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

Transmission media characteristics – Characteristics of optical components and subsystems

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Generic characteristics of Raman amplifiers and Raman amplified subsystems

ITU-T Recommendation G.665

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ITU-T Recommendation G.665

Generic characteristics of Raman amplifiers and Raman amplified subsystems

Summary

This Recommendation identifies the definitions and test methods of performance parameters of the following fibre Raman amplifiers and Raman amplified subsystems:

- reverse pumped distributed Raman amplifier;
- forward pumped distributed Raman amplifier;
- bidirectionally pumped distributed Raman amplifier;
- reverse pumped distributed, composite Raman amplifier;
- bidirectionally pumped distributed, composite Raman amplifier;
- discrete Raman amplifier.

This Recommendation describes the classification, the type code, and the reference models of various Raman amplifiers. It also outlines the general characteristics of the Raman amplifiers, and defines the performance and testing parameters for the Raman amplifiers.

Source

ITU-T Recommendation G.665 was approved on 13 January 2005 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

FOREWORD

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CONTENTS

ITU-T Recommendation G.665

Generic characteristics of Raman amplifiers and Raman amplified subsystems

1 Scope

This Recommendation identifies the definitions and test methods of performance parameters of optical fibre Raman amplifiers and Raman amplified subsystems. In the case of distributed or discrete Raman amplifiers (forward pumped, reverse pumped, bidirectionally pumped) or composite distributed Raman and discrete amplifiers, the generic characteristics of those amplifiers and subsystems are also specified.

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

– ITU-T Recommendation G.662 (1998), *Generic characteristics of optical amplifier devices and subsystems.*

– ITU-T Recommendation G.663 (2000), *Application related aspects of optical amplifier devices and subsystems.*

– ITU-T Recommendation G.664 (2003), *Optical safety procedures and requirements for optical transport systems.*

– IEC 61290 series, *Optical Amplifier Test Methods.*

– IEC 61291 series, *Optical fibre amplifiers (General aspects).*

– IEC 61292 series, *Technical Reports of Optical Amplifiers.*

– IEC 60825 series, *Safety of laser products*.

3 Abbreviations

This Recommendation uses the following abbreviations:

ASE	Amplified Spontaneous Emission
C	Optical connector associated with the Raman amplifier
DOP	Degree of Optical Polarization
DRS	Double Rayleigh Scattering
EDFA	Erbium-Doped Fibre Amplifier
FP_i	Signal ingress point for the Forward Pumped Raman Amplifier
FP_o	Signal egress point for the Forward Pumped Raman Amplifier
FRA	Fibre Raman Amplifier

GMP	Gain Measurement Point
MPI	Multi-Path Interference
OA	Optical Amplifier
OAR	Optically Amplified Receiver
OAT	Optically Amplified Transmitter
ORL	Optical Return Loss
PDG	Polarization-Dependent Gain
PMD	Polarization Mode Dispersion
RIN	Relative Intensity Noise
RP_i	Signal ingress point for the Reverse Pumped Raman Amplifier
RP_o	Signal egress point for the Reverse Pumped Raman Amplifier
Rx	Receiver (Optical)
SRS	Stimulated Raman Scattering
Tx	Transmitter (Optical)

4 Terms and Definitions

This clause outlines the definitions of various distributed Raman amplifiers and the discrete Raman amplifier. The performance parameters for these Raman amplifiers are also defined in this clause.

4.1 Distributed and discrete Raman amplifier

Definitions of distributed and discrete Raman amplifiers are given in this clause. Further information can be obtained in IEC 61292-3 for these Raman amplifiers.

4.1.1 distributed Raman amplifier: Distributed Raman amplifiers are amplifiers where the amplification effect is achieved via a portion of the optical fibre used for transmission. Such amplifiers are deemed to be distributed since part or all of the transmission fibre is used for amplification purposes. Distributed Raman amplifiers can be further classified into three sub-categories:

- ***Forward pumped Raman amplifier***: The pump energy and signal co-propagate along the transmission fibre.
- ***Reverse pumped Raman amplifier***: The pump energy and signal propagate in opposite directions in the transmission fibre.
- ***Bidirectionally pumped Raman amplifier***: The pump energy is applied in both ends of the transmission fibre. In this case, part of the pump energy co-propagates with the signal and part of the pump energy counter-propagates with the signal inside the transmission media.

4.1.2 discrete Raman amplifier: A discrete Raman amplifier is an amplifier for optical signals whose amplification effect is achieved via the fibre SRS effect, where all of the physical components of the amplifier are completely contained inside the device.

