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1. Introduction

This document makes recommendations for the design of the transport network links in order to meet the requirements of various User Requirements Specifications (URS) given to Eskom Telecommunications form other Eskom line groups

2. Supporting clauses

2.1 Scope

2.1.1 Purpose

The purpose of this document is to provide a guide to the telecommunications network planning engineer (regional and national) on how to design telecommunications transport network links to meet performance requirements specified by customers.

The document also supersedes ETDG 0457 Spur Link Configuration Requirements to Meet SLAs and TST0104 Standard for Performance Objectives for Eskom MTN bearer Media.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited Divisions.

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 9001, Quality Management Systems.

[2] ITU-T Recommendation G.803 (03/00) Architecture of Transport Networks Based on the Synchronous Digital Hierarchy(SDH)

[3] ITU-T Recommendation G.841 (10/98) Types and Characteristics of the Synchronous Digital Hierarchy (SDH) Network Protection Architectures.

[4] ITU-T Recommendation G.707 (01/07) Network Node Interface for the Synchronous Digital Hierarchy (SDH).

[5] ITU-T Recommendation G.828 (03/00) Error performance parameters and objectives for international, constant bit-rate synchronous digital paths.

[6] ITU-T Recommendation G.826 (12/02) Error performance parameters and objectives for international constant Bit Rate Digital Paths at or Above the Primary Rate.

[7] ITU-T Recommendation G.827 (09/03) Availability performance parameters and objectives for end-to-end international constant bit-rate digital paths

[8] ITU-T Recommendation G.957 (03/06) Optical interfaces for equipment and systems relating to the synchronous digital hierarchy

[9] ITU-T Recommendation G.691 (03/06) Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers

[10] ITU-T Recommendation G.652 (11/09) Characteristics of a single-mode optical fibre and cable

[11] ITU-T Recommendation F.1668-1 (01/07) Error performance objectives for real digital fixed wireless links used in 27 500 km hypothetical reference paths and connections

[12] TPC 41-5, Fibre Optic Cable System Acceptance Testing, V Naidu, August 2010

[13] ITU-R F.695 (1990) Availability Objectives for Real Digital Radio-Relay Links forming Part of a High-Grade Circuit Within An Integrated Services Digital Network

[14] Cigre Document 84, Application of Wideband Communication Circuits to Protection – Prospects and Benefits, Working Group 05 of Study Committee 34, September 1991

[15] DST 240-46264031 Fibre-optic Design Standard – Part 2: Substations rev. 0, T Gosai, August 2012.

[16] 32-9: Definition of Eskom documents.

[17] 32-644: Eskom documentation management standard.

[18] 474-65: Operating Manual of the Steering Committee of Wires Technologies (SCOWT).

2.2.2 Informative

[19] ITU-T Recommendation G.709 (02/12) Interfaces for the optical transport network.

[20] TST0104 Standard for Performance Objectives for Eskom MTN bearer Media, ASJ Helberg, December 1994

[21] ETDG 0588 Design Guide for Teleprotection Circuit Bearing Links, N Mahlanyane, October 2010

[22] ETDG 0457 Spur Link Configuration Requirements to Meet SLAs, N Mahlanyane, March 2006

2.3 Definitions

2.3.1 General

Definition	Description
Availability	Availability of an item to be in a state to perform a required function at a given instant of time or at any instant of time within a given time interval, assuming that the external resources, if required, are provided.
Background Block Error Ratio (BBER)	The ratio of Background Block Errors (BBE) to total blocks in available time during a fixed measurement interval. The count of total blocks excludes all blocks during Severely Errored Seconds
Errored Second Ratio (ESR)	The ratio of errored seconds to total seconds in available time during a fixed measurement interval
Severely Errored Second Ratio (SESR):	The ratio of Severely Errored Seconds to total seconds in available time during a fixed measurement interval

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
BBER	Background Block Error Ratio
BER	Bit Error Rate
BME	Bandwidth Management Equipment
CD	Chromatic Dispersion
ESR	Errored Second Ratio

Abbreviation	Description
FO	Fibre Optic
IP	Internet Protocol
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
OLTE	Optical Line Terminating Equipment
OTDR	Optical Time-Domain Reflectometer
PDH	Plesiochronous Digital Hierarchy
PMD	Polarisation Mode Dispersion
SDH	Synchronous Digital Hierarchy
SESR	Severely Errored Second Ratio
TDM	Time Division Multiplexing
URS	User Requirements Specification

2.5 Roles and responsibilities

Not Applicable.

