SDH

Pocket Guide | **Synchronous Digital Hierarchy**

JDSU

Content

Introduction

With some 750 million telephone connections in use today and the number of Internet users continuing to grow rapidly, network providers have been faced with the task of trying to deal effectively with increased telephone traffic. In response to the growing market needs, a number of methods and technologies have been developed within the last 50 years to address these market needs in as economical a way as possible.

In the field of communications engineering, this resulted in the introduction of frequency division multiplex (FDM) systems whereby each individual telephone channel was modulated with a different carrier frequency. The signals could then be shifted into different frequency ranges enabling several telephone connections to be transmitted over a single cable.

With the advent of semiconductor circuits and the continuing demand for telephone capacity, a new type of transmission method, pulse code modulation (PCM) was developed in the 1960s.

With PCM (multiple use of a single line by means of digital time-domain multiplexing), the analog telephone signal is first sampled at a bandwidth of 3.1 kHz, quantized and encoded then transmitted at a bit rate of 64 kbps. When 30 such coded channels are collected together into a frame along with the necessary signaling information, a transmission rate of 2048 kbps is achieved.

This is known as the primary rate and is used throughout the world with the exception of the USA, Canada, and Japan, where a primary rate of 1544 kbps (formed by combining 24 channels) is used.

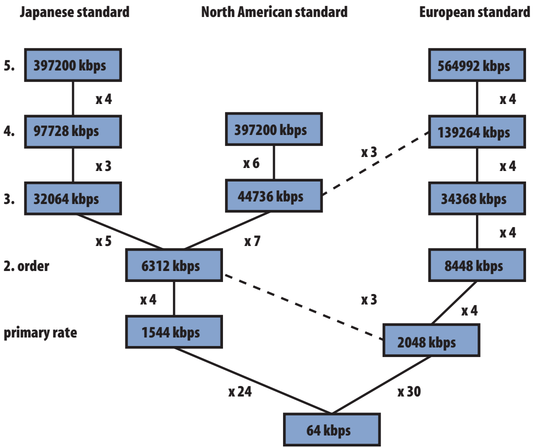
The demand for greater bandwidth however, meant that more stages of multiplexing were needed throughout the world. A practically synchronous – or plesiosynchronous – digital hierarchy was developed in response. As there are slight differences in timing signals, justification or stuffing is necessary when forming the multiplexed signals.

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

Towards the end of the 1980s, the synchronous digital hierarchy (SDH) was introduced, paving the way for a worldwide, unified network structure. SDH is ideal particularly for network providers, as it delivers an efficient, economical network management system that can be easily adapted to accommodate the demand for "bandwidth-hungry" applications and services.

This pocket guide aims to provide an introduction to synchronous communications without going into the "bits and bytes".

figure 1 Summary of plesiochronous transmission rates



Why SDH?

With the introduction of PCM technology in the 1960s, communications networks were gradually converted to digital technology during the years that followed. To cope with the demand for ever-higher bit rates, a multiplex hierarchy or plesiosynchronous digital hierarchy (PDH) evolved. 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. This fundamental difference in developments made the set up of gateways 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 of the disadvantages inherent in PDH. In turn, network providers began to benefit from the many technological and economic advantages this new technology introduced including:

High transmission rates

Transmission rates of up to 10 Gbps 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. It is now no longer necessary to apply the complex and costly procedure of demultiplexing then remultiplexing the plesiosynchronous structure.

High availability and capacity matching

With SDH, network providers can react quickly and easily to the requirements of their customers. For example, leased lines can be switched in a matter of minutes. The network provider can use standardized network elements (NE) that can be controlled and monitored from a central location via a telecommunications management network (TMN) system.

Reliability

Modern SDH networks include various automatic back-up circuit and repair mechanisms which are designed to cope with system faults and are monitored by management. As a result, failure of a link or an NE does not lead to failure of the entire network.

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 (LAN, WAN, etc.). It is also able to handle more recent services such as video on demand and digital video broadcasting via ATM.

Interconnection

SDH makes it much easier to set up gateways 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 thus reducing equipment costs.

The trend in transport networks is toward ever-higher bit rates, such as STM-256 (time division multiplex, TDM). The current high costs of such NEs however are a restricting factor. The alternative lies in dense wavelength division multiplexing (DWDM), a technology enabling the multiple use of singlemode optical fibers. As a result, a number of wavelengths can be used as carriers for the digital signals and transmitted simultaneously through the fibers. (See DWDM Pocket Guide for more information.)

Connected to the introduction of DWDM is the tendency toward the "all-optical network". Optical add/drop multiplexers (OADM) are already available commercially and the first field trials are in progress for optical cross connects (OXC). In terms of the ISO-OSI layer model, this development basically means the introduction of an additional DWDM layer below the SDH layer (see figure 2). Future systems are therefore quite likely to combine higher multiplex rates with the use of DWDM.

The synchronous digital hierarchy in terms of a layer model

Telecommunications technologies are generally explained using so called layer models. SDH can also be depicted in the same way.

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. This is usually a glass fiber or possibly radio or satellite link. The regenerator section is the path between regenerators. Part of the regenerator section overhead (RSOH) is available for the signaling required within this layer.

The remainder of the overhead, the multiplex section overhead (MSOH) is used for multiplex section needs. The multiplex section covers the part of the SDH link between multiplexers. The carriers or virtual containers (VC) are available as payload at the two ends of this section. The two VC layers represent a part of the mapping process. Mapping is the procedure whereby the tributary signals, such as PDH and ATM are packed 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 uppermost layer represents the applications of the SDH transport network.

figure 2 The SDH layer model

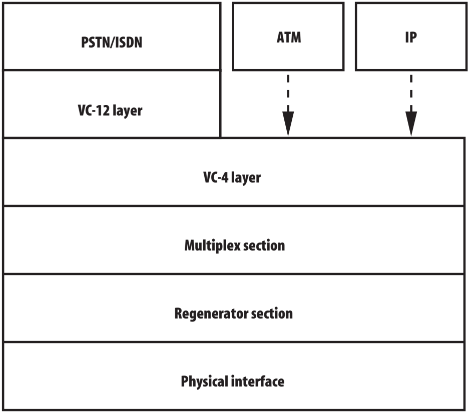
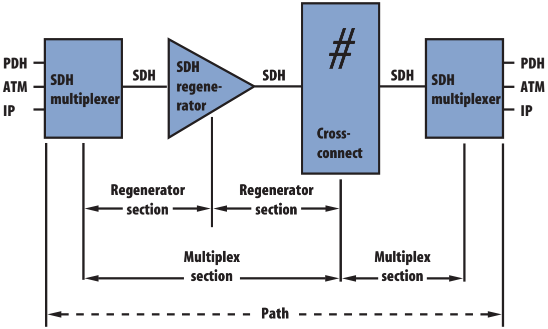