4.2 Optical signal power parameters

Parameters	Definitions	Notes
4.2.1 Equivalent input power	The power at the input reference point when the Raman pump is de-activated.	For a reverse pumped Raman amplifier, the input reference point is at point RP_i in Figure 1. For other Raman amplifier configurations, see 5.3.
4.2.2 Large-signal output stability	see 4.9/G.661	
4.2.3 Saturation output power (gain compression power)	see 4.11/G.661	
4.2.4 Nominal output signal power	see 4.12/G.661	
4.2.5 Maximum total output power	see 4.25/G.661	
4.2.6 Input power range	see 4.28/G.661	
4.2.7 Output power range	see 4.29/G.661	

4.3 Gain parameters

Parameters	Definitions	Notes
4.3.1 Raman on-off gain	IEC 61291-1, 3.1.18 and 3.1.19 The increase in signal optical power at the gain measurement point (GMP) defined in 5.3 when the Raman pump is activated compared to the signal optical power at the GMP when the Raman pump is de-activated.	Applicable to distributed Raman amplifiers.
4.3.2 Net Gain	Net Gain is defined as the combined Raman On-Off gain and the gain from the OA, if applicable, with the loss between the input and output reference points of the amplifier subtracted from it.	
4.3.3 Channel net gain	Net Gain for each channel at a given wavelength in a multichannel configuration.	
4.3.4 Small-signal net gain	see 4.1/G.661	
4.3.5 Reverse small-signal net gain	see 4.2/G.661	
4.3.6 Maximum net small-signal gain	see 4.3/G.661	
4.3.7 Maximum small-signal net gain wavelength	see 4.4/G.661	
4.3.8 Maximum small-signal net gain variation with temperature	see 4.5/G.661	

Parameters	Definitions	Notes
4.3.9 Small-signal net gain wavelength bandwidth	see 4.6/G.661	
4.3.10 Small signal net gain stability	see 4.8/G.661	

4.4 Gain spectrum parameters

Parameters	Definitions	Notes
4.4.1 Average slope of Multichannel net gain spectrum envelope	For the wavelength λ_i and its correspondent net gain G_i, it is possible to approximate G_i via linear equation: $$\hat{G}_i = b\lambda_i + a$$ Where a and b are chosen such that $\sum_{i=0}^{n}(\hat{G}_i - G_i)^2$ is minimized. The average slope of multichannel net gain spectrum envelope will be the b in the above linear equation.	Also refer to IEC 61291-1, 3.1.7, gain-slope under single wavelength operation
4.4.2 Power wavelength band	see 3.1/G.662	
4.4.3 Multichannel net gain variation	IEC 61291-4, IEC 61291-1, 3.1.10	
4.4.4 Net Gain cross-saturation	IEC 61291-4, IEC 61291-1, 3.1.11	For multichannel operation
4.4.5 Multichannel net gain-change difference	IEC 61291-4, IEC 61291-1, 3.1.13	
4.4.6 Multichannel net gain tilt	IEC 61291-4, IEC 61291-1, 3.1.14	

4.5 Noise parameters

Parameters	Definition
4.5.1 Multi-path interference (MPI)	For Raman amplifiers with high gains, the noise from Rayleigh scattering may become dominant. In addition to ASE increased by single Rayleigh scattering, the forward propagating signal may be Rayleigh scattered twice. Such DRS may cause an increase in MPI. Measurements of MPI are referenced in Appendix I. Also refer to IEC 61291-1, 3.1.35, multi-path interference (MPI) figure of merit, and IEC 61291-1, 3.1.36, double Rayleigh scattering figure of merit.
4.5.2 Differential relative intensity noise of optical signal	The ratio between the input relative intensity noise (RIN) and the output RIN of the optical signal. This is mainly caused by MPI in Raman amplifiers.

Parameters	Definition
4.5.3 Effective noise figure (NF)	The effective noise figure is the noise figure of an equivalent discrete optical amplifier placed at the end of the optical fibre, which produces the effective gain and the same ASE output power as the distributed amplification. In the case of a composite amplifier, this includes the gain and ASE noise of the conventional OA. Also refer to IEC 61291-1, 3.1.41, equivalent total noise figure.
4.5.4 Channel effective noise figure	For multiple channel operation, the effective noise figure measured at a channel's centre frequency will be the channel effective noise figure.
4.5.5 Forward amplified spontaneous emission (ASE) power level	see 4.14/G.661
4.5.6 Reverse ASE power level	see 4.15/G.661
4.5.7 Effective noise factor (F)	The effective noise figure expressed in linear form.
4.5.8 Signal-spontaneous noise figure	see 4.34/G.661
4.5.9 Spontaneous-spontaneous optical bandwidth ($B_{sp\text{-}sp}$)	see 4.35/G.661
4.5.10 ASE bandwidth	see 4.36/G.661

4.6 Pump power parameters

Parameters	Definitions
4.6.1 Minimum pump power	The lowest pump power(s) available at RP_i (for reverse pumping) and/or FP_o (for forward pumping) from the Raman pump source(s) for which the operation of the Raman amplifier is stable.
4.6.2 Maximum pump power	The highest pump power(s) available at RP_i (for reverse pumping) and/or FP_o (for forward pumping) from the Raman pump source(s).
4.6.3 RIN of pump laser	Relative Intensity Noise of pump energy.