2.6 Process for monitoring

Not Applicable.

2.7 Related/supporting documents

Not Applicable.

3. Objectives

This document describes standards of performance applicable to the Eskom Telecommunications Transport Network in terms of availability and quality.

3.1 Error Performance Objectives

This recommendation aligns the design of paths with recommendation [6] ITU-T G.826 for Plesiochronous Digital Hierarchy (PDH) paths and [5] ITU-T G.828 for Synchronous Digital Hierarchy (SDH) paths, as well as [11] ITU-R F.1668-1. The following are design objectives set out in [6] ITU-T G.826 and [5] ITU-T G.828, respectively.

Table 1: [6] ITU-T G.826 Error Performance Objectives for PDH Links

Rate, Mbit/s	1.5 to 5	>5 to 15	>15 to 55
Bit/block	800-5000	32000-8000	4000-20 000
ESR	0.04	0.05	0.075
SESR	0.002	0.002	0.002
BBER	2×10^{-4}	2×10^{-4}	2×10^{-4}

Table 2: [5] ITU-T G.828 Objectives for SDH Links

Rate, kbit/s	2 240 (VC-12)	150 336 (VC-4)	601 344 (VC-4-4c)	2 405 376 (VC-4-16c)	9 621 504 (VC-4-64c)
Blocks/s	2000	8000	8000	8000	8000
ESR	0.01	0.04	Not Significant	Not Significant	Not Significant
SESR	0.002	0.002	Not Significant	Not Significant	Not Significant
BBER	5×10^{-5}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-3}

The design objectives set out in [20] TST0104 Performance Objectives for Eskom MTN Bearer Media are therefore, more stringent that those recommended by the ITUT for a 27500km hypothetical reference path. As a result the objectives identified in [20] TST0104 are mandatory. [20] TST0104 considers reference length of 1000km and a hop or spur distance shorter than 280km (the minimum hop defined in the ITU-T hypothetical reference). These values are given in table 3.

Table 3: Error Performance objectives for Eskom's Telecommunications Transport Network

Rate, Mbit/s	Up to 8	Up to 51	>=155
ESR	5.6×10^{-4}	3.825×10^{-3}	8.16×10^{-3}
SESR	2.24×10^{-5}	1.02×10^{-4}	1.02×10^{-4}
BBER	2.24×10^{-6}	1.02×10^{-5}	1.02×10^{-5}

Equipment receiver threshold parameters that shall be used when designing a hop, shall be those specified for a maximum bit error ratio (BER) of 1 x 10-6

3.2 Availability Objectives

Channel availability is a function of the availability of the equipment, propagation losses and other factors such as human factor. Each of these factors contributes, in varying proportions, to the total channel unavailable time. For circuit design purposes, each of these factors is apportioned a percentage of the allowed unavailable time, as was presented in [21] ETDG 0588 (adapted from [20] TST0104). The apportionments are with respect to an overall annual unavailability objective of 0.3% for high grade backbone portions ([13] ITU-R F.695). Table 4 provides a breakdown of the annual unavailability apportionment for the main outage categories.

Table 4: Annual unavailability apportionment for the main outage categories

Factor	Annual Unavailability Apportionment (%)	Percentage of apportionment to 0.3% total
Equipment	0.1	33.30%
Backbone Propagation Outage:	0.01	3.33%
Spur Propagation Outage:	0.14	46.67%
Other Factors	0.05	16.67%
TOTAL	**0.3**	

It is further stated in [22] ETDG0457 that [20] TST0104 used a reference path length of 1000 km, which translate to about 20 hops of an average length of 50 km and that the end-to-end stated network availability of 99.7% (0.3% unavailability) is over a period of 1 year. This, therefore, translates to 99.975% monthly availability (0.025% unavailability) of the same path length. Table 4 provides a breakdown of the monthly unavailability apportionment for the main outage categories.

