INTERNATIONAL STANDARD

IEC 60728-6

First edition
2001-01

Cabled distribution systems for television and sound signals –

Part 6: Optical equipment

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International Electrotechnical Commission 3, rue de Varembé Geneva, Switzerland
Telefax: +41 22 919 0300 e-mail: inmail@iec.ch IEC web site http://www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

CABLED DISTRIBUTION SYSTEMS FOR TELEVISION AND SOUND SIGNALS –

Part 6: Optical equipment

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.

3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.

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6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60728-6 has been prepared by subcommittee 100D: Cabled distribution systems, of IEC technical committee 100: Audio, video and multimedia systems and equipment.

The text of this standard is based on the following documents:

FDIS	Report on voting
100/169/FDIS	100/198/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

The committee has decided that the contents of this publication will remain unchanged until 2002. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition; or
- amended.

A bilingual version of this standard may be issued at a later date.

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INTRODUCTION

Standards of the IEC 60728 series deal with cable networks for television signals, sound signals and interactive services including equipment, systems and installations

– for headend-reception, processing and distribution of sound and television signals and their associated data signals, and
– for processing, interfacing and transmitting all kinds of interactive multimedia signals using all applicable transmission media.

They cover all kinds of networks such as

– CATV-networks,
– MATV-networks and SMATV-networks,
– individual receiving networks,

and all kinds of equipment, systems and installations installed in such networks.

The scope of these standards extends from antennas and special signal source inputs to headend or other interface points, to networks as a whole up through system outlets, or terminal inputs where no system outlet exists.

The standardization of any user terminals (i.e. tuners, receivers, decoders, multimedia terminals, etc.) is excluded.

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CABLED DISTRIBUTION SYSTEMS FOR TELEVISION AND SOUND SIGNALS –

Part 6: Optical equipment

1 Scope

This part of IEC 60728 lays down the measuring methods, performance requirements and data publication requirements of optical equipment of cable networks for television signals, sound signals and interactive services.

This standard

– applies to all optical transmitters, receivers, amplifiers, splitters, directional couplers, isolators, multiplexers, connectors and splices used in cable networks;

– covers the frequency range 5 MHz to 3 000 MHz;

NOTE The upper limit of 3 000 MHz is an example, but not a strict value. The frequency range or ranges, over which the equipment is specified, shall be published.

– identifies guaranteed performance requirements for certain parameters;

– lays down data publication requirements with guaranteed performance;

– describes methods of measurement for compliance testing.

All requirements and published data relate to minimum performance levels within the specified frequency range and in well-matched conditions as might be applicable to cable networks for television signals, sound signals and interactive services.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60728. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 60728 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60068-2 (all parts), *Environmental testing – Part 2: Tests*

IEC 60416, *General principles for the formulation of graphical symbols*

IEC 60417-1, *Graphical symbols for use on equipment – Part 1: Overview and application*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60617 (all parts), *Graphical symbols for diagrams*

IEC 60728-1:1986, *Cabled distribution systems – Part 1: Systems primarily intended for sound and television signals operating between 30 MHz and 1 GHz*

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IEC 60728-2, *Cabled distribution systems for television and sound signals – Part 2: Electromagnetic compatibility of equipment* [1)]

IEC 60728-3: 1997, *Cabled distribution systems for television and sound signals – Part 3: Active coaxial wideband distribution equipment*

IEC 60728-5, *Cabled distribution systems for television and sound signals – Part 5: Headend equipment* [1)]

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification, requirements and user's guide* [1)]

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this part of IEC 60728, the following definitions apply.

3.1.1
optical transmitter
device for converting electrical signals into optical signals. It consists of a light source (for example, laser) and its associated components as well as all components between the coaxial input and optical output connectors

3.1.2
optical receiver
device for converting optical signals into electrical signals. It consists of a detector (for example, PIN-diode) and its associated components as well as all the components between the optical input and coaxial output connectors

3.1.3
optical amplifier
device for amplifying optical signals direct. It consists of an active medium (and its associated components), which amplifies the optical signal without demodulation or regeneration

3.1.4
optical isolator
device which transports optical power in one direction only

3.1.5
optical fibre splice
permanent joint of two fibre ends

3.1.6
splitter
device in which the signal power at the (input) port is divided equally or unequally between two or more (output) ports

NOTE Some forms of this device may be used in the reverse direction for combining signal energy.

3.1.7
directional coupler
splitter in which the attenuation between any two output ports exceeds the sum of the attenuations between the input port and each of those output ports

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[1)] To be published

3.1.8
multiplexer
device in which the signal energy covering a frequency band at one input port is divided between two or more output ports each of which covers a part of that frequency band

NOTE 1 For example, a diplexer is a two-port multiplexer.

NOTE 2 Some forms of this device may be used in the reverse direction for combining.

3.1.9
extinction ratio
ratio of the high-level ϕ_h optical power to the low-level ϕ_l optical power of a modulated optical transmitter:

$$e = \frac{\phi_h}{\phi_l} \qquad (1)$$

This term is mainly used for digital systems

3.1.10
optical modulation index
the optical modulation index is defined as:

$$m = \frac{\phi_h - \phi_l}{\phi_h + \phi_l} \qquad (2)$$

where ϕ_h is the highest and ϕ_l is the lowest instantaneous optical power of the intensity modulated optical signal. This term is mainly used for analogue systems

3.1.11
noise figure/factor
figures of merit describing the internally generated noise of an active device. The noise factor NF is the ratio of the carrier-to-noise ratio at the input to the carrier-to-noise ratio at the output of an active device, assuming the incoming carrier is noise-free:

$$\text{NF} = \frac{C_1 / N_1}{C_2 / N_2} \qquad (3)$$

where

C_1 is the signal power at the input;

C_2 is the signal power at the output;

N_1 is the noise power at the input
(ideal thermal noise for electrical devices; quantum noise for optical devices);

N_2 is the noise power at the output.

In other words, the noise factor is the ratio of noise power at the output of an active device to the noise power at the same point if the device had been ideal and added no noise:

$$\text{NF} = \frac{N_{2,\text{actual}}}{N_{2,\text{ideal}}} \qquad (4)$$

The noise factor is dimensionless and is often expressed as noise figure F in dB:

$$F = 10 \lg \text{NF} \qquad (5)$$

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3.1.12
relative intensity noise (RIN)
ratio of the mean square of the intensity fluctuations in the optical power of a light source to the square of the mean of the optical output power

NOTE The value for the RIN can be calculated from the results of a carrier-to-noise measurement for the system (see 4.19).

3.1.13
noise equivalent power (NEP)
notional optical power which, when applied to the input of a noiseless optical receiver, would give rise to an electrical output noise power density equal to that observed at the output of an actual receiver under consideration

NOTE The *NEP* can be calculated from the carrier-to-noise ratio C/N (see 4.19) of a receiver using:

$$NEP = \frac{mP}{\sqrt{2B}} 10^{-\frac{1}{20}\mathrm{C/N}} \qquad (6)$$

In this equation, m is the optical modulation index, P is the received optical power and B is the bandwidth. The *NEP* shall be expressed in units of W/√Hz.

3.1.14
equivalent input noise current density
notional input noise current density which, when applied to the input of an ideal noiseless device, would produce an output noise current density equal in value to that observed at the output of the actual device under consideration

NOTE It can be calculated from the carrier-to-noise ratio C/N (see 4.19) of a device or system using:

$$I_\mathrm{r} = \sqrt{\frac{C}{Z 10^{\frac{1}{10}\mathrm{C/N}}}} \qquad (7)$$

In this equation, C is the amplitude of the carrier at the input of the device or system and Z is its input impedance. The equivalent input noise current density shall be expressed in units of A/√Hz.

3.1.15
bit error rate (BER)
number of erroneous bits at the output of a system divided by the total number of received bits. This term is used in digital transmission systems

3.1.16
responsivity
ratio of the output current of a photodiode to the incident optical power

$$r_\mathrm{s} = \frac{I}{P} \qquad \text{(static responsivity)} \qquad (8)$$

$$r_\mathrm{d} = \frac{dI}{dP} \qquad \text{(dynamic responsivity)} \qquad (9)$$

For practical purposes, static and dynamic responsivities can be assumed to be equal.

3.1.17
voltage responsivity of an optical receiver
ratio of the change of output voltage to the change of the incident optical power

$$r_\mathrm{V} = \frac{dU}{dP} \qquad (10)$$

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3.1.18
chromatic dispersion
minus the change of group travel time per unit length of fibre per change of wavelength

NOTE The velocity at which an optical pulse travels on a fibre depends on its wavelength.

3.1.19
wavelength
the wavelength λ of light in vacuum is given by

$$\lambda = \frac{c}{f} \tag{11}$$

where

c is 2,99793 $\times$ 10^8 m/s (speed of light in vacuum);

f is the optical frequency.

Although the wavelength in dielectric material such as fibres is shorter than in a vacuum, only the wavelength of light in a vacuum is used

3.1.20
chirp
incidental frequency modulation caused by the intensity modulation of a laser diode

NOTE Chirping effectively broadens the laser spectral bandwidth. Due to the chromatic dispersion of the fibre, parts of the spectrum travel at different speeds, resulting in harmonic distortion of the transferred signal.

3.1.21
polarization
projection of the electric vector on a plane perpendicular to the direction of transmission of the polarized light wave

3.1.22
linewidth
spectral bandwidth of an individual mode of a laser, defined as the difference between those optical frequencies at which the amplitude reaches or first falls to half of the maximum amplitude

3.1.23
coherence time and coherence length
coherence time is the time which light needs to travel the coherence length; coherence length is the reciprocal of 2π times the linewidth. Both values are used to describe the phase stability of a light source

3.1.24
well-cleaved
well-cleaved end of a fibre has a clean plane front perpendicular to the axis of the fibre

3.1.25
amplified spontaneous emission (ASE)
part of an optical amplifier's output power caused by photons emitted from excited ions whose lifetime was over before their energy was used for amplification

3.1.26
directivity
attenuation between the output port and interface port minus the attenuation between input and interface port, of any equipment or system

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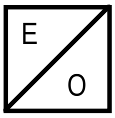
3.1.27
central wavelength
average of those wavelengths at which the amplitude of a light source reaches or last falls to half of the maximum amplitude

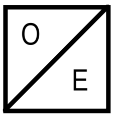
3.1.28
spectral width
difference of those wavelengths at which the amplitude of a light source reaches or last falls to half of the maximum amplitude

3.2 Symbols

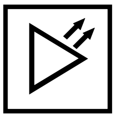
The following graphical symbols are used in the figures of this standard. These symbols are either listed in IEC 60617 or based on symbols defined in IEC 60617.

