

SDH

Pocket Guide

Synchronous Digital Hierarchy



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Introduction

With some 1,200 million telephone connections in use today and the number of Internet users growing rapidly, network providers must deal effectively with increased telephone traffic. In response, several methods and technologies have been developed within the last 50 years to address these market needs as economically as possible.

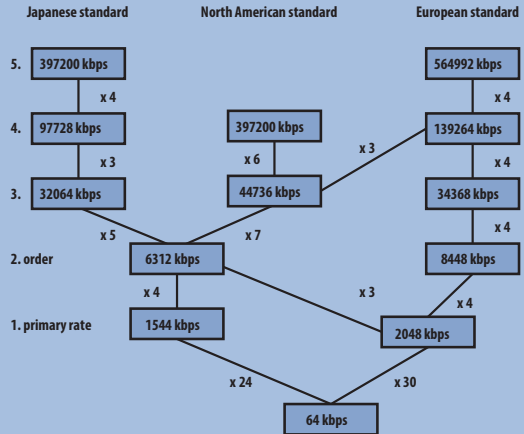
Then communications engineers introduced frequency division multiplex (FDM) systems that modulated each individual telephone channel with a different carrier frequency. The signals could then be shifted into different frequency ranges to transmit several telephone connections over a single cable.

The advent of semiconductor circuits and a continuing demand for telephone capacity in the 1960s resulted in the development of the pulse code modulation (PCM) transmission method.

With PCM (using a single line multiple times through digital time-domain multiplexing), the analog telephone signal is first sampled at a 3.1 kHz bandwidth, quantized and encoded and then transmitted at a 64 kbps rate. Collecting 30 such coded channels together into a frame along with the necessary signaling information can achieve a 2048 kbps transmission rate.

This 2048 kbps primary rate is used throughout the world except in the USA, Canada, and Japan, which use a 1544 kbps primary rate (formed by combining 24 channels), see Figure 1.

Figure 1. Summary of plesiochronous transmission rates



The demand for greater bandwidth, however, resulted in the need for more multiplexing stages throughout the world. A practically synchronous — or plesiosynchronous — digital hierarchy was developed in response. Slight differences in timing signals necessitates justification or stuffing to form the multiplexed signals.

Inserting or dropping an individual 64 kbps channel to or from a higher digital hierarchy requires a lot of complex and expensive multiplexer equipment.

Synchronous digital hierarchy (SDH) was introduced in the 1980s, paving the way for a worldwide, unified network structure. SDH is ideal for network providers, because it delivers an efficient, economical network management system that easily adapts to accommodate bandwidth-consuming applications and services.

This pocket guide introduces synchronous communications without going into the “bits and bytes.”

Why SDH?

Communications networks gradually converted to digital technology after PCM was introduced in the 1960s. A multiplex hierarchy known as plesiosynchronous digital hierarchy (PDH) evolved to cope with the demand for ever-higher bit rates. The bit rates start with the basic multiplex rate of 2 Mbps with further stages of 8, 34, and 140 Mbps. In North America and Japan, however, the primary rate is 1.5 Mbps with additional stages of 6 and 44 Mbps, as shown in Figure 1 on page 5. This fundamental developmental difference made gateway setup between the networks both difficult and expensive.

In response to the demand for increased bandwidth, reliability, and high-quality service, SDH developed steadily during the 1980s, eliminating many inherent disadvantages in PDH. In turn, network providers began to benefit from the many technological and economic advantages this new technology introduced as discussed in this section.

High transmission rates

Transmission rates of up to 10 G can be achieved in modern SDH systems making it the most suitable technology for backbones, the superhighways in today's telecommunications networks.

Simplified add and drop function

Compared to the older PDH system, low-bit-rate channels can be easily extracted from and inserted into the high-speed bit streams in SDH, eliminating the need for costly demultiplexing and remultiplexing the plesiosynchronous structure.

High availability and capacity matching

SDH enables network providers to react quickly and easily to their customers' requirements, such as switching leased lines in just minutes. Network providers can use standardized network elements (NE) that they can control and monitor from a central location with a telecommunications management network (TMN) system.

Reliability

Modern SDH networks include various automatic backup-circuit and repair mechanisms that management can monitor to cope with system faults so that link or NE failures do not lead to an entire network failure.

Future-proof platform for new services

SDH is the ideal platform for a wide range of services including POTS, ISDN, mobile radio, and data communications, such as LAN and WAN. It can also handle more recent services such as video on demand and digital video broadcasting via ATM.

Interconnection

SDH simplifies gateway setup between different network providers and to SONET systems. The SDH interfaces are globally standardized, making it possible to combine NEs from different manufacturers into a single network which reduces equipment costs.

The trend in transport networks is toward ever-higher bit rates such as STM-256 (time division multiplex, TDM); however, these NEs can be cost-prohibitive. Another cheaper alternative is dense wavelength division multiplexing (DWDM) which uses multiple single-mode optical fibers to transmit digital signals through several fibers simultaneously. (See the DWDM Pocket Guide for more information.)

DWDM is closely associated with the "all-optical network." In terms of the ISO-OSI layer model, OADM and optical cross-connect (OXC) development basically means introducing an additional DWDM layer below the SDH layer (see Figure 2).

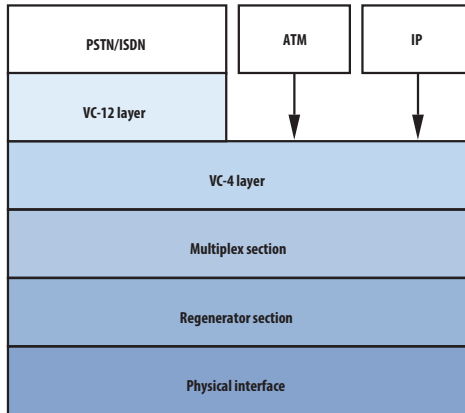
Therefore, future systems will likely combine higher multiplex rates with DWDM.

The synchronous digital hierarchy in terms of a layer model

Telecommunications technologies like SDH are generally explained using so-called layer models.

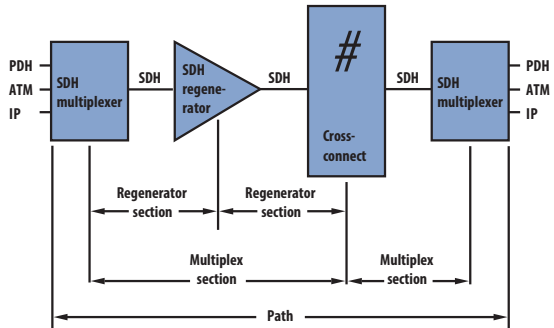
The uppermost layer represents the applications of the SDH transport network.

Figure 2. The SDH layer model



SDH networks are subdivided into various layers directly related to the network topology. The lowest layer is the physical layer, which represents the transmission medium, usually a glass fiber or possibly a radio or satellite link. The regenerator section is the path between regenerators, see Figure 3. Part of the regenerator section overhead (RSOH) is available for the signaling required within this layer.

Figure 3. Path section designations

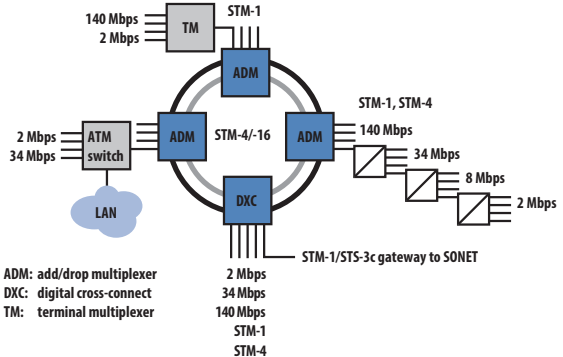


The remainder of the overhead, the multiplex section overhead (MSOH) is used for multiplex section needs and covers the part of the SDH link between multiplexers. The carriers or virtual containers (VC) are available as payload at each end of this section which represent a part of the mapping process, the procedure of packing the tributary signals such as PDH and ATM into SDH transport modules. VC-4 mapping is used for 140 Mbps or ATM signals and VC-12 mapping is used for 2 Mbps signals.

