# An overview of ITU-T G.709

## Application Note: 1379

As increasing demands are made on the world's communications networks, new standards emerge to cater for the challenges that these demands make. ITU-T G.709 "Interface for the optical transport network (OTN)" is one of the latest recommendations. It has been developed to meet two requirements: to cater for the transmission needs of today's wide range of digital services, and to assist network evolution to higher bandwidths and improved network performance. Furthermore, it takes another step towards the all-optical network.

This paper provides a brief overview of ITU-T G.709 signal structures, and examines the testing requirements for ITU-T G.709 compliant network equipment.

Agilent Technologies

## Introduction

SONET/SDH is now a mature digital transport technology, established in virtually every country in the world. When SONET/SDH was first conceived in the early 1980s, telecommunications traffic was predominantly voice. During the last five years there has been an explosion in the demand for bandwidth driven mainly by internet access, e-commerce and mobile telephony. This increase in demand has, so far, been satisfied through a combination of increased line rates (TDM – time division multiplexing) and transmitting multiple wavelengths through a single fiber (DWDM – dense wave division multiplexing).

But as the network evolves to higher line rates, the physical limits of the transport medium (optical fiber) becomes critical. And, there remains an over-riding requirement to control the cost of providing an improving service to customers.

The latest recommendation from the ITU is G.709 “Interface for the optical transport network (OTN)” builds on the experience and benefits gained from SDH and SONET to provide a route to the next-generation optical network. Indeed, the OTN is widely regarded as the lifeline to increased bandwidth capacity. Many of the concepts in ITU-T G.709 have their roots in SDH/SONET, for example a layered structure, in-service performance monitoring, protection and other management functions. However, some key elements have been added to continue the cycle of improved performance and reduced cost. These include:

- Management of optical channels in the optical domain
- Forward error correction (FEC) to improve error performance and enable longer optical spans

ITU-T G.709 also provides a standardized method for managing optical wavelengths (channels) end to end without the need to convert an optical signal into the electrical domain. (Today’s DWDM networks are typically managed as a series of point-to-point links with a path through the network requiring many expensive optical/electrical/optical {O/E/O} conversions.) Thus, ITU-T G.709 along with the advent of all-optical switches (using MEMs and bubble technology) opens the door to potentially extensive cost savings in the network.

# ITU-T G.709 framing structure and byte definitions

The ITU-T G.709 frame (figure 1) has three distinct parts, two that are broadly similar to a SDH/SONET frame:

- Overhead area for operation, administration and maintenance functions
- Payload area for customer data

In addition, the G.709 frame also includes a foward error control (FEC) block.

FEC has been used in telecommunications for many years, mainly in the areas of satelite communications and undersea transport. FEC has been important in enabling communications to maintain acceptable performance quality in ‘noisy’ environments at the same time as keeping infrastructure costs in check.

As transmission bit rates increase to 10 Gb/s and beyond, physical parameters of the optical fiber play a more significant part in degrading transmitted pulses of light. FEC provides additional coded data to enable error checking and correction by a receiving device. ITU-T G.709 includes a standardized method of FEC that enables long haul transmission at higher line rates without degraded performance.

The FEC scheme used in the ITU-T G.709 standard is a Reed-Solomon RS(255,239) code. This means that for every 239 bytes of data, an additional 16 bytes (255-239=16) of data is added for error correction. The RS(255,239) code can correct up to eight symbol errors in the code word when used for error correction, and can detect sixteen symbol errors in the FEC code word when used for error detection only.

In the optical transport unit (OTU) frame, each row contains 16 FEC blocks of 16 bytes for the row, thus making 64 FEC blocks (4 x 16) for every OTU frame.

The FEC for the OTU frame uses 16-byte interleaved codecs. This results in the serial bit stream (10.71 Gb/s for example) being converted into 16 parallel signals for processing. This architecture helps improve the error correction on error bursts and countering interleaving that may split up closely spaced errors.

The size of the frame is four rows of 4080 bytes (figure 2). Data is transmitted serially beginning at the top left, first row, followed by the second row and so on.

There are three line rates currently defined in ITU-T G.709:

1. 2,666,057.143 kbit/s – optical channel transport unit 1 (OTU1)
2. 10,709,225.316 kbit/s – optical channel transport unit 2 (OTU2)
3. 43,018,413.559 kbit/s – optical channel transport unit 3 (OTU3)

Unlike SONET/SDH, as the line rate increases, the G.709 frame size (4 x 4080) remains the same and the frame rate increases. This is a departure from the fundamental 8 kHz frame rate that has been a foundation of digital telecommunication networks designed to carry predominantly voice traffic.

