White Paper
HiSilicon Optoelectronics 25G Tunable DWDM Optical Module

HISILICON
OPTOELECTRONICS

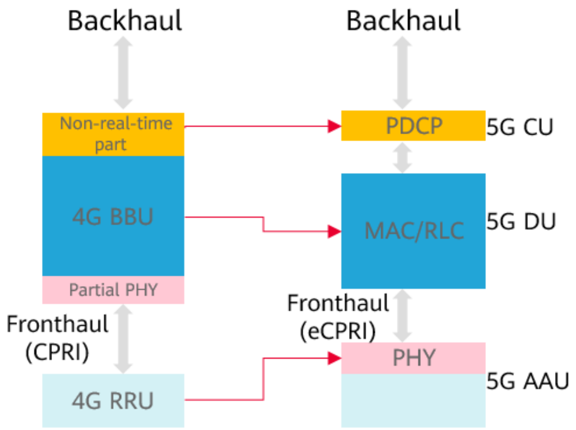
CONTENTS

1. 5G Poses New Requirements on Fronthaul Networks

Since 2020, with the continuous promotion of global 5G deployment, 5G has been one of the hottest topics in the industry. 5G-led mobile Internet and Internet of Things (IoT) services have become the main driving force behind mobile communications development. Unlike 2G, 3G, and 4G, 5G not only upgrades mobile communications technologies but also provides a driving platform for the digital world and network infrastructure for IoT, thereby reshaping our society.

With the large-scale commercial use of 5G active antenna units (AAUs), the number of antennas increases from 8T8R to 64T64R, and the air interface bandwidth increases from 20 MHz to 100 MHz. If the Common Public Radio Interface (CPRI) splitting position does not change, the bandwidth will increase 40-fold (from 10 Gbps to 400 Gbps). Therefore, the industry intends to use the enhanced CPRI (eCPRI) splitting solution to deploy partial baseband processing function of the baseband unit (BBU) on the AAU, as shown in Figure 1-1. In this way, the bandwidth requirement and implementation cost between the BBU and the AAU can be lowered. The non-real-time part of the original BBU is isolated and redefined as a centralized unit (CU), which is responsible for processing non-real-time protocols and services. The remaining functions of the BBU are redefined as a distributed unit (DU), which is responsible for processing physical layer protocols and real-time services.

Figure 1-1 Function modules of a 4G/5G RAN



Take 100 MHz air interface bandwidth and 64T64R as an example. In eCPRI mode, the fronthaul bandwidth requirement between the 5G AAU and 5G DU decreases to 25G. In addition, the mature Ethernet industry chain can be reused to meet the demands for massive deployment in wireless fronthaul networks. Therefore, 25G has been widely used in 5G networks and has become the mainstream fronthaul interface rate in the 5G era.

2. Fronthaul Network Transport Solution Evolution

By the first half of 2022, more than 1.85 million base stations have been deployed in China. According to available statistics, there are thousands of 5G commercial application cases in over 100 industries. Especially, 5G has witnessed great prosperity in emerging fields, such as live streaming, telemedicine, smart manufacturing, smart mining, and smart port. Take the Chinese market as an example: It is estimated that operators will deploy over 5 million base stations within the lifecycle of 5G.

To meet the latency and bandwidth requirements of emerging services, 5G RAN will inherit the centralized BBU deployment of 4G and use DU centralization as a mainstream networking architecture. At the same time, with the massive deployment of 5G base stations, operators will face great pressure in providing matching network maintenance capabilities and optical cable/pipe resources. Against this backdrop, the industry chain is in urgent needs of an economical, efficient, and reliable transport solution for fronthaul networks. At the early stage of 5G deployment, the major transport modes used by fronthaul networks include dark fiber, passive transport, and active/semi-active transport.

- Dark fiber solution: Idle fiber resources on the live network are used directly to speed up site deployment. However, operators' pipe hole and pipe resources are limited, and massive base station deployment consumes fiber resources quickly, which in turn, results in low fiber utilization and unsustainable fiber resources.