The components of a synchronous network

The schematic diagram in Figure 4 shows an SDH ring structure with various tributaries. The mixture of different applications is typical of the data transported by SDH. Synchronous networks must be able to transmit plesiochronous signals and be able to handle future services, such as ATM, which requires using the various NEs discussed in this section.

Figure 4. Schematic diagram of hybrid communications networks



Current SDH networks consist of four NE types. The topology (that is the ring or mesh structure) is governed by the requirements of the network provider.

Regenerators

Regenerators, as the name implies, regenerate the clock and amplitude relationships for incoming data signals that have been attenuated and distorted by dispersion. They derive their clock signals from the incoming data stream. Messages are received by extracting various 64 kbps channels (for example, service channels E1 and F1) from the regenerator section overhead (RSOH) and then can be sent also using these channels.



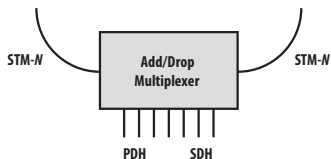
Terminal multiplexers

Terminal multiplexers are used to combine plesiochronous and synchronous input signals into higher-bit-rate STM-N signals.



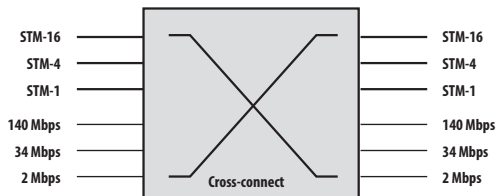
Add/drop multiplexers

Plesiochronous and lower-bit-rate synchronous signals can be extracted from or inserted into high-speed SDH bit streams using add/drop multiplexers (ADMs). This feature enables ring structure setup, which, in the event of a fault, can automatically back up path switching using elements in the ring.



Digital cross-connects

Digital cross-connects (DXC) offer the broadest functionality such as mapping PDH tributary signals into virtual containers and switching various containers up to and including VC-4.



**Network element
management**

The telecommunications management network (TMN) is also regarded as an element in the synchronous network (find more information on TMN in the SDH network on page 49). All the SDH network elements mentioned thus far are software-controlled and, therefore, can be monitored and controlled remotely – one of the most important SDH features.

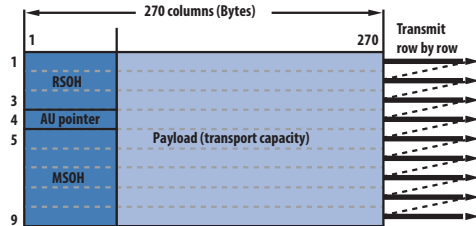
Optical fibers are the most commonly used physical medium in SDH networks, likely because of their insusceptibility to interference and their ability to transmit at very high speeds. However, their drawback is relatively high procurement and installation costs. Single-mode fibers are the preferred medium for 1310 and 1550 nm optical windows.

SDH signals can also be transmitted via radio link or satellite paths – a flexible option when setting up transmission paths quickly, as part of a mobile radio network or in difficult terrain. However, the disadvantages are limited bandwidth (currently up to STM-4) and complexity in linking such paths into the network management system.

The STM-1 frame format

A 155.52 Mbps frame defined in ITU-T recommendation G.707 is known as the synchronous transport module (STM). Since this frame is the first level of the synchronous digital hierarchy, it is known as STM-1 (see Figure 5). It comprises a byte matrix of 9 rows and 270 columns. Transmission is row by row, starting with the byte in the upper-left corner and ending with the byte in the lower-right corner. The frame repetition rate is 125 ms. Each byte in the payload represents a 64 kbps channel. The STM-1 frame can transport any PDH tributary signal (≤ 140 Mbps).

Figure 5. Schematic diagram of STM-1 frame



Section overhead

The first nine bytes in each of the nine rows are called the section overhead (SOH), shown in Figure 6. G.707 makes a distinction between the regenerator section overhead (RSOH) and the multiplexer section overhead (MSOH) so that the functions of certain overhead bytes can be coupled with the network architecture. Table 1 describes the individual functions of the bytes.

Figure 6. Overview of STM-1 overhead

A1	A1	A1	A2	A2	A2	J0	X	X
B1	.	.	E1	.		E1	X	X
D1	.	.	D2	.		D3		
AU pointer								
B2	B2	B2	K1			K2		
D4			D5			D6		
D7			D8			D9		
D10			D11			D12		
S1					M1	E2		

X Reserved for national use

- Media-dependent use (radio-link, satellite)

Table 1. Overhead bytes and their functions

Overhead Byte	Function
A1, A2	Frame alignment
B1, B2	Quality monitoring, parity bytes
D1 . . . D3	QECC network management
D4 . . . D12	QECC network management
E1, E2	Voice connection
F1	Maintenance
J0 (C1)	Trace identifier
K1, K2	Automatic protection switching (APS) control
S1	Clock quality indicator
M1	Transmission error acknowledgment

Path overhead

The path overhead (POH) monitors quality and indicates the container type. Combining the POH with a container forms a virtual container, or VC. The format and size of the POH depends on the container type. There are two distinctly different POH types—VC-3/4 POH and VC-11/12 POH.

VC-3/4 POH

J1	Path indication
B3	Quality monitoring
C2	Container format
G1	Transmission error acknowledgment
F2	Maintenance
H4	Superframe indication
F3	Maintenance
K3	Automatic protection switching
N1	Tandem connection monitoring

The VC-3/4 POH is the high-order path overhead for transporting 140 Mbps, 34 Mbps, and ATM signals.

VC-11/12 POH

V5	Indication and error monitoring
J2	Path indication
N2	Tandem connection monitoring
K4	Automatic protection switching

The VC-11/12 POH is the low-order path for transporting 1.544 Mbps, 2.048 Mbps, and ATM signals.

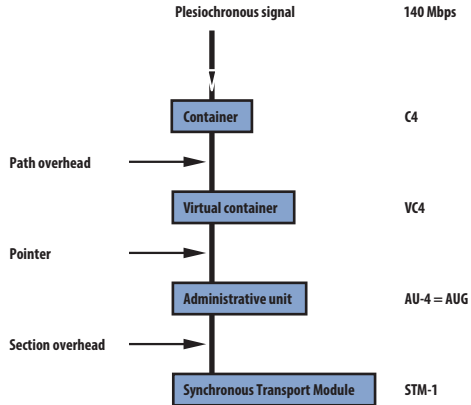
How does SDH transport PDH, ATM, and IP signals?

The heterogeneous nature of modern network structures makes it necessary for all PDH, ATM, and IP signals to be transported over the SDH network using a process for matching the signals to the network called mapping. The container is the basic package unit for tributary channels. A special container (*C-n*) is provided for each PDH tributary signal and is always significantly larger than the payload it is transporting. The remaining capacity is partly used for justification (stuffing) in order to equalize out-timing inaccuracies in the PDH signals.

Where synchronous tributaries are mapped, fixed fill bytes are inserted instead of justification bytes. A virtual container (*VC-n*) consists of the container and the POH which is transmitted unchanged over a path through the network. The next step in forming a complete *STM-N* signal is adding a pointer to indicate the start of the POH. The unit that the pointer and virtual container form is called the administrative unit (*AU-n*) or tributary unit (*TU-n*).

Several TUs together form a tributary unit group (*TUG-n*) that in turn is collected together into a VC. One or more AUs form an administrative unit group (AUG). Finally, the AUG plus the SOH form the *STM-N*. Figure 7 shows the insertion of a 140 MHz tributary into an *STM-1*.

Figure 7. Inserting a 140 Mbps tributary into an STM-1



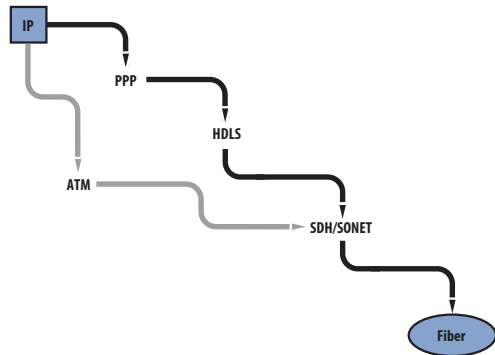
ATM signals can be transported throughout the SDH network in C11, C12, C3, and C4 containers. Container transport capacity does not meet the continually increasing ATM bandwidth requirement; therefore, methods have been developed to transmit the ATM payload in a multiple (n) C-4 (virtual or contiguous concatenation). For example, a quadruple C-4 can be transmitted in an STM-4. See section on "Contiguous concatenation".