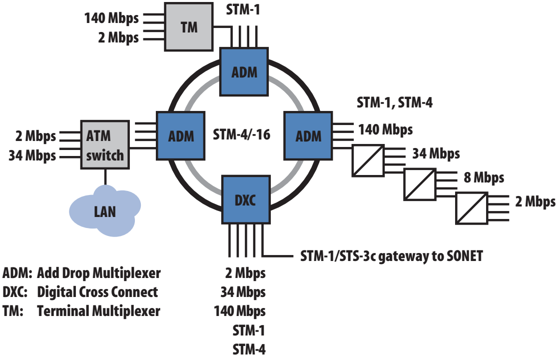
figure 3   Path section designations



The components of a synchronous network

Figure 4 is a schematic diagram of an SDH ring structure with various tributaries. The mixture of different applications is typical of the data transported by SDH. Synchronous networks must have the ability to transmit plesiochronous signals as well as the capability to handle future services such as ATM. This requires the use of the various NEs which are discussed in this section.

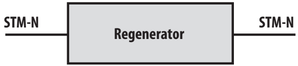
figure 4 Schematic diagram of hybrid communications networks



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

Regenerators

Regenerators, as the name implies, have the job of regenerating the clock and amplitude relationships of the incoming data signals which 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, F1) in the regenerator section overhead (RSOH) and can also be output using these channels.

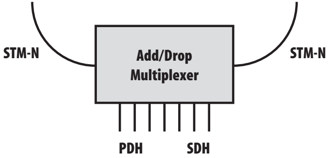


Terminal multiplexers

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

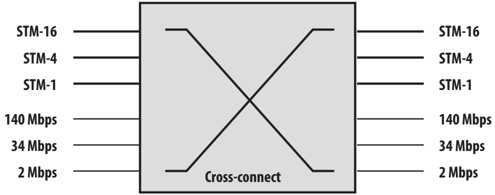
Add/drop multiplexers (ADM)

Plesiochronous and lower bit rate synchronous signals can be extracted from or inserted into high-speed SDH bit streams by means of ADMs. This feature makes it possible to set up ring structures, which have the advantage that in the event of a fault, automatic back-up path switching is possible using elements in the ring.



Digital cross-connects (DXC)

This NE has the widest range of functions. It allows mapping of PDH tributary signals into virtual containers as well as the switching of 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 (more information on TMN in the SDH network can be found on page 55). All the SDH network elements mentioned so far are software-controlled and can thus be monitored and remotely controlled – one of the most important features of SDH.

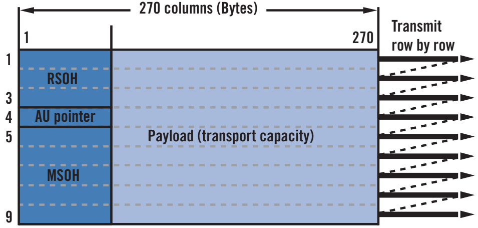
Optical fibers are the physical medium most commonly used in SDH networks. The advantage of these fibers is that they are not susceptible to interference and can transmit at very high speeds. The disadvantage is in the relatively high cost of procurement and installation. Singlemode fibers are the medium of choice in the first and second optical windows (1310 nm and 1550 nm).

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 limited bandwidth (currently up to STM-4) and complexity in linking such paths into the network management system are a disadvantage.

The STM-1 frame format

A frame with a bit rate of 155.52 Mbps is defined in ITU-T recommendation G.707 and 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 is capable of transporting any PDH tributary signal (≤ 140 Mbps).

figure 5 Schematic diagram of STM-1 frame



Section overhead (SOH)

The first nine bytes in each of the nine rows are called the overhead. G.707 makes a distinction between the RSOH and the MSOH. The reason for this is so that the functions of certain overhead bytes can be coupled with the network architecture. The table below 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) when combined with a container forms a virtual container. The POH has the task of monitoring quality and indicating the type of container. The format and size of the POH depends on the container type. A distinction is made between two 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. This path is 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 used for the low-order path. ATM signals and bit rates of 1.544 Mbps and 2.048 Mbps are transported within this path.

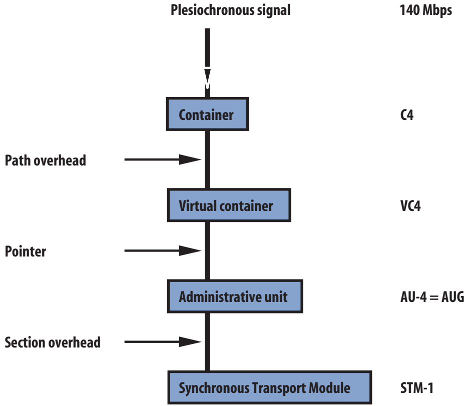
How are PDH, ATM and IP signals transported by SDH?

The heterogeneous nature of modern network structures has made it necessary for all PDH, ATM. and IP signals to be transported over the SDH network. The process of matching the signals to the network is 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 to be transported. 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) is made up of the container formed, together with the path overhead (POH). This is transmitted unchanged over a path through the network. The next step towards formation of a complete STM-N signal is the addition of a pointer indicating the start of the POH. The unit formed by the pointer and the virtual container is referred to as 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 Inserting a 140-Mbps tributary into an STM-1



ATM signals can be transported in the SDH network in C11, C12, C3, and C4 containers. Since the container transport capacity does not meet the continually increasing ATM bandwidth requirement, methods have been developed for transmitting the ATM payload in a multiple (n) C-4 (virtual or contiguous concatenation). As an example, a quadruple C-4 can be transmitted in an STM-4 (see section on "Contiguous concatenation").

