Ring testing enhances reliability of SDH and SONET ring structures.

Application Note 60

Advanced Network Test Solutions:

Efficient line-up of SDH and SONET ring structures

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Contents

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Efficient testing of synchronous rings

Ring structures are normally used instead of linear structures whenever transmitted information needs to be protected in broadband networks. SDH and SONET rings represent the simplest and most cost-effective means of linking several network elements together (Fig. 1). Before network structures of this kind can be commissioned, the interaction of all their constituent elements must be tested, and an acceptance measurement carried out to verify that the complete network is functioning reliably.

Advanced Network Tester ANT-20

With its extensive range of measuring functions, the Advanced Network Tester ANT-20 is the ideal solution for all measurement tasks that arise when synchronous SDH or SONET rings are commissioned and calibrated.

Despite its extraordinary flexibility and functionality, the ANT-20 is one of the most compact instruments in its class. Its design is specially tailored to mobile needs: although lightweight and small in volume, it boasts an unusually large display, which is also optionally available as a high-contrast TFT color monitor. Operator handling is simplified by the optimized touchscreen.

Testing enhances reliability

SDH and SONET networks with ring structures (Fig. 1) are extremely economical and offer excellent protection against network failures thanks to their automatic protection switching mechanisms.

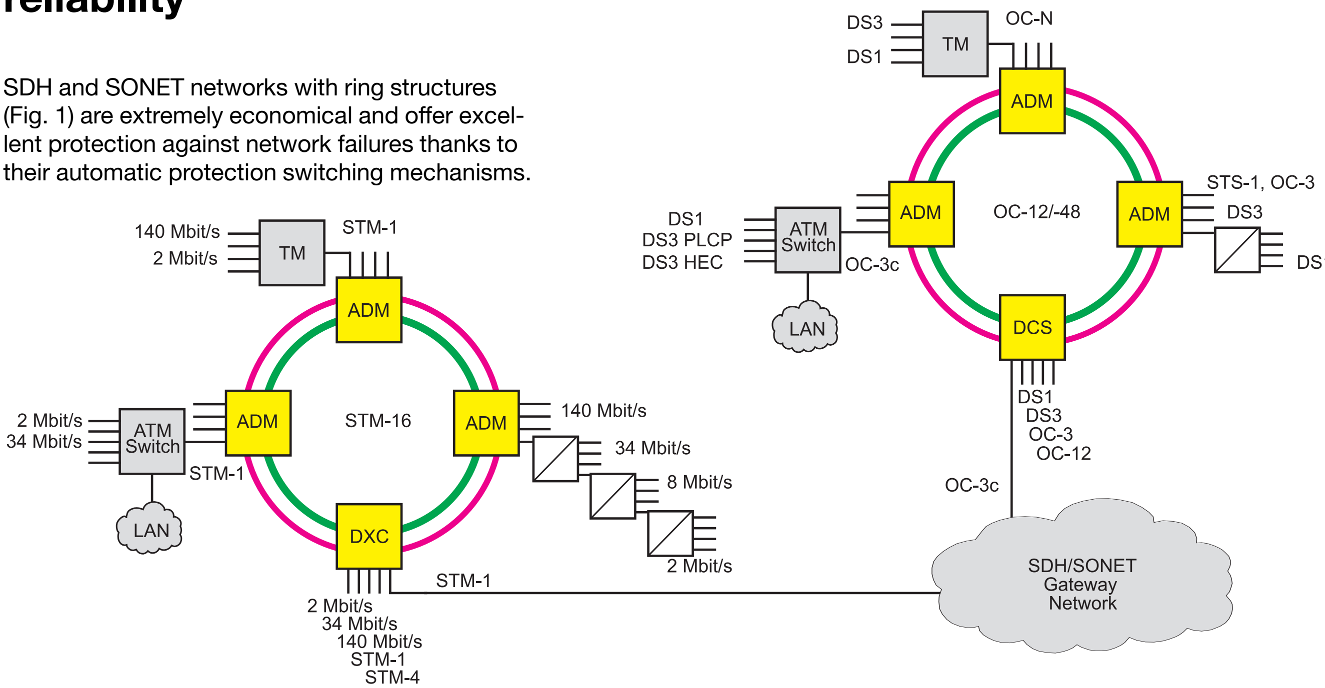


Fig. 1: SDH and SONET ring structures with various tributaries

The SDH signals are transported in a dual ring consisting of *working channels* (e.g. the outer ring) and *protection channels,* which handle all traffic in the event of a fault or a degradation of signal quality. Network failures are thus prevented and transmission quality guaranteed.

Practical experience has shown that networks of this kind can sometimes be problematic to install and commission, even though their constituent elements have previously been subjected to careful testing by the manufacturers. Even if the various network elements function perfectly in isolation, unexpected phenomena may still occur after the network is actually installed. An SDH ring is therefore normally commissioned by the system vendor after installation, and then lined-up and tested by the network operator within the framework of the acceptance procedure. The quality parameters that are measured are specified in accordance with the recommendations of international standardization bodies (Tables 1 and 2).

The measurements themselves are concerned above all with meeting the following demands:
- Reducing the time required for the acceptance procedure to a minimum
- Ensuring dependable functioning of the network
- Verifying compliance with standards

This Application Note describes the measurement procedures that are nowadays standard practice when synchronous rings are commissioned and calibrated. The Appendix contains various technical details.

