4B2: Performance and availability

RECOMMENDATION ITU-R S.1062-1

ALLOWABLE ERROR PERFORMANCE FOR A HYPOTHETICAL REFERENCE DIGITAL PATH OPERATING AT OR ABOVE THE PRIMARY RATE

(Question ITU-R 75/4)

(1994-1995)

The ITU Radiocommunication Assembly,

considering

a) that satellites operating in the fixed-satellite service play an important role in providing reliable international digital communications;

b) that satellite link performance must be sufficient to allow compliance with overall end-to-end performance objectives and in turn end-user quality objectives;

c) that satellite link performance is generally distance independent;

d) that Recommendation ITU-R S.614 specifies satellite link performance objectives which comply with the objectives specified in ITU-T Recommendation G.821;

e) that the error performance for connections operating at or above the primary rate has been specified by the ITU-T in ITU-T Recommendation G.826;

f) that in defining error performance criteria, it is necessary to take into account all foreseeable error-inducing mechanisms, especially time-varying propagation conditions and interference;

g) that satellite systems can be designed to meet a wide range of performance requirements,

recommends

1 that future and, wherever possible, existing satellite links within the public switched network operating at or above the primary rate should be designed to at least meet the specifications set forth in ITU-T Recommendation G.826. An example set of design masks derived from G.826 parameters is presented in Note 1;

2 that the methodology explained in Annex 1 can be used to generate the necessary bit-error probability (BEP) (see Note 4) design masks specified in Note 1. The same methodology can be used at a 155 Mbit/s rate to derive the mask in Note 2;

3 that the following Notes should be regarded as part of the Recommendation:

NOTE 1 – In order to fully comply with the requirements of ITU-T Recommendation G.826, the bit-error probability (BEP) divided by the average number of errors per burst (BEP /α, see § 3 of Annex 1) at the output (i.e. at either end of a two-way connection) of a satellite hypothetical reference digital path (HRDP) forming part of an international connection operating at or above the primary rate including 155 Mbit/s should not exceed during the total time (worst month) the design masks defined by the values given in Table 1 and also in the BEP masks given in Fig. 4.

NOTE 2 – Although Note 1 assures full compliance with ITU-T Recommendation G.826, a more stringent mask may be desirable or necessary for certain services.

TABLE 1

Bit rate (Mbit/s)	Percentage of total time (worst month)	BEP/α
1.5	0.2 2.0 10.0	7×10^{-7} 3×10^{-8} 5×10^{-9}
2.0	0.2 2.0 10.0	7×10^{-6} 2×10^{-8} 2×10^{-9}
6.0	0.2 2.0 10.0	8×10^{-7} 1×10^{-8} 1×10^{-9}
51.0	0.2 2.0 10.0	4×10^{-7} 2×10^{-9} 2×10^{-10}
155	0.2 2.0 10.0	1×10^{-7} 1×10^{-9} 1×10^{-10}

In this case the BEP at the output (i.e. at either end of a two-way connection) of a satellite HRDP operating at or above the primary rate up to and including 155 Mbit/s should not exceed during the total time (worst month) the design mask defined by the values given in Table 2:

TABLE 2

Percentage of total time (worst month)	BEP/α	For α = 10 (BEP)
0.2 2 10	1×10^{-7} 1×10^{-9} 1×10^{-10}	1×10^{-6} 1×10^{-8} 1×10^{-9}

NOTE 3 – The HRDP referred to in this Recommendation is specified in Recommendation ITU-R S.521.

NOTE 4 – The BEP ratios given in Notes 1 and 2 could be estimated by BER measurement over a sufficiently long period of time. A method for measuring BERs as a function of percentage of time is given in Annex 1 of Recommendation ITU-R S.614.

NOTE 5 – For ease of application of this Recommendation the values for the objectives given in Notes 1 and 2 are given in terms of total time and represent the limits of a BEP performance model utilizing the method outlined in Annex 1. In arriving at the objectives given in Notes 1 and 2 the errors occurring during the unavailable time have been excluded from the calculation of the objectives. An explanation of the relationship between available time and total time is given in Note 7. The objectives for BEPs given in Note 1 are not unique in meeting the requirements of ITU-T Recommendation G.826. Other BEP masks may be used by the designer where appropriate as long as these masks satisfy ITU-T Recommendation G.826.

NOTE 6 – This Recommendation will find its primary application in satellite systems operating below 15 GHz. The extension of the performance requirements given in this Recommendation to systems operating at higher frequencies is the subject of further study.

