

APPLICATION NOTE

**Using a Philips Optical
Receiver
in CATV Applications**

AN98060

Using a Philips Optical Receiver in CATV Applications

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1 INTRODUCTION

For many years, Philips wideband hybrid modules have been used in CATV amplifiers. All these modules have a $75\ \Omega$ input and output impedance. Since 1994, Philips Semiconductors also offers wideband amplifier modules with an optical input and an electrical $75\ \Omega$ output. These modules have type numbers that end with the letters 'BO' or start with the letters 'BGO', sometimes followed by an extension (e.g./FC0), indicating that the optical input is connectorized. These modules are sensitive for modulated laser light with a wavelength between 1290 and 1600 nm.

Since 1998, Philips Semiconductors offers the low cost versions of their optical receiver modules, i.e. BGE883BO and BGE887BO.

An increasing amount of systems use redundancy in the network, which is reached by designing double ring-networks. Because of the redundancy in the optical path, it became necessary to monitor the optical input signal continuously. Based on the presence of an optical input signal, it is decided to switch the amplifier part of the module on or off. This is possible with modules with external biasing of the pin-diode (via pin 4). The amplifier part of the module can be switched on or off via pin 5, dependent on the presence of an optical input signal. The modules with external photodiode biasing are the BGE847BO and the BGO847.

Since 2000, Philips Semiconductors offers an improved module on distortion, Equivalent Input Noise (EIN) and flatness, the BGO847. Above mentioned modules are intended for the forward path. For the return path, Philips offers the BGE67BO and the BGE67BO/4M.

This application note describes how to use these optical receiver modules. In this document, when we speak of an 'optical receiver', we refer to an optical receiver module intended for CATV applications.

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2 MECHANICAL OUTLINES, PINNING AND GLASS FIBRE OF THE MODULE

2.1 Mechanical outlines

Unconnectorized optical receivers are encapsulated in a SOT115T (with pin 4 for external photodiode biasing) or SOT115U outline. For a detailed specification See Chapter 13 "Package outlines". Connectorized optical receivers are encapsulated in a SOT115X (FC0) or SOT115Y (SC0) outline. For detailed information of the connectors and the packages, see Chapters 12 and 13 respectively.

2.2 Pinning

The pinning of the BGE883BO and the BGE887BO is:

PIN	DESCRIPTION
1	voltage output to monitor the photodiode current (typ. 0.85 V/mW)
2	common
3	common
5	+V _B
7	common
8	common
9	75 Ω electrical output

The pinning of the BGE847BO and the BGO847 is:

PIN	DESCRIPTION
1	voltage output to monitor the photodiode current (typ. 0.85 V/mW)
2	common
3	common
4	+V _B of the photodiode
5	+V _B of the amplifier
7	common
8	common
9	75 Ω electrical output

2.3 Glass fibre

2.3.1 DIMENSIONS OF THE SIECOR GLASS FIBRE

The optical input of the presently produced Philips optical receivers is a single mode glass fibre of Siecor (Corning SMF-28, type 1R41-31131-24). This glass fibre is double coated.

The dimensions of this glass fibre are

Nominal mode field diameter	9.3 μm ± 5 μm
Cladding diameter	125 μm ± 1 μm
Primary coating diameter	245 μm ± 10 μm
Secondary coating diameter	900 μm

The mechanical characteristics are:

Bending radius	min. 32 mm
Pulling force	max. 6 Newton

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2.3.2 STRIPPING OF GLASS FIBRE

The glass fibres used for optical receivers are double coated, so stripping of this glass fibre is a double activity. Stripping can be done mechanically:

1. Strip the secondary coating with a mechanical stripper. The diameter of the closed stripper must be 0.40 mm. Do not strip more than a length of ± 1.5 cm at once.
2. Strip the primary coating with a mechanical stripper. The diameter of this stripper must be 0.18 mm. The primary coating of the NKF glass fibre can also be removed by dissolving the coating with di-chlorine-methylene (CH_2Cl_2).

Many strippers are available on the market, both manually as automatically. We want to mention one of the several possibilities here.

Two mechanical strippers that can be used are:

1. Radikor fibre stripper, article no. 650952, type 3756, 0.40 mm red
2. Radikor fibre stripper, article no. 650956, type 3755, 0.18 mm blue.

These strippers can be ordered at:

Radikor Electronics B.V.
De Steiger 131
1351 AM Almere
The Netherlands
tel. +31 (0)36 5312554
fax +31 (0)36 5312465
www.radikor.nl

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3 SPECIFICATION:

The specification of optical receivers contains a table with the main parameters of the device. In this chapter, these parameters are explained.

3.1 Responsivity

The responsivity of an optical receiver is defined as:

$$\text{responsivity} = \frac{\text{output voltage [V]}}{\text{input power of modulated light [W]}}$$

The responsivity is given in V/W and can be calculated to A/W as follows:

$$\text{Responsivity} \left[\frac{\text{A}}{\text{W}} \right] = \frac{\text{Responsivity} \left[\frac{\text{V}}{\text{W}} \right]}{\text{load impedance} [\Omega]}$$

and can be the calculated to W/W:

$$\text{Responsivity} \left[\frac{\text{W}}{\text{W}} \right] = \frac{\text{Responsivity} \left[\frac{\text{V}}{\text{W}} \right]^2}{\text{load impedance} [\Omega]}$$

The responsivity of an optical receiver is determined with a network analyzer. First this analyzer is calibrated with a calibrated optical reference receiver, the HP83411C. This reference receiver has one optical input and two electrical outputs; a 50 Ω RF output and a DC output. The responsivity of the two outputs is given. The RF output responsivity is given in A/W and as a function of the frequency. The DC output at pin 1 has a responsivity of 2 V/W of the unmodulated light. After the calibration, the responsivity of an optical receiver is measured compared to the reference receiver.