The three frame rates (and period) are:

1. 20.420 kHz (48.971 ms) for OTU1
2. 82.027 kHz (12.191 ms) for OTU2
3. 329.489 kHz (3.035 ms) for OTU3

Note: The period is an approximated value, rounded to three digits.

This means that to carry one SDH/SONET 10 Gb/s frame, for example, requires approximately eleven OTU2 optical channel frames.

The optical transport module overhead consists of four functional areas (figure 3):

Figure 1

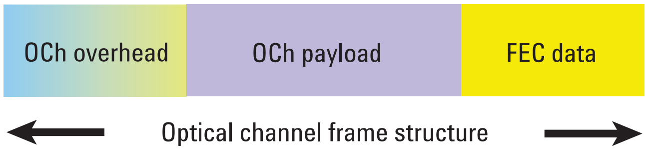


Figure 3. ITU-T G.709 Figure 5-1

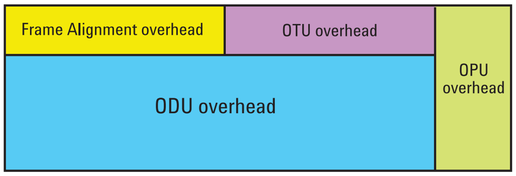
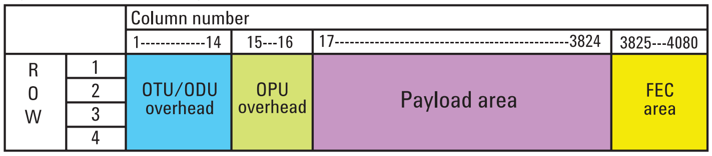


Figure 2. ITU-T G.709 Figure 11-1



OTU – Optical transport unit
ODU – Optical data unit
OPU – Optical payload unit
FEC – Forward error correction

## Frame alignment

When using serial blocks of data (that is, bytes and frames) in a transmission system, the receiving equipment must be able to identify the block boundaries. The ability to identify the ‘starting point’ in the OTN is accomplished through the use of framing bytes which are transmitted every frame.

The frame alignment area contains a 6-byte frame alignment signal (FAS) in row 1 columns 1-6 (figure 4). The byte values are the same as in SDH/ SONET, F6F6F6282828, and are transmitted unscrambled.

The ability to frame-up, identify out-of-frame (OOF), and loss-of-frame (LOF) conditions is a fundamental requirement for any receiving equipment. The equipment needs to find the start of a frame before it can find the management and customer data it needs to process.

## Overhead byte locations and naming

| **Abbreviations** | |
|---|---|
| APS/PCC | Automatic protection switching/ protection communication channel |
| EXP | Experimental |
| FAS | Frame alignment signal |
| FTFL | Fault type and fault location |
| GCC0-3 | General communication channel |
| JC | Justification control |
| MFAS | Multi frame alignment signal |
| NJO | Negative justification opportunity |
| PM | Path monitoring |
| PSI | Payload structure identifier |
| RES | Reserved |
| SM | Section monitoring |
| TCM ACT | Tandem connection monitoring activation |
| TCM1-6 | Tandem connection monitoring |

Optical channel frame-stress testing requires the ability to generate sequences of errored/error-free FAS words to verify that error and alarm conditions are entered and exited at levels defined in the recommendations. For example, when adding frame errors up to the level needed to generate OOF alarms and LOF alarms in network equipment, correct entry and exit points for these events can only be verified using test equipment that gives complete control over the FAS bytes.

When designing in a ‘standards’ environment, this level of testing gives the confidence that designs will inter-operate with other vendor equipment.

Some of the OTU and optical data unit (ODU) overhead signals span multiple OTU frames. Because of this, a multi-frame alignment signal (MFAS) byte is defined in row 1 column 6. The value of the MFAS byte is incremented each frame thereby providing a 256 frame multi-frame. The MFAS byte is scrambled along with all the other bytes in the OTU frame.

## Optical transport unit (OTU) overhead

The OTU overhead, located at row 1 columns 8-14 (figure 4), provides supervisory functions. Additionally, it conditions the signal for transport between 3R (re-timing, reshaping and regeneration) regeneration points in the OTN.