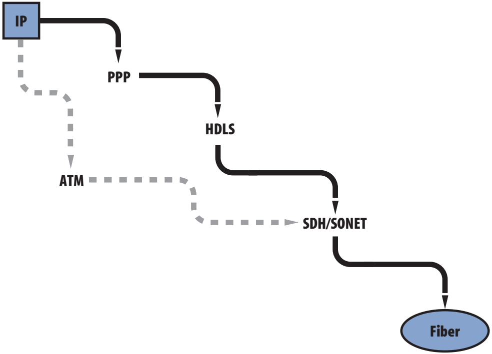
IP – Internet Protocol

The increased Internet traffic requires a technology to transport the IP packets to the physical layer. This transport below IP is described by Packet over SONET/SDH, as one possible route.

From the network layer the IP packets need to be delivered to the underlying layers: the datalink and physical layers. The actual transmission below the transport layer is called Packet over SONET/SDH (PoS).

This transmission can be achieved via alternative routes, two of which are illustrated in figure 8.

figure 8 Alternative routes to transmit IP packets to the fiber



The route chosen (indicated by the solid line) is recommended by the Internet Engineering Task Force (IETF).

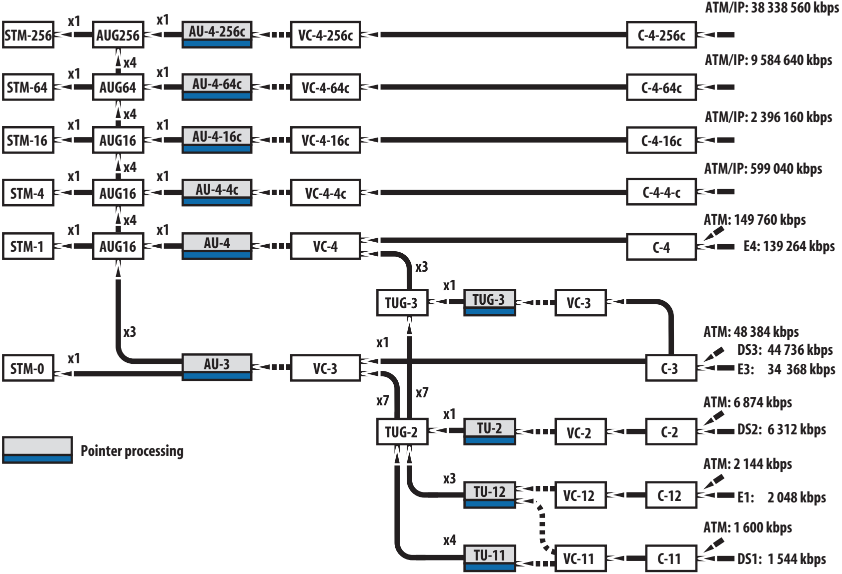


figure 9 Mapping in SDH

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. A point worth mentioning is the so-called sub-STM or STM-0 signal, an interface used in SDH/SONET links, radio links and satellite connections. The STM-0 has a bit rate of 51.84 Mbps.

SDH is used worldwide with the exception of the USA, Canada, and Japan. Specification on the synchronous optical network (SONET) transmission technology – the American equivalent of SDH – 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 bit rate is transmitted over an optical cable system, the signal is designated OC-1 (optical container). Table 2 details the additional SONET and equivalent SDH signals and bit rate levels in the hierarchy.

table 2 SONET/SDH signal and bit rate hierarchy

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

These hierarchy levels basically match the plesiosynchronous bit rates commonly used in these countries. Of all the levels listed above, only STS-1, OC-3, OC-12, OC-48 and OC-192 are currently utilized.

As the table indicates, there are points where transition between SDH and SONET systems are possible. Matching is relatively simple, as gateway issues were taken into consideration during development of SDH. Only minor adjustments need to be made to certain overhead bytes. SONET terminology is however, quite different with the packing unit for example referred to as a virtual tributary (VT-n) as opposed to virtual container.

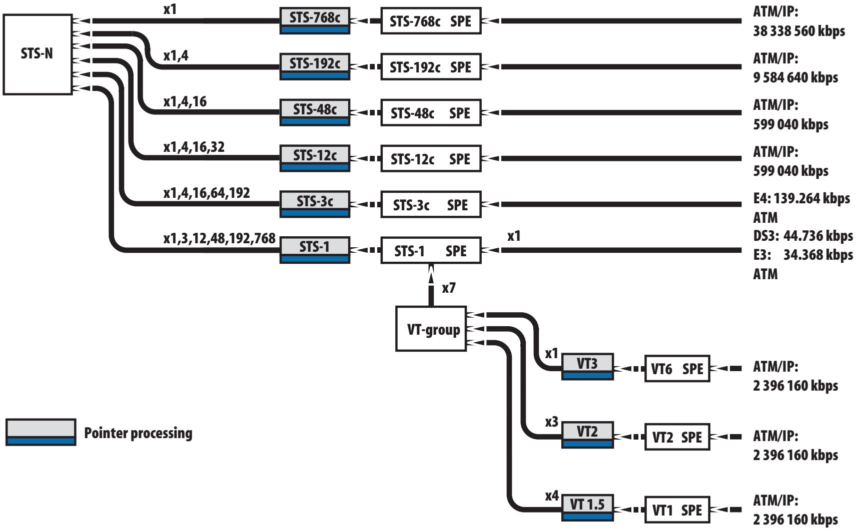
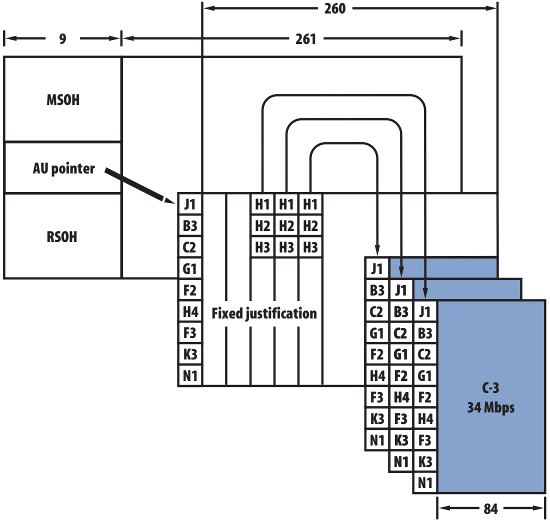


figure 10 SONET multiplexing scheme

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.