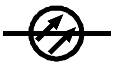


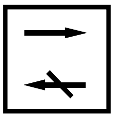
Optical transmitter [10-14-01]

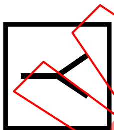


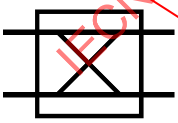
Optical receiver [10-14-01]

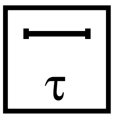

Optical amplifier [02-09-01, 10-15-01]


Optical fibre [10-23-1]

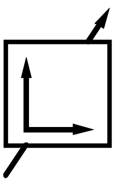

Isolator [10-08-20]


Coupler [02-01-01, 10-09-04]


Directional coupler [02-01-01, 10-09-09]



Delay line [10-16-23]


Polarization control device

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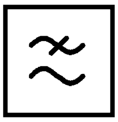
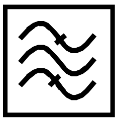
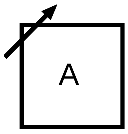


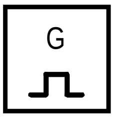
Low-pass filter [10-16-5]



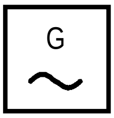
Bandpass filter [10-16-6]



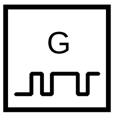
Variable attenuator [10-16-02]



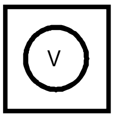
Pulse generator [10-13-04]



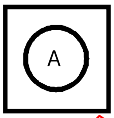
Sine-wave generator [10-13-02]



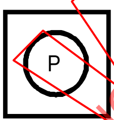
Bit pattern generator



Voltmeter [02-01-01, 08-02-01]

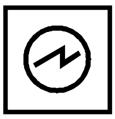


Current meter [02-01-01, 08-01-01]

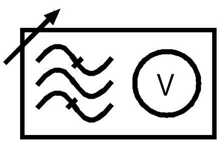


Power meter [02-01-01, 08-01-01]

Bit error detector [02-01-01, 08-01-01]



Oscilloscope [02-01-01, 08-02-10]



Selective voltmeter [02-01-02, 02-03-01, 08-01-01, 10-16-06]

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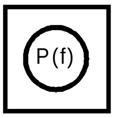
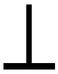
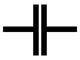


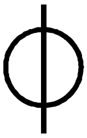
Spectrum analyser [02-01-01, 08-01-01]

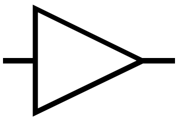

RF choke [04-03-01]

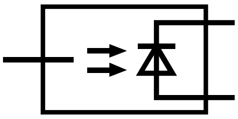

Ground [02-15-04]


Resistor [04-01-01]


Capacitor [04-02-01]


DC power supply [02-16-03]


Amplifier [10-15-01]


Photodiode with fibre pigtail [10-24-02]

3.3 Abbreviations

The following abbreviations are used in this standard:

AC	alternate current
AGC	automatic gain control
ALC	automatic level control
ASE	amplified spontaneous emission
BER	bit error rate
CATV	community antenna television (network)
C/N	carrier-to-noise ratio
CSO	composite second order
CTB	composite triple beat
CW	continuous wave
dB	decibel
DC	direct current
EMC	electromagnetic compatibility
IF	intermediate frequency
MATV	master antenna television (network)
MTBF	mean time between failure

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NEP	noise equivalent power
NF	noise figure
PS	polarization stability
PRBS	pseudo random bit sequence
RF	radio frequency
RIN	relative intensity noise
SMATV	satellite master antenna television (network)
XM	composite cross-modulation

4 Methods of measurement

4.1 General measurement requirements

For all methods of measurements described in this section, the following requirements shall be considered.

4.1.1 Input specification

The following conditions shall be obtained from the device specification:

– supply voltage(s);

– control signal(s), if any, with correct impedance, level and frequency.

4.1.2 Measurement conditions

Unless otherwise specified, all measurement shall be carried out under the following conditions:

– the ambient or reference point temperature shall be (25 ± 5) °C;

– the ambient humidity shall be in the range 40 % to 70 %;

– sufficient care shall be taken to ensure that optical reflection does not impair the accuracy of the measurement;

– during measurement any control input signal(s) shall be held constant.

4.2 Optical power

4.2.1 Purpose

The purpose of this test method is to measure the average optical power emanating from the end of a test fibre. The test fibre and the coupling means shall be as specified by the manufacturer. The optical power shall be expressed in dBm.

4.2.2 Equipment required

4.2.2.1 An **optical power meter** with a range suitable for the expected power. The detector system of the power meter shall have a sufficiently large area to collect all the radiation from the test fibre and a spectral sensitivity compatible with the light source. A minimum accuracy of ±10 % is recommended.

4.2.2.2 A length of **fibre** for connecting the light source to the power meter.

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4.2.2.3 A cladding mode stripper if the fibre has no cladding mode stripping coating.

4.2.2.4 Test **signal generator**(s).

4.2.3 General measurement requirements

4.2.3.1 A digital transmitter shall be modulated with a pseudo random bit sequence (PRBS) having a sequence length of at least $2^{15} – 1$, with the specified pulse repetition frequency and pulse width at the specified extinction ratio. Analogue transmitters shall be modulated with at least one modulation carrier at the specified optical modulation index.

4.2.3.2 Cladding modes shall be stripped from the fibre by means of suitable cladding mode stripping techniques.

4.2.4 Procedure

4.2.4.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.2.4.2 Connect the equipment as shown in figure 1.

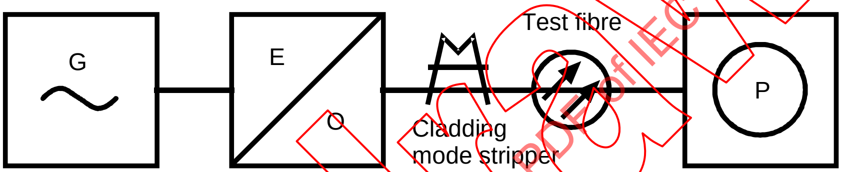

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Figure 1 – Measurement of optical power

4.2.4.3 Connect the optical output of the device under test to the detector (a power meter) through the test fibre and the specified coupling means.

4.2.4.4 Measure and record the output power using the power meter.

4.2.5 Potential sources of error

4.2.5.1 The inaccuracy of the power meter, for example, if its dark current is not sufficiently low.

4.2.5.2 The attenuation of the test fibre and the specified coupling means.

4.3 Loss, isolation, directivity and coupling ratio

The measurement of the following parameters is based on the measurement of optical power, and therefore no special methods of measurement are given for these items:

– loss of fibres, connectors, multiplexers, and optical isolators;
– gain of optical amplifiers;
– directivity of optical couplers;
– isolation of optical isolators, multiplexers and optical couplers.

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4.3.1 General measurement requirements

4.3.1.1 Optical couplers, multiplexers and isolators shall be tested with a light source suitable for the specified wavelength range.

4.3.1.2 All optical inputs or outputs not involved during the measurement shall be terminated to make sure that no reflected light can impair the accuracy of the measurement.

4.3.2 Principle of measurement

4.3.2.1 Connect the light source to the power meter and measure the optical output power P_1 of the light source (see 4.2).

4.3.2.2 Connect the device under test to the light source and the optical power meter as shown in figure 2 and measure the power P_2.

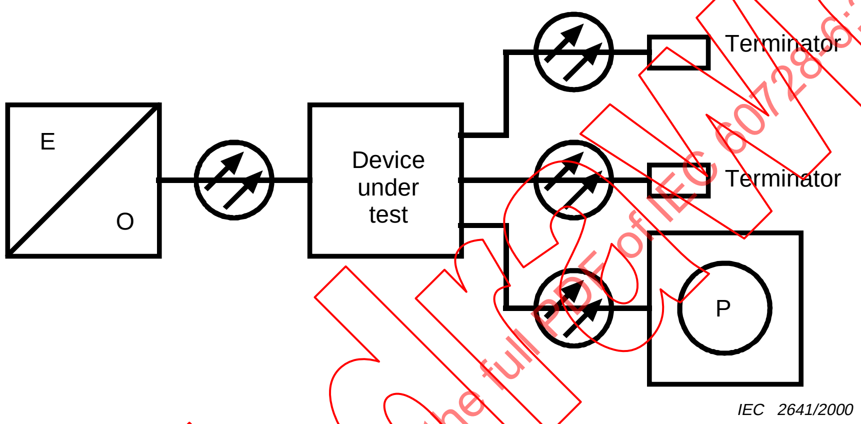

Figure 2 – Measurement of optical loss, directivity and isolation

4.3.2.3 The loss, gain, directivity or isolation is calculated by

$$a = 10 \lg \frac{P_1}{P_2} \qquad (12)$$

4.4 Return loss

4.4.1 Purpose

Reflection of the transmitted light occurs at the boundary of two different dielectric media. The return loss is the reflectance which is the ratio of the incident optical power P_{in} to the reflected optical power P_{back}, expressed in dB. The purpose of this test is to measure the return loss of an optical equipment.

4.4.2 Equipment required

4.4.2.1 A fused **fibre coupler** with a directivity higher than the return loss to be measured.

4.4.2.2 A continuous **light source**.

4.4.2.3 An optical **power meter** with a dynamic range higher than the return loss to be measured**.**

4.4.2.4 Lengths of **fibre** for connecting the optical equipment.

4.4.2.5 Two **optical terminators** with reflection ideally 20 dB better than the return loss to be measured.

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4.4.2.6 A **well-cleaved end of a fibre**, which provides 14,5 dB return loss.

4.4.3 General measurement requirements

The length of the fibre for connecting the light source to the coupler shall be longer than the coherence length of the light source.

4.4.4 Procedure

4.4.4.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.4.4.2 Connect the equipment as shown in figure 3.

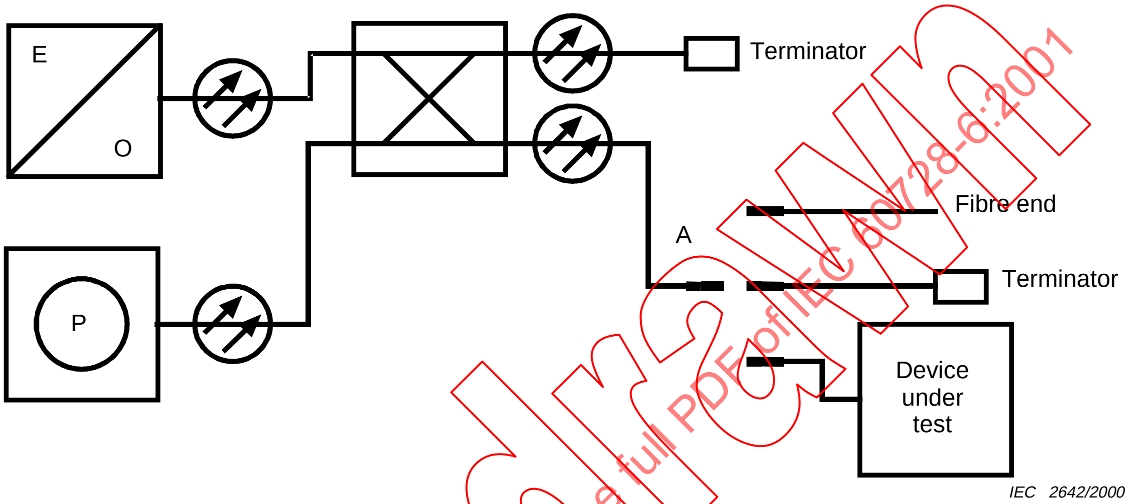

Figure 3 – Measurement of the optical return loss

4.4.4.3 Connect the well-cleaved fibre end with 14,5 dB return loss to port A of the coupler and note the reading P_1 of the power meter.

