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

Transmission media and optical systems characteristics – Characteristics of optical components and subsystems

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Characteristics of adaptive chromatic dispersion compensators

ITU-T Recommendation G.667

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ITU-T Recommendation G.667

Characteristics of adaptive chromatic dispersion compensators

Summary

ITU-T Recommendation G.667 contains parameters and definitions for devices providing adaptive chromatic dispersion compensation. These devices are needed for transmission and detection of optical signals in a system exhibiting high levels of dynamic variation of chromatic dispersion which would otherwise impair system operation. Single and multichannel line adaptive dispersion compensators are described, as well as single and multichannel adaptive dispersion compensating transmitters and receivers which may comprise electrical or optical forms of chromatic dispersion compensation. Information on single channel and multichannel adaptive chromatic dispersion compensation implementation, as well as principles of adaptive dispersion compensation, can be found in informative appendices.

Source

ITU-T Recommendation G.667 was approved on 14 December 2006 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

FOREWORD

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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.

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

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CONTENTS

ITU-T Recommendation G.667

Characteristics of adaptive chromatic dispersion compensators

1 Scope

This Recommendation contains parameters and definitions for devices providing adaptive chromatic dispersion compensation needed for transmission and detection of optical signals in a system exhibiting dynamic variation of chromatic dispersion. The adaptive dispersion compensating devices described include both single and multichannel applications. This Recommendation defines requirements and key parameters for adaptive dispersion compensators (ADC). This Recommendation distinguishes line adaptive dispersion compensators from adaptive dispersion compensating transmitters and receivers which may comprise electrical as well as optical forms of chromatic dispersion compensation.

2 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 G.650.2] 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 G.652] ITU-T Recommendation G.652 (2005), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.653] ITU-T Recommendation G.653 (2006), *Characteristics of a dispersion-shifted single-mode optical fibre and cable*.

[ITU-T G.654] ITU-T Recommendation G.654 (2006), *Characteristics of a cut-off shifted single-mode optical fibre and cable*.

[ITU-T G.655] ITU-T Recommendation G.655 (2006), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.

[ITU-T G.656] ITU-T Recommendation G.656 (2006), *Characteristics of a fibre and cable with non-zero dispersion for wideband transport*.

[ITU-T G.661] ITU-T Recommendation G.661 (2006), *Definition and test methods for the relevant generic parameters of optical amplifier devices and subsystems*.

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

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

[ITU-T G.666] ITU-T Recommendation G.666 (2005), *Characteristics of PMD compensators and PMD compensating receivers*.

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

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

3 Terms and definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined in [ITU-T G.671]:

– channel frequency range;

– channel insertion loss;

– channel insertion loss deviation;

– phase ripple;

– insertion loss;

– polarization dependent loss;

– polarization dependent reflectance;

– polarization mode dispersion.

This Recommendation uses the following term defined in ITU-T Rec. G.692:

– maximum central frequency deviation.

This Recommendation uses the following term defined in ITU-T Rec. G.698.1:

– maximum spectral excursion.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 ADC transmitter: An optical transmitter containing adaptive chromatic dispersion compensation functionality.

3.2.2 ADC receiver: An optical receiver containing adaptive chromatic dispersion compensation functionality.

3.2.3 dispersion compensation parameter: This parameter depends on the type of dispersion compensation device, and describes the achievable dispersion compensation performance of an ADC.

For an ADC transmitter, the transmission performance related to dispersion of the ADC transmitter can be changed adaptively according to the dispersion change of the optical transmission link in which it is operating. The dispersion compensation parameter is the dispersion accommodation value of the optical transmitter signal that can be achieved by the ADC transmitter over the channel frequency range.

For a line ADC, the dispersion compensation value between the input port and the output port of the line ADC can be changed adaptively according to the dispersion change of the optical transmission link in which the line ADC is operating. The dispersion compensation parameter is the dispersion compensation value between the input port and the output port that can be achieved by the line ADC device over the channel frequency range.

For an ADC receiver, the dispersion tolerance of the receiver can be changed adaptively according to the residual dispersion value of the optical transmission link. The dispersion compensation parameter is the acceptable residual dispersion value of the optical input signal to the ADC receiver over the channel frequency range while the BER remains lower than the specified limit.

3.2.4 dispersion compensation tuning range: The difference between the maximum value of the dispersion compensation parameter and the minimum value of the dispersion compensation parameter of an ADC device (measured as ps/nm).

3.2.5 dispersion compensation tuning time: For an ADC transmitter or a line ADC, this is the time duration from the start of a change of the dispersion compensation parameter to the time after which it remains within the limits of the new target value plus and minus the specified tolerance. This is illustrated in Figure 3-1.

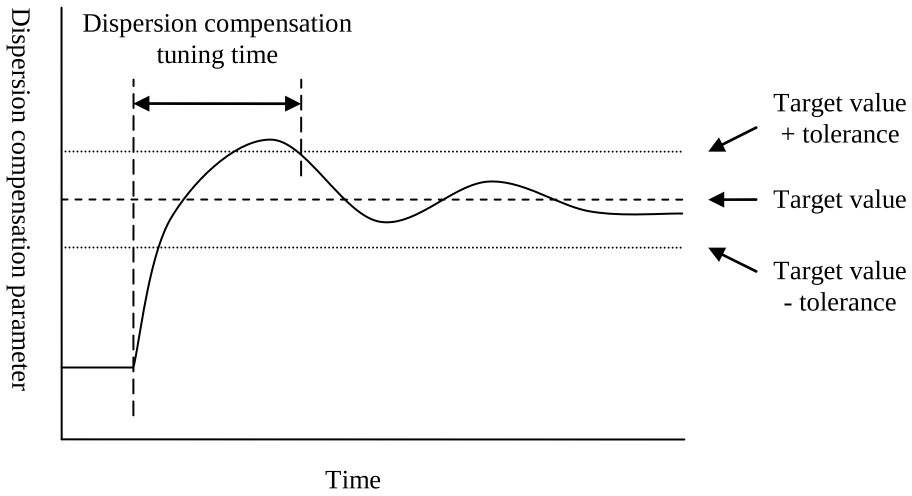

Figure 3-1 – Illustration of dispersion compensation tuning time for an ADC transmitter or a line ADC

For an ADC transmitter, the specified tolerance is the specified error of the dispersion accommodation value.

For a line ADC, the tolerance is the specified error of the dispersion compensation value.

For an ADC receiver, the dispersion compensation tuning time is the time duration from a step change of the input signal residual dispersion to the time after which the BER remains lower than the specified limit. This is illustrated in Figure 3-2.

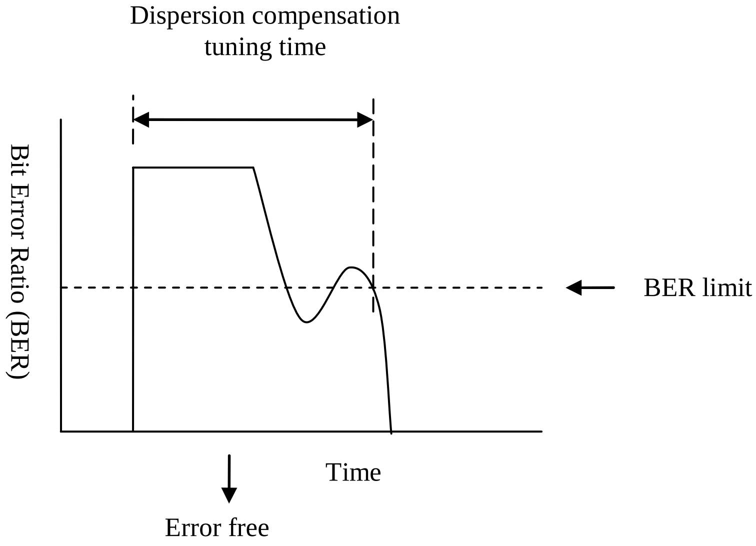

Figure 3-2 – Illustration of dispersion compensation tuning time for an ADC receiver

NOTE – The tuning time will depend on the range between the current state and the new target state.

3.2.6 maximum rate of change of dispersion compensation parameter: This is the maximum rate of change of link chromatic dispersion with time that can be adequately compensated for by the ADC device.

This parameter depends on the type of the dispersion compensation device.

For an ADC transmitter or a line ADC, this is the maximum value of the rate of change of link chromatic dispersion with time (in ps/nm/s) that can be compensated for while maintaining the residual dispersion of the link within the specified tolerance.

For an ADC receiver, this is the maximum value of the rate of change of link chromatic dispersion with time (in ps/nm/s) that can be tolerated while meeting the specified BER.

3.2.7 minimum optical signal-to-noise ratio: The value of optical signal-to-noise ratio (OSNR) at point MPI-R to achieve the specified BER for the optimum link residual dispersion. This parameter depends on the type of optical system.

For a single-channel system, this is the minimum value of the ratio of the signal power to the noise power density (referred to 0.1 nm) at the signal wavelength.

For a multichannel system, this is the minimum value of the ratio of the signal power in the wanted channel to the highest noise power density (referred to 0.1 nm) in the range of the central frequency plus and minus the central frequency deviation or the maximum spectral excursion.

3.2.8 OSNR penalty due to chromatic dispersion: The difference in the optical signal-to-noise ratio at point MPI-R to achieve the specified BER between optimum link residual dispersion and the worst value for all specified values of link residual dispersion.

3.2.9 ADC receiver sensitivity: The value of mean received power at point MPI-R to achieve the specified BER. This must be met for the optimum link residual dispersion with a worst-case transmitter, but does not have to be met with degradations of the optical path other than dispersion.

3.2.10 ADC receiver sensitivity penalty due to chromatic dispersion: The difference in the mean received power at point MPI-R to achieve the specified BER between optimum link residual dispersion and the worst value for all specified values of link residual dispersion. This does not have to be met with degradations of the optical path other than dispersion.