The OTU overhead consists of three bytes for section monitoring (SM), a two-byte general communications channel (GCC0), and two bytes reserved for future international standardization.

The SM channel is structured as follows (figure 5):

Figure 5. ITU-T G.709 Figure 15-2

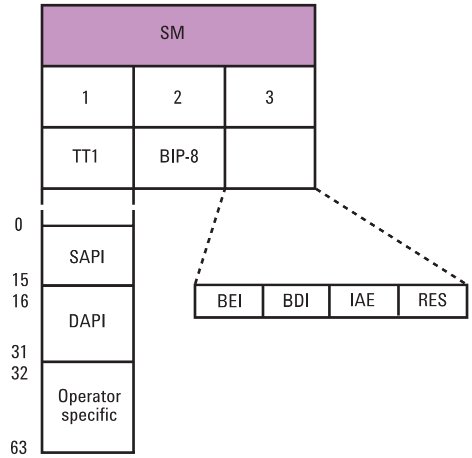
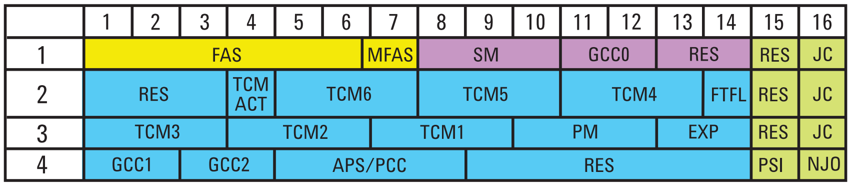


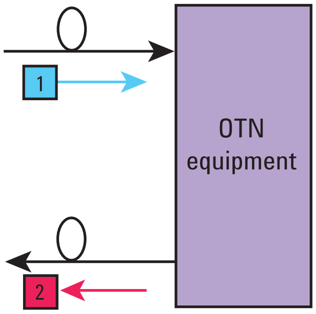
Figure 4. ITU-T G.709 Figure 15-12



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | FAS | | | | | | MFAS | SM | | | GCC0 | | RES | | RES | JC |
| 2 | RES | | | TCM ACT | TCM6 | | | TCM5 | | | TCM4 | | | FTFL | RES | JC |
| 3 | TCM3 | | | TCM2 | | | TCM1 | | | PM | | | EXP | | RES | JC |
| 4 | GCC1 | | GCC2 | | APS/PCC | | | | RES | | | | | | PSI | NJO |

Figure 6

| Section Monitoring | |
|---|---|
| 1 | 2 |
| Detected input condition | Response transmitted upstream |
| BIP-8 errors | BEI |
| Alarm | BDI |
| Framing error | IAE |



The single-byte trail trace identifier (TTI) is defined to transport a 64-byte message (similar to the functionality of J0 in SONET/SDH). The message contains a source and destination identifier used for routing the OTU signal through the network. There are also bytes allocated for operator-specific use.

The 64-byte message is aligned with the OTU multi-frame and is therefore transmitted four times per multi-frame (256/64) sequence.

Testing the TTI functionality involves sending valid messages into a network device and verifying that the signal is routed to the appropriate output port.

Testing that the network device accurately identifies incorrect or corrupt TTI messages is also a requirement. This can be performed using test equipment that allows transmission of flexible user-defined sequences in the TTI byte locations.

When testing for correct termination/transparency in network elements (NEs), it is vital to check that TTI messages are passed through the NE unaltered. This is particularly important if the signal is intended for an endpoint downstream from the device-under-test.

ITU-T G.709 uses bit interleaved parity (BIP) checks for in-service performance monitoring, and a BIP-8 byte is defined in the section monitoring (SM) overhead (figure 5). There are two main differences between the implementation of B1 BIPs in SDH/SONET and the SM BIP in ITU-T G.709.

First, the SM BIP-8 is calculated only over the OPU payload and OPU overhead areas of the frame (columns 15 to 3824); in SDH/SONET, the B1 BIP-8 is calculated over an entire frame, including overhead. Second, the calculated BIP-8 value for the frame is inserted into the BIP-8 SM location of frame i+2; in SDH/SONET, the BIP-8 value is inserted into the next frame

For section monitoring, a four-bit backward error indicator (BEI) signal is defined to signal upstream the number of bit-interleaved blocks that have been identified in error by the section monitoring sink function using the BIP-8 code. The BEI has nine valid values, namely 0-8 errors detected in the SM BIP-8 byte. The remaining values can only occur from some unrelated condition and are interpreted as zero errors.

