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

Transmission media characteristics – Characteristics of
optical components and subsystems

Characteristics of PMD compensators and PMD compensating receivers

ITU-T Recommendation G.666

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ITU-T Recommendation G.666

Characteristics of PMD compensators and PMD compensating receivers

Summary

This Recommendation contains parameters and definitions for devices providing Polarization Mode Dispersion (PMD) compensation needed for transmission and detection of optical signals in a system exhibiting high levels of PMD which would otherwise cause unacceptable levels of system outage. Single and multichannel line PMD compensators are described, as well as single and multichannel PMD compensating receivers. Information on test configurations and implementation options can be found in informative appendices.

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.

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CONTENTS

ITU-T Recommendation G.666

Characteristics of PMD compensators and PMD compensating receivers

1 Scope

This Recommendation contains parameters and definitions for devices providing Polarization Mode Dispersion (PMD) compensation needed for transmission and detection of optical signals in a system exhibiting high levels of PMD. The PMD compensating devices described include both single and multichannel applications. This Recommendation defines requirements and key parameters for first and higher order PMD compensators (PMDC) and includes dynamic PMD characteristics. This Recommendation distinguishes Line PMDCs from PMDC receivers which may comprise electrical as well as optical forms of PMD compensation.

2 References

2.1 Normative references

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

– ITU-T Recommendation G.650.2 (2005), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable.*

– ITU-T Recommendation G.652 (2005), *Characteristics of a single-mode optical fibre and cable.*

– ITU-T Recommendation G.653 (2003), *Characteristics of a dispersion-shifted single-mode optical fibre and cable.*

– ITU-T Recommendation G.654 (2004), *Characteristics of a cut-off shifted single-mode optical fibre and cable.*

– ITU-T Recommendation G.655 (2003), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable.*

– ITU-T Recommendation G.656 (2004), *Characteristics of a fibre and cable with non-zero dispersion for wideband optical transport.*

– ITU-T Recommendation G.661 (1998), *Definition and test methods for the relevant generic parameters of optical amplifier devices and subsystems.*

– ITU-T Recommendation G.662 (2005), *Generic characteristics of optical amplifier devices and subsystems.*

– ITU-T Recommendation G.665 (2005), *Generic characteristics of Raman amplifiers and Raman amplified subsystems.*

– ITU-T Recommendation G.671 (2005), *Transmission characteristics of optical components and subsystems.*

– ITU-T Recommendation G.694.1 (2002), *Spectral grids for WDM applications: DWDM frequency grid.*

2.2 Informative references

– ITU-T G-series Recommendations – Supplement 39 (2003), *Optical system design and engineering considerations*.

3 Definitions

This Recommendation defines the following terms:

3.1 first order DGD vector: The first order DGD vector $\vec{\Omega}(\omega)$ is defined as $\vec{\Omega}(\omega) = \tau\,\vec{q}$ with the Differential Group Delay (DGD) τ and the principal state of polarization vector $\vec{q}$ in Stokes Space which is a unit vector.

3.2 DGD rate of change: The "DGD rate of change" is defined as the derivative of the DGD with respect to time, i.e., $\left|\dfrac{\partial \tau}{\partial t}\right|$, and is measured in ps/ms.

3.3 polarization rotation speed: The "polarization rotation speed" (PRS) is the absolute value of the temporal change of the Stokes vector $\vec{S}$, i.e., $PRS = \left|\dfrac{\partial \vec{S}}{\partial t}\right|$, and is measured in rad/ms.

3.4 second order PMD: Second-order PMD (SOPMD) is defined by $SOPMD = \vec{\Omega}_{\omega} = \tau_{\omega}\vec{q} + \tau\,\vec{q}_{\omega}$. This is the derivative of the first-order DGD vector with respect to the optical frequency ω. The SOPMD consists of two terms, namely $\tau_{\omega}\vec{q}$ and $\tau\,\vec{q}_{\omega}$. The first term, $\tau_{\omega}\vec{q}$, represents the Polarization-dependent chromatic dispersion term (PCD) while $\tau\,\vec{q}_{\omega}$ is the so-called depolarization term which describes the PSP unit vector rotation with respect to frequency (at the centre frequency of the signal). The corresponding magnitudes of these quantities are given as follows: Magnitude of the SOPMD = $\left|\vec{\Omega}_{\omega}\right|$, magnitude of the depolarization = $\left|\tau\,\vec{q}_{\omega}\right|$, magnitude of the PCD = $\left|\tau_{\omega}\right|$.