4 Abbreviations

This Recommendation uses the following abbreviations:

ADC	Adaptive Dispersion Compensation
ADC-Rx	Adaptive Dispersion Compensating Receiver
ADC-Tx	Adaptive Dispersion Compensating Transmitter
BER	Bit Error Ratio
DEMUX	Demultiplexer
DFE	Decision Feedback Equalization
EDC	Electrical Dispersion Compensation
FBG	Fibre Bragg Grating
FFE	Feed Forward Equalization
LADC	Line Adaptive Dispersion Compensator
M-ADC-Rx	Multichannel Adaptive Dispersion Compensating Receiver
M-ADC-Tx	Multichannel Adaptive Dispersion Compensating Transmitter
M-LADC	Multichannel Line Adaptive Dispersion Compensator
MLSE	Maximum Likelihood Sequence Estimation
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
PDL	Polarization-Dependent Loss
PMD	Polarization Mode Dispersion
RZ	Return to Zero
S-ADC-Rx	Single-Channel Adaptive Dispersion Compensating Receiver
S-ADC-Tx	Single-Channel Adaptive Dispersion Compensating Transmitter
S-LADC	Single-Channel Line Adaptive Dispersion Compensator
VIPA	Virtually-Imaged Phased-Array
VSB	Vestigial Side Band
WDM	Wavelength Division Multiplexing

5 Reference configurations

ADCs are intended to be used to reduce dispersion-induced signal degradations in optical transmission systems with dynamic dispersion change. Therefore, characteristics of ADCs must be considered – at least in part – in conjunction with a whole transmission system.

ADCs are expected to be used in at least two applications:

The first is to use the ADC to compensate for slow changes of link dispersion over time due to environmental effects, such as temperature. This is referred to as a slow change link dispersion application.

The second is to use the ADC to compensate for sudden step changes of link dispersion due to switching or other transmission link re-configuration process. This is referred to as a step change link dispersion application.

A generic configuration of a transmission system with ADC(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 ADC(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.

In the following clauses optical line ADCs (LADC) are distinguished from ADC transmitters and receivers. A black box approach is applied for the line ADCs, ADC transmitters and receivers. Monitoring and control (if present) is included in the black box. Further information concerning the implementation options of all of these devices can be found in Appendix I and details of the underlying technology used in them are contained in Appendix II.

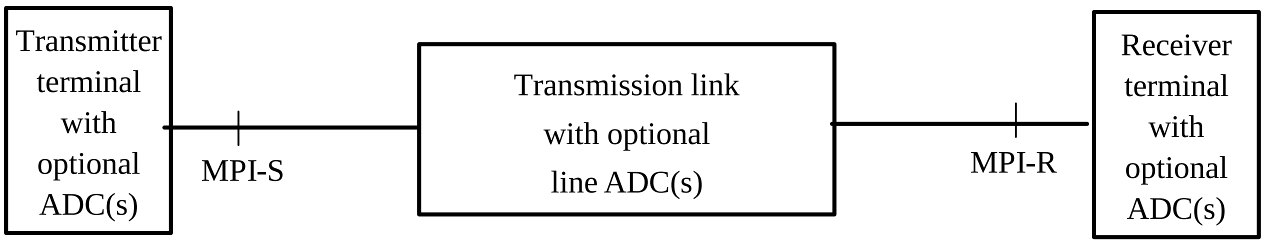

Figure 5-1 – Generic configuration of a transmission system with ADCs

5.1 Line ADCs

Line ADCs have an optical input port and an optical output port and no O-E-O conversion is performed on the signal passing from one to the other. A single-channel line ADC (S-LADC) can handle a single-channel optical signal while a multichannel line ADC (M-LADC) is constructed for a multichannel optical signal. Both types are illustrated schematically in Figures 5-2 and 5-3 respectively.

Figure 5-2 – Reference configuration of a single-channel line ADC (S-LADC)

Figure 5-3 – Reference configuration of a multichannel line ADC (M-LADC)

5.2 ADC transmitters

In the case of ADC transmitters (ADC-Tx), the ADC functionality is embedded in the transmitter black box. There are a number of options of how to realize ADC transmitters. Single-channel ADC transmitters are distinguished from multichannel ADC transmitters.

A schematic diagram of a single-channel ADC transmitter (S-ADC-Tx) is shown in Figure 5-4. A single-channel optical signal outputs at the reference point MPI-S.

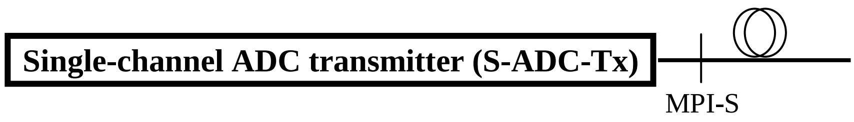

Figure 5-4 – Reference configuration of a single-channel ADC transmitter

A multichannel ADC transmitter is presented schematically in Figure 5-5. A multichannel optical signal outputs at the reference point MPI-S. There is an ADC before the multiplexer (MUX) and within the transmitter Tx for individual optical channels and/or an ADC after the multiplexer acting on the combined signal from all of the transmitters.

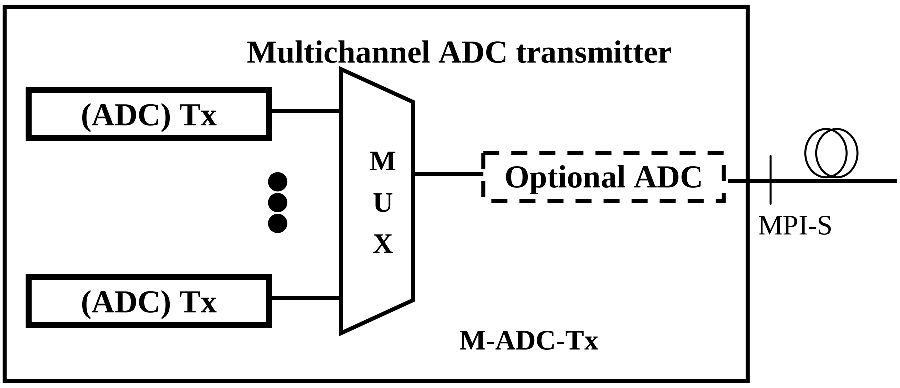

Figure 5-5 – Reference configuration of a multichannel ADC transmitter (M-ADC-Tx)

5.3 ADC receivers

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

A schematic diagram of a single-channel ADC receiver (S-ADC-Rx) is shown in Figure 5-6. A single-channel optical signal enters the receiver at the reference point MPI-R. The signal is then detected with ADC functionality.

Figure 5-6 – Reference configuration of a single-channel ADC receiver

A multichannel ADC receiver is presented schematically in Figure 5-7. A multichannel optical signal enters the receiver terminal at the reference point MPI-R. The ADC function may be performed after and/or in front of the DEMUX.

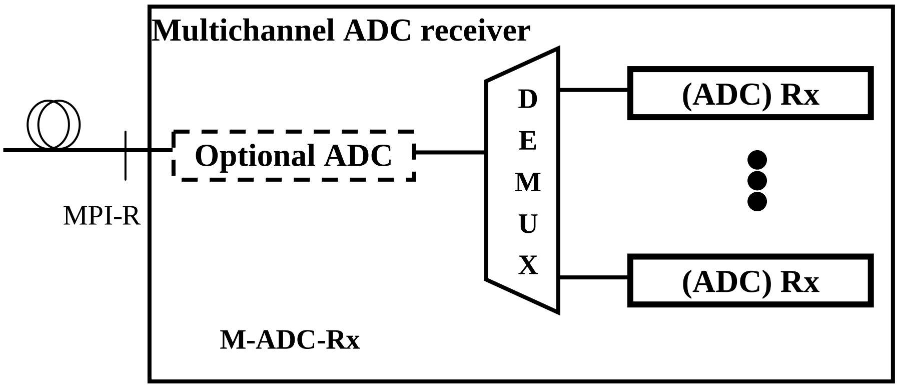

Figure 5-7 – Reference configuration of a multichannel ADC receiver (M-ADC-Rx)

6 Parameters of ADCs

In this clause, parameters for ADCs are presented. Common parameters for all ADC types are summarized in Table 6-1. Additional parameters for the various ADC types are included in Tables 6-2 to 6-7.

Table 6-1 – Common parameters

Parameters	Reference point	Unit	Examples (for illustration of particular applications only)
Fibre type			
Line fibre type	MPI-S →R_S or MPI-S →R_M or S_S → MPI-R or S_M → MPI-R or MPI-S →MPI-R	–	G.652.A-D, G.653, G.654, G.655, G.656
Optical signal characteristics			
Minimum bit rate	R_S or R_M or MPI-S or MPI-R	Gbit/s	
Maximum bit rate	R_S or R_M or MPI-S or MPI-R	Gbit/s	
Modulation format (or "signal format")	R_S or R_M or MPI-S or MPI-R	–	"Any format", "only NRZ", "NRZ and RZ"

Table 6-1 – Common parameters

Parameters	Reference point	Unit	Examples (for illustration of particular applications only)
Dispersion-independent parameters of the preceding optical path			
Maximum accumulated polarization mode dispersion	R_S or R_M or MPI-R	ps	
Parameters related to dispersion			
Minimum dispersion compensation tuning range	$R_S \rightarrow S_S$ or $R_M \rightarrow S_M$ or MPI-S or MPI-R	ps/nm	
Maximum dispersion compensation tuning time[a)]	$R_S \rightarrow S_S$ or $R_M \rightarrow S_M$ or MPI-S or MPI-R	s	
Minimum rate of change of dispersion compensation parameter [b)]	$R_S \rightarrow S_S$ or $R_M \rightarrow S_M$ or MPI-S or MPI-R	ps/nm/s	

a) This parameter must be met for an ADC used in a step change link dispersion application.

b) This parameter must be met for an ADC used in a slow change link dispersion application.