IP – Internet Protocol

Increased Internet traffic requires a technology to transport the IP packets to the physical layer. Packet over SONET/SDH is one possible method for transporting IP packets to the layers below.

IP packets must be delivered from the network layer to the underlying datalink and physical layers. The actual transmission below the transport layer is called Packet over SONET/SDH (PoS) and can be achieved using the two alternative routes illustrated in Figure 8. The Internet Engineering Task Force (IETF) recommends using the route indicated with the solid line.

Figure 8. Alternative routes for transmitting IP packets to the fiber



The differences between SDH and SONET

Figure 9 gives an overview of the mappings currently possible according to ATM mapping and ITU-T recommendation G.707. Note the so-called sub-STM or STM-0 signal interfaces that are used in SDH/SONET links, radio links, and satellite connections. The STM-0 has a bit rate of 51.84 Mbps.

SDH is used throughout the world except in the USA, Canada, and Japan, where they use synchronous optical network (SONET) transmission technology specification – the SDH equivalent which began in the USA during the mid 1980s. SONET has a base bit rate of 51.84 Mbps and is designated STS-1 (synchronous transport signal). When a bit rate is transmitted over an optical cable system, the signal is designated as OC-1 (optical container). Table 2 details the SONET and equivalent SDH signals and their associated bit rates in the hierarchy.

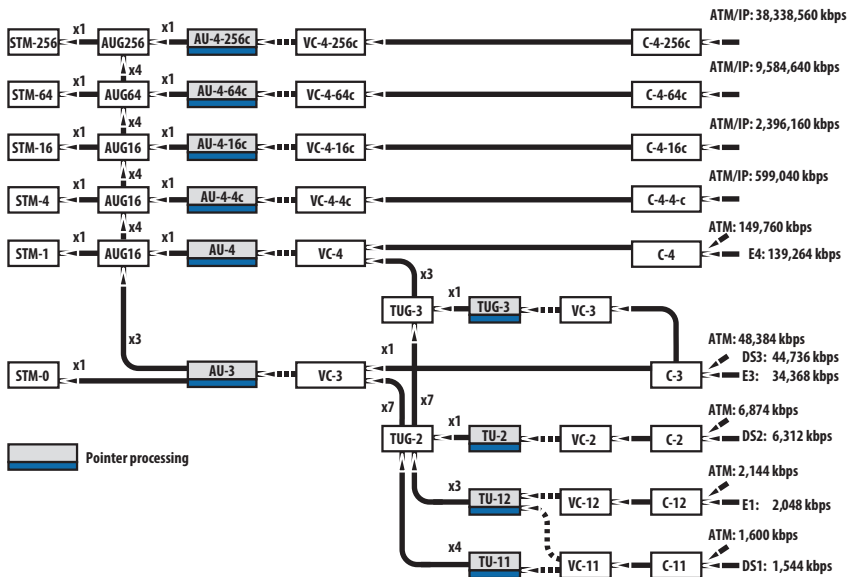


Figure 9. Mapping in SDH

Table 2. SONET/SDH signal and bit-rate hierarchy

SONET Signal		Bit Rates (Mbps)	Equivalent SDH Signal
STS-1	OC-1	51.84	STM-0
STS-3	OC-3	155.52	STM-1
STS-12	OC-12	622.08	STM-4
STS-48*	OC-48	2488.32	STM-16
STS-192*	OC-192	9953.28	STM-64
STS-768	OC-768	39813.12	STM-256

The hierarchy levels shown in Table 2 closely match the plesiosynchronous bit rates commonly used in these countries. Of all the levels listed, only STS-1, OC-3, OC-12, OC-48, and OC-192 are currently used.

Table 2 also indicates there are points where transition between SDH and SONET systems are possible. Matching is relatively simple, as gateway issues were considered during the development of SDH. Only minor adjustments need to be made to certain overhead bytes. However, SONET terminology is quite different; for example, the packing unit is referred to as a virtual tributary (VT-*n*) rather than a virtual container (VC-*n*). Figure 10 shows the SONET multiplexing scheme.

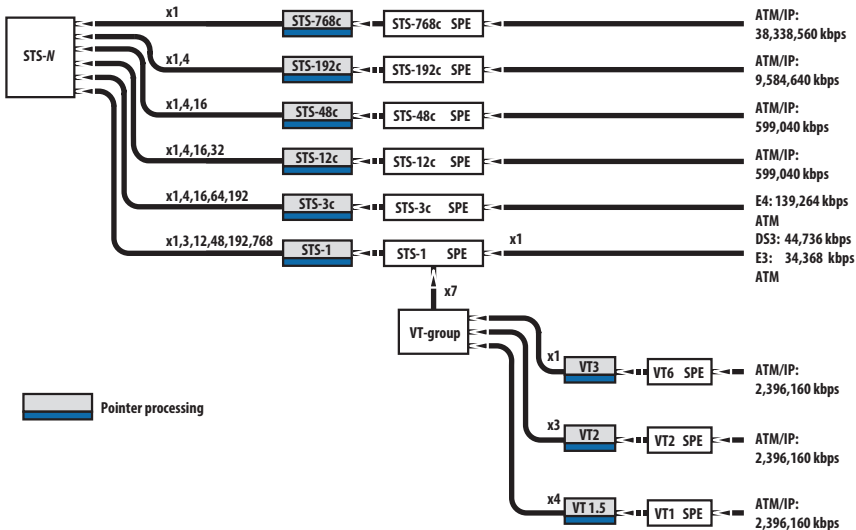


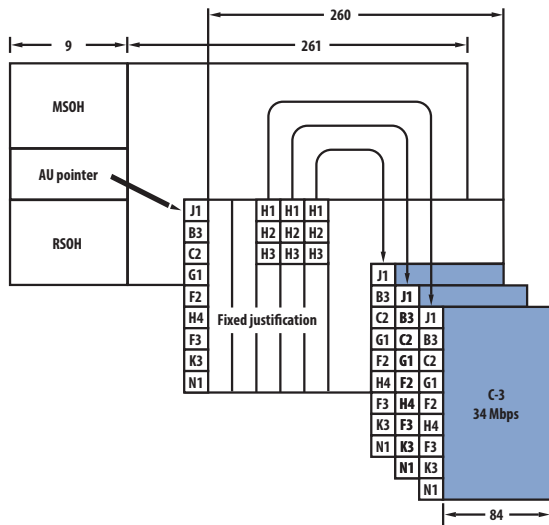
Figure 10. SONET multiplexing scheme

Pointer procedures

The use of pointer procedures also gives synchronous communications a distinct advantage over the plesiochronous hierarchy. Pointers are used to localize individual virtual containers in the payload of the synchronous transport module. The pointer may directly indicate a single VC-*n* virtual container from the upper level of the STM-1 frame. Chained pointer structures can also be used. The AU-4 pointer initially indicates the VC-4 overhead. Three further pointers are located at fixed positions in the VC-4 and are used to indicate the start of the three VC-3 virtual containers relative to the VC-4. Figure 11 illustrates the pointer procedure using C3 mapping as an example.

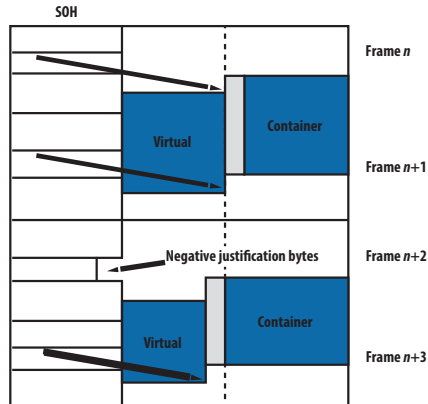
SDH multiplexers are controlled from a highly accurate central clock source running at 2.048 MHz. Pointer adjustment may be necessary if phase variations occur in the actual network; or when feeding the connection through various provider networks, the AU pointer can be altered in every fourth frame with prior indication. The virtual container is then shifted precisely by three bytes. Therefore, pointer activity is a good indicator for clock variations within a network.