NOTE 7 – A period of unavailable time begins at the onset of ten consecutive severely errored seconds (SES) events. These 10 s are considered to be part of unavailable time. A new period of available time begins at the onset of ten consecutive non-SES events. These 10 s are considered to be part of available time. For rates at or above the primary rate, an SES is defined as a second which contains ≥ 30% errored blocks or at least one severely disturbed period (see ITU-T Recommendation G.826, § 3.1.1 and Annex 1). Unavailability threshold values for BEP can be determined such that the unavailable state is reached with a probability = 0.5. These values are shown in Table 4.

NOTE 8 – The objectives given in Notes 1 and 2 are given in terms of percentage of the worst month. These monthly percentages correspond to the following yearly percentages:

– 10% of worst month 4.0% of year

– 2% of worst month 0.6% of year

– 0.2% of worst month 0.04% of year.

NOTE 9 – In order to comply with Notes 1 and 2 at frequencies greater than 10 GHz, it may be advantageous to make use of fade countermeasures including adaptive forward error-correction (FEC) coding, power control or site diversity. Information on site diversity operation is given in Annex 1, Recommendation ITU-R S.522.

NOTE 10 – The preferred method of verifying digital satellite performance is on the basis of in-service measurements (ISM). These measurements would utilize the block error detection schemes which are related to the inherent block size and structure of the transmission system. FEC, scrambling and differential encoding have an impact on interpretation of the measurements (see Annex 1, § 3).

NOTE 11 – The error performance described in Notes 1 and 2 was developed based on the use of an HRDP in the international portion of the link (e.g. switched international gateway-to-switched international gateway). Other applications of the HRDP within the connection are possible (e.g. end office-to-end office) and the error performance objectives can be adjusted accordingly.

NOTE 12 – Existing and future satellite links within the public switched network should, whenever possible, be designed/upgraded to the performance objectives specified in this Recommendation. However, it may not always be practical to upgrade an existing system which was designed to comply with Recommendation ITU-R S.614.

NOTE 13 – The methods described in this Recommendation can be applied to the design of satellite links in private networks, although the BER masks may not be appropriate depending on the configuration of the network and the services carried.

NOTE 14 – The performance objectives shall be met for the relevant end-to-end transmission having the maximum rate rather than the ostensible transmission rate. For instance, if the transmission rate over a satellite link is 6 Mbit/s and the maximum transmission rate involved between the end points is 2 Mbit/s, the performance objectives for 2 Mbit/s transmission shall be applied in designing the satellite link.

ANNEX 1

1 ITU-T Recommendation G.826 – Definitions, parameters and objectives

Consistent with ITU-T Recommendation G.821, the requirements of ITU-T Recommendation G.826 are given in terms of errored intervals (EI). The terminology between the two Recommendations is similar but the definitions of the parameters are different. For ITU-T Recommendation G.826, the EI are defined in terms of errored blocks (EB) as opposed to individual bit errors. The purpose of this specification is to allow the verification of adherence to the performance requirements of ITU-T Recommendation G.826 on an in-service basis. The specification of performance in terms of block errors instead of bit errors has important consequences for systems where the errors tend to occur in groups, such as systems employing scrambling and FEC. The block used in ITU-T Recommendation G.826 is that group of contiguous bits that normally makes up the inherent monitoring block or frame of the transmission system being employed.

1.1 Definitions

Events

– *Errored block (EB)*

A block in which one or more bits are in error.

– *Errored second (ES)*

A 1 s period with one or more errored blocks. SES defined below are a subset of ES.

– *Severely errored second (SES)*

A 1 s period which contains ≥ 30% errored blocks (see Note 1) or at least one severely disturbed period (SDP) (see Note 2).

For out-of-service (OOS) measurements, an SDP occurs when, over a minimum period of time equivalent to four contiguous blocks or 1 ms, whichever is larger, either all the contiguous blocks are affected by a high binary error density of $\geq 10^{-2}$, or a loss of signal information is observed. For in-service monitoring purposes, an SDP is estimated by the occurrence of a network defect. The term defect is defined in the relevant Annexes (2, 3 or 4 of ITU-T Recommendation G.826) for the different network fabrics: plesiochronous digital hierarchy (PDH), synchronous digital hierarchy (SDH) or cell-based, respectively.

NOTE 1 – For historical reasons, SESs on some PDH systems are defined with a different percentage of errored blocks (see Annex 2 of ITU-T Recommendation G.826).