Table 6-2 – Parameters for single-channel line ADC (S-LADC)

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 or spectral excursion	R_S	GHz	
Parameters related to optical power			
Minimum input power	R_S	dBm	
Maximum input power	R_S	dBm	
Minimum insertion loss (incl. optional OA unit)[a)]	$R_S \rightarrow S_S$	dB	
Maximum insertion loss (incl. optional OA unit)[a)]	$R_S \rightarrow S_S$	dB	
Maximum insertion loss deviation (incl. optional OA unit)[a)]	$R_S \rightarrow S_S$	dB	
Maximum reflectance at the input port	R_S	dB	
Maximum polarization-dependent reflectance at the input port	R_S	dB	
Maximum polarization-dependent loss (PDL)	$R_S \rightarrow S_S$	dB	
Maximum polarization mode dispersion (PMD)	$R_S \rightarrow S_S$	ps	
Parameters related to dispersion			
Maximum phase ripple	$R_S \rightarrow S_S$	rad	

a) If the line ADC includes an optional optical amplifier, additional parameters are required. For details see ITU-T Recs G.661 and G.662.

Table 6-3 – Parameters for multichannel line ADC (M-LADC)

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
Minimum channel spacing	R_M	GHz	100, 200
Maximum central frequency deviation or spectral excursion	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)[a)]	$R_M \rightarrow S_M$	dB	
Maximum channel insertion loss (incl. optional OA unit)[a)]	$R_M \rightarrow S_M$	dB	
Maximum channel insertion loss deviation (incl. optional OA unit)[a)]	$R_M \rightarrow S_M$	dB	
Maximum reflectance at the input port	R_M	dB	
Maximum polarization-dependent reflectance at the input port	R_M	dB	
Maximum polarization mode dispersion (PMD)	$R_M \rightarrow S_M$	ps	
Maximum polarization-dependent loss (PDL)	$R_M \rightarrow S_M$	dB	
Parameters related to dispersion			
Maximum channel phase ripple	$R_M \rightarrow S_M$	rad	
a) If the line ADC includes an optional optical amplifier, additional parameters are required. For details see ITU-T Recs G.661 and G.662.			

Table 6-4 – Parameters for single-channel ADC transmitter (S-ADC-Tx)

Parameters	Reference point	Unit	Examples (for illustration of particular applications only)
General single-channel optical parameters			
Nominal central optical frequency	MPI-S	THz	
Maximum central frequency deviation or spectral excursion	MPI-S	GHz	
Parameters related to optical power			
Minimum output power	MPI-S	dB	
Maximum output power	MPI-S	dB	
Maximum return loss at the output port	MPI-S	dB	

Table 6-5 – Parameters for multichannel ADC transmitter (M-ADC-Tx)

Parameters	Reference point	Unit	Examples (for illustration of particular applications only)
General multichannel optical parameters			
Maximum number of channels	MPI-S	–	
Nominal channel central frequencies	MPI-S	THz	191.9 + 0.2*m, m = 0 to 19
Minimum channel spacing	MPI-S	GHz	100, 200
Maximum central frequency deviation or spectral excursion	MPI-S	GHz	
Parameters related to optical power			
Minimum channel output power	MPI-S	dBm	
Maximum channel output power	MPI-S	dBm	
Maximum return loss at the output port	MPI-S	dB	

Table 6-6 – Parameters for single-channel ADC receiver (S-ADC-Rx)

Parameters	Reference point	Unit	Examples (for illustration of particular applications only)
General single-channel optical parameters			
Nominal central optical frequency	MPI-R	THz	
Maximum central frequency deviation or spectral excursion	MPI-R	GHz	
Parameters related to optical power			
Minimum input power	MPI-R	dBm	
Maximum input power	MPI-R	dBm	
Maximum reflectance at the input port	MPI-R	dB	
Maximum polarization-dependent reflectance at the input port	MPI-R	dB	
Single channel transmission system parameters			
Maximum OSNR penalty due to chromatic dispersion[a)]	MPI-R	dB	
Minimum optical signal-to-noise ratio[a)]	MPI-R	dB	
Maximum ADC receiver sensitivity penalty due to chromatic dispersion[b)]	MPI-R	dB	
Minimum ADC receiver sensitivity[b)]	MPI-R	dBm	
a) These parameters must be met for an ADC receiver used in a link containing amplifiers. b) These parameters must be met for an ADC receiver used in a link without amplifiers.			

Table 6-7 – Parameters for multichannel ADC receiver (M-ADC-Rx)

Parameters	Reference point	Unit	Examples (for illustration of particular applications only)
General multichannel optical parameters			
Maximum number of channels	MPI-R	–	
Nominal channel central frequencies	MPI-R	THz	191.9 + 0.2*m, m = 0 to 19
Minimum channel spacing	MPI-R	GHz	100, 200
Maximum central frequency deviation or spectral excursion	MPI-R	GHz	
Parameters related to optical power			
Minimum channel input power	MPI-R	dBm	
Maximum channel input power	MPI-R	dBm	
Maximum reflectance at the input port	MPI-R	dB	
Maximum polarization-dependent reflectance at the input port	MPI-R	dB	
Multichannel transmission system parameters applied to each channel			
Maximum OSNR penalty due to chromatic dispersion[a)]	MPI-R	dB	
Minimum optical signal-to-noise ratio[a)]	MPI-R	dB	
Maximum channel ADC receiver sensitivity penalty due to chromatic dispersion[b)]	MPI-R	dB	
Minimum channel ADC receiver sensitivity [b)]	MPI-R	dBm	

a) These parameters must be met for an ADC receiver used in a link containing amplifiers.

b) These parameters must be met for an ADC receiver used in a link without amplifiers.

Appendix I

Single-channel and multichannel ADC implementation

(This appendix does not form an integral part of this Recommendation)

I.1 Single or multichannel line ADC implementation

A single-channel line ADC (as shown generically in Figure 5-2) or a multichannel line ADC (as shown generically in Figure 5-3) can be realized by different implementation schemes. One option for a line ADC is presented in Figure I.1 using a tuneable dispersion compensator together with a chromatic dispersion monitor unit. The optical signal passes through the line ADC from the input reference point R_S (or R_M) to the output reference point S_S (or S_M). In this implementation, the control signal for the tuneable dispersion compensator is derived from a dispersion monitor that is within the S-LADC or M-LADC black box.

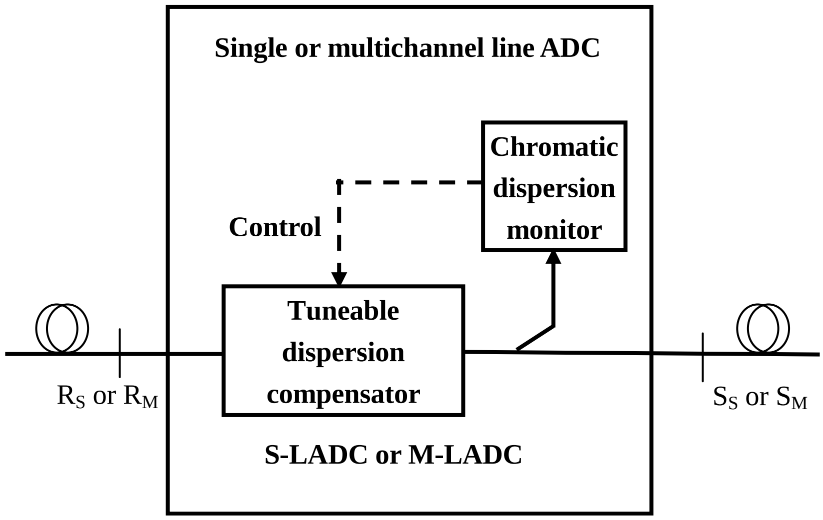

Figure I.1 – Implementation option A of a single-channel line ADC (S-LADC) or a multichannel line ADC (M-LADC)

An alternative implementation is the use of a feedback signal from other optical node(s) as shown in Figure I.2. The dispersion-related information, e.g., the dispersion value of the whole optical line that the line ADC is compensating, or dispersion-related signal quality information from the optical receiver, which is gathered by a dispersion-related information exchange system within the whole optical line that the line ADC is compensating, is used to adjust the tuneable dispersion compensator to achieve optimized chromatic dispersion compensation performance.

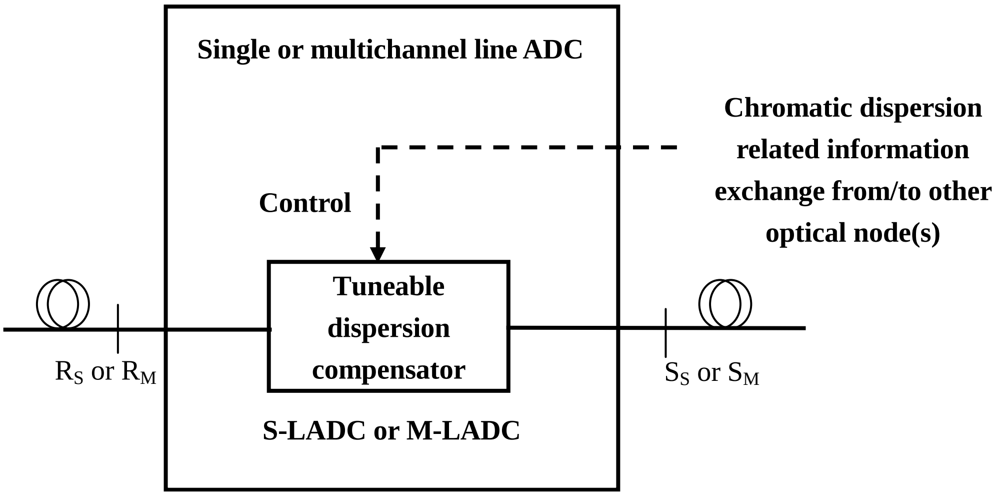

Figure I.2 – Implementation option B of a single-channel line ADC (S-LADC) or a multichannel line ADC (M-LADC)

I.2 Single-channel ADC transmitter implementation

A single-channel ADC transmitter (as shown generically in Figure 5-4) can also be realized by different implementation schemes. One option is presented in Figure I.3. The optical signal exits from the ADC transmitter at reference point MPI-S. The feedback signal from/to other optical node(s) shown in Figure I.3 allows the ADC transmitter to operate in an optimized regime. The dispersion-related information, e.g., the dispersion value of the whole optical line that the ADC transmitter is compensating, or dispersion-related signal quality information from the optical receiver, which is gathered by a dispersion-related information exchange system within the whole optical line that the line ADC is compensating, is used to control the dispersion compensation of the tuneable dispersion transmitter to achieve optimized chromatic dispersion compensation performance.