For section monitoring a single bit, backward defect indication (BDI) is defined to convey the signal-fail status determined in a section termination sink function in the upstream direction. It is set to ‘1’ to indicate a defect, otherwise it is set to ‘0’.

A single incoming alignment error (IAE) bit is defined to indicate that an alignment error has been detected on the incoming signal

Two further bits of the SM bytes, reserved for future standardization, are set to ‘00’

Testing the section monitoring functionality requires the ability to stimulate the device-under-test (DUT) with various alarm and error conditions and check that the DUT gives appropriate responses (figure 6). This testing may involve measuring the time taken to respond to an input stimulus. In this case, test equipment with a wide range of event trigger outputs can be useful.

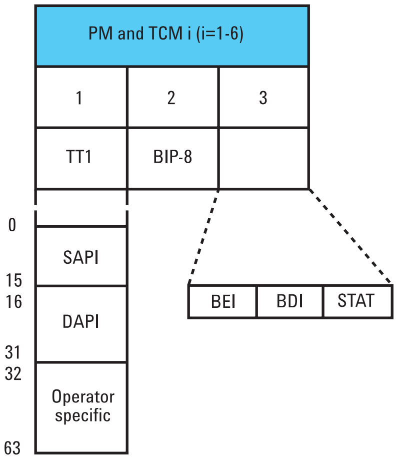
A two byte general communications channel (GCC0) is defined in row 1 columns 11 and 12. These bytes provide a clear channel connection between OTU termination points. The format of the data carried in this channel is not defined. The GCC0 channel is likely to carry network management data, so when testing a device at the design stage, performing a BER test in the GCC channels may be adequate to verify performance quality.

## Optical channel data unit (ODU) overhead

The ODU overhead resides in columns 1-14 of rows 2, 3 and 4 of the OTN frame. The ODU information structure provides tandem connection monitoring (TCM), end-to-end path supervision, and client signal adaptation via the optical channel payload unit (OPU).

The path monitoring (PM) field in the ODU has a similar structure and function to the section monitor field in the OTU overhead (figure 7).

Figure 7. ITU-T G.709 Figure 15-3



The ODU also defines six fields for TCM. TCM enables a network operator to monitor the error performance of a signal transiting from its own network ingress and egress points.

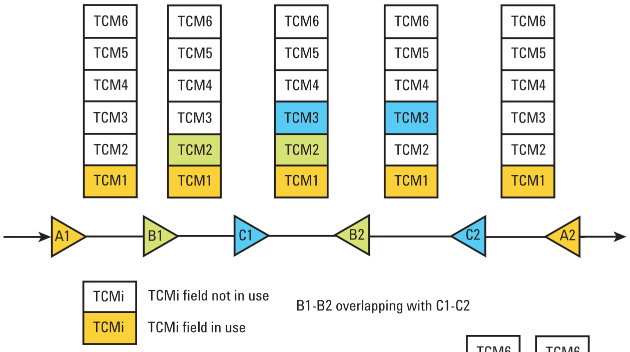
The six TCM fields have the same structure as the PM field, and support monitoring of ODU connections for one or more of the following applications:

- UNI-to-UNI monitoring of the ODU connection through the public network
- NNI-to-NNI monitoring of the ODU through a network operator
- Sub-layer monitoring for protection switching, and detection of signal fail or degrade conditions
- Monitoring a tandem connection for fault localization or verification

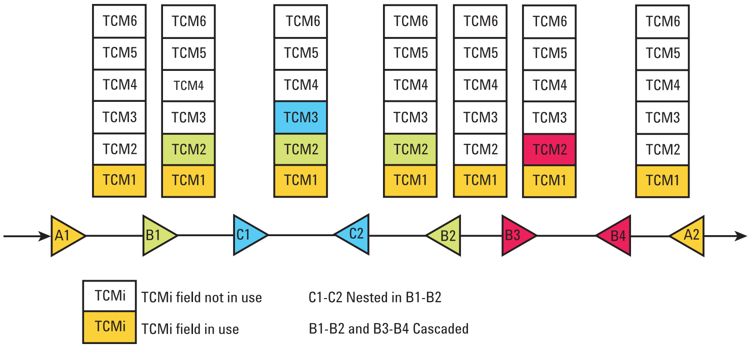
The six TCM fields provide support for tandem connection monitoring in a variety of network configurations, and can cope with nested, overlapping and cascaded topologies as illustrated in figure 8.

