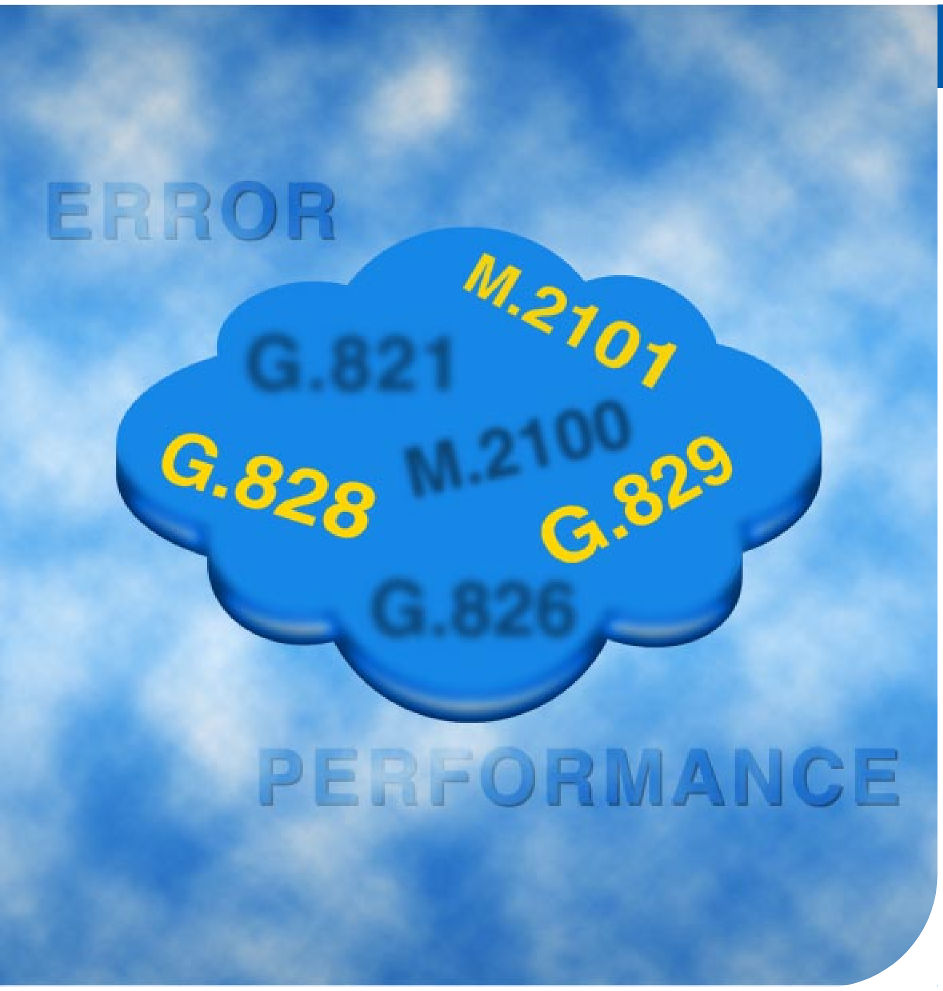
Understanding ITU-T Error Performance Recommendations

Application Note 62



ITU-T Recommendations on Physical Layer Error Performance in Digital Transmission Systems

Wavetek Wandel Goltermann
Communications Test Solutions

List of abbreviations

AIS	Alarm Indication Signal
ATM	Asynchronous Transfer Mode
BBE	Background Block Error
BBER	Background Block Error Ratio
BIP	Bit Interleaved Parity
CRC	Cyclic Redundancy Check
DSL	Digital Subscriber Line
EB	Errored Block
ES	Errored Second
ESR	Errored Second Ratio
HP	Higher Order Path
HRP	Hypothetical Reference Path
IG	International Gateway
ISDN	Integrated Services Digital Network
ITU	International Telecommunication Union
LOM	Loss of Multiframe
LOP	Loss of Pointer
LP	Lower Order Path
OAM	Operation and Maintenance
PDH	Plesiochronous Digital Hierarchy
PLM	Payload Label Mismatch
RDI	Remote Defect Indication
SDH	Synchronous Digital Hierarchy
SEP	Severely Errored Period
SEPI	Severely Errored Period Intensity
SES	Severely Errored Second
SESR	Severely Errored Second Ratio
TCM	Tandem Connection Monitoring
TIM	Trace Identifier Mismatch
TMN	Telecommunication Management Network
TU	Tributary Unit
UNEQ	Unequipped

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ITU-T Recommendations on Physical Layer Error Performance in Digital Transmission Systems[1]

1 Introduction

Error performance at the physical layer of digital communications equipment is a major factor in determining transmission quality. Measurements of error performance form the basis of operation of a number of test sets from Wavetek Wandel Goltermann.

Since error performance is a critical component of transmission quality in digital networks, the ITU-T has published a number of Recommendations laying down error performance parameters and objectives. Important examples include Recommendations G.821, G.826, G.828, G.829, I.356 and the M.21xx series. This article describes the meanings of these Recommendations using G.821/G.826 on the one hand and M.2100 on the other. It also considers the relationship between G.826, G.828 and the other M-series Recommendations mentioned. Brief reference is also made to Recommendation G.829.

Important Error Performance Recommendations

Recommendation G.821: *Error performance of an international digital connection operating at a bit rate below the primary rate*

Recommendation G.826: *Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate*

Recommendation G.828: *Error performance parameters and objectives for international, constant bit rate synchronous digital paths*

Recommendation G.829: *Error performance events for* SDH *multiplex and regenerator sections*

Recommendation I.356: ATM *cell transfer performance*

Recommendation M.2100: *Performance limits for bringing-into-service and maintenance of international* PDH *paths, sections and transmission systems*

Recommendations M.2101 and M.2101.1: *Performance limits for bringing-into-service and maintenance of international* SDH *paths and multiplex sections*

Recommendation M.2110: *Bringing-into-service of international* PDH *paths, sections and transmission systems and* SDH *paths and multiplex sections*

Recommendation M.2120: PDH *path, section and transmission system and* SDH *path and multiplex section fault detection and localization procedures*

2 Prehistory

In 1980, the first version of CCITT Recommendation G.821 was adopted. It defined the bit error performance of international ISDN connections with a bit rate of 64 kbit/s [4]. By 1996, G.821 had reached its fourth version. The technical content remained unchanged as the bit rate range was extended to N × 64 kbit/s. Here, N is chosen such that the bit rate is below the rate of the PDH primary systems. Annex D was deleted and with it any reference to higher bit rates. In addition, the Degraded Minute (DM) error performance parameter was suppressed.

For a good while, G.821 was "the" standard for planning, installing and operating digital networks. This Recommendation also influenced the development of transmission equipment and error measuring equipment used in these networks.

Over the years, however, difficulties in practical use of G.821 came to light. There are two main issues:

a) The error performance requirements in G.821 are based exclusively on 64 kbit/s connections. Real-life error monitoring is generally performed on transmission systems operating at significantly higher bit rates. The results obtained were "normalized" to a 64 kbit/s channel. Annex D to G.821 specified a method for doing this. However, the method was disputed from its inception, and Annex D has now been deleted. With the introduction of new broadband services, it makes little sense to normalize results to 64 kbit/s anyway.

(*Annex D to Recommendation G.821 stipulated proportional conversion of the error count measured at a higher bit rate and allocation to a 64 kbit/s channel. For instance, when measuring at a bit rate of 2048 kbit/s, one divides by a factor of 2048 : 64 = 32 to obtain the error count for 64 kbit/s. This method is no longer recommended. However, some WWG test sets still allow users to exploit this technique for investigating older test objects.*)

b) The definitions of the error performance parameters in G.821 are based on measurement of errored bits and thus on measurement of the bit error ratio. However, errored bits can be clearly recognized only if the bit sequence being monitored is known. This highly complicates measurements during operation of a system ("in-service measurements").

1 As part of restructuring of the International Telecommunication Union (ITU, Geneva) in March 1993, the standardization sector ITU-T was carved out of the former CCITT (International Consultative Committee for Telephony and Telegraphy).

3 Recommendation G.826[2]

As these problems came to light, work was eventually taken up on a new Recommendation, which later came to be known as G.826 with the title: "*Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate*" [5]. After much preliminary work, G.826 was approved in July 1983, thus complementing G.821 issued in 1980.