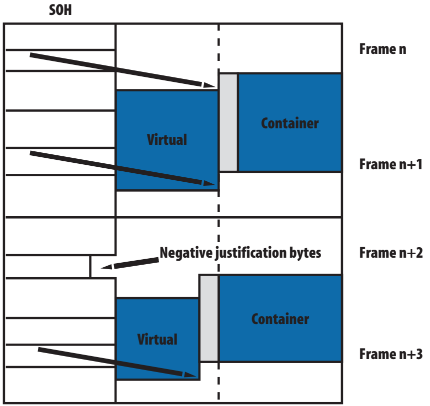
figure 11 Schematic diagram of C-3 mapping



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 real network or if the connection is fed through the networks of different providers. The AU pointer can be altered in every fourth frame with prior indication. The virtual container is then shifted by precisely three bytes. Pointer activity is therefore a good indication of clock variations within a network.

figure 12 Negative pointer justification

If the pointer is shifted to a later point in time (to the right in figure 12), the three bytes immediately preceding it are ignored. If the transmitting source is in advance of the actual clock, space for extra capacity must be provided. This takes place at the pointer position into which three bytes are inserted each time. If a further clock adjustment is not made, this configuration is propagated throughout the network.



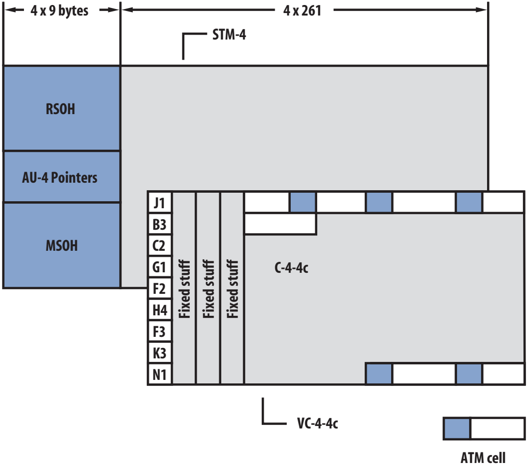
This allows for the free insertion in time of user signals into the next higher frame structure in the form of virtual containers without the need for larger buffers. However, changes in the phase location of the virtual container relative to the superior frame can be corrected by appropriate pointer actions. Such changes and shifts in phase can be caused by changes in propagation, delay in the transmission medium or by non-synchronous branches in the real network.

When a multiplex bundle is resolved, pointer procedures make it immediately possible to locate every user channel from each STM-N frame, which considerably simplifies drop and insert operations within a network node. In contrast, complete demultiplexing of every level of a plesiochronous hierarchy signal is required in order to access a particular tributary channel.

AU-4 contiguous concatenation

This mechanism is provided to allow bit rates in excess of the capacity of the C-4 container to be transmitted. For example, the AU-4-4c is intended for transporting B-ISDN bit rates. The advantage of this method is that the payload does not have to be split up, since a virtually contiguous container is formed within an STM-4. The payloads of several consecutive AU-4s are linked by setting all the pointers to a fixed value – the concatenation indicator (CI) – with the exception of the pointer for the first AU-4. If pointer activity becomes necessary, this takes place for all concatenated AU-4s equally. Figure 13 illustrates how the payload of ATM cells can be transmitted as a whole.

figure 13 Virtual concatenation

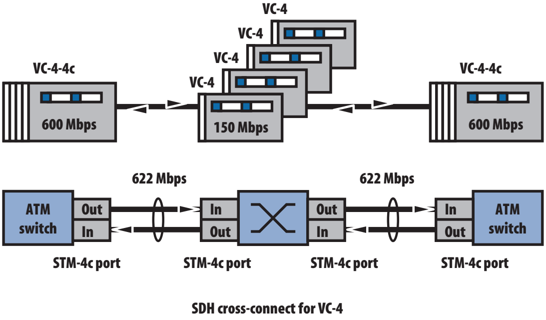


The first pointer indicates byte J1. All other pointers are set to concatenation indication (CI) ATM Cell.

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. Ensuring the integrity of the payload is the task of the NE on the receiving side. These NEs reassemble the payload of the individual virtually concatenated VC-4s into a unit, even if different pointer values are present.

figure 14 Principle of contiguous concatenation



Transmission at higher hierarchy levels

To achieve higher bit rates, AU-3/4s are multiplexed into STM-N frames.

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

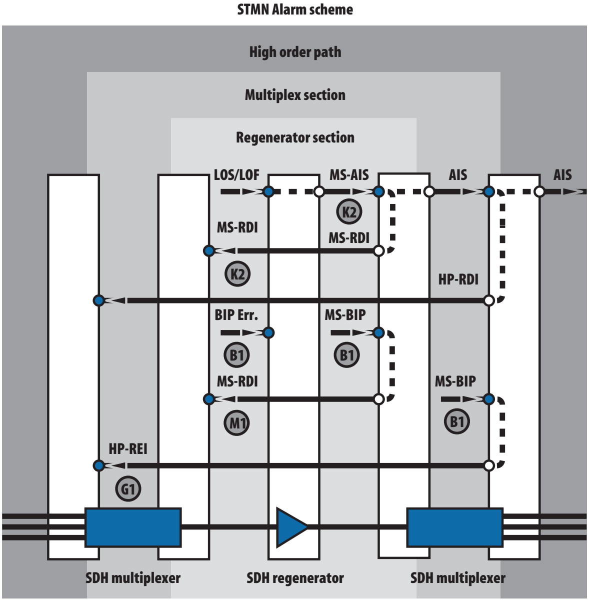
The STM-N frame structures are basically N times the STM-1 structure. For example, the STM-4 overhead is four times the size of the STM-1 overhead. The SOH content is specified for each stage individually. For this, the A1, A2 and B2 bytes are formed N times. The frame alignment of an STM-256 frame is composed of 64 A1 bytes (byte No. 705 to No. 768) followed by 64 A2 bytes. The other bytes are reserved for future international standardization.