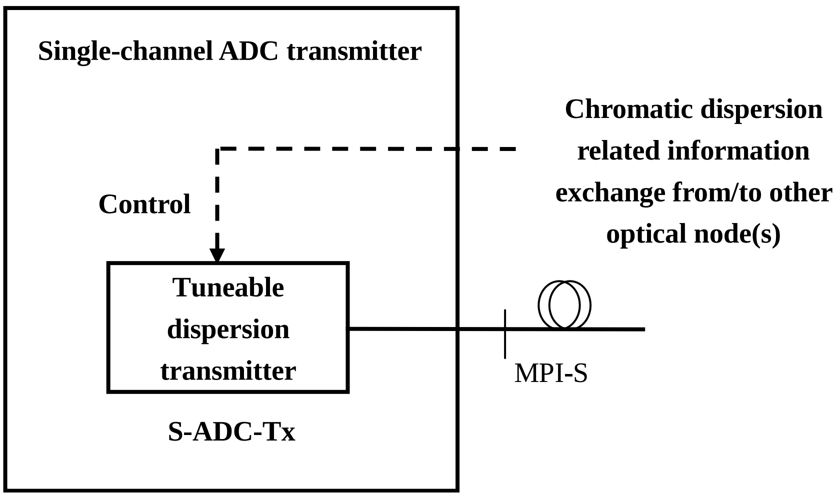

Figure I.3 – Implementation option of a single-channel ADC transmitter (S-ADC-Tx)

I.3 Multichannel ADC transmitter implementation

Three implementation options for a multichannel ADC transmitter (as shown generically in Figure 5-5) are illustrated in Figures I.4 to I.6. Option A includes an optical ADC after the multiplexer with conventional transmitters. Option B uses only single-channel ADC transmitters and a multiplexer. Option C uses a combination of both single-channel ADC transmitters and a multichannel optical ADC after the multiplexer.

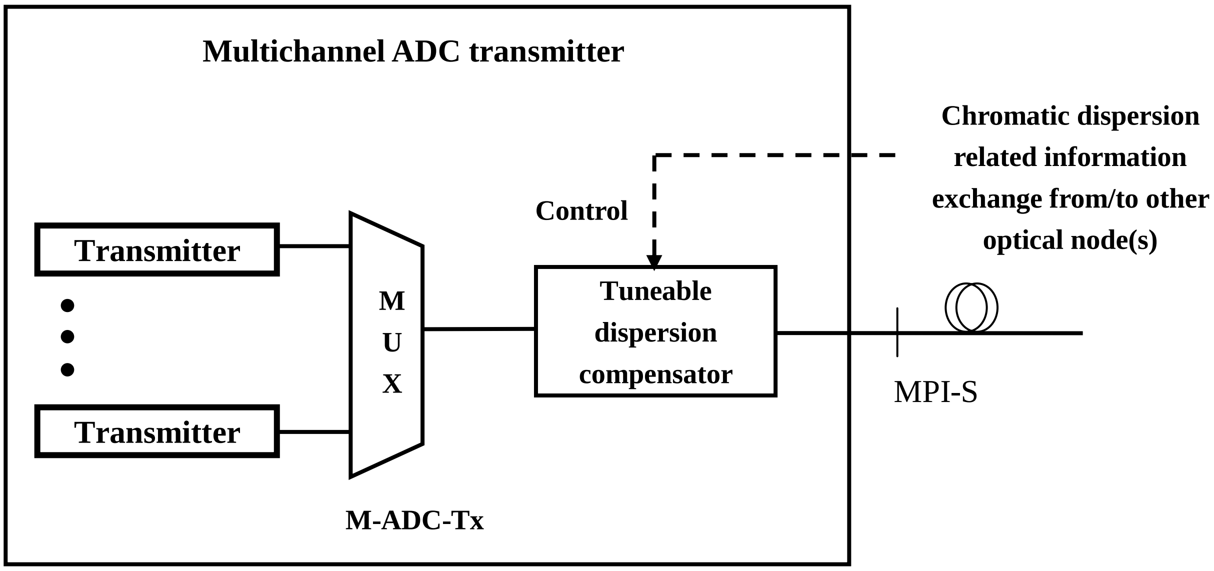

Figure I.4 – Implementation option A of a multichannel ADC transmitter (M-ADC-Tx)

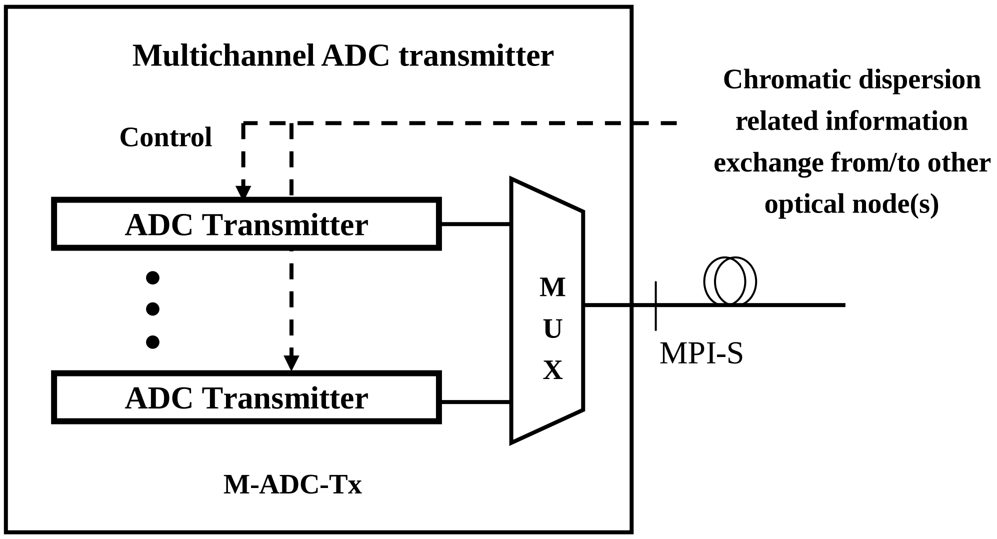

Figure I.5 – Implementation option B of a multichannel ADC transmitter (M-ADC-Tx)

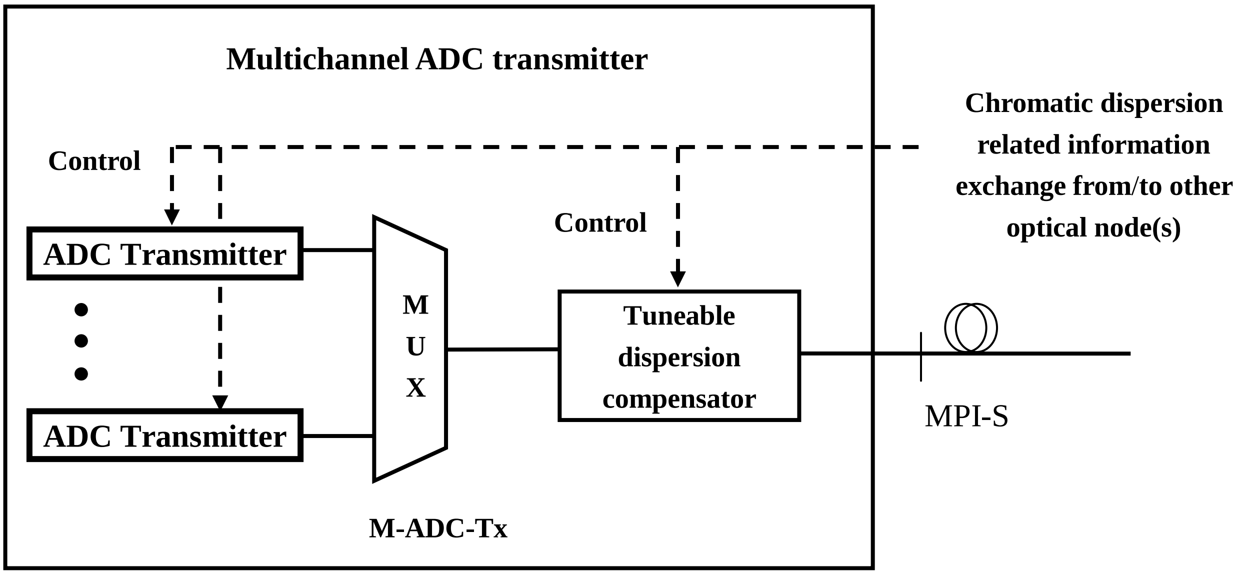

Figure I.6 – Implementation option C of a multichannel ADC transmitter (M-ADC-Tx)

I.4 Single-channel ADC receiver implementation

Single-channel ADC receivers (as shown generically in Figure 5-6) can be realized by different implementation schemes. One option is a single-channel line tuneable dispersion compensator as presented in Figure I.2 together with a conventional receiver. The optical signal at the reference point MPI-R passes through an optical tuneable dispersion compensator before entering the receiver. The dispersion of the optical tuneable dispersion compensator may be controlled using the dispersion-related signal quality information from the optical receiver allowing the tuneable dispersion compensator to operate in an optimized regime. An alternative option is to use the dispersion value of the whole optical line the S-ADC-Rx is compensating, which is not shown in Figure I.7.

