

# Arrayed Waveguide Grating

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## Introduction

Arrayed Waveguide Gratings (AWG) are optical planar devices that are usually used as multiplexers/demultiplexers. These design of these devices are based on an array of waveguides with both imaging and dispersive properties. Although AWGs are also known under different names such as Phased Arrays (PHASARs), and Waveguide Grating Routers (WRGs), AWG is the most frequently used term in the telecommunications industry.

Light waves of different wavelengths interfere linearly with each other, thus multiple optical channels with slightly different wavelengths can be transmitted over a single optical fiber with minimal crosstalk between the channels. Based on this principle, AWGs can be used to multiplex multiple channels of different wavelengths on a single optical fiber at the transmitter and also be used to demultiplex them back into their individual channels of different wavelengths at the receiver.

Due to their ability to multiplex large numbers of wavelengths into a single optical fiber, AWGs are commonly used as optical multiplexers and demultiplexers in a Wavelength Division Multiplexed (WDM) system. There are other areas of application such as signal processing, measurement, and sensing. Silica-on-Silicon and Indium Phosphide (InP) based semiconductor are the most deployed technologies in the AWG market. The modal field matches well with that of an optical fiber, thus making them easy to couple with losses of less than 0.1dB. In addition, there is also a very low propagation loss of less than 0.05dB/cm. InP is the dominant technology for operation in the telecom window.

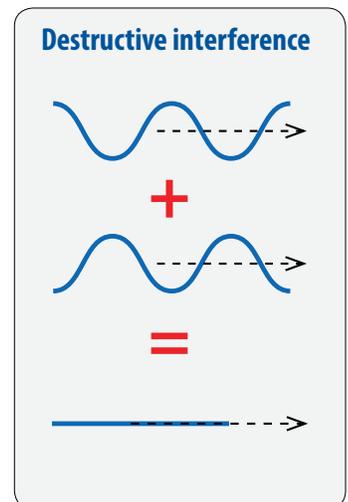
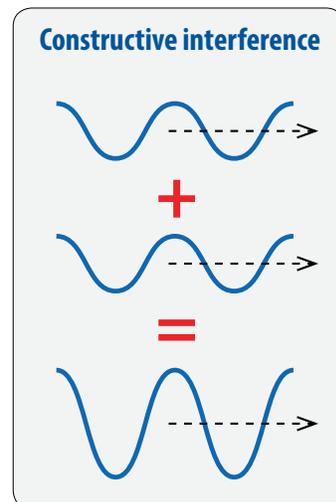
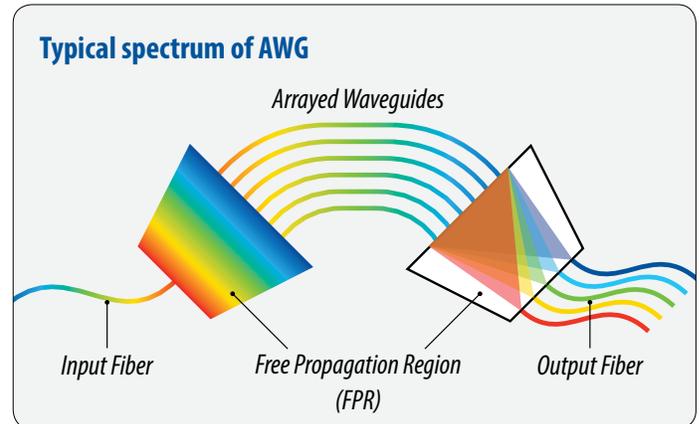