3.5 OSNR penalty due to DGD: An optical signal that has been subject to a DGD requires a larger OSNR at the receiver to achieve BER = 10^{-12} than an optical signal which has not been affected by DGD (i.e., DGD = 0), assuming the same receiver input power in both cases. This OSNR difference is called the OSNR penalty due to DGD.

3.6 PMDC receiver sensitivity: The value of mean received power at point MPI-R to achieve the specified BER. This must be met across all states of input polarization with a worst-case transmitter, but does not have to be met with degradations of the optical path other than the PMD.

4 Abbreviations

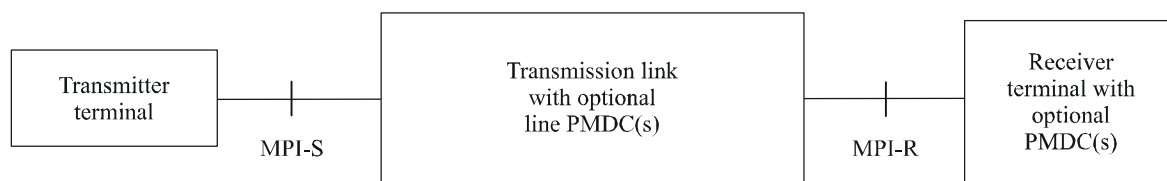This Recommendation uses the following abbreviations:

BER	Bit Error Ratio
DEMUX	Demultiplexer
DGD	Differential Group Delay
LPMDC	Line Polarization Mode Dispersion Compensator
M-LPMDC	Multichannel Line Polarization Mode Dispersion Compensator
M-PMDC-Rx	Multichannel Polarization Mode Dispersion Compensating Receiver
MPI	Main Path Interface

MUX   Multiplexer

NRZ   Non-Return to Zero

OA   Optical Amplifier

O-E-O   Optical-Electrical-Optical (conversion)

OSNR   Optical Signal-to-Noise Ratio

PCD   Polarization-dependent Chromatic Dispersion

PDL   Polarization-Dependent Loss

PMD   Polarization Mode Dispersion

PMDC   Polarization Mode Dispersion Compensator

PMDC-Rx   Polarization Mode Dispersion Compensating Receiver

RZ   Return to Zero

S-LPMDC   Single-Channel Line Polarization Mode Dispersion Compensator

S-PMDC-Rx   Single-Channel Polarization Mode Dispersion Compensating Receiver

SOPMD   Second Order PMD

WDM   Wavelength Division Multiplexing

5   Reference configurations

PMDCs are intended to be used in optical transmission systems in order to reduce PMD-induced signal degradations. Therefore, characteristics of PMDCs must be considered, at least in part, in conjunction with a whole transmission system.

A generic configuration of a transmission system with PMDC(s) is shown in Figure 5-1. It consists of a transmitter terminal, a receiver terminal and a transmission link in between with optional Line PMDC(s). A single-channel system contains a single-channel transmitter and receiver terminal while a multichannel transmitter and receiver terminal is used in a multichannel system. The receiver terminal can also contain optional PMDC functionalities and is called a "PMDC receiver" in this case. In the following clauses Optical Line PMDCs (LPMDC) are distinguished from PMDC receivers. A black box approach is applied for the PMDCs and PMDC receivers. Monitoring and control (if present) is included in the black box.

Figure 5-1/G.666 – Generic configuration of a transmission system with PMDCs

5.1   Line PMDCs

Line PMDCs have an optical input and an optical output port and no O-E-O conversion is performed inside a line PMDC. A Single-Channel Line PMDC (S-LPMDC) can handle a single-channel optical signal while a Multichannel Line PMDC (M-LPMDC) is constructed for a multichannel optical signal. Both types are illustrated schematically in Figures 5-2 and 5-3, respectively.