The output impedance of an optical receiver is 75 Ω and the output of a calibrated reference receiver is 50 Ω. For calibration, an additional minimum loss pad is needed to convert the 50 Ω output impedance into a 75 Ω output. This minimum loss pad has an attenuation of 5.7 dB for power. When the calibration is done with a calibrated reference receiver, the calibration data has to be adapted for this minimum loss pad. The calibration data is given in A/W, so the current attenuation of the minimum loss pad has to be calculated:

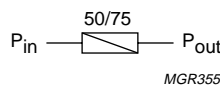


Fig.1 Minimum loss pad.

$$P_{\text{in}} = I_{\text{in}}^2 \times Z_{\text{in}}$$

$$P_{\text{out}} = I_{\text{out}}^2 \times Z_{\text{out}}$$

$$P_{\text{out}} = P_{\text{in}} - 5.7 \text{ dB} = 0.269 \times P_{\text{in}} = 0.269 \times I_{\text{in}}^2 \times Z_{\text{in}}$$

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$$I_{\text{out}}^2 \times Z_{\text{out}} = 0.269 \times I_{\text{in}}^2 \times Z_{\text{in}}$$

$$\frac{I_{\text{out}}}{I_{\text{in}}} = \sqrt{\left(\frac{0.269 \times Z_{\text{in}}}{Z_{\text{out}}}\right)} = \sqrt{\left(\frac{0.269 \times 50}{75}\right)} = 0.4236 \quad \text{and} \quad \frac{I_{\text{out}}}{I_{\text{in}}} = \sqrt{\left(\frac{0.269 \times Z_{\text{in}}}{Z_{\text{out}}}\right)} = \sqrt{\left(\frac{0.269 \times 75}{50}\right)} = 0.6353$$

The current attenuation of a minimum loss pad from 50 to 75 Ω is $20 \times \log(0.4236) = -7.46$ dB.

The current attenuation of a minimum loss pad from 75 to 50 Ω is $20 \times \log(0.6353) = -3.94$ dB.

The responsivity measurement of an optical receiver has to be corrected for the Calibrated Reference Receiver (Cal.Ref.Rec.) and the minimum loss pad.

Example:

Current attenuation minimum loss pad = -7.46 dB

50 MHz Cal.Ref.Rec._(responsivity) = 0.44659 A/W = -7.00 dB

50 MHz measured responsivity DUT = 36 dB.

The network analyzer is calibrated as 'thru-line', with the calibrated reference receiver and minimum loss pad as thru-line. The measured 50 MHz responsivity has to be corrected for this 'thru-line':

$$\begin{aligned} \text{Responsivity DUT} &= \text{measured resp.} + \text{current att} + \text{Cal.Ref.Rec.}_{(\text{responsivity})} \\ &= +36 \text{ dB} + -7.46 \text{ dB} + -7.00 \text{ dB} \\ &= 21.54 \text{ dB} \\ &= 11.93 \text{ A/W} \\ &= 895.5 \text{ V/W (in } 75 \Omega) \end{aligned}$$

3.2 Flatness of the frequency response

The flatness of the frequency response can be calculated in different ways. The two most important methods are the cable curve method and the straight line method. The cable curve method has been used mostly in the past, while the straight line method gains acceptance and becomes more and more important at the present. Both methods will be discussed in Sections 3.2.1 and 3.2.2, respectively, since the preferred method depends on the module type.

3.2.1 CABLE CURVE METHOD

The flatness of the response of an optical receiver is defined as the maximum deviation from an absolute flat response over a given frequency range, after the slope of the receiver over this frequency range has been optimized and equalized by means of a certain cable length to give the best result for flatness. This means that an 'ideal response curve' for the receiver is calculated and the flatness is the maximum deviation of this 'ideal response curve'.

Calculation:

To determine the flatness, the measured response curve values are compared with an 'ideal response curve' derived from a mathematical model. The formula used is as follows:

$$\text{Responsivity} = R + C \sqrt{\left(\frac{f_x}{f_1}\right)}$$

where

R is a constant

C is a cable constant

f_x is the desired frequency

f_1 is the start frequency

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The Cable constant (C) must be optimized during the flatness determination so that the response curve best fits the measured response curve figures. The start value for C is calculated using the formula:

$$C_{\text{start}} = \frac{R_n - R_1}{\sqrt{\left(\frac{f_n}{f_1} - 1\right)}}$$

where

R_n is the measured response at the stop frequency

R_1 is the measured response at the start frequency

f_n is stop frequency

f_1 is start frequency.

The value of R is chosen in such a way that the maximum positive deviation of the measured response from the 'ideal response curve' is the same as the maximum negative deviation. The value of C is adapted by ± 0.001 dB until the 'ideal response curve' best fits the measured curve.

The flatness of the module response is the maximum deviation in measured response from the optimized response formula.