Table 5: Monthly unavailability apportionment of the main outage categories

Factor	**Monthly Unavailability Apportionment (%)**	**Percentage of apportionment to 0.025% total**
Equipment	0.008333	33.30%
Backbone Propagation Outage:	0.000833	3.33%
Spur Propagation Outage:	0.011667	46.67%
Other Factors	0.004167	16.67%
TOTAL	**0.025**	

The apportionment to other factors in both table 4 and 5, is an allowance for human related errors. As mentioned in [20] TST0104, this apportionment should be minimised by proper training and supervision; and even though designs allow some leeway for these errors, it should not be considered as permission for negligence

3.2.1 Transmission Medium

From table 5, the total monthly unavailability, U, due to both backbone and spur propagation outage, for the referenced 20 hop circuit is 0.0125%. Therefore, the required monthly unavailability for a single hop is:

$$U\ (1\ \text{hop}) = 0.0125/20 = 0.000625\% \quad (1)$$

The availability, A, of that one hop is therefore:

$$A\ (1\ \text{hop}) = 100-U = 100\% - 0.000625\% = 99.999375\% \quad (2)$$

The propagation path (transmission medium), particularly that of the microwave links shall, as a result, be designed with a minimum worst month target availability of 99.999%. The design objective shall take into consideration rain fade and diffraction loss. The use of frequency diversity only as a means to increase availability is not supported, as it offers minimal increase in availability. The additional frequency would be more optimally used if it carries traffic

3.2.2 Equipment Availability

The equipment availability is calculated as follows,

$$A\ (\%) = 100 \times MTBF/\ (MTBF + MTTR) \quad (3)$$

Where

- A is availability
- MTBF (Mean Time Between Failures) is a figure provided by the manufacturer of the equipment and is an indication of the equipment's reliability.
- MTTR (Mean Time to Repair) is an indicator of how quickly a failed piece of equipment can be restored back to service by manual means.

MTTR takes into account factors such as travel to site, time to repair on site, availability of spares and the time to obtain the necessary spares. It is, therefore, defined by the operations and maintenance department's efficiency and is not a derived figure. The higher MTTR figure, the more reliable the equipment needs to be (higher MTBF figure) in order to satisfy the availability allowance to equipment. Consequently, equipment availability is a function of equipment reliability, maintenance and operations' efficiency.

Equipment unavailability is calculated:

$$U\ (\%) = 100 \times (1-A). \quad (4)$$

And availability as:

A (%) = 100 x (1-U). (5)

For n pieces of equipment connected in series on a path, the overall equipment unavailability is

U = U1 + U2 + U3 +……. + Un. (6)

For 2 parallel systems, such as in the case of 1+1 protected equipment, the overall system unavailability is:

U = U1 x U2. (7)

Where,

U1 and U2 are unavailability figures for the working and back up equipment respectively.

From table 5, the total monthly unavailability, (U), due to equipment outage, for the referenced 20 hop circuit is 0.008333%, which equates to an availability requirement of 99.99167%.

Therefore, the required monthly unavailability for a single hop is:

U (1 hop) = 0.008333/20 = 0.0004165%. (8)

The availability, A, of that one hop is therefore:

A (1 hop) = 100-U= 100% - 0.0004165% = 99.9995835%. (9)

Assuming a fixed worst case MTBF figure of 300000 hours (11.42 years) for terminal equipment (150000 hours for a link), the following availability figures may be achieved for an unprotected link.

Table 6: Equipment Availability for 150 000 hour link MTBF

Mean Time to Repair (Hours)	**Equipment Unavailability (%)**	**Equipment Availability (%)**
12	0.00799936	99.99200064
6	0.00399984	99.99600016
5	0.003333222	99.99666678
4	0.002666596	99.9973334
3	0.00199996	99.99800004
2	0.001333316	99.99866668
1	0.000666662	99.99933334

As can be seen from table 6, with assumed MTBF for an unprotected link, it would not be possible to meet the required equipment unavailability/availability of equation 8 and 9. This would require a mean time to repair of less than 1 hour.