The fault type and fault location (FTFL) field is also related to the monitoring of a tandem connection span. The FTFL channel is a 256-byte message transmitted across multiple frames and aligned with the ODU MFAS. The message conveys both forward and backward fault information and the message structure is shown in figure 9.

Figure 8. ITU-T G.709 Figure 15-17



ITU-T G.709 Figure 15-16



Currently the fault indication codes located in bytes 0 (forward) and 128 (backward) provide only ‘signal fail’, ‘signal degrade’ and ‘no fault’ information. Further codes are likely to be developed in the future.

The TCM activation (TCM ACT) field is also related to tandem connection monitoring and is located in the ODU overhead. Its definition is for further study.

Two two-byte general communications channel fields, GCC1 and GCC2, are defined in row 4 columns 1 to 4. These bytes provide a clear channel connection between ODU termination points. The format of the data carried in this channel is not defined. The main purpose of these bytes is to carry operator management data.

Two fields (RES) are reserved for future standardization and are located in row 2 columns 1-3 and row 4 columns 9-14. These bytes are normally set to all zeros.

Finally, a two-byte experimental (EXP) field is defined for experimental purposes. This field will not be subject to future standardization.

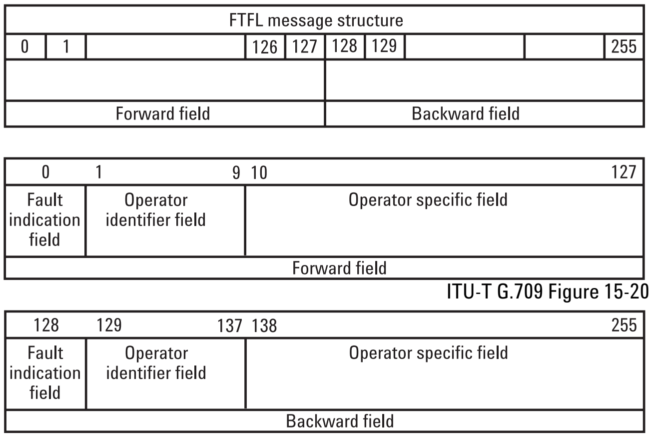
## Optical channel payload unit (OPU) overhead

The OPU overhead is added to the OPU payload and contains information to support the adaptation of client signals. The OPU overhead is located in rows 1-4 of columns 15 and 16 and is terminated where the OPU is assembled and disassembled.

The OPU overhead byte definitions vary depending on the client signal being mapped into the OPU payload. ITU-T G.709 currently defines mappings for constant bit rate signals (for example, STM-16/64/256), both bit-synchronous and asynchronous mapping, ATM cells, generic framing procedure (GFP) frames, synchronous constant bit stream, and a test pseudo random bit sequence (PRBS) pattern.

Figure 10 shows the OPU2 overhead used when asynchronously mapping a 10 Gb/s SDH/SONET signal into the OPU2 payload.

Figure 9. ITU-T G.709 Figure 15-20



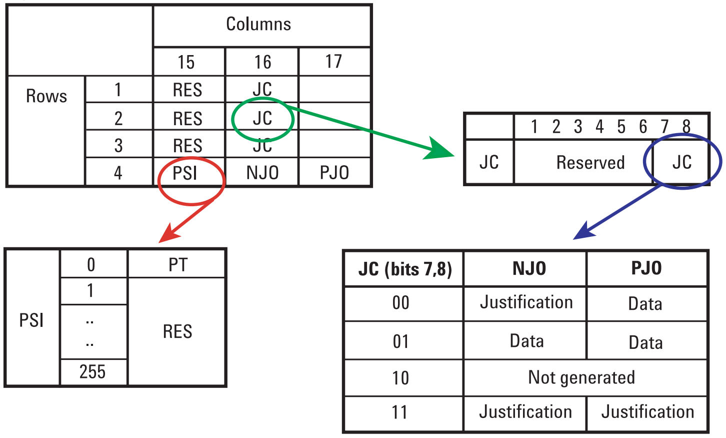
ITU-T G.709 Figure 15-20

ITU-T G.709 Figure 15-21

| Fault indication codes | |
|---|---|
| Fault Code | Definition |
| 0000 0000 | No fault |
| 0000 0001 | Signal fail |
| 0000 0010 | Signal degrade |
| 0000 0011<br>..<br>..<br>1111 1111 | Reserved for future standardization |