The new Recommendation had to meet the following requirements:

- Suitable for higher bit rates ($\geq$ 1.5 Mbit/s) without "normalization"
- In-service measurement of error performance parameters
- Non-transmission-medium dependent
- Non-transmission-system dependent (to support PDH, SDH, cell-based systems)
- More demanding objectives than G.821 in view of advances in newer transmission systems

How these requirements were met in Recommendation G.826 is shown below.

3.1 Range of Applications of Recommendation G.826

The Recommendation was conceived for international constant bit rate digital paths at or above the primary rate (1544 or 2048 kbit/s). The term digital path is defined in ITU-T Recommendation M.60 [11]. Transmission systems belonging to a path are connected between digital distribution frames or terminal equipment. The path end points can thus lie on the premises of end users if the overhead information is available there. In this case, G.826 also covers the customer access. Digital paths conforming to Recommendation G.826 can be transported over any type of transmission system, whether plesiochronous, synchronous or cell-based. The influence of the ATM layer is not taken into account (ATM = Asynchronous Transfer Mode). For ATM, Recommendation I.356 applies [8].

The specifications in G.826 apply end-to-end to a hypothetical reference path (HRP) having a length of 27,500 km. There are no variations for different transmission media (e.g. optical fiber, digital radio relay, metallic cable and satellite transmission systems).

Figures 1 and 2 illustrate the applications of G.826. Points A and B in Figure 1 are physical interfaces, e.g. to ITU-T Recommendation G.703 [5]. It is clear from Figure 2 that G.826 applies only to the physical layer and not the ATM layers.

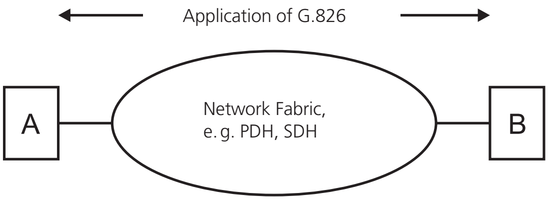
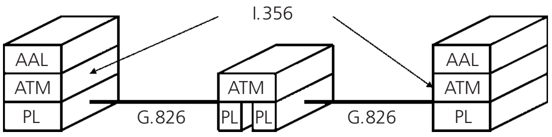


Fig. 1: Application of Recommendation G.826 for a non-ATM end-to-end transmission path



AAL – ATM Adaptation Layer
ATM – ATM Layer
PL – Physical Layer

Fig. 2: Application of Recommendation G.826 for ATM networks

2 A new version of Rec. G. 826 was published in 1998. This article takes into account the latest version.

What is a block?

A block is a set of consecutive bits associated with the path; each bit belongs to one and only one block. Consecutive bits may not be contiguous in time.

The error events

Errored Block (EB)
A block in which one or more bits are in error.

Errored Second (ES)
A one-second period with one or more errored blocks or at least one defect.

Severely Errored Second (SES)
A one-second period which contains 30% errored blocks or at least one defect.

Background Block Error (BBE)
An errored block not occurring as part of an SES

Severely Errored Period (SEP)
A period of time during which at least three but not more than 9 consecutive severely errored seconds (SES) occur.

The error parameters

Errored Second Ratio (ESR)
The ratio of ES to total seconds in available time during a fixed measurement interval.

Severely Errored Second Ratio (SESR)
The ratio of SES to total seconds in available time during a fixed measurement interval.

Background Block Error Ratio (BBER)
The ratio of Background Block Errors (BBE) to total blocks in available time during a fixed measurement interval.

Severely Errored Period Intensity (SEPI)
The number of SEP events in available time, divided by the total available time in seconds.

3.2 Block Error Measurement

During work on G.826, the aim from the very start was to facilitate “in-service” error performance assessment, making use of error monitoring equipment included in the actual transmission systems. This required a shift away from the prevailing technique of bit error measurement in G.821 and towards block error measurement.

Block monitoring takes advantage of the error monitoring equipment built into today’s transmission systems. The CRC technique (CRC = Cyclic Redundancy Check) and bit parity monitoring are employed. Errors must be detected with at least 90% probability. This requirement is met by the CRC-4 and BIP-8 techniques, but not by BIP-2 (BIP = Bit Interleaved Parity).

3.3 Definitions for Error Events and Parameters

Recommendation G.826 is based on monitoring of four error events. These events are defined in accordance with the block error evaluation principle described above. Definitions of these four events are given on the side. Regarding SEP/SEPI see section 4.2.

To simplify testing, a defect is included in the definition of the Severely Errored Second (SES). Defects are defined for various transmission systems (PDH, SDH, cell-based) (see section 3.7). It should be recalled that there are error structures that do not generate a defect but still cause significant transmission impairment. No SES would occur even though a major impairment is present.

It should also be noted that one older error event (the degraded minute) was not included in G.826. This parameter has proven impractical and was also deleted from Recommendation G.821.

Measurement of the events defined above provides absolute counts. For practical reasons, it is preferred to work with ratios. Recommendation G.826 uses three relative parameters (“error parameters”) listed on the side.

In accordance with the definition of error events, blocks occurring within severely errored seconds are not considered when computing the Background Block Error Ratio (BBER).

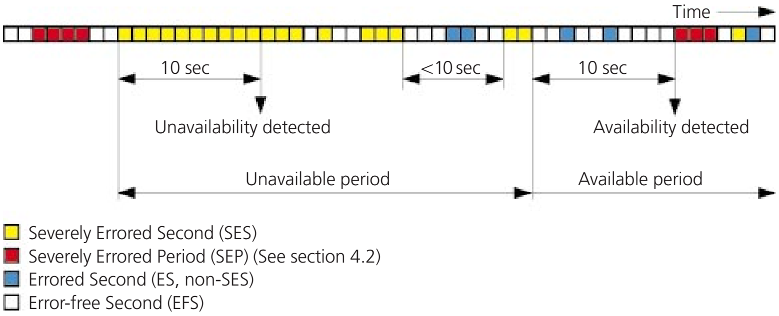
Note that for all three definitions when forming the ratios, only the time during which the transmission system is available is considered (see section 3.4).

3.4 Availability of the Transmission System

It was mentioned in section 3.3 that various parameters are computed only when the transmission system is available. For the purposes of Recommendation G.826, availability ends at the start of a time interval containing at least ten consecutive severely errored seconds in at least one direction of transmission.

The system becomes available again at the start of a time interval consisting of at least ten seconds that are not severely errored. Figure 3 shows an example of how to determine availability.

Fig. 3: Example of unavailability determination



3.5 Objectives for Error Performance

The most important part of Recommendation G.826 is the specification of the required objectives for error performance. A table (partly reproduced in Figure 4) gives the end-to-end objectives for the 27,500 km reference path. A digital path must simultaneously meet all of the objectives given in the table for its bit rate. The proposed observation interval is one month.

The table in Figure 4 has a number of qualifications:

For VC-4-4c concatenated containers in a 601 Mbit/s path, the block length is 75,168 bits/block. This is outside the range in the table. The associated BBER figure is 4×10^{-4}. It is also mentioned that ESR error objectives are not realistically applicable at high bit rates since even if the error ratio is low, the probability of observing block errors and thus errored seconds is high. There are thus no ESR specifications for the bit rate range 160 to 3500 Mbit/s[3].

Fig. 4: End-to-end error performance objectives for a 27,500 km digital HRP

Bit rate Mbit/s	1.5 to 5	>5 to 15	>15 to 55	>55 to 160	>160 to 3 500
Bits/block	800 to 5000	2000 to 8000	4000 to 20000	6000 to 20000	15000 to 30000
ESR	0.04	0.05	0.075	0.16	not specified
SESR	0.002	0.002	0.002	0.002	0.002
BBER	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	10^{-4}

One disadvantage when it comes to using the objectives is the variable block lengths for the different bit rates. Future improvements here would help to improve accuracy of measurement results.

Both directions of transmission on a path are monitored independently and must fulfil the objectives **simultaneously.** If this is not so, then the Recommendation is unfulfilled.

3.6 Allocating Error Objectives to the Reference Path

The error objectives from Figure 4 are allocated by Recommendation G.826 to individual portions of the reference path. The reference path is divided into two national portions at the ends of the path and an international portions (Figure 5).

Each national portion is allocated a block allowance of 17.5% of the end-to-end objective. Each national portion also receives 1% per 500 km covered[4]. If a satellite hop is used in the national portion, it can take up 42% of the tolerable errors. This 42% replaces the distance-based allowance.