Figure 5-2/G.666 – Reference configuration of a single-channel line PMDC (S-LPMDC)

Figure 5-3/G.666 – Reference configuration of a multichannel line PMDC (M-LPMDC)

5.2 PMDC receivers

In the case of PMDC receivers (PMDC-Rx), the PMDC functionality is embedded in the receiver terminal. There are a number of options regarding how to realize PMDC receivers. Single-channel PMDC receivers are distinguished from multichannel PMDC receivers.

A schematic diagram of a single-channel PMDC receiver (S-PMDC-Rx) is shown in Figure 5-4. A single-channel optical signal enters the receiver terminal at the reference point MPI-R. There the PMDC functionality is performed and the signal is then detected. Implementation details on single-channel PMDC receivers (e.g., optical vs electrical) can be found in Appendix II.

Figure 5-4/G.666 – Reference configuration of a single-channel PMDC receiver

A multichannel PMDC receiver is presented schematically in Figure 5-5. A multichannel optical signal enters the receiver terminal at the reference point MPI-R. There, it either passes a PMDC before entering a demultiplexer (DEMUX) and the receivers Rx for the individual optical channels, or it passes directly through the demultiplexer where all of the receivers are PMDC Rx. Further implementation details can be found in clause II.2.
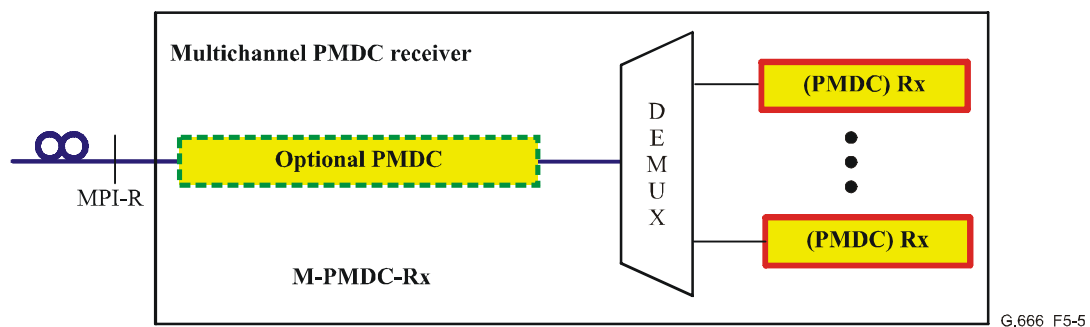

Figure 5-5/G.666 – Reference configuration of a multichannel PMDC receiver (M-PMDC-Rx)

6 Parameters of PMDCs

In this clause, parameters for PMDCs are presented. Some parameters apply to all PMDC types and they are summarized in Table 6-1. In the following Tables 6-2 to 6-5, additional parameters can be found which apply to the individual PMDC types.

Table 6-1/G.666 – Common parameters which apply to all PMDC types

Parameters	Reference point	Unit	**Examples** (for illustration of particular applications only)
Fibre type			
Line fibre type	MPI-S $\rightarrow$ R$_S$ or MPI-S $\rightarrow$ R$_M$ or MPI-S $\rightarrow$ MPI-R	–	G.652.D, G.653, G.654, G.655, G.656
Parameters related to optical power			
Minimum total input power	R$_S$ or R$_M$ or MPI-R	dBm	
Maximum total input power	R$_S$ or R$_M$ or MPI-R	dBm	
Maximum reflectance at the input port	R$_S$ or R$_M$ or MPI-R	dB	
Polarization dependent reflectance at the input port	R$_S$ or R$_M$ or MPI-R	dB	
Optical signal characteristics			
Minimum bit rate	R$_S$ or R$_M$ or MPI-R	Gbit/s	
Maximum bit rate	R$_S$ or R$_M$ or MPI-R	Gbit/s	
Modulation format (or "signal format")	R$_S$ or R$_M$ or MPI-R	–	"Any format", "only NRZ", "NRZ and RZ"
Polarization-independent parameters of the preceding optical path			
Minimum amount of accumulated Chromatic Dispersion	MPI-S $\rightarrow$ R$_S$ or MPI-S $\rightarrow$ R$_M$ or MPI-S $\rightarrow$ MPI-R	ps/nm	
Maximum amount of accumulated Chromatic Dispersion	MPI-S $\rightarrow$ R$_S$ or MPI-S $\rightarrow$ R$_M$ or MPI-S $\rightarrow$ MPI-R	ps/nm	
Polarization parameters at the input port			
Maximum average input DGD	R$_S$ or R$_M$ or MPI-R	ps	
Maximum instantaneous input DGD	R$_S$ or R$_M$ or MPI-R	ps	
Maximum polarization rotation speed	R$_S$ or R$_M$ or MPI-R	rad/ms	
Maximum DGD rate of change	R$_S$ or R$_M$ or MPI-R	ps/ms	
Maximum magnitude of the PCD	R$_S$ or R$_M$ or MPI-R	ps^2	
Maximum magnitude of the depolarization	R$_S$ or R$_M$ or MPI-R	ps^2	