For maintenance purposes, values different from 30% may be used and these values may vary with transmission rate.

NOTE 2 – SDP events may persist for several seconds and may be precursors to periods of unavailability, especially when there are no restoration/protection procedures in use. SDPs persisting for T s, where $2 \leq T < 10$ (some network operators refer to these events as “failures”) can have a severe impact on service, for example the disconnection of switched services. The only way ITU-T Recommendation G.826 limits the frequency of these events is through the limit for the severely errored seconds ratio (SESR).

– *Background block error (BBE)*

An errored block not occurring as part of an SES.

1.2 Parameters

Error performance should only be evaluated while the path is in the available state. For a definition of the entry/exit criteria for the unavailable state see Annex 1 of ITU-T Recommendation G.826.

– *Errored second ratio (ESR)*

The ratio of ES to total seconds in available time during a fixed measurement interval.

– *Severely errored seconds 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 errored blocks to total blocks during a fixed measurement interval, excluding all blocks during SES and unavailable time.

1.3 Performance objectives

The end-to-end objectives of ITU-T Recommendation G.826 are given in Table 3. The performance objectives are given as a function of transmission system bit rate. The ranges of block sizes accommodated at these bit rates are also given. As stated above, the block size will be that associated with the frame structure of the transmission system. Ranges of block size are given so as not to prejudice the development of future transmission systems. These objectives are specified for available time.

TABLE 3

End-to-end performance objectives for a 27 500 km international digital connection at, or above, the primary rate

Rate (Mbit/s)	1.5 to 5	> 5 to 15	> 15 to 55	> 55 to 160	> 160 to 3 500	> 3 500
Bits/block	2 000-8 000[(1)]	2 000-8 000	4 000-20 000	6 000-20 000	15 000-30 000[(2)]	For further study
ESR	0.04	0.05	0.075	0.16	[(3)]	For further study
SESR	0.002	0.002	0.002	0.002	0.002	For further study
BBER	3×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	10^{-4}	For further study

(1) VC-11 and VC-12 (ITU-T Recommendation G.709) paths are defined with a number of bits/block of 832 and 1 120 respectively, i.e., outside of the recommended range for 1.5 to 5 Mbit/s paths. For these block sizes, the BBER objective for VC-11 and VC-12 is 2×10^{-4}.

(2) Because bit-error ratios are not expected to decrease dramatically as the bit rates of transmission systems increase, the block sizes (bits) used in evaluating very high bit-rate paths should remain within the range of 15 000 to 30 000 bits/block. Preserving a constant block size for very high bit-rate paths results in relatively constant BBER and SESR objectives for these paths.

As currently defined, VC-4-4c (ITU-T Recommendation G.709) is a 601 Mbit/s path with a block size of 75 168 bits/block. Since this exceeds the maximum recommended block size for a path of this rate, VC-4-4c paths should not be estimated in service using this table. The BBER objective for VC-4-4c using the 75 168 bit block size is taken to be 4×10^{-4}. There are currently no paths defined for bit rates greater than VC-4-4c (> 601 Mbit/s). Digital sections are defined for higher bit rates and guidance on evaluating the performance of digital sections can be found below.

(3) Due to the lack of information on the performance of paths operating above 160 Mbit/s, no ESR objectives are recommended at this time. Nevertheless, ESR processing should be implemented within any error performance measuring devices operating at these rates for maintenance or monitoring purposes.

Independent of the actual distance spanned, any satellite hop in the international or national portion receives a 35% allocation of the end-to-end objectives. The performance objectives for a satellite HRDP are given in Table 4 for transmission rates between 1.5 and 3 500 Mbit/s.

TABLE 4

Satellite hypothetical reference digital path performance objectives for an international or national digital connection operating at, or above, primary rate

Rate (Mbit/s)	1.5 to 5	> 5 to 15	> 15 to 55	> 55 to 160	> 160 to 3 500
ESR	0.014	0.0175	0.0262	0.056	[(1)]
SESR	0.0007	0.0007	0.0007	0.0007	0.0007
BBER	1.05×10^{-4}	0.7×10^{-4}	0.7×10^{-4}	0.7×10^{-4}	0.35×10^{-4}

(1) Due to the lack of information on the performance of paths operating above 160 Mbit/s, no ESR objectives are recommended at this time. Nevertheless, ESR processing should be implemented within any error performance measuring devices operating at these rates for maintenance or monitoring purposes.

1.4 Monitoring blocks

The block used in ITU-T Recommendation G.826 is the inherent monitoring block of the transmission system employed. Table 5 shows the block size and number of blocks/s for various transmission rates.