## Operation Principle and Device Characteristics

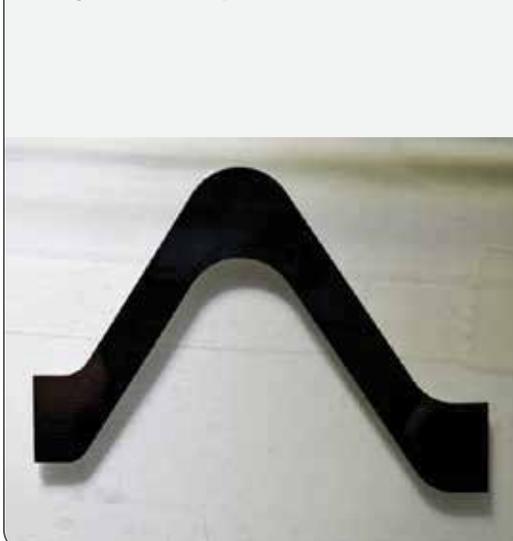
An AWG is made up of mainly 3 parts, which are the input/output fiber, the Free Propagation Region (FPR), and array waveguides.

Light wave of multiple different wavelengths enter the FPR through the input fiber. Within the FPR, the light wave is no longer confined within an optical fiber and becomes divergent and enters a waveguide array. The expanded light is then captured by the array waveguide which propagates it towards the output array aperture.

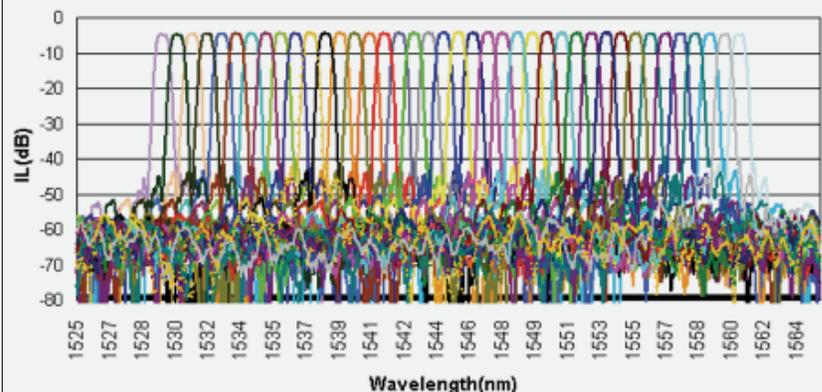
The individual waveguides have varying lengths with the inner guides being shorter than the outer ones. The length difference of adjacent waveguide paths is equal to the integer multiple of the central wavelength of the DeMUX. This causes the wavelengths to arrive at the other end of the FPR at slightly staggered time, with the signals from the inner waveguide arriving first and the outer waveguide arriving last. The length of the array waveguides is chosen such that the optical path length difference between adjacent waveguides equals an integer multiple of the central wavelength of the demultiplexer. Hence, the wavelengths from the individual arrayed waveguides arrive at the input aperture of the output coupler at different phases. The multiple light beams interfere constructively and converges at a single focal point at the output of the output coupler.



**Image of AWG chip**



**Typical spectrum of AWG**



There are also AWG designed with multiple input and an equal number of outputs. Such an AWG has a cyclical behavior with where a signal going into Input N will reappear at Output 1, if the frequency is increased by an amount equal to the channel spacing.

This device is called a cyclical wavelength router. This type of AWG can function as an add-drop multiplexers and wavelength switches.

Depending on the configuration of AWGs and wavelength switches, add-drop multiplexers can be made.

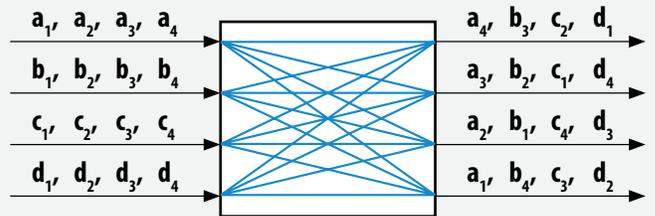
The most basic add-drop multiplexer can be made by using two  $1 \times N$  AWGs with identical wavelength response.

By combining demultiplexers with switches, configurable add-drop multiplexers can be made. This configuration allows the wavelengths to be added and dropped with an external control signal. The more (de)multiplexers added to the configuration increases the insertion loss of the multiplexer.