Increasing the assumed MTBF to 600000 hours for terminal equipment (300000 hours for a link, as assumed in [21] ETDG 0588) results in the equipment unavailability/availability figures of table 7.

Table 7: Equipment Availability figures for 300 000 hour link MTBF

Mean time to Repair (Hours)	**Equipment Unavailability (%)**	**Equipment Availability (%)**
12	0.00399984	99.99600016
6	0.00199996	99.99800004
5	0.001666639	99.99833336
4	0.001333316	99.99866668
3	0.00099999	99.99900001
2	0.000666662	99.99933334
1	0.000333332	99.99966667

As shown in table 7, a MTTR of less than 2 hours (with a 300000 hour link MTBF) would be required to meet the unavailability/availability requirement of equations 8 and 9, for an unprotected link.

Equipment protection (1+1 hot standby) can be used to improve the equipment availability. When equipment protection is applied, backing up the equipment component with the lowest MTBF should take priority; although, this may not always be possible. Equipment protection becomes almost meaningless if the component which is most susceptible to failures cannot be protected.

Using equation (7), and assuming hitless switching, as well as link MTBF figures of 150000 hours, the availability/unavailability figures in table 8 are obtained.

Table 8: Equipment Availability figures 1+1 Hot Standby with Hitless Switching

MTBF A (hours)	MTBF B (hours)	MTBF for 1+1 (hours)	Mean time to Repair (Hours)	Equipment Unavailability (%)	Equipment Availability (%)
150000	150000	22500000000	12	5.33333×10^{-8}	99.99999995
150000	150000	22500000000	6	2.66667×10^{-8}	99.99999997
150000	150000	22500000000	5	2.22222×10^{-8}	99.99999998
150000	150000	22500000000	4	1.77778×10^{-8}	99.99999998
150000	150000	22500000000	3	1.33333×10^{-8}	99.99999999
150000	150000	22500000000	2	8.88889×10^{-9}	99.99999999
150000	150000	22500000000	1	4.44444×10^{-9}	99.999999996

Table 8 shows that equipment protection allows for the required availability/unavailability figures of equation 8 and 9 to be met.

The additional loss introduced by a coupler (either symmetrical or asymmetrical, when equipment protection is used must be taken into account, when links a designed. A worst month target availability of 99.999% shall still be the objective.

3.2.3 Path Protection – Dual Routes

Using [7] ITU-T G.827 as reference, the following formula is used to calculate unavailability of an end-to-end protected path:

$U_{end\text{-}to\text{-}end}$ = (UR1 x UR2) +URA + URB, (10)

where UR1 and UR2 are the unavailability ratios of each parallel routes/path, URA and URB are the unavailability ratios of the terminal equipment (inclusive of the protection switching).

Using the assumed monthly end to end 99.975% monthly availability (0.025% unavailability) of the 20 hop reference (table 5), for each path, as well as terminal equipment unavailability/ availability of table 6 (150000 hour MTBF), the following given in table 9 are obtained.

Table 9: End to End Availability of a Dual Route Topology, for Terminal MTBF figures of 150 000 hours

Mean Time to Repair (Hours)	Terminal Equipment A and B Unavailability ratio, U_{RA}, U_{rB}	Path 1 unavailability ratio, U_{R1}	Path 2 unavailability ratio, U_{R2}	End to End Unavailability ratio, $U_{end\text{-}to\text{-}end}$	End to End Availability, $A_{end\text{-}to\text{-}end}$ (%)
12	7.99936×10^{-5}	0.00025	0.00025	0.00016005	99.98399503
6	3.99984×10^{-5}	0.00025	0.00025	8.00593×10^{-5}	99.99199407
5	3.33322×10^{-5}	0.00025	0.00025	6.67269×10^{-5}	99.99332731