TABLE 5

Relationship between bit rate, block size and number of blocks per second

Bit rate (Mbit/s)	Block size (bits)	Number of blocks/s
1.544	4 632	333 1/3
2.048	2 048	1 000
6.312	3 156	2 000
44.736	4 760	9 398 63/119
51.84	6 480	8 000
155.52	19 440	8 000

2 Bit-error probability masks

The set of parameters and objectives as defined in ITU-T Recommendation G.826 is not suitable for the transmission system design. It must be transformed into a bit-error probability versus percentage-of-time distribution, also called a bit-error probability mask, in such a way that any digital transmission designed to meet the mask would also meet the objectives of the Recommendation. The transform, however, does not result in a "unique" mask.

2.1 Probability of the basic events

It is well known that transmission errors over satellite links occur in bursts where the average number of errors per burst is, among other factors, a function of the scrambler and the forward error correction (FEC) code. Consequently, a successful model of the digital performance over satellite links has to take into account this bursty nature. One statistical model that can adequately represent the random occurrence of bursts is the Neyman-A contagious distribution, where the probability of k errors occurring in N bits, $p(k)$, is:

$$P(k) = \frac{\alpha^k}{k!} \, e^{-\frac{BEP \cdot N}{\alpha}} \sum_{j=0}^{\infty} \frac{j^k}{j!} \left(\frac{BEP \cdot N}{\alpha} \right)^j e^{-j\alpha}$$

where:

α : average number of errored bits in a burst of errors

BEP : bit error probability.

If $N = N_B$ is taken as the number of bits in a block of data, then the probability of zero errors in a block is:

$$P(0) = e^{-\frac{BEP \cdot N_B}{\alpha}} \sum_{j=0}^{\infty} \left[\left(\frac{BEP \cdot N_B}{\alpha} \right)^j \Big/ j! \right] e^{-j\alpha} \cong e^{-\frac{BEP \cdot N_B}{\alpha}} \quad \text{for all practical values of } \alpha.$$

The probability of an errored block, P_{EB}, is then given by:

$$P_{EB} = 1 - P(0) = 1 - e^{-\frac{BEP \cdot N_B}{\alpha}} = 1 - e^{-N_B \cdot BEP_{CRC}(t)}$$

where $BEP_{CRC}(t) = BEP/\alpha$, and the BEP_{CRC} is explicitly shown as a function of time. The probability of an errored second, $P_{ES}(t)$, can then be expressed as:

$$P_{ES}(t) = 1 - e^{n \cdot P_{EB}(t)}$$

where n is the number of blocks per second.

Since the probability of k errored blocks in a total of n blocks, $P_{n,k}(t)$, is given by:

$$P_{n,k}(t) = \frac{n!}{(n - k)!\, k!} \left(1 - P_{EB}(t)\right)^{n-k} P_{EB}^{k}(t)$$

then, the probability of an SES, $P_{ES}(t)$, is:

$$P_{SES}(t) = \sum_{k=0.3n}^{n} P_{n,k}(t) = 1 - \sum_{k=0}^{0.3n-1} P_{n,k}(t) = 1 - \sum_{k=0}^{0.3n-1} \frac{n!}{(n - k)!\, k!} \left(1 - P_{EB}(t)\right)^{n-k} P_{EB}^{k}(t)$$

2.2 Generation of masks

Assuming a general form of the mask given in Fig. 1, and using the probability formula given above one can compute the ESR. The ESR defined as the total errored seconds (seconds with one or more errored blocks) divided by the total available seconds, T_a, is given by:

$$ESR = \frac{\int_{T_a} P_{ES}(t)\, \mathrm{d}t}{T_a}$$

Similarly, the SESR is given by:

$$SESR = \frac{\int_{T_a} P_{SES}(t)\, \mathrm{d}t}{T_a}$$

If $P_{ES}(t)$ and $P_{SES}(t)$ are assumed to be piece-wise constant in time, then ESR and SESR can be expressed as:

$$ESR = \sum_{i=1}^{M} P_{ES_i} \cdot \Delta t_i$$

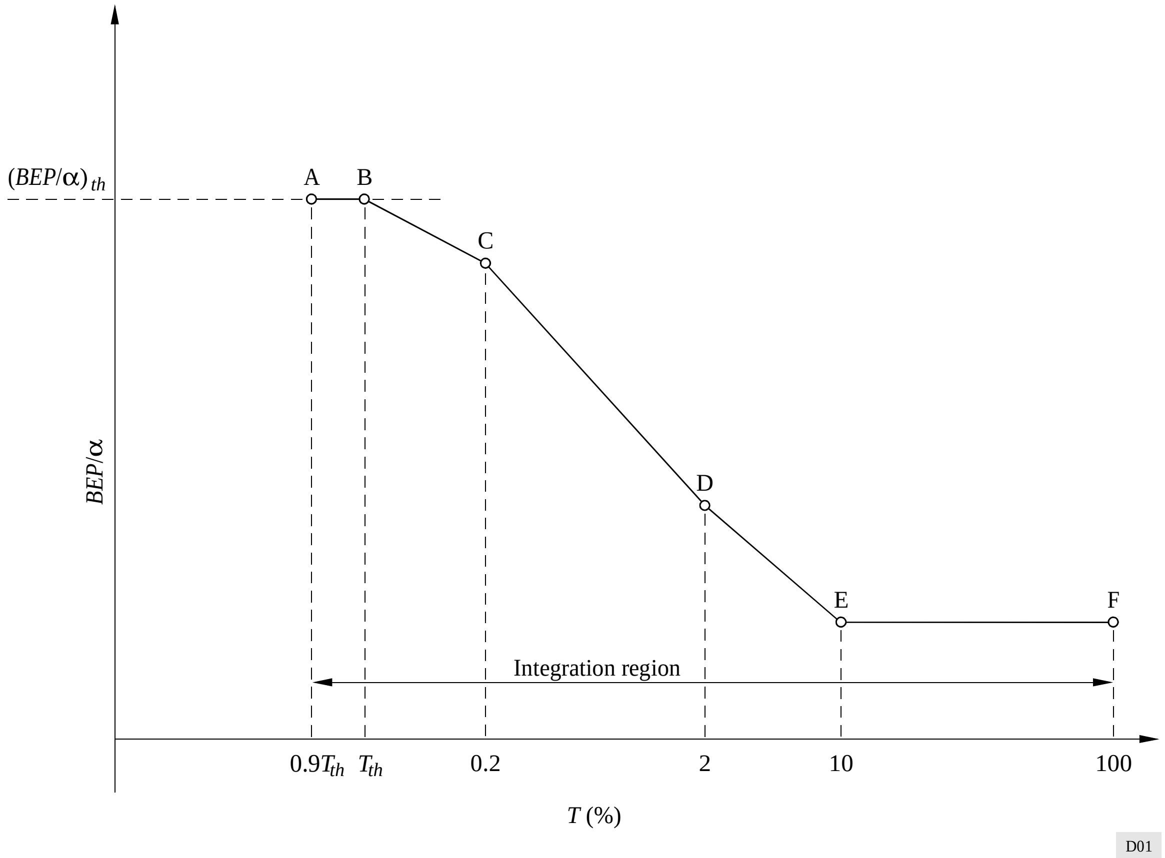
and

$$SESR = \sum_{i=1}^{M} P_{SES_i} \cdot \Delta t_i$$

Where M is the total number of time intervals, $P_{ES_i}(t)$ and $P_{SES_i}(t)$ are the probability of an ES and SES respectively in the i-th time interval divided by T_a.

FIGURE 1

General form of mask



BBER is defined as the ratio between errored blocks to the total blocks during available seconds, excluding all blocks during SES. Thus:

$$BBER = \frac{\int_{T_a} \left(\sum_{k=1}^{0.3n} P_{n,k}(t) \cdot k \right) dt}{n \cdot \left(T_a - \int_{T_a} P_{SES}(t) \cdot dt \right)} = \frac{\sum_{k=1}^{0.3n} \left(\frac{1}{T_a} \int_{T_a} P_{n,k}(t) \cdot dt \right) \cdot k}{n \cdot (1 - SESR)}$$

If $\overline{P_{n,k}} = \frac{\int_{T_a} P_{n,k} \cdot dt}{T_a}$ is set, then BBER can be expressed as:

$$BBER = \frac{\sum_{k=1}^{0.3n} \overline{P_{n,k}} \cdot k}{n \cdot (1 - SESR)}$$

The unavailability threshold (T_{th}) is defined by P_{SES} = 0.933. This value corresponds to a probability of ten consecutive SES of 0.50.

The corresponding values of BEP_{th}/α, at various data rates, are included in Fig. 2 and are also listed in Table 6.