The international portion is allocated a block allowance of the overall objective of 2% for each intermediate country and 1% per terminating country. A maximum of four intermediate countries is assumed. Moreover, in the international portion there is a distance-based allowance of 1% per 500 km system length. Here, a satellite hop is allocated 35% of the allowable overall errors.

When computing the system lengths, the actual route length is used. If it is unknown, the air route distance is used and multiplied by a factor of 1.25 or 1.5 respectively.

The values obtained in this manner are rounded up to the next integer divisible by 500. If the computation for the international portion produces an allowance of <6% of the overall objective, a 6% allowance is allocated.

In both the national and international portions, G.826 uses a hybrid allocation technique with distance-based and block allowances. Practical experience has shown this to be more effective than a simple “per km” allowance. Accordingly, the error performance of a transmission path is determined not only by its length but also by its complexity (e.g. due to an accumulation of multiplex equipment). This allocation yields the values given in Figure 6.

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3 At a transmission rate of 160 Mbit/s an assumed bit error ratio of 10^{-8} would result in about 1.6 errors per second, if the errors are equally distributed vs. time. Under these conditions, only errored seconds would occur.

4 The new Recommendation G.828 allocates 0.2% per 100 km to the national portions. With this approach, shorter distances can be considered more appropriately.

Anomalies	
a_1	Errored frame alignment signal
a_2	Errored block as indicated by an EDC
Defects	
d_1	Loss of signal
d_2	Alarm indication signal detected
d_3	Loss of frame alignment

PDH performance criteria

Types of paths	SES threshold
VC-11	600
VC12	600
VC-2	600
VC-3	2400
VC-4	2400
VC-4-4c	2400

SDH SES BIP thresholds

Near end defects	Kind of path
LP UNEQ	Lower-order paths
LP TIM	
TU LOP	
TU AIS	
HP LOM	Higher-order paths
HP PLM	
HP UNEQ	
HP TIM	
AU LOP	
AU AIS	

Far end defects	Kind of path
LP RDI	Lower-order paths
HP RDI	Higher-order paths

SDH defects resulting in SES

Anomalies	
a_1	Errored ATM cell (detected by an EDC in the F3 OAM cell)
a_2	Errored or corrected cell header
a_3	Corrected F3 cell header
a_4	Loss of a single F3 cell
Defects	
d_1	Loss of two consecutive OAM cells
d_2	Detection of transmission path alarm indication signal (TP-AIS)
d_3	Loss of cell delineation
d_4	Loss of signal

Anomalies and defects for cell-based systems

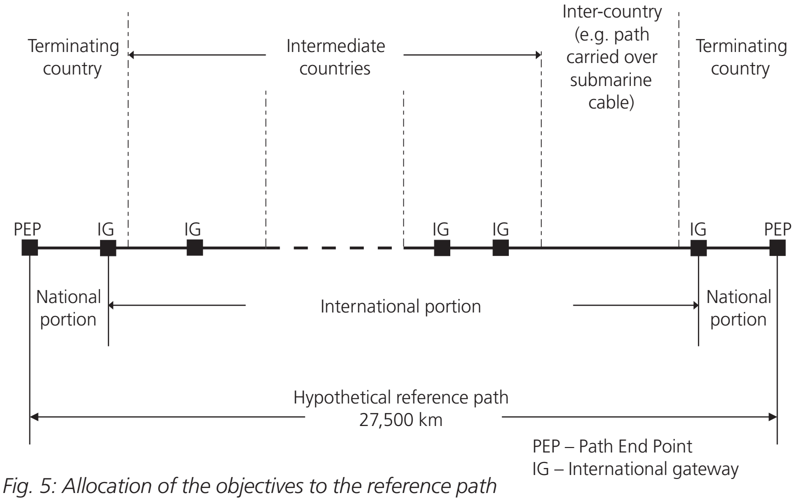


Fig. 5: Allocation of the objectives to the reference path

National portions (fixed)	35 %
Terminating countries (fixed)	2 %
International portions (fixed)	8 %
Distance-based allocation	55 %
Total	100 %

Fig. 6: Allocation of the objectives to a path (numerical values)

3.7 Error Performance Criteria used in Actual Practice

The error objectives given in Figure 4 apply in general and do not make reference to particular system implementations. For practical applications, G.826 offers three Annexes with more precise specifications for PDH, SDH and cell-based systems.

For these three system families, error criteria are specified that take into account the unique properties of these families and enable more practical usage. A distinction is made between defects and anomalies that lead to different error events.

3.7.1 Criteria for PDH Systems

For PDH systems, anomalies and defects are defined according to the list given here.

3.7.2 Criteria for SDH Systems

SDH systems basically use frame-oriented error monitoring equipment (BIP-n = Bit Interleaved Parity over n bits). The obvious choice was to equate SDH frames with G.826 blocks.

Theoretical computation of the conversion factor between BIP violations and block errors always assumes certain error models and can produce a factor not quite equal to one. Since fixed error models are not applicable in real life, however, for the purposes of G.826 a conversion factor of one was chosen for the sake of simplicity.

A detected BIP violation is thus directly interpreted as an errored block (and thus an Errored Second, ES).

When it comes to severely errored seconds, Recommendation G.826 is very precise. Under the above conditions, the chosen thresholds correspond to 30% errored blocks, as specified in the SES definition.

In SDH systems too, a time interval in which a defect occurs is considered a severely errored second. The criteria for defects are the path-layer defects in ITU-T Recommendations G.707 and G.783 [2] [3]. There is a distinction between defects at the near and far ends and also between lower-order and higher-order paths (see tables).

3.7.3 Criteria for Cell-based Systems

In cell-based systems, the cells are transmitted as a pure stream of cells without any framing (e.g. SDH frame). The Recommendations in the I.432 series [9] describe interfaces for such systems.

Anomalies and defects are also defined for cell-based systems. Here, a block is a sequence of cells between two OAM cells.

Note: Operation And Maintenance cells (OAM) are used for error performance monitoring in ATM systems. F3 cells monitor the digital path.

Occurrence of at least one anomaly or defect results in an errored block. Severely errored seconds are counted if 30% errored blocks are counted, or a defect.

3.8 Flow chart

Taking into account the definitions of anomalies, defects and availability, the (simplified) flow chart in Figure 7 is obtained.

Error monitoring detects anomalies (e.g. due to block errors) and defects. Anomalies and defects result in errored blocks or severely errored time segments. Taking into account the boundary conditions as defined, errored seconds and severely errored seconds (ES and SES) are then derived.

The quantities cES, cSES and cBBE are the counter results for ES, SES and BBE. The counters are reset at the start of a measurement. % EB means the ratio of errored blocks within an errored second to the total number of blocks per second. If 30% errored blocks are counted in a second, then SES is triggered. At the end of measurement period P, the Recommendation G.826 parameters can be computed as follows, taking into account Unavailable Seconds (UAS):

$$ESR = \frac{cES}{P - UAS}$$

$$SESR = \frac{cSES}{P - UAS}$$

$$BBER = \frac{cBBE}{(P - UAS - cSES) \times \text{blocks per second}}$$

In the simplified flow chart, the transition between "Availability" and "Unavailability" is not handled properly. All that the flow chart shows is that error events are counted only if the system is available.

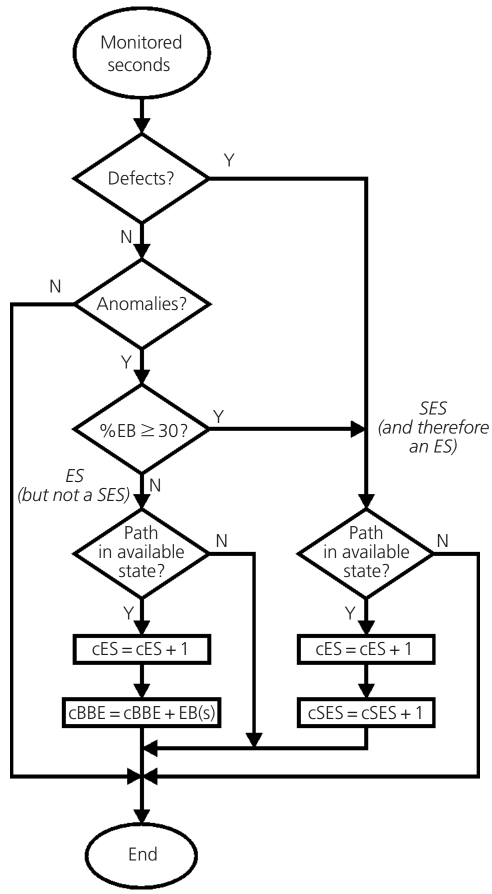


Fig. 7: Flow chart illustrating the recognition of anomalies, defects, errored blocks, ES, SES and BBE

3.9 Presenting Measurement Results

Many Wavetek Wandel Goltermann error test sets can evaluate errors as specified in Recommendation G.826.