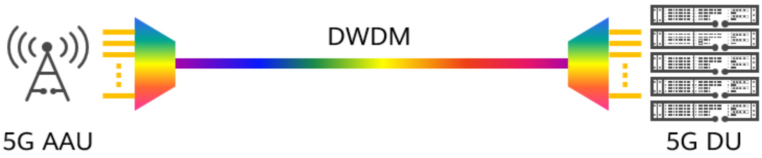
Figure 2-1 Gray light-based wireless fronthaul solution

- CWDM-based colored light transport solution: Compared with the dark fiber solution that uses gray optical modules, the coarse wavelength division multiplexing (CWDM) solution provides optical modules with six or more wavelengths, which mitigates the pressure of insufficient optical fibers and accelerates the deployment of 5G base stations. However, similar to the gray light solution, the CWDM solution lacks management and O&M methods. After a large number of 5G base stations are deployed, operators will face great challenges in service provisioning and network O&M.

Figure 2-2 CWDM-based wireless fronthaul solution

- DWDM-based colored light transport solution: The most obvious advantage of dense wavelength division multiplexing (DWDM) lies in large system capacity. Currently, a typical 25G DWDM system supports more than 40 wavelengths. Its single-fiber capacity is 40 times that of the gray light solution and 6.7 times that of the CWDM solution. This system will greatly decelerate fiber consumption. In addition, by using tunable lasers, DWDM requires only one type of optical modules to support dozens of wavelengths, significantly reducing the pressure on spare parts and the difficulty in network design. To facilitate maintenance and use, the DWDM-based colored light transport solution is also planning to introduce technologies such as pilot tone modulation on the basis of gray light and CWDM. Moreover, in this solution, optical modules can be managed by a management software platform on the network device side, further improving network O&M efficiency.

Figure 2-3 DWDM-based wireless fronthaul solution



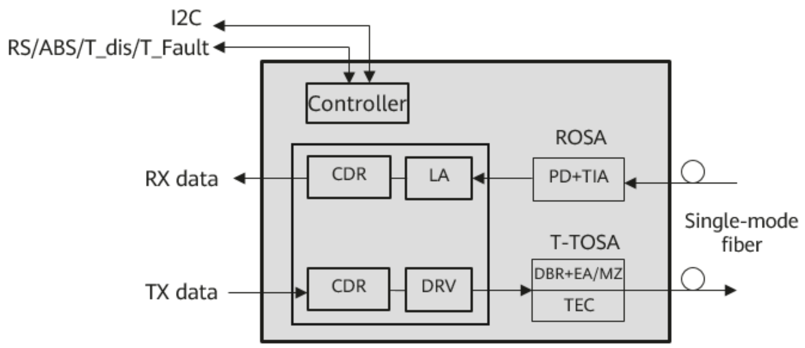
3. Key Technologies of the 25G Tunable DWDM Optical Module

The 25G Tunable DWDM optical module, as a key part of the colored light fronthaul transport solution, provides the following functions:

- Sending: Converts internal electrical signals into optical signals of various formats, and transmits optical signals to client-side devices.
- Receiving: Receives optical signals of various formats from client-side devices, and converts optical signals into internal electrical signals.
- Reporting: Reports the performance indicators of client-side optical interfaces and the working status of client-side lasers.

The following figure shows the functional block diagram of the 25G Tunable DWDM optical module. Its core components include the 25G tunable TOSA, 25G ROSA, and oRFIC. (TOSA: transmitter optical sub-assembly; ROSA: receiver optical sub-assembly; oRFIC: optical radio frequency integrated circuit)

Figure 3-1 Functional block diagram of the 25G Tunable DWDM optical module



3.1 25G Tunable TOSA

The 25G tunable TOSA is a core component for implementing the DWDM colored light fronthaul transport solution. It performs E/O conversion by loading input high-speed electrical signals to optical waves of specific wavelengths. Additionally, it has the following features:

- Wide wavelength adjustment range with high adjustment precision
- High bandwidth, supporting 25G transmission rate
- Compact size and low power consumption, meeting Small Form-factor Pluggable (SFP) requirements

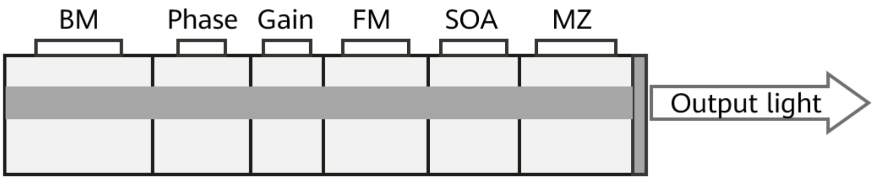
- High reliability, supporting outdoor application environments in wireless scenarios

The key technologies of 25G tunable TOSA include the high-performance optical chip, compact structure design, high-precision wavelength adjustment, and pilot tone modulation.