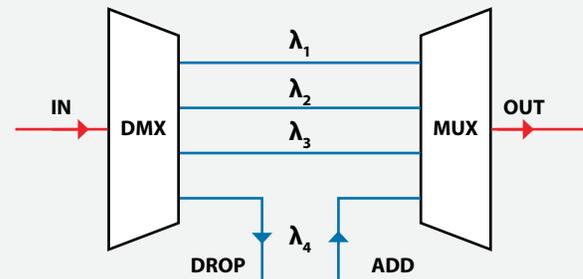
Add-drop multiplexers with lower insertion loss can be made by combining a single  $(N+1) \times (N+1)$  AWG with a wavelength router in a loop-back configuration.

The demultiplexed wavelengths are fed into switches where they can be switched to the drop port or be looped back to the wavelength router which will then multiplex them back into the output port.

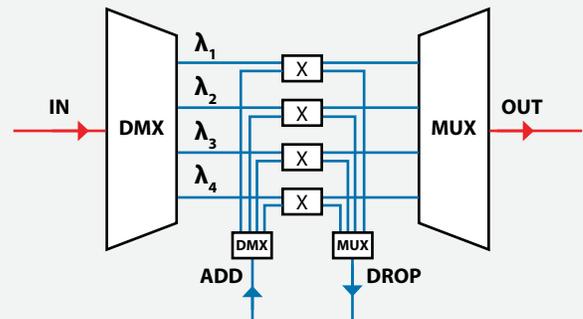
### Wavelength router



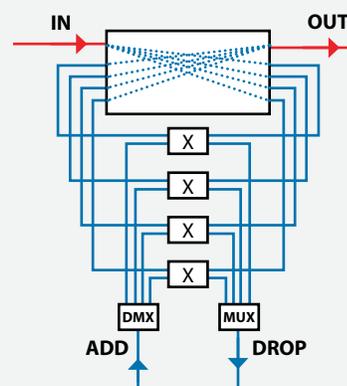
### Multiplexer with fixed add-drop channel



### Add-drop multiplexer with wavelength router



### Reconfigurable add-drop multiplexer with 2x2 switch



## Different AWG Technologies

There are many technologies deployed to develop AWGs. The two main technologies used for AWG manufacturing are the silica-on-silicon technology and the Indium Phosphide based semiconductor technology.

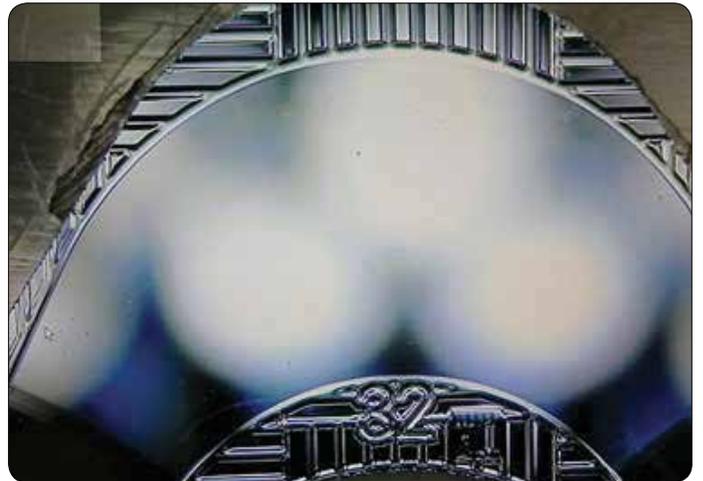
### Silica-on-Silicon (SoS) AWG

SoS AWG was introduced in the market in the early 1990's and holds the largest share of the AWG market. SoS is a type of Planar Lightwave Circuit (PLC) that are fabricated on planar substrates by depositing layers of glass with high silica content on the wafer. The composition of the glass layers is very similar to an optical fiber which makes it easy to couple with optical fibers due to its close modal field match.