4.7 Pump leakage parameters

Parameters	Definitions	Notes
4.7.1 Pump leakage to output	see 4.20/G.661	In a composite amplifier, the pump leakage has the components contributed by the Raman amplifier and components contributed by the OA.
4.7.2 Pump leakage to input	see 4.21/G.661	In a composite amplifier, the pump leakage has the components contributed by the Raman amplifier and components contributed by the OA.

4.8 Polarization dependent parameters

Parameters	Definitions	Notes
4.8.1 DOP of pump laser	IEC 61291-1, 3.1.56, the degree of polarization of pump laser.	
4.8.2 Polarization-dependent gain (PDG)	see 4.10/G.661	
4.8.3 Polarization mode dispersion (PMD)	see 4.31/G.661	The PMD of a Raman amplification device combines both the PMD effect due to the transmission fibre and the PMD effect due to the amplification device. The PMD effect contributed via fibre is specified in the ITU-T G.650 series Recommendations.

4.9 Channel addition/removal response

Parameters	Definitions
4.9.1 Channel addition/removal (steady-state) gain response	IEC 61291-4, IEC 61291-1, 3.1.15 Steady-state change in channel gain of any one of the channels due to the addition/removal of one or more other channels, for a given multichannel configuration.
4.9.2 Channel addition/removal transient gain response	IEC 61291-4, IEC 61291-1, 3.1.16 For a given multichannel configuration, the maximum change in channel gain of any one of the channels due to the addition/removal of one or more other channels during the transient period after channel addition/removal.
4.9.3 Channel addition/removal transient response time	IEC 61291-4, IEC 61291-1, 3.1.17 Time period from the addition/removal of a channel to the time when the output power level of that or another channel reaches and remains within + N dB ~ – N dB from its steady-state value.

4.10 Reflectance parameters

Parameters	Definitions
4.10.1 Input reflectance	see 4.16/G.661
4.10.2 Output reflectance	see 4.17/G.661
4.10.3 Maximum reflectance tolerable at input	see 4.18/G.661
4.10.4 Maximum reflectance tolerable at output	see 4.19/G.661
4.10.5 Maximum reflectance tolerable at input and output	see 4.38/G.661

4.11 Insertion loss parameters

Parameters	Definitions
4.11.1 Out-of-band insertion loss	see 4.22/G.661. For distributed Raman amplifiers, this is equal to the net gain for out-of-band wavelengths.
4.11.2 Out-of-band reverse insertion loss	see 4.23/G.661. For distributed Raman amplifiers, this is equal to the net gain in the reverse direction for out-of-band wavelengths.
4.11.3 In-band insertion loss	see 4.37/G.661. For distributed Raman amplifiers, this is equal to the loss between the input and output reference points of the amplifier.

4.12 Other parameters

Parameters	Definitions	Notes
4.12.1 Maximum power consumption	see 4.24/G.661	
4.12.2 Operating temperature	see 4.26/G.661	
4.12.3 Optical connections	see 4.27/G.661	
4.12.4 Channel allocation	IEC 61291-4, IEC 61291-1, 3.1.23	

5 Classification

5.1 Rules of classification

The devices with Raman amplification can be classified as follows:

- forward pumped Raman amplifiers;
- reverse pumped Raman amplifiers;
- bidirectionally pumped Raman amplifiers;
- discrete Raman amplifiers (including composite discrete Raman/erbium amplifiers);
- composite forward pumped Raman and discrete amplifiers;
- composite reverse pumped Raman and discrete amplifiers;
- composite bidirectionally pumped Raman and discrete amplifiers.

The above classification covers both the single-channel case and the multichannel case.

5.2 Type code

This clause includes the regulation of type codes of Raman amplifiers and their examples. The Raman amplifier type code specified consists of a capital letter, a number and two lower case letters:

Capital letter	Number	Lower case letter 1	Lower case letter 2

5.2.1 Capital letter

C —— Raman amplifier

5.2.2 Number

1. discrete amplifiers (e.g., post-amplifiers and/or booster amplifiers);
2. discrete pre-amplifiers;
3. discrete line amplifiers;
4. discrete OAT (optically amplified transmitter);
5. discrete OAR (optically amplified receiver);
6. distributed Raman amplifiers;
7. composite distributed and discrete amplifiers.

5.2.3 Lower case letters

Lower case letter 1:

a amplifiers for analog, single (wavelength) channel transmission;

b amplifiers for digital, single (wavelength) channel transmission;

c amplifiers for digital, multichannel (wavelength) transmission.

Lower case letter 2:

f forward pumped;

r reverse pumped;

b bidirectionally pumped.

5.2.4 Examples of type code

There could be many combinations of the above type code elements (Capital letter, number, and lower case letters) to produce a valid type code. Two of those valid type codes are shown here as examples.