FIGURE 2

P_{SES} versus BEP/α

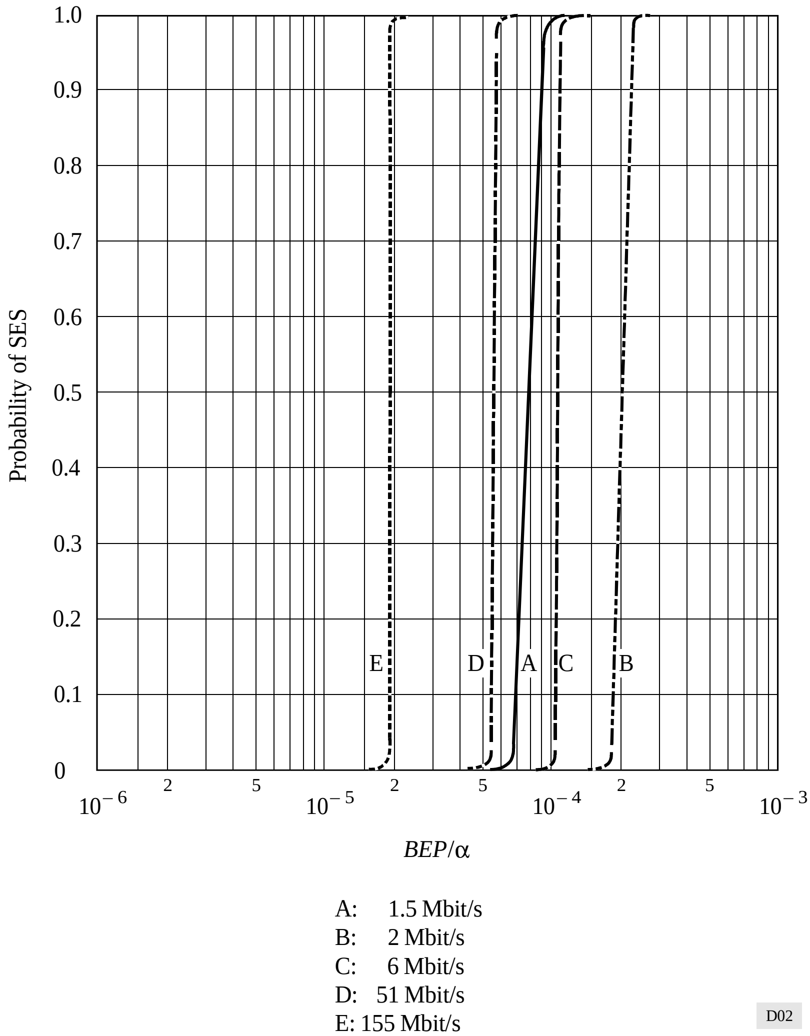


TABLE 6

Bit rate (Mbit/s)	BEP_{th}/α
1.544	9.00×10^{-5}
2.048	1.90×10^{-4}
6.432	1.17×10^{-4}
51.84	5.68×10^{-5}
155.52	1.89×10^{-5}

In selecting the value of BEP_{th}/α for the generation of the masks, however, attention should be paid to the fact that modems experience loss of synchronization at a certain BEP threshold, denoted here by BEP_{mod}. Based on the above considerations, the value of BEP_{th}/α to be used is given by the formula:

$$BEP_{th}/\alpha = \min(BEP_{th}/\alpha \text{ of Table 6; } BEP_{mod}/\alpha)$$

For most modems in operation today, BEP_{mod} is well approximated by the value 1.0×10^{-3}.

The above method will result in an infinite number of masks meeting the ITU-T Recommendation G.826 performance objectives. Therefore, the following process is used to define a mask and to determine points C, D, E and F of the mask (see Fig. 1).

Step 1 – Set the mask values at 100%, 10%, 2% and 0.2% of the time (points C, D, E and F).

Step 2 – Determine the value BEP_{th}/α.

Step 3 – Choose an unavailability threshold time value, T_{th}, ($T_{th} < 0.2\%$).

Step 4 – Assume a straight line between points B and C.

Step 5 – Calculate ESR, SESR and BBER by integrating over the region between 0.9 T_{th} and 100% (see Note 1).

NOTE 1 – Based on results given in Recommendation ITU-R S.579, showing propagation attenuation events which do not result in unavailable time, a "propagation availability factor" of 10% was used for driving these masks. Therefore, 10% of T_{th} was incorporated into the available time to account for the cases where BEP is worse than BEP_{th} but recovers in less than 10 s.