3.2.2 STRAIGHT LINE METHOD

For some module types, the flatness of the frequency response is calculated according to the straight line method. This means, that the responsivity of the optical receiver is measured at 40 and 870 MHz. The deviation from the interpolated line between 40 and 870 MHz is called the flatness. It is measured according peak-to-valley, so a peak of 0.7 dB and a valley of 0.2 dB will result in a flatness of $0.7 + 0.2 = 0.9$ dB.

3.3 Slope of the frequency response

Equal to flatness, the slope of the frequency response can be calculated in different ways. The two most important methods are the cable curve method and the straight line method. The cable curve method has been used mostly in the past, while the straight line method gains acceptance and becomes more and more important at present. Both methods will be discussed in Sections 3.3.1 and 3.3.2 respectively, since the preferred method depends on the used module type.

3.3.1 CABLE CURVE METHOD

The slope of a module is the difference between the 'ideal gain' at the start frequency and the 'ideal gain' at the stop frequency. See Section 3.2.1, "Cable curve method" of the section "Flatness of the frequency response".

3.3.2 STRAIGHT LINE METHOD

The slope of a module is the difference between the gain at the start frequency and the gain at the stop frequency. See Section 3.2.2, "Straight line method" of the section "Flatness of the frequency response".

3.4 Input and output return losses

The output return loss of an optical receiver is the measured $-s_{22}$ of the output of this module in dB. This s_{22} is the $20\log_{10}$ of the reflection coefficient, which indicates the matching between the output impedance and the characteristic impedance of 75 Ω .

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The input return loss of an optical receiver is the optical back reflection of the photodiode, measured at the fibre. The Optical Back Reflection is $10\log_{10}(P_{\text{refl}}/P_{\text{in}})$, in which P_{in} is the optical input power and P_{refl} is the reflected power back into the fibre. At a level of -45 dB input reflection, 0.0032% of the total optical input power is reflected back into the fibre.

3.5 Second order distortion

The second order distortion product is the difference in dB between the peak level of an RF signal at the measurement frequency and the peak level of the signal at the measurement frequency caused by two Continuous Wave (CW) signals with their second order modulation product ($f_1 \pm f_2$) at the measurement frequency.

The second order distortion of an optical receiver is measured with two lasers. Both lasers are modulated with a CW carrier, which together cause a distortion product at the measurement frequency. For the second order measurement of an optical receiver, the settings are related to the optical input signal; the optical un-modulated input power and the modulation index. The measurement starts with a calibration. First one laser is modulated with a CW signal at the measurement frequency. The optical power level and modulation index are equal to the ones used for the distortion frequencies. The output power at the measurement frequency is set as 0 dB level.

During measurement, the two lasers are modulated by a CW carrier. The distortion is measured by measuring the distance between the 0 dB level and the power level at the measurement.

Example:

P_{optical}	= 0.5 mW per laser
$m_{\text{modulation index}}$	= 40%
f_1	= 133.25 MHz
f_2	= 721.25 MHz
$f_{\text{measurement}}$	= 854.50 MHz

- Two lasers are set at an (DC) optical output power level of 0.5 mW each
- One laser is modulated for 40% at 854.5 MHz
- The output power measured at 854.5 MHz is set as 0 dB level.

After this calibration:

- Two lasers are modulated for 40% with 133.25 and 721.25 MHz
- The distortion power is measured at the frequency $f_1 + f_2 = 854.5$ MHz compared to the 0 dB level. This distance is the second order distortion.

3.6 Third order distortion

The third order distortion product is the difference in dB between the peak level of an RF signal at the measurement frequency and the peak level of the signal at the measurement frequency caused by three CW signals with their third order modulation product ($f_1 + f_2 - f_3$) at the measurement frequency.

The third order distortion of an optical receiver is measured with three lasers. These lasers are modulated with a CW carrier, which together cause a distortion product at the measurement frequency. For the third order measurement of an optical receiver, the settings are related to the optical input signal; the optical un-modulated input power and the modulation index. The measurement starts with a calibration. First one laser is modulated with a CW signal at the measurement frequency. The optical power level and modulation index are equal to the ones used for the distortion frequencies. The output power at the measurement frequency is set as 0 dB level. During measurement, the three lasers are modulated by a CW carrier. The distortion is measured by measuring the distance between the 0 dB level and the power level at the measurement frequency.

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Example:

P_{optical}	= 0.33 mW per laser
$m_{\text{modulation index}}$	= 60%
f_1	= 133.25 MHz
f_2	= 265.25 MHz
f_3	= 721.25 MHz
$f_{\text{measurement}}$	= 853.25 MHz

- Three lasers are set at a (DC) optical output power level of 0.33 mW each
- One laser is modulated for 60% at 853.25 MHz
- The output power measured at 853.25 MHz is set as 0 dB level.

After this calibration:

- Three lasers are modulated for 60% at 133.25, 265.25 and 721.25 MHz
- The distortion power is measured at the frequency $-f_1 + f_2 + f_3 = 853.25$ MHz compared to the 0 dB level. This distance is the third order distortion.

3.7 Total current consumption

The total current consumption I_{tot} is the total DC current consumption of an optical receiver when a DC voltage supply of 24 V is applied to pins 4 and 5.

3.8 Photodiode bias current

The photodiode bias current I_{pin4} is the DC-current consumption of the photodiode bias circuit of an optical receiver when a DC voltage supply of 24 Volts is applied to pin 4.

3.9 Equivalent input noise

The diagram of the measurement set-up to measure the equivalent input noise of the optical receiver is shown in Fig.2.