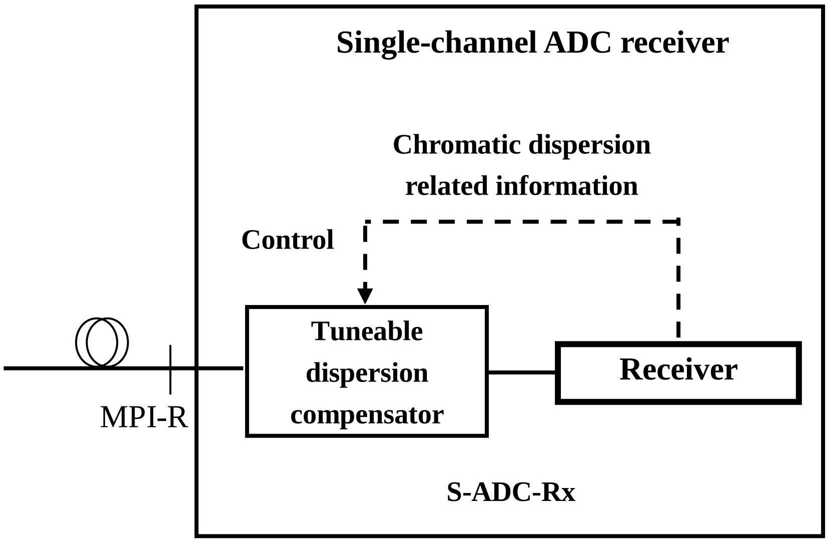

Figure I.7 – Implementation option A of a single-channel ADC receiver (S-ADC-Rx)

An alternative implementation is the use of a receiver including electrical dispersion compensation (EDC) as indicated in Figure I.8. No additional optical device is used for the purpose of chromatic dispersion compensation. Instead, the ADC function is achieved inside the receiver by electrical means.

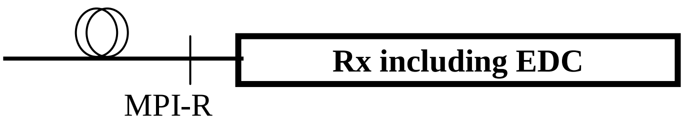

Figure I.8 – Implementation option B of a single-channel ADC receiver (S-ADC-Rx)

NOTE – Although the two implementations discussed above (optical or EDC) are not specified differently within this Recommendation, in [b-ITU-T G.959.1] applications appropriate to the use of optical dispersion compensators are given a suffix of "D" and applications appropriate to the use of EDC-based compensators are given a suffix of "E".

A combination of the two above implementations is also possible as shown in Figure I.9.

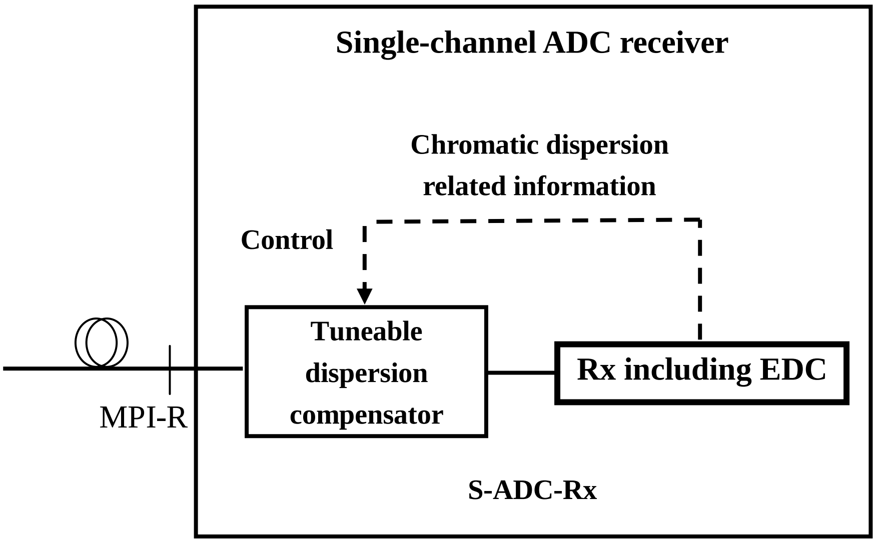

Figure I.9 – Implementation option C of a single-channel ADC receiver (S-ADC-Rx)

I.5 Multichannel ADC receiver implementation

Similarly to clause I.4, three implementation options for multichannel ADC receivers are illustrated in Figures I.10 to I.12. Option A includes an optical ADC in front of the demultiplexer with conventional receivers. Option B uses only ADC receivers. Option C uses a combination of both an optical ADC in front of the demultiplexer and ADC receivers. In either option B or C the ADC receivers can be implemented either optically or electrically. As for the single-channel case, the dispersion of the ADC function may be controlled using the dispersion-related signal quality information from the optical receiver allowing the ADC to operate in an optimized regime. An alternative option is to use the dispersion value of the whole optical line the M-ADC-Rx is compensating, which is not shown in Figures I.10 to I.12.

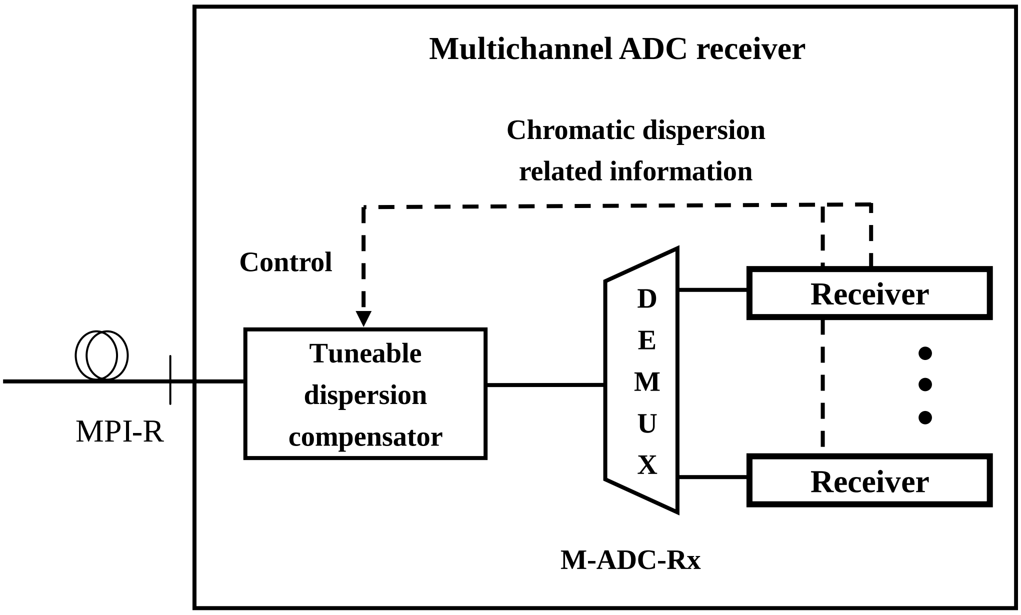

Figure I.10 – Implementation option A of a multichannel ADC receiver (M-ADC-Rx)

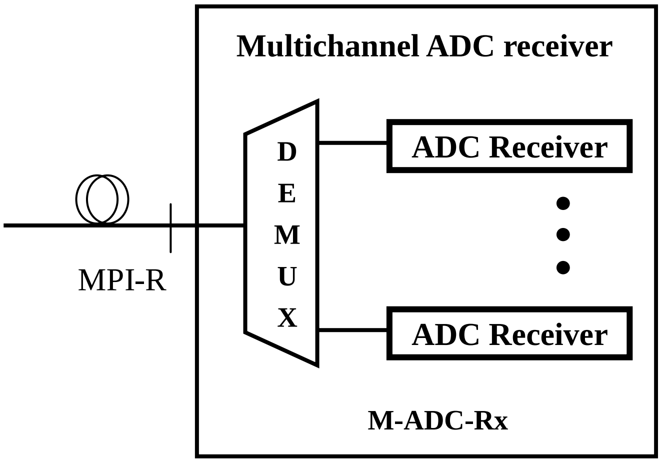

Figure I.11 – Implementation option B of a multichannel ADC receiver (M-ADC-Rx)