Table 1: Measurement tasks in SDH rings

Measurement task	ITU-T Recommendation
Payload transparency	G.826
DCC transparency	G.826
ADM functionality	
Ring synchronization: Jitter analysis Pointer analysis Wander analysis	 G.823, G.783 G.783 G.813
APS switch-over time	G.841
APS protocol capture	G.841
Network management: Alarm sensor LOS Alarm sensors B1, B2, B3 Path trace J2 (TIM)	 G.775, G.958 G.783 G.707

Table 2: Measurement tasks in SONET rings

Measurement task	Standard	
	Bellcore	ANSI
Payload transparency	GR-499	T1.514
DCC transparency		
ADM functionality	GR-496	
Ring synchronization: Jitter analysis Pointer analysis Wander analysis	 GR-253	 T1.105.03 T1.105.09
APS switch-over time	GR-1230	T1.105.01
APS protocol capture	GR-1400	
Network management: Alarm sensors Path trace J2 (TIM)	GR-253	T1.231

Commissioning synchronous rings

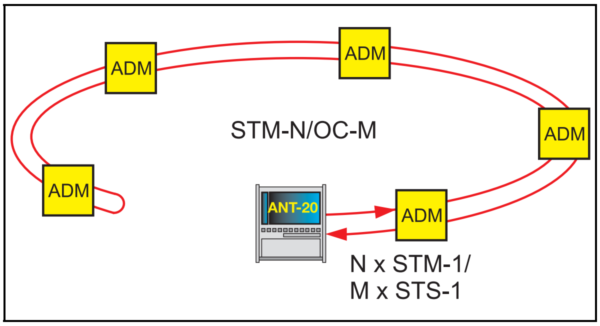


Fig. 2: Bit error test in a synchronous ring (SDH/SONET)

When a synchronous ring is commissioned, its functions are verified by means of bit error ratio tests on the user channels (payload transparency) and the data communication channels (DCC transparency). Since the BERTs are performed as loop measurements, the ring must be interrupted and an SDH/SONET analyzer (ANT-20) inserted at the optical interfaces which are accessible as a result. Once the network elements have been reconfigured accordingly, this setup allows loop measurements that are valid for all elements to be carried out (Fig. 2).

Measuring payload transparency

The payload transparency must be verified across the entire ring by testing all four VC-4 channels one at a time for bit errors, for example in an STM-4 ring. Fig. 2 shows the test configuration that is used for this purpose. The test signal is a pseudo-random bit sequence (PRBS), which is incorporated in a C-4 container as a BULK signal (ITU-T O.181).

The transmission quality is measured by means of a long-term analysis over a 24-hour period in accordance with ITU-T G.826. Compliance with this standard guarantees a defined minimum quality on the transmission link. (Note: ITU-T Recommendation G.826 is currently being revised; it is likely that the final version will specify stricter criteria in some cases.)
It is important that the measurement also detects sporadic, time-dependent errors. In addition to analyzing performance, the ANT-20 also *simultaneously* captures anomalies and defects (anomaly/defect analysis function). The transmit clock must be extracted from the receiver in the ANT-20, in order to prevent unwanted pointer actions. The timing extraction function is set to “from receiver” for this purpose.

Measuring DCC transparency

Another commissioning measurement is derived from the TMN (Telecommunications Management Network) functions, which are the software means of controlling the network elements. This measurement is carried out on the data communication channels (DCC), which are located in the section overhead of an SDH ring (RSOH D1 to D3 and MSOH D4 to D12) or in the transport overhead of a SONET ring (SOH: D1 to D3, LOH: D4 to D12). Their functional reliability depends on the transmission functionality and quality in these OH bytes (DCC transparency). The test procedure is as described above, i.e. a bit error ratio test is performed on the relevant channels in the configuration shown in Fig. 2.

Abbreviations

AIS	Alarm Indication Signal
ADM	Add & Drop Multiplexer
APS	Automatic Protection Switching
ATM	Asynchronous Transfer Mode
C-n	Container, n = 1 . . . 4
DCC	Data Communication Channel
FAS	Frame Alignment Signal
J0	Regenerator Section Trace
J1	Path Trace (POH in VC-3,4)
J2	Path Trace (POH in VC-1,2)
LOF	Loss of Frame
LOH	Line Overhead
LOS	Loss of Signal
LSS	Loss of Sequence Synchronization
MS-AIS	Multiplexer AIS
MSOH	Multiplexer Section Overhead
OC	Optical Carrier
OC-N	Optical Carrier, N = 1; 4; 16
OH	Overhead
OOF	Out of Frame
OOS	Out of Service
POH	Path Overhead
PRBS	Pseudo-Random Binary Sequence
RDI	Remote Defect Indicator
RSOH	Regenerator Section Overhead
SD	Signal Degrade
SDH	Synchronous Digital Hierarchy
SF	Signal Fail
SOH	Section Overhead
SPRING	Shared Protection Ring
STM	Synchronous Transport Module
STM-N	Synchronous Transport Module, level N = 1; 4; 16; 64
STS	Synchronous Transport Signal
TIM	Trace Identifier Mismatch
TMN	Telecommunications Management Network
TOH	Transport Overhead
TSE	Test Sequence Error
UI	Unit Interval
VC	Virtual Container

Line-up of synchronous rings

The purpose of calibration is to ensure that all the network elements and their specific functions are correctly configured. This prevents disturbances from occurring later on during operation, which would be considerably more expensive to rectify.

Testing the ADM functionality

The add & drop multiplexers (ADM) are tested one at a time to ensure that the add & drop function is correctly configured. The tributaries are looped for this test at each ADM in the open ring (Fig. 3), and their contents returned. The ADMs are then function-tested individually, with the preceding elements switched transparently in each case.
All 63 × 2 Mbit/s channels are tested in this configuration to check their freedom from alarms and bit errors. The SCAN function of the ANT-20, which enables the channels to be tested separately, consecutively and automatically, thereby cutting the required time, is used for this purpose.