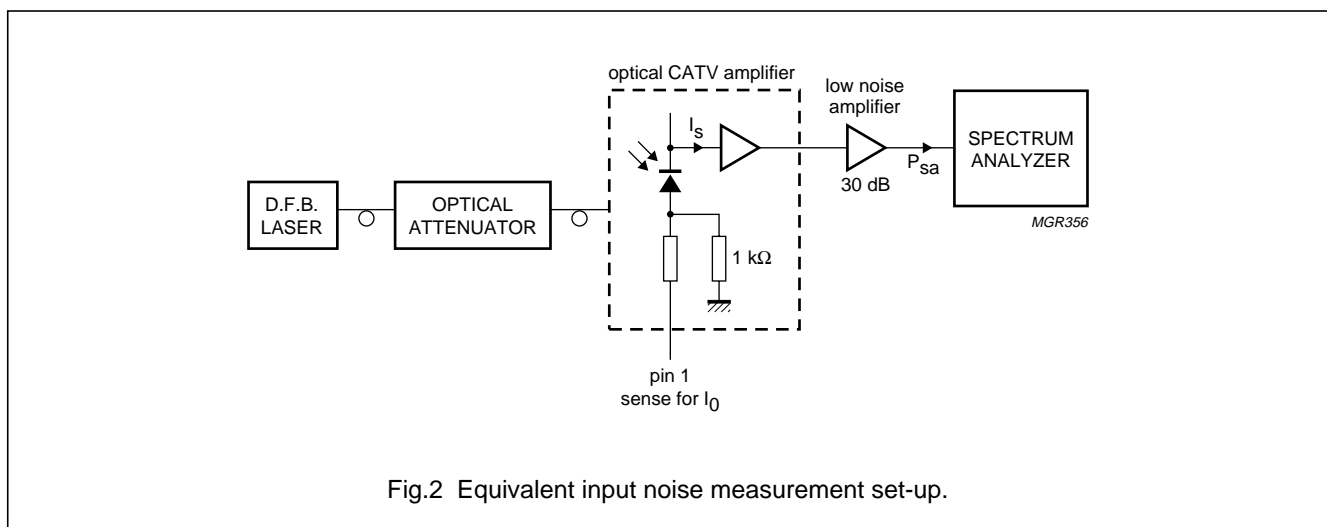


Fig.2 Equivalent input noise measurement set-up.

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The total noise power measured at the spectrum analyzer (P_{sa}) consists of three parts:

$$P_{sa} = \text{laser noise} + \text{photodiode shot noise} + \text{optical receiver noise (thermal)}$$

The noise power at the spectrum analyzer is frequency dependent. This noise power can be calculated with:

$$P_{sa} = (RIN \times I_0^2 + 2 \times I_0 \times e + I_n^2) \times (B \times Rd) [W] \quad (1)$$

where:

P_{sa}	is the noise power measured at the spectrum analyzer	[W]
RIN	is the relative intensity noise of the laser source	[dB/Hz]
I_0	is the DC detector current (= $V_{pin1}/1 \text{ k}\Omega$)	[A]
e	= 1.6×10^{-19}	[Coulomb = A/Hz]
I_n	is the receiver equivalent noise current	[A/ $\sqrt{\text{Hz}}$]
B	is the resolution bandwidth of spectrum analyzer	[Hz]
Rd	is the responsivity of the optical CATV ampl. = $\frac{P_{sa}}{I_s^2}$	[Ω]

The receiver equivalent input noise (I_n), which is also frequency dependent, can be calculated out of this noise power measurement. For this calculation, a few assumptions are made:

- Relative Intensity Noise (RIN) of the used laser is more than 160 dB/Hz (DFB laser)
- The responsivity of the DUT is constant over the used optical input span
- No optical reflections in the used measurement equipment ($< -60 \text{ dB}$)
- The noise floor of the used spectrum analyzer is much lower than the receiver noise. If necessary, use a good pre-amplifier as given in the diagram of Fig.2.

3.9.1 MEASUREMENT

1. Measure the P_{sa} with no optical input signal ($I_0 = 0 \text{ mA}$, $V_{pin1} = 0 \text{ V}$). The measured power is the receiver noise power.
2. Adjust the optical power of the laser to the maximum value which will be used (e.g. 2 mW), at this level the RIN of the laser source should be better than 160 dB/Hz.
3. Set the optical attenuator at 0 dB loss.
4. Measure the P_{sa} for at least four different optical input powers by adjusting the optical attenuator (e.g. 0.2, 1, 1.5 or 2 mW) and measure the corresponding I_0 given with the formula $I_0 = \frac{V_{pin1}}{1 \text{ k}\Omega}$. The RIN of the laser stays constant in this measurement because the laser current has not been changed. The measurement results in the P_{sa} as a function of I_0 .