Table 6-2/G.666 – Parameters which apply to a Single-Channel Line PMDC (S-LPMDC)

Parameters	Reference point	Unit	Examples (for illustration of particular applications only)
General single-channel optical parameters			
Nominal central optical frequency	R_S	THz	
Maximum central frequency deviation	R_S	GHz	
Parameters related to optical power			
Minimum insertion loss (incl. optional OA unit)	$R_S \rightarrow S_S$	dB	
Maximum insertion loss (incl. optional OA unit)	$R_S \rightarrow S_S$	dB	
Maximum insertion loss deviation	$R_S \rightarrow S_S$	dB	
Noise figure (if an OA unit is used)	$R_S \rightarrow S_S$	dB	
Polarization dependent loss (PDL)	$R_S \rightarrow S_S$	dB	
Polarization parameters related to the output port (Note 1)			
Maximum average output DGD (Note 2)	S_S	ps	
Maximum instantaneous output DGD (Note 2)	S_S	ps	
Maximum magnitude of the SOPMD (Note 2)	S_S	ps^2	
NOTE 1 – In order to ensure transverse compatibility between line PMDCs and optical receivers, additional parameters may be required.			
NOTE 2 – These parameters must be met for input PMD within the limits indicated in the "polarization parameters at the input port" section in Table 6-1.			

Table 6-3/G.666 – Parameters which apply to a Multichannel Line PMDC (M-LPMDC)

Parameters	Reference point	Unit	Examples (for illustration of particular applications only)
General multichannel optical parameters			
Maximum number of channels	R_M	–	
Nominal channel central frequencies	R_M	THz	191.9 + 0.2 m, m = 0 to 19
Channel spacing	R_M	GHz	200
Maximum central frequency deviation	R_M	GHz	
Parameters related to optical power			
Minimum channel input power	R_M	dBm	
Maximum channel input power	R_M	dBm	
Minimum channel insertion loss (incl. optional OA unit)	$R_M \rightarrow S_M$	dB	
Maximum channel insertion loss (incl. optional OA unit)	$R_M \rightarrow S_M$	dB	
Maximum channel insertion loss deviation	$R_M \rightarrow S_M$	dB	
Noise figure (if an OA unit is used)	$R_M \rightarrow S_M$	dB	
Polarization dependent loss (PDL)	$R_M \rightarrow S_M$	dB	

Table 6-3/G.666 – Parameters which apply to a Multichannel Line PMDC (M-LPMDC)

Parameters	Reference point	Unit	**Examples** (for illustration of particular applications only)
Polarization parameters applied to each channel related to the output port (Note 1)			
Maximum average output DGD (Note 2)	S_M	ps	
Maximum instantaneous output DGD (Note 2)	S_M	ps	
Maximum magnitude of SOPMD (Note 2)	S_M	ps^2	
NOTE 1 – In order to ensure transverse compatibility between line PMDCs and optical receivers, additional parameters may be required.			
NOTE 2 – These parameters must be met for input PMD within the limits indicated in the "polarization parameters at the input port" section in Table 6-1.			