3.1.1 High-Performance Monolithic Integrated Optical Chip

The single optical chip integrated with tunable lasers and modulators is the core of the 25G tunable TOSA. The tunable laser part uses the multi-segment distributed Bragg reflector (DBR) structure, and the modulator part uses the Mach-Zehnder (MZ) modulator. The following figure shows the structure.

Figure 3-2 Structure of a monolithic integrated DBR+MZ chip

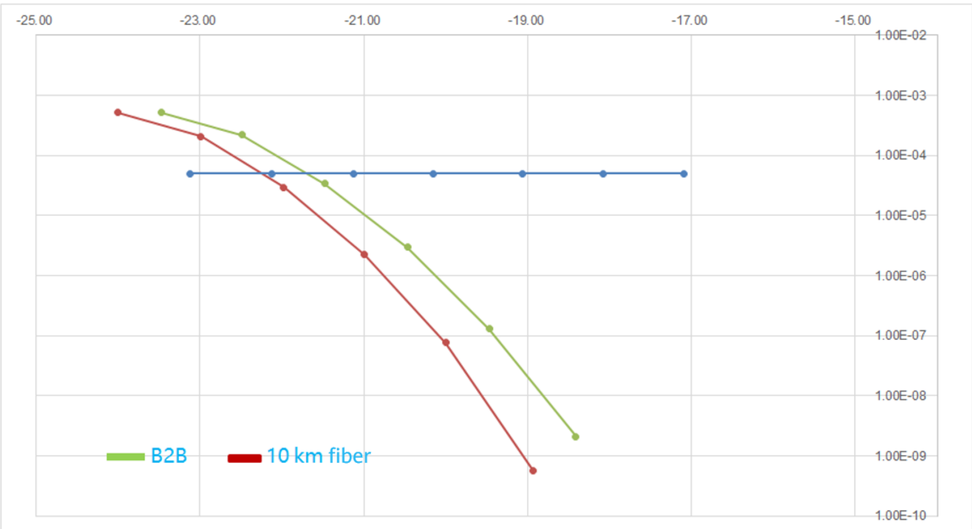


The tunable laser part includes the back mirror (BM), phase, gain, front mirror (FM), and semiconductor optical amplifier (SOA) parts. The gain part is the active area of the laser. The FM, BM, and phase parts implement quasi-continuous and linear adjustment of the output wavelength of the laser through thermal adjustment. The SOA part amplifies the output light.

The MZ modulator modulates the output light from the tunable laser. As the transmission wavelengths are in the C band, the modulator adopts a negative chirp design to optimize the transmission performance.

As shown in Figure 3-3, in 10 km transmission over a long fiber, the tunable TOSA with the negative chirp design achieves a lower BER compared with the back-to-back transmission mode. The sensitivity after long fiber transmission is 1 dB to 2 dB higher than that of similar products in the industry. With proper module design and working point selection, the tunable TOSA supports a maximum transmission distance of 15 km at a rate of 25G.

Figure 3-3 BERs after back-to-back transmission and long fiber transmission

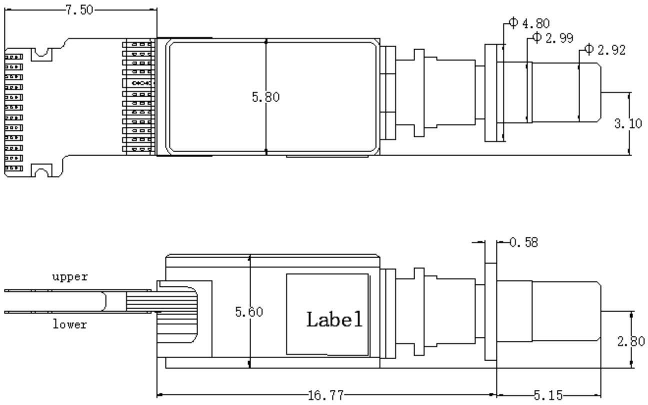


3.1.2 Compact Structure Design

Based on the preceding monolithic integrated chip, the 25G tunable TOSA applies hermetic packaging to ensure its stability and reliability in complex environments. With the highly integrated chip, the component package is compact. Additionally, with fewer materials required during component packaging, the packaging process is simplified.

On the 25G tunable TOSA, the optical interfaces are standard LC interfaces, and the electrical interfaces use the dual-FPC mode. The following figure shows the dimensions of the 25G tunable TOSA. Compared with the industry average, HiSilicon Optoelectronics 25G tunable TOSA has 10% shorter main body, optimizing the overall layout of an optical module.