The screenshot below (Figure 12) shows how in-service measurement results captured by WWG's ANT-20 Advanced Network Tester are displayed.

The following were evaluated: Errored Blocks (EB), Background Block Error Ratio (BBE), Errored Seconds (ES), Error-Free Seconds (EFS), Severely Errored Seconds (SES) and Unavailable Seconds (UAS). Figures 21 and 22 show the conditions for obtaining such measurement results.

4 Tighter Error Limits for Modern SDH Systems

Although Recommendation G.826 found broad use in the specification of PDH systems, very soon it was mainly applied to SDH systems. It became apparent that the target values in G.826, which to a large extent were influenced by PDH technology and older communications media, did not match the capabilities of modern SDH systems based on fiber optics technology. Doubts were also cast on whether the target values in G.826 were sufficient to ensure adequate transmission of ATM cells over SDH installations. As a result, work started in 1997 on the development of the new Recommendation G.828, with the aim of specifying tighter target values for error performance applying to modern SDH systems.

As the title "*Error performance parameters and objectives for international, constant bit rate synchronous digital paths*" indicates, G.828 also describes the error performance of digital paths, but is restricted exclusively to SDH.

Recommendation G828 has basically the same structure as G.826. Here, too, great emphasis is placed on the ability to make in-service measurements using the block-based measurement concept.

As well as the closer error limits, the following points stand out from a comparison with G.826:

4.1 Precise Path Definitions

During work on Recommendation G.828, it was discovered that no precise definitions for SDH path and reference path exist in the ITU literature. These have therefore been defined in G.828 as follows:

Hypothetical Reference Path

A Hypothetical Reference Path (HRP) *is defined as the whole means of digital transmission of a digital signal of a specified rate, including the path overhead, between equipment at which the signal originates and terminates. An end-to-end* Hypothetical Reference Path *spans a distance of 27,500 km.*

SDH Digital Path

An SDH *digital path is a trail carrying an* SDH *payload and associated overhead through the layered transport network between the path terminating equipment.*
A digital path may be bi-directional or unidirectional and may comprise both customer owned portions and network operator owned portions.

4.2 New Error Event, New Error Parameter

The proposal to introduce a new error event and a new error parameter led to long and difficult discussions. The suggestion to include the error event "*Severely Errored Period* (SEP)" in G.828 was based on the results of practical measurements. A SEP is defined as a period of time during which at least three but not more than 9 consecutive severely errored seconds (SES) occur. A period of consecutive SES can have the same effect as a micro-interruption and may lead to a severe impairment of the service supported by the SDH path.

The parameter corresponding to SEP is called "*Severely Errored Period Intensity* (SEPI)" and has the dimension 1/time. Although a very conservative target value of 0.0002/s was suggested for this parameter (this would have permitted about 518 micro-interruptions per month) it was not possible to fix this target value in G.828. Based on their measurement results, some network operators felt it unnecessary to monitor this new error parameter. Other operators defended the monitoring of SEPI just as vigorously.

Recommendation G.828 therefore contains only the definitions of SEP and SEPI in a separate section, terming them optional specifications, stating that their use requires further study.

Such studies must particularly also take the customer access to the communications network (*the last mile*) into account. Since the error limits stipulated in G.828 are independent of the transmission medium, the path in the customer access segment could be a radio link or xDSL link, for example. In such cases, the favorable measurement results claimed by those opposing implementation of SEP may not be achievable.

4.3 Tandem Connection Monitoring

The new Recommendation G.828 also takes account of *Tandem Connection Monitoring*, a feature of modern SDH systems that was unknown when G.826 was being developed. The lists of defects leading to the triggering of a severely errored second (SES) are much longer as a result. This is shown by the following tables, which are taken from Recommendation G.828.

Near end defects (NOTES 5, 6, 7)			**Kind of path**
Path termination	**Non-Intrusive Monitor**	**Tandem Connection**	
LP UNEQ (NOTE 3)	LP UNEQ (NOTES 3, 4)	LPTC UNEQ (NOTE 3)	Applicable to lower order paths and lower order tandem connections
LP TIM	LP TIM	LPTC TIM	
—	—	LPTC LTC	
—	LP VC AIS (NOTE 2)	—	
TU LOP	TU LOP	TU LOP	
TU AIS	TU AIS	TU AIS	
HP LOM (NOTE 1)	HP LOM (NOTE 1)	HP LOM (NOTE 1)	
HP PLM	HP PLM	HP PLM	
HP UNEQ (NOTE 3)	HP UNEQ (NOTES 3, 4)	HPTC UNEQ (NOTE 3)	Applicable to higher order paths and higher order tandem connections
HP TIM	HP TIM	HPTC TIM	
—	—	HPTC LTC	
—	HP VC AIS (NOTE 2)	—	
AU LOP	AU LOP	AU LOP	
AU AIS	AU AIS	AU AIS	

NOTE 1 – This defect is not related to VC-3.

NOTE 2 – VC AIS defect applies to monitoring a path at an intermediate point by means of non-intrusive monitoring.

NOTE 3 – Paths not actually completed, e.g. during path set-up, will contain the unequipped VC-n signal.

NOTE 4 – Two types of non-intrusive monitor functions are defined in Recommendation G.783. The original (version 1) type detect the UNEQ defect when an unequipped or a supervisory-unequipped VC signal is received. The advanced (version 2) type detects the UNEQ condition as type 1 but validates this condition by means of checking the content of the trace identifier; the receipt of a supervisory-unequipped VC signal will not result in an UNEQ defect. Neither will the receipt of a supervisory-unequipped VC signal result in the contribution of UNEQ condition to performance monitoring; if the supervisory-unequipped VC signal was not the expected signal, TIM defect will contribute to performance monitoring instead.

NOTE 5 – The above defects are path defects only. Section defects such as MS AIS, RS TIM, STM LOF and STM LOS give rise to an AIS defect in the path layers.

NOTE 6 – When a near-end SES is caused by a near-end defect as defined above, the far-end performance event counters are not incremented, i.e., an error-free period is assumed. When a near-end SES results from $\geq$ 30% errored blocks, the far-end performance evaluation continues during the near-end SES. This approach does not allow reliable evaluation of Far-End data if the Near-End SES is caused by a defect. It should be noted in particular, that the evaluation of Far-End events (such as SES or Unavailability) can be inaccurate in the case where Far-End SESs occur in coincidence with Near-End SESs caused by a defect. Such inaccuracies cannot be avoided, but are negligible in practice because of the low probability of the occurrence of such phenomena.

NOTE 7 – Refer to Recommendation G.783 for defects contributing to performance monitoring in each trail termination sink function.

Figure 8: Near-end defects leading to SES

Far end defects			Kind of path
Path termination	**Non-Intrusive Monitor**	**Tandem Connection**	
LP RDI	LP RDI	LPTC TC RDI	Applicable to lower order paths and lower order tandem connections
HP RDI	HP RDI	HPTC TC RDI	Applicable to higher order paths and higher order tandem connections

Figure 9: Far-end defects leading to SES

4.4 Comparison of Target Error Limit Values in Recommendations G.828 and G.826

As well as defining the new specifications SEP and SEPI, and taking *Tandem Connection Monitoring* into account, the new Recommendation defines tighter target values for error performance. This particularly affects the parameters *Errored Second Ratio* (ESR) and *Background Block Error Ratio* (BBER). Figure 10 shows Table 1/G.828 together with the target values that it includes. The corresponding values from G.826 for ESR and BBER are shown in brackets for comparison.

NOTE 2 regarding BBER is of interest: This mentions that, for increasing block size, the BBER values cannot be kept constant or even improved. (Also refer to section 4.5.)

