NX7000 OPTICAL PHASE-MODULATION ANALYZER —REAL-TIME SIMULTANEOUS MEASUREMENT OF MODULATED PHASE DISTRIBUTION AND DEMODULATED WAVEFORM—

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We have developed a new measurement instrument, NX7000, for evaluating and monitoring the signal quality of phase-modulated optical signals in the next-generation 40-Gbps optical communication networks. Measurement of the differential constellation/phasor diagrams and demodulated signals of 40-Gbps differential phase-shift keying (DPSK) and differential quadrature phase-shift keying (DQPSK) signals using the NX7000 enables quantitative analysis and evaluation of the signals. The instrument will help users to develop and improve their products for 40-Gbps transmission systems. The NX7000 is based on our original technology in which we use 1-bit delayed self-homodyne detection and high time-resolution signal sampling in order to analyze DPSK/DQPSK signals directly. This paper outlines the basis and features of the NX7000.

INTRODUCTION

The expansion of broadband networks including Fiber To The Home (FTTH), and the change of network infrastructure such as the integration of the telephone communication and video broadcasting services, have caused a rapid increase of backbone network traffic in inter-city networks. The average amount of network traffic at Japan's main Internet exchange (IX) points reached approximately 800 Gbps in November 2007, according to the Ministry of Internal Affairs and Communications(1). This figure was 2.5 times higher than that in November 2004.

Against this background, telecommunication carriers have been developing high-speed, large-capacity transmission systems to build the infrastructure for next-generation networks (NGN), and so have been investing heavily in those transmission systems. In the latest optical transmission system using wavelength

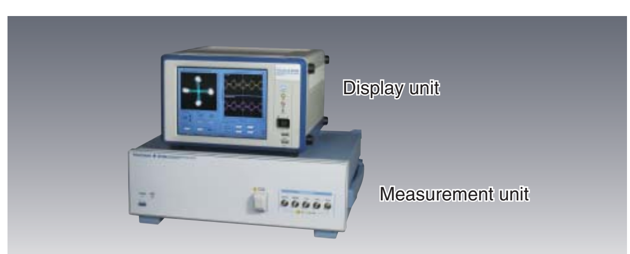

Figure 1 External View of NX7000

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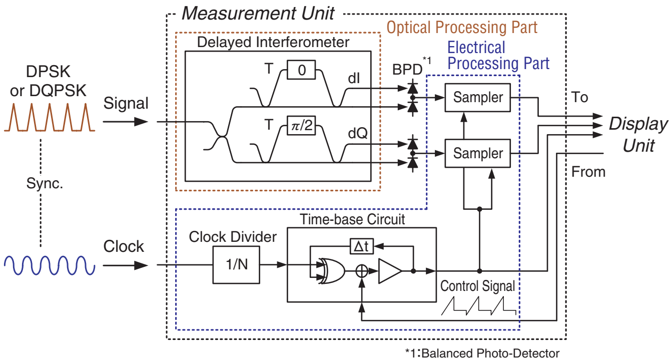

Figure 2 NX7000 Measurement Unit Block Diagram

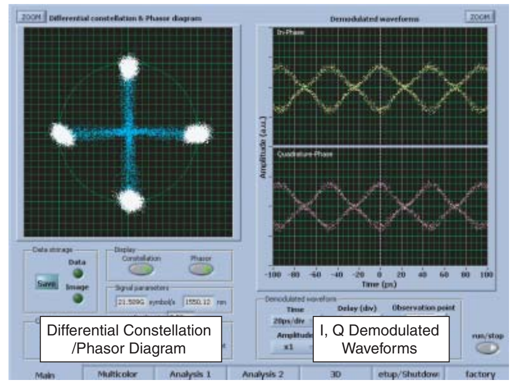

Figure 3 Example of Screen

division multiplexing (WDM) technology, the transmission speed is mainly 10 Gbps for each optical fiber and wavelength. The speed of 40 Gbps is expected in the next generation to raise total transmission capacity.