Table 6-4/G.666 – Parameters which apply to a Single-Channel PMDC Receiver (S-PMDC-Rx)

Parameters	Unit	**Examples** (for illustration of particular applications only)
General single-channel optical parameters		
Nominal central optical frequency	THz	
Maximum central frequency deviation	GHz	
Single-channel transmission system parameters		
Maximum OSNR penalty due to DGD	dB	
Minimum PMDC receiver sensitivity	dBm	

Table 6-5/G.666 – Parameters which apply to a Multichannel PMDC Receiver (M-PMDC-Rx)

Parameters	Unit	**Examples** (for illustration of particular applications only)
General multichannel optical parameters		
Maximum number of channels	–	
Nominal channel central frequencies	THz	191.9 + 0.2 m, m = 0 to 19
Channel spacing	GHz	200
Maximum central frequency deviation	GHz	
Parameters related to optical power		
Minimum channel input power	dBm	
Maximum channel input power	dBm	
Multichannel transmission system parameters applied to each channel		
Maximum OSNR penalty due to DGD	dB	
Minimum PMDC receiver sensitivity	dBm	

Appendix I

Measurements of parameters of PMDCs

This appendix covers approaches to the measurement of the parameters of PMDCs. A test configuration should contain a transmission link with PMD tuning capabilities (thus including the transmission fibre and a PMD emulator) followed by the PMDC and a test instrumentation to measure the PMDC characteristics.

There are two different categories of PMDCs, namely PMDC receivers and Line PMDCs. PMDC receivers include S-PMDC-Rxs and M-PMDC-Rxs. Line PMDCs include S-LPMDCs and M-LPMDCs. A generic approach to measurement of parameters for these PMDCs is shown below.

I.1 Measurement of parameters for PMDC receivers

A generic test configuration for measuring parameters of PMDC receivers is shown in Figure I.1. For reasons of simplicity, a single-channel transmitter and receiver terminal is assumed. The single-channel optical signal passes a transmission link which contains an adjustable PMD emulator and an optical noise source. Additional optical components (not shown here) are used to ensure constant optical input power at the reference point MPI-R in front of the PMDC receiver.
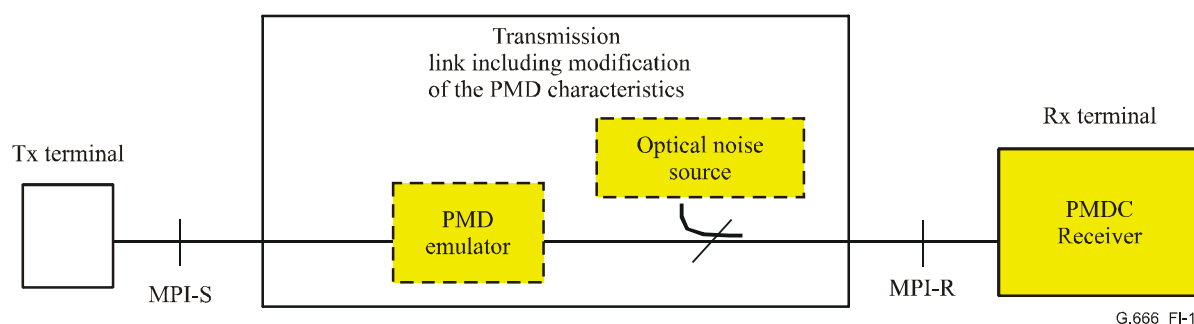

Figure I.1/G.666 – Generic configuration for measuring parameters of PMDC receivers

In order to measure the OSNR penalty with respect to DGD, a first order PMD emulator is adjusted to DGD values in the DGD interval $0 \le \tau \le \tau_{max}$. Here, τ denotes the Differential Group Delay (DGD), and τ_{max} is the limit of the first order PMD that the receiver is required to tolerate.

The BER is measured versus OSNR (while maintaining a constant optical input power P_{in} at MPI-R). The BER curve at a value $\tau > 0$ may be shifted with respect to the BER curve at zero DGD (i.e., at $\tau = 0$). A schematic view of this behaviour is shown in Figure I.2. The PMD-induced penalty at BER $= 10^{-12}$ between a polarization state with DGD τ and the zero DGD state ($\tau = 0$) is denoted as $\Delta(\tau)$.
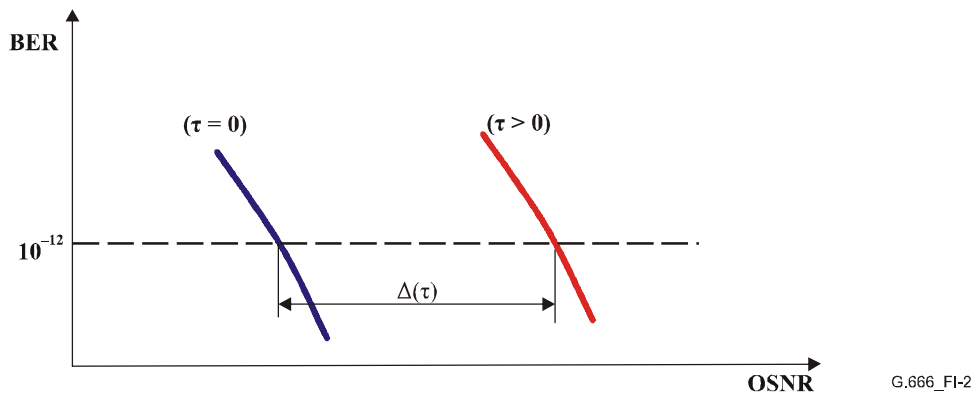
Figure I.2/G.666 – Schematic view of the BER versus OSNR for zero and non-zero DGD τ