4.4.4.4 Connect the second terminator to port A of the coupler and note the reading P_2 of the power meter.

4.4.4.5 Connect the device under test to port A of the coupler and note the reading P_3 of the power meter. If the device under test has more than one optical port, the other ports shall be terminated with low reflection.

4.4.4.6 The return loss of the device shall be calculated from:

$$a_r = 14{,}5 + 10 \lg \frac{P_1 - P_2}{P_3 - P_2} \quad \text{(dB)} \qquad (13)$$

4.4.5 Potential sources of error

4.4.5.1 The return loss of the connection at port A shall be at least as high as the return loss of the device under test. Otherwise, the dynamic range of the measurement will suffer.

4.4.5.2 If the impedance matching of the terminators produces a reflection which is not much less than the reflection of the device under test, the accuracy will suffer.

4.4.5.3 The instability of the light source.

4.4.5.4 The inaccuracy of the power meter.

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4.5 Saturation of output power of an optical amplifier

4.5.1 Purpose

The purpose of this test method is to measure the mean optical output power of a test fibre whose far end is connected to the optical output port of a saturated optical amplifier. The saturated optical output power shall be expressed in dBm.

4.5.2 Equipment required

4.5.2.1 A **light source** of suitable wavelength and output power for driving the optical amplifier.

4.5.2.2 A calibrated **variable optical attenuator** for adjusting the optical power fed to the optical amplifier.

4.5.2.3 Three lengths of **fibre** for connecting the equipment.

4.5.2.4 An **optical power meter** with a range suitable for the expected power. The detector system of the power meter shall have a sufficiently large area to collect all the radiation from the fibre and a spectral sensitivity compatible with the light source. A minimum accuracy of ±10 % is recommended.

4.5.2.5 A **cladding mode stripper** if the fibre has no cladding mode stripping coating.

4.5.2.6 An **optical isolator** and connecting length of fibre for use when the optical amplifier to be tested does not incorporate one**.**

4.5.3 General measurement requirements

Cladding modes shall be stripped from the fibre by means of suitable cladding mode stripping techniques.

4.5.4 Procedure

4.5.4.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.5.4.2 Connect the equipment as shown in figure 4.

4.5.4.3 Connect the optical output of the device under test to the detector (a power meter) through the specified coupling means.

4.5.4.4 Starting with low input power levels, decrease the attenuation of the variable optical attenuator in suitable steps. During this procedure, measure and record the output power using the power meter.

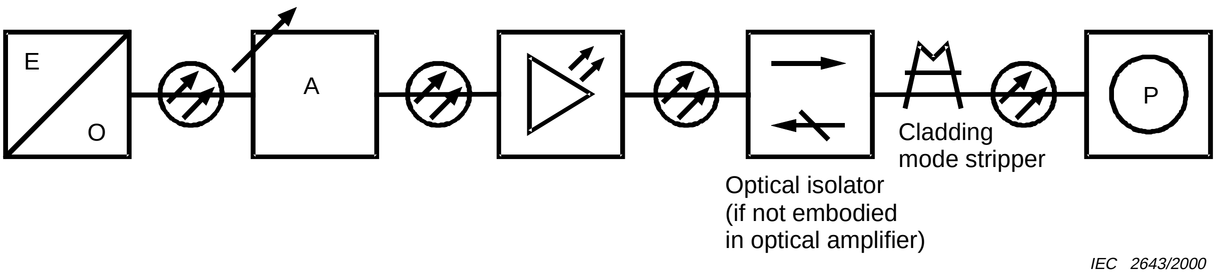

Figure 4 – Measurement of the saturation of the optical output power

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4.5.4.5 A typical result of this measurement is shown in figure 5. At low input levels the output power increases linearly. At higher input levels the gain decreases. The saturated output power is reached when the output power lags 3 dB behind the extrapolated linear value.

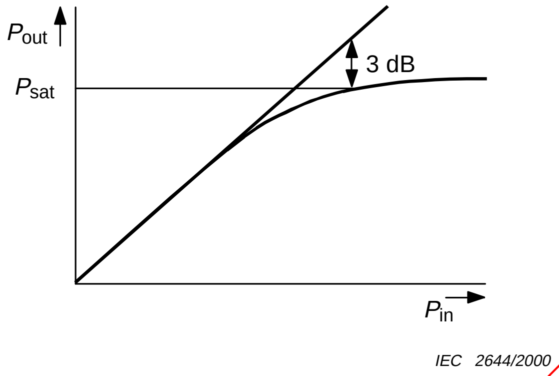

Figure 5 – Saturated optical output power

4.5.5 Potential sources of error

4.5.5.1 The attenuation of the fibres and the coupling means.

4.5.5.2 The inaccuracy of the optical power meter and the optical attenuator.

4.5.5.3 The amplitude and wavelength instability of the light source.

4.5.5.4 The amplified spontaneous emission (ASE) at the output port of the amplifier.

4.6 Influence of polarization

4.6.1 Purpose

The purpose of this test method is to measure the effect of polarization changes on loss or gain under specified conditions. The polarization stability shall be expressed as the logarithmic ratio, in dB, of the maximum and minimum amplitude at the output of a device when the polarization at the input changes between 0° and 360°.

4.6.2 Equipment required

4.6.2.1 A **light source** with a wavelength suitable for the device under test. The polarization of the emanating light shall be constant.

4.6.2.2 A **polarization control device** capable of changing the polarization of the test signal by 360°.

4.6.2.3 An **optical power meter** with a range suitable for the expected power at the output of the device under test. The detector system of the power meter shall have a sufficiently large area to collect all the radiation from the fibre and a spectral sensitivity compatible with the light source. A minimum accuracy of ±10 % is recommended.

4.6.2.4 Lengths of **fibre** for connecting the optical devices. These shall be short enough, straight, unstressed and not birefringent to ensure that the polarization is not changed by them.

4.6.2.5 A **cladding mode stripper** if the fibre has no cladding mode stripping coating.

4.6.3 Procedure

4.6.3.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

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4.6.3.2 Connect the equipment as shown in figure 6.

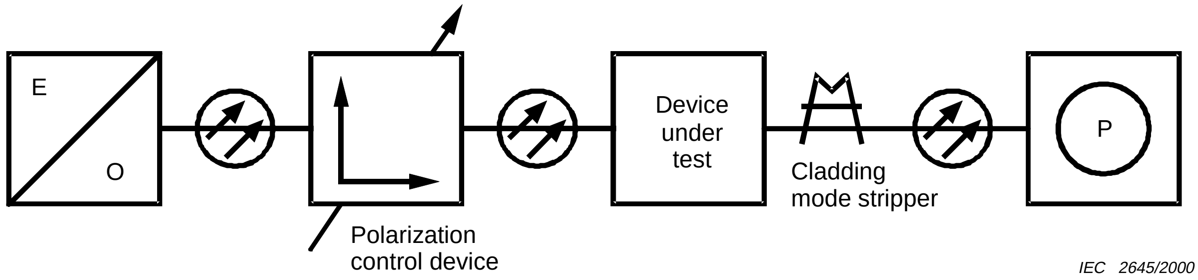

Figure 6 – Measurement of the polarization stability

4.6.3.3 Vary the polarization of the light fed to the device under test by 360° (in not less than 1 s in the case of optical amplifiers). Record the minimum (P_{min}) and the maximum power (P_{max}) at the output.

4.6.3.4 The polarization stability *PS* is derived as follows:

$$PS = 10 \lg \frac{P_{max}}{P_{min}} \qquad (14)$$

4.6.4 Potential sources of error

4.6.4.1 The inaccuracy of the power meter and the polarization control device.

4.6.4.2 The amplitude and wavelength instability of the light source.

4.7 Central wavelength and spectral width under modulation

4.7.1 Purpose

The purpose of this test method is to measure the central wavelength λ_0 of the spectrum and the spectral width $\Delta\lambda$ of a transmitter under modulation. The central wavelength and the spectral width shall be expressed in nm. The method described is not suitable for light sources and transmitters with very narrow spectral width (single-mode laser) or for measuring the chirp of transmitters (see 4.8).

4.7.2 Equipment required

4.7.2.1 An **optical spectrum analyser** with a wavelength range suitable for the transmitter to be tested.

4.7.2.2 A length of **fibre** for connecting the transmitter to the optical spectrum analyser.

4.7.2.3 A test **signal generator** for modulating the transmitter.

4.7.3 General measurement requirements

A digital transmitter shall be modulated with a pseudo random bit sequence (PRBS) having a sequence length of at least $2^{15} - 1$, with the specified pulse repetition frequency and pulse width at the specified extinction ratio. Analogue transmitters shall be modulated with at least one modulation carrier at the specified optical modulation index.

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4.7.4 Procedure

4.7.4.1 Connect the equipment as shown in figure 7.

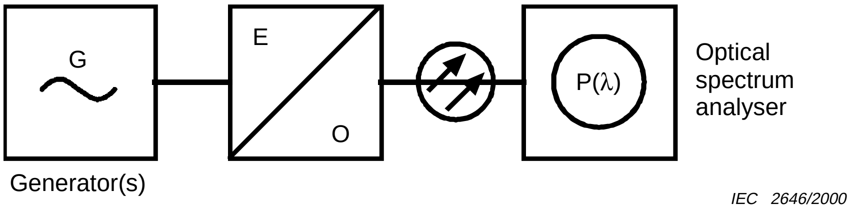

Figure 7 – Measurement of central wavelength and spectral width under modulation

4.7.4.2 Measure the power level of the highest power spectrum using the optical spectrum analyser.

4.7.4.3 Set the optical spectrum analyser to a short wavelength and then adjust it to a progressively longer wavelength. Record the wavelength λ_1, at which half of the maximum peak reading is obtained or exceeded for the first time.

4.7.4.4 Set the optical spectrum analyser to a long wavelength and then adjust it to a progressively shorter wavelength. Record the wavelength λ_2, at which half of the maximum peak reading is obtained or exceeded for the first time.

4.7.4.5 The central wavelength is calculated from

$$\lambda_0 = \frac{\lambda_1 + \lambda_2}{2} \quad (15)$$

4.7.4.6 The spectral width is calculated from

$$\Delta\lambda = \lambda_2 - \lambda_1 \quad (16)$$

4.7.5 Potential sources of error

4.7.5.1 The inaccuracy of the optical spectrum analyser.

4.7.5.2 Mode partition noise and instability of the transmitter. This can be avoided by averaging a suitable number of measurements.

4.7.5.3 Using connectors with angled front can lead to wrong wavelength readings if the input of the optical spectrum analyser is not a fibre.

4.7.5.4 Any temperature instability of the device.

4.8 Linewidth and chirp of transmitters with single-mode lasers

4.8.1 Purpose

The purpose of this test method is to measure the linewidth and the frequency modulation, or chirp, of a transmitter with single-mode laser. The linewidth shall be expressed in MHz. The chirp shall be expressed in MHz/mA.

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4.8.2 Equipment required

4.8.2.1 An **RF signal generator** which can be gated on and off with a 50 % duty cycle so that the transmitter is operating unmodulated for a time, τ, and then modulated for an identical time. The magnitude and the waveform of the generated signal shall be suitable for the transmitter to be tested. The signal frequency shall be lower than the linewidth of the transmitter to be tested.