C6cr: reverse pumped distributed Raman amplifier for digital multichannel transmission.

C7bb: bidirectionally pumped composite amplifier for digital single channel transmission.

5.3 Reference model

The reference models of various Raman amplification devices are defined in this clause.

In the illustrations below, a reference point name with a subscript (i) indicates the signal input reference point and the subscript (o) indicates the signal output reference point.

In each case the point labelled GMP is the Gain Measurement Point, at which two signal power measurements are made. One is the signal power measured when the Raman pumps are on (P_{ON}) and the other is the signal power measured when the Raman pumps are off (P_{OFF}).

The Raman on-off gain is then defined as $10\text{Log}\left(\frac{P_{ON}}{P_{OFF}}\right)$

The connectors labelled "C" in Figures 1 to 6 are connectors directly associated with the Raman pump unit (where present) and are considered to be part of the amplification device. This view of connectors is different from the view of the IEC. More on this subject has been presented in Appendix III.

The reverse pumped Raman amplifier is shown in Figure 1.

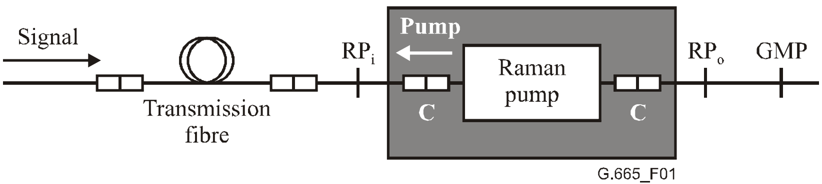

Figure 1/G.665 – Reverse pumped Raman amplifier

RP_i is the Reverse Pumped signal input reference point

RP_o is the Reverse Pumped signal output reference point

The net gain is the On-Off gain with the loss between the reference points RP_i and RP_o subtracted from it, as defined in 4.3.2.

The forward pumped Raman amplifier is depicted in Figure 2.

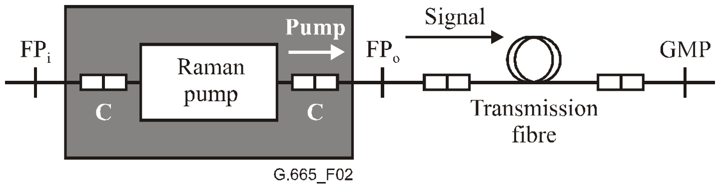

Figure 2/G.665 – Forward pumped Raman amplifier

FP_i is the Forward Pumped signal input reference point

FP_o is the Forward Pumped signal output reference point

The net gain is the on-off gain with the loss between the reference points FP_i and FP_o subtracted from it.

The bidirectionally pumped Raman amplifier is illustrated in Figure 3.

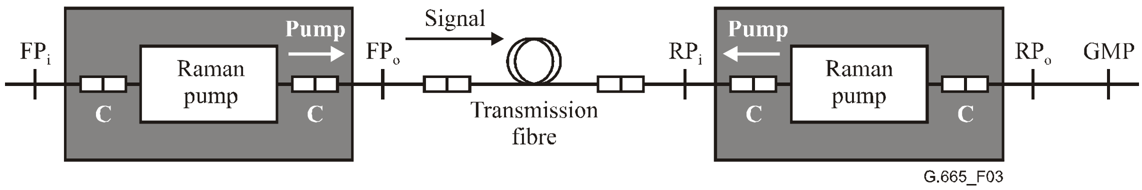

Figure 3/G.665 – Bidirectionally pumped Raman amplifier

The net gain is the On-Off gain with the loss between the reference points FP_i and FP_o and the reference points RP_i and RP_o subtracted from it.

The composite reverse pumped Raman amplifier is shown in Figure 4.

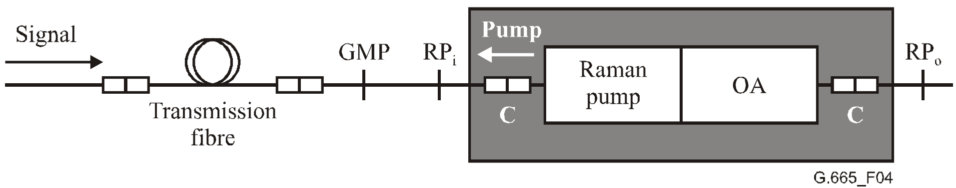

Figure 4/G.665 – Reverse pumped, composite Raman amplifier

The forward pumped, composite Raman amplifier can be viewed as a forward pumped Raman amplifier followed by an optical amplifier. Therefore, this configuration will not be further discussed in this Recommendation.

The bidirectionally pumped composite Raman amplifier is illustrated in Figure 5.