Step 6 – Select a new value of T_{th} and repeat steps 4 and 5 until the maximum values for ESR, SESR, and BBER are found for any $T_{th} < 0.2\%$ of the time.

If the ITU-T Recommendation G.826 objectives for ESR, SESR and BBER are satisfied for all $T_{th} < 0.2\%$, then the mask defined by points C, D, E, and F is considered to meet the ITU-T Recommendation G.826. Moreover, the above process ensures that a link unavailability of less than 0.2% of the time is achieved. As a consequence of the iterative process in steps 4, 5 and 6, any straight line between points B and C, where B can be anywhere between 0% and 0.2% of the time, will meet ITU-T Recommendation G.826 objectives and the unavailability objectives. Therefore, the general shape of the mask can be further simplified by extending the mask vertically from point C as shown in Fig. 3.

Using the above process with the additional assumptions that:

– BEP/α corresponding to points E and F are the same,

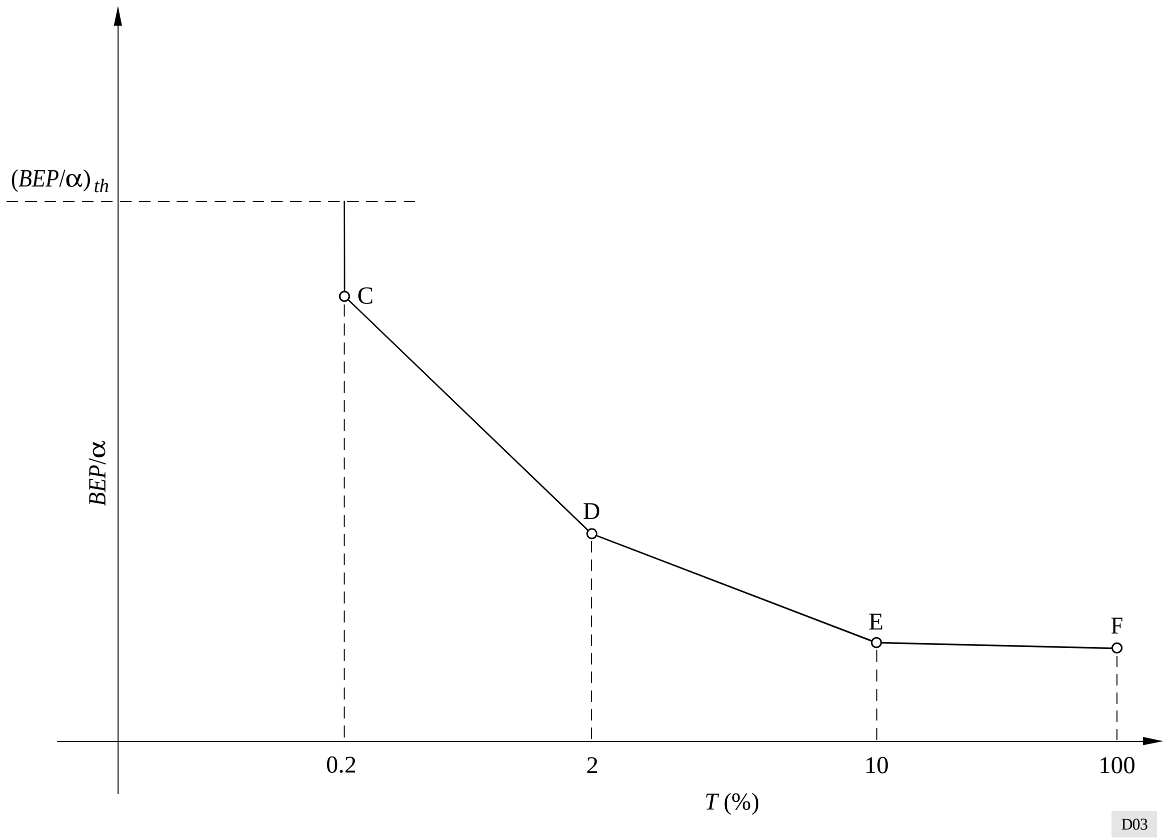
– BEP/α corresponding to points E and D differ by one decade,

an example set of masks for various transmission bit rates was generated and is shown in Fig. 4.

In developing these masks it was assumed that $BEP_{mod} = 1 \times 10^{-3}$. In addition, for 1.5 Mbit/s mask the ratio between BEP/α values corresponding to points E and D was changed from 10 to 3 in order to achieve a smooth mask.