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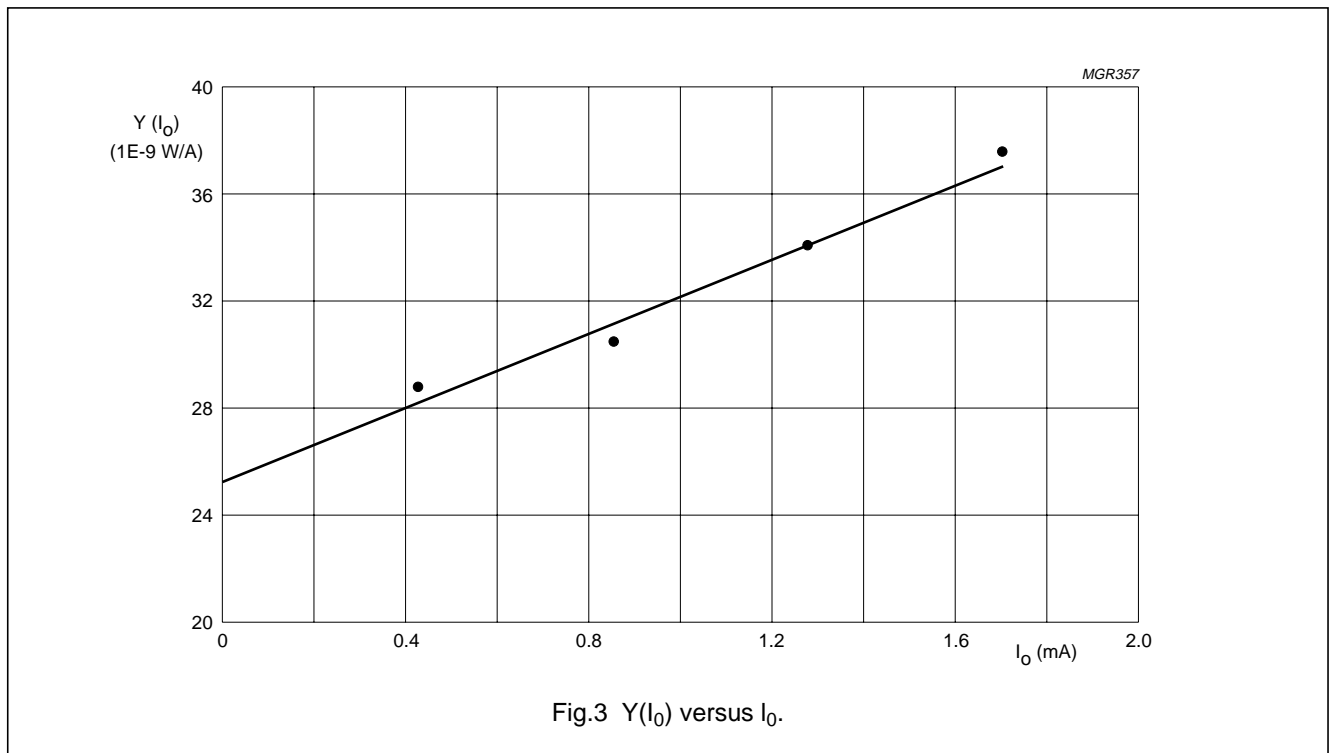
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3.9.2 CALCULATION

To calculate the receiver equivalent input noise, a help function has been defined:

$$Y(I_0) = \left(\frac{P_{sa}(I_0) - P_{sa}(0)}{I_0} \right) = (RIN \times I_0 + 2 \times e) \times B \times Rd \quad (2)$$

$Y(I_0)$ can be calculated for the measured P_{sa} values and plotted as function of I_0 (dotted points in Fig.3):



With this graph, the value for $Y(0)$ ($I_0 = 0$) can be found.

For $I_0 = 0$ (no optical input signal):

$$P_{sa}(0) = I_n^2 \times B \times Rd \quad (\text{see formula (1)}) \quad \text{and} \quad Y(0) = 2 \times e \times B \times Rd \quad (\text{see formula (2)})$$

These two formulas combined give the formula to calculate the receiver Equivalent Input Noise (EIN)

$$I_n = \sqrt{\left(\frac{2 \times e \times P_{sa}(0)}{Y(0)} \right)} \quad [A/\sqrt{\text{Hz}}]$$

where:

$P_{sa}(0)$ is the measured noise power at the spectrum analyzer without an optical input signal

$Y(0)$ is the I_0 value out of the graph $Y(I_0)$ versus I_0

I_n is the receiver equivalent noise current

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4 PHOTODIODE CURRENT MONITOR PIN

An optical signal which is applied to a reverse biased photodiode will generate electron-hole pairs, resulting in a current. The ratio between the optical input signal and the output current of the photodiodes is the responsivity of a photodiode. This responsivity depends on the used wavelength, the so-called spectral sensitivity.

The photodiodes used in the Philips optical receivers have a minimum responsivity of 0.85 A/W at 1310 nm. Pin 1 of the Philips optical receivers can be used to monitor the un-modulated optical input power (DC). The design of these receivers is such that the DC output current of the photodiode flows into a 1 kΩ transfer resistor. Via a 10 kΩ resistor the voltage drop over the transfer resistor can be measured with a high ohmic voltmeter with an input resistance which is greater than 10 MΩ. A low ohmic voltmeter will influence the voltage drop. Because of the use of a 1 kΩ transfer resistor, the current monitor pin will have a typical output voltage of 0.85 V/mW.