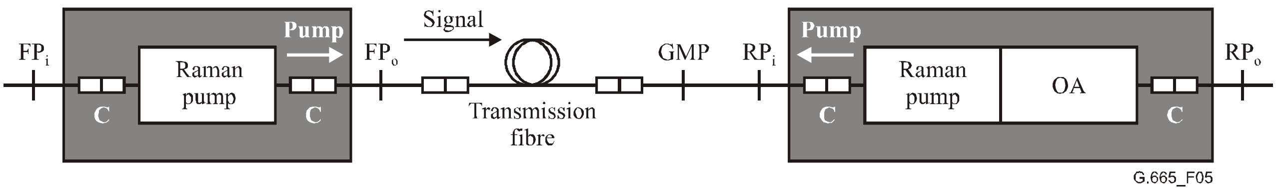

Figure 5/G.665 – Bidirectionally pumped, composite Raman amplifier

The discrete Raman amplifier is illustrated in Figure 6.

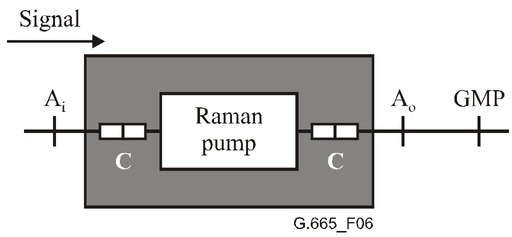

Figure 6/G.665 – Discrete Raman amplifier

The generic characteristics of this class of the Raman amplifier are similar to the discrete Optical Amplifier discussed in ITU-T Rec. G.661 and will not be repeated in this Recommendation. The reference points A_i and A_o mark the input and output reference points respectively of the discrete Raman amplifier.

6 Generic Characteristics of Raman amplification devices

This clause outlines the generic characteristics of the various distributed Raman amplifiers and the composite amplifiers.

The table entries outline various measurement points at which the parameters are to be measured. NA indicates the measurement for the parameter under the amplifier configuration is Not Applicable. The GMP (Gain Measurement Point) and the reference points (FP_i, FP_o, RP_i and RP_o) are all defined in 5.3. See Tables 1 and 2.

Table 1/G.665 – Generic characteristics of distributed Raman amplifiers

	Reverse pumped		Forward pumped		Bidirectionally pumped	
	Single channel	**Multi channel**	**Single channel**	**Multi channel**	**Single channel**	**Multi channel**
Gain passband range	GMP	NA	GMP	NA	GMP	NA
Channel allocation	NA	GMP	NA	GMP	NA	GMP
Maximum difference of channel gains	NA	GMP	NA	GMP	NA	GMP
Channel gain spectrum average slope	NA	GMP	NA	GMP	NA	GMP
Channel addition/removal gain response (steady-state)	NA	GMP	NA	GMP	NA	GMP
Raman on-off gain	GMP		GMP		GMP	
Effective noise figure	GMP		GMP		GMP	
Differential relative intensity noise of optical signal	Between the signal at the input point of the pumped optical fibre and the signal at RP_o.		Between the signal at FP_i and the signal at the output point of the pumped optical fibre.		Between the signals at FP_i and RP_o.	
Input power range	NA		FP_i		FP_i	
Equivalent input power range	RP_i		FP_i		FP_i	
Output power range	RP_o		NA		RP_o	
Reflectance at signal input interface	RP_i		FP_i		FP_i	
Reflectance at signal output interface	RP_o		FP_o		RP_o	
Reflectance at pump output interface	RP_i		FP_o		FP_o & RP_i	
Maximum reflectance tolerable at signal input interface	RP_i		FP_i		FP_i	
Maximum reflectance tolerable at signal output interface	RP_o		FP_o		RP_o	
Maximum reflectance tolerable at pump output interface	RP_i		FP_o		FP_o & RP_i	
Pump power	RP_i		FP_o		FP_o & RP_i	
Pump leakage to signal input (upstream)	NA		FP_i		FP_i	
Pump leakage to signal output	RP_o		NA		RP_o	
Applicable optical connection	RP_i, RP_o		FP_i, FP_o		FP_i, FP_o, RP_i, RP_o	
RIN of pump laser	RP_i		FP_o		FP_o & RP_i	
DOP of pump laser	RP_i		FP_o		FP_o & RP_i	