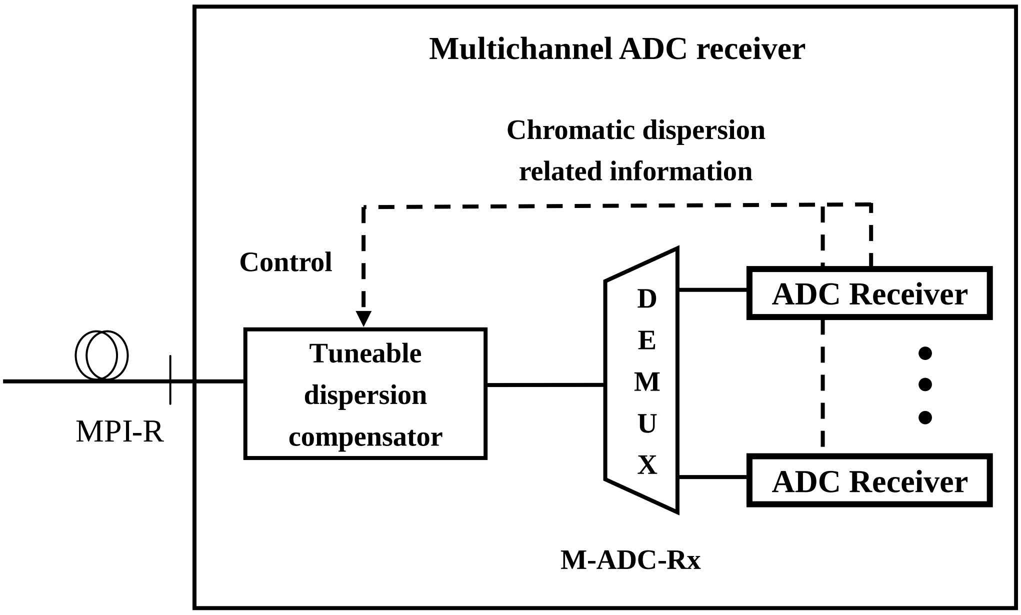

Figure I.12 – Implementation option C of a multichannel ADC receiver (M-ADC-Rx)

Appendix II

Principles of adaptive dispersion compensation (ADC)

(This appendix does not form an integral part of this Recommendation)

II.1 Introduction

Chromatic dispersion in a single-mode fibre is a combination of material dispersion and waveguide dispersion and it contributes to pulse broadening and distortion in a digital signal. It does this by inducing a frequency-dependent phase shift of the signal travelling in the fibre, which causes pulse broadening of the optical waveform at the receiver.

For links where the chromatic dispersion would otherwise be too large, a dispersion compensation device is used to compensate the chromatic dispersion of the optical path. At present, various different types of dispersion accommodation (DA) technology are used. For example, passive dispersion compensation (PDC), self-phase modulation (SPM), prechirp (PCH), and dispersion-supported transmission (DST) are included in ITU-T Rec. G.691.

In some applications, the chromatic dispersion of the optical path varies with time or optical network re-configuration to such an extent that, to avoid signal degradations at the receiver, an adaptive dispersion compensator is used to dynamically compensate the chromatic dispersion change of the optical link.

II.2 Adaptive dispersion compensation applications

ADCs are expected to be used in at least two applications: compensation of slow changes in link dispersion and compensation of step changes in link dispersion.

II.2.1 Slow change link dispersion application

In this application, the ADC(s) are used to compensate for slow changes of link dispersion over time due to environmental effects.

One example application is an ultra-long-haul 10-Gbit/s optical transmission system. Since the chromatic dispersion in a fibre varies with time/temperature, the residual dispersion of each channel varies accordingly. If the variation of channel residual dispersion exceeds the dispersion tolerance of the transmitter-receiver pair, a single or multichannel adaptive dispersion compensator is needed to dynamically compensate for the chromatic dispersion change of the optical link.

Similarly, for a long-distance 40-Gbit/s optical transmission system, since the dispersion tolerance of a transmitter-receiver pair is typically much lower than that of 10-Gbit/s systems, dynamically adjusted dispersion compensation may also be needed to compensate for the optical link fibre dispersion variation with time/temperature.

Since the variation of fibre chromatic dispersion with time/temperature is slow, the minimum rate of change of dispersion compensation parameter is used to specify the tuning performance of the ADCs.

II.2.2 Step change link dispersion application

In this application, the ADC(s) are used to compensate for sudden step changes of link dispersion due to switching or other transmission link re-configuration process.

One example application is illustrated in Figure II.1. A DWDM optical signal is originally routed through DWDM line segment A. After re-configuration, the route is changed from segment A to segment B. Since the link dispersion of DWDM line segment A is different from DWDM line segment B, a step change of channel residual dispersion occurs. If the step change of channel residual dispersion exceeds the dispersion tolerance of the transmitter-receiver pair, a single or multichannel adaptive dispersion compensator is needed to dynamically compensate for the chromatic dispersion change of the optical link.

Since the change of dispersion in this case occurs as a step, the maximum dispersion compensation tuning time parameter is used to specify the tuning performance of the ADC(s).

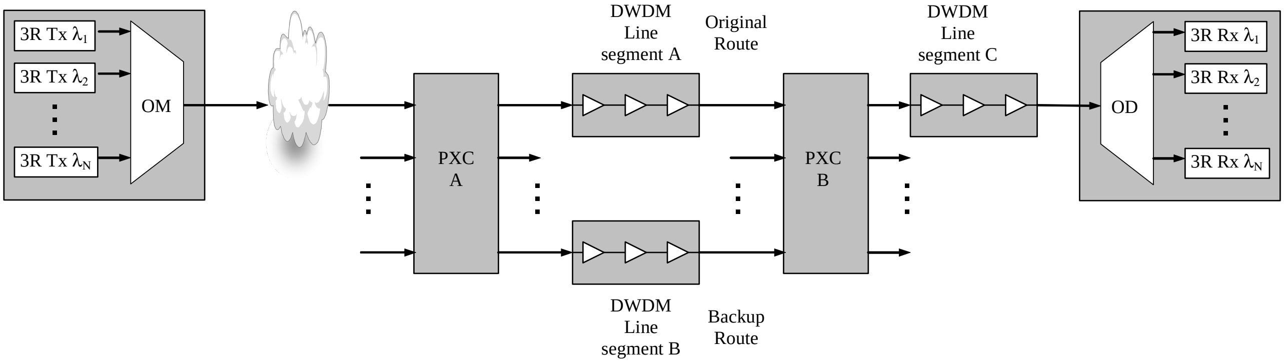

Figure II.1 – Example step change link dispersion application

II.3 Principles of adaptive dispersion compensation

As discussed in clause 5, three types of adaptive dispersion compensator are defined in this Recommendation: pre-compensation, line compensation, and post-compensation. This is illustrated in Figure II.2.

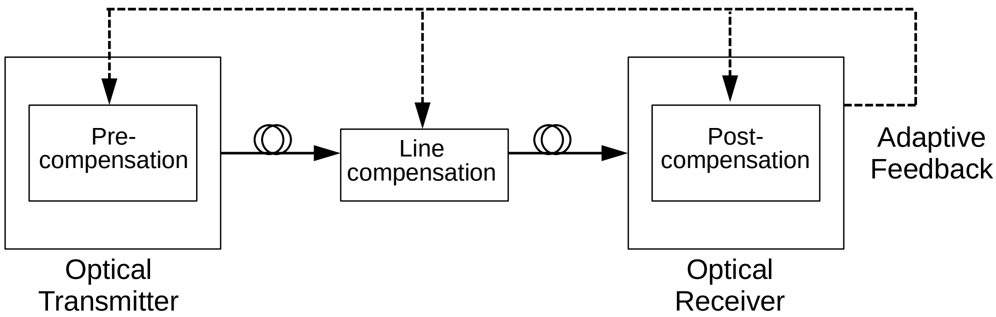

Figure II.2 – Adaptive dispersion compensation principles

However, as can be seen from the discussion contained in Appendix I, the underlying technology used in these devices for dispersion compensation falls into the three main categories of:

– optical dispersion compensators (which can appear in any of the three locations);

– receiver-based electronic dispersion compensators;

– transmitter-based electronic dispersion compensators.

II.3.1 Optical dispersion compensators

Several different types of tuneable dispersion compensation technologies can be used, such as fibre Bragg gratings (FBG), virtually-imaged phased-arrays (VIPA), and Gires-Tournois etalons, etc.

FBGs are reflection-based devices created by modulating the refractive index of a fibre core. Dispersion tuning is accomplished by applying strain (usually via a thermal gradient) to a linearly chirped grating. A single FBG can provide wideband, low-loss, flat-top channelized dispersion compensator with high tuning resolution and low tuning speed. A typical FBG tunable dispersion compensation arrangement is illustrated in Figure II.3 [b-PAINCHAUD].

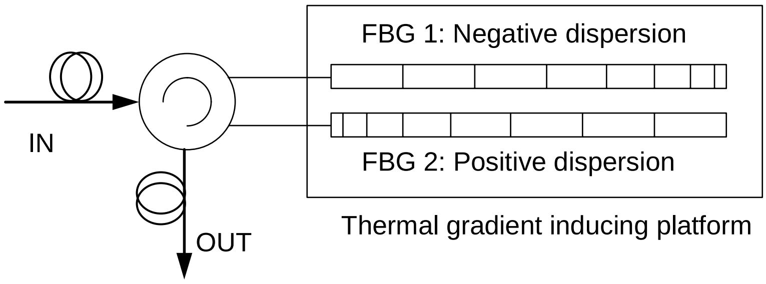

Figure II.3 – Basic FBG-based compensator structure

VIPAs employ a combination of mirrors and lenses to adjust the optical propagation length [b-SHIRASAKI]. VIPAs have a wideband channelized response, high tuning resolution, moderate tuning speed, and high insertion loss. A typical VIPA-based tunable dispersion compensation arrangement is illustrated in Figure II.4.