ITU-T G.709 Figure 15-6

Figure 10



| | | Columns | | |
|---|---|---|---|---|
| | | 15 | 16 | 17 |
| Rows | 1 | RES | JC | |
| | 2 | RES | JC | |
| | 3 | RES | JC | |
| | 4 | PSI | NJO | PJO |

| | 1 2 3 4 5 6 | 7 8 |
|---|---|---|
| JC | Reserved | JC |

| PSI | | |
|---|---|---|
| PSI | 0 | PT |
| | 1 | RES |
| | .. | |
| | .. | |
| | 255 | |

| JC (bits 7,8) | NJO | PJO |
|---|---|---|
| 00 | Justification | Data |
| 01 | Data | Data |
| 10 | Not generated | |
| 11 | Justification | Justification |

OPU2, O/H for synch mapping of 10 Gb/s SDH/SONET

## Testing optical channel devices and hierarchical structures

The justification control (JC) bytes are used to control the negative justification opportunity (NJO) or positive justification opportunity (PJO). The mapping process generates the JC, NJO and PJO values respectively.

The demapping process interprets the JC, NJO and PJO values according to the table in figure 10. A majority vote (that is, two out of three) is used to make the justification decision to protect against an error in one of the three JC signals.

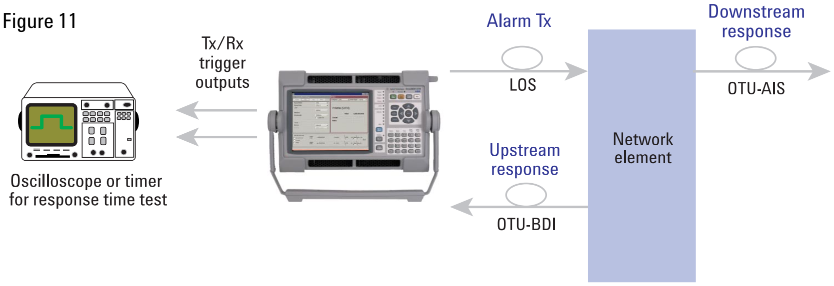
The payload structure identifier (PSI) field is defined to transport a 256-byte message aligned with the OTU MFAS. PSI0 contains the payload type (PT) identifier that reports the type of payload being carried in the OPU payload to the receiving equipment. Of the 256 possible values available, some are already defined: 288 values are reserved for future standardization, some are not available, while others are reserved exclusively for proprietary use.

Guaranteed availability of bandwidth plus a high level of service quality is a consistent customer demand. Modern networks are designed with a high degree of intelligence to help satisfy these demands. This intelligence is delivered in the management 'overhead' that is transmitted with customer data. The communications network 'senses' its own condition through the use of parity checks, error detection and alarm status that's carried in the overhead channels.

In today's world of standardization and interoperability, it is vital that new designs comply with relevant standards and recommendations. To ensure the designs of new ITU-T G.709 compliant network equipment meet customer's expectations, a range of tests is required during the design, verification, and manufacturing stages. These tests can be divided into the following broad areas:

- Conformance
- Stimulus response
- Stress test
- Client signal mapping/ demapping
- Parametric

Figure 11



Oscilloscope or timer for response time test

### Stimulus/response testing

This type of test involves sending a stimulus signal into the DUT and monitoring for appropriate outputs due to the stimulus. In the OTN, a single stimulus may result in several simultaneous responses. The example below (figure 11) shows the test set-up and expected responses to a detected loss of signal (LOS) at a receiver input.

This type of test must be repeated for all possible input stimuli that the DUT is expected to respond to. A list of possible stimuli is shown in figure 12.