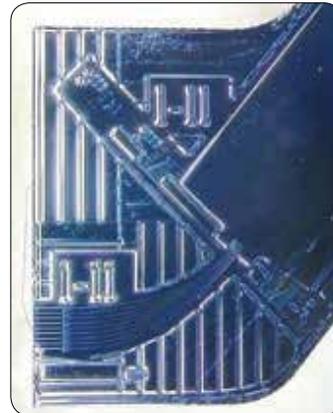
This results in low coupling and propagation attenuation.

Another advantage of the PLC fabrication of the SoS AWG is its excellent heat dissipation properties which makes it suitable for deployment in an outside plant network environment. The majority of commercially available SoS AWG has the majority share of the AWG market due to its lower cost of manufacturing and

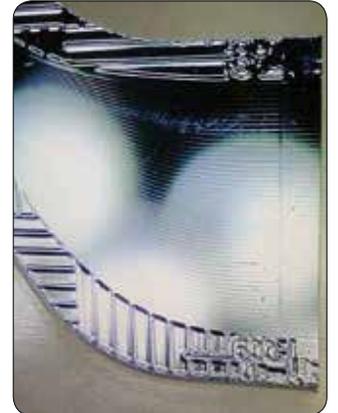
*Silica-on-Silicon AWG chip*



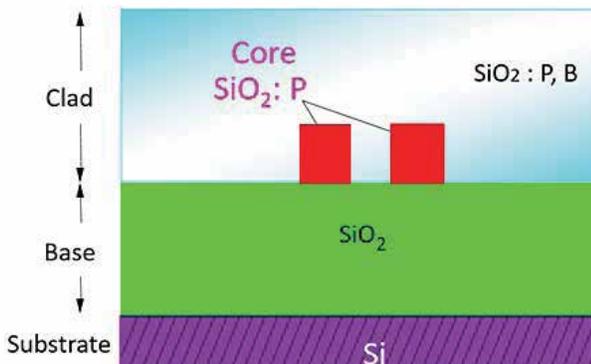
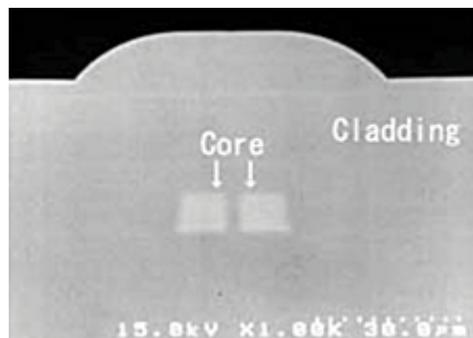
*Input part*