In 40-Gbps optical signal transmission, a 1-bit time slot is about 25 ps, which is quite short. Under this condition, even if waveform distortion caused by optical fiber dispersion is small, a reading error in transmission might occur. For this reason, conventional On-Off Keying (OOK), which represents digital data as the presence or absence of a carrier wave, is not suitable for long-haul transmission, so Phase-Shift Keying (PSK) has been introduced. This modulation conveys data by shifting phases of a carrier wave, and realizes highly efficient long-haul transmission with excellent tolerance of both dispersion and nonlinear optical effect.

To evaluate the signal quality of optical phase-shift keying modulation, it is not sufficient to measure the optical signal-to-noise ratio (OSNR) and analyze the eye patterns of the signal intensity waveform; a different analysis with a new index and approach is necessary. Especially in Differential Phase-Shift Keying (DPSK) and Differential Quadrature Phase-Shift Keying (DQPSK), both of which are expected to be used in 40-Gbps optical signal transmission, it is important to analyze the relative amplitude and phase difference (equivalent to the amount of differential modulation) between signal bits, since these directly affect the demodulation results in the transmission.

Yokogawa has proposed techniques for analyzing and evaluating signals quality of DPSK/DQPSK signals based on creative instrumentation methods, and has verified their advantages since other researchers considered introducing optical phase-shift keying[(2)(3)(4)(5)]. The NX7000 is the world's first measurement instrument for testing and evaluating 40-Gbps DPSK/DQPSK signals, which will help users to develop and improve their products for 40-Gbps transmission systems. The following section describes the NX7000 in detail.

SYSTEM CONFIGURATION AND FEATURES

Figure 1 shows an external view of the NX7000. It consists of a measurement unit and a display unit. The measurement unit measures input optical signals of light. The display unit processes the acquisition data and displays the measurement results, and also controls the entire hardware.

Figure 2 shows the circuit block diagram of the measurement unit. It consists of an optical processing part and an electrical processing part. The former part detects phase angles of measured signals using a delayed interferometer, while the latter samples electrical data converted from optical signals.

The NX7000 has the following features:

- Highly precise and stable measurement of 40-Gbps DPSK/DQPSK signals by using delayed self-homodyne detection, which does not need a reference laser light source.
- Real-time simultaneous observation with two display functions: the differential constellation/phasor diagrams, and the demodulated waveform of in-phase and quadrature-phase components in the measured signals.
- Available for of the C-band and L-band optical signals, both of which are WDM frequency channels.
- Various analysis functions such as histogram analysis, Q-value analysis, and so on.

Figure 3 shows an example of screenshot by the NX7000. It is difficult to objectively evaluate this instrument because there is no similar instrument in the market yet. However, Yokogawa believes that this instrument offers remarkable performance and functions for the target users.

SPECIFICATIONS

Table 1 lists the main specifications of the NX7000 for DQPSK signals. The figures in the table were measured using a prototype. Figure 4 shows an example of the display of analysis functions.

CORE TECHNOLOGY

The core technologies of this instrument are explained below.

Optical phase measurement with delayed self-homodyne detection

In the conventional method of measuring the phase of phase

Table 1 NX7000 Main Specifications and Functions

ITEM	Specifications
Modulation format	Differential phase modulation signal (DPSK, DQPSK)
Signal bit rate	39.8 to 44.6 Gbps
Measurement wavelength range	1530 to 1600 nm
Input optical level	10 mW or less (peak power)
Measurement accuracy	±10% or less (intensity), ±5° or less (phase)
Residual noise	±3% rms or less (intensity), 3° rms or less (phase)
Polarization dependency	±10% or less (intensity), ±10° or less (phase)
Jitter timing	1 ps rms or less (except input clock jitter)
Analysis functions	Histogram, Average, Variance, Q-value analysis, Estimated BER