Mean Time to Repair (Hours)	**Terminal Equipment A and B Unavailability ratio, U_{RA}, U_{rB}**	**Path 1 unavailability ratio, U_{R1}**	**Path 2 unavailability ratio, U_{R2}**	**End to End Unavailability ratio, $U_{end-to-end}$**	**End to End Availability, $A_{end-to-end}$ (%)**
4	2.6666×10^{-5}	0.00025	0.00025	5.33944×10^{-5}	99.99466056
3	1.99996×10^{-5}	0.00025	0.00025	4.00617×10^{-5}	99.99599383
2	1.33332×10^{-5}	0.00025	0.00025	2.67288×10^{-5}	99.99732712
1	6.66662×10^{-6}	0.00025	0.00025	1.33957×10^{-5}	99.99866043

Using the MTBF figures of 1+1 hot standby equipment (table 8) with a dual route topology, the availability/unavailability figures of table 10 are calculated.

Table 10: End to End Availability of a Dual Route Topology, with hot standby terminal equipment protection

Mean Time to Repair (Hours)	**Hot standby Terminal Equipment A and B Unavailability ratio, U_{RA}, U_{rB}**	**Path 1 unavailability ratio, U_{R1}**	**Path 2 unavailability ratio, U_{R2}**	**End to End Unavailability ratio, $U_{end-to-end}$**	**End to End Availability, $A_{end-to-end}$ (%)**
12	5.33333E-10	0.00025	0.00025	6.35667E-08	99.99999364
6	2.66667E-10	0.00025	0.00025	6.30333E-08	99.9999937
5	2.22222E-10	0.00025	0.00025	6.29444E-08	99.99999371
4	1.77778E-10	0.00025	0.00025	6.28556E-08	99.99999371
3	1.33333E-10	0.00025	0.00025	6.27667E-08	99.99999372
2	8.88889E-11	0.00025	0.00025	6.26778E-08	99.99999373
1	4.44444E-11	0.00025	0.00025	6.25889E-08	99.99999374

Appendix A provides a summary of the availability provided in tables 6, 8, 9 and 10 with an MTTR of 12 hours.

3.2.3.1 Recommended Protection Schemes

As defined, in ITU-T Recommendations [3] G.841 and [2] G.803 path and traffic protection schemes available to the SDH technology are Multiplexer Section Protection, Sub-Network Connection Protection, and Multiplex Section Shared Protection Ring (MS Spring). Attributes of these protection schemes are given in sections 3.2.3.1.1 to 3.2.3.1.3.

3.2.3.1.1 Multiplexer Section Protection (MSP)

a) Applies on point-to-point physical networks.

b) Does not provide protection against node failures

c) It provides protection for the multiplex section and not the entire path. i.e. node to node traffic flow protection

d) It can be implemented in either in the 1+1 (dedicated protection) mode or the 1:N (shared protection)

e) In the 1+1 mode the protected traffic flows on both the working and protection path. The end node continuously selects the superior flow in terms of quality. Theoretically, the MSP 1+1 will therefore introduce no switching time.

f) In the 1:N the traffic flows exclusively on the protected path until a switch over event occurs in which case the traffic will then be switched to the protection path. The backup path can offer protection to more than one paths in the MSP 1:N protection scheme. Theoretically, there will be switching time from the working to the backup path in the MSP 1:N protection scheme, however this will be limited to a maximum of 50ms.

g) Events that trigger MSP switching are signal failure, signal degradation and forced switching from the local craft terminal or network management system.

h) Switching time restricted to a maximum of 50ms.

i) It is widely available as a feature of SDH equipment currently available in the market.

j) It allows for low priority traffic to be carried on the protection path until the path is required by the protected traffic.

MSP shall be used as a protection scheme for long haul back bone links, especially on radio links below 10 GHz (MSP 1+1 and MSP 1:N). Where frequency diversity is used on the radio links, low priority traffic should be allowed until protection path until the path is required by the protected traffic.

3.2.3.1.2 Sub-Network Connection Protection (SNCP)

Sub-Network Connection Protection (SNCP) provides duplicate paths. When implemented in a ring topology, the working channel flows in one direction and the protection channel flows in the opposite direction. Should there be a failure of degradation on the working channel the node on the receiving end of the working channel switches over to the protection channel coming from the opposite direction. Some of the SNCP protection scheme features are

a) Switching time restricted to a maximum of 50ms.

b) It is a multiplex section protection scheme.

c) It can be implemented in a ring and mesh network topology.

d) It provides protection against both transmission medium and node failures.

e) Target switching time is less than 50ms.

f) Protection is provided at any VC level (Higher order and Low order)

g) The protection channel can be used to carry low priority traffic if not needed for the protected traffic.