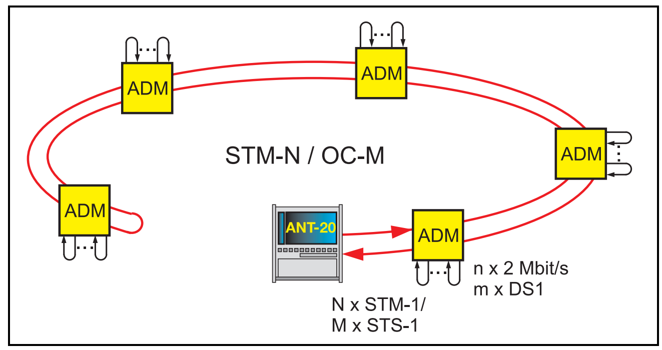


Fig. 3: ADM functionality measurement

Ring synchronization test based on a jitter analysis

During normal operation, one network element in the ring is synchronized with an external reference, while the others obtain their timing signals from the receive clock of the line bit rate. On delivery, the timing extraction circuit for the network elements is normally set to freewheeling mode (internal clock source). When the network is commissioned, it must be set manually in the network management system according to the timing extraction priority table. Account must also be taken of redundant routes.
If the configuration is incorrect, the ring will not be properly synchronized. High jitter values (up to several UI) will appear at the output of the tributary as a result. The output jitter measurement shown in Fig. 4 provides an initial indication of whether or not the ring is perfectly synchronized.
This measurement entails routing the test signal through each ADM. Abnormally high jitter values are a pointer to misconfigured network elements. Further clues can then be obtained by referring to the timing extraction priority table.

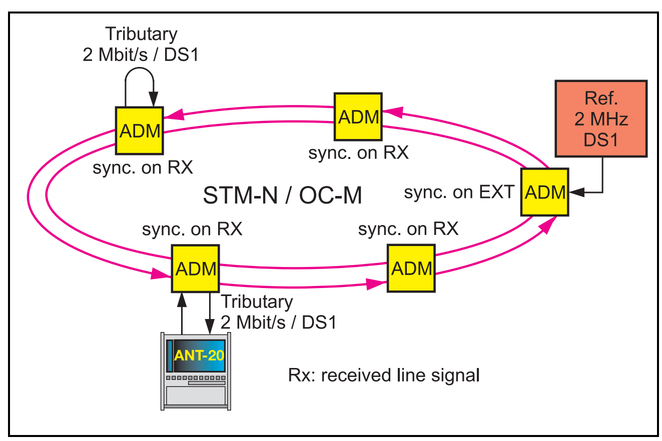


Fig. 4: Output jitter measurement

Ring synchronization test based on a pointer analysis

Although the jitter analysis provides an initial indication of the clock quality of the ring, it does not allow any conclusions to be drawn with regard to long-term drift. A finer analysis, based on the captured pointer actions, is necessary for this purpose. It is important to record not only the direction of the pointer actions, but also their distribution over a period of time.

The test configuration used to do so is shown in Fig. 5. An ANT-20 is coupled into the ring as a monitor, directly upstream of the externally synchronized NE, via the built-in optical power splitter. The test signal thus passes through all the NEs before it is analyzed, so that the influence of every NE connected to the network timing circuit is taken into account. “High clock quality” means that even isolated single pointer actions must be recorded and analyzed down to the exact second. A measurement lasting at least 24 hours is essential in order to obtain meaningful results.
If a large number of pointer actions, or actions with a discontinuous time distribution, are detected, the faulty network element must be pinpointed. The pointer analysis must be conducted on all preceding ADMs step by step, until the cause of the actions – and thus of the synchronization error – is identified.

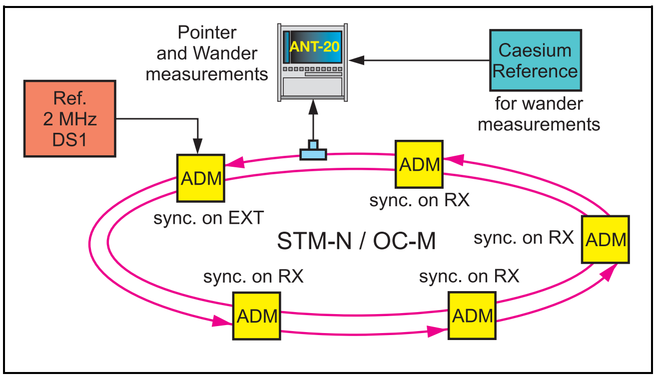
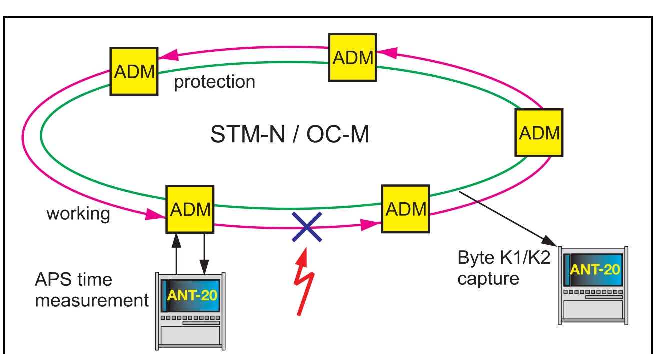


Fig. 5: Pointer and wander analysis

One of the major advantages of the ANT-20 is that it allows transmission quality and all possible errors and alarms to be observed simultaneously. Correlations between different events can thus be visualized easily. The measurement described here can also be performed in service providing an isolated monitor point is available for connecting the ANT-20.
Note: In order to prevent an LSS alarm, the pattern expected by the receiver should be set to “traffic”.