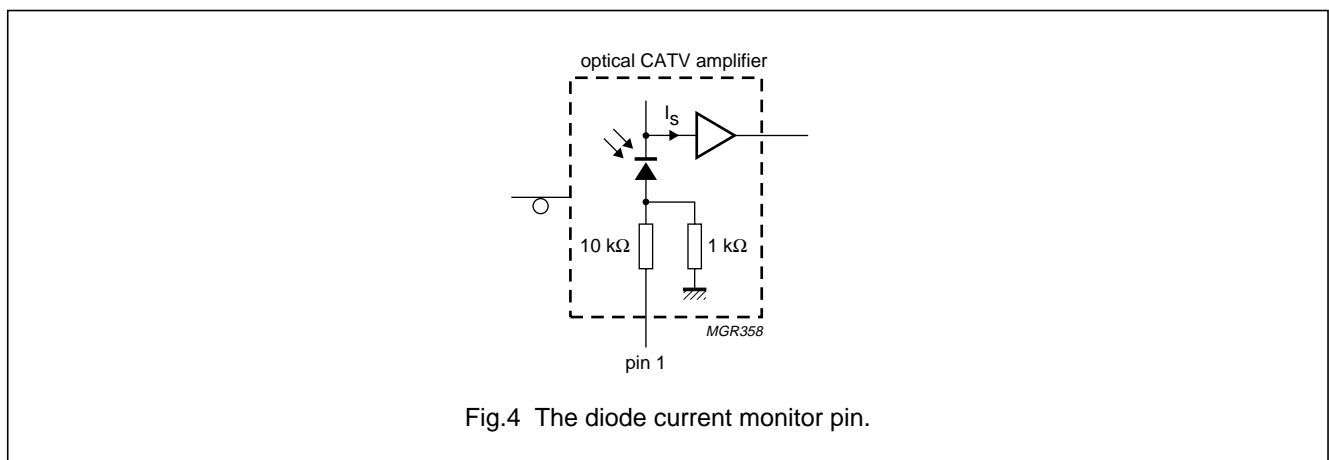


Fig.4 The diode current monitor pin.

The pin 1 output voltage depends on several items:

- P_{opt} is the optical input power at the receiver
- R_{resp} is the responsivity of the used photodiode
- $R_{transfer}$ is the value of the transfer resistor

The optical input power can be measured with an optical power meter at a surface where the optical link can be separated and connected to this meter. The loss after this point (connector loss), has to be subtracted of the measured optical power. The loss of a connector is maximal 0.5 dB. The responsivity of the used photodiodes is specified as >0.85 A/W. The transfer resistor is developed for 1 kΩ. The accuracy of this substrate resistor is $\pm 1\%$. After the assembly of the total receiver, this accuracy is decreased to $1000 \Omega \pm 10\%$ due to some temperature steps during the assembly process.

The pin 1 accuracy is:

$$V_{pin 1} = (P_{opt} - \text{Connector loss}) \times R_{resp} \times R_{transfer}$$

$$V_{pin 1 (min)} = P_{opt} \times 0.891 \times 0.85 \times 900 = 0.68 \text{ V/mW} \quad 0.77 \text{ V/mW without any connector loss}$$

$$V_{pin 1 (max)} = P_{opt} \times 1 \times 0.95 \times 1100 = 1.05 \text{ V/mW} \quad 0.93 \text{ V/mW with 0.5 dB connector loss}$$

All Philips optical receivers are checked on pin 1 voltage between 0.75 and 1 V/mW.

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5 OPTICAL RECEIVER TEST SETUP

For the diagram of the optical receiver test set-up which is used by Philips, see Fig. 5. At the left side of this diagram, three lasers are placed, biased via three laser power supplies.

In order to measure d_2 and d_3 , these three lasers have to be modulated by three RF-generators. The input of one laser can be switched to either the output of the RF-generator or to port one of the s-parameter test set. This allows the measurement of the responsivity.

The light of the lasers is combined by two 'splitter/combiners' and applied to the input of the adjustable optical attenuator. After the optical attenuator, the light is split into a 5% and a 95% part. The 5% part is used to adjust and monitor the optical (DC) light, available at the 95% output of the splitter. The ratio between the 5% and 95% output of the splitter is measured and added as correction factor in the optical power meter. The 95% output of the splitter is connectorized and can be connected to the Calibrated Optical Reference Receiver (CORR) or to the Device Under Test (DUT).

The output of the CORR can be connected to a power meter to adjust the optical modulated light for the d_2 and d_3 measurement. The output of the CORR can also be connected to port 2 of the s-parameter test-set to calibrate for the responsivity measurement. After calibration, the 95% output of the splitter is connected to the DUT.

For the EIN measurement the voltage at pin 1 of the DUT can be measured with a multimeter. To measure the responsivity and s_{22} , the output of the DUT can be switched to port 2 of the s-parameter test-set. The output of the DUT can also be connected to the input of a spectrum analyzer to measure d_2 and d_3 . When a 30 dB amplifier is connected between the output of the DUT and input of the spectrum analyzer, the EIN can be measured.

The equipment used in the test setup:

- 3 lasers CQF94/D from Philips
- 3 RF-generators HP8657A from Hewlett-Packard
- 3 laser power supplies PLPS2000 from Philips
- 3 splitter/combiners from Gould (with a 50/50%, 30/70% and 5/95% ratio respectively)
- An adjustable optical attenuator HP8156A from Hewlett-Packard
- An optical power meter HP8153A from Hewlett-Packard
- A calibrated optical reference receiver HP83411C from Hewlett-Packard
- A spectrum/network analyzer HP4396A from Hewlett-Packard
- A 75 Ω s-parameter test-set HP85046B from Hewlett-Packard
- A 30 dB low noise amplifier, several 50 and 75 Ω switches, 50/75 Ω minimum loss pads, multimeters, a power supply, relay actuator and a computer for automated measurement
- Powermeter HP473B.