Figure 11. Schematic diagram of C-3 mapping



When phase variations require pointer adjustments, the pointer is shifted to a later time (to the right, as Figure 12 shows) and it ignores the three bytes immediately preceding it.

Figure 12. Negative pointer justification



If the transmitting source precedes the actual clock, it inserts three bytes at the pointer position to add space for extra capacity. If no further clock adjustments are made, this configuration is then propagated throughout the network.

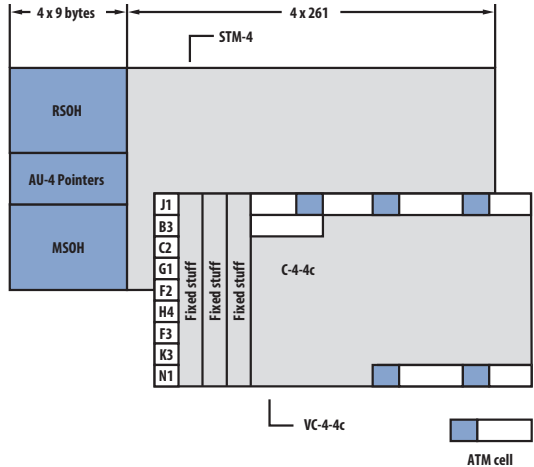
Negative pointer justification lets you insert user signals into the time gap where the three bytes were inserted in the next higher frame structure as virtual containers without the need for larger buffers. However, changes in the phase location of the virtual container relative to the superior frame can be corrected with appropriate pointer actions. Propagation changes, delays in the transmission medium, or nonsynchronous branches in the actual network can cause these changes and phase shifts.

When a multiplex bundle is resolved, pointer procedures enable immediate location of every user channel from each STM-*N* frame, which considerably simplifies drop and insert operations within a network node. In contrast, it requires completely demultiplexing every plesiochronous hierarchy signal level to access a particular tributary channel.

AU-4 contiguous concatenation

The AU-4 contiguous concatenation mechanism allows transmission of bit rates that exceed the C-4 container's capacity. For example, the AU-4-4c is intended to transport B-ISDN bit rates. Using this method avoids the need to split up the payload, because a virtually contiguous container is formed within an STM-4. Setting all but the first AU-4 pointer – the concatenation indicator (CI) – to a fixed value lets you link several consecutive AU-4 payloads to a fixed value. If pointer activity becomes necessary, this will occur for all concatenated AU-4s equally. Figure 13 illustrates how to transmit a payload of ATM cells as a whole.

Figure 13. Virtual concatenation

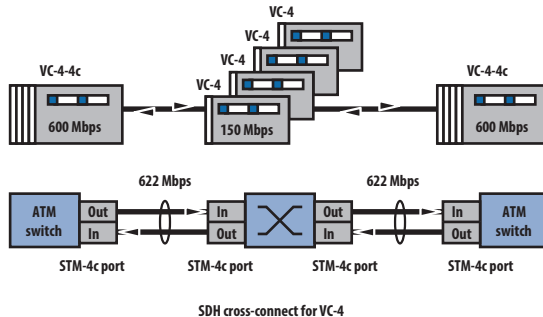


The first pointer indicates byte J1. All other pointers are set to concatenation indication (CI) ATM cell.

AU-4 virtual concatenation

If the cross-connects in the SDH network are unable to switch complete VC-4-4cs, the method described previously cannot be used to transmit ATM payloads. On the transmit side, four complete VC-4s with four identical pointer values are combined into an AUG. The individual VC-4s are transported independently through the network. The receiving NE must ensure the payload's integrity. These NEs reassemble the payload of the individual virtually concatenated VC-4s into a unit, even those with varying pointer values, as Figure 14 shows.

Figure 14. Principle of contiguous concatenation



Transmission at higher hierarchy levels

Multiplexing AU-3/4s into STM-N frames achieves higher bit rates.

The following hierarchy levels are defined in SDH:

STM-1	155.52 Mbps
STM-4	622.08 Mbps
STM-16	2488.32 Mbps
STM-64	9953.28 Mbps
STM-256	39813.12 Mbps

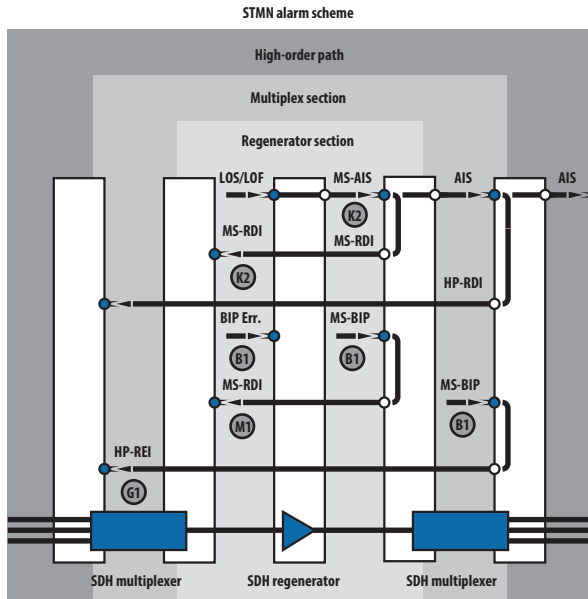
The STM-*N* frame structures are basically *N* times the STM-1 structure. For example, the STM-4 overhead is four times the size of the STM-1 overhead. The SOH content is specified for each stage individually. For this, the A1, A2 and B2 bytes are formed *N* times. The frame alignment of an STM-256 frame is composed of 64 A1 bytes (byte Nos. 705 to 768) followed by 64 A2 bytes. The other bytes are reserved for future international standardization.

Error and alarm monitoring

Several alarm and error messages are integral to SDH networks where they are referred to as defects and anomalies, respectively. They are coupled with network sections and the corresponding overhead information. This section discusses the advantage of this detailed information.

Complete circuit failure can cause a loss of signal (LOS) alarm in the receiving NE that triggers subsequent messages or alarm indication signals (AIS) similar to those shown in Figure 15. The transmitting side learns of the failure when it receives the remote defect indication (RDI) alarm. The alarm messages are transmitted in fixed bytes in the SOH or POH; for example, byte G1 is used for the HP-RDI alarm.

Figure 15. Overview of major defects and anomalies



If the received signal contains bit errors, the sensor indicates BIP errors, which differs from a complete circuit failure. Therefore, this alarm is referred to as an anomaly and is indicated back toward the transmission's origin. The return message or is called a remote error indication (REI). Table 3 lists the possible defects and anomalies, the corresponding bytes, and their definitions.

Table 3. Anomalies and defects in SDH

	Anomalies/Defects	Detection Criteria
LOS	Loss of signal	A drop in incoming optical power level causes a high bit error rate
OOF	Out of frame	A1, A2 errored for $\geq 625 \mu\text{s}$
LOF	Loss of frame	If OOF persists for $\geq 3 \text{ ms}$
RS BIP Error	Regenerator section BIP error (B1)	Mismatch of the recovered and computed BIP-8 Covers the whole STM- <i>N</i> frame
RS-TIM	Regenerator section trace identifier mismatch	Mismatch of the accepted and expected trace identifier in byte J0
MS BIP error	Multiplex section BIP error (B2)	Mismatch of the recovered and computed <i>N</i> x BIP-24 Covers the whole frame except RSOH
MS-AIS	Multiplex section alarm indication signal	K2 (bits 6, 7, 8) = 111 for 3 frames

Table 3. (continued)