Fig. 6: APS functional test



Ring synchronization test based on a wander analysis

If extreme precision is essential, an additional long-term wander analysis should be performed, to allow the wander contributions of the individual network elements to be assessed and clues to be derived with regard to their causes. The test configuration shown in Fig. 5 is used for this purpose. An external cesium normal (e.g. Schomandl Frequency Standards) is however required for this exceptionally accurate measurement.

The measurement takes place over a period of 24 hours, simultaneously with a performance analysis in accordance with ITU-T G.826 and a capture of anomalies and defects. If any wander components occur, the cause must be identified in the same way as with the pointer analysis, i.e. the ANT-20 must be connected to the different ring segments one at a time until the faulty NE is found. The ANT-20 permits wander to be measured not only at the standard bit rate of 2 Mbit/s, but also at any common bit rate up to 2.5 Gbit/s. This is useful, because it facilitates measurements at bit rates that are suitable for clock distribution.

A further advantage of the ANT-20 is the option of evaluating the measured parameters directly using offline software (MTIE/TDEN). The extremely complex post-processing work on an external PC which is otherwise usual can thus be dispensed with.

Measuring the APS switch-over times

Conformance with the prescribed switch-over time from “working line” to “protection line” if an APS mechanism (automatic protection switching) is installed is highly critical. If the switch-over does not take place within the stipulated time, an avalanche effect may be set off. There is a deluge of alarms and either the complete ring or certain route segments may no longer be serviceable.
The switch-over time is determined by means of an out-of-service measurement on the PDH or SDH/SONET tributaries of the ADMs. When the system is switched over, alarms and bit errors (TSE = test sequence errors) appear at these ports, depending on the configuration. They remain present for the duration of the switch-over process.

It is important to measure the length of the interruption at the tributary, and not merely the K1/K2 switch-over times of the APS protocol.
The extremely flexible ANT-20 allows several different events to be selected as measurement parameters:

– SDH: MS-AIS, AU-AIS, TU-AIS, TSE
– SONET: AIS-L, AIS-P, AIS-V, TSE

The switch-over times are specified as 50 ms. The ANT-20 measures the duration of the event on the tributary with a resolution of 1 ms, even if the signal exhibits bit error rates of up to $2 \cdot 10^{-4}$. A second ANT-20, which generates the additional alarm types SF (B2 $1 \cdot 10^{-3}$) and SD (B2 $1 \cdot 10^{-6}$) in “Through” mode plus LOS, LOF and MS-AIS (AIS-L) in OOS mode, can be used to measure the APS.
Further information about the APS mechanisms for the different ring architectures can be found in the Technical Appendix.

Example: Typical APS measurement sequence

1. The signal structure is configured with the Signal Structure Editor of the ANT-20 and the APS time measurement is started.
2. The APS is activated by manually interrupting the working line. An event is either generated with a second ANT-20 in “Through” mode or set via the network management system.
3. The ANT-20 measures the duration of the interruption and compares it with the expected value. Simple interpretation of the event in the form “passed” or “failed”.

Testing the APS protocol for compliance with standards

If it is not possible to conform to the specified switch-over time, or if the system cannot be switched over at all because of a lack of communication between the NEs, a detailed error analysis must be carried out in order to determine the cause. Capturing all communications between the NEs during the switch-over permits each of the steps that make up the process to be evaluated separately. The byte capture function of the ANT-20 facilitates a detailed analysis of the K1/K2 bytes of the APS protocol (Appendix: Tables 1 and 2). This is one area in which the ANT-20 has a crucial edge over its competitors. Conventional testers only measure the switch-over time, without providing any means of conducting a systematic analysis in the event of an error. The ANT-20, on the other hand, analyzes the APS protocol by capturing up to 200 changes in the K1/K2 combinations. Each byte change is displayed in plain text, together with the number of frames and a time stamp. The protocol sequence can thus be analyzed fast and any invalid commands detected easily.
The ANT-20 can either be connected to the protection line as a monitor or looped into it in “Through” mode. This feature enables it to considerably simplify the complex measurements that are necessary for installation and fault localization.

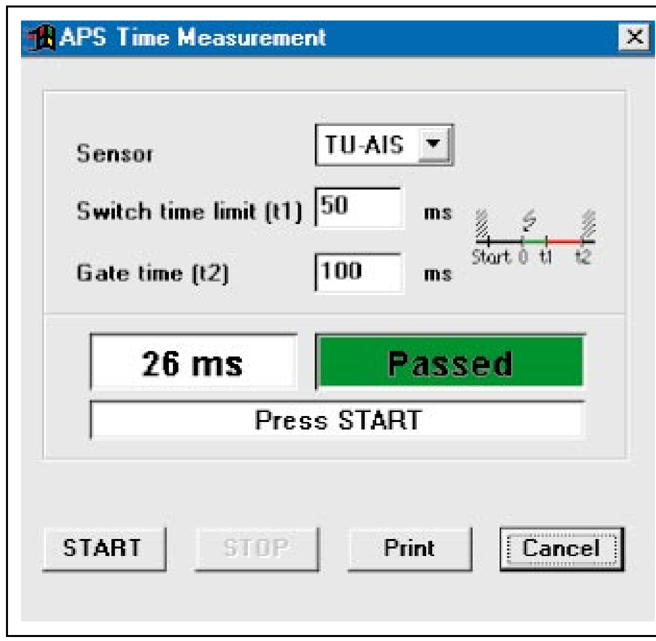
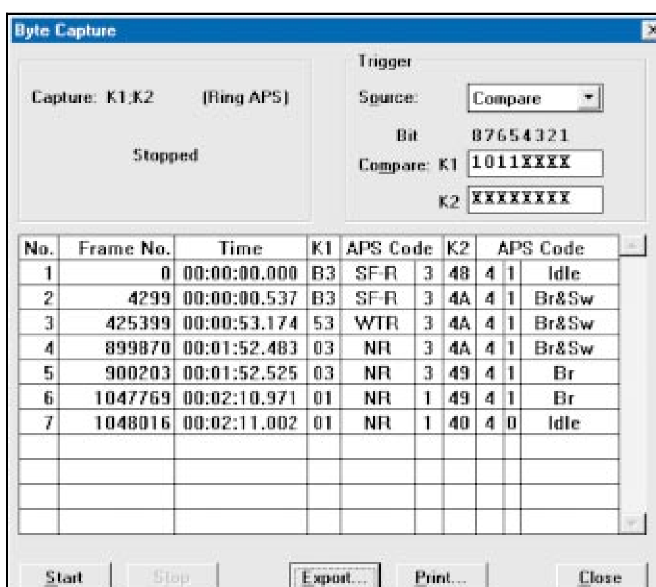


