INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.663

Amendment 1
(01/2003)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Transmission media characteristics – Characteristics of optical components and subsystems

---

Application related aspects of optical amplifier devices and subsystems

Amendment 1: Amendments to Appendix II

ITU-T Recommendation G.663 (2000) – Amendment 1

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TESTING EQUIPMENTS	G.500–G.599
TRANSMISSION MEDIA CHARACTERISTICS	G.600–G.699
General	G.600–G.609
Symmetric cable pairs	G.610–G.619
Land coaxial cable pairs	G.620–G.629
Submarine cables	G.630–G.649
Optical fibre cables	G.650–G.659
Characteristics of optical components and subsystems	**G.660–G.699**
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
QUALITY OF SERVICE AND PERFORMANCE	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DIGITAL TERMINAL EQUIPMENTS	G.7000–G.7999
DIGITAL NETWORKS	G.8000–G.8999

For further details, please refer to the list of ITU-T Recommendations.

ITU-T Recommendation G.663

Application related aspects of optical amplifier devices and subsystems

Amendment 1

Amendments to Appendix II

Summary

This amendment contains editorial additions and technical updates, to the clause II.4.1 of Appendix II to ITU-T Recommendation G.663 (version of 04/2000) related to the Polarization Mode Dispersion.

Source

Amendment 1 to ITU-T Recommendation G.663 (2000) was prepared by ITU-T Study Group 15 (2001-2004) and approved under the WTSA Resolution 1 procedure on 31 January 2003.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

ITU-T Recommendation G.663

Application related aspects of optical amplifier devices and subsystems

Amendment 1

Amendments to Appendix II

1) Clause 2 – References

Add the following new references:

[18] ITU-T Recommendation G.691 (2000), *Optical interfaces for single channel STM-64, STM-256 and other SDH systems with optical amplifiers*.

[19] IEC 61282-3:2002, *Fibre optic communication system design guides – Part 3: Calculation of polarization mode dispersion*.

2) Clause II.4.1

Replace clause II.4.1 as follows:

II.4.1 Polarization mode dispersion

II.4.1.1 Description of the effects

It is well known that the fundamental mode of a circularly symmetric dielectric waveguide is doubly degenerate. In a real optical fibre this degeneracy is split by birefringence. The birefringence may be introduced deliberately, as in polarization-maintaining fibre for example, or it may be an unwanted by-product of fibre manufacture or cable manufacture. In this case the birefringence is introduced in a random way by, for example, geometrical or stress-induced perturbations.

The propagation constants, $\beta_i(\omega)$, of the two orthogonal modes can be expanded in a Taylor series around the centre frequency, ω_0;

$$\beta_i(\omega_0) = \beta_i(\omega_0) + \left.\frac{\partial \beta_i}{\partial \omega}\right|_{\omega=\omega_0}(\omega-\omega_0) + \frac{1}{2}\left.\frac{\partial^2 \beta_i}{\partial \omega^2}\right|_{\omega=\omega_0}(\omega-\omega_0)^2 + \ldots$$

where the $\beta_i(\omega_0)$ is the phase velocity v_p, $\frac{\partial \beta_i}{\partial \omega}$ is related to the group velocity v_g, and $\frac{\partial^2 \beta_i}{\partial \omega^2}$ is related to the dispersion of the group velocity (or chromatic dispersion, D) etc.

With the development of dispersion-shifted fibres and the deployment of systems operating near the dispersion-zero wavelength, the contribution to the dispersion from the second order term, or chromatic dispersion, reduces and the first order term can now become significant. For the case of birefringent fibres, this first order term leads to a group delay called polarization dispersion. This polarization dispersion introduces a differential group delay between orthogonal states of polarization. Although the effect of Polarization Mode Dispersion (PMD) is to change randomly the polarization state of a pulse propagating in a fibre, it is possible to define a pair of orthogonal states or "principal states" at the input whose output states are orthogonal and show no dependence on wavelength to first order. (In some situations, however, this approximation falls apart and the principal states can show a wavelength dependence, leading to a further system degradation through a coupling to chromatic dispersion.)