	Anomalies/Defects	Detection Criteria
MS-REI	Multiplex section remote error indication	Number of detected B2 errors in the sink side encoded in byte M1 of the source side
MS-RDI	Multiplex section remote defect indication	$K2$ (bits 6, 7, 8) = 111 for $\geq z$ frames ($z = 3$ to 5)
AU-AIS	Administrative unit alarm indication signal	All ones in the AU pointer bytes H1 and H2
AU-LOP	Administrative unit loss of pointer	8 to 10 NDF enable 8 to 10 invalid pointers
HP BIP error	HO path BIP error (B3)	Mismatch of the recovered and computed BIP-8 Covers entire VC- n
HP-UNEQ	HO path unequipped	$C2 = 0$ for ≥ 5 frames
HP-TIM	HO path trace identifier mismatch	Mismatch of the accepted and expected trace identifier in byte J1
HP-REI	HO path remote error indication	Number of detected B3 errors in the sink side encoded in byte G1 (bits 1, 2, 3, 4) of the source side
HP-RDI	HO path remote defect indication	$G1$ (bit 5) = 1 for $\geq z$ frames ($z = 3, 5, \text{ or } 10$)

Table 3. (continued)

	Anomalies/Defects	Detection Criteria
HP-PLM	HO path payload label mismatch	Mismatch of the accepted and expected Payload Label in byte C2
TU-LOM	Loss of multiframe $X = 1$ to 5 ms	H4 (bits 7, 8) multiframe not recovered for X ms
TU-AIS	Tributary unit alarm indication signal	All ones in the TU pointer bytes V1 and V2
TU-LOS	Tributary unit loss of pointer	8 to 10 NDF enable 8 to 10 invalid pointers
LP BIP error	LO path BIP error	Mismatch of the recovered and computed BIP-8 (B3) or BIP-2 (V5 bits 1, 2) Covers entire VC- n
LP-UNEQ	LO path unequipped	VC-3: C2 = 0 for ≥ 5 frames VC- m ($m = 2, 11, 12$): V5 (bits 5, 6, 7) = 000 for ≥ 5 multiframes
LP-TIM	LO path trace identifier mismatch	Mismatch of the accepted and expected trace identifier in byte J1 (VC-3) or J2

Table 3. (continued)

	Anomalies/Defects	Detection Criteria
LP-REI	LO path remote error indication	VC-3: Number of detected B3 errors in the sink side encoded in byte G1 (bits 1, 2, 3, 4) of the source side VC- m ($m = 2, 11, 12$): If one or more BIP-2 errors detected in the sink side, byte V5 (bits 3) = 1 on the source side
LP-RDI	LO path remote defect indication	VC-3: G1 (bit 5) = 1 for $\geq z$ frames VC- m ($m = 2, 11, 12$): V5 (bit 8) = 1 for $\geq z$ multiframes ($z = 3, 5, \text{ or } 10$)
LP-PLM	LO path payload label mismatch	Mismatch of the accepted and expected payload label in byte C2 or V5 (bits 5, 6, 7)

Back-up network switching

Modern society is almost completely dependent on communications technology. Network failures, whether due to human error or faulty technology, can be expensive for users and network providers alike. As a result, the subject of fall-back mechanisms is currently one of the most discussed in SDH. A wide range of standardized mechanisms has been incorporated into synchronous networks to compensate for network element failures.

Automatic protection switching (APS)

Two basic types of protection architecture are distinguished in APS: linear protection mechanism, which is used for point-to-point connections, and ring protection mechanism, which can take on many different forms. Both mechanisms use spare circuits or components to provide the back-up path. Switching is controlled by the overhead bytes K1 and K2.

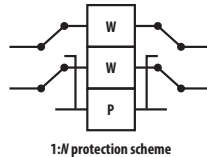
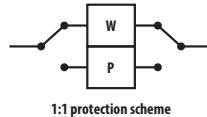
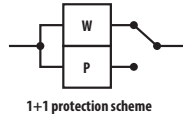
Linear protection

The simplest form of back-up is the so-called 1 + 1 APS, where each working line is protected by one protection line. If a defect occurs, the protection agent in the NEs at both ends switches the circuit over to the protection line. The switchover is triggered by a defect such as LOS. An acknowledgment in the backward channel initiates switching at the far end.

A 1+1 architecture includes 100 percent redundancy, as there is a spare line for each working line (shown in Figure 16). Economic considerations have led to the preferential use of 1:N architecture, particularly for long-distance paths. Here, several working lines are protected by a single back-up line. If switching is necessary, the two ends of the affected path are switched over to the back-up line.

The 1+1 and 1:N protection mechanisms are standardized in ITU-T recommendation G.783. The reserve circuits can be used for lower-priority traffic, which can simply be interrupted if the circuit is needed to replace a failed working line.

Figure 16. Linear protection schemes



Ring protection

Ring structures offer greater cost savings over linear structures for carrying greater communications bandwidths over optical fibers. A ring is the simplest and most cost-effective method for linking several network elements.

Several protection mechanisms are available for this type of network architecture, some of which have been standardized in ITU-T recommendation G.841. However, some basic distinctions must be observed between ring structures with unidirectional and bidirectional connections.

Unidirectional rings

Figure 17 shows the basic APS principle for unidirectional rings. Assuming an interruption in the circuit occurs between network elements A and B, direction y remains unaffected. However, direction x would have to find an alternative path. Therefore, switching the connection to the alternative path for NEs A and B while the other NEs C and D switch through the back-up path, known as a line-switched process.

Figure 17. Two-fiber unidirectional path switched ring

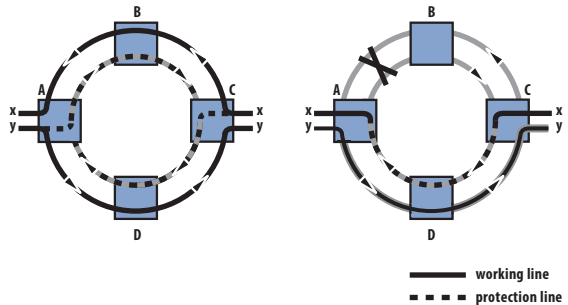
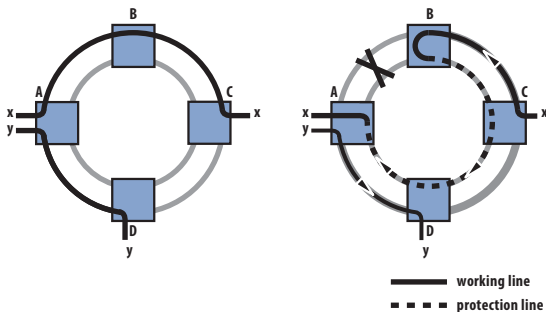


Figure 18 shows a simpler method called the bidirectional line-switched ring where traffic is transmitted simultaneously over both the working and protection lines. If an interruption occurs, the receiver (in this case A) would switch to the protection line and immediately take up the connection.

Bidirectional rings

In this network structure, connections between NEs are bidirectional (Figure 18). The overall network capacity can be split up over several paths, each with one bidirectional working line. Unidirectional rings require an entire virtual ring for each path. If a fault occurs between neighboring elements A and B, NE B triggers protection switching to control network element A using the K1 and K2 bytes in the SOH.

Figure 18. Two-fiber bidirectional line-switched ring (BLSR) working line and protection line

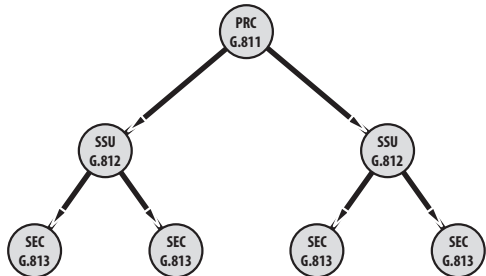


Bidirectional rings with four fibers provide even greater protection because each fiber pair transports both working and protection channels or 1:1 protection, which is 100 percent redundant. However, this increased protection comes with higher costs.

Synchronization

Failure to guarantee synchronization can result in considerable degradation in network functionality and sometimes even total failure. To avoid this, synchronize all NEs to a central clock generated by a highly precise, primary reference clock (PRC) that conforms to ITU-T recommendation G.811 which specifies 1×10^{-11} accuracy. The clock signal must then be distributed throughout the network. This hierarchical structure passes the signal on through subordinate synchronization supply units (SSU) and synchronous equipment clocks (SEC) using the same synchronization signal paths as those used for SDH communications.