*Output part*



*Image of cross section*



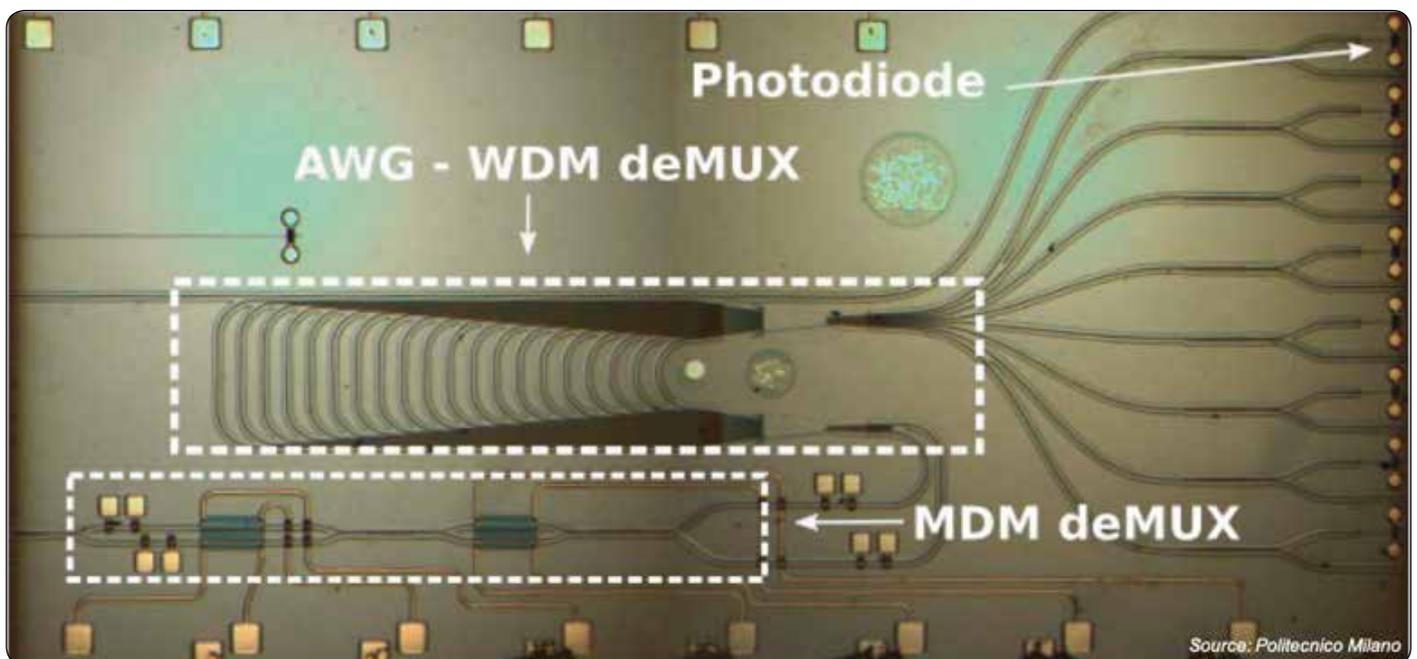
*AWG module*



## Indium Phosphide (InP)-based AWG

InP-based AWG is a semiconductor-based AWG that can be integrated to multiple active devices such as optical amplifiers and switches on a single chip. InP-based AWG can be manufactured in a compact package due to the large index-contrast of InP-based waveguides. The optical attenuation, coupling losses, and crosstalk performance of InP-based AWGs are not as good as silica based AWGs. Such a disadvantage is a barrier for InP-based AWG to be more widely deployed as a stand-alone device.

The potential of InP-based AWG to be integrated in circuits with multiple functionalities such as WDM transceivers, and optical add-drop multiplexers is its biggest advantage. This allows for manufacturers to integrate AWG functionalities onto active equipment to create InP-based Photonic Integrated Circuits (PICs) to lower network deployment cost. For example, add-drop multiplexing functions can be done at the transceiver without the need for an external multiplexer. This reduces the component and installation cost, as well as potential optical attenuation from multiple optical connectors.