Bit rate (kbit/s)	Path type	Blocks/s	ESR	SESR	BBER	SEPI (NOTE 3)
1 664	VC-11, TC-11	2 000	0.01 (0.04)	0.002	5×10^{-5} (2×10^{-4})	—
2 240	VC-12, TC-12	2 000	0.01 (0.04)	0.002	5×10^{-5} (2×10^{-4})	—
6 848	VC-2, TC-2	2 000	0.01 (0.05)	0.002	5×10^{-5} (2×10^{-4})	—
48 960	VC-3, TC-3	8 000	0.02 (0.075)	0.002	5×10^{-5} (2×10^{-4})	—
150 336	VC-4, TC-4	8 000	0.04 (0.16)	0.002	1×10^{-4} (1×10^{-4})	—
601 344	VC-4-4c, TC-4-4c	8 000	(NOTE 1)	0.002	1×10^{-4} (1×10^{-4})	—
2 405 376	VC-4-16c, TC-4-16c	8 000	(NOTE 1)	0.002	1×10^{-4} (1×10^{-4})	—
9 621 504	VC-4-64c, TC-4-64c	8 000	(NOTE 1)	0.002	1×10^{-3} (NOTE 2)	—

NOTE 1 – ESR objectives tend to lose significance for applications at high bit rates and are therefore not specified for paths operating at bit rates above 160 Mbit/s. Nevertheless, it is recognized that the observed performance of synchronous digital paths is error-free for long periods of time even at Gbit/s rates; and that significant ESR indicates a degraded transmission system. Therefore, for maintenance purposes ES monitoring should be implemented within any error performance measuring devices operating at these rates.

NOTE 2 – This BBER objective corresponds to a equivalent bit error ratio of 8.3×10^{-10}, an improvement over the bit error ratio of 5.3×10^{-9} for the VC-4 rate. Equivalent Bit Error Ratio is valuable as a rate-independent indication of error performance, as BBER objectives cannot remain constant as block sizes increase.

NOTE 3 – SEPI objectives require further study.

Figure 10: End-to-end target values for the error performance of a 27,500 km SDH-HRP

4.5 Problems in Error Detection with Increasing Block Size

One uncertainty in the target value definitions of Recommendation G.826 was given by the failure to provide exact information about the size of the blocks to be evaluated. This disadvantage has been corrected in G.828, a precise block length being defined for each bit rate as shown in figure 10.

Figure 11 shows that the number of blocks monitored per second for bit rates from VC-3 up to VC-4-64c remains constant at 8,000. This means that the block size increases with increasing bit rate. At the same time, BIP-8 is retained for error detection.

This increasing block size results in a steady reduction in the effectiveness of error monitoring as the bit rate increases. Larger bit error rates can not be detected accurately in this way. As a result of wide-ranging theoretical considerations, it was suggested that the number of blocks to be monitored per second should increase along with the bit rate so as to achieve an approximately constant block size. Each VC-4 *Virtual Container* should be evaluated separately, so this would have meant evaluating 4 × 8,000, 16 × 8,000 or 64 × 8,000 blocks per second for VC-4-4c, VC-4-16c and VC-4-64c respectively. This would mean that the block size above VC-4 would remain constant at 18,792 bits.

Regardless of the correctness of the theory behind such considerations, it was not possible to implement this in the Recommendation, because it would have meant changing the corresponding hardware Recommendations that were already at a late stage of development. The considerations were, however, reflected in the new Recommendation G.829 (see section 5).

Bit rate (kbit/s)	Path type	Blocks/s	SDH Block size in G.828	EDC
1 664	VC-11, TC-11	2 000	832 bits	BIP-2
2 240	VC-12, TC-12	2 000	1 120 bits	BIP-2
6 848	VC-2, TC-2	2 000	3 424 bits	BIP-2
48 960	VC-3, TC-3	8 000	6 120 bits	BIP-8
150 336	VC-4, TC-4	8 000	18 792 bits	BIP-8
601 344	VC-4-4c, TC-4-4c	8 000	75 168 bits	BIP-8
2 405 376	VC-4-16c, TC-4-16c	8 000	300 672 bits	BIP-8
9 621 504	VC-4-64c, TC-4-64c	8 000	1 202 688 bits	BIP-8

Figure 11: Block sizes in error monitoring of SDH paths

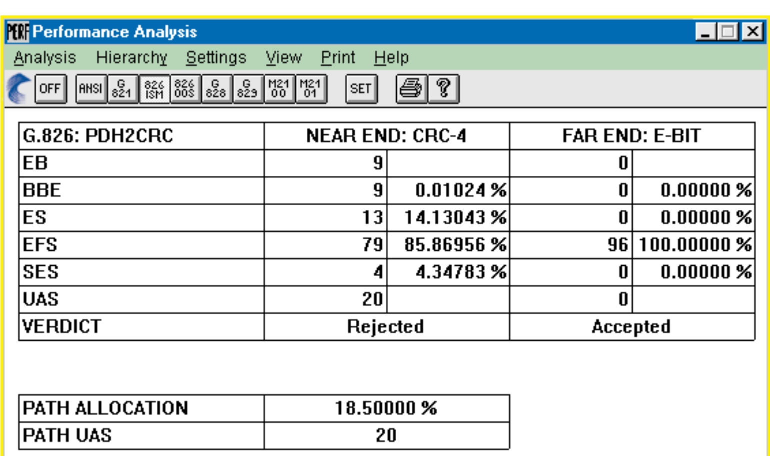
4.6 Differences Between Recommendations G.821 and G.826/G.828

4.6.1 Differences in the Basic Concept

Section 2 already pointed out some differences between the two Recommendations. The main points are as follows:

- G.821 deals with connections.
- G.821 is used only for bit rates below the bit rates of primary systems.
- G.821 is based on measuring bit errors.
- Since there are no overheads at these bit rates, in-service measurements (ISM) are either impossible or very difficult.
- G.826 and G.828 deal with paths.
- G.826 and G.828 are used for bit rates at or above the primary system bit rates.
- G.826 and G.828 are based on measuring block errors.
- By using existing error detection circuitry, in-service measurements are possible.

Due to the potential for in-service measurements in particular, G.826 has superseded the older G.821. G.826 even says that it is “currently the only Recommendation required for designing the error performance of digital paths at or above the primary rate”.



G.826: PDH2CRC	NEAR END: CRC-4		FAR END: E-BIT	
EB	9		0	
BBE	9	0.01024 %	0	0.00000 %
ES	13	14.13043 %	0	0.00000 %
EFS	79	85.86956 %	96	100.00000 %
SES	4	4.34783 %	0	0.00000 %
UAS	20		0	
VERDICT	Rejected		Accepted	

PATH ALLOCATION	18.50000 %
PATH UAS	20

Figure 12: Error evaluation to Recommendation G.826 using the ANT-20 Analyzer

Now that G.828 has been approved, this new Recommendation will gain in importance with regard to modern SDH systems, and will itself supplant G.826 and particularly G.821.

4.6.2 Comparing Requirements for Error Performance

According to section 3, one of the aims in drafting G.826 – and also, later on, G.828 – was to bolster the objectives for error performance compared to the older G.821. A direct comparison is not possible due to the differences in defining the error events. To enable comparison, we must know how the bit error ratio relates to the errored block. This relationship is a function of the error distribution vs. time. For example, if errors occur in a burst, Recommendation G.821 would count a number of bit errors, while G.826/G.828 might count only one errored block. On the other hand, if the errors are equally distributed vs. time, then each bit error can produce a block error. However, it can be verified that depending on the error model, the requirements of Recommendation G.826 and G.828 can be much tougher than G.821.

It should also be noted that in terms of the defined error limits, Recommendations G.821 and G.826/G.828 are not fully compatible. An addendum to G.821 from the year 1996 makes reference to this issue.

Improving the harmony between these two Recommendations is the object of further standardization work.

5 The New Recommendation G.829

Along with G.828, the new Recommendation G.829 "E*rror performance events for* SDH *multiplex and regenerator sections*" was also approved in March 2000. In contrast with the Recommendations in the G-series already mentioned, G.829 does not define any target values. It merely describes the error events for SDH multiplex and regenerator sections. One reason for the omission of objectives lies with the skepticism, aired by several network operators, towards accepting regulations governing network components that are often the responsibility of national authorities. Regardless of this, the definition of the error events is important in connection with bringing-into-service and maintaining SDH sections, because measurement results will only be comparable if the same definitions of events are used.

G.829, too, is based on the principle of monitoring block errors, allowing measurements to be made in-service. Accordingly, the Recommendation defines the block size, number of blocks per SDH frame, number of blocks transmitted per second and the error detection code (EDC) to be used for the various SDH bit rates up to STM-64.