Error and alarm monitoring

Large numbers of alarm and error messages are an integral part of SDH networks. In SDH, these are referred to as defects and anomalies, respectively. They are coupled to network sections and the corresponding overhead information. The advantage of this detailed information is illustrated as follows.

Complete failure of a circuit results for example, in a loss of signal (LOS) alarm in the receiving NE. This alarm triggers a complete chain of subsequent messages in the form of alarm indications signals (AIS) as shown in figure 15. The transmitting side is informed of the failure by the return of a 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. Since this is not the same as a complete failure of the circuit, the alarm here is referred to as an anomaly that is indicated back in the direction of transmission. The return message is referred to as 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	Drop in incoming optical power level causes high bit error rate
OOF	Out of frame	A1, A2 errored for ≥625 µs
LOF	Loss of frame	If OOF persists for ≥ 3 ms (to be defined)
RS BIP Error	Regenerator Section BIP Error (B1)	Mismatch of the recovered and computed BIP-8 Covers the whole STM-N frame
RS-TIM	Regenerator Section Trace Identifier Mismatch	Mismatch of the accepted and expected Trace Identifier in byte J0

table 3 (continued)

	Anomalies/Defects	Detection criteria
MS BIP Error	Multiplex Section BIP Error (B2)	Mismatch of the recovered and computed N 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
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 $\geq$ 5 frames

table 3 (continued)

	Anomalies/Defects	Detection criteria
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 or 10)
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

table 3 (continued)

	Anomalies/Defects	Detection criteria
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 ≥z frames VC-m (m = 2, 11, 12): V5 (bit 8) = 1 for ≥z multiframes (z = 3, 5 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 in order to compensate for failures in network elements.

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.

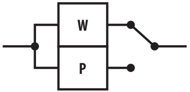
Linear protection

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. Switching at the far end is initiated by the return of an acknowledgment in the backward channel.

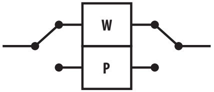
1+1 architecture includes 100 percent redundancy, as there is a spare line for each working line. Economic considerations have led to the preferential use of 1:N architecture, particularly for long-distance paths. Here, several working lines are protected by a single back-up line. If switching is necessary, 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.

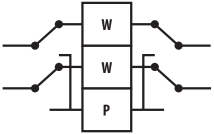
figure 16 Linear protection schemes



1+1 protection scheme



1:1 protection scheme



1:N protection scheme

Ring protection

The greater the communications bandwidth carried by optical fibers, the higher the cost saving in ring structures when compared with linear structures. A ring is the simplest and most cost-effective way of linking a number of network elements.

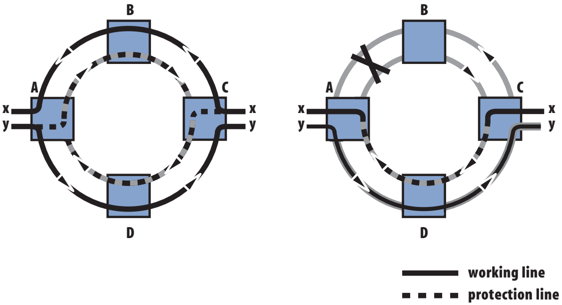
A number of protection mechanisms are available for this type of network architecture, some of which have been standardized in ITU-T recommendation G.841. There are some basic distinctions to be observed however between ring structures with unidirectional and bidirectional connections.

Unidirectional rings

Figure 17 shows the basic principle of APS for unidirectional rings. Assuming an interruption in the circuit occurs between network elements A and B, direction y would be unaffected. An alternative path would however have to be found for direction x. The connection would therefore be switched to the alternative path in NEs A and B while the other NEs (C and D) would switch through the back-up path. This is known as a line-switched process.

A simpler method would be to use the path-switched ring (figure 18). In this case, traffic would be transmitted simultaneously over both the working and protection line. Should there be an interruption, the receiver (in this case A) would switch to the protection line and immediately take up the connection.

figure 17 Two-fiber unidirectional path switched ring



Bidirectional rings

In this network structure, connections between NEs are bidirectional (figure 18). The overall capacity of the network can be split up for several paths, each with one bidirectional working line. For unidirectional rings, an entire virtual ring is required for each path. If a fault occurs between neighboring elements A and B, network element B triggers protection switching and controls network element A by means of the K1 and K2 bytes in the SOH.

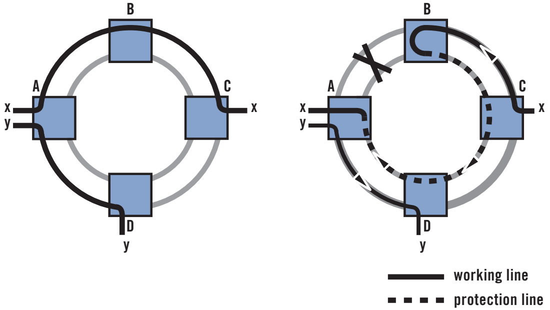


figure 18 Two-fiber bidirectional line-switched ring (BLSR) working line protection line

Bidirectional rings with four fibers provide even greater protection. Each pair of fibers transports working and protection channels. This results in 1:1 protection, that is 100 percent redundant. This improved protection is however coupled with relatively high costs.

Synchronization

If synchronization is not guaranteed, this can result in considerable degradation in network functionality and even total failure. To avoid such scenarios, all NEs are synchronized to a central clock. This central clock is generated by a high-precision, primary reference clock (PRC) unit conforming to ITU-T recommendation G.811. This specifies an accuracy of 1x10-11. This clock signal must be distributed throughout the entire network. A hierarchical structure is used, in which the signal is passed on by the subordinate synchronization supply units (SSU) and synchronous equipment clocks (SEC). The synchronization signal paths can be the same as those used for SDH communications.

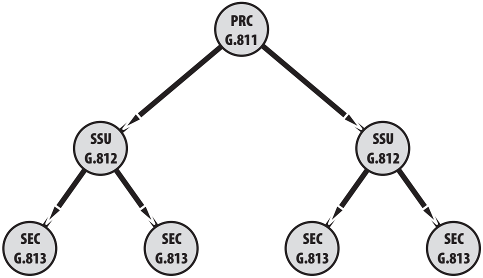


figure 19 Clock supply hierarchy structure

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 this is not possible, the NE switches to holdover mode. In this situation, the clock signal is kept relatively accurate by controlling the oscillator, applying the stored frequency correction values for the previous hours and taking the temperature of the oscillator into account.