4.8.2.2 A **fibre-optic Mach-Zehnder interferometer** with a delay line producing a delay difference τ between the 2 arms and with a polarization controller in one of the arms.

4.8.2.3 An **optical receiver** with a 1 dB bandwidth higher than the expected frequency deviation of the optical output signal of the transmitter to be tested.

4.8.2.4 An electrical **spectrum analyser** with a bandwidth greater than the expected frequency deviation of the optical output signal of the transmitter to be tested.

4.8.2.5 Lengths of **fibre** for connecting the optical equipment.

4.8.2.6 An **optical isolator**, if not embodied in the transmitter, to prevent reflected light from perturbing the lineshape of the transmitter**.**

4.8.2.7 An **RF voltmeter** with the same input impedance as the optical transmitter to be measured.

4.8.3 General measurement requirements

The delay time τ (identical to the gating time τ of the signal generator) shall be at least three to five times the coherence time of the transmitter to make sure that the combining signals from the two arms of the interferometer are uncorrelated.

4.8.4 Procedure

4.8.4.1 Connect the equipment as shown in figure 8.

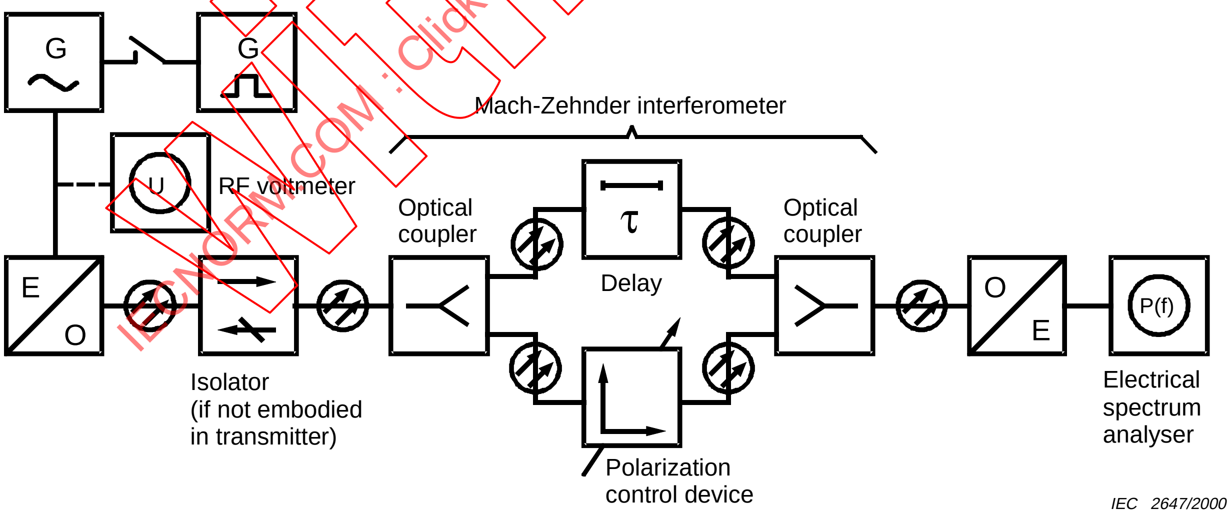

Figure 8 – Measurement of the chirp and the linewidth of transmitters

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4.8.4.2 For measuring the linewidth, turn off the signal generator.

4.8.4.3 For measuring chirp, the generator shall be gated on and off as described in 4.8.2. For adjusting the output level of the signal generator, switch it into continuous mode. Replace the transmitter by the RF voltmeter and choose an output level resulting in an optical modulation index of the transmitter in the range of m = 0,5 to 0,7. Note the reading U of the RF voltmeter. Reconnect the optical transmitter and turn on the gating signal.

4.8.4.4 Adjust the polarization controller to maximize the amplitude displayed by the spectrum analyser.

4.8.4.5 Locate the –3 dB roll-off of the electrical power starting at the lowest frequency of the spectrum shown by the spectrum analyser.

NOTE If the –3 dB roll-off exceeds the range of the spectrum analyser a smaller optical modulation index may be used. Care has to be taken to ensure stable operation of the laser.

4.8.4.6 If the signal generator is turned off, the frequency reading at this point represents the linewidth of the transmitter. If the inverse of this linewidth is not lower than the delay time τ, the measurement shall be repeated with a higher delay time.

4.8.4.7 With the signal generator turned on, the spectrum is broadened. The change in frequency reading Δf at the –3 dB point is the total chirp in MHz.

4.8.4.8 The chirp is calculated from

$$C = \Delta f \frac{Z}{U} \tag{17}$$

where

C is the chirp;

Δf is the change in frequency reading (total chirp);

Z is the input impedance of the optical transmitter;

U is the output level of the signal generator.

4.8.5 Potential sources of error

4.8.5.1 This linewidth measurement technique is strictly correct only for transmitters with a Lorentzian lineshape.

4.8.5.2 Asymmetric spectra will lead to wrong results.

4.8.5.3 Additionally the following features of the equipment can impair the accuracy of the measurement:

– the inaccuracy of the spectrum analyser;

– instability of the transmitter.

4.9 Extinction ratio

4.9.1 Purpose

The purpose of this test method is to measure the extinction ratio of a digital transmitter under specified conditions.

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4.9.2 Equipment required

4.9.2.1 A **pulse pattern generator**.

4.9.2.2 An **oscilloscope** with a DC-coupled input which has a frequency range suitable for the test pulses.

4.9.2.3 A **PIN-photodiode** with 1 dB bandwidth much larger than the bit rate of the transmitter to be tested.

4.9.2.4 A **DC power supply** which provides a voltage less than the breakdown voltage of the PIN-diode.

4.9.2.5 A **resistor** with low capacitance and inductance.

4.9.2.6 A low-loss **capacitor**.

4.9.2.7 A length of **fibre** for connecting the transmitter to the PIN-diode.

NOTE A DC-coupled calibrated receiver may be used instead of the PIN-diode, the resistor and the power supply.

4.9.3 General measurement requirements

The test signal generator shall produce a pseudo random bit sequence (PRBS) with a sequence length of at least $2^{15} - 1$ with the specified pulse repetition frequency, pulse width and level.

4.9.4 Procedure

4.9.4.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.9.4.2 Apply the specified input signal. Connect the equipment as shown in figure 9.

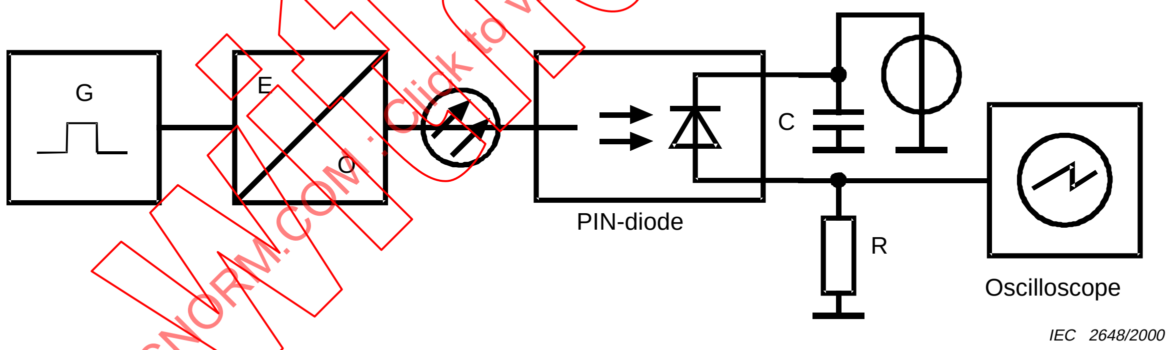

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Figure 9 – Measurement of the extinction ratio

4.9.4.3 The signal shown on the display of the oscilloscope is proportional to the modulated intensity of the optical power. Its lowest level U_l and its highest level U_h relative to zero shall be recorded.

4.9.4.4 The extinction ratio is calculated from

$$e = \frac{U_h}{U_l} \tag{18}$$

4.9.5 Potential sources of error

4.9.5.1 The inaccuracy of the oscilloscope.

4.9.5.2 The frequency response and the dark current of the PIN-diode.

4.9.5.3 The operating bias point of the PIN-diode at very high optical input levels.

4.10 Optical modulation index

4.10.1 Purpose

The purpose of this test method is to measure the individual optical power modulation index (modulation index per channel) of a transmitter under specified conditions. This method is not suitable for measuring the total modulation index of a transmitter modulated by a multi-channel signal.

4.10.2 Equipment required

4.10.2.1 A **selective voltmeter** or spectrum analyser with a defined input impedance.

4.10.2.2 A **PIN-photodiode** with 1 dB-bandwidth much larger than that of the transmitter to be tested.

4.10.2.3 A **DC power supply** which provides a voltage less than the breakdown voltage of the PIN-diode.

4.10.2.4 A **DC current meter**.

4.10.2.5 An **RF choke** suitable for the frequencies at which the tests are to be carried out.

4.10.2.6 A terminating **resistor** (50 Ω or 75 Ω), suitable for the frequencies at which the tests are to be carried out, for use when the selective voltmeter or spectrum analyser has a high input impedance.

4.10.2.7 A low-loss **capacitor** with an impedance much lower than that of the selective voltmeter (spectrum analyser) at the frequencies at which the tests are to be carried out.

4.10.2.8 A length of **fibre** for connecting the transmitter to the PIN-diode.

NOTE A calibrated receiver may be used instead of the PIN-diode, the RF choke, the resistor and the capacitor if the DC of the detector can be measured.

4.10.3 Procedure

4.10.3.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.10.3.2 Apply the specified input signal. Connect the equipment as shown in figure 10.

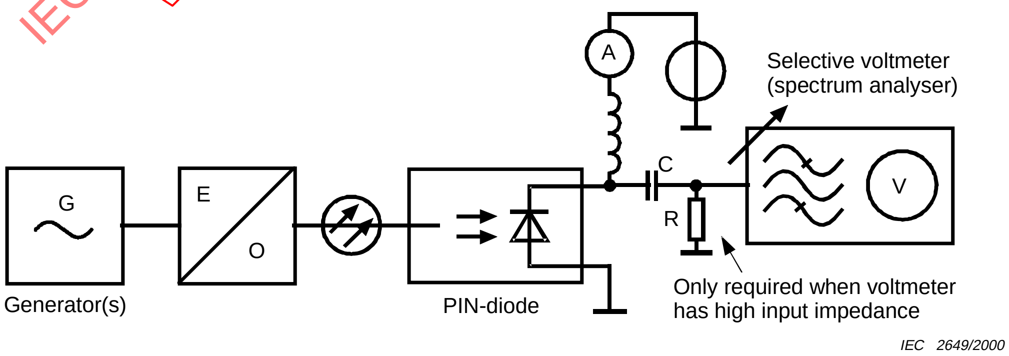

Figure 10 – Measurement of the optical modulation index

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4.10.3.3 Tune the selective voltmeter (spectrum analyser) to the frequency of the channel at which the individual optical modulation index is to be measured.

4.10.3.4 Record the readings of the DC meter and the selective voltmeter (spectrum analyser). The optical modulation index is calculated from

$$m = \frac{\sqrt{2}U}{RI} \qquad (19)$$

where

I is the reading of the DC meter;

U is the reading of the selective voltmeter (spectrum analyser);

R is the resistance of the resistor or the input impedance of the selective voltmeter or spectrum analyser.