FIGURE 3

Simplified mask



3 Relationship between bit-error ratio and error-event ratio

It is well known that errors on satellite links employing FEC and scrambler schemes tend to occur in clusters. The appearance of the clusters, which can also be called error events, is random following a Poisson distribution. The resulting block error rate is the same as if it were caused by randomly (Poisson distributed) occurring bit errors with a bit-error ratio BER/α, where α (used in § 2.1 to account for the burstiness of errors) is the average number of errored bits within a cluster, α also represents the ratio between the bit-error ratio and error-event ratio.

Statistical properties of the clusters of errors are dependent on the FEC/scrambler scheme used. Computer simulations and measurements of various FEC schemes (without scrambler or differential encoding) were used to determine the factor α. These results are given in Table 7.

Laboratory measurements of the INTELSAT IDR type digital transmissions (FEC R = 3/4 plus scrambler) led to an $\alpha = 10$ over the range of BER 10^{-4} to 10^{-11}. An $\alpha = 5$ was determined in the same measurements for the INTELSAT IBS type digital transmissions (FEC R = 1/2 plus scrambler).

From Table 7 and the results of the measurements it appears that α could be in a range of 1 to 10 for the cases investigated. Further studies of other types of FEC/scrambler schemes are required. The impact of parameter α on the performance model could be assessed as follows.

The masks in Figs. 1 and 2 were generated using $\alpha = 10$. If, for example, no FEC/scrambler ($\alpha = 1$) were used, the models would be shifted by one decade and the BER requirements would be more stringent (by one decade).

FIGURE 4

Generated masks for satellite hops

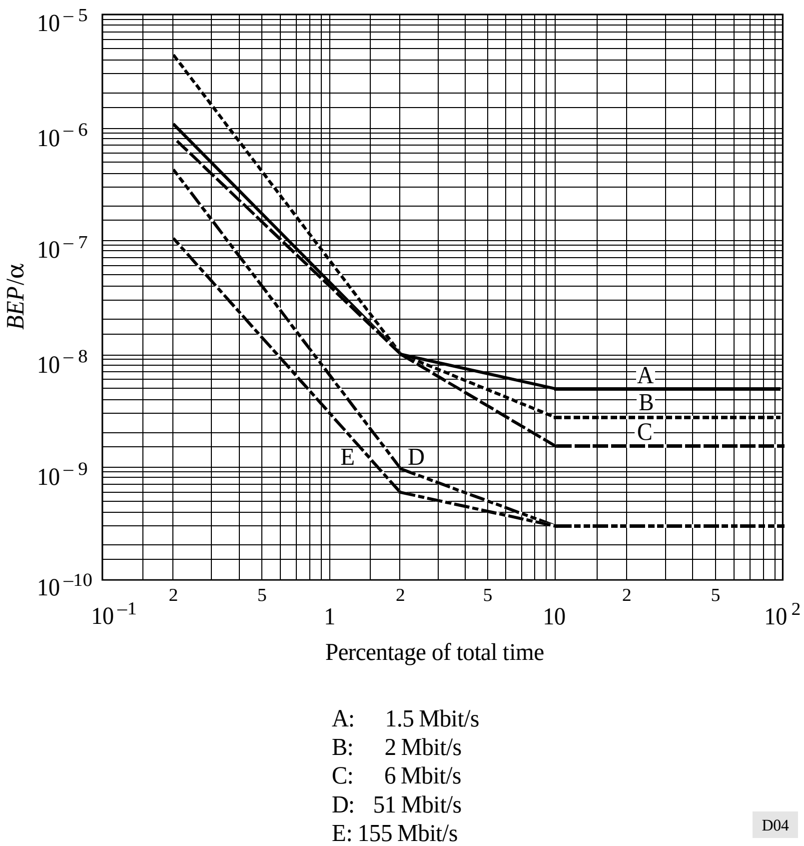


TABLE 7

Factor for various FEC schemes

	Without FEC	With FEC		
Bit rate (Mbit/s)		1/2	3/4	7/8
1.544	1.0	2.7	5.1	6.6
2.048	1.0	3.4	6.8	8.2
6.312	1.0	2.6	5.1	7.0
51.84	1.0	2.8	5.4	7.2
155.52	1.1	2.8	4.9	7.2

4 Conclusions

The results of studies have shown that the masks required for meeting the Recommendation ITU-T G.826 are transmission rate dependent. The design masks are also dependent on the error distribution which in turn are influenced by the FEC/scrambler scheme applied.

Service requirements need also to be taken into account in deriving the allowable error design masks.