Fig. 7: Result of a switch-over time measurement



No.	Frame No.	Time	K1	APS Code		K2	APS Code		
1	0	00:00:00.000	B3	SF-R	3	48	4	1	Idle
2	4299	00:00:00.537	B3	SF-R	3	4A	4	1	Br&Sw
3	425399	00:00:53.174	53	WTR	3	4A	4	1	Br&Sw
4	899870	00:01:52.483	03	NR	3	4A	4	1	Br&Sw
5	900203	00:01:52.525	03	NR	3	49	4	1	Br
6	1047769	00:02:10.971	01	NR	1	49	4	1	Br
7	1048016	00:02:11.002	01	NR	1	40	4	0	Idle

Fig. 8: Example of a protocol sequence for a 2-fiber MS shared protection ring

Network management: Alarm sensors

By testing the alarm sensors, it is possible to tell whether or not error states have been detected correctly by the system components and transferred to the network management system via the appropriate data communication channels (DCC). These functions are normally only verified by means of random tests on a tributary. Various "typical" sensors are stimulated and checked, in order to establish whether they cause the corresponding error messages (e.g. LOS, B2, AIS, etc.) to be received and indicated on the management system.

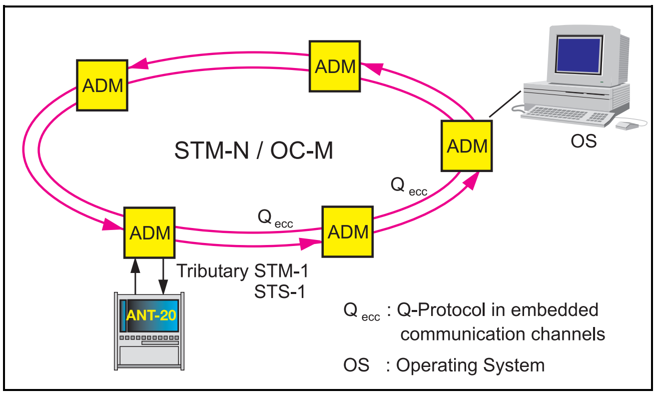
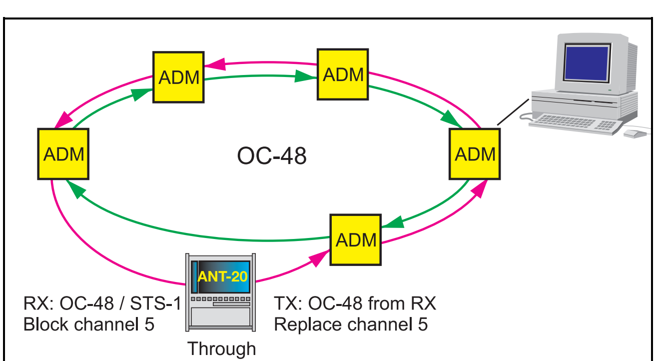


Fig. 9: Alarm sensor test

Network management: Path trace

Large numbers of tributaries can only be interconnected correctly if it is possible to assign each payload unequivocally to its own source (routing check). This is identified in the various hierarchies by means of the OH bytes J0, J1 and J2, in an ASCII data chain consisting of 15 (or 64) characters. This function is tested by generating a path trace on an arbitrarily selected 2 Mbit/s channel and comparing it with the expected value in the network element. The path trace is then modified, in order to determine whether the network element subsequently triggers a TIM alarm (trace identifier mismatch) as well as the corresponding RDI alarm (remote defect indication) in the reverse direction. The ANT-20 allows strings made up of any possible ASCII characters to be generated using the ASCII Editor.



Highly optimized testing thanks to automation

The large number of ring tests makes automation advisable. Network operators particularly have recognized the need to achieve a drastic reduction in the times required for line-up, maintenance and repair measurements by implementing automatic test routines. This extra convenience is offered by the "Test Sequencer" tool of the ANT-20. It permits existing test scenarios (sensor, jitter and error tests) to be assembled in order to obtain user-defined sequences. All tests on standard network elements are possible. In addition to the huge time saving, this method also ensures reproducible results. Furthermore, the same test sequences can be reused for troubleshooting measurements.

Line-up of SONET rings (USA)

The test methods used for SONET rings (USA) are basically similar to those described by the international SDH standard (Tables 1 and 2). A few important differences that must be remembered when SONET rings are tested are described in brief below.