4.10.4 Potential sources of error

The following features of the equipment can impair the accuracy of the measurement. A method with higher accuracy is given in 4.20.

4.10.4.1 The inaccuracy of the DC meter.

4.10.4.2 The inaccuracy of the selective voltmeter (spectrum analyser).

4.10.4.3 The frequency response of the PIN-diode.

4.10.4.4 Differences between the static responsivity and the dynamic responsivity of the PIN-diode. A correction factor shall be used for calculating the modulation index in this case.

4.11 Voltage responsivity of an optical receiver

4.11.1 Purpose

The purpose of this test method is to measure the voltage responsivity of a receiver under specified conditions. The voltage responsivity shall be expressed in V/W.

4.11.2 Equipment required

4.11.2.1 A suitable **RF generator**.

4.11.2.2 A **transmitter** with known differential efficiency and optical output power compatible with the range of optical input power of the receiver under test.

4.11.2.3 A length of **fibre** for connecting the transmitter to the receiver.

4.11.2.4 A **cladding mode stripper**, if the fibre has no cladding mode stripping coating.

4.11.2.5 An **RF voltmeter**.

4.11.3 General measurement requirements

4.11.3.1 Care shall be taken to ensure that all the optical output power is coupled to the receiver.

4.11.3.2 The automatic gain control (AGC) (if any) for the receiver shall be disabled. The gain shall be set to maximum.

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4.11.4 Procedure

4.11.4.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.11.4.2 Connect the equipment as shown in figure 11.

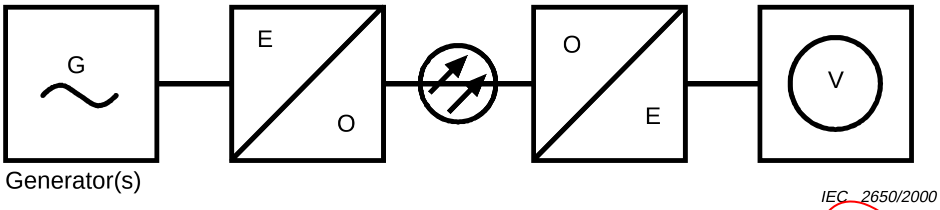

Figure 11 – Measurement of the voltage responsivity of an optical receiver

4.11.4.3 Adjust the amplitude of the generator to obtain the optical modulation index required.

4.11.4.4 Measure the RF voltage at the frequencies of interest.

4.11.4.5 The voltage responsivity is calculated from

$$r_V = \frac{\sqrt{2}U}{mP} \qquad (20)$$

where

m is the optical modulation index;

P is the received optical power;

U is the output voltage.

4.11.5 Potential sources of error

4.11.5.1 The inaccuracy of the voltmeter.

4.11.5.2 The attenuation of the fibre and the optical connectors.

4.11.5.3 The inaccuracy of the output level of the generator.

4.11.5.4 The uncertainty of the characteristic of the transmitter.

4.11.5.5 The saturation of the optical receiver when the AGC is disabled.

4.12 Frequency range and flatness

4.12.1 Purpose

The purpose of this test method is to measure the frequency range and the flatness of optical transmitters and receivers under specified conditions. The frequency range shall be expressed in Hz and the flatness in dB.

4.12.2 Equipment required

4.12.2.1 A **signal generator** with a frequency range greater than the expected range of the device to be tested.

4.12.2.2 An **RF voltmeter** for the amplitude versus frequency response.

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4.12.2.3 If the device to be tested is a transmitter, an optical receiver with known frequency response (**calibrated receiver**) is needed. If the device to be tested is a receiver, an optical transmitter with known frequency response (**calibrated transmitter**) is needed.

4.12.2.4 A length of **fibre** for connecting the transmitter and the receiver.

NOTE A network analyser may be used instead of the signal generator and the voltmeter. A spectrum analyser with tracking generator may also be used. A swept generator with broadband diode detector may be used if all measurements are taken at the same detected signal level by re-adjustment of the generator level to maintain this condition.

4.12.3 Procedure

4.12.3.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.12.3.2 Connect the equipment as shown in figure 12.

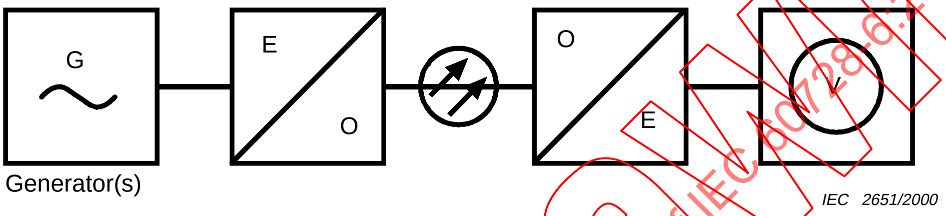

Figure 12 – Measurement of the frequency range and flatness

4.12.3.3 Measure the signal output voltage at a sufficient number of frequencies covering the specified frequency range. The readings shall be corrected by the known frequency response of the respective calibrated device.

4.12.4 Potential sources of error

4.12.4.1 The inaccuracy of the frequency and the amplitude of the test generator.

4.12.4.2 The inaccuracy of the voltmeter.

4.12.4.3 The inaccuracy of the calibrated receiver (transmitter).

4.12.4.4 The inaccuracy of the measuring equipment mentioned in the note of 4.12.2.4.

4.13 Composite second-order distortion (CSO) of optical transmitters

4.13.1 Purpose

The purpose of this test method is to measure the CSO of optical transmitters modulated by multiple carriers. The definition of CSO is primarily valid for electrical amplifiers but also applies to devices with an optical output. In this case it is related to the electrical signals which modulate the light. The CSO shall be expressed in dB.

4.13.2 Equipment required

4.13.2.1 All equipment required for measuring CSO of electrical amplifiers (see IEC 60728-3).

4.13.2.2 An optical receiver with CSO at least 10 dB better than the CSO expected of the transmitter to be tested. The CSO of optical receivers can be estimated from the results of a receiver intermodulation measurement (see 4.16).

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4.13.2.3 A length of **fibre** for connecting the transmitter to the receiver.

4.13.2.4 If the optical output power of the transmitter is higher than the specified input power of the receiver, an **optical attenuator** shall be used to reduce the power.

4.13.3 Procedure

4.13.3.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.13.3.2 Connect the equipment as shown in figure 13.

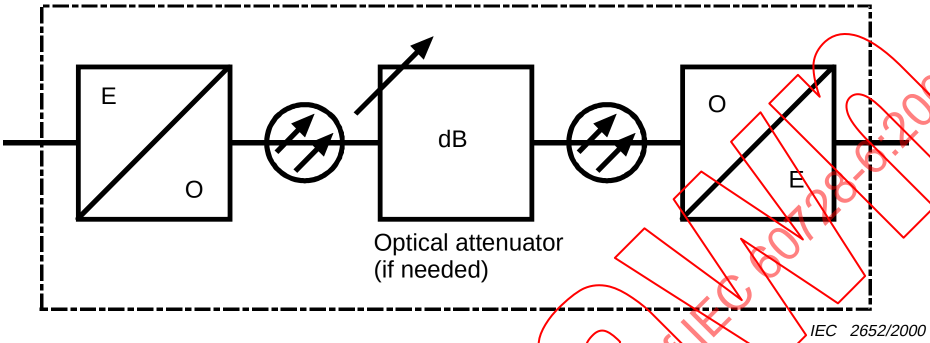

Figure 13 – Device under test for measuring CSO of optical transmitters

4.13.3.3 The device under test shown in figure 13 provides an electrical input and an electrical output. Therefore, it can be treated as an electrical amplifier. The procedure for measuring CSO (see IEC 60728-3) can be used for this arrangement. The result is the figure which shall be given as the CSO of the optical transmitter.

4.13.3.4 To make sure that the distortion of the receiver can be neglected, a second measurement shall be carried out with a different attenuation between the optical transmitter and the optical receiver. If the result changes, it indicates that the receiver distortion is too high.

4.13.4 Potential sources of error

The figure measured is the CSO of the whole optical system. The influence of the optical receiver can be neglected only if its CSO is much better than that of the transmitter, but there is no direct way of measuring the CSO of an optical receiver. It can only be estimated from the results of an intermodulation measurement. This estimate is not very accurate, because the laws of addition of the beats are frequency-dependent and not well known.

4.14 Composite triple beats (CTB) of optical transmitters

4.14.1 Purpose

The purpose of this test method is to measure the CTB of optical transmitters modulated with multiple carriers. The definition of CTB is primarily valid for electrical amplifiers but also applies to devices with an optical output. In this case it is related to the electrical signals which modulate the light. The CTB shall be expressed in dB.

4.14.2 Equipment required

4.14.2.1 All equipment required for measuring CTB of electrical amplifiers (see IEC 60728-3).

4.14.2.2 An **optical receiver** with CTB at least 15 dB better than the CTB expected for the transmitter to be tested. The CTB of optical receivers can be estimated from the results of a receiver intermodulation measurement (see 4.16).

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4.14.2.3 A length of **fibre** for connecting the transmitter to the receiver.

4.14.2.4 If the optical output power of the transmitter is higher than the specified input power of the receiver, an **optical attenuator** shall be used to reduce the power.

4.14.3 Procedure

4.14.3.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.14.3.2 Connect the equipment as shown in figure 14.

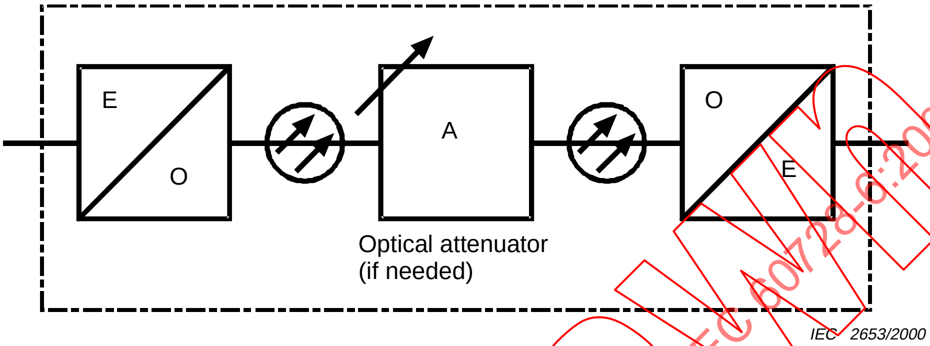

Figure 14 – Device under test for measuring CTB of optical transmitters

4.14.3.3 The test configuration shown in figure 14 provides an electrical input and an electrical output; it can therefore be treated as an electrical amplifier. The procedure for measuring CTB (see IEC 60728-3) can be used for this arrangement. The result is the figure which shall be given as the CTB of the optical transmitter.

4.14.3.4 To make sure that the distortion of the receiver can be neglected, a second measurement shall be carried out with a different attenuation between the optical transmitter and the optical receiver. If the result changes, it indicates that the receiver distortion is too high.

4.14.4 Potential sources of error

The figure measured is the CTB of the whole optical system. The influence of the optical receiver can be neglected only if its CTB is much better than that of the transmitter, but there is no direct way of measuring the CTB of an optical receiver. It can only be estimated from the results of an intermodulation measurement. This estimate is not very accurate, because the laws of addition of the beats are frequency-dependent and not well known.