Figure 12

| Stimulus | Description |
|---|---|
| LOS | Loss of signal |
| LOF | Loss of frame |
| OOF | Out of frame |
| OOM | Out of multiframe |
| OTU-AIS | OTU alarm indication signal |
| OTU-IAE | OTU incoming alignment error |
| OTU-BDI | OTU backwards defect indication |
| ODU-AIS | ODU alarm indication signal |
| ODU-OCI | ODU open connection indication |
| ODU-LCK | ODU locked |
| ODU-BDI | ODU backwards defect indication |
| FAS | Frame error |
| MFAS | Multi-frame error |
| OTU-BIP8 | OTU BIP error |
| OTU-BEI | OTU backwards error indication |
| ODU-BIP8 | ODU BIP error |
| OTU-BEI | OTU backwards error indication |
| FEC block error | Uncorrectable FEC block |

Standards and recommendations usually define the response time to a detected event, either in frames or in a time period. In the latter case, it is useful to use test equipment with event trigger outputs that can be connected to measuring equipment (for example, timer or oscilloscope) to determine the DUT response time to an event (see figure 11). Triggers are set for initiating the LOS signal and for the OTU-BDI reponse.

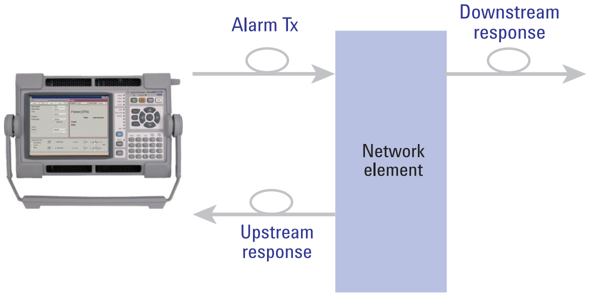
## Alarm stress testing

This type of test really comes under the banner of 'conformance testing'. Standards normally define entry and exit criteria for alarm events, usually specified by a number of frames or sometimes in a time period. A possible test configuration is shown figure 13. In this instance, it is useful for test equipment to simulate a stimulus condition (alarm) for a variable number of frames or time. This allows an alarm condition to be simulated for a variable number of frames and the number varied to confirm that the entry criterion is met precisely. A similar test can be performed to verify the exit criterion for the event.

For example, on detection of an alarm such as OTU-BDI (detected by '1' in bit 5 of byte 3 of the SM field of the OTU overhead), a network device should signal this to the management system when it has been set for five consecutive frames. By using test equipment that can generate this condition for one, two, three, four and more consecutive frames, it is possible to verify that the alarm condition is entered at exactly the correct point. A similar test can verify the alarm exit condition.

This type of testing must be performed for every possible alarm event to ensure conformance to the recommendation, and interoperability with other vendor equipment.

Figure 13



## Mapping/demapping testing

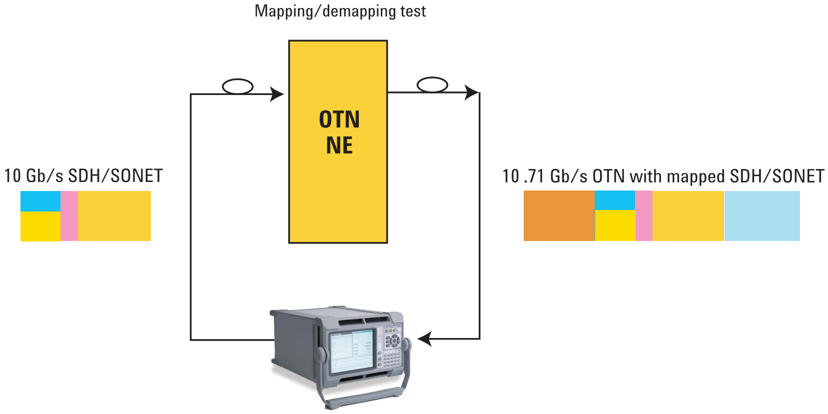
The optical transport hierarchy has been designed to transport a range of payloads. Today, there are defined mappings for SDH/SONET, ATM and generic framing procedure (GFP) frames. When mapping SDH/SONET signals into the OPU, rate differences between the client and OPU clocks are accommodated through the use of justification (stuffing). The maximum difference that can be accommodated between OPU and client clocks is +/- 65 ppm. With a bit rate tolerance of +/- 20 ppm for the OPU clock, the client's bit rate tolerance can be +/- 45 ppm.

A configuration for mapping testing is shown in figure 14.

The bit rate of the input client test signal is varied across its maximum allowable range (normally +/- 20 ppm for SDH/SONET line signals). The DUT maps the client signal into the optical channel frame and the tester verifies that this has been performed without any error or alarm events at the OTN or SDH/SONET levels.