Table 2/G.665 – Generic characteristics of composite Raman amplifiers

	Reverse pumped		Bidirectionally pumped	
	Single channel	**Multichannel**	**Single channel**	**Multichannel**
Gain passband range	GMP	NA	GMP	NA
Channel allocation	NA	GMP	NA	GMP
Maximum difference of channel gains	NA	GMP	NA	GMP
Channel gain spectrum average slope	NA	GMP	NA	GMP
Channel addition/removal gain response (steady-state)	NA	GMP	NA	GMP
Raman on-off gain when the OA is operational	GMP		GMP	
Effective noise figure	RP_o		RP_o	
Differential relative intensity noise of optical signal	Between the signal at the input point of the pumped optical fibre and the signal at RP_o.		Between the signals at FP_i and RP_o.	
Input power range	NA		FP_i	
Equivalent input power range	RP_i		FP_i	
Output power range	RP_o		RP_o	
Reflectance at signal input interface	RP_i		FP_i	
Reflectance at signal output interface	RP_o		RP_o	
Reflectance at pump output interface	RP_i		RP_i & FP_o	
Maximum reflectance tolerable at signal input interface	RP_i		FP_i	
Maximum reflectance tolerable at signal output interface	RP_o		RP_o	
Maximum reflectance tolerable at pump output interface	RP_i		RP_i & FP_o	
Pump power	RP_i		RP_i & FP_o	
Pump leakage to signal input	NA		FP_i	
Pump leakage to signal output	RP_o		RP_o	
Applicable optical connection	RP_i, RP_o		RP_i, RP_o, FP_i, FP_o	
RIN of pump laser	RP_i		RP_i & FP_o	
DOP of pump laser	RP_i		RP_i & FP_o	

7 Performance parameters and test parameters

This clause contains a minimum list of performance and test parameters of Raman amplifiers and Raman amplified subsystems. The specific values of those parameters must be determined from the application in the relevant system Recommendation rather than being specified here.

Table 3/G.665 – Performance and test parameters

	Parameters	Unit	Test method
Functional parameters	Channel allocation (Note 1)	nm	
	Power wavelength band (Note 2)	nm	
	Raman On-Off Gain	dB	IEC 61290-1
	Multichannel gain variation (flatness) (Note 1)	dB	IEC 61290-1
	Steady state Channel addition/removal gain response (Note 1)	dB	IEC 61290-1
	Transient state Channel addition/removal gain response (Note 1)	dB	IEC 61290-1
	Effective noise figure	dB	IEC 61290-3
	Differential relative intensity noise of optical signal (Note 3)	dB/Hz	IEC 61292-2
	Input power range	dBm	IEC 61290-2
	Maximum total output power	dBm	IEC 61290-2
	Maximum reflectance tolerable at signal input interface	dB	IEC 61290-5
	Maximum reflectance tolerable at signal output interface	dB	IEC 61290-5
	Reflectance at signal input interface	dB	IEC 61290-5
	Reflectance at signal output interface	dB	IEC 61290-5
	Pump power	dBm	IEC 61290-2
	Pump leakage to signal input or output	dBm	IEC 61290-6
	RIN of pump laser	dB/Hz	IEC 61292-2 or IEC 61290-3
	DOP of pump laser	%	IEC 61290-11
	Fibre type		
	Optical connection		
	Fibre length	km	
	Power consumption	W	
	PMD (Note 3)	ps	IEC 61290-11
	PDG	dB	IEC 61290-1

Table 3/G.665 – Performance and test parameters

<table>
<tr><th></th><th colspan="2">Parameters</th><th>Unit</th><th>Test method</th></tr>
<tr><td rowspan="9">Environmental parameters</td><td colspan="2">Operating temperature</td><td>°</td><td>IEC 61290-8</td></tr>
<tr><td colspan="2">Maximum operating relative humidity</td><td>%</td><td>IEC 61290-8</td></tr>
<tr><td rowspan="2">Maximum operating vibration severity</td><td>Range of Frequencies</td><td>Hz</td><td>IEC 61290-8</td></tr>
<tr><td>Amplitude</td><td>mm p-p</td><td>IEC 61290-8</td></tr>
<tr><td colspan="2">Storage temperature</td><td>°</td><td>IEC 61290-8</td></tr>
<tr><td colspan="2">Maximum storage relative humidity</td><td>%</td><td>IEC 61290-8</td></tr>
<tr><td rowspan="2">Maximum transport shock severity</td><td>Acceleration</td><td>G</td><td>IEC 61290-8</td></tr>
<tr><td>Duration</td><td>ms</td><td>IEC 61290-8</td></tr>
<tr><td colspan="5">NOTE 1 – For multichannel amplifiers only.
NOTE 2 – For single channel amplifiers only.
NOTE 3 – Although it is possible to determine these parameters for distributed amplifiers, they are only recommended standardization for the discrete cases.</td></tr>
</table>

8 Optical safety

For the distributed Raman amplifiers, because of high optical power (potentially above +30 dBm) being injected into the fibre, the safety procedures outlined in ITU-T Rec. G.664, IEC 61292-4, IEC 60825-1, and IEC 60825-2 need to be observed. IEC 60825-1 and IEC 60825-2 must be observed. In addition, ITU-T Rec. G.664 deals with application of APR and startup and shutdown procedures, and IEC 61292-4 provides informative reference for other concerns including the potential for fire and physical damage.

Appendix I

Measurements of MPI for lightwave transmission system

I.1 Time domain extinction measurement [1]

In this method, the signal into the Raman amplifier is gated on and off using an acoustic-optic switch. The signal out of the amplifier is then sampled using a second switch, either in phase to measure the signal or out of phase to measure the Rayleigh scattered power. This method requires fast high-extinction acoustic-optic switches. This work could also be done with a gated OSA.