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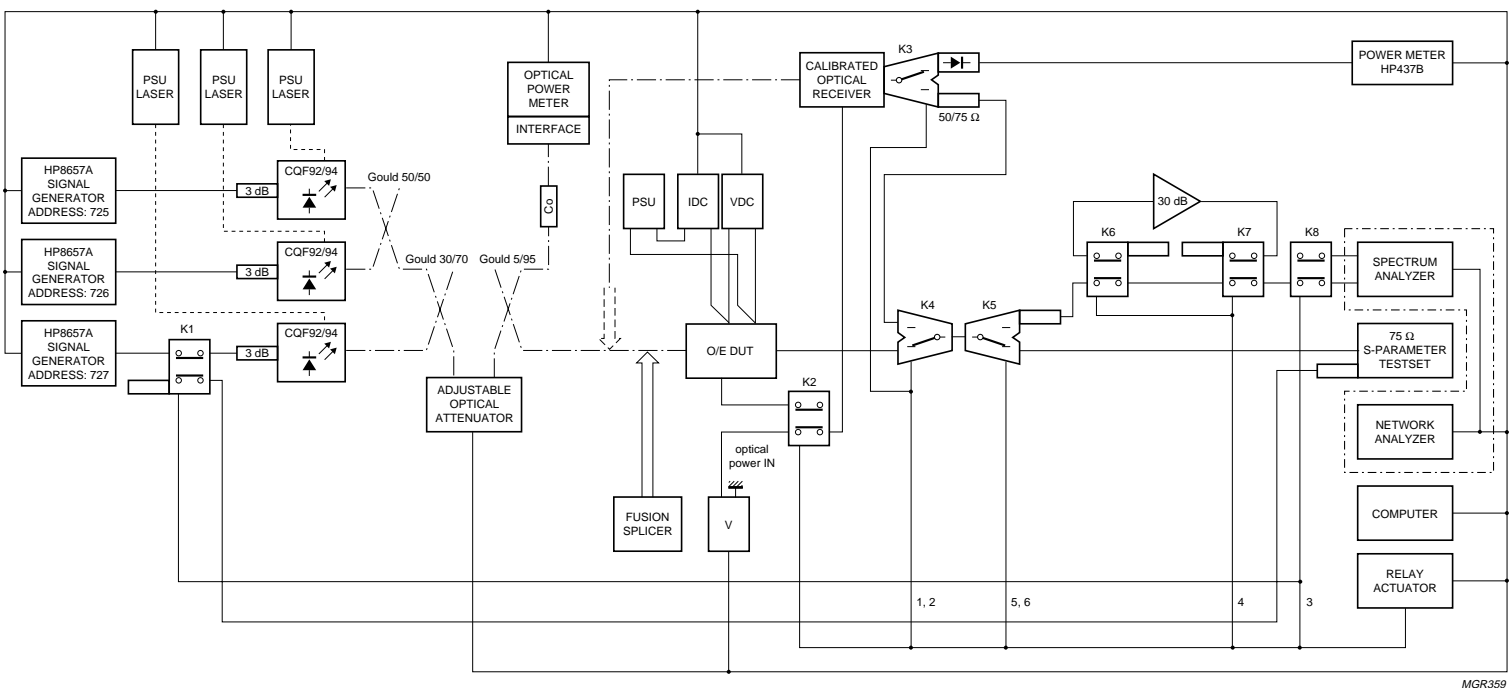


Fig.5 Optical receiver test setup.

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6 CIRCUIT DIAGRAM OF AN OPTICAL RECEIVER

The circuit diagram of an optical receiver is shown in Fig.6.

The photodiode at the input of an optical receiver converts light into electrical current. The matching networks matches the photodiode to the push-pull amplifiers. The transformers used in this matching network amplify the photodiode current. This matching network has been patented by Philips Semiconductors, number PHN 14.489. The push-pull amplifiers are standard CATV amplifiers with a standard output transformer. The total gain of the push-pull amplifier, including the matching network, is ± 21.5 dB.

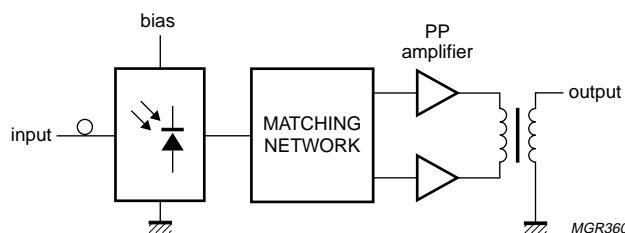


Fig.6 Circuit diagram of the an optical receiver.

7 OUTPUT VOLTAGE CALCULATION

An optical receiver converts an amplitude modulated (AM) optical signal into an electrical RF signal. This chapter describes the calculation of this conversion. The output voltage of an optical receiver can be calculated with the formula:

$$\text{Output Voltage (peak)} = \text{Responsivity} \times \text{Optical Input Power} \times \text{Modulation Index}$$

where:

Output voltage	is the electrical output voltage in 75Ω , at the output of the optical receiver module, given in mV
Responsivity	is the conversion ratio of an optical receiver module, given as electrical output voltage per optical input power given in V/W
Optical input power	is the unmodulated optical power at the input of the optical receiver module, given in mW
Modulation index	is the amplitude modulation index of the optical input signal, given in percentage (%).