As alluded to in the first paragraph above, the birefringence introduced to the fibre is caused by local random and asymmetric mechanisms such as stress, bending and twisting. These random birefringence mechanisms redefine the local birefringence axes along the length of the fibre, thus causing random coupling between the polarization modes along the length of the fibre. The cabling process also introduces a certain amount of random birefringence and random mode coupling. The fibre length between such changes is usually referred to as the coupling length, which for a fibre is usually quoted as the ensemble average of all of the local coupling lengths. Furthermore, changes in local environmental conditions, such as temperature for example, cause fluctuations in the local birefringence axes, thus causing random polarization coupling. As a result of the randomly changing polarization coupling, the magnitude of the Differential Group Delay (DGD) becomes a statistically varying function. It can be shown that distribution of differential group delays is described by a Maxwellian distribution function, defined by:

$$P(\Delta\tau) = \frac{32\Delta\tau^2}{\pi^2\langle\Delta\tau\rangle^3}\exp\left[-\frac{4\Delta\tau^2}{\pi\langle\Delta\tau\rangle^2}\right]$$

where $\Delta\tau$ is the differential group delay between the two principal states, and $\langle\Delta\tau\rangle$ is the mean differential group delay (usually referred to as the PMD value). As a consequence of the statistical nature of polarization mode dispersion, the magnitude of $\langle\Delta\tau\rangle$ increases with the square root of the fibre or cable length, for lengths much longer than the coupling length. Polarization mode dispersion is usually quoted in units of ps or ps/√km. The unit of ps is usually reserved for single optical elements which have a fixed dispersion (e.g., a coupler or isolator) or short fibre sections which do not exhibit mode coupling.

II.4.1.2 Induced transmission limitations

In a digital transmission system, the principal effect of polarization mode dispersion is to cause intersymbol interference. As an approximate rule of thumb, a 1-dB penalty occurs when the total instantaneous differential group delay equals 0.3 T, and both principal states of polarization are excited equally (gamma = 0.5), where T is the bit period. This is a commonly used value for the maximum tolerable system power penalty and the related instantaneous DGD can also be considered, in the same way, as the maximum tolerable system value: $DGD_{max} \leq 0.3T$. The relationship between DGD_{max} and PMD value is to be determined on the base of the Maxwellian probability distribution choosing a proper adjustment factor, that is related to the desired maximum outage probability. For example, a value of the adjustment factor equal to 3, i.e., $DGD_{max} = 3 \cdot$PMD value, corresponds to an outage probability of approx. 4×10^{-5}, see ITU-T Rec. G.691 [18]. Higher bit rate systems have shorter bit periods, so they tolerate less differential group delay. Current studies, e.g., IEC 61282-3 [19], indicate that optical fibres and cables will be specified according to either the $DGD_{max,}$ defined above or to the mean level of Differential Group Delay (PMD value). Using the example value of the adjustment factor of 3, the system design rule for PMD impairments becomes: PMD value ≤ 0.1T.

In optical transmission systems operating at 10 Gbit/s, a statistical specification of 0.5 ps/sqrt(km) has been proposed for concatenated links of optical fibre cable. From the Maxwell statistics, the probability that the 1 dB penalty at 10 Gbit/s is exceeded for a 400 km span is less than 4×10^{-5} (see ITU-T Rec. G.691). Here, the contribution of other components to PMD is not taken into account. The PMD impairment can therefore be seen as a system power penalty combined with a probability that this penalty will be exceeded.