The measurement set-up shown in Figure I.1 can also be used to measure the OSNR penalty with respect to both the DGD and SOPMD. In this case, a second order PMD emulator is used. This PMD emulator can be adjusted to any pair of values (τ, Ω') in the DGD interval $0 \leq \tau \leq \tau_{max}$ and the SOPMD interval $0 \leq \Omega' \leq \Omega'_{max}$. Here, τ denotes the Differential Group Delay (DGD), $\Omega' = \left| \vec{\Omega}_\omega \right|$ denotes the amount of SOPMD whereby $\vec{\Omega}_\omega$ is the derivative of the first order DGD vector $\vec{\Omega}(\omega)$, and τ_{max} and Ω'_{max} are the limits of the first and second order PMD that the receiver is required to tolerate.

The same principle is applied as shown in Figure I.2. However, the BER curves are measured as a function of two PMD parameters, namely DGD and SOPMD. A schematic view of this behaviour is shown in Figure I.3.
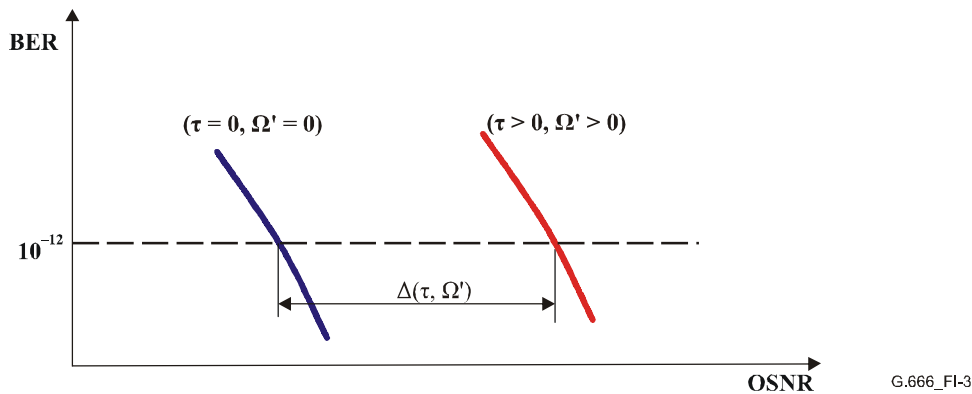

**Figure I.3/G.666 – Schematic view of the BER versus OSNR for
zero and non-zero DGD τ and SOPMD Ω'**

The BER is measured versus OSNR (rather than versus optical input power) at the reference point MPI-R for the following reason: PMD usually becomes an issue for very high data rates (10 Gbit/s and above) and long optically transparent link lengths. In other words, PMD usually becomes an issue in multi-span transmission systems which (per definition) include optical amplifiers (OAs). OSNR is a fundamental limitation of such multi-span systems due to noise accumulation of the OAs. The minimum OSNR that the system can tolerate is given by the minimum OSNR in the absence of any PMD-induced distortions plus the additional penalty $\Delta(\tau, \Omega')$ due to the impact of DGD and SOPMD. The additional penalty $\Delta(\tau, \Omega')$ in dB is represented by the amount that the OSNR must be improved in the presence of PMD to maintain the required BER.