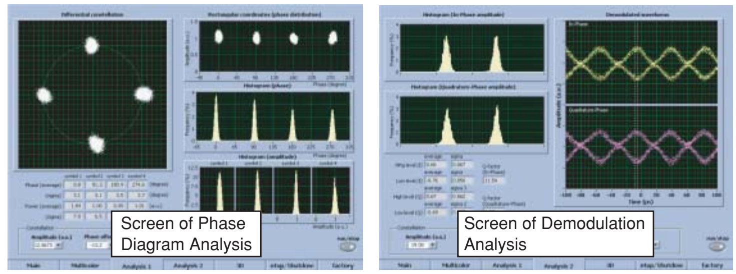

Figure 4 Example Screen of Analysis Function

modulated signals, the phases of orthogonal components (in-phase and quadrature-phase components) are measured with a reference clock source from a local oscillator synchronized with the carrier frequency of the measured signal. This method is well established and widely used in the fields of wireless communication networks such as wireless local area networks (LAN) and terrestrial digital TV broadcasting. However, the method is not readily applicable to optical measurement since it is difficult to prepare a reference clock source with high precision that corresponds to a laser source radiating at approximately 190-THz single-mode frequency with ±1 MHz accuracy. Moreover, the reference clock source must be highly stable and has to be able to tune in to the signal carrier frequency in case-by-case measurements. It is not practical to include such a high-performance, high-quality laser source in the measurement system, even though the wavelength accuracy of wavelength tunable laser sources now commercially available is around ±10 pm (equivalent to a frequency of ±1.25 GHz).

Therefore, the NX7000 uses 1-bit delayed self-homodyne detection without requiring a local oscillator, where the phases of the preceding signal bits of the signals are used as relative phase references instead of preparing an optical reference for phase measurement. By this method of the self-homodyne detection, the NX7000 realizes highly precise and stable measurement independent of the measured signals in principle. Furthermore, DPSK/DQPSK signals with the NX7000 are measured on an equivalent scheme of their demodulation by using 1-bit-delay interferometry, so that the amount of relative amplitude and phase variations between signal bits, which is necessary for evaluating DPSK/DQPSK signals, are directly measured without measuring the absolute amplitude and phase.

Real-time simultaneous measurement of differential constellation/phasor diagrams and demodulated waveforms under time-base control

The differential interference signal element dI and dQ components are acquired by temporally scanning the sampling positions in the same manner as sequential sampling by a conventional sampling oscilloscope. From the gathered data samples, 3-dimensional differential distributions on dI, dQ, and time coordinates are constructed, and the transitional amplitude and phase variations are calculated by post-processing to display the differential constellation/phasor diagrams and the in-phase and quadrature-phase demodulated waveforms of the measured DPSK or DQPSK signals.

To evaluate and analyze DPSK/DQPSK signals, it is important to analyze a differential constellation diagram which shows the amplitude/phase condition at the original point of the signal pulses corresponding to a diagram of DPSK/DQPSK signal symbols. It is possible to select valid data from the gathered data samples depending on the scanning sequence, but it would take a long time to collect and record enough samples for analysis. Therefore, the NX7000 performs two separate processes alternately: one process for making a differential constellation diagram, by sampling perfectly synchronized with the measured signal without a scanning procedure; and the other for making a differential phasor diagram and in-phase and quadrature-phase demodulated waveforms by sampling with a scanning procedure.

The NX7000 then alternately displays the results of these two processes. To realize this function, a time-based circuit in a phase-locked loop (PLL) implementation has been developed. This circuit dynamically adjusts the sample timing (clock phase for sampling) based on control signals.

Figure 3 shows an example of measuring 43-Gbps RZ (Return to Zero)-DQPSK signals. The differential constellation diagram (white, 20,000 pt), differential phasor diagram (blue, 5,000 pt), in-phase demodulated waveform (yellow, 5,000 pt), and quadrature-phase demodulated waveform (pink, 5,000 pt) are displayed, each updated at about 10 frames per second. This figure shows that the NX7000 can perform real-time observation without compromising the measurement accuracy.