For systems operating at 40 Gbit/s, the mean differential group delay equal to one-tenth of a bit period, 0.1 T, corresponds to 2.5 ps. As a general assumption, part of this tolerated value could be allocated to the cable and part to optical repeaters, depending on the link characteristics (PMD quality of used fibers and subsystems). The total PMD of a link encompassing optical fibers and optical subsystems is the quadratic sum (square root of the sum of the squares) of the fiber and subsystems PMD:

$$PMD_{TOT} = \left[PMD_F^2 + \sum_i PMD_{Ci}^2 \right]^{1/2}$$

where

PMD_{TOT}: TOTAL PMD link (ps)

PMD_F: PMD of concatenated optical fibre cables (ps)

PMD_{Ci}: PMD value of the ith subsystem (ps)

For example, considering a PMD value of the concatenated optical fibre cables of the link of 0.1 ps/sqrt(km), (that can be considered advisable at 40 Gbit/s), 2.0 ps is the PMD cable contribution on 400 km long links. According to the previous formula, this still leaves a 1.5 ps PMD margin for optical subsystems. Assuming the use of 4 optical subsystems with a PMD value of 0.6 ps, the total PMD will be below the 2.5 ps limit stated before for 40 Gbit/s systems.

$$PMD_{TOT} = \sqrt{\left(0.1 \cdot \sqrt{400}\right)^2 + 4 \cdot (0.6)^2} = 2.33\,ps < 2.5\,ps$$

The second or higher order PMD may give a non-negligible effect on the total PMD penalty. Further study is required.

Furthermore, in long-haul amplifier systems employing polarization scramblers (devices which deliberately modulate the polarization state of a signal laser so that it appears to be unpolarized), the polarization mode dispersion causes an increase in the degree of polarization of the signal. This degrades system performance through interactions with polarization-dependent loss and polarization hole burning (see following clauses). In an analogue system, the interaction of polarization mode dispersion with laser chirp leads to a second order distortion proportional to the modulation frequency. A further second order penalty, independent of modulation frequency, is incurred when additional polarization-dependent loss is present in the system.

It has also been shown, and mentioned briefly above, that a second order effect can cause a coupling between polarization mode dispersion and chromatic dispersion. This is caused by the wavelength dependence of the differential group delay, and more importantly, the wavelength dependence of the principal states of polarization. This leads to a statistical contribution to the chromatic dispersion. This is an area which is not well understood and is under study. The use of chromatic dispersion compensating devices also has an unclear impact on the PMD penalty. The impact of higher launched channel power on nonlinear PMD also requires further study.

For amplified 1550 nm systems, PMD is likely to be more of an issue for vintage fibres operating on 10 Gbit/s or higher TDM systems than for newer G.652, G.653 or G.655 fibres.

II.4.1.3 Methods to minimize the induced limitation

Given that the problem arises from birefringence, much of the effort in reducing the effects of polarization mode dispersion have been concerned with minimizing the birefringence introduced by fibre or cable manufacture. Care is taken to optimize fibre production to ensure geometrical and optical circular symmetry, and/or to induce polarization mode coupling. Optical cables are manufactured using materials and processes which minimize the residual strain in the cable structure across the fibre. Elaborate cable structures can also be used which introduce a circular component to the induced birefringence. By careful design, such an effect can counteract linear birefringence to produce a cable with a resultant zero polarization mode dispersion. Typically, the mean polarization mode dispersion of fibres and cables lie in the range:

$$0 < \langle \Delta\tau \rangle < 0.5 \quad ps/\sqrt{km}$$

Furthermore, improved fibre designs show smaller PMD values, e.g., 0.1 ps/sqrt(km), as mentioned earlier.

Additionally, another method to reduce the effect of PMD is dynamic PMD compensation. A PMD compensator can accept at its input a signal affected by PMD and would provide at its output a signal with reduced distortion. It generally consists of PMD equaliser, PMD monitor and Feed-back controller. The equaliser and the monitor can be implemented in the optical or in the electrical domain. There is also the possibility for mixed or hybrid solutions. The feed-back controller takes decisions on the basis of the monitored information according to a predefined algorithm and drives the equaliser according to the decisions. Dynamic PMD compensation is currently performed on a per-wavelength channel basis.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series B	Means of expression: definitions, symbols, classification
Series C	General telecommunication statistics
Series D	General tariff principles
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	**Transmission systems and media, digital systems and networks**
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Construction, installation and protection of cables and other elements of outside plant
Series M	TMN and network maintenance: international transmission systems, telephone circuits, telegraphy, facsimile and leased circuits
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks and open system communications
Series Y	Global information infrastructure and Internet protocol aspects
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2003