Also refer to IEC 61290-10-1 and IEC 61290-10-2.

I.2 Electrical measurement [2]

The amount of MPI in a system can be determined using a photodiode and electrical spectrum analyser by measuring the noise produced when the signal beats with a delayed version of itself. However, the Raman amplifier will produce spontaneous emission, which will also generate other beat noises at the receiver. This measurement method subtracts these other noise sources so that the MPI can be determined. The measurement method concerns calibration against an MPI simulator and subtracting ASE caused beat noise.

Also refer to IEC 61290-3-2.

Appendix II

Physical and equivalent models of distributed Raman amplifiers

In distributed or composite Raman amplifiers, an extended length of the optical transmission fibre is used to achieve amplification. Performance analysis could be performed via simulation if a set of parameters related to the transmission fibre, such as SRS gain spectrum, non-linear coefficients and attenuation coefficient, are available. Those fibre parameters are obtainable in the research environment but are seldom available in the real applications.

In order to simplify evaluation of the system performance, the distributed amplification can be considered equivalent to discrete amplification if amplification parameters are measured at the end of the transmission fibre. That arrangement will also be useful when the Raman amplifiers are compared with the traditional EDFA links.

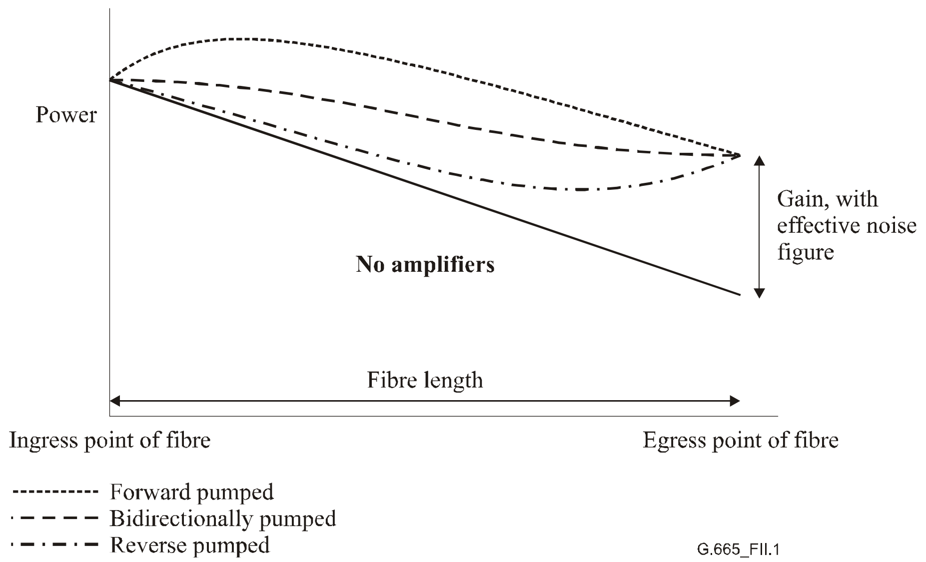

Figure II.1/G.665 – Power distribution along transmission fibre, with three kinds of distributed Raman amplifiers

As shown in Figure II.1, for all kinds of distributed Raman amplifiers, the signal power is increased at the egress point of the transmission fibre, while the signal power at the ingress point is not changed. From the performance point of view, what matters is how much signal power and noise eject from the egress point of fibre, rather than the exact power distributions along the transmission fibre. It is therefore convenient to use an equivalent model of a discrete amplifier at the egress point of the fibre, as shown in Figure II.2. The virtual amplifier produces the same effective gain and ASE output power as the distributed amplification. Because the ASE produced within the fibre of the distributed amplifier is also partially reduced by the attenuation of this fibre, the ASE output power can be lower than physically realizable from such a discrete amplifier. The virtual amplifier is given an input reference point, and an output reference point, R_{equ} & S_{equ}.