Clock "islands" must be avoided at all costs, as these drift out of synchronization over time and lead to total failure. Such islands are prevented by signaling the NEs with the aid of synchronization status messages (SSM – part of the S1 byte). The SSM informs the neighboring NE of the clock supply status and is part of the overhead. Certain problems can arise at the gateways between networks with independent clock supplies. SDH NEs can compensate for clock offsets within certain limits by means of pointer operations. Pointer activity is thus a reliable indicator of clock supply problems.

Telecommunications management network (TMN) in the SDH network

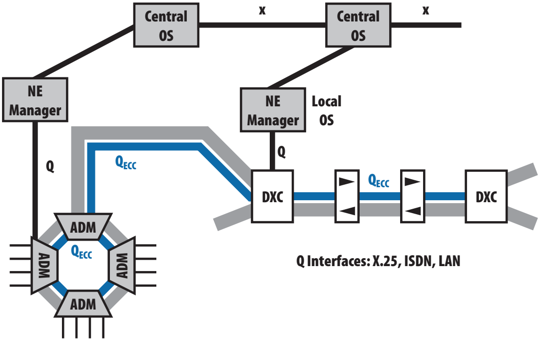
The principle of telecommunications management network (TMN) technology was established in 1989, with the publication by the CCITT (now ITU-T) recommendation M.3010. The functions of a TMN are expressed as: operation, administration, maintenance, and provisioning (OAM&P). This includes monitoring of network performance and checking of 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. The agents in turn each handle several managed objects (MOs). The manager is included in the operating system (OS) which forms the "control center" for the network as a whole or in part. In SDH networks, the agents are located in the NEs. An MO may be a physical unit, for example a plug-in card, or multiplex section, but 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. Another management unit operates at the service level to monitor billing charges for example.

These tasks are performed in modern telecommunications networks by using the common management information protocol (CMIP). The simple network management protocol (SNMP) is often mentioned in this context and is basically a simplified form of CMIP. SNMP is mainly used in data communications, however, and cannot cope with the requirements of large telecommunications networks. The Q3 interface, which is where the exchange of data between manager and agent takes place, is the point of reference for CMIP. CMIP is also used where several TMNs or their managers are linked together via the X interface.

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

figure 20 TMN overlay



To distinguish the implementation in the SOH from data channels from the Q interface, the term QECC protocol is used. Such networks are called SDH management networks (SMN) and are primarily responsible for managing NEs. SMNs can also be subdivided into SDH management subnetworks (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

Although trouble-free operation of all NEs should have been guaranteed by standardization on the part of various bodies (ITU, ETSI, ANSI, Bellcore), problems still arise, particularly when NEs from different sources are linked together. Transmission problems also occur at gateways between networks run by different providers.

The measurement facilities built into the system provide only an approximate location of a fault. Separate measuring equipment in contrast, is of much greater use particularly when monitoring individual channels, and more data relevant to clearing the fault can be obtained. The only areas that are covered by both network management and measurement procedures are long-term analysis and system monitoring.

Separate measuring equipment, of course, finds further application in the fields of research and development, production, and installation. These areas in particular require test equipment with widely differing specifications.

In production and installation for example, systems manufacturers configure their NEs or entire networks according to customer requirements and use measuring techniques that check everything operates as it should. The equipment is then installed on the customer's site and put into operation. Test equipment is essential at this stage to eliminate any faults that may have occurred during production and installation and to verify correct functioning. Such test equipment needs to be portable, robust, and capable of performing test sequences in order to reproduce repeat measurements and long-term analyses reliably and quickly.

With network providers, fault clearance and maintenance are the main areas of deployment for measuring equipment. The continuing process of network optimization is also a major area in which test equipment needs to be portable. It must also be reasonably priced, suitable for in and out-of-service measurements, and provide users with a rapid, easily interpreted display of results.

Generally speaking SDH test equipment must also be capable of fulfilling the following measurement tasks:

– Mapping analysis
– Alignment of port interfaces
– Measurements with structured test signals
– Measurements on add/drop multiplexers
– Delay measurements
– Testing of automatic protection switching (APS)
– Simulation of pointer activity
– In-service SDH measurements:
  Alarm analysis
  Path trace monitoring
  Pointer analysis
  Checking the system's in-built sensors
  Drop and insert measurements
  Checking network synchronization
  Measurements on the TMN interface
– Error performance measurement
– Jitter and wander analysis

Some of these measurements are discussed in more detail below.

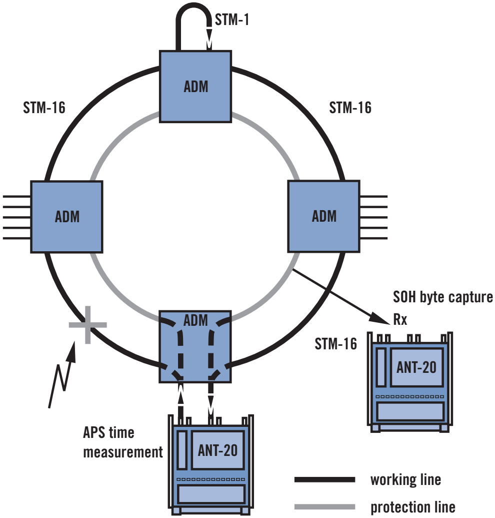
Sensor tests

These measurements are performed in order to check the reaction of system components to defects and anomalies. Anomalies are faults such as parity errors. Defects result in the interruption of a connection. As an example, an NE must react to an LOS alarm by sending an AIS to the subsequent NEs and transmitting an RDI signal in the return path (figure 10).

