temperatures of curbside AWG, T = 0, 10, 20, 30, 40, 50 ^{o}C (individual curves from left to right, respectively), passband separation is maintained at 150 GHz (1.2 nm).

Figure 3. The controlled temperature of hub AWG, when curbside AWG temperature was ramped up from 0 to 50 ^{o}C in 45 minutes.

Figure 1.



OSA
3dB coupler
ASE
source
attenuator
3dB splitter
curb
AWG
Tx
LED
TEC
Variable optical
attenuator
OA
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TEC
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instrument
TEC
driver
DAC
ADC
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Linux
control PC

Figure 2.

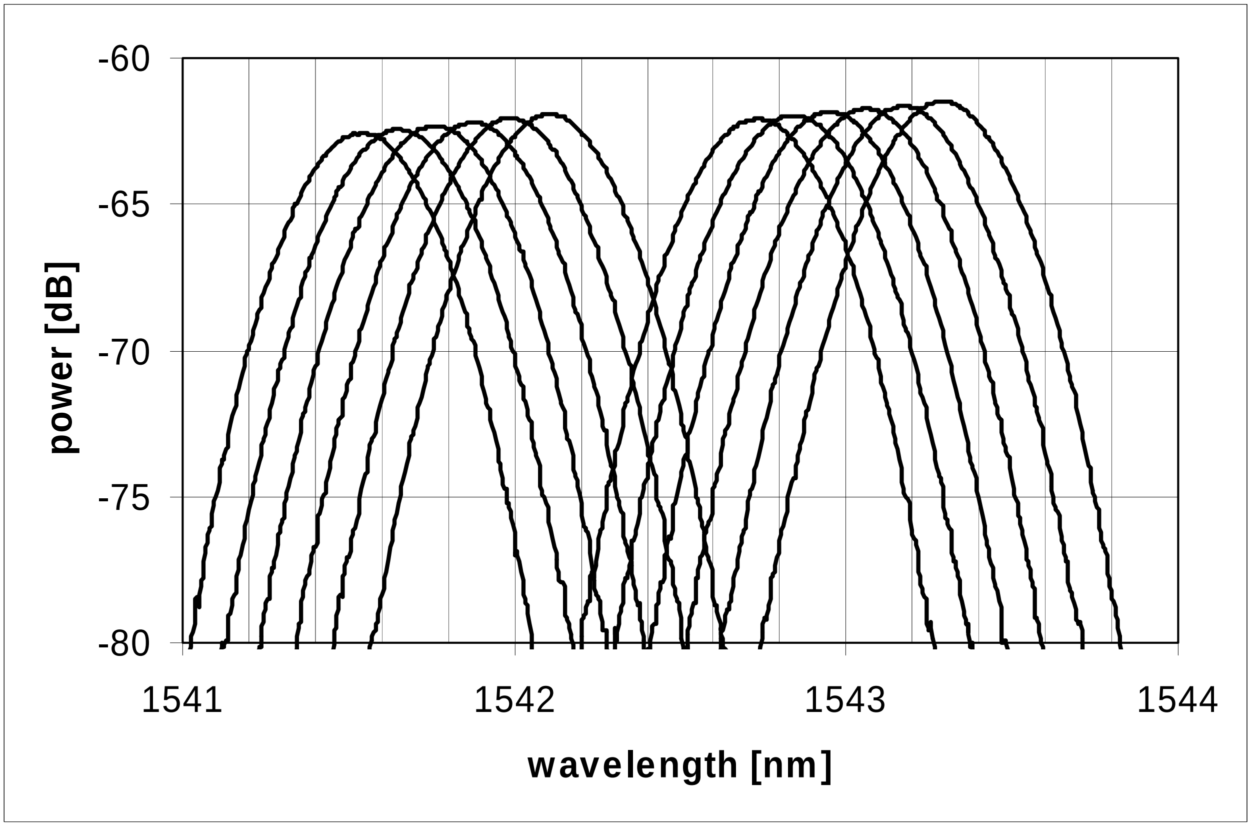
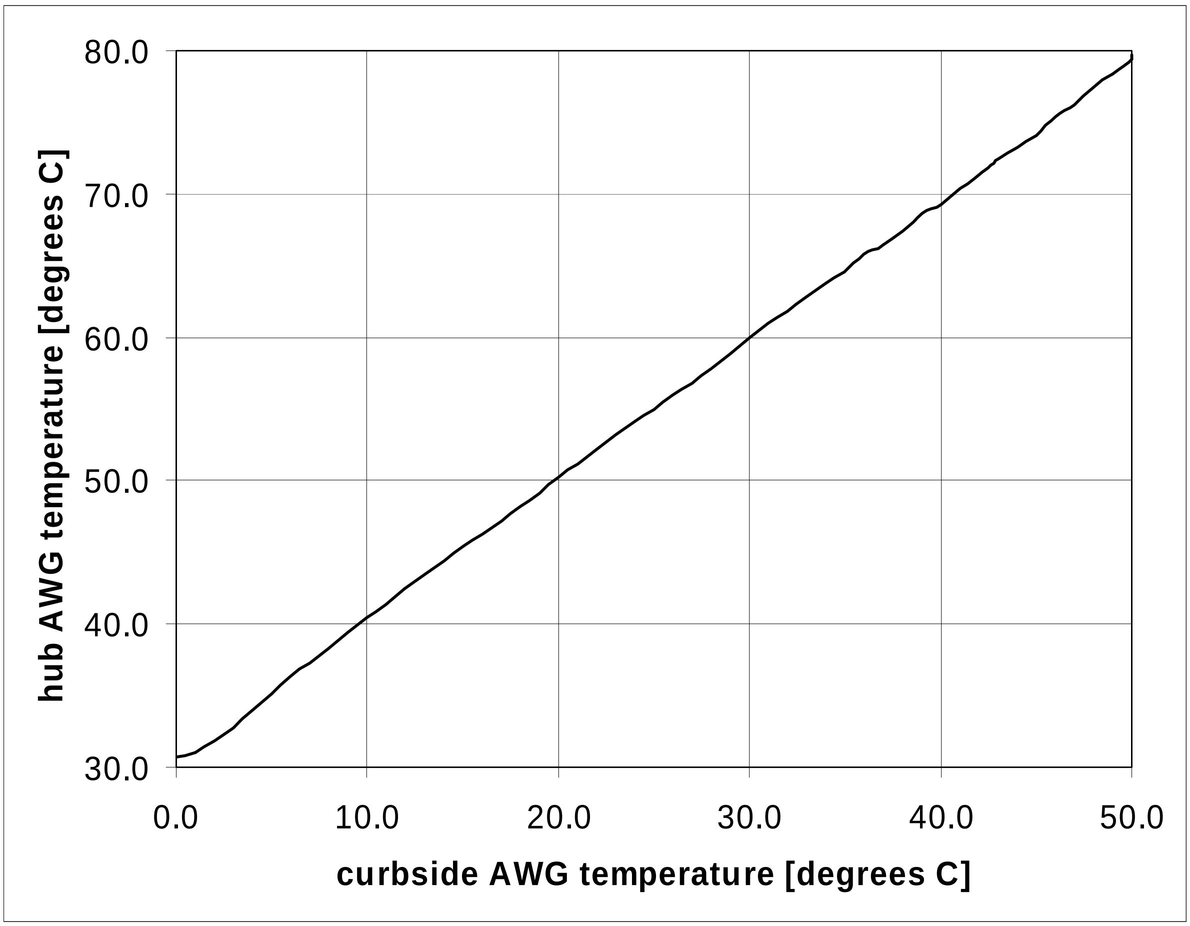


Figure 3.



80.0
70.0
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hub AWG temperature [degrees C]
curbside AWG temperature [degrees C]