4.15 Composite cross-modulation of optical transmitters

4.15.1 Purpose

The purpose of this test method is to measure the composite cross-modulation of optical transmitters modulated with multiple carriers. The definition of composite cross-modulation is primarily valid for electrical amplifiers but also applies to devices with an optical output. In this case, it is related to the electrical signals which modulate the light. The cross-modulation shall be expressed in dB.

NOTE The method described in IEC 60728-3 for active coaxial equipment is not applicable to optical equipment !

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4.15.2 Equipment required

4.15.2.1 Signal generators covering the appropriate vision carrier frequencies as listed in annex C of IEC 60728-3, all having the required modulation facilities, and linearity at the depth of modulation to be used.

NOTE It is recommended that the modulation frequency approximate the line scan frequency of the TV signals in order to include effects which may be caused by the low-frequency circuits (for example, decoupling) in the equipment to be tested. The modulation frequency should not be a multiple of the power supply frequency. Any symmetrical modulation waveform (excluding pulse modulation) may be used providing the same signal generator is used for both calibration and measurement, and the modulation depth and waveform remain the same.

4.15.2.2 A modulating voltage **generator** of sufficient output to provide common modulation of the signal generators in 4.15.2.1.

4.15.2.3 A **combiner, matching device, attenuators, filters**, etc., to obtain the correct signal levels, matching and reduction of spurious signals.

4.15.2.4 A **spectrum analyser** with 1 kHz IF bandwidth and 10 Hz video bandwidth capability.

4.15.2.5 A bandpass filter for each channel to be tested or a tunable bandpass filter. This filter shall attenuate the other channels present on the system to be tested sufficiently to ensure that the products generated by non-linearity in the spectrum analyser itself do not contribute significantly to the cross-modulation products to be measured. The passband of this filter shall be flat at least to within 1 dB over the frequency range of interest, and shall be well matched over the complete frequency band. If necessary, a fixed attenuator shall be connected to the input of the filter.

4.15.2.6 An **optical receiver** with high linearity.

4.15.2.7 A length of **fibre** for connecting the transmitter to the receiver.

4.15.2.8 If the optical output power of the transmitter is higher than the specified input power of the receiver, an **optical attenuator** shall be used to reduce the power.

4.15.3 Procedure

4.15.3.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.15.3.2 Connect the equipment as shown in figure 15.

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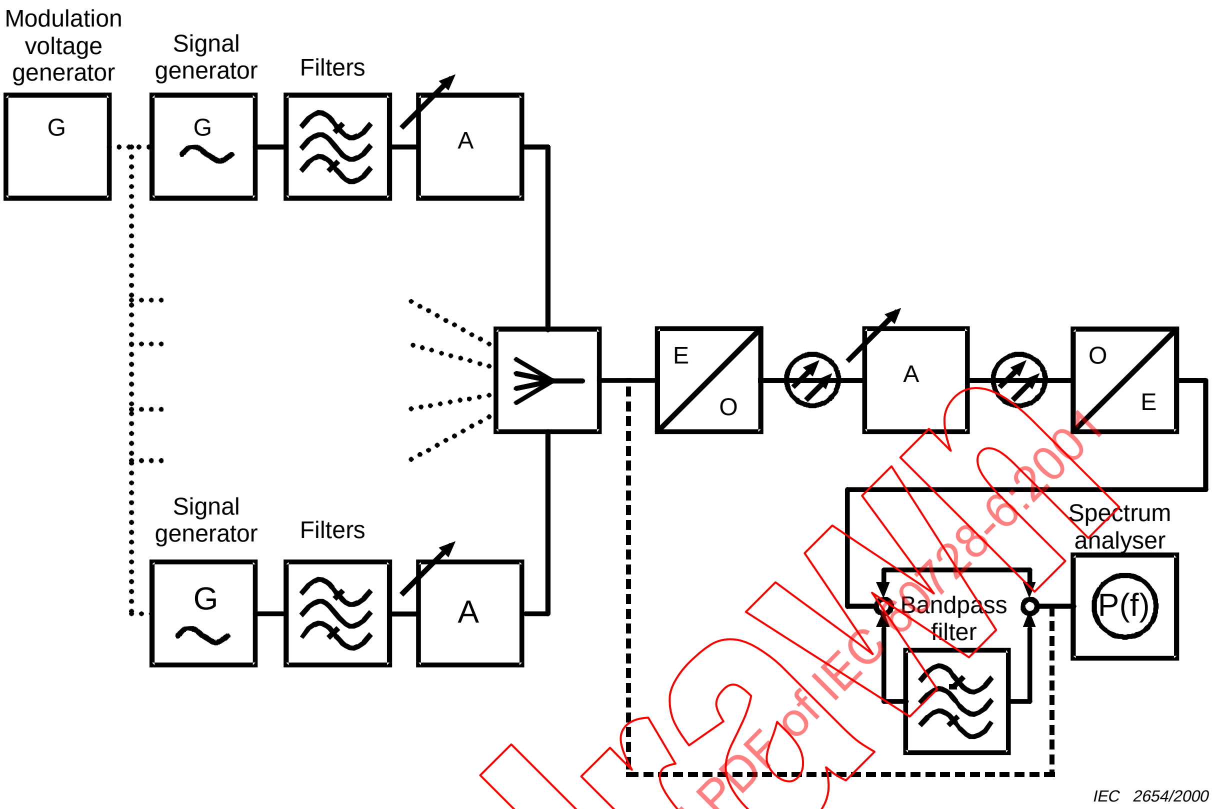

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Figure 15 – Arrangement for measuring composite cross-modulation of optical transmitters

4.15.3.3 Connect the output of the RF combiner to the input of the spectrum analyser.

4.15.3.4 Select each signal generator in turn, set the modulation depth and adjust the output to give the RF peak level needed to obtain the specified input level for the optical transmitter to be tested.

4.15.3.5 Connect the output of the optical receiver to the spectrum analyser.

4.15.3.6 Adjust the spectrum analyser as follows:

– IF bandwidth	1 kHz
– video bandwidth	10 Hz
– horizontal scale	5 kHz/div
– vertical scale	10 dB/div
– scan time	5 s/div

4.15.3.7 Tune the spectrum analyser to the channel on which the measurement is to be made so as to display the vision carrier and a frequency range of 25 kHz on either side of the carrier.

4.15.3.8 Switch off all other channels and switch on the modulation of the channel to be measured.

4.15.3.9 Insert the bandpass filter corresponding to the channel to be measured and adjust the input attenuator to correct for the attenuation of the filter.

NOTE When using a spectrum analyser with minimum video filtering capabilities greater than 10 Hz, the composite cross-modulation may be noisy and should be read at the middle of the trace.

4.15.3.10 Adjust the sensitivity of the spectrum analyser together with its internal and/or external input attenuators in such a way that the responses to the first sidebands, approximately 15 kHz on either side of the vision carrier, correspond to a full-scale reference. At the same time, the noise level shall be at least 10 dB lower than the distortion level expected.

4.15.3.11 Switch off the modulation of the wanted carrier and switch on all the other carriers.

4.15.3.12 Switch on the modulation of every second one of the other carriers.

4.15.3.13 Measure the amplitude of the sidebands on either side of the wanted carrier caused by the total composite cross-modulation transfer. The difference in dB between the full-scale reference and the largest of the sidebands, corrected as in table 1 of IEC 60728-3 to obtain the ratio referred to 100 % modulation, shall be noted.

4.15.3.14 Repeat the previous step with the modulation of the previously modulated carriers turned off and the modulation of the other half of the unwanted carriers turned on.

4.15.3.15 The composite total cross-modulation can be calculated from:

$$XM = 20\ \lg\left(10^{\frac{XM_1}{20}} + 10^{\frac{XM_2}{20}}\right) \qquad (21)$$

where

XM_1 is the first measured value, in dB;

XM_2 is the second measured value, in dB.

4.15.3.16 Repeat steps 4.15.3.7 to 4.15.3.15 of this procedure, each time selecting a different wanted signal, until all channels used in this test have been selected.

4.15.3.17 To make sure that the distortion of the receiver can be neglected, a second measurement shall be carried out with a different attenuation between the optical transmitter and the optical receiver. If the result changes, it indicates that the receiver distortion is too high.

4.15.3.18 The worst-case maximum output level giving the required signal to composite total cross-modulation ratio shall be noted for publication.

4.15.4 Potential sources of error

The figure measured is the composite cross-modulation of the whole optical system. The influence of the optical receiver can be neglected only if its cross-modulation is much better than that of the transmitter, but there is no direct way of measuring the cross-modulation of an optical receiver. The only way to make sure that the receiver has no influence on the result is to repeat the measurement several times with different optical levels at the receiver's input.

4.16 Receiver intermodulation

4.16.1 Purpose

This method is applicable to the measurement of the carrier to second- and third-order intermodulation products and triple beats produced in optical receivers with high linearity. The method described is not applicable to coherent receivers. The intermodulation shall be expressed in dB.

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4.16.2 Equipment required

4.16.2.1 Two **signal generators** for second- and third-order intermodulation and three signal generators for triple beats covering the frequencies at which the tests are to be carried out.

4.16.2.2 Two **transmitters** with similar optical output power but slightly different wavelengths. The difference of the frequencies of the emitted light shall be greater than the bandwidth of the receiver to be tested.

4.16.2.3 An **optical coupler** with similar loss in both paths.

4.16.2.4 Two **variable optical attenuators** with a range great enough to cover the range of the optical input power of the receiver to be tested.

4.16.2.5 A **variable electrical attenuator** with a range greater than the signal-to-intermodulation ratio expected.

4.16.2.6 A **selective voltmeter** covering the frequency range of the receiver to be tested.

4.16.2.7 Lengths of **fibre** for connecting the transmitters to the coupler and the coupler to the receiver.

4.16.3 General measurement requirements

4.16.3.1 Unless otherwise required, the reference levels used in the measurements shall be the normal operating levels specified for the receiver. If the specified levels are not constant over the frequency range then the levels of all the test signals shall be quoted in the results.

4.16.3.2 Where the receiver to be measured includes automatic level control (ALC) pilot signals of the correct type, frequency and level shall be maintained throughout the tests.

4.16.4 Procedure

4.16.4.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.16.4.2 Connect the equipment as shown in figure 16.

