Development of 10 Gb/s Tunable Transponder Module

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ABSTRACT Because transponder modules of fixed (non-tunable) wavelength have been used in DWDM transmission, a number of module varieties corresponding to the number of individual wavelengths must be provided. A tunable transponder module has been accordingly developed, incorporating a tunable CW LD, wavelength locker, modulator, controller and receiver into a compact package. It is compliant with the 300-pin MSA *de fact* industrial standard. With these tunable transponder modules, the number of module varieties is reduced by a factor of as much as eight.

1. INTRODUCTION

The capacity of optical communication networks is being increased due to the vast growth in internet traffic originating in North America in the 1990s. This evolution is primarily due to wavelength division multiplexing (WDM) technology, which propagates plural optical signals on a single optical fiber, as well as to optical fiber amplification (OFA) technology.

The transponder module is one of the key components making up a long-haul WDM transmission system, and integrates optical transceiver, electrical multiplexer/demultiplexer and control circuits into a compact package. Since the commonly used transponder module is not tunable in wavelength, a number of transponder module varieties corresponding to the number of individual wavelengths must be provided. With a 10 Gb/s transponder module, the number of module varieties can be reduced by a factor of as much as eight due to wavelength tunability.

Accordingly a 10 Gb/s tunable transponder module has been developed by the authors, and is reported in this paper.

2. APPLICATIONS AND FUNCTIONS

2.1 Applications

Transponder modules are used in a variety of optical transmission systems, but here we wish to focus on long-haul WDM transmission systems as the major application. Figure 1 shows an example of long-haul transmission. At the terminal station, uncolored optical signals from a cross connect switch (XC) are converted to different wavelengths from λ_1 to λ_n. Each colored optical signal is processed by the multiplexer (MUX) for single fiber transmission, followed by OFA, and then transmitted by optical fiber. Figure 2 shows an example of the transmission equipment, in which there are a number of transponder cards corresponding to necessary numbers of wavelengths which convert from 1310 nm signals to 1500 nm (λ_1 to λ_n) signals and vice-versa. Each transponder card contains two transponder (TRP) modules, one for short-reach (SR TRP) and one for long-reach (LR TRP). The optical signal is converted via electrical signals by the two TRPs. The uncolored optical signal (10 Gb/s) is received at the SR TRP and subdivided into 16 lines of 622 Mb/s

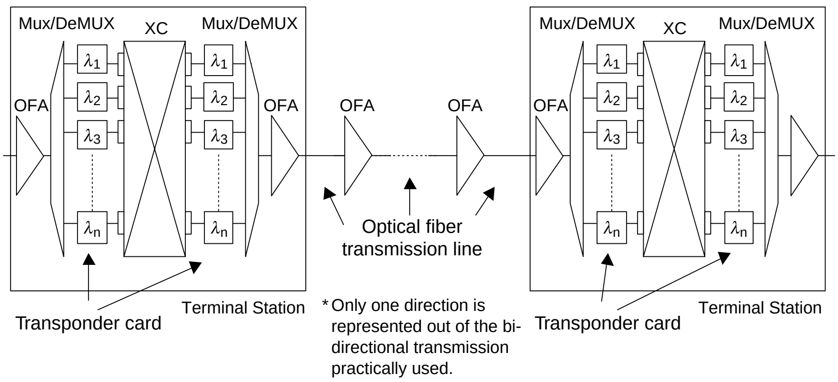

Figure 1 Example of long-haul transmission.

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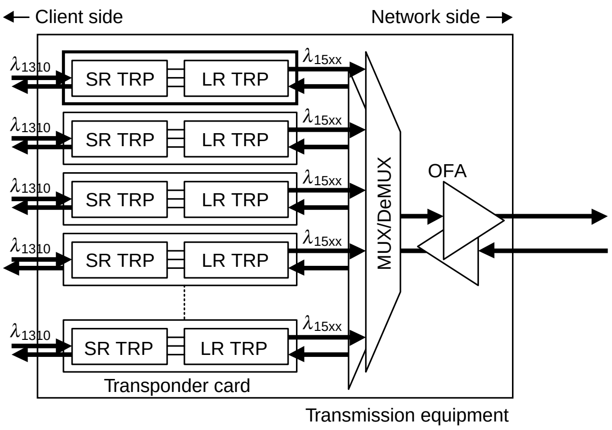


Figure 2 Example of transmission equipment.

electrical signals for output. The 622 Mb/s signals are subjected to forward error correction, monitoring, etc. outside the transponder module, and again multiplexed to a 10 Gb/s signal at the LR TRP. The 10 Gb/s signal is converted to an optical signal of a particular wavelength for WDM transmission.

2.2 Functions

Each transponder module installed on the transponder card has following functions.