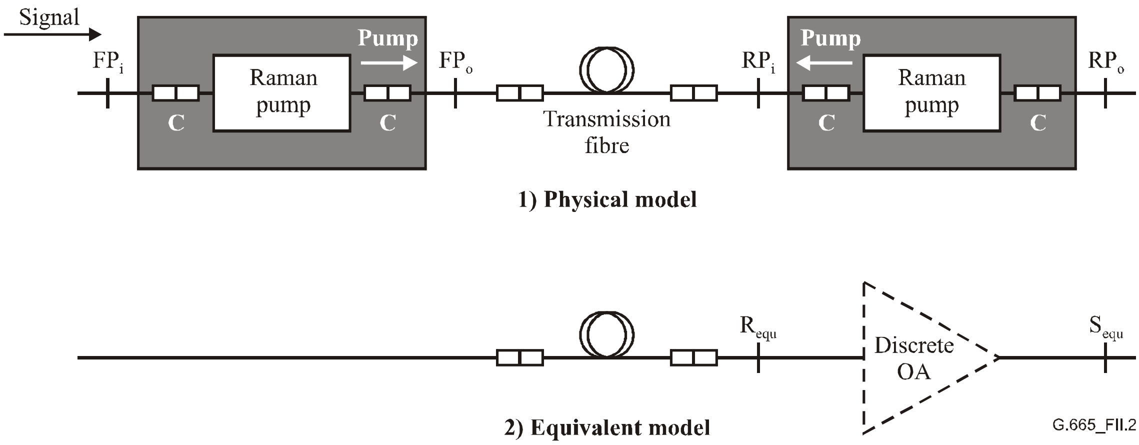

Figure II.2/G.665 – Physical model and equivalent model of distributed Raman amplifiers

Equivalent input parameters can be defined at the equivalent input reference point when the power of the pump laser injecting into the transmission fibre is shut down. Under this condition, the equivalent input power and input OSNR can be measured. The output parameters can be measured at the equivalent output reference point when the pump source is active. Under this condition, the output power and output OSNR can be measured.

By following IEC 61290, the effective noise figure and on-off gain can be determined using the equivalent input power, input & output OSNR, and output power. This final effective NF and on-off gain could be used for a simplified system evaluation.

Appendix III

Considerations of splice and connector loss

This appendix describes the differences in interface conventions between ITU-T and IEC for optical links and components. The reader is advised to note the resulting consequences in the systematic difference of accounting for connector and joint losses.

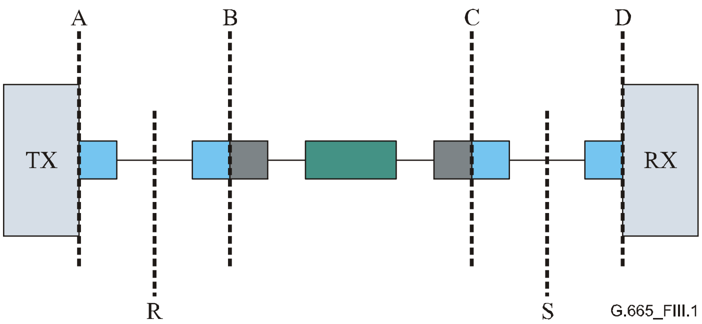

Figure III.1/G.665 – Example link with alternative interfaces

Normally, systems and applications Recommendations are developed in the ITU-T, while test and measurement procedures and device specifications are developed in the IEC. Each organization has a convention for defining interfaces and reference points which is wholly self-consistent, but does result in slightly different outcomes.

ITU-T defines interfaces shown in Figure III.1 as R and S. To the left of the R interface is regarded as the Transmitter/Source. The points between R and S are considered the link or span and the points to the right of Point S are considered the Receiver. The actual location of the reference point may or may not correspond to a physically accessible point. Often, it is a point inside of the fibre which must be cut to explicitly access the interface.

IEC defines interfaces as always at physical points such as connectors or splice locations. These are shown in Figure III.1 as locations A, B, C, and D. Losses are defined as the loss between two interfaces. The power is measured with the link as shown, referenced to the link without the section shown. For example, to measure the loss of the connector pair and the device (shown in the gray box) between B and C, the power at the receiver would be measured with the device inserted in the link. Then the reference power would be measured at the receiver with the connector joined at points B and C as shown in Figure III.2. This results in the loss of the device and one connector pair. The existence of connectors is illustrative, and alternatively the interfaces could be splice points. Connectors (or optical splices) are always assumed to be of the same type and yield the same loss when mated or interchanged in the IEC context.

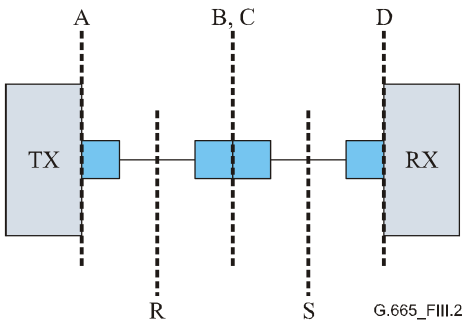

Figure III.2/G.665 – Reference configuration for IEC measurement of loss

In the ITU-T case, the loss would be specified between points R and S, resulting in the loss of the device and two connector pairs. The ITU-T interface is never defined as occurring in the middle of the connector. Therefore, ITU-T span losses will always differ from the IEC test method losses by the loss of one joint or connector as appropriate. In the ITU-T context, the losses of the connector or joint are defined to be explicitly the actual connector losses for connectors between the interface points. No inter-changeability of connectors is implied.

The user is advised to take this difference into consideration when comparing device specifications and testing reports (IEC Publications) versus link and span designs (ITU-T Recommendations).

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