Figure 3-4 Critical dimensions of the 25G tunable TOSA



Based on the highly integrated optical chip and the compact package, the tunable TOSA is suitable for batch manufacturing. With lower costs, it is more competitive in massive delivery in the 5G market.

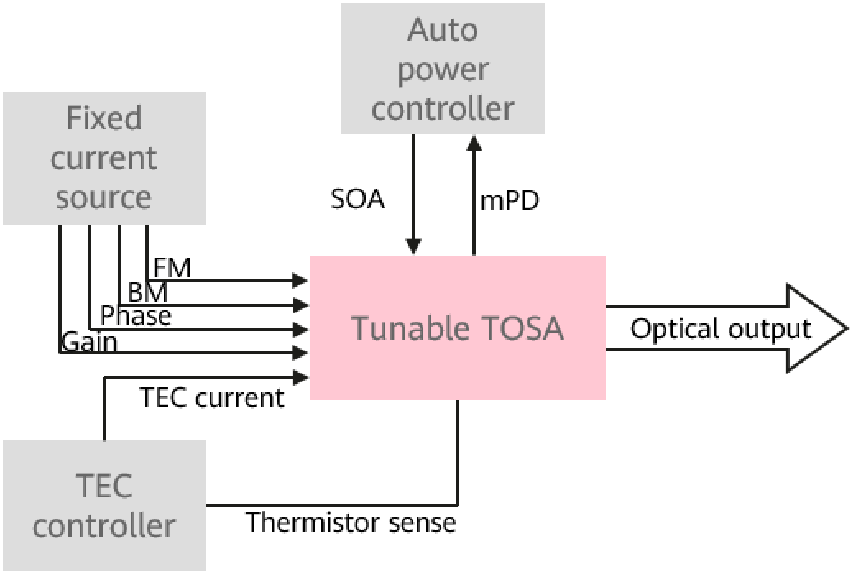
3.1.3 High-Precision Wavelength Adjustment and Long-Term Stability

The features of the 25G tunable TOSA and the precision and stability of its peripheral drive circuits ensure high-precision wavelength adjustment and long-term stability.

For the 25G tunable TOSA, the monolithic integrated DBR+MZ design enables sufficient mode margin for each wavelength. In addition, the component-level low-stress structure design and special packaging process ensure long-term wavelength stability.

To achieve excellent performance, the 25G tunable TOSA must use a correct drive mode. The following figure shows the recommended drive mode for wavelength and power control. The temperature control circuit consisting of the thermoelectric cooler (TEC) and the thermistor ensures a stable operating temperature. Because no wavelength locking structure exists, after the current values of the FM, BM, and phase parts are properly set, a high-resolution constant current source is used for driving. Then, the monitor photodiode (mPD) reports the output optical power of the component, and the SOA adjusts the output optical power.

Figure 3-5 Block diagram of component wavelength and power control



With proper peripheral circuits, the 25G tunable TOSA supports 48-wavelength DWDM with 100 GHz channel spacing, and ensures that the frequency drift is less than 12.5 GHz in the entire lifecycle.

3.1.4 Pilot Tone Modulation for Higher O&M Efficiency

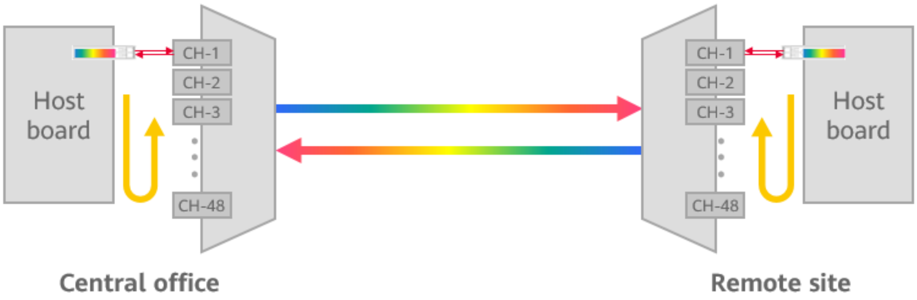
The massive deployment of 5G base stations poses new challenges to fast network provisioning. To improve O&M efficiency, the 25G tunable TOSA colored optical module superimposes low-frequency modulation signals on normal optical signals to obtain an out-of-band pilot tone modulation information channel. The OAM information carried in this information channel simplifies optical-layer management, as shown in the following figure.