- converts a 10 Gb/s electrical signal into a 10 Gb/s optical signal
- converts a 10 Gb/s optical signal into a 10 Gb/s electrical signal
- multiplexes 16 lines of 622 Mb/s electrical signals into a 10 Gb/s signal
- demultiplexes a 10 Gb/s electrical signal into 16 lines of 622 Mb/s signals

3. STANDARD AND CLASSIFICATION

3.1 Standardization

Eleven transponder vendors have organized the MSA group, and released Issue 1 of the 300-pin 10 Gb/s Transponder MSA Document in April 2002. The latest release is Issue 4 of August 2003. The document is a *de fact* industrial standard, even for transponder vendors that are not member of the MSA group, and various transponders compliant with the 300-pin MSA standard have been released. Following are the basic items standardized in the 300-pin MSA.

- Electrical signal interfaces such as data, clock, control and alarm
- Power supply
- Type of electrical connector (Meg-array 300-pin connector)
- Pin assignment of electrical 300-pin connector
- Physical dimensions

Table 1 Classification of transponders.

Class	Applicable distance
SR (Short-Reach)	Short distance transmission on the client side inside terminal stations
IR (Intermediate-Reach)	Intermediate distances up to 40 km
LR (Long-Reach)	Point-to-point long-distance transmissions up to 80 km or long-haul transmissions with OFA

3.2 Classification

Transponder modules are classified according to the transmission distance as shown in Table 1. SR transponders are mainly used to the client side inside terminal stations. IR transponders are used for transmission over medium distances up to 40 km. LR transponders are used for long-distance transmissions from 40 to 80 km, and with OFA for even greater distances. Since 10 Gb/s transmission over 1310 nm single mode fiber is degraded by wavelength dispersion, external modulator is used for IR and LR transponders. The developed tunable transponder module uses a Mach-Zender type external modulator for long-haul transmission with OFA.

4. FEATURES

The developed tunable transponder has a tunable wavelength over 8 channels at 50 GHz spacing, reducing the numbers of transponder varieties for transponders required by a factor of eight.

4.1 Structure

The structure of the tunable transponder module is shown in Figure 3.

On the transmission side, 16 lines of 622 Mb/s electrical signals supplied from outside the transponder module are multiplexed into a 10 Gb/s electrical signal. This 10 Gb/s signal is then converted to an optical signal by a tunable DFB LD and Mach-Zender type modulator.

The tunable DFB LD provides wavelength tunability over eight channels (wavelengths) for 50 GHz spacing with wavelength locker integrated, and Mach-Zender type external modulator with $LiNbO_3$ achieves the higher optical extinction ratio required for long-haul transmission.

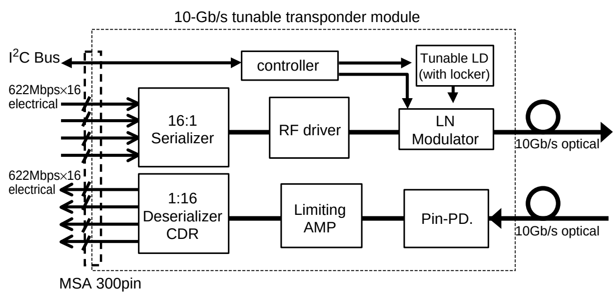


Figure 3 Structure of tunable transponder module.

Figure 4 Appearance of tunable transponder.

On the receiver side, the 10 Gb/s optical signal is received and converted into an electrical signal by PIN-PD (Photodiode), followed by adjustment by means of a limiting amplifier to the optimum level, and is then divided into 16 lines of 622 Mb/s electrical signals by a deserializer.

To control the thermally tunable LD, external modulator and alarms, a microprocessor is installed. Controls and alarms can be communicated to an external controller not only by parallel interface but also over an I^2C serial bus interface.

4.2 Appearance

The appearance of the transponder module is shown in Figure 4. Though there are physical limitations to incorporating a DFB LD and Mach-Zender type modulator into the module, the same compact size as for SR and IR transponder modules (88.9×114.3×14.5 mm) has been achieved. The case is made of aluminum alloy for effective heat dispersion.

4.3 Specifications

Table 2 shows the specifications of the tunable transponder. Transmission rates includes the SONET/SDH standard 9.95 Gb/s, and 10.66 and 10.709 Gb/s are also available for the forward error correction (FEC) rate, which is commonly used for long-haul transmission.

More than +5 dBm of optical output and less than -17 dBm of sensitivity makes possible a loss budget of over 22 dB at zero dispersion and over 20 dB at dispersion of ±1000 ps/nm in transmission.

5. EVALUATION

5.1 Wavelength Tuning

A thermally tunable LD in the transponder module is deployed, so that the wavelength is changed by controlling the temperature. Figure 5 shows the trace of varying wavelength from channel 1 (1541.35 nm) to channel 8 (1544.13 nm) after locking in each channel.

5.2 Transmission Characteristics

Figure 6(a) shows the eye pattern at channel 1 and Figure 6(b) is the eye pattern at channel 8 at a case temperature of 25°C. Figure 6(c) and (d) shows the eye pattern at channel 1 at case temperatures of -5°C and 70°C. At each wavelength and temperature, good extinction ratios of over 13 dB are achieved.

Table 2 Specifications of tunable transponder.