Block & replace

This supplementary test method is often used in the USA to stimulate the switch-over process. The ring is closed and the ANT-20 is looped into the active fiber in "Through" mode (Fig. 10). In this configuration, the ANT-20 then receives the optical STM-16/OC-48 signal, for example, replaces one synchronous channel, including the POH, and re-transmits the modified signal. The same channel is subsequently analyzed in the receiver (block). Two crucial functions can now be tested:

– Transparency of the replaced channel across the entire ring (payload and configuration of the ADMs),
– Stimulation of the NE sensors responsible for the APS switch-over. This is tripped by B1, B2 or B3, depending on the configuration of the NE. The ANT-20 allows the various error thresholds to be tested in "Through" mode.

Fig. 10: Ring test based on the block & replace method

Technical Appendix

– Recommendations
– Linear protection
– Ring protection

Recommendations

In addition to the active, working channels, SDH and SONET networks also contain protection channels, which are able to handle the active traffic instead in the event of a fault (e.g. an interrupted fiber) or a degradation of the signal quality. This automatic protection switching mechanism (APS) prevents network failures and guarantees transmission quality.

Protection architectures

There are two fundamentally different protection architectures for APS:

– **Linear protection –** linear multiplex section protection (linear MSP) according to ITU-T G.783 and ANSI T1.105.1 for point-to-point links,
– **Ring protection –** multiplex section shared protection ring (MSSP ring) according to ITU-T G.841 and ANSI T1.105.1 for ring structures.

Both these protection mechanisms make use of alternate circuits or components. The signaling procedures required for the switch-over are transferred in overhead bytes K1 and K2 of the SOH (SDH) or the TOH (SONET) (Table A-1 and Table A-3).

Linear protection – G.783/T1.105.1
(in future in ITU-T G.841)

Recommendations G.783/T1.105.1 define the *linear* protection (linear MSP) method. The three different protection mechanisms that are available are shown in Table A-2.

Table: A-2: Linear protection architectures

1 + 1:	– Traffic is transmitted simultaneously on the working line and the protection line. – Both lines transport 100 % traffic. – In the event of a fault, the receiver is switched over to the protection line.
1 : 1:	– Traffic is transmitted on one channel only. – No traffic, or only low-priority traffic, is transmitted on the protection line, 100 % protection. – In the event of a fault, both the generator and the receiver are switched over to the protection line.
1 : N:	– Traffic is transmitted on the working line. No traffic, or only low-priority traffic, is transmitted on the protection line. – N lines share one protection line. – In the event of a fault, the protection line takes care of the traffic on the defective channel. – Common, economical protection method.

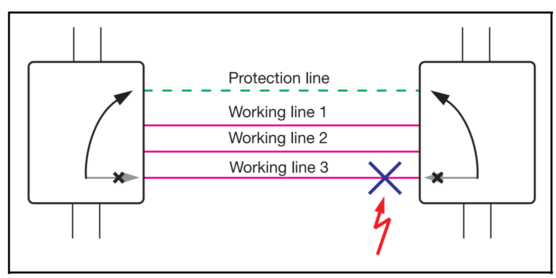


Fig. A-1: 1:N linear protection (N = 3)

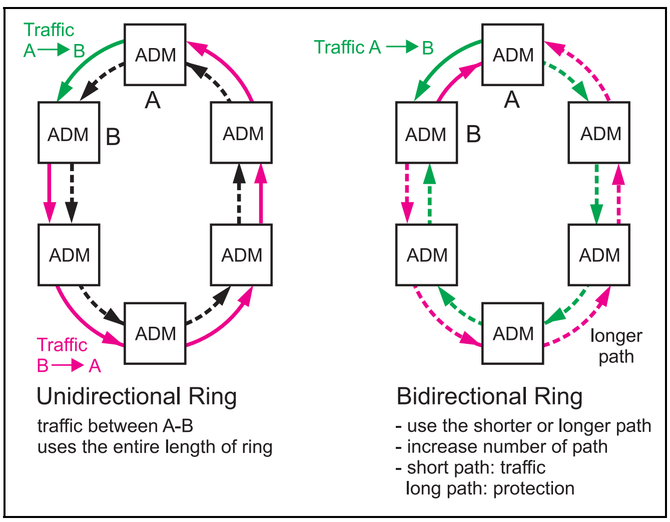
The simplest form of protection switching is referred to as 1+1 APS. Each working line is pro-

Table: A-1: K1 protocol for a linear MSP or MSSP ring (K1 indicates a protection switching request and the number of the requesting channel)

K1 Byte	**G. 841 (MS shared protection rings)**	**G.783 (Linear MS protection)**
1 2 3 4 5 6 7 8	**Bridge Request Code (Bits 1–4)**	**Request Codes (Bits 1–4)**
1 1 1 1	Lockout of Protection (Span) or Signal Fail (Protection) LP-S	Lockout of Protection
1 1 1 0	Forced Switch (Span) FS-S	Forced Switch
1 1 0 1	Forced Switch (Ring) FS-R	Signal Fail High Priority
1 1 0 0	Signal Fail (Span) SF-S	Signal Fail Low Priority
1 0 1 1	Signal Fail (Ring) SF-R	Signal Degrade High Priority
1 0 1 0	Signal Degrade (Protection) SD-P	Signal Degrade Low Priority
1 0 0 1	Signal Degrade (Span) SD-S	*Not used*
1 0 0 0	Signal Degrade (Ring) SD-R	Manual Switch
0 1 1 1	Manual Switch (Span) MS-S	*Not used*
0 1 1 0	Manual Switch (Ring) MS-R	Wait to Restore
0 1 0 1	Wait-To-Restore WTR	*Not used*
0 1 0 0	Exerciser (Span) EXER-S	Exercise
0 0 1 1	Exerciser (Ring) EXER-R	*Not used*
0 0 1 0	Reverse Request (Span) RR-S	Reverse Request
0 0 0 1	Reverse Request (Ring) RR-R	Do not Revert
0 0 0 0	No Request NR	No Request
	Destination Node Identification (Bits 5–8) (Node for which that K1 byte is destined)	**Channel Number (Bits 5–8)**
0 0 0 0	0	Null channel
0 0 0 1	1	Working channel 1
0 0 1 0	2	Working channel 2
. . . .	3–14	Working channel 3–14
1 1 1 1	15	Extra traffic channel