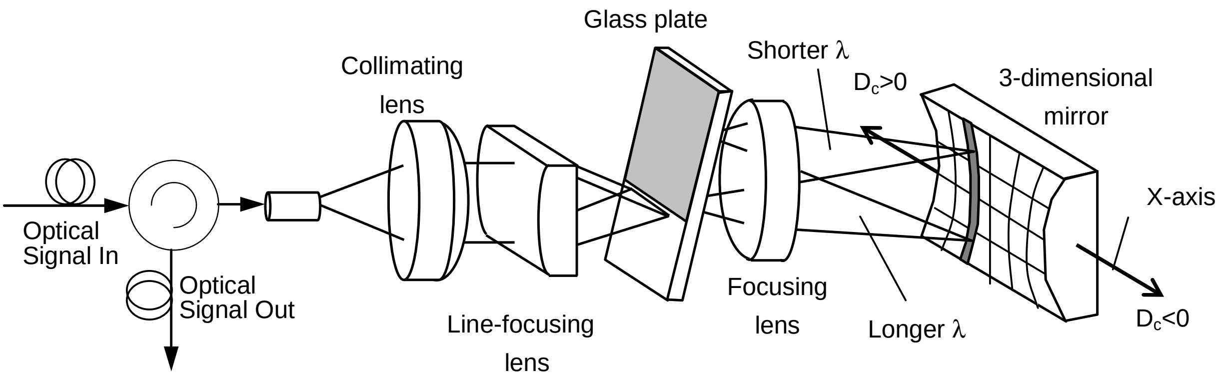

Figure II.4 – Basic VIPA structure

The Gires-Tournois etalon has an inherent periodic time delay which can be exploited to provide tunable dispersion compensation by varying the separation of the etalon mirrors. A multichannel flat-top dispersion compensator can be realized using multiple etalons although this approach suffers from high insertion loss. The dispersion is tuned by changing the angle of input light to the etalon. Etalons offer high tuning speed with poor tuning resolution. One arrangement for this type of dispersion compensator is illustrated in Figure II.5.

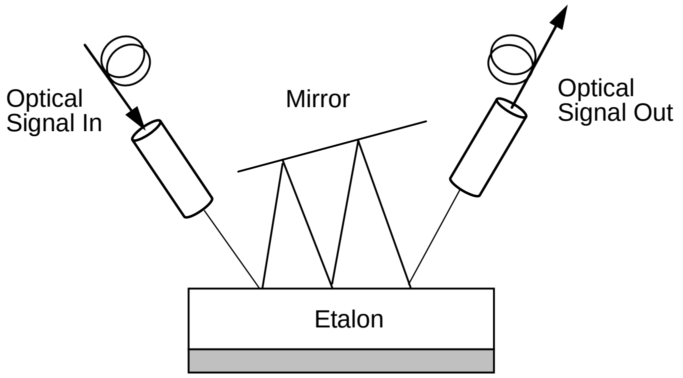

Figure II.5 – Basic Gires-Tournois etalon structure

II.3.2 Receiver-based electronic dispersion compensators

There are several different types of receiver-based electronic dispersion compensation (EDC) techniques. In all cases, however, an adaptive data processor is used to reduce the inter-symbol interference of the optical to electrical converted signal that was introduced by chromatic dispersion and other non-linear effects. This is shown in Figure II.6.

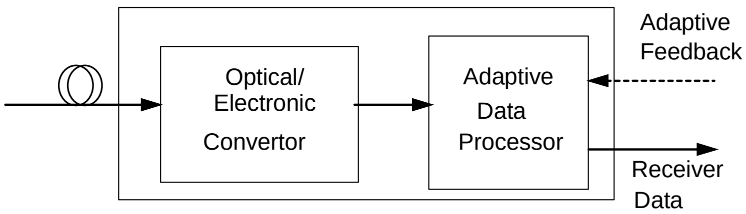

Figure II.6 – Basic receiver-based electronic dispersion compensation structure

The different adaptive data processor technologies that are currently being used are: feed forward equalization (FFE), decision feedback equalization (DFE), and maximum likelihood sequence estimation (MLSE).

FFE provides linear ISI equalization. The filter coefficients are tuned to optimize a performance criterion such as minimum mean squared error. This is illustrated in Figure II.7 [b-WATTS]. The boxes labelled t_s are delays which are usually of 0.5- or 1-bit duration.

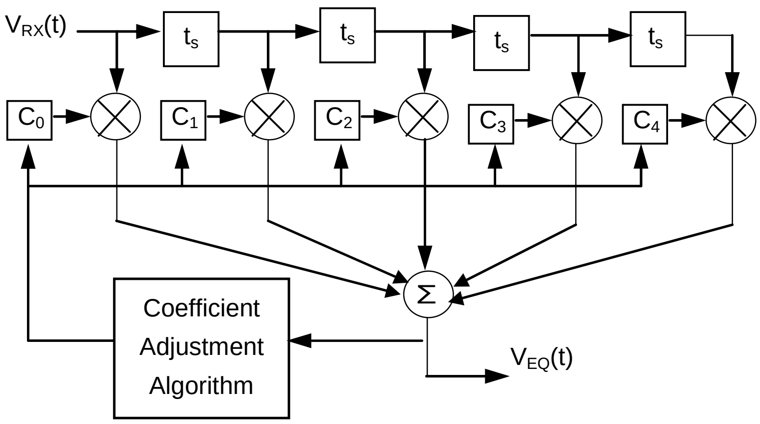

Figure II.7 – Basic FFE structure

In contrast to this, DFE takes the output of the decision circuit and via a tapped delay line adds or subtracts a proportion of the previously detected bits. This is illustrated in Figure II.8 [b-WATTS].

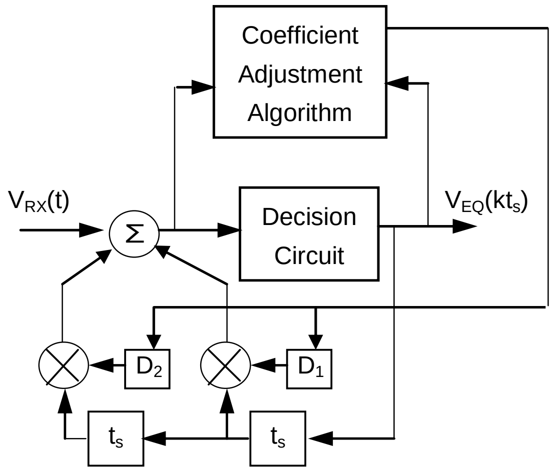

Figure II.8 – Basic DFE structure

The two processes described above (FFE and DFE) can also be used together as shown in Figure II.9 which combines the linear FFE equalizer with a non-linear feedback DFE equalizer [b-WATTS].

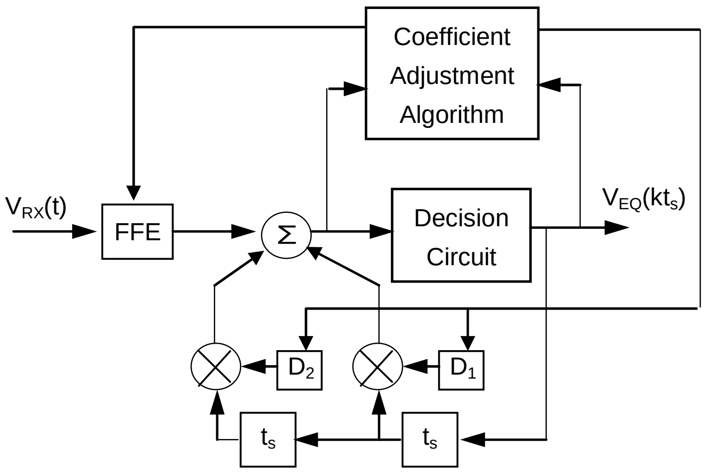

Figure II.9 – Combined FFE and DFE structure

MLSE compares the received waveform against a set of expected waveforms over several bits to determine the most likely transmitted bit sequence. This is shown in Figure II.10 [b-WATTS]. The received signal is digitized at a sample rate at least twice the data rate. For an N-bit data sequence, a 2^{N-1} state Viterbi decoder determines the most likely data sequence based on the state-based channel model stored in the channel estimator.

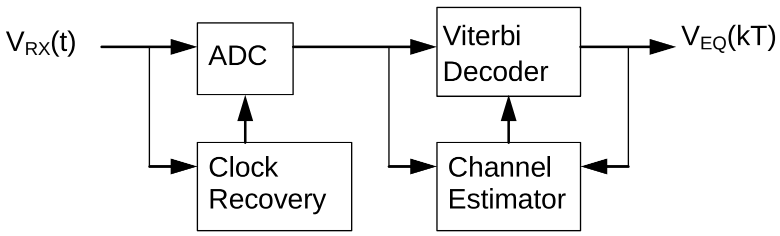

Figure II.10 – Basic MLSE structure

II.3.3 Transmitter-based electronic dispersion compensators

Transmitter-based pre-compensation uses electronic techniques that manipulate both the amplitude and phase of the tuneable transmitter within an adaptive dispersion compensator in order to transmit an optical signal which is distorted at the transmitter, but is undistorted after propagation through the transmission path dispersion. This is illustrated in Figure II.11 [b-McNICOL].

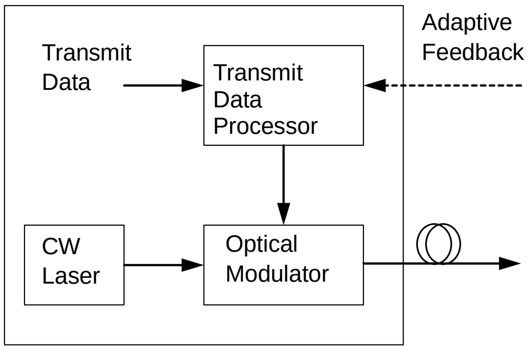

Figure II.11 – Basic transmitter-based electronic dispersion compensation structure

II.4 Chromatic dispersion monitoring

As can be seen from Figures I.2 to I.12, the dispersion of adaptive dispersion compensators can be controlled according to dispersion-related information, which can be link residual dispersion information or other general dispersion-related performance monitoring information using signal related performance, such as the bit-error ratio (BER), eye opening or Q factor, etc.

As can be seen from Figure I.1, some configurations that employ adaptive dispersion compensators incorporate a dispersion monitoring function. Three categories of methods for doing this are:

– monitoring the electrical spectrum;

– monitoring the amplitude of a pilot tone;

– monitoring the time delay between the upper and lower sidebands.