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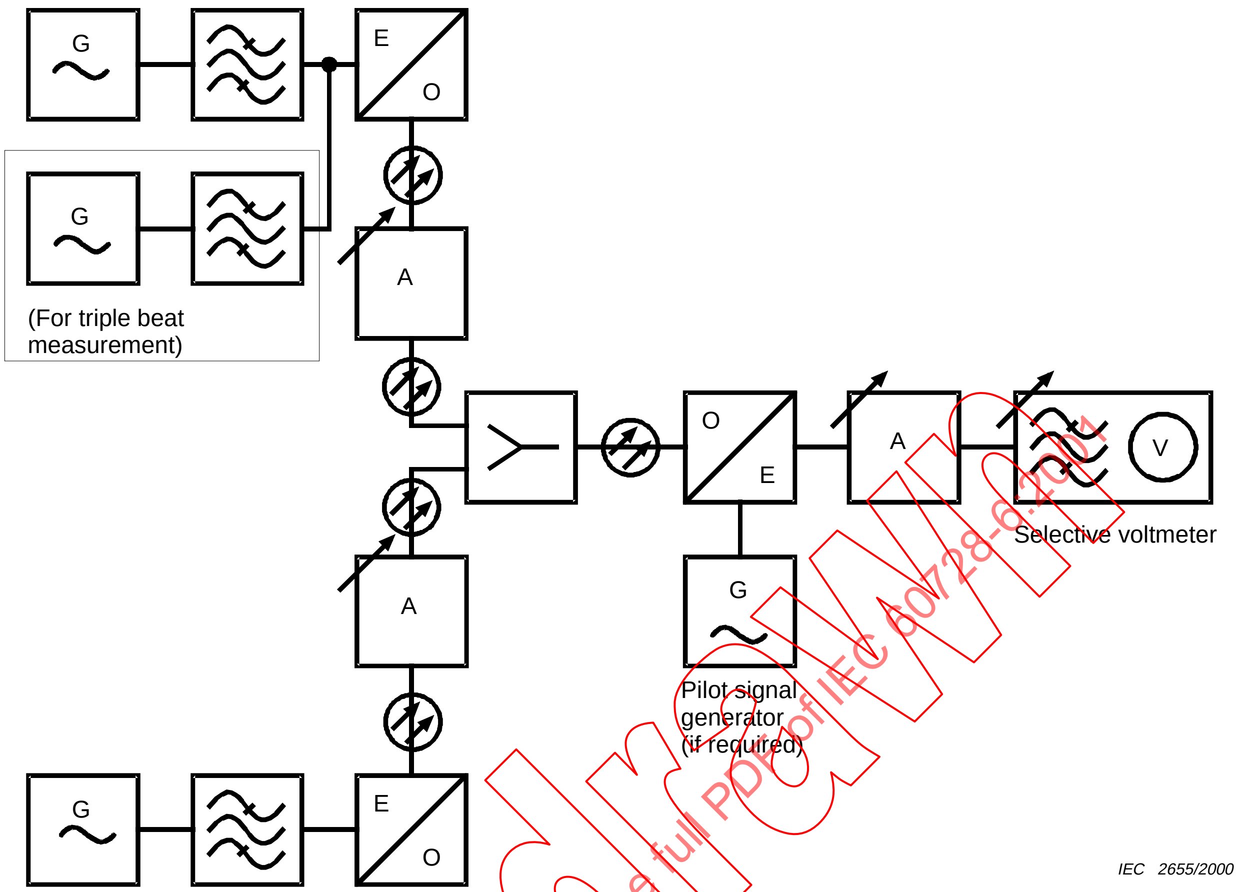

Figure 16 – Arrangement of test equipment for measuring receiver intermodulation

4.16.4.3 Carry out measurements with the test signals widely and closely spaced over each band of interest at frequencies capable of producing significant products within the overall frequency range.

4.16.4.4 Carry out measurements over the full specified range of optical input power of the receiver.

4.16.4.5 Adjust the optical attenuators to obtain the same optical level at the output of the optical coupler for both transmitters.

4.16.4.6 A check should be made to determine if harmonics and other spurious signals at the outputs of the signal generators are likely to affect materially the results of the measurements.

4.16.4.7 Set the signal generators to the frequencies of the test signals and adjust their outputs to obtain a modulation index of m = 0,4 per carrier for both transmitters. With three generators for triple beat measurements a modulation index of m = 0,3 per carrier shall be used.

4.16.4.8 Connect the variable attenuator and selective voltmeter to the point of measurement. Tune the meter to each test signal and note the attenuator value a_1 required to obtain a convenient meter reading R for the reference signal. The attenuator value a_1 should be slightly greater than the signal to intermodulation product ratio expected at the point of measurement.

4.16.4.9 Tune the meter to the intermodulation product to be measured and reduce the attenuator setting to the value a_2 required to obtain the same meter reading R.

4.16.4.10 When using three carriers, care shall be taken that the intermodulation products of the transmitter with two carriers do not coincide with the intermodulation products to be measured.

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4.16.4.11 When measuring levels of intermodulation products, it may be necessary to insert a filter at the input to the meter (see appendix B of IEC 60728-3). In such instances, the insertion loss (in dB) of the filter at the frequency of the products shall be added to the attenuator value a_2.

4.16.4.12 The signal to intermodulation product ratio, in dB, is given by

$$S/I = a_1 - a_2 \qquad (22)$$

where

a_1 is the attenuator value for the test signal used as a reference, in dB;

a_2 is the attenuator value for the intermodulation product, in dB.

4.16.5 Potential sources of error

4.16.5.1 The inaccuracy of the selective voltmeter.

4.16.5.2 The inaccuracy of the filter attenuation.

4.16.5.3 The inaccuracy of the variable attenuator.

4.16.5.4 The inaccuracy of the modulation index.

4.17 CSO of optical amplifiers

Under consideration.

4.18 CTB of optical amplifiers

Under consideration.

4.19 Carrier-to-noise ratio

4.19.1 Purpose

The purpose of this test method is to measure the carrier-to-noise ratio of optical transmitters and receivers.

In passing through an analogue transmission system, the carrier-to-noise ratio of a given input signal C/N_{in} is deteriorated by internal noise sources N_i (see figure 17).

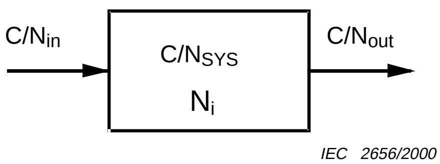

Figure 17 – System with internal noise sources

The magnitude of this noise can also be expressed as a carrier-to-noise ratio C/N_{SYS}. C/N_{SYS} is equivalent to the carrier-to-noise ratio of the output signal with a noise-free input signal. It can be calculated from measured carrier-to-noise ratios at the input and the output of the system.

$$C/N_{SYS} = -10 \lg\left(10^{-\frac{1}{10}C/N_{in}} - 10^{-\frac{1}{10}C/N_{out}}\right) \qquad (23)$$

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In optical transmission systems, both the transmitter and the receiver contribute to the noise of the system. Because of the different kind of signals there is no direct way of measuring the carrier-to-noise ratio for the transmitter or the receiver independently. Therefore, the individual figures have to be calculated from system measurements using a receiver with known noise behaviour for obtaining the transmitter noise and vice versa. The carrier-to-noise ratio shall be given in dB.

4.19.2 Equipment required

4.19.2.1 A **selective voltmeter** with a known noise bandwidth less than that of the channel to be measured.

4.19.2.2 A **CW signal generator** covering the frequencies at which the tests are to be carried out. The amplitude of the generator shall be adjustable to obtain an optical modulation index of $m = 0{,}2$.

4.19.2.3 A **variable attenuator** with a range greater than the carrier-to-noise ratio expected.

4.19.2.4 An **optical attenuator** with a range great enough to accomplish the following tasks: testing the transmitter, the optical attenuator is used to adjust the received optical power to the specified range of the receiver. Testing the receiver, the optical attenuator is used to measure the carrier-to-noise ratio as a function of the optical input power.

4.19.2.5 A **reference receiver** (figure 18) for testing an optical transmitter or a reference transmitter for testing an optical receiver.

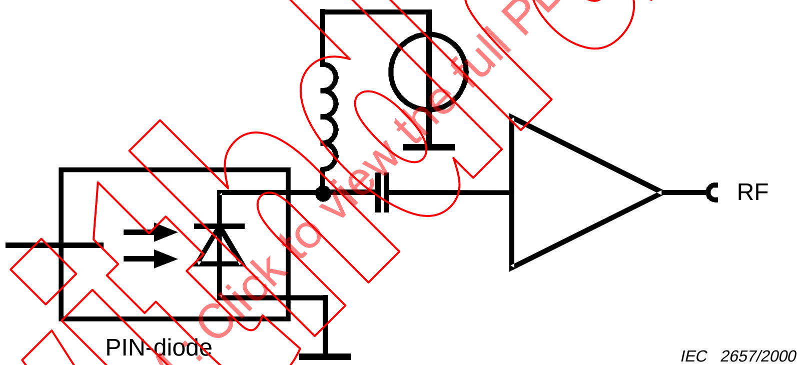

Figure 18 – PIN diode receiver

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4.19.2.5.1 Reference transmitter

Using a laser for the transmitter, the noise is caused by fluctuations of the light output power. It depends on the modulation frequency and can be described by the relative intensity noise (RIN). It can be easily converted to a carrier-to-noise ratio:

$$C/N_{TX} = 10\,\lg\frac{m^2}{2B} - RIN \qquad (24)$$

where

m is the optical modulation index;

RIN is the relative intensity noise, in dB/Hz;

B is the bandwidth, in Hz.

4.19.2.5.2 Reference receiver

Since the noise behaviour of a PIN-diode receiver is well known, it can be used as a reference receiver. One part of the receiver noise is the photodiode shot noise. The other part of the receiver noise is the available thermal noise of the following amplifier. The carrier-to-noise ratio of a PIN-diode receiver can be calculated:

$$C/N_{RX} = 10 \lg\left(\frac{m^2 P_0^2 r^2}{2B(2erP_0 + I_r^2)}\right) \tag{25}$$

where

m is the optical modulation index;

P_0 is the optical power incident on the photodiode;

r is the responsivity of the photodiode;

B is the bandwidth;

e is $1{,}6 \times 10^{-19}$ As (charge of an electron);

I_r is the effective spectral noise current density of the amplifier in A/√Hz.

NOTE Additional items may be necessary, for example, to ensure correct calibration and operation of the test equipment (see IEC 60728-1).

4.19.3 General measurement requirements

4.19.3.1 The test set-up shall be well matched (electrically and optically), and the sensitivity of the measuring equipment (see IEC 60728-1) shall be well known over the frequency range of the channel to be measured. The optical return loss shall be better than that allowed by the specification of the transmitter.

4.19.3.2 Where the system to be measured includes automatic level control (ALC), pilot signals of the correct type and frequency and level shall be maintained throughout the tests.

4.19.3.3 The selective voltmeter shall be calibrated and checked for satisfactory operation.

4.19.4 Procedure

4.19.4.1 The method for measuring the carrier-to-noise ratio of analogue optical transmission systems is nearly the same as for cabled distribution systems (see IEC 60728-1). In this case, the system under test consists of an optical receiver connected to an optical transmitter via an optical attenuator (see figure 19).