tected by one protection line. If an alarm occurs, a switch-over is initiated at both ends of the connection by the protection agent integrated in the network element. The switch-over is triggered by a defect (e.g. LOS). The switch-over at the opposite end is tripped by a feedback signal in the reverse direction.
The 1+1 architecture is 100% redundant. There is one protection line for each working line. The 1:N architecture is preferred for long-range networks for reasons relating to cost. Here, several working lines share the same protection line (Fig. A-1). The 1+1 and 1:N protection mechanisms are standardized in the ITU-T Recommendations. Protection lines can be used for low-priority traffic, which is however interrupted in the event of a switch-over.

Fig. A-2: Possible protection architectures (ring protection)



Ring protection – G.841/T1.105.1

There are various possible types of protection mechanism for ring structures, only some of which are standardized. The extremely complex MSSP ring method is described in ITU-T Recommendation G.841 (and ANSI T1.105.1). This method draws a basic distinction between

- **unidirectional and**
- **bidirectional ring structures**

Unidirectional rings: The information is only transmitted in one direction. A connection to a neighboring network element may consequently require the entire length of the ring (B → A traffic in Fig. A-2). The drawback of this principle is that significant propagation time variations can occur in both transmission directions.

Bidirectional rings: The connections between the individual network elements in this structure are bidirectional (Fig. A-2). The shorter of the two connections is used as the working line and the longer one as the protection line. If a fault occurs between two neighboring network elements A and B, element B initiates a switch-over and controls element A by means of the K1 and K2 bytes of the SOH.

Table A-3: K2 protocol for a linear MSP or MSSP ring (K2 indicates the bridge status with the channel number and the protection architecture)

K2 Byte	G.841 (MS Shared Protection Rings)	G.783 (Linear MS Protection)
1 2 3 4 5 6 7 8	**Source Node Identification (Bits 1–4)** (Node's own identification)	**Channel Number (Bits 1–4)**
0 0 0 0 0 0 0 1 0 0 1 0 . . . . 1 1 1 1	0 1 2 3–14 15	Null channel Working channel 1 Working channel 2 Working channel 3–14 Extra traffic channel
	Path Code (Bit 5)	**MSP Architecture (Bit 5)**
0 1	Short Path Code (S) Long Path Code (L)	1 + 1 architecture 1 : N architecture
	Status (Bits 6–8)	**(Bits 6–8)**
1 1 1 1 1 0 1 0 1 1 0 0 0 1 1 0 1 0 0 0 1 0 0 0	MS-AIS MS-RDI *Reserved for future use* *Reserved for future use* *Reserved for future use* Bridged and Switched (Br & Sw) Bridged (Br) Idle	MS-AIS MS-RDI *Reserved for future use (Note 1)* *Reserved for future use (Note 2)* *Reserved for future use* *Reserved for future use* *Reserved for future use* *Reserved for future use*

Note 1: Planned for bidirectional switching (ANSI T1.105.01)
Note 2: Planned for unidirectional switching (ANSI T1.105.01)

Unidirectional path-switched ring (UPSR)

This protection switching mechanism functions as follows (Fig. A-3):

- Network elements B and E transmit on both fibers. Traffic thus flows simultaneously on the working line and on the protection line.
- In the event of a fault (e.g. interruption between network elements C and D), the receiver of element E is switched over to fiber 2 (red fiber in Fig. A-3, right), where it finds a connection immediately.
- A path-switched ring is distinguished by its simple switch-over mechanism.
- No knowledge of the ring configuration is required.

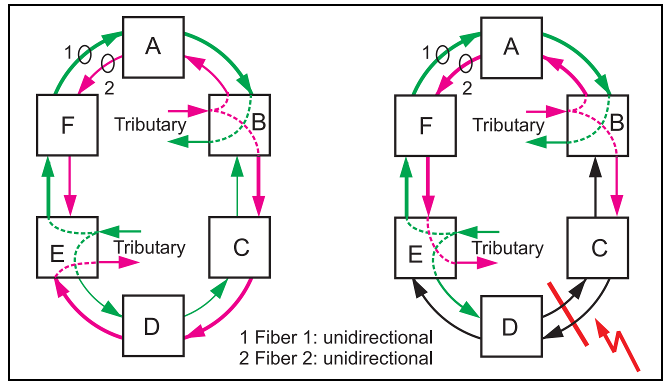


Fig. A-3: Unidirectional path-switched ring (UPSR)

Unidirectional line-switched ring (ULSR)

This protection switching mechanism functions as follows (Fig. A-4):

- Network elements B and E transmit on fiber 1 (working line).
- An interruption is assumed between network elements C and D. The E → B direction is not affected. An alternate route must be found for the A → B direction, however. The working line (red fiber) is therefore looped through to the protection line (blue fiber) in network elements C and D, while the remaining NEs are switched to "Through" mode.
- The APS sequence is controlled by means of the K bytes.
- This protection mechanism is known as "line-switched".
- A knowledge of the ring configuration is essential.