SNCP protection shall be used on all thinks that are designed to form part of a ring topology.

3.2.3.1.3 Multiplex Section Shared Protection Ring (MS-SPRing)

This is a ring based multiplex section protection mechanism. In this protection scheme working channels carry the protected traffic and the protection channels provide protection for the same traffic. The protected traffic is carried over the working channels bi-directionally. At any node in the protected multiplex sections or spans the incoming tributary travels in one direction and its associated tributary travels in the opposite direction over the same span on separate fibres. When a ring switch event is triggered, working channels in the direction of the failed span are switched on to the protection channels travelling in the opposite direction.

a) This is an SDH multiplex section protection scheme

b) It can only be implemented and operated in a ring topology

c) It provides protection against node failures

d) It provides protection for all the multiplex sections in a ring, that is all the multiplex sections within a ring share the same protection channel

e) Implemented in fibre rings, 2-fiber or 4-fibre MS-SPRing channels on each fibre span are divided into two, one half are working channels and another half protection channels. In the 4-fibre MS-SP ring working and protection channels have dedicated fibre. The 4-fibre implementation offers more re-routing options than the 2-fibre implementation such as transoceanic ring-switching and span switching.

f) Protection provided at VC-4 level. As such it cannot be implemented at STM-1. It can be implemented at STM-4 with some limitations. For these reasons, many implementations in equipment are at STM-16 and STM-64 levels.

g) The protection path can be used for low priority traffic which can be bumped when a switchover event occurs in order to give way for the protected traffic.

h) Allows up to 16 nodes in a ring

i) Switching time restricted to a maximum of 50ms

j) Provides revertive switching. This means once failed span or node has been restored back to service the traffic flow will revert back to the original working channels.

k) Automatic switch installation criteria include signal failure and signal degradation.

Given that MS-SPRing requires a minimum of 2 fibres, provides protection at VC-4 level and allows for up 16 nodes in a ring, with the intention of optimizing fibre cores, SNCP shall therefore be used as a minimum protection scheme for ring protection.

However, given the ever increasing requirements for bandwidth, multi fibre protection schemes like MS-SPRing, require investigation, especially for future transport network, for example [19] ITU-T Recommendation G.709 for Optical Transport Network (OTN).

3.3 Latency Objectives

Table 11 provides estimates listed in [14] document number 084 published by Cigre that influence end-to-end transmission delays. As can be seen, delays due to equipment processing the traffic, as well as propagation through the transmission medium, ibre or microwave, all add to the end-to-end transmission delay.

Formula (11) may be used to calculate hop transmission delay for nxE1 (multiple 2048 Kbit/s) traffic over microwave PDH technology (equation 11) and for nxE1 traffic over PDH OLTE (equation 12). Equation (13) and equation (14) may be used to calculate hop transmission delay for SDH over microwave and SDH over fibre optic, respectively.

D_{total} (µs) = E1Mux + E1Demux +l x MW + 2*ODU (11)

D_{total} (µs) = E1Mux + (l x OptProp) +OSP+ E1Demux (12)

D_{total} (µs) = (2*ODU) + (l x MW) (13)

D_{total} (µs) =(l x OptProp) + OSP (14)

Where,

- D_{total} is the total transmission delay in micro seconds over the circuit path.
- E1 Mux Time is the time taken to demultiplex multiple E1s
- E1 Demux Time is the time to multiplex multiple E1s
- l is the hop distance in kilometres.
- MW is microwave propagation delay
- ODU is microwave outdoor unit (ODU) signal processing delay
- OptProp Optical Fiber Propagation delay
- OSP is Optical Signal Processing delay

Table 11: Contributions by different elements / processes to the overall transmission delay

Equipment/Process	**Delay (μs)**
2/8 De/Multiplexing (IDU & OLTE)	30
Microwave Signal Processing (ODU)	30
SDH Cross-connection (ADM)	Negligible
Optical Signal Processing	2
Optical Fibre Propagation	5/km
MW Propagation	3.3/km

Naturally, if a circuit traverses many different transmission mediums and technologies, a combination of the delay times given in Table 11 and equations (11-14) will have to be used to calculate end-to-end delay.