Figure 3-6 Network application based on pilot tone modulation

The pilot tone modulation information channel enables wavelength auto-negotiation and automatic wavelength allocation in fronthaul networking. During live-network construction, no manual intervention or support from parent devices is required. Optical modules are plug-and-play, greatly reducing the provisioning workload. The 25G tunable TOSA uses high-performance lasers, providing a large link budget margin. Therefore, the sensitivity loss (0.5–1 dB) caused by pilot tone modulation can be controlled within the margin, without compromising fiber transmission performance. This solution does not involve complex circuits and significantly improves network O&M efficiency at lower costs.

In addition, with the tunable wavelength and pilot tone modulation features of the tunable TOSA, the optical module can implement wavelength auto-negotiation. In this way, wavelengths at the central office (CO) and remote site can be automatically adjusted to ensure normal network communication. The wavelength auto-negotiation process of the tunable TOSA is as follows: The wavelength adjustment starts from the initial wavelength in sequence. Both ends send the local wavelength information to the peer end at the same time. After each end receives the wavelength information from the peer end, they complete handshaking, thereby completing the wavelength configuration.

Figure 3-7 Wavelength auto-negotiation scenario



In the wavelength auto-negotiation scenario, both the CO and remote site can use the same module type, and you do not need to check the module types at the two ends separately. The transmit and receive wavelengths can be randomly paired within the wavelength adjustment range supported by the tunable TOSA. In addition, to enable easy configuration, the optical module using the tunable TOSA can save wavelengths upon power-off. After the optical module is powered on, the wavelength adjustment is performed from the wavelength that was successfully negotiated last time. The optical module also supports manual wavelength configuration, and a software configuration switch can be used to select wavelength auto-negotiation or manual wavelength configuration as required. In typical service scenarios, wavelength auto-negotiation in 48-wavelength networking can be completed within 3 minutes.

3.2 25G ROSA

The ROSA converts optical signals into electrical signals. You can select the PIN ROSA or APD ROSA solution as required.

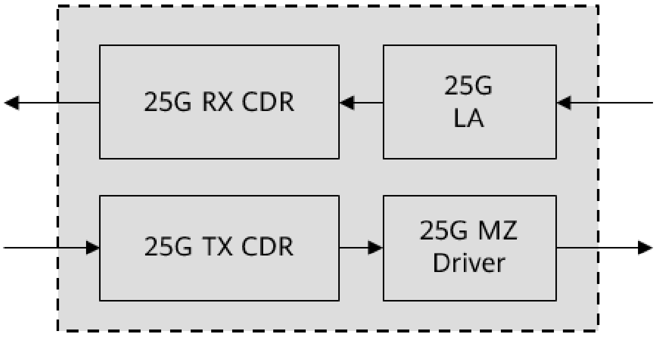
The transmit optical power and extinction ratio of the transmit-end tunable TOSA are high, and the overall transmission performance is good. Therefore, a PIN ROSA at the receive end can cover most applications in 10 km transmission at a lower cost. In 15 km transmission scenarios or scenarios with large link loss, APD ROSA can also be used to obtain better sensitivity and larger optical power budget.

3.3 oRFIC

The key components of oRFIC include DRV and TIA. To implement SFP/SFP28 packaging, the integrated DRV Combo solution is typically used on the transmit side. In this solution, a single chip integrates the receive CDR, transmit CDR, DML DRV, and LA functions to drive the tunable TOSA and shape the received and transmitted electrical signals. The integrated solution significantly reduces power consumption and PCB layout area, simplifying design, improving reliability, and lowering costs.

On the receive side, TIA and PIN/APD are used together to amplify weak electrical signals converted from optical signals.

Figure 3-8 oRFIC of the 25G Tunable DWDM optical module



4. Summary

The 5G era is here. 25G fronthaul interfaces can use Ethernet protocols and allow abundant O&M methods. In addition, the underlying industry chain of 25G Ethernet optical modules can be reused. All these make 25G fronthaul interfaces the preference for the industry. Currently, the number of wireless base stations and consequent CAPEX increase sharply. In this context, a more cost-effective 25G fronthaul optical module is required. The limited fiber resources of operators also drive the demand for colored optical modules.

HiSilicon Optoelectronics 25G Tunable DWDM optical module can meet the requirements of 5G fronthaul networks for large capacity, high reliability, and easy O&M, thereby building diversified access pipes for 5G fronthaul.