APS time measurements

A special mechanism operates in SDH networks in the event of a fault that allows the faulty link to be automatically rerouted over a back-up circuit (see APS section above). This function is controlled using overhead bytes K1 and K2. Switching over to the protection line must take place in less than 50 ms. External equipment is needed to ensure this and to measure the response time, that is the loss of a specific test pattern or triggering of a preset alarm when a connection is intentionally interrupted (figure 22). The measurement is important as a delayed response can result in considerable degradation in performance and even total failure of the network leading to loss of income for the network provider.

figure 22 Checking APS response time



ITU-T error performance recommendations

The quality of digital links is determined with the aid of bit error ratio tests (BERT). The results of such measurements must, however, be classified in some way, not least because the quality of a transmission path is often the subject of a contract between the network provider and the telecommunications user. For this reason, an objective means of classifying a line as either "good" or "bad" is required. The ITU-T recommen dations G.821, G.826, G.828, G.829, M.2100, and M.2101 are internationally recognized standards which specify these parameters.

G.821

This recommendation was originally specified for international circuit-switched n x 64 kbps connections and expanded to include higher bit rates. A hypothetical reference connection is the basis used 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 to be unavailable from the first of at least ten consecutive SESs. The circuit is available from the first of at least ten consecutive seconds which are not SESs.

The original version of G.821 also included:

– Degraded minute (DM): a one-minute time interval in which the bit error ratio exceeds 10–6.
– Derived parameter:
– Error-free second (EFS): a one-second, time interval in which no bit errors occur.

The disadvantage of this method is that it relies on the evaluation of bit errors and so the test channel must be taken out of service to perform the measurement.

G.826 This recommendation, issued in 1993, takes higher bit rates into account and allows in-service measurement as it relies on the evaluation of block errors.

G.826 definitions include:

– Errored second (ES): a one-second, time interval containing one or more errored blocks.
– Errored block (EB): a block containing one or more errored bits.
– Severely errored second (SES): a one-second, time interval in which more than 30 percent of the blocks are errored or which contains at least one severely disturbed period (SDP).
– Background block error (BBE): an errored block that is not an SES.
– Unavailable second (US): see under G.821, above.

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– Background block error (BBE): an errored block that is not an SES.
– Unavailable second (US): see under G.821, above.

The results are referred to as the measurement time. This gives the following error parameters: errored seconds ratio (ESR), severely errored seconds ratio (SESR) and background block error ratio (BBER). The specified quality requirements refer to a particular path. The recommended measurement time for G.821 and G.826 is 30 days.

G.828 Although recommendation G.826 found broad use in the specification of PDH systems, it was applied predominantly to SDH systems. It became apparent that the target values in G.826 – which to a large extent were influenced by PDH technology – did not match the capabilities of modern SDH systems based on fiber optic technology. As a result, work commenced on the development of the new recommendation G.828, with the aim of specifying tighter target values for error performance concerning modern SDH systems. The suggestion to include the error event severely errored period (SEP) in G.828 was based on the results of practical measurements. An SEP is defined as a period of time during which at least three but not more than nine consecutive, SESs occur. A period of consecutive SES can have the same effect as a microinterruption and may lead to a severe impairment of the service supported by the SDH path.

G.829 Together with G.828, the new recommendation G.829 "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, G.829 does not define any target values but describes the error events for SDH multiplex and regenerator sections.

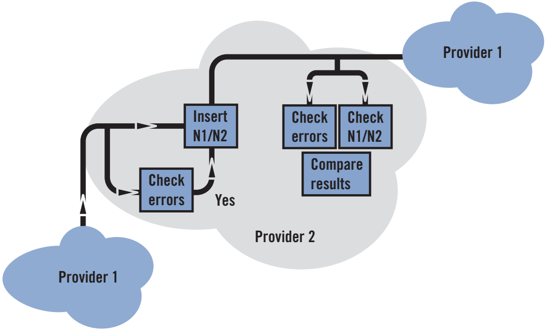
M.2100 Recommendation M.2100 specifically applies to commissioning and maintenance. Commissioning consists of a 15-minute line up phase followed by a 24-hour in-service measurement. Once the lineup phase is completed successfully, errors may occur within certain limits. If this is the case, the line remains in service but must continue to be monitored for a further seven days. The measurement procedures are defined in M.2110 and M.2120. The limit values are derived form the performance parameters specified in G.821 and G.826.

M.2101 This recommendation, though similar to M.2100 in terms of purpose and format, deals exclusively with SDH systems. The recommendation includes tables addressing "bringing-into-service" performance objectives.

Tandem connection monitoring (TCM)

Overhead byte B3 is used to monitor the quality of a path and is evaluated at the start and end of the path. However, it is becoming increasingly necessary to determine the quality of individual segments of a path which might pass through the networks of different providers. In such cases, it is especially important to be able to demonstrate that high quality is guaranteed in one's own network. When a fault occurs, the question of who bears the responsibility and the costs of making the repairs is one that warrants an answer. TCM allows monitoring of the performance of path segments with the aid of the N bytes in the POH. The high-order and low-order POH parity bytes are evaluated by the NEs. The number of errors detected is indicated to the end of the TCM using the N1 or N2 byte. This error count is compared again with the number of parity errors detected at the end of the TCM. The difference is the number of errors occurring within the TCM.

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



Jitter measurements

The term jitter refers to phase variations in a digital signal in which the edges of the digital signal may differ from the expected ideal positions in time. Jitter is described in terms of its amplitude (expressed in unit intervals, UI) and its frequency. If the jitter frequency is below 10 Hz, it is described as "wander". Signals affected by jitter cannot be sampled accurately. In an extreme situation, this might result in misinterpretation of the input signal leading to single errors or error bursts and a corresponding degradation in transmission quality. Jitter and wander can also be the cause of buffer under-flow or overflow, which causes bit slips. The theoretical limit of correct sampling at high jitter frequencies is half the bit width. Distortion and additive noise means that the actual limit must be set much lower than this. The causes of jitter lie chiefly in the clock sources for NEs such as regenerators and add/drop multiplexers. The various types of jitter are illustrated in table 4.

table 4 Causes of 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. This results in 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. This is done by incrementing or decrementing the pointer by one unit.
Intrinsic jitter	Jitter at the output of a device that 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 the insertion of stuffing bits. These stuffing bits must be removed when the signal is demultiplexed. The gaps that occur as a result are equalized by means of a smoothed clock signal. This smoothing however is imperfect, resulting in stuffing and wait-time jitter.

table 4 (Continued)

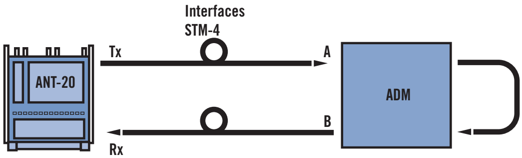
Jitter type	Cause
Pattern jitter	Distortion in the digital signal leads to so-called inter-symbol interference, or time-domain impulse cross-talk. This results in interference between consecutive pulses in a digital signal which leads to jitter that is pattern-dependent.
Wander	Wander is a slow drift in the significant instants of a digital signal from their ideal equidistant positions in time. These delay variations occur for example in optical fibers as a result of diurnal temperature variations.