II.4.1 Monitoring the electrical spectrum

When an optical signal is detected by a photodiode, the square-law detection process plays a useful role in identifying the frequency components of the optical signal which have been reduced in magnitude or nullified due to chromatic dispersion. The amplitude (power) change within a specific frequency band is directly related to the amount of chromatic dispersion that the signal has been subjected to within that frequency band [b-DEVAUX]. The electrical spectra of optical signals with different chromatic dispersions $|D_n|$ are shown in Figure II.12, where $|D_1| < |D_2| < |D_3|$. Since the power within the specific frequency band Δf uniquely corresponds to the specific chromatic dispersion $|D_n|$, the required monitoring signal can be obtained.

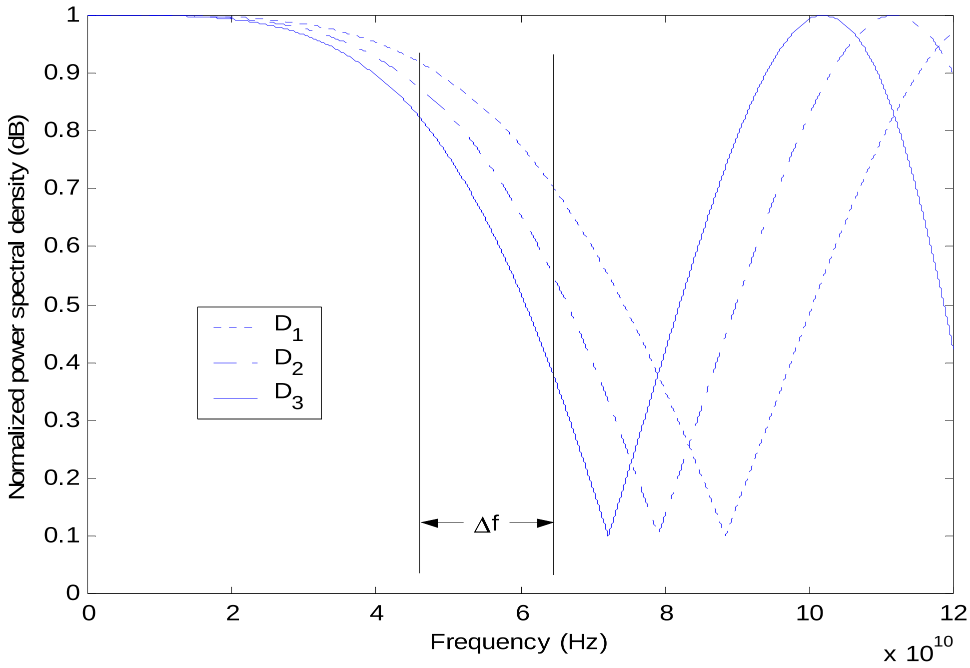

Figure II.12 – Electrical spectrum of the detected signal

II.4.2 Monitoring the amplitude of a pilot tone

By adding a pilot tone to the optical signal at an appropriate frequency, the same phenomenon discussed in clause II.4.1 can be monitored by simply measuring the level of the pilot tone at the detector output using a narrow electrical filter [b-PETERSEN].

Figure II.13 shows the observed electrical power spectrum for different accumulated dispersions where the power of tone-n is decreasing with the chromatic dispersion increasing from (a) to (c).

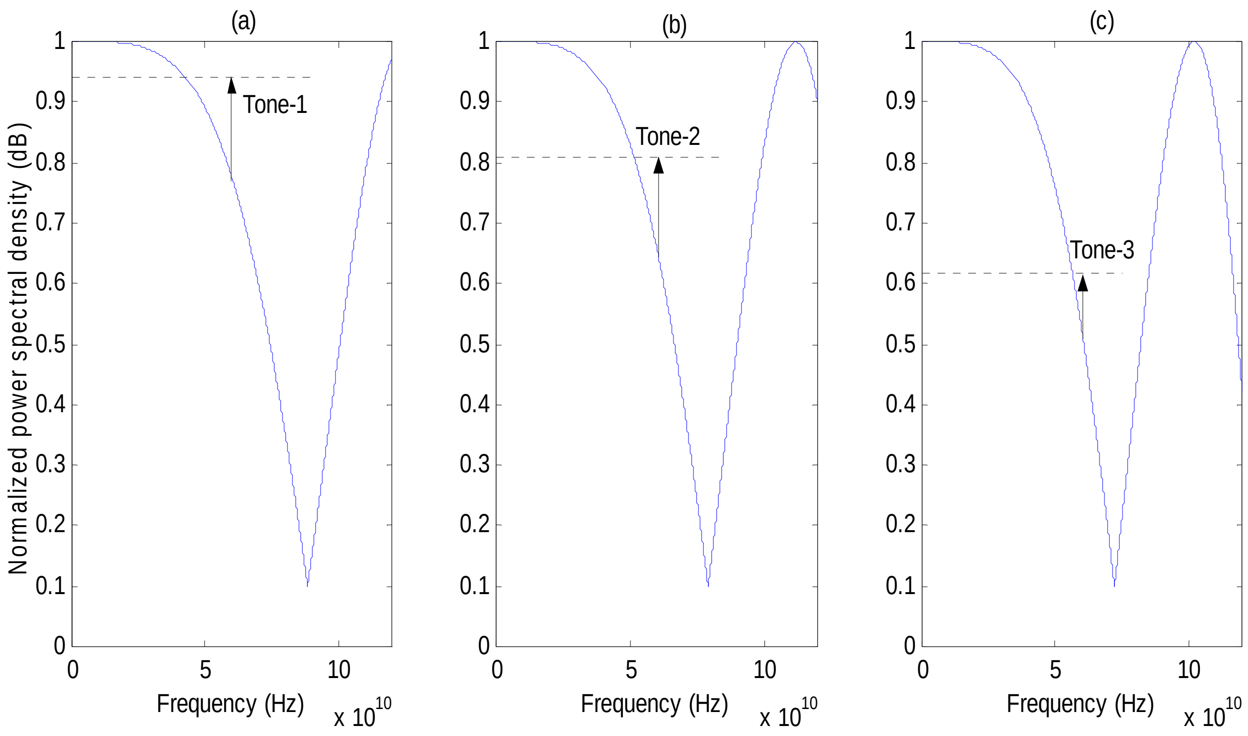

Figure II.13 – Electrical spectrum of the detected signal with pilot tone

II.4.3 Monitoring the time delay between the upper and lower sidebands

This scheme uses a filter to select the upper and lower vestigial sideband (VSB) signal in the data and monitors the relative clock phase-shift $\Delta\phi$ caused by dispersion [b-QIAN]. VSB filtering is implemented by tuning the filter apart from the spectral centre of the signal as shown in Figure II.14 for an RZ signal. Since the two sidebands occupy different wavelength ranges, fibre chromatic dispersion induces a relative group delay, and thus, a small clock phase-shift between the lower and upper VSB signals.

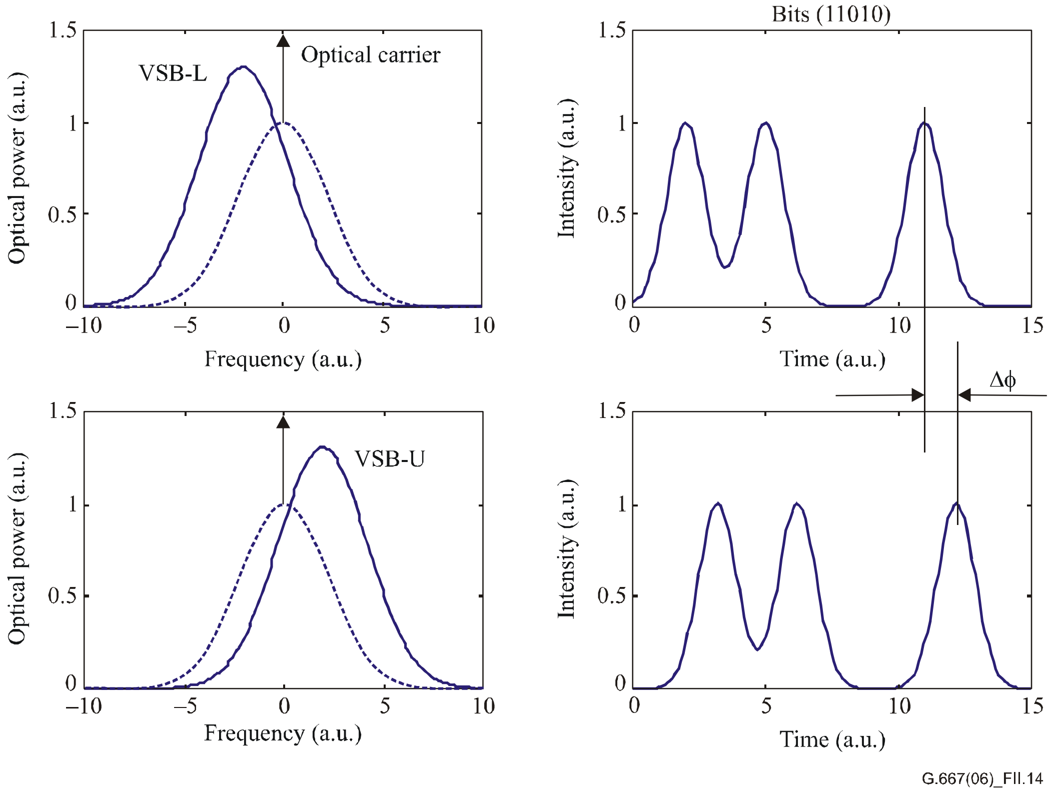

Figure II.14 – Dispersion monitoring using VSB filters

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