Data compensation algorithm for highly precise and accurate measurement

The NX7000 needs highly accurate optical and electrical devices in order to maintain highly precise and accurate measurement because it measures signals using the interference of light. However, it is not sufficient merely to adjust devices because they vary in quality. Therefore, the NX7000 use Yokogawa's unique data compensation algorithm in order to improve the measurement accuracy.

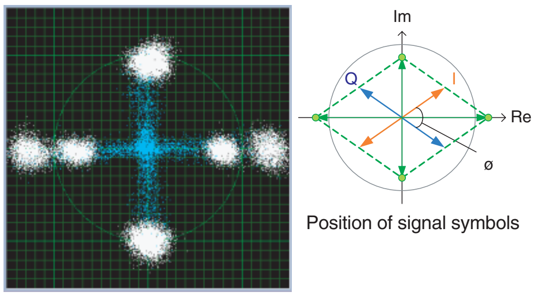

Figure 5 Example of Application 1

(Shifting the bias voltage of the modulator in the signal generator)

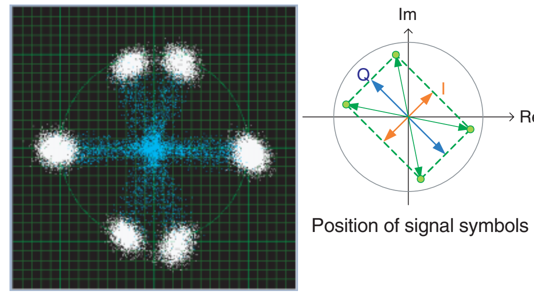

Figure 6 Example of Application 2

(Shifting the modulation amplitude of the modulator in the signal generator)

EXAMPLES OF APPLICATIONS

Figures 5 and 6 show diagrams based on conditions of signal generation on a 43-Gbps RZ-DQPSK signal generator. Figure 5 shows the measured result when changing the orthogonal relation between in-phase element and quadrature-phase components of DQPSK signals. This diagram is obtained by adjusting the bias voltage of a MZI (Mach-Zehnder Interferometer)-type optical modulator used in the signal generator. The absolute amplitude and phase of four signal symbols on the complex plane form rhombus shaped with different amplitudes due to the compounding of in-phase and quadrature-phase field vectors. The delayed self-homodyne detection used in the NX7000 creates diagrams by using the interference of the signal symbols. Therefore, the change can be observed by separating the amplitude diagram in one direction. This indicates that highly sensitive observation is achieved with the same level of change that a receiver obtains. Figure 6 shows the result when changing the single-side modulation amplitude of modulator driver signals. Both diagrams show significant results based on the change of signals. By using these diagrams from the NX7000, we can adjust the signal generator to be in the optimal, high-quality condition.

CONCLUSION

This paper described the NX7000 analyzer for measuring high-speed signals of optical phase modulation for 40-Gbps DPSK/DQPSK. The NX7000 will be used for evaluating and adjusting 40-Gbps optical transmission systems, devices, and components, as well as for troubleshooting network errors.

The NX7000 features various unique core technologies, and evaluates signals on the physical layer of a network. Yokogawa has also developed an optical IP transport analyzer, the NX4000[6], for research and development and production testing for optical transmission systems. The target field of the NX4000 is testing and evaluation on higher layers of a network. For example, the NX4000 is used to see whether or not a network system complies with the Synchronous Optical Network/ Synchronous Digital Hierarchy (SONET/SDH) standards or Optical Transport Network (OTN) standards.

The 40-Gbps network market will take off in FY2008. We hope our measurement solutions for NGN technologies will help construct 40-Gbps optical transmission systems and speed up the development of optical devices, thereby contributing to building the next-generation information network infrastructure.

The development of the world's first NX7000 required the help of many people. We thank all of them for their support. ◆

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