The definition of the SES thresholds, i.e. the number of errored blocks that triggers a SES, is a major part of Recommendation G.829. This threshold is set at 30% errored blocks for both Recommendations G.826 and G.828.

This threshold could not be used for multiplex and regenerator sections, however. Because the error detection mechanisms at path and section level are different, identical thresholds would mean that there would be no compatibility between the two levels. This would result in a severely errored second (SES) being triggered at the section level by a certain number of errored blocks without a corresponding SES being detected at the path level. The reverse situation could also occur. The thresholds were fixed after comprehensive theoretical investigation to give the best possible compatibility between the two levels.

The table below shows the threshold values that were determined for SDH multiplex sections for the bit rates from STM-0 to STM-64. The abbreviation "EBs" stands for errored blocks.

Bit rate	STM-0	STM-1	STM-4	STM-16	STM-64
SES threshold	15% EBs	15% EBs	25% EBs	30% EBs	30% EBs

Figure 13: SES thresholds for SDH multiplex sections as per Recommendation G.829

As mentioned, Recommendation G.829 covers multiplex and regenerator sections. The definitions for regenerator sections are limited to radio link and satellite systems, however.

The principle of a fixed block length is applied in the case of regenerator sections. Since these regulations are media-specific, it was possible to arrive at the desired definition in terms of fixed block lengths. This is shown in figure 14.

STM-N	Block size	Blocks per frame	Blocks/s	EDC
STM-0	6 480 bits	1	8 000	BIP-8
STM-1	19 440 bits	1	8 000	BIP-8
STM-4	19 440 bits	4	4 × 8 000	4 × BIP-8
STM-16	19 440 bits	16	16 × 8 000	16 × BIP-8

Figure 14: Block sizes, blocks per second and EDC for regenerator sections

6 The M.21xx-series Recommendations

6.1 Differences in Purpose for G- and M-series Recommendations

Differences in purpose between Recommendations G.821, G.826 and G.828 and the M.21xx series start with their different origins: The G-series Recommendations are from ITU-T Study Group 13 (General network aspects), while the M series are from Study Group 4 (Network maintenance and TMN). The main differences in purpose for these two series of Recommendations are as follows:

- G.821, G.826 and G.828 define long-term performance objectives to be met.
- G.821, G.826 and G.828 require very long test intervals (one month).
- The M-series Recommendations are particularly useful when bringing-into-service new transmission equipment. They are intended to assure that the requirements of the G series are met in every case (e.g. taking into account aging of components).
- As a general rule, the requirements of the M series are tougher than those of the G series considered here.
- For practical reasons, the M.21xx-series Recommendations allow short test intervals.

6.2 Recommendation M.2100

Recommendation M.2100 ("*Performance limits for bringing-into-service and maintenance of international* PDH *paths, sections and transmission systems*") describes how to bring into service PDH systems and their components and what objectives must be met in this process [12]. Here, in terms of error performance, the basis is Recommendations G.821 (for 64 kbit/s) and G.826 (for higher bit rates) and in terms of timing performance (synchronization, jitter and wander), Recommendations G.822 and G.823/G.824.

6.2.1 Comparison of Error Objectives in M.2100 and G.826

Reference performance objectives (RPO) are an important parameter in Recommendation M.2100. The values are chosen to assure that the requirements of G.826 are met on the long-term. This is done by setting the base values in M.2100 to only 50% of the limits in G.826. Figure 15 compares these values.

System level	Primary		Secondary		Tertiary		Quaternary	
Rec.	G.826	M.2100	G.826	M.2100	G.826	M.2100	G.826	M.2100
ESR	0.04	0.02	0.05	0.025	0.075	0.0375	0.16	0.08
SESR	0.002	0.001	0.002	0.001	0.002	0.001	0.002	0.001

Fig. 15: Performance objectives in Recommendations G.826 and M.2100

The table shows the values for the hypothetical reference path with a length of 27,500 km. For bit rates at or above the primary rate, Recommendation M.2100 takes only into account the international portion of a path. Therefore, only 63% of the objectives in Figure 15 may be used for this portion, as stipulated by G.826 for the "International portion".

Note: 63% is the difference between the overall 100% allowance for a 27,500 km reference path minus 37% for the national portion. For the national portion, G.826 defines a block allowance of 2 × 17,5% and a distance-based allowance of 2% corresponding to an assumed minimum length of 2 × 500 km. The result is as stated: 37%. See also Figure 6.

6.2.2 Recommendation M.2100 in the Real World

Recommendation M.2100 is intended to enable dimensioning of portions of a transmission path (the M.2100 term is path core element, PCE) so that all requirements from Figure 15 are met. A practical application of this for the Errored Seconds (ES) parameter, based on the example of bringing a system into service, will now be considered.

As a general rule, paths are composed of sub-elements of different length. Reference performance objectives (RPOs) must be assigned to each of them. As an aid, M.2100 includes tables showing the acceptable RPO allocations. Figure 16 gives an excerpt from one of these tables specifying distance-based objectives for intermediate countries and countries at the end of a path. There are similar tables for submarine cables and satellites.

Path core element	Allocation (% of end-to-end objective)
distance ≤ 500 km	2.0 %
500 km < distance ≤ 1000 km	3.0 %
1000 km < distance ≤ 2500 km	4.0 %
2500 km < distance ≤ 5000 km	6.0 %
5000 km < distance ≤ 7500 km	8.0 %
distance > 7500 km	10.0 %

Fig. 16: Allocation of performance objectives to path core elements

The percent figures in the second column of the table refer to the objectives valid for M.2100 from Figure 15. For example, to determine the ES objective for a portion of a path operating at the primary bit rate and having a length of 4000 km, one must take 6% of 0.02. This objective is then the starting point for measurements during bringing-into-service and maintenance of transmission equipment.

Unlike the case of Recommendation G.826 (whose objectives require long-term measurements over a one-month interval), the real world does not look kindly on bringing into service and maintenance measurements that require very long test intervals.

Thus, M.2100 also allows shorter test intervals, e.g. one day. Of course, with shorter tests the measurement uncertainty increases, which must be taken into account when interpreting results.

Recommendation M.2100 describes the basic conditions as shown in the graphics in Figure 17 and the following equations. Initially for bringing a system into service (bringing-into-service objective, BISO), one assumes as a reference quantity 50% of the starting value above to assure that even as the equipment ages, there is still enough room to conform to the given limits.

In other words, BISO = RPO/2.

RPO is computed with the formula
RPO = PO × A × TP.

In this formula, PO (performance objective) is the objective taken from the table in Figure 15. A is the allowance for the portion of a path (path allowance) according to the table in Figure 16, and TP (test period) the measurement time in seconds.

The limits S1 and S2 for the uncertainty range of the measurement are computed with the following formulae:

S1 = RPO/2 – D and S2 = RPO/2 + D

For D, the (pragmatic) value is assumed to be:

$D = 2 \times \sqrt{\text{BIS Objective}}$

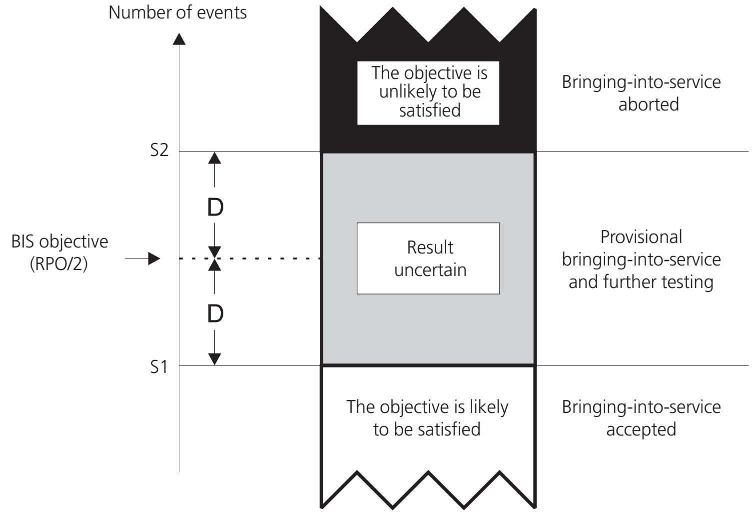


Fig. 17: Bringing-into-service (BIS) limits and conditions

In actual numbers, this results in the following for a test time of one day:

Total allowable number of errored seconds per day = 0.02 × 86,400 = 1728 ES

Of which 6%
(for a 4000 km portion) = 0.06 × 1728 = 104 ES/day

Bringing-into-service objective = 0.5 × 104 = 52 ES/day

Thus, during bringing into service, for a 4000 km sub path of a primary system a maximum of 52 errored seconds per day can be accepted.