Item	Condition	Specifications
Loss budget	@±1000 ps/nm @0 ps/nm	Min. 20 dB Min. 22 dB
Transmission rate		9.95/10.66/10.709 Gb/s
Power consumption	+3.3 V, +5.0 V, -5.2 V	Typ. 14 W
Operating temperature	Case temperature	-5~70°C
Size	Excluding heat sink and projecting part	3.5×4.5×0.53 inch (88.9×114.3×13.5 mm)
Output power	$PRBS2^{31}$ -1	Min. +5 dBm
Extinction ratio	$PRBS2^{31}$ -1	Min. +11 dB
Wavelength		1530~1620 nm
Tunability		8 ch×50 GHz
Sensitivity	BER 10^{-12} average @0 ps/nm	Min. -17 dBm
Overload	BER 10^{-12} average	Min. -4 dBm

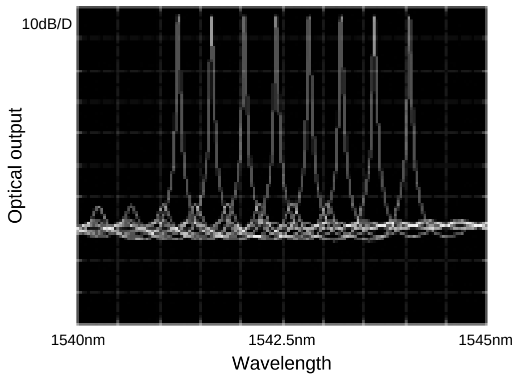
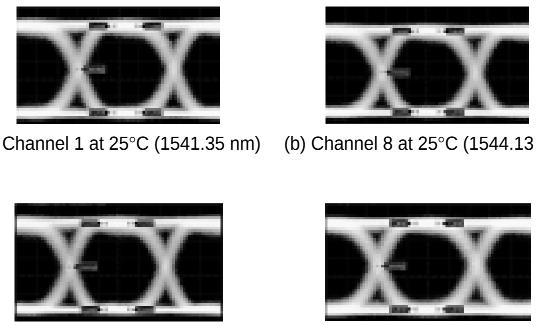


Figure 5 Trace of wavelength tuning.



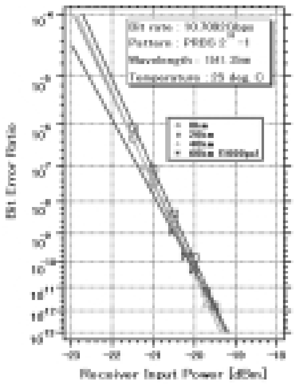
(a) Channel 1 at 25°C (1541.35 nm) (b) Channel 8 at 25°C (1544.13 nm)

(c) Channel 1 at -5°C (1541.35 nm) (d) Channel 1 at 70°C (1541.35 nm)

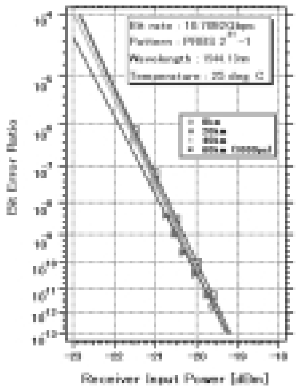
Figure 6 Eye patterns.

5.3 Receiver Characteristics

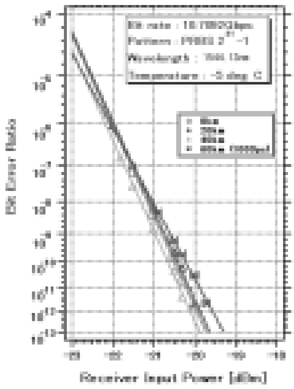
As receiver characteristics, Figure 7 shows the bit error ratio (BER) vs. optical input level for 0~60 km optical fiber transmission; (a) and (b) show the measurements at channel 1 and 8 at a case temperature of 25°C; (c) and (d) show the measurements at channel 8 and 1 at case temperatures of -5°C and 70°C. In all cases, the BER of 10^{-12} is achieved at an optical input level of less than -19



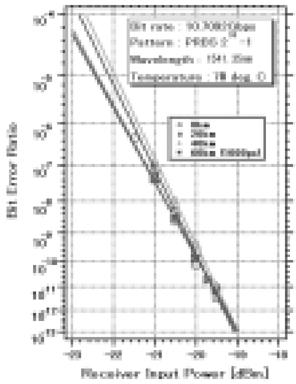
(a) Channel 1 at 25°C (1541.35 nm)



(b) Channel 8 at 25°C (1544.13 nm)



(c) Channel 8 at -5°C (1544.13 nm)



(d) Channel 1 at 70°C (1541.35 nm)

Figure 7 Bit error ratio vs. optical receiving power.

dBm. In addition, the dispersion penalty due to optical fiber is less than 0.5 dB. Good receiver performance is achieved.

6. CONCLUSION

A 10 Gb/s tunable transponder with 8-ch wavelength tunability at 50-GHz spacing has been developed and achieved good transmitter and receiver performance over the desired wavelength tuning range at the desired temperature range.

The development of this tunable transponder is strongly expected to contribute to greater economy and flexibility in WDM transmission systems.

REFERENCES

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