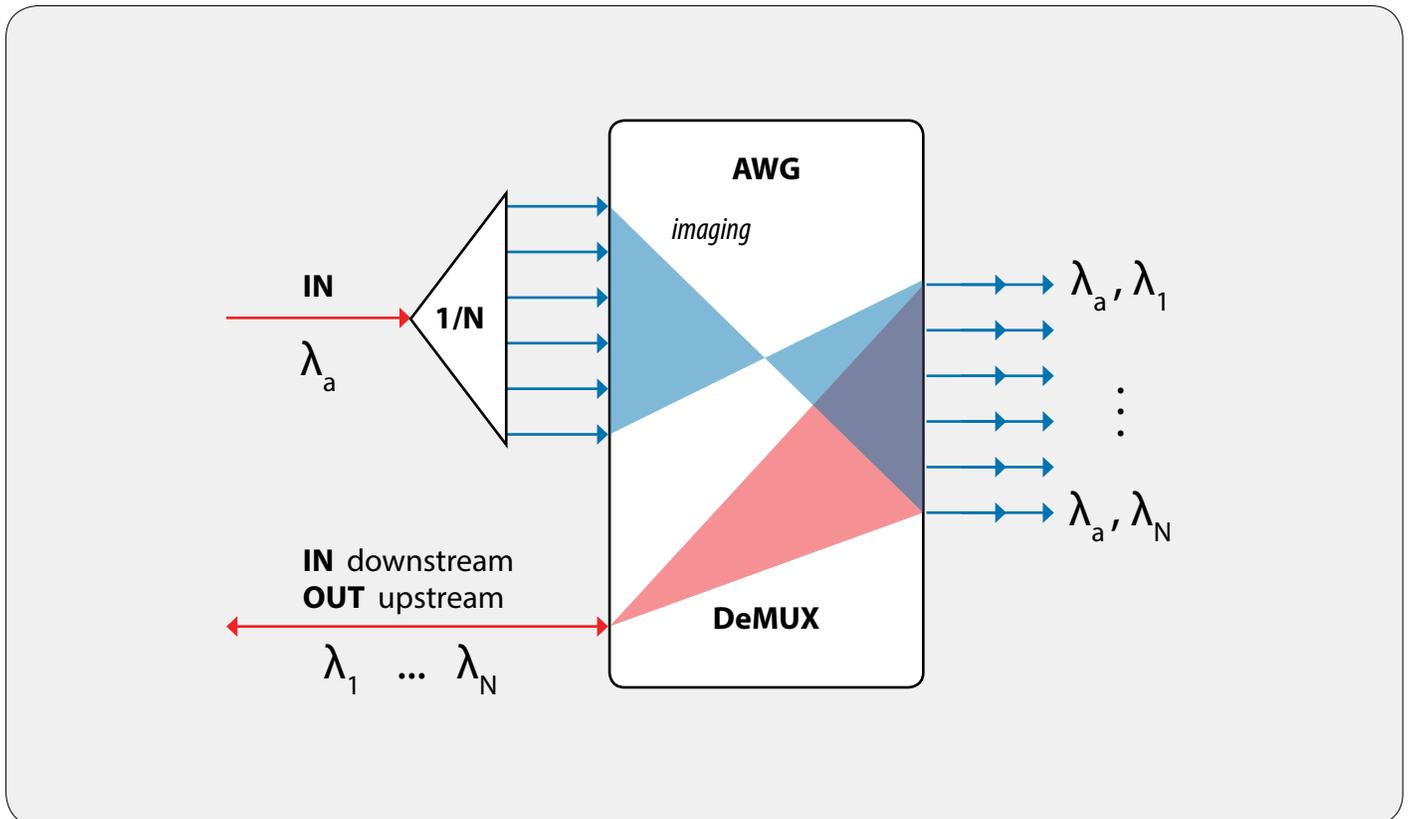


## Applications

There are a large number of applications where AWGs can be deployed, ranging from complex telecommunication cross-connects to very simple add-drop multiplexers. In the telecommunication industry, AWGs are mostly used as (de) multiplexers in WDM networks. This is traditionally deployed in long-haul networks such as international, national, and regional transport networks.

The majority of Passive Optical Networks (PON) deployed globally uses wavelength-independent optical splitter for power splitting and time division multiplexing for upstream and downstream transmission. This enables a lower cost of deployment and removes the need to manage wavelengths to individual connections downstream from the optical splitter.

With the increasing demand for higher bandwidth, AWGs have started to be used in the access network to allow multiple wavelengths to be transmitted from the exchange to the end user without significant changes to the existing optical fiber network. WDM-PON is a technology where multiple WDM channels are transmitted over the same optical network from an Optical Line Terminal (OLT) that is housed in the exchange. WDM-PON channels can be overlaid on top of existing PON networks using demultiplexing and imaging properties of an AWG to direct specific wavelength channels to individual subscribers. The upstream channels are multiplexed by the AWG and directed to one output port.