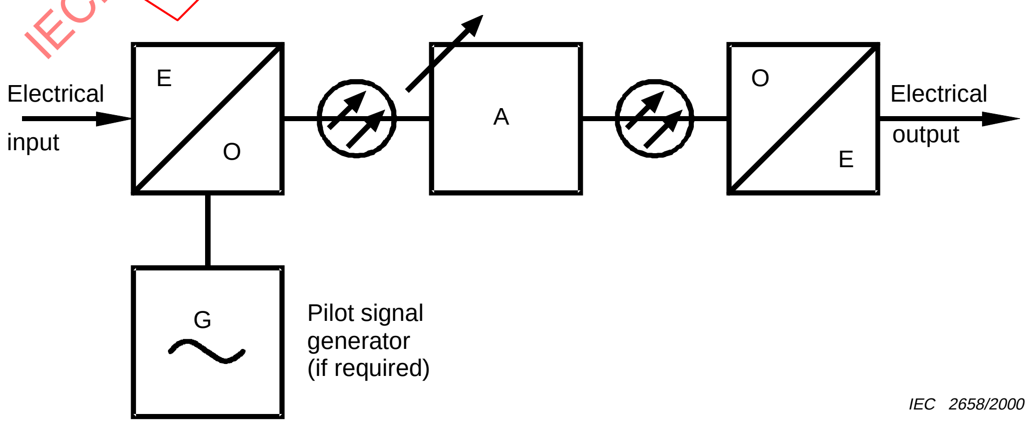

Figure 19 – Optical transmission system under test

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4.19.4.2 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.19.4.3 Connect the equipment as shown in figure 20.

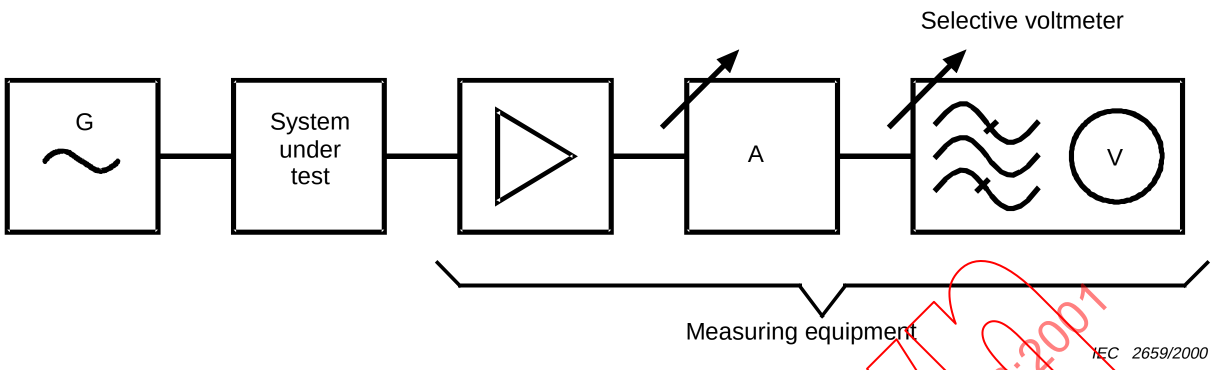

Figure 20 – Arrangement of test equipment for carrier-to-noise measurement

4.19.4.4 Set the signal generator to the carrier frequency of the channel to be tested. The amplitude of the signal generator shall be set to obtain a modulation index of m = 0,2. The result of this measurement might be extrapolated to other modulation indices using equation 26.

4.19.4.5 Connect the variable attenuator and selective voltmeter (and any other items if required – see IEC 60728-1) to the point of measurement. Tune the voltmeter to the reference signal and note the attenuator value a_1 required to obtain a convenient voltmeter reading R. The attenuator value a_1 should be slightly greater than the signal-to-noise ratio expected at the point of measurement.

4.19.4.6 Retune the voltmeter within the channel so that it is influenced only by random noise. Reduce the attenuator setting to the value a_2 required to obtain again the same voltmeter reading R.

4.19.4.7 The carrier-to-noise ratio of the system in dB is given by

$$C/N_{SYS} = a_1 - a_2 - C_m - C_b + 20 \lg \frac{m}{0,2} \qquad (26)$$

where

a_1 is the attenuator value for the reference signal;

a_2 is the attenuator value for the noise;

C_m is the voltmeter level correction factor;

C_b is the bandwidth correction factor;

m is the specified modulation index.

According to equation 23, the carrier-to-noise ratios of the transmitter and the receiver can be calculated from the measured carrier-to-noise ratio of the whole system:

a) for the receiver:

$$C/N_{RX} = -10 \lg\left(10^{-\frac{1}{10}C/N_{SYS}} - 10^{-\frac{1}{10}C/N_{TX}}\right) \qquad (27)$$

b) for the transmitter:

$$C/N_{TX} = -10 \lg\left(10^{-\frac{1}{10}C/N_{SYS}} - 10^{-\frac{1}{10}C/N_{RX}}\right) \qquad (28)$$

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where

C/N_{SYS} is the measured C/N of the system;

C/N_{TX} is the C/N of the transmitter;

C/N_{RX} is the C/N of the receiver.

4.19.5 Potential sources of error

4.19.5.1 The inaccuracy and the calibration of the selective voltmeter.

4.19.5.2 The inaccuracy of the variable attenuator.

4.19.5.3 The method actually determines carrier (plus noise)-to-noise ratio; however, the difference between this and the carrier-to-noise ratio is very small if the value exceeds 15 dB. The method assumes that the random noise is evenly distributed within the channel.

4.20 Method for combined measurement of relative intensity noise (RIN), optical modulation index and equivalent input noise current

4.20.1 Purpose

With this method the relative intensity noise and the optical modulation index of the transmitter as well as the equivalent input noise current of the receiver can be calculated from the noise measurement of the complete optical system.

The noise of an optical system consisting of a transmitter and a PIN-diode receiver is determined by the following noise sources:

– the relative intensity noise of the transmitter;
– the shot noise of the PIN-diode of the receiver;
– the effective spectral input noise current of the optical receiver, which includes all receiver-related noise sources excluding shot noise.

Knowing the appropriate quantities, the carrier-to-noise ratio for the whole system can be calculated from

$$C/N = 20 \lg m - 10 \lg 2B - 10 \lg\left(10^{-\frac{1}{10}\mathrm{RIN}} + \left(\frac{2e}{rP_{\mathrm{opt}}} + \frac{I_r^2}{r^2 P_{\mathrm{opt}}^2}\right)\right) \qquad (29)$$

where

RIN is the relative intensity noise, in dB/Hz;

m is the optical modulation index;

P_{opt} is the optical power incident on the photodiode;

r is the responsivity of the photodiode;

B is the bandwidth;

e is $1{,}6 \times 10^{-19}$ As (charge of an electron);

I_r is the effective spectral noise current density in $A/\sqrt{Hz}$.

With known responsivity r, the values of RIN, m and I_r can be extracted from a sufficiently large set of measurements of C/N versus P_{opt} using methods of curve fitting.

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4.20.2 Equipment required

4.20.2.1 A **DC meter** with a range suitable for the currents of the photodiode of the receiver.

4.20.2.2 A **selective voltmeter** with a known noise bandwidth less than that of the channel to be measured.

4.20.2.3 A **CW signal generator** or a multi-carrier signal generator covering the frequencies at which the tests are to be carried out. The amplitude of the generator(s) shall be adjustable so that the sum of the individual modulation indices exceeds 0,2.

4.20.2.4 A **variable attenuator** with a range greater than the carrier-to-noise ratio expected.

4.20.2.5 An **optical attenuator** with a range great enough to adjust the received optical power to the specified range of the receiver.

4.20.2.6 An **optical power meter** with a range suitable for the expected power. The detector system of the power meter shall have a sufficiently large area to collect all the radiation from the fibre and a spectral sensitivity compatible with the transmitter. A minimum accuracy of ±10 % is recommended.

4.20.2.7 Two lengths of **fibre** for connecting the equipment.

4.20.3 General measurement conditions

For this measurement a total optical modulation index of at least m = 0,2 shall be used to avoid instability of the transmitter.

4.20.4 Procedure

4.20.4.1 Set the supply voltage(s) and any control input signal(s) to the specified value(s).

4.20.4.2 Connect the equipment as shown in figure 21.

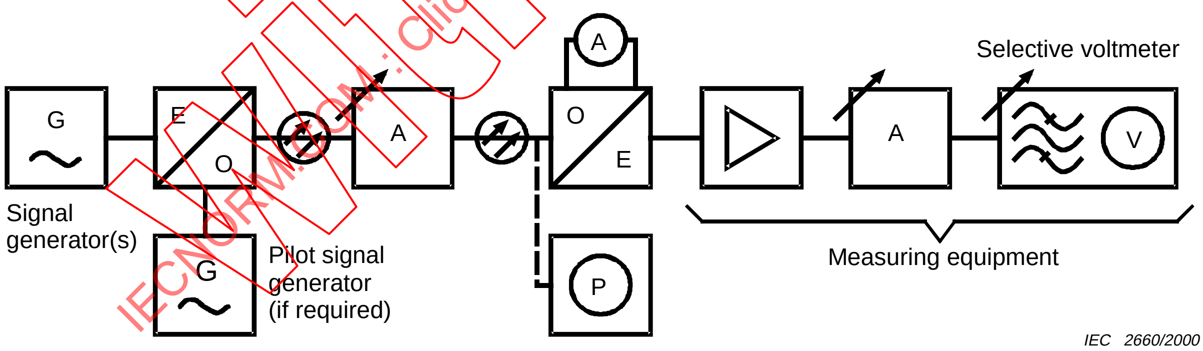

Figure 21 – Measurement set-up for determination of the noise parameters and the optical modulation index

4.20.4.3 Adjust the optical attenuator to an output level suitable for the optical receiver.

4.20.4.4 Record the reading P_1 of the optical power meter.

4.20.4.5 After replacing the optical power meter by the optical receiver, measure the current I_1 of the photodiode.

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4.20.4.6 Reconnect the optical power meter and adjust the optical attenuator to a different optical power P_2.

4.20.4.7 Replace the optical power meter by the optical receiver and measure the current I_2 of the photodiode.

4.20.4.8 The responsivity of the photodiode can be calculated by

$$r = \frac{I_2 - I_1}{P_2 - P_1} \tag{30}$$

4.20.4.9 Connect the variable attenuator and selective voltmeter (and other items if required – see IEC 60728-1) to the output of the receiver.

4.20.4.10 As described in 4.19 a set of (5 to 15) C/N-measurements shall be carried out over the range of the optical input power of the receiver**.**

4.20.4.11 The values for RIN, *m* and I_r can be extracted from the measurements by methods of curve fitting to equation 29.

4.20.5 Potential sources of error

4.20.5.1 The following features of the test equipment can impair the accuracy of the measurement:

4.20.5.2 The inaccuracy and the calibration of the selective voltmeter.

4.20.5.3 The inaccuracy of the variable attenuator.

4.20.5.4 The inaccuracy of the power meter.

4.20.5.5 The attenuation of the fibre and the optical connectors.

NOTE Provided that the measurement errors are of purely deterministic nature and remain constant over the whole measurement range, the relations between wrong and real values of the parameters to be calculated are stated as follows:

$$C/N' = \xi\, C/N$$
$$P'_{opt} = \upsilon\, P_{opt}$$

$$m = \sqrt{\frac{\nu}{\xi}}\, m'$$
$$\Rightarrow RIN = \upsilon \times RIN$$
$$I_r = \frac{I'_r}{\sqrt{\upsilon}}$$

where

C/N, P_{opt}, *m*, *RIN*	are the right values;
C/N′, P'_{opt}, *m′*, *RIN′*	are the wrong values;
υ, ξ	are error factors.

Statistical errors will be averaged depending on the number of measurements carried out.

4.21 Noise figure of optical amplifiers

4.21.1 Purpose

The purpose of this test method is to measure the noise figure of optical amplifiers. The noise figure shall be expressed in dB.

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