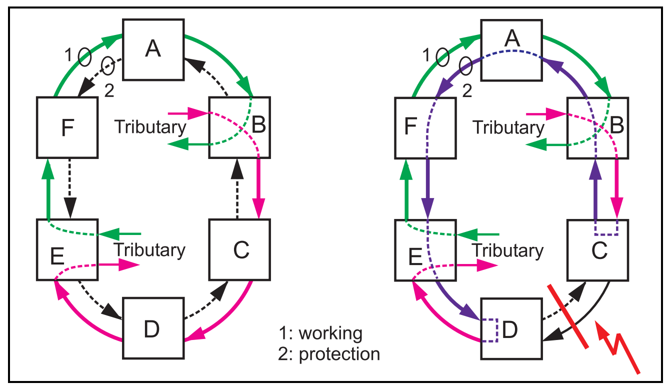


Fig. A-4: Unidirectional line-switched ring (ULSR)

Example: Basic APS sequence

1. A network element (NE) detects an error (e.g. LOS, LOF or a high bit error rate) and initiates a switch-over process.
2. The K1 and K2 bytes of the SOH are used to transfer the required information to the network elements and to control the necessary actions.
3. All network elements on either side of the interruption are switched over from "working line" to "protection line". All other elements loop through the protection line.
4. The connection is reactivated.
   Traffic flows via the "diversion".
5. After the fault has been cleared: return to the original mode, providing "revertive mode" is configured.

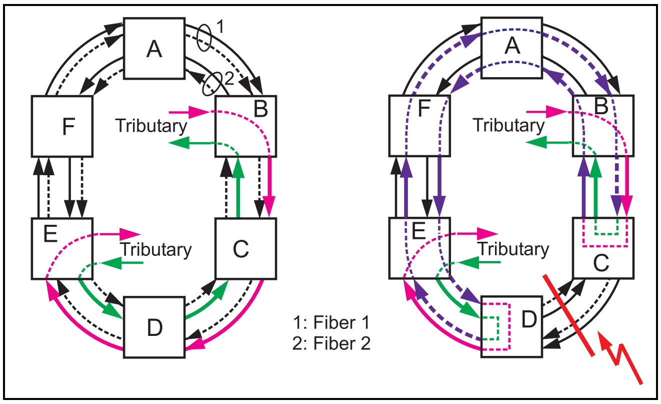


Fig. A-5: Two fiber bidirectional line-switched ring (BLSR)

Two-fiber bidirectional line-switched ring (BLSR)
This protection switching mechanism functions as follows (Fig. A-5):

- The connections between the individual network elements in this structure are bidirectional. Each fiber has 50% protection capacity.
- An interruption is assumed between network elements C and D. An alternate route must be found for both transmission directions. The working lines in network element C (red fiber) and network element D (green fiber) are therefore looped through to the protection line (blue fiber), while the remaining NEs are switched to "Through" mode.
- The APS sequence is controlled by means of the K1 and K2 bytes of the SOH/TOH.
- This switching mechanism is complex and involves the complete ring. A knowledge of the ring configuration is therefore essential.

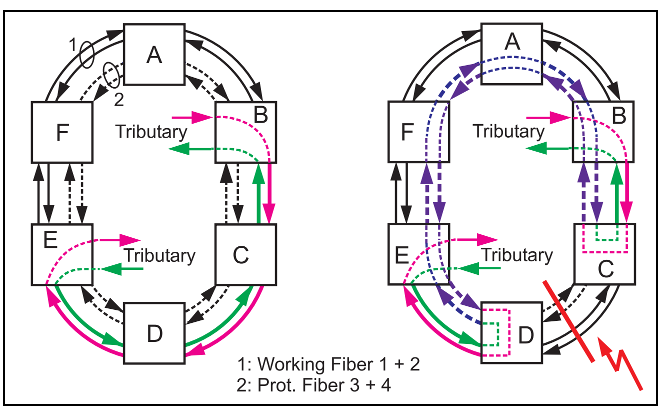


Fig. A-6: Four fiber bidirectional line-switched ring (BLSR)

Four-fiber bidirectional line-switched ring (BLSR)
This protection switching mechanism functions as follows (Fig. A-6):

- The working lines and the protection lines each consist of two fibers. 1:1 protection (100%) is therefore achieved.
- If, for example, an interruption occurs between network elements C and D, the working lines in these two elements (the red fiber in C and the green fiber in D) are looped through to the protection line, while the remaining network elements loop the protection line through.
- The connection is reactivated.
- A knowledge of the ring configuration is essential for this complex switching mechanism.

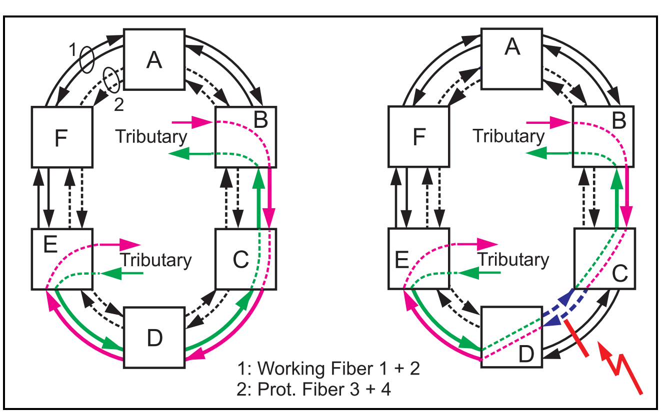


Fig. A-7: Four fiber bidirectional span-switched ring (BLSR)

Four-fiber bidirectional span-switched ring (BLSR)
This protection switching mechanism functions as follows (Fig. A-7):

- The working lines and the protection lines each consist of two fibers. 1:1 protection (100%) is therefore achieved.
- If an interruption is assumed between network elements C and D, only these two elements are switched over (span between C and D), while none of the other elements in the ring are affected. Even if several interruptions occur, a dependable connection is still guaranteed.
- A knowledge of the ring configuration is essential.

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