Figure 19. Clock supply hierarchy structure



The clock signal is regenerated in the SSUs and SECs with the aid of phase-locked loops. If the clock supply fails, the affected NE switches over to a clock source with the same or lower quality. If a clock source is unavailable, the NE switches to holdover mode which keeps the clock signal relatively accurate by controlling the oscillator, applying stored frequency correction values for the previous hours, as well as considering the oscillator's temperature.

Avoid clock "islands" at all costs, as they will eventually drift out of synchronization leading to a total failure. These islands can be prevented using synchronization status messages (SSM – part of the S1 byte) to signal the NEs. The SSM informs the neighboring NE of the clock supply status as part of the overhead. Certain problems can arise at the gateways between networks with independent clock supplies; however, SDH NEs can somewhat compensate for clock offsets through pointer operations. Pointer activity can be a reliable indicator of clock supply problems.

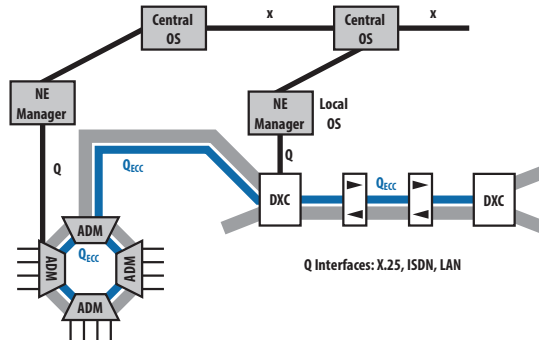
Telecommunications management network (TMN) in SDH networks

The telecommunications management network (TMN) technology principle was established in 1989, with the publication by the CCITT (now ITU-T) recommendation M.3010. The TMN functions are expressed as: operation, administration, maintenance, and provisioning (OAM&P), which includes monitoring network performance and checking for error messages, among other things.

To provide these functions, TMN uses object-oriented techniques based on the open system interconnection (OSI) reference model. The TMN model comprises one manager that handles several agents, which in turn each handle several managed objects (MOs). The manager included in the operating system (OS) forms the “control center” for the whole network or perhaps just part of it. In SDH networks, the agents are located in the NEs. An MO may be a physical unit, such as a plug-in card, or a multiplex section, but it can also occur as a logical element such as a virtual connection. TMN can also distinguish between logical management units. For example, one management unit operates at network level, handling individual NEs while another management unit operates at the service level to perhaps monitor billing charges.

These tasks are performed in modern telecommunications networks using the common management information protocol (CMIP) or the simple network management protocol (SNMP), which is basically a simplified form of CMIP. However, SNMP is mainly used in data communications because it cannot handle the requirements of large telecommunications networks. The Q3 interface, where data exchanges between the manager and agent occur, is the CMIP reference point. CMIP is also used where several TMNs or their managers are linked together via the X interface (see Figure 20).

Figure 20. TMN overlay



Since large quantities of data are not generally required to exchange information in the TMN, embedded communication channels (ECC) or data communication channels (DCC) capacity is sufficient for managing SDH networks. Channels D1 to D3 with a 192 kbps (DCCp) capacity are used for SDH-specific NE management, whereas channels D4 to D12 with a 576 kbps (DCCm) capacity are used for non-SDH-specific purposes (see Figure 21).

Q ECC protocol distinguishes the implementation in the SOH from data channels from the Q interface. Such networks are called SDH management networks (SMN) and primarily manage the NEs. SMNs can also be subdivided into SDH management sub-networks (SMS).

Figure 21. D bytes in the STM-1 SOH

	A1	A1	A1	A2	A2	A2	J0	X	X
	B1	.	.	E1	.		E1	X	X
DCC _p →	D1	.	.	D2	.		D3		
AU pointer									
	B2	B2	B2	K1			K2		
	D4			D5			D6		
DCC _m →	D7			D8			D9		
	D10			D11			D12		
	S1					M1	E2	X	X

SDH measurement tasks

NE operation should be trouble-free when providers adhere to ITU, ETSI, ANSI, and Bellcore standards; however, problems still occasionally arise, especially when linking NEs from different sources together. Transmission problems can also occur at gateways between networks owned by different providers.

The measurement facilities built into the system provide only approximates for fault locations. Other measuring equipment can be of much greater use especially for monitoring individual channels because you can obtain more data relevant to clearing the fault. The only areas that cover both network management and measurement procedures are long-term analysis and system monitoring.

Separate measuring equipment offers additional research and development, production, and installation applications which are areas that require test equipment with widely varied specifications.

In production and installation, systems manufacturers configure their NEs or entire networks to customer requirements and conduct measurements to ensure proper operation. The equipment is then installed at the customer's site and put into operation. Test equipment is essential at this stage to eliminate faults that may have occurred during production and installation and to verify proper functioning. Therefore, the test equipment must be portable, robust, and capable of performing test sequences to reproduce repeat measurements and long-term analyses reliably and quickly.

Network providers deploy portable test equipment to clear faults, for maintenance, and for the continual process of network optimization. Therefore, it must be reasonably priced, suitable for both in- and out-of-service measurements, and quickly display results for easy interpretation.

Generally, SDH test equipment must:

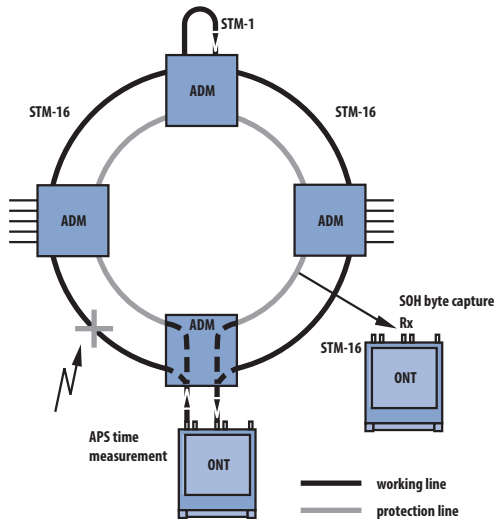
- Perform mapping analysis
- Align port interfaces
- Perform measurements on structured test signals
- Perform measurements on add/drop multiplexers
- Perform delay measurements
- Test automatic protection switching (APS)
- Simulate pointer activity
- Perform measurements on in-service SDH:
 - Analyze alarms
 - Monitor path trace
 - Analyze pointers
 - Check built-in system sensors
 - Perform drop and insert measurements
 - Check network synchronization
 - Perform measurements on the TMN interface
- Perform error performance measurements
- Conduct jitter and wander analysis

Some of these measurements are discussed in more detail on the pages that follow.

Sensor tests Sensor tests are conducted to check the system component's reactions to defects and anomalies. Defects can interrupt connections and anomalies are faults, such as parity errors. For example, an NE reacts to an LOS alarm by sending an AIS to the subsequent NEs and transmitting an RDI signal in the return path (refer to Figure 10).

APS time measurements In the event of a fault, a special mechanism in SDH networks automatically reroutes the faulty link over a back-up circuit (see the APS section on page 42). This function is controlled using overhead bytes K1 and K2. Switchover to the protection line must occur within 50 ms, which requires external equipment to ensure that it does. This equipment also measures the response time or detects the loss of a specific test pattern or a trigger from a preset alarm when a connection is intentionally interrupted, see Figure 22. This measurement is important as a delayed response can considerably degrade performance or a total network failure can occur, causing the network provider to lose revenue.

Figure 22. Checking APS response time



ITU-T error performance recommendations

Digital link quality is determined through bit error ratio tests (BERT). The results of which somehow must be classified, because transmission path quality is often the subject of a service level agreement (SLA) between the network provider and the telecommunications user. Therefore, an objective method is needed to classify a line as either “good” or “bad”. ITU-T recommendations G.821, G.826, G.828, G.829, M.2100, and M.2101 are internationally recognized standards that specify just such parameters for objective classification.

G.821

ITU-T recommendation G.821 was originally specified for international circuit-switched $n \times 64$ kbps connections and was expanded to include higher bit rates. A hypothetical reference connection is used as the basis for determining quality parameters and comprises an international long-distance segment, a national segment, and a subscriber access segment.