## Mobile Fronthaul Network

Mobile communications have evolved from a simple voice application to high speed data networks. Mobile networks started with the deployment of GSM infrastructures using a Time Division Multiplexing (TDM) backhaul network which dominated the global mobile industry over CDMA. However, GSM is not designed to support data heavy applications, thus data-optimized mobile technology such as 3G and WCDMA was created which uses the Asynchronous Transfer Mode (ATM) which replaced the TDM network. This allowed the convergence of voice and data transmission as it supported best-effort connectivity services as well as fixed bandwidth. Soon, LTE (Long Term Evolution) was introduced which moved from an ATM network to an IP based network. The mobile backhaul network infrastructure started to transform to utilize technologies such as Carrier Ethernet and MPLS which optimizes data management over L2 and L3.

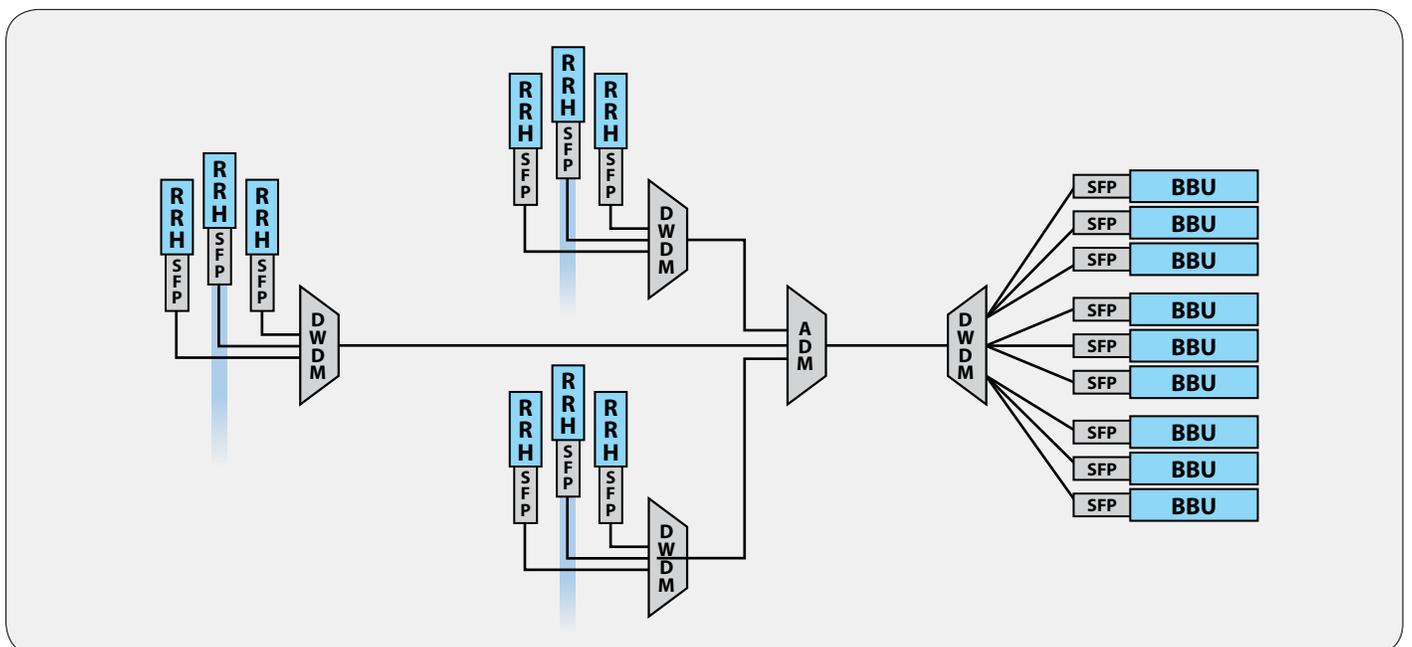
The aggregation of digitized RF signals from various antennas can be done through the CPRI (Common Private Radio Interface) interface. With an IP based network, there is higher demand in network synchronization, jitter, and delay requirements. Higher inter-cell bandwidth demand also puts a high load onto the network, especially if the network is based on the traditional centralized architecture.