I.2 Measurement of parameters for Line PMDCs

A generic test configuration for measuring parameters of Line PMDCs is shown in Figure I.4.
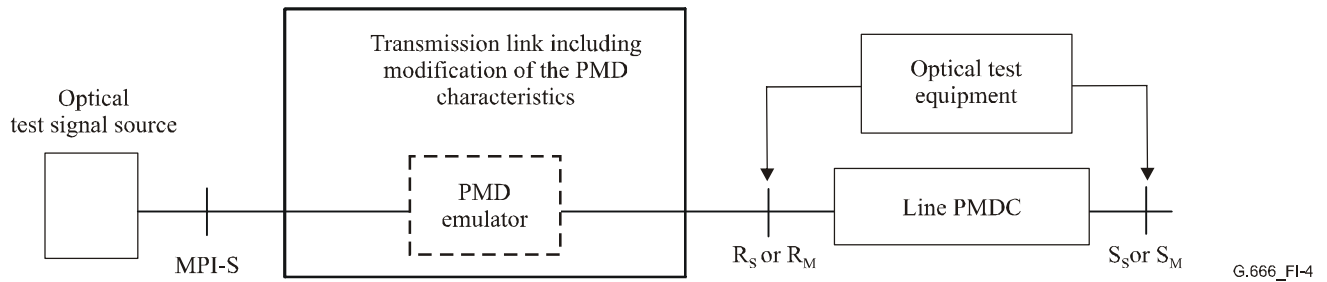

Figure I.4/G.666 – Generic configuration for measuring parameters of Line PMDCs

In the case of Line PMDCs, only optical parameters are measured at the input and the output port of the Line PMDC. The BER is not measured.

Appendix II

Single-channel and multichannel PMDC receiver implementation

II.1   Single-channel PMDC receiver implementation

Single-channel PMDC receivers (as shown generically in Figure 5-4) can be realized by different implementation schemes. One option is a single-channel line PMDC (S-LPMDC) as presented in Figure II.1, together with a conventional receiver. The optical signal behind the reference point MPI-R passes through an optical PMDC before entering the receiver. The optional feedback loop shown with a dashed line in Figure II.1 allows the PMDC to operate in an optimized regime.
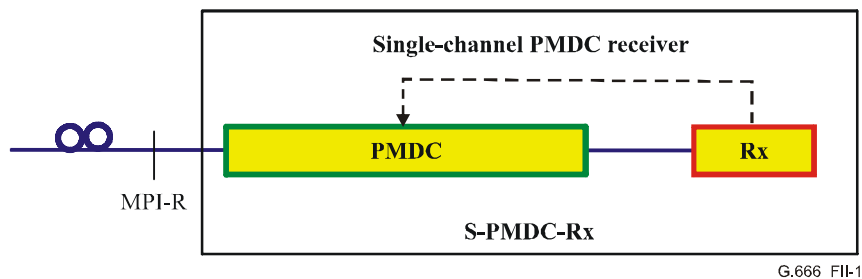

**Figure II.1/G.666 – Implementation option A of a single-channel
PMDC receiver (S-PMDC-Rx)**

An alternative implementation is the use of a receiver including electrical PMDC, as indicated in Figure II.2. No additional optical device is used for the purpose of PMD compensation. Instead, the PMDC function is achieved inside the receiver by electrical means.

Figure II.2/G.666 – Implementation option B of a single-channel PMDC receiver (S-PMDC-Rx)

A combination of the two above implementations is also possible as shown in Figure II.3.
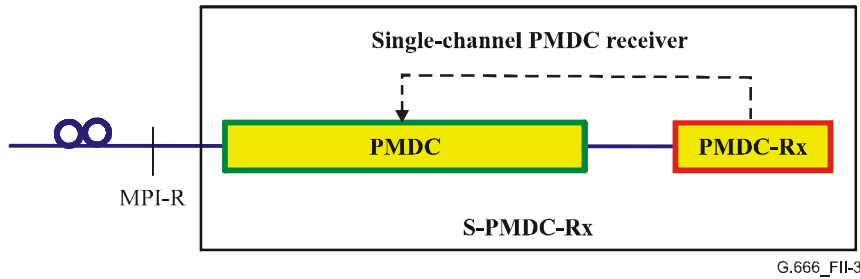

Figure II.3/G.666 – Implementation option C of a single-channel PMDC receiver (S-PMDC-Rx)