D is computed as $D = 2 \times \sqrt{52} = 14.42$

Then,
S1 = 52 – 14.42 ≈ 37 and S2 = 52 + 14.42 ≈ 66

	ES (2%) 1 day				ES 7 days	SES (0.1%) 1 day				SES 7 days
Path allocation	RPO	BISO	S1	S2	BISO	RPO	BISO	S1	S2	BISO
0.50%	9	4	0	8	30	0	0	0	1	2
1.00%	17	9	3	15	60	1	0	0	2	3
1.50%	26	13	6	20	91	1	1	0	2	5
2.00%	35	17	9	26	121	2	1	0	3	6
2.50%	43	22	12	31	151	2	1	0	3	8
3.00%	52	26	16	36	181	3	1	0	4	9
3.50%	60	30	19	41	212	3	2	0	4	11
4.00%	69	35	23	46	242	3	2	0	4	12
4.50%	78	39	26	51	272	4	2	0	5	14
5.00%	86	43	30	56	302	4	2	0	5	15
5.50%	95	48	34	61	333	5	2	0	5	17
6.00%	104	52	37	66	363	5	3	0	6	18
6.50%	112	56	41	71	393	6	3	0	6	20
63.00%	1089	544	498	591	3810	54	27	17	38	191

Fig. 18: Bringing-into-service performance objectives for primary systems

For test lengths of one day, Recommendation M.2100 contains extensive tables with numerical values for RPO, BISO, S1 and S2 with path allowances in the range 0.5 to 63% for Errored Seconds (ES) and Severely Errored Seconds (SES).

Values for BISO with test lengths of 7 days are also given. Figure 18 shows an excerpt from one of these tables. The 6% path allowance row contains the numbers from the above example.

These tables save M.2100 users the trouble of doing many calculations. Once the percent allowance for the path elements is known, the figures for bringing a system into service can be read off.

6.3 Recommendations M.2101.1 and M.2101

Alongside M.2100, the subject under discussion here also involves Recommendations M.2101.1 and M.2101 ("*Performance limits for bringing-into-service and maintenance of international* SDH *paths and multiplex sections*") [13] [14]. These Recommendations are very close to M.2100 in terms of purpose and format, but deal exclusively with SDH systems. M.2101.1 and M.2101 include useful tables as described above, and the computational techniques for determining parameters are essentially the same. The two M-series Recommendations for SDH systems (also see figure 19) can thus be considered as the equivalent of Recommendation M.2100 for PDH systems.

The similar numbering and identical titles of the two Recommendations can lead to confusion. It should be noted that M.2101.1 is the older of the two Recommendations, and was originally intended to be supplemented with a Recommendation numbered M.2101.2. M.2101.1 is based on the performance Recommendation G.826 and was approved before the completion of G.828.

Recommendation M.2101 was developed parallel to Recommendation G.828, and takes its specifications and target values into account (including SEP). M.2101 was approved in June 2000. It was planned that M.2101.1 would be withdrawn on the acceptance of M.2101 (hence the identical titles). Agreement on this could not be reached, however, since, it was argued, SDH systems dimensioned according to G.826 will continue to be in service for some time to come and scrapping M.2101.1 would mean there was no Recommendation governing putting such systems into service.

The decision was made therefore to allow Recommendation M.2101.1 to coexist initially alongside M.2101. The intention is, however, to incorporate the important specifications from M.2101.1 into an Annex to M.2101, after which M.2101.1 will be deleted. The revised edition of M.2101 would then take Recommendations G.826 **and** G.828 into account.

6.4 Application of G-series and M-series Recommendations

Figure 19 summarizes the applications of the Recommendations discussed here. It includes all four of the G-series Recommendations and the corresponding M-series Recommendations.

Figure 19: Application of the G-series and M-series Recommendations

Recommendation	**G.821**	**G.826**	**G.828**	**G.829**	**M.2100**	**M.2101[2)]**
Application	Long-term error performance (OOS)	Long-term error performance (ISM/OOS)	Long-term error performance (ISM/OOS)	Error event definition	BIS limits ISM/OOS (PDH)	BIS limits ISM/OOS (SDH)
Monitored element	N × 64 kbit/s connections	PDH/SDH/ cell-based paths	SDH paths	SDH sections	PDH paths, sections, systems	SDH paths, sections
Min. Bit rate	64 kbit/s	1.5 Mbit/s VC-11	VC-11	Sub-STM-0	64 kbit/s	VC-11, STM-0
Max. Bit rate	31(24) × 64 kbit/s	3500 Mbit/s VC-4-4c	VC-4-64c	STM-64	140 Mbit/s	VC-4-64c, STM-64
Evaluation period	30 days	30 days	30 days	—	24 h, 2 h, 7 days	24 h, 2 h, 7 days, (15 min)
Error detection mechanism	Bit error	Block error	Block error	Block error	Bit error, block error	Block error
Error event	ES, SES	ES, SES[1)], BBE	ES, SES[1)], BBE	ES, SES[1)], BBE	as G.821 and G.826	as G.826, G.828, G.829

1) Severely Errored Seconds, (SES) are also derived from detected defects such as *Loss of Signal (LOS), Loss of Frame Alignment (LOF), Alarm Indication Signal (AIS)* or *Remote Defect Indication (RDI).*

2) Recommendation M.2101.1 still covers paths based on G.826. The inclusion of the corresponding values into M.2101 is planned.

6.5 Other Recommendations in the M.21xx Series

As well as Recommendations M.2100, M.2101.1 and M.2101, there are a number of other Recommendations in the M.21xx series, which are of importance in describing the error performance of digital communications equipment.

6.5.1 Recommendation M.2102

Recommendation M.2102 ("*Maintenance thresholds and procedures for recovery mechanisms* (*Protection and restoration*) *of international* SDH VC *trails* (*paths*) *and multiplex sections*") [15] deals with spare circuits for use when faults occur, when transmission performance drops or during maintenance work. This Recommendation defines thresholds for switchover to spare circuits for SDH VC paths.

6.5.2 Recommendation M.2110

Recommendation M.2110 ("*Bringing-into-service of international* PDH *paths, sections and transmission systems and* SDH *paths and multiplex sections*") [16] is also clearly related to M.2100 and M.2101 from its name. M.2110 takes an in-depth look at the procedures used for bringing transmission equipment into service. One major distinction is between in-service and out-of-service measurements. For out-of-service measurements, this Recommendation refers to the test equipment Recommendations (O.150 [18], O.151 [19] and O.181 [23]), which are covered by instruments from WWG. Initial measurements are to be performed during bringing-into-service using pseudo random bit sequences generated by external test sets.

As a first step, a measurement is made over a 15-minute interval using pseudo random bit sequences; test signals are preferred in which the pseudo random bit sequence is contained in a pulse frame ("framed" measurements). During this measurement, the test object must remain available and no errors may occur. If this condition is not fulfilled, the procedure may be repeated twice.

If errors still occur, then the error sources must be eliminated before proceeding (see also Recommendation M.2120 below).

If the first step is successful, a 24-hour test is performed as the second step. This part can be performed in-service with real traffic, assuming the test object allows in-service measurements (ISM).

Otherwise, external test equipment is required as before.

During the measurement, the test object must remain available. If this condition is not fulfilled, the measurement may be repeated once. If the error still occurs, then the source must be determined and eliminated before proceeding.

At the end of the 24-hour test interval, the results are compared with limits S1 and S2, as shown in the graphics in Figure 20. This Figure is a modified version of Figure 17. However, in Figure 20 there is a distinction between in-service and out-of-service measurements.

If steps one and two are performed with external test sets, the following conditions hold:

1. If the results for ES and SES are less than or equal to S1, the path is brought into service.

2. If the results for ES or SES (or for both) are greater than S2, the path cannot be brought into service. Troubleshooting and fault elimination should begin according to Recommendation M.2120.

3. If the measurement results for ES or SES (or for both) are between S1 and S2, then the affected network operators can decide to bring the path into service or perform additional measurements.

If ISM equipment is used to make in-service measurements, then conditions 1 and 2 still hold as given above. Condition 3 stipulates that the path can be provisionally brought into service, but the final assessment must be based on the result of a 7-day test. Figure 20 shows this also.

A 7-day test is required only if the preceding measurements generated unsatisfactory results.