Radio Base Stations (RBS) consists of a Radio Frequency Unit (RU) which generates the radio signal, and a Baseband Unit (BBU), which processes the user and control data. While the RU is mounted on a pole, the BBU is usually installed at the base of the pole. The inter-cell transmission latency between BBUs becomes a bottleneck with higher bandwidth requirements. A new network architecture is required.

Rather than housing the BBUs with the RUs, the BBUs can be housed in a central location which significantly increases inter-cell communication. This architecture is crucial for the deployment of LTE-Advanced networks due to its tight inter-cell coordination requirements. The RUs, now referred to as RRH (Remote Radio Heads) can remain mounted on a pole. Another advantage of this architecture is the reduction in power requirements since the processing unit of the network do not need to be housed remotely.

The centralization of the BBUs is also known as C-RAN (Centralized Radio Access Network or Cloud Radio Access Network). With higher bandwidth and transmission distance demands between the C-RAN and RRHs, optical fiber is the natural transmission medium of choice. The optical fiber network between the C-RAN and RRH is often referred to as the mobile fronthaul network.

A simple fronthaul network can be designed as a point-to-point fiber network. However this requires a high number of optical fiber run from the central office to each RRH. An effective way of deploying a high bandwidth fronthaul network with minimal access network fiber is by implementing C/DWDM technology to maximize fiber bandwidth utilization while minimizing installation cost. Each RRH can be assigned with a dedicated wavelength which essentially creates a "point-to-point" connection between the BBU and RRH. Such a network can even be overlaid on an existing GPON access network, provided there is sufficient attenuation overhead to support the additional losses from the C/DWDM (de)multiplexers.



## Summary

Understanding the need of the market, SENKO has embarked on the mission to make good and reliable AWGs since the early 2000s. Currently, Senko offers Athermal AWG integrated optical circuit built by Polymer approach (SoS substrate) that exceeds industrial requirements by ensuring a more stable and reliable performance with temperature ranging from  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ . Other than guaranteeing excellent optical performance coupled with high reliability, SENKO's AWG offers customizable specifications and a high degree of uniformity across high channel counts (DWDM spectrum). Working with end-users, SENKO is also able to offer customized packaging and integration.



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## Biography



**Dr. Bernard HL Lee** is currently the Regional Technology Director at SENKO Advanced Components. He started his career in optical communications when he was appointed as a Senior Research Office for the European Union IST project known as DAVID in 2000. In 2003, he joined Telekom Malaysia R&D where he has held various technical and management positions there including the Head of Photonic Network Research and also Head of Innovation and Communications. Bernard then joined the parent company, Telekom Malaysia (TM) in 2010 as the Assistant General Manager of the Group Business Strategy Division where he oversees the company's business direction. Bernard obtained his RCDD accreditation in 2016. Bernard is also a member of the International Electrotechnical Commission (IEC), the Institute of Engineering and Technology (IET) and was also the Director of the Board of the Fiber-To-The-Home Council APAC. He is currently the Malaysia Country Chair for BICSI Southeast Asia.



**Ryo Konno** is currently the Product Line Manager at SENKO Advanced Components. With the extensive sales experience in Japan, UK, and USA, he took lead on sales strategy and established great relationships with major equipment companies. He also gained unique view of developing new Fiber Optical components which contribute to space saving, higher density and maintain high reliability serving critical role in next generation optical module to support 5G and 400G+. Ryo is also a member of Gen-Z and Open Compute Project (OCP).



**Mac Watanabe**, master of engineering, senior product engineer at SENKO advanced Components. He has more than 25years experiences for fiber optics industry, researched and established for PLC splitter assembly technologies in early stage on 1990s before FTTH movement rises. He had unique working experiences in Japan, United states and China, linked as Learned background technologies, Grown with the latest marketing and Great tact of mass manufacturing. Through several years freelance engineer experiences were also helping his all balanced skills. Currently is investigating with new product development of fiber optics related for passive and active components.

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