II.2 Multichannel PMDC receiver implementation

Similarly to clause II.1, there are three implementation options for multichannel PMDC receivers. These are illustrated in Figures II.4-II.6. Option A includes an optical PMDC in front of the demultiplexer with conventional receivers. Option B uses only PMDC receivers. Option C uses a combination of both an optical PMDC in front of the demultiplexer and PMDC receivers.
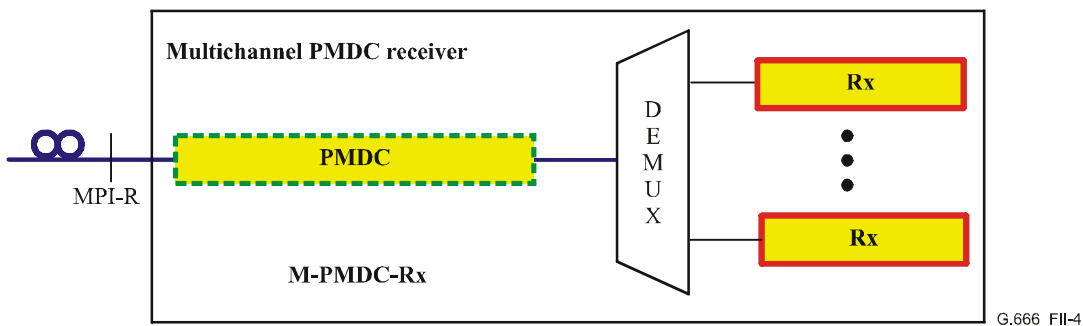

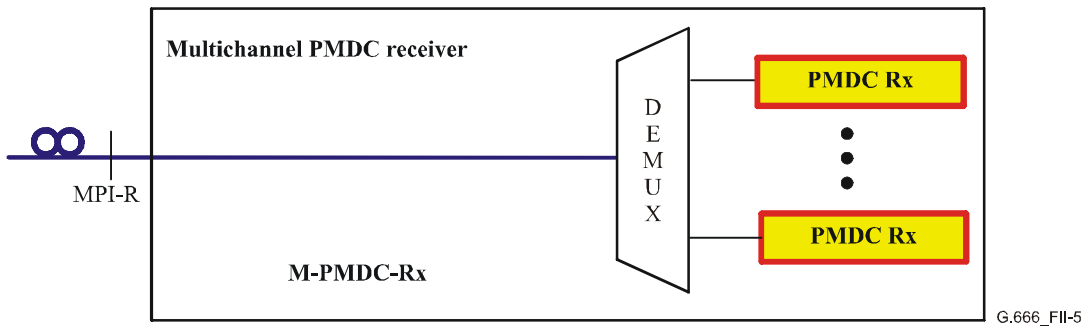**Figure II.4/G.666 – Implementation option A of a multichannel PMDC receiver (M-PMDC-Rx)**

Figure II.5/G.666 – Implementation option B of a multichannel PMDC receiver (M-PMDC-Rx)
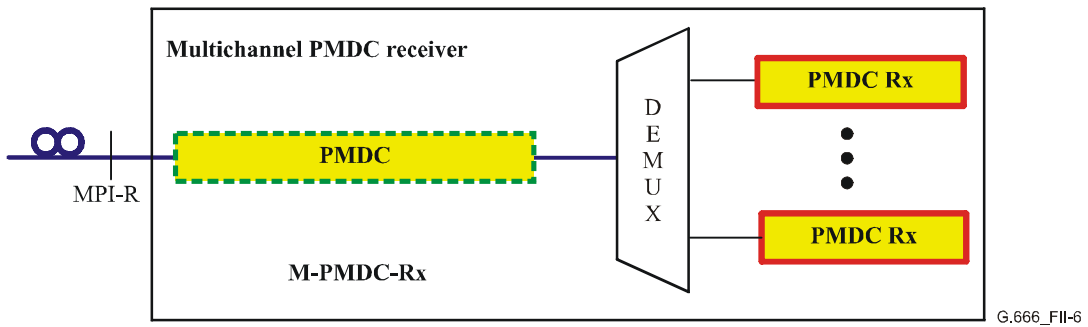

Figure II.6/G.666 – Implementation option C of a multichannel PMDC receiver (M-PMDC-Rx)

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