Other causes of jitter are interference signals and phase noise. Jitter caused by interference signals is also called non-systematic jitter. Phase noise can occur despite the use of a central clock as a result of thermal noise and drift in the oscillator used. Various measurement methods have been developed for the different causes of jitter.

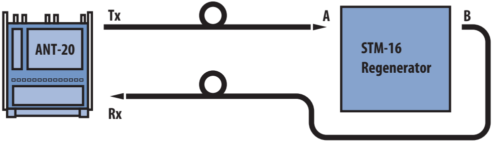
Measurements

– Maximum tolerable jitter (MTJ)
  Every digital input interface must be able to tolerate a certain amount of jitter before bit errors or synchronization errors occur. The measurement is made by feeding the input of the device under test with a digital signal modulated with sinusoidal jitter from a jitter generator.

A bit error tester monitors the output of the device for bit errors and alarms which eventually occur as the jitter amplitude is increased.



– Jitter transfer function (JTF)
  The JTF of an NE indicates the degree to which jitter is passed on to the output.



– Output jitter, intrinsic jitter
  Evaluation of broadband jitter using standardized combinations of high-pass and low-pass filters.
– Mapping jitter
– Pointer jitter
  Measurement of permitted pointer jitter is performed by feeding the synchronous demultiplexer with an SDH signal containing defined sequences of pointer activity.

– Combined jitter

Jitter at PDH outputs is caused by stuffing during mapping and by pointer activity.

– Wander analysis

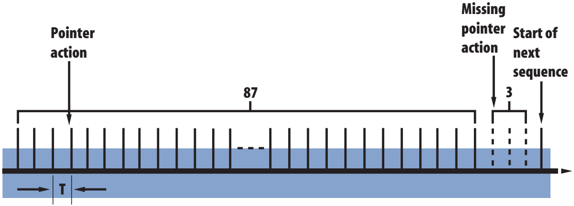
An external, high-precision reference signal is required for performing wander measurements. The phase of the signal under test is compared with the reference signal phase. The very low frequency components require appropriately long measurement times of up to 12 days.

Simulating pointer activity

If the jitter behavior of a tributary output in response to pointer activity is to be tested, pointer sequences must be used. These sequences have been defined by the ITU-T to guarantee network stability even under extreme conditions.

Pointer sequence 87-3 INC

This is a sequence of steady pointer increments where three pointer actions are omitted after a sequence of 87 actions. This kind of sequence can occur as a result of loss of synchronization in an NE and can cause very large jitter amplitudes.



87-3 sequence

Overview of current ITU-T recomm endations relevant to SDH

G.703	Physical/electrical characteristics of hierarchical digital interfaces
G.707	Network node interface for the synchronous digital hierarchy (SDH)
G.709	Interface for the optical transport network (OTN)
G.772	Protected monitoring points provided on digital transmission systems
G.774	SDH information model for the network element view
G.774.01	SDH performance monitoring 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 from the network element view
G.774.05	SDH management of the connection supervision functionality (HCS/LCS) for the network element view
G.780	Vocabulary of terms for SDH networks and equipment
G.783	Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks (replaces G.781, G.782 and G.783 version of 01/94)
G.784	Synchronous digital hierarchy (SDH) management
G.803	Architectures of transport networks based on the synchronous digital hierarchy (SDH)

G.810	Definitions and terminology for synchronization networks
G.811	Timing requirements at the output of primary reference clocks suitable for plesiochronous operation of international digital links
G.813	Timing characteristics of SDH equipment slave clocks (SEC)
G.825	The control of jitter and wander in digital networks based on the SDH
G.826	Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate
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
G.841	Types and characteristics of SDH network protection architectures
G.842	Interworking of SDH network protection architectures
G.957	Optical interfaces for equipments and systems relating to the SDH
G.958	Digital line systems based on the SDH for use on optical fiber cables
M.2101	Performance limit for bringing into service and maintenance of international SDH paths, and multiplex sections
M.2110	Bringing into service international paths, sections and transmission systems
M.2120	Digital path, section, and transmission system fault detection and localization

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-N 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-n	Administrative unit, level n = 3, 4
AUG	Administrative unit group

B

B1	BIP-8 parity word in regenerator section (RSOH)
B2	BIP-N 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-N	Bit interleaved parity, N bits
BSHR	Bidirectional self-healing ring

C

C-n	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
E2	Electrical interface signal, 8448 kbps
E3	Electrical interface signal, 34368 kbps
E4	Electrical interface signal, 139264 kbps
E1	Service channel (voice) in regenerator section (RSOH)

E

E2	Service channel (voice) in multiplex section (MSOH)
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-N	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

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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
SPRING	Shared protection ring
STM	Synchronous transport module

S

STM-N	Synchronous transport module, level N = 1, 4, 16, 64
STS	Synchronous transport signal

T

TMN	Telecommunications management network
TU	Tributary unit
TU-m	Tributary unit, level m = 1...3
TUG-m	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-Xc	Concatenated virtual container, level n, X concatenated VCs
VP	Virtual path

W

WDM	Wavelength division multiplexing

Available Reference Guides:

ATM Pocket Guide
TP/EN/PG04/0400/AE

DWDM Pocket Guide
DWDM/PG/OPT/05-02/AE/ACT00278

Packet over SONET/SDH Pocket Guide
PoS/PG/OPT/01-02/AE/ACT00074

Q-factor Pocket Guide
QFACTOR/PG/OPT/11-01/AE/ACT00055

SDH Pocket Guide
SDH/PG/OPT/06-02/AE/ACT00279

SONET Pocket Guide
TP/EN/PG03/0201/AE

Notes

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