3.4 Link Budget

3.4.1 Microwave Link Budget

Given that all radio links deployed in the network are digital in nature (PDH, SDH), a specific fade margin will not be recommended (unlike in the design of analogue systems). The quality objectives set out in sections 3.1 Error Performance and 3.2.1 Transmission Medium (worst month target availability of 99.999% (inclusive of rain fade and multipath)), at a receiver threshold with a maximum bit error ratio (BER) of 1 x 10^{-6}, shall therefore, be met.

ICS Telecom shall be the de facto standard radio planning tool used to design microwave links in Eskom Telecommunications.

3.4.2 Optical Link Budget

There is presently no de facto standard optical link planning tool used in Eskom Telecommunication. As a result, mathematical models will be used to calculate optical link budget.

As specified in [15] DST 240-46264031, Eskom has standardised on single mode with [10] ITU-T Recommendation G.652.D attributes

For link design purposes representatives values mentioned in Appendix I of [10] ITU-T Recommendation 652 and presented in table 12, should be used:

Table 12: [10] ITUT G.652 Representative values of concatenated optical fibre links

Coefficient	**Wavelength Region**	**Typical Link Budget**
Attenuation coefficient, α	1260 nm-1360 nm	0.5 dB/km
	1530 nm-1565 nm	0.25 dB/km
	1565 nm-1625 nm	0.35 dB/km
Chromatic dispersion coefficient	D_{1550}	17 ps/nm × km
	S_{1550}	0.056 ps/nm^2 × km

Attenuation, A of a link can then be calculated using equation (16) below:

$$A = \alpha L + \alpha_s x + \alpha_c y \quad (16)$$

Where,

- α, is the typical attenuation coefficient of the fibre cables in a link;
- α_s , is the mean splice loss;
- x, is the number of splices in a link;

- α_c is the mean loss of line connectors (maximum 0.5 dB);
- *y,* is the number of line connectors in a link (if provided);
- *L,* is the link length, in km.

Given recent improvements in fusion splice technology, as well as improvements in intrisic attenuation coefficient of the fibre cables, a total average attenuation coefficient (inclusive of splice losses) of 0.25 dB/km, generally suffices for link budget calculations on Eskom deployed fibre. [12] TPC 41-5 Fibre Optic Cable System Acceptance Testing, has standardised on an average single mode fibre splice loss less than or equal to 0.05 dB.

Equation (17) may be used to calculate typical chromatic dispersion (to determine the amount of dispersion compensation that is required) for use in optical link design (especially for channel bit rates greater than and equal to 10 GBit/s):

$$D_{Link}(\lambda) = L_{Link}[D_{1550} + S_{1550}(\lambda - 1550)] \quad [ps/km] \qquad (17)$$

Where,

- D_{Link} (λ), is the total link dispersion at wavelength, λ
- D_{1550} is the chromatic dispersion coefficient, see table 13
- S_{1550}, is the chromatic dispersion slope coefficient, see table 13

Where optical time-domain reflectometer (OTDR) results are available, those results shall be used for the link design. However, as recommended in [8] ITU-T G. 957 typical margins between a beginning-of-life, nominal temperature receiver and its end-of-life, worst-case counterpart, are desired to be in the 2 to 4 dB range. Therefore, an end-of-line optical margin of 4 dB shall into optical link budgets.

[8] ITU-T Recommendation G.957 provides parameters listed in tables 14 (STM-1), table 15 (STM-4) and table 16 (STM-16) for optical small form factor pluggable (SFP) interfaces. Specific equipment manufacturer specification shall, however, be referred to and/or used to perform link planning, especially if/when amplifiable cards are used.