The demapping process can also be verified with the tester generating OTN frames containing mapped SDH/SONET frames.

Figure 14



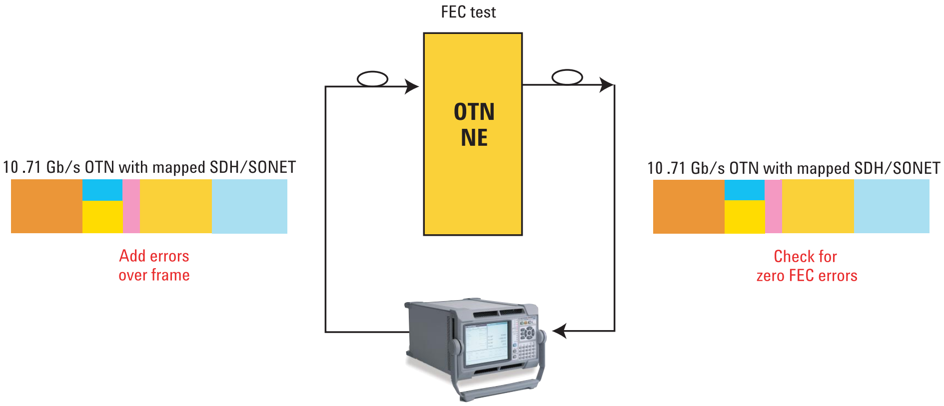
### Forward error correction (FEC) testing

FEC is a key element of the OTN and is used to provide improved quality of service and longer span lengths. Using a tester that generates correctly structured OTN frames and that can also generate a range of frame errors is useful in validating FEC functionality in new device designs.

A test configuration is shown in figure 15.

The Reed-Solomon coding scheme combined with the use of 16-byte interleaved codecs makes this implementation of FEC particularly good at correcting bursts of errors. In the configuration shown below, it is possible to add increasing rates of errors at the input to the DUT and monitor the error performance at the DUT output. In this way, it is possible to verify that errors at the input are actually corrected by the DUT.

Figure 15



## Glossary

| Abbreviation | Description |
|---|---|
| DUT | Device under test |
| DWDM | Dense wave division multiplexing |
| FEC | Forward error correction |
| MEMS | Micro Electro Mechanical Systems |
| OCh | Optical channel |
| ODU | Optical data unit |
| OPU | Optical payload unit |
| OTN | Optical transport network |
| OTU | Optical transport unit |
| prbs | Pseudo random bit sequence |

## Conclusion

To satisfy demand for bandwidth, control costs and still remain competitive, service providers are deploying the next generation OTN. The OTN includes forward error correction (FEC) and enhanced network management. This is seen as the best value-for-money solution for bandwidth at 10 Gb/s and above.

NEMs that manufacture devices for the OTN must ensure they are fully compliant with ITU-T G.709. However, to do this, NEMS need an OTN tester that will verify every aspect of the recommendation, thereby ensuring interoperability and standardization. This means service provides can have complete confidence in the product, and in improved performance to end users.

## Product literature

You'll find further details of the OmniBER OTN's capability in the product specification publications no. 5988-3653EN and configuration guide publication no. 5988-3654EN or at www.agilent.com/comms/otn

## Related products

The Agilent Technologies OnmiBER 718 communications performance analyzer is the proven SONET/SDH one-box test solution. It provides full T-carrier/PDH and SONET/SDH up to 2.5 Gb/s, including concatenated payloads, ATM, Jitter and POS. For further information, refer to publication no. 5968-8740E

OmniBER 718

The OnmiBER 725 combines best in class SDH and SONET jitter capability at all rates up to 2.5 Gb/s, with differential electrical interfaces. Offering unframed PRBS signals it's the ideal choice for testing optical components and modules. For further information, refer to publication no. 5988-0327EN.

OmniBER 725

Focused on field applications, the J2127A transmission test sets cover all rates from 64 kb/s up to 10 Gb/s. Supporting SONET/SDH and T-carrier/PDH configurations, the test set offers simultaneous monitoring technology for faster turn-up and troubleshooting. For further information, refer to publication no. 5988-2569EN.

Transmission test set

*Agilent Technologies manufactures the OmniBER OTN under a quality system approved to the international standard ISO 9001 plus TickIT (BSI Registration Certificate No FM 10987).*

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Printed in USA 1st September, 2001
5988-3655EN

Agilent Technologies