G.821 definitions:

- Errored second (ES): A one-second time interval in which one or more bit errors occurs.
- Severely errored second (SES): A one-second time interval in which the bit error ratio exceeds 10^{-3} .
- Unavailable second (US): A circuit is considered unavailable at the beginning of at least 10 consecutive SESs, and it is considered available when the first of at least 10 consecutive seconds are not severely errored.

The original G.821 version also included:

- Degraded minute (DM): A one-minute interval with bit error ratio exceeding 10^{-6}
- Derived parameter
- Error-free second (EFS): A one-second interval without bit errors

Unfortunately, this method requires taking the test channel out of service to evaluate bit errors.

G.826 The G.826 recommendation issued in 1993 involves block errors so it allows for in-service measurements.

G.826 definitions include:

- Errored second (ES): A one-second interval with one or more errored blocks.
- Errored block (EB): A block with one or more errored bits.
- Severely errored second (SES): A one-second interval where more than 30 percent of the blocks are errored blocks or that contain at least one severely disturbed period (SDP).
- Background block error (BBE): An errored block that is not an SES.
- Unavailable second (US): See previous section G.821.

The results or measurement time gives these error parameters: errored seconds ratio (ESR), severely errored seconds ratio (SESR), and background block error ratio (BBER). Each quality requirement refers to a particular path. Both G.821 and G.826 recommend a 30-day measurement interval.

- G.828** Although recommendation G.826 was broadly specified for use in PDH systems, it has been applied predominantly in SDH systems. It was soon apparent that the target values in G.826, significantly influenced by PDH technology, failed to meet the capabilities of modern SDH systems, which are based on fiber-optic technology. ITU-T then developed the G.828 recommendation with tighter error performance target values appropriate for modern SDH systems, including the severely errored period (SEP) error event based on practical measurement results. An SEP is an interval that contains at least three but not more than nine consecutive SESs. A period of consecutive SES can have the same effect as a micro-interruption and may severely impair service that the SDH path supports.
- G.829** Together with G.828, the new G.829 recommendation “Error performance events for SDH multiplex and regenerator sections” was also approved in March 2000. In contrast to the recommendations in the G-series mentioned previously, G.829 does not define any target values but rather describes the SDH multiplex and regenerator section error events.

M.2100 Recommendation M.2100 applies specifically to commissioning and maintenance. Commissioning consists of a 15-minute lineup phase followed by a 24-hour in-service measurement. After successfully completing the lineup phase, errors may still occur within certain limits. In this case, the line must be monitored for another 7 days while remaining in service. Recommendations M.2110 and M.2120 define the measurement procedures with limit values derived from performance parameters specified in recommendations G.821 and G.826.

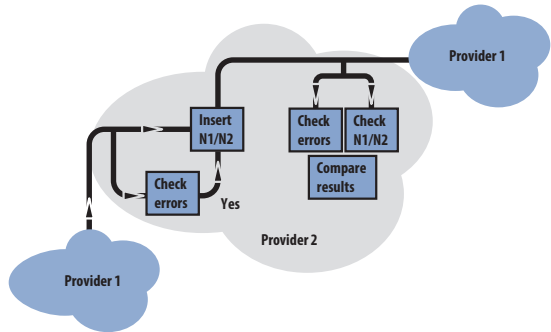
M.2101 Although recommendation M.2101 is similar to M.2100 in its purpose and format, it deals exclusively with SDH systems and includes tables that address “bringing-into-service” performance objectives.

Tandem connection monitoring

Overhead byte B3 is used to monitor the path quality and is evaluated from the path’s start to its end. It has become increasingly necessary to determine the quality for individual path segments which may pass through networks owned by various providers, making it necessary for the owner of each segment of a network be able to guarantee high quality through verifiable results. When a fault does occur, the question of who bears the responsibility and the costs for making the repairs is one that warrants an answer. Tandem connection monitoring (TCM) allows path segment performance

monitoring using the POH N bytes. The NEs evaluate high-order and low-order POH parity bytes where the number of errors detected is indicated toward the end of the TCM using the N1 or N2 byte. This error count is subtracted from the number of parity errors detected at the TCM end and the difference equals the number of errors occurring within the TCM, as illustrated in Figure 23.

Figure 23. Path parity check on the respective network limits; comparison using N1/N2 bytes



Jitter measurements

Jitter refers to phase variations in a digital signal where the digital signal edges may differ from the expected ideal positions in time. Jitter is described in terms of its amplitude (expressed in unit intervals, or UI) and its frequency. Jitter frequencies below 10 Hz are described as “wander.” Signals affected by jitter cannot be sampled accurately. In extreme situations, the input signal can be misinterpreted leading to single errors or error bursts that can degrade transmission quality. Jitter and wander can also cause buffer under-flow or overflow resulting in bit slips. The theoretical correct sampling limit at high jitter frequencies is half the bit’s width. If distortion or additive noise occurs, the actual limit should be set much lower. NE clock sources such as regenerators and add/drop multiplexers often are the cause of jitter. Table 4 illustrates the various types of jitter.

Table 4. Sources for jitter

Jitter Type	Cause
Mapping jitter	Mapping of asynchronous tributary signals into synchronous transport signals requires bit stuffing in order to match the bit rates, causing mapping jitter when the signal is demapped.
Pointer jitter	If the SDH transmission bit rates are not synchronous, the timing of the transported payload containers must be matched to the outgoing frame by incrementing or decrementing the pointer by one unit.
Intrinsic jitter	Jitter at the device output is fed with a jitter-free input signal.
Stuffing and wait-time jitter	Non-synchronous digital signals must be matched during multiplexing to the higher-bit-rate system by inserting stuffed bits, which must then be removed during signal de-multiplexing. Gaps that occur as a result are equalized with a smooth clock signal, which is imperfect and therefore causes stuffing and wait-time jitter.

Table 4. (Continued)

Jitter Type	Cause
Pattern jitter	Digital signal distortion leads to so-called intersymbol interference, or time-domain impulse crosstalk, which causes interference between consecutive pulses in a digital signal that leads to pattern-dependent jitter.
Wander	Wander is a slow drift in significant digital signal instances away from the ideal equally spaced intervals. For example, these delay variations occur in an optical fiber due to temperature fluctuations.

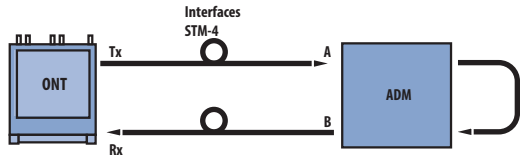
Interference signals and phase noise also cause jitter. Jitter caused by interference signals is known as non-systematic jitter. Phase noise due to thermal noise and drift from the oscillator can occur despite using a central clock. Various measurement methods have been developed to more accurately measure the causes for jitter.

Measurements

- Maximum tolerable jitter (MTJ)

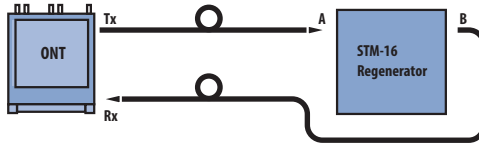
Every digital input interface must tolerate a certain amount of jitter before bit errors or synchronization errors occur. Measurements are made by feeding a digital signal modulated with sinusoidal jitter from a jitter generator into the device under test.

A bit error tester then monitors the device output for bit errors and alarms which will eventually occur as the jitter amplitude increases.



- Jitter transfer function (JTF)

The NE's jitter transfer function indicates the extent that input jitter passes through to the output.



- Output jitter, intrinsic jitter

Evaluating broadband jitter using standardized combinations of high-pass and low-pass filters

- Mapping jitter

- Pointer jitter

Permitted pointer jitter can be measured by feeding an SDH signal with defined sequences of pointer activity into the synchronous demultiplexer.

- Combined jitter

Stuffing during the mapping and pointer activity causes jitter at PDH outputs.