Table 13: [8] ITU-T G.957 recommended values for STM-1 optical SFP interfaces

	Unit	**Values**			
Digital Signal Nominal Bit Rate	kbit/s	155 520 (STM-1)			
Application Code		S-1.1	S-1.2	L-1.1	L-1.2
Operating wavelength range	nm	1261-1360	1430-1580	1263-1360	1480-1580
Max mean launched power	dBm	−8	-8	0	0
Minimum mean launched power	dBm	−15	−15	-5	-5
Minimum Sensitivity	dBm	−28	−28	−34	−34
Minimum Overload	dBm	−8	−8	−10	−10
Optical Path Penalty	dB	1	1	1	1

Table 14: [8] ITU-T G.957 recommended values for STM-4 optical SFP interfaces

	Unit	Values			
Digital Signal Nominal Bit Rate	kbit/s	622 080 (STM-4)			
Application Code		S-4.1	S-4.2	L-4.1	L-4.2
Operating wavelength range	nm	1293-1334/ 1274-1356	1430-1580	1280-1335	1480-1580
Max mean launched power	dBm	−8	-8	+2	+2
Minimum mean launched power	dBm	−15	−15	-3	-3
Minimum Sensitivity	dBm	−28	−28	−28	−28
Minimum Overload	dBm	−8	−8	−8	−8
Optical Path Penalty	dB	1	1	1	1

Table 15: [8] ITU-T G.957 recommended values for STM-16 optical SFP interfaces

	Unit	Values			
Digital Signal Nominal Bit Rate	kbit/s	2 488 320 (STM-16)			
Application Code		S-16.1	S-16.2	L-16.1	L-16.2
Operating wavelength range	nm	1260-1360	1430-1580	1280-1335	1500-1580
Max mean launched power	dBm	0	0	+3	+2
Minimum mean launched power	dBm	−5	-5	-2	-2
Minimum Sensitivity	dBm	−18	−18	−27	−28
Minimum Overload	dBm	0	0	-9	-9
Optical Path Penalty	dB	1	1	1	2
Maximum dispersion	ps/nm	N/A	N/A	N/A	1600

[9] ITU-T G.691 provides parameters listed in table 17 for STM-64 optical interfaces (with passive dispersion compensation). However, it should be noted that further study is required on the deployment of links with data rates that are greater than or equal to 10 Gbit/s (especially with respect to the use of wavelength division multiplexing, dispersion compensating techniques, coherent detection, etc).

Table 16: [9] ITU-T G.691 recommended values for STM-64 optical SFP interfaces

	Unit	Values
Digital Signal Nominal Bit Rate	kbit/s	9 953 280 (STM-64)
Application Code		L-64.2a
Operating wavelength range	nm	1530-1565
Max mean launched power	dBm	+2
Minimum mean launched power	dBm	-2
Minimum Sensitivity	dBm	−28

	Unit	Values
Minimum Overload	dBm	-9
Optical Path Penalty	dB	2
Maximum dispersion	ps/nm	1600
Maximum Group Delay	ps	30

For deployment of links with data rates that are greater than or equal to 10Gbit/s, it is imperative to obtain Fibre Optic Cable test results, as stipulated in [12] TPC 41-5 Fibre Optic Cable System Acceptance Testing, particularly Polarisation Mode Dispersion (PMD) figures to ensure compliance to table 17. This is due to PMD being an inherent property of fibre and as a result, a specific value which cannot be specified.

As mentioned in [9] ITU-T Rec G.691, total PMD in the link corresponding to a worst-case path penalty of 1 dB is considered. Further, a maximum PMD of a tenth of the bit period indicates a probability of 4×10^{-5} for a path penalty of larger than 1 dB. These values are also standardised in [12] TPC 41-5.

Table 17: Maximum Average PMD for Different Bit Rates

Bit rate (GBit/s)	Bit Period, (ps)	Maximum Average PMD over the link length, (ps)
2.5	400	40
10	100	10 (with no Forward Error Correction)
40	25	2.5

4. Authorization

This document has been seen and accepted by:

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5. Revisions

Date	Rev	Compiler	Remarks
March 2018	2	K Jose	The existing document was expiring.Needed to be revised..
April 2013	1	K Setlhapelo	First Issue.

6. Development team

The following people were involved in the development of this document:

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