The measurement mentioned above as step two (24-hours) can be included in the 7-day interval.

6.5.3 Recommendation M.2120

Recommendation M.2120 is entitled "PDH *path, section and transmission system and* SDH *path and multiplex section fault detection and localization procedures*" [17]. It is the fourth in the series of important Recommendations on bringing a system into service. M.2120 gives methods for use in troubleshooting. In the context of external test sets, section 4.1/M.2120 dealing with out-of-service measurements is important. If the transmission system under test can transport any traffic at all, it is recommended to use frame analyzers as described in Recommendations O.161 [20], O.162 [21] and O.163 [22]. If traffic is completely interrupted, then pseudo random bit sequences are preferred for troubleshooting (test sets from Recommendations O.150, O.151 and O.181). Here, "framed" signals are preferred once more.

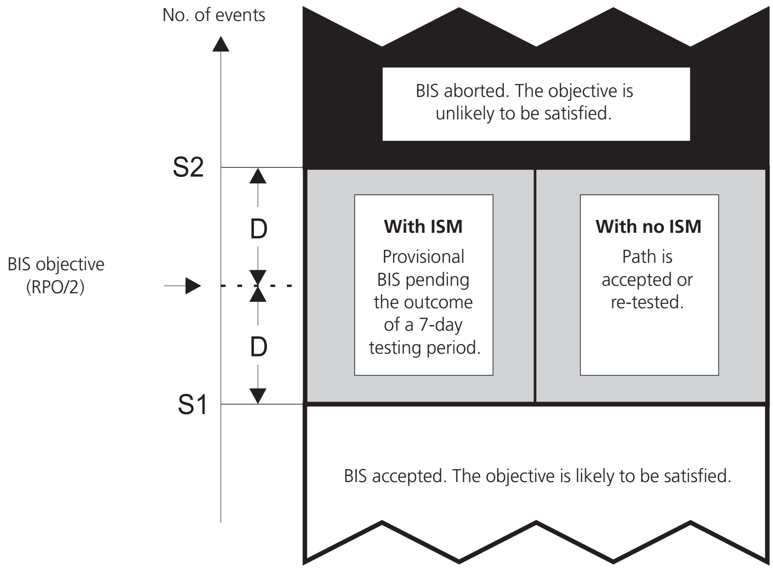


Fig. 20: Bringing-into-service (BIS) limits and conditions

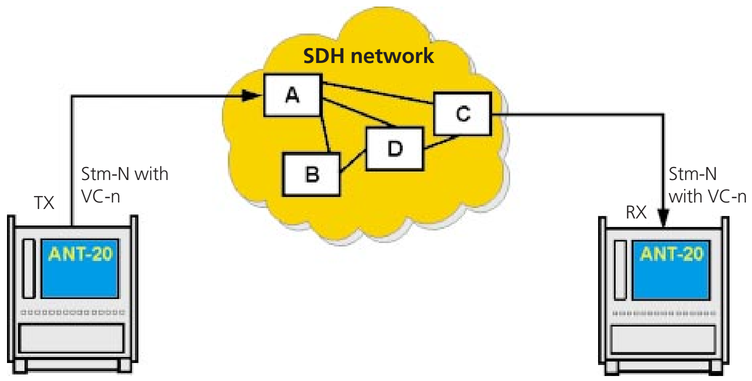


Fig. 21: Out-of-service measurements from A to B using ANT-20

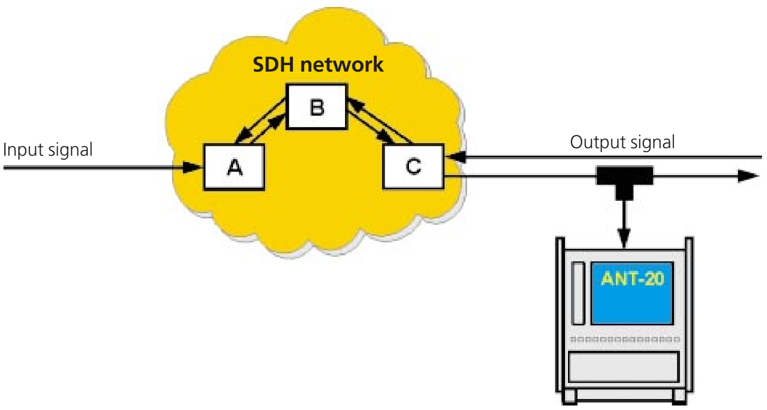


Fig. 22: Far-end in-service measurements (from C to A) evaluating RDI (remote defect indication).

6.6 Outlook for Future M-series Recommendations

Also worthy of mention is the M.22yy series, which will cover ATM transmission equipment. As of this date (July 2000), the following Recommendations are planned:

M.2201
Performance objectives, allocations and limits for international ATM *permanent and semi-permanent virtual path connections.*

M.2210
Bringing-into-service procedures for ATM VPs *and* VCs.

M.2220
Maintenance procedures for ATM VPs *and* VCs.

This series is structured similarly to the M.21xx series described above. These Recommendations will cover analogous areas in ATM transmission technology.

7 Recommendations in the I Series

In regard to transmission performance of digital transmission systems, two Recommendations in the I series should also be mentioned:

I.356 – B-ISDN ATM *layer cell transfer performance* [8].

I.610 – B-ISDN *operation and maintenance principles and functions* [10].

Both Recommendations deal with the ATM layer and thus go beyond the scope of this paper on the physical layer. However, these Recommendations are important to the test and measurement industry since Recommendation O.191 for ATM test equipment [24] is based significantly on I.356 and I.610.

8 Bibliography

[1] ITU-T Recommendation G.703 – *Physical/electrical characteristics of hierarchical digital interfaces*

[2] ITU-T Recommendation G.707 – *Network node interface for the synchronous digital hierarchy* (SDH)

[3] ITU-T Recommendation G.783 – *Characteristics of synchronous digital hierarchy* (SDH) *equipment functional blocks*

[4] ITU-T Recommendation G.821 – *Error performance of an international digital connection operating at a bit rate below the primary rate and forming part of an integrated services digital network*

[5] ITU-T Recommendation G.826 – *Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate*

[6] ITU-T Recommendation G.828 – *Error performance parameters and objectives for international, constant bit rate synchronous digital paths*

[7] ITU-T Recommendation G.829 – *Error performance events for* SDH *multiplex and regenerator sections*

[8] ITU-T Recommendation I.356 – B-ISDN ATM *cell transfer performance*

[9] ITU-T Recommendation I.432 – B-ISDN *User-Network Interface – Physical layer specification*

[10] ITU-T Recommendation I.610 – B-ISDN *operation and maintenance principles and functions*

[11] ITU-T Recommendation M.60 – *Maintenance terminology and definitions*

[12] ITU-T Recommendation M.2100 – *Performance limits for bringing-into-service and maintenance of international* PDH *paths, sections and transmission systems*

[13] ITU-T Recommendation M.2101.1 – *Performance limits for bringing-into-service and maintenance of international* SDH *paths and multiplex sections*

[14] ITU-T Recommendation M.2101 – *Performance limits for bringing-into-service and maintenance of international* SDH *paths and multiplex sections*

[15] ITU-T Recommendation M.2102 – *Maintenance thresholds and procedures for recovery mechanisms (Protection and restoration) of international* SDH VC *trails (paths) and multiplex sections*

[16] ITU-T Recommendation M.2110 – *Bringing-into-service of international* PDH *paths, sections and transmission systems and* SDH *paths and multiplex sections*

[17] ITU-T Recommendation M.2120 – PDH *path, section and transmission system and* SDH *path and multiplex section fault detection and localization procedures*

[18] ITU-T Recommendation O.150 – *General requirements for instrumentation for performance measurements on digital transmission equipment*

[19] ITU-T Recommendation O.151 – *Error performance measuring equipment operating at the primary rate and above*

[20] ITU-T Recommendation O.161 – *In-service code violation monitors for digital systems*

[21] ITU-T Recommendation O.162 – *Equipment to perform in-service monitoring on* 2 048, 8 448, 34 368 *and* 139 264 *kbit/s signals*

[22] ITU-T Recommendation O.163 – *Equipment to perform in-service monitoring on* 1 544 *kbit/s signals*

[23] ITU-T Recommendation O.181 – *Equipment to assess error performance on* STM-N *interfaces*

[24] ITU-T Recommendation O.191 – *Equipment to measure the cell transfer performance of* ATM *connections*

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