- Wander analysis

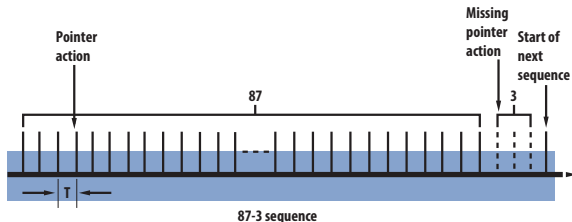
Wander measurements require an external, highly precise reference signal. The phase of the signal under test is then compared to the reference signal phase. Very low-frequency components require appropriately long measurements lasting up to 12 days.

Simulating pointer activity

Pointer sequences defined by the ITU-T must be used when testing jitter behavior in a tributary output in response to pointer activity to guarantee network stability under extreme conditions.

Pointer sequence 87-3 INC

Pointer sequence 87-3 INC refers to a sequence of 87 steady pointer increments followed by 3 missing, or omitted, pointer actions and can occur after an NE loses synchronization and can cause very large jitter amplitudes.



Overview of ITU-T recommendations relevant for SDH

G.703	Physical/electrical characteristics of hierarchical digital interfaces
G.707	Network node interface for the synchronous digital hierarchy (SDH) Replaces 1993 versions of ITU-T G.707, G.708, G.709.
G.709	Interface for the optical transport network (OTN)
G.772	Protected monitoring points provided on digital transmission systems
G.774	SDH management information model for the network element view
G.774.02	SDH configuration of the payload structure for the network element view
G.774.03	SDH management of multiplex-section protection for the network element view
G.774.04	SDH management of subnetwork connection protection for the network element view
G.774.05	SDH management of connection supervision functionality (HCS/LCS) for the network element view
G.780	Terms and definitions for synchronous digital hierarchy (SDH) networks
G.783	Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks
G.784	Management aspects of synchronous digital hierarchy (SDH) transport network elements
G.803	Architecture of transport networks based on the synchronous digital hierarchy (SDH)
G.810	Definitions and terminology for synchronization networks
G.811	Timing characteristics of primary reference clocks
G.812	Timing requirements of slave clocks suitable for use as node clocks in synchronization networks

G.813	Timing characteristics of SDH equipment slave clocks (SEC)
G.825	The control of jitter and wander in digital networks which are based on the SDH
G.826	End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections
G.828	Error performance parameters and objectives for international, constant bit-rate synchronous digital paths
G.829	Error performance events for SDH multiplex and regenerator sections
G.831	Management capabilities of transport network based on the SDH
G.832	Transport of SDH elements on PDH networks - Frame and multiplexing structures
G.841	Types and characteristics of SDH network protection architectures
G.842	Interworking of SDH network protection architectures
G.957	Optical interfaces for equipment and systems relating to the SDH
G.958	(Withdrawn) Digital line systems based on the SDH for use on optical fiber cables
M.2101	Performance limits for bringing into service and maintenance of international multi-operator SDH paths and multiplex sections
M.2110	Bringing into service international multi-operator paths, sections, and transmission systems
M.2120	International multi-operator paths, sections, and transmission systems fault detection and localization procedures
O.150	General requirements for instrumentation for performance measurements on digital transmission equipment
O.172	Jitter and wander measuring equipment for digital systems which are based on the SDH
O.181	Equipment to assess error performance on STM- <i>N</i> SDH interfaces

Abbreviations

A

A1	RSOH frame synchronization byte; 1111 0110
A2	RSOH frame synchronization byte; 0010 1000
ADM	add/drop multiplexer
AIS	alarm indication signal
APS	automatic protection switching (channels K1, K2)
ATM	asynchronous transfer mode
AU	administrative unit
AU- <i>n</i>	administrative unit, level $n = 3, 4$
AUG	administrative unit group

B

B1	BIP-8 parity word in regenerator section (RSOH)
B2	BIP- <i>N</i> x 24 parity word in multiplex section (MSOH)
B3	BIP-8 parity word in VC-3, 4 path (POH)
BBE	background block error (G.826)
BBER	background block error ratio (G.826)
BER	bit error ratio
BIP-2	BIP-2 parity word in VC-1, 2 path (POH)
BIP- <i>N</i>	bit interleaved parity, <i>N</i> bits
BSHR	bidirectional self-healing ring

C

C- <i>n</i>	container, $n = 1$ to 4
C2	signal label (VC-3, 4 POH)
CAS	channel-associated signaling
CCM	cross-connect multiplexing
CMIP	common management information protocol
CSES	consecutive severely errored seconds

D

D1–3	196 kbps DCC for regenerator section (RSOH)
D4–12	576 kbps DCC for multiplex section (MSOH)
DCC	data communication channel
DCN	data communication network
DWDM	dense wavelength division multiplexing
DXC	digital cross-connect

E

E1	electrical interface signal, 2048 kbps; used as service channel voice in the regenerator section (RSOH)
E2	electrical interface signal, 8448 kbps; used as service channel (voice) in the multiplex section (MSOH)

E

E3	electrical interface signal, 34368 kbps
E4	electrical interface signal, 139264 kbps
EBC	errored block count
ECC	embedded communication channel
EDC	error detection code
EFS	error-free second
ES	errored second (G.826)
ESR	errored seconds ratio (G.826)

F

F1	user channel, for example, for operational service purposes (RSOH)
F2	path user channel for an end-to-end connection (POH)
FAS	frame alignment signal

G

G1	end-to-end path status (POH)
----	------------------------------

H

H1	pointer byte 1: bit nos. 1 to 4: new data flag; bit nos. 5, 6: (unspecified), bit nos. 7, 8: pointer value (highest 2 bits)
H2	pointer byte 2: pointer value (lowest 8 bits)
H3	pointer byte 2: negative justification opportunity
H4	payload indication (POH)
HDLC	High Level Data Link Control

I

IP	Internet protocol
ISDN	integrated services digital network
ISO	International Standardization Organization

J

J0	regenerator section trace (RSOH)
J1	path trace (POH in VC-3, 4)
J2	path trace (POH in VC-1, 2)

K

K1, K2	(MSOH) APS channels for APS signaling and back-up line switching
K3, K4	(POH) APS channels for APS signaling and back-up line switching

L

LAN	local area network
LO	lower order
LOF	loss of frame
LOM	loss of multiframe
LOP	loss of pointer
LOS	loss of signal

M

M1	MS-REI byte (MSOH)
MI	management information
MO	managed object
MS	multiplexer section
MS-AIS	multiplexer section AIS
MSOH	multiplexer section overhead
MTIE	maximum time interval error

N

N1, 2	network operator bytes (POH)
NDF	new data flag
NE	network element

O

OAM	operation, administration, and management
OC- <i>N</i>	optical carrier, $N = 1, 4, 16$
OH	overhead
OOF	out of frame
OSI	open system interconnection

P

PDH	plesiochronous digital hierarchy
PLL	phase-locked loop
POH	path overhead
PoS	packet over SONET/SDH
PPP	point-to-point protocol
PRBS	pseudorandom binary sequence
PRC	primary reference clock

Q

QoS quality of service

R

RDI remote defect indicator

REI remote error indicator

ROSE remote operations service element

RSOH regenerator section overhead

S

S1 synchronization status byte (MSOH)

SDH synchronous digital hierarchy

SEC SDH equipment clock

SEP severely errored period

SES severely errored second

SESR severely errored seconds ratio

SHR self-healing ring

SMN SDH management network

SMS SDH management subnetwork

SOH section overhead

S

SPRING	shared protection ring
STM	synchronous transport module
STM- <i>N</i>	synchronous transport module, level $N = 1, 4, 16, 64$
STS	synchronous transport signal

T

TMN	telecommunications management network
TU	tributary unit
TU- <i>m</i>	tributary unit, level $m = 1...3$
TUG- <i>m</i>	tributary unit group, level $m = 1, 2$

U

UAS	unavailable second
UAT	unavailable time
UNEQ	unequipped
UI	unit interval

V

V5 POH byte (VC-1, 2)

VC virtual container

VC- n virtual container, level $n = 1, 2, 3, 4$

VC- n - X c concatenated virtual container, level n , X concatenated VCs

VP virtual path

W

WDM wavelength division multiplexing

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