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Example:

A practical situation is:

Optical input power is 1 mW (0 dBm).

Modulation index $m = 3.7\%$.

Responsivity = 900 V/W (the typical responsivity of the BGE887BO/BGE847BO and BGO847).

Output Voltage (peak) = Responsivity \times Optical Input Power \times Modulation Index

$$\begin{aligned} V_{out(peak)} &= R_{resp} \times P_{i(opt)} \times m && \text{mV} \\ V_{out(peak)} &= 900 \times (1 \times 10^{-3}) \times 0.037 && \text{mV} \\ V_{out(peak)} &= 33.3 && \text{mV} \\ V_{out(average)} &= V_{out(peak)} / \sqrt{2} && \text{mV} \\ V_{out(average)} &= 33.3 / \sqrt{2} = 23.5 && \text{mV} \\ V_{out(dBmV)} &= 20 \times \log(23.5) = 27.4 && \text{dBmV} \end{aligned}$$

For any other input power and/or modulation index the output voltage can be calculated similarly.

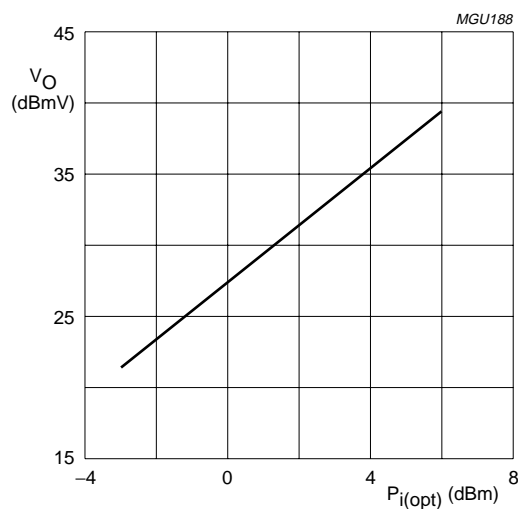
The calculation of the responsivity from V/W into A/W and W/W is given below:

$$\text{Responsivity [A/W]} = \text{Responsivity [V/W]} / \text{Load impedance (75 } \Omega \text{)}$$

$$\text{Responsivity [W/W]} = \text{Responsivity [V/W]}^2 / \text{Load Impedance (75 } \Omega \text{)}$$

An important property of the optical receiver is the relation between the optical input signal level and the electrical output signal level. An increase of the optical input signal with 1 dB results in an increase of 2 dB electrical output signal. See Fig.7.

The explanation of this 1:2 ratio is as follows: The optical input power is linearly converted into an electrical current by the photodiode. The electrical input power of the amplifier, is equal to $I_{in}^2 \times Z_{in}$. The fact that $P_{in} = I_{in}^2 \times Z_{in}$ leads to the 1 dB optical = 2 dB electrical relationship. See Fig.7.



Modulation index = 3.7%; Responsivity = 900 V/W.

Fig.7 Output voltage as a function of the optical input power $P_{i(opt)}$.

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8 CARRIER TO NOISE RATIO CALCULATION

The Carrier (C) to Noise ratio (N) of an optical link (from laser to the output of the receiver) can be determined by the

following equation:
$$\frac{C}{N} = \frac{0.5 \times m^2 \times I_{pd}^2}{2 \times e \times I_{pd} \times B + RIN \times I_{pd}^2 \times B + I_n^2 \times B}$$

where:

m	is the modulation index optical input signal	[%]
I_{pd}	is the photodiode current (= $V_{pin1}/1 \text{ k}\Omega$)	[A]
e	is the 1.6×10^{-19}	[Coulomb = A/Hz]
B	is the bandwidth (= 5 MHz)	[Hz]
RIN	is the relative intensity noise of the laser	[1/Hz]
I_n	is the equivalent input noise optical receiver	[A/ $\sqrt{\text{Hz}}$]

Example:

m	= 5%
I_{pd}	= 1 mA ($V_{pin1} = 1 \text{ V}$)
e	= 1.6×10^{-19} (C)
B	= 5×10^6 Hz
RIN	= 3.2×10^{-16} (1/Hz) (= -155 dB/Hz)
I_n	= 7 pA/ $\sqrt{\text{Hz}}$

$$\frac{C}{N} = \frac{0.5 \times (0.05)^2 \times (1 \times 10^{-3})^2}{2 \times (1.6 \times 10^{-19}) \times (1 \times 10^{-3}) \times (5 \times 10^6) + (3.2 \times 10^{-16}) \times (1 \times 10^{-3})^2 \times (5 \times 10^6) + (7 \times 10^{-12})^2 \times (5 \times 10^6)}$$

$$\frac{C}{N} = -55.6 \text{ dBc}$$

9 APPLICATION CONSIDERATIONS

9.1 BGE887BO and BGE883BO

The BGE887BO has been designed for an optical input power of approximately 0 dBm. Because higher optical input powers are sometimes used in optical systems, Philips designed the BGE883BO. In this chapter the differences between the BGE883BO and BGE887BO are explained. The BGE887BO has been designed for an optical input power range between -3 and +3 dBm. At higher input powers, the second and third order intermodulation of the BGE887BO is limiting for normal use. The BGE883BO has been designed for an optical input power range between 0 and 6 dBm (3 dB higher than the BGE887BO). Compared to the BGE887BO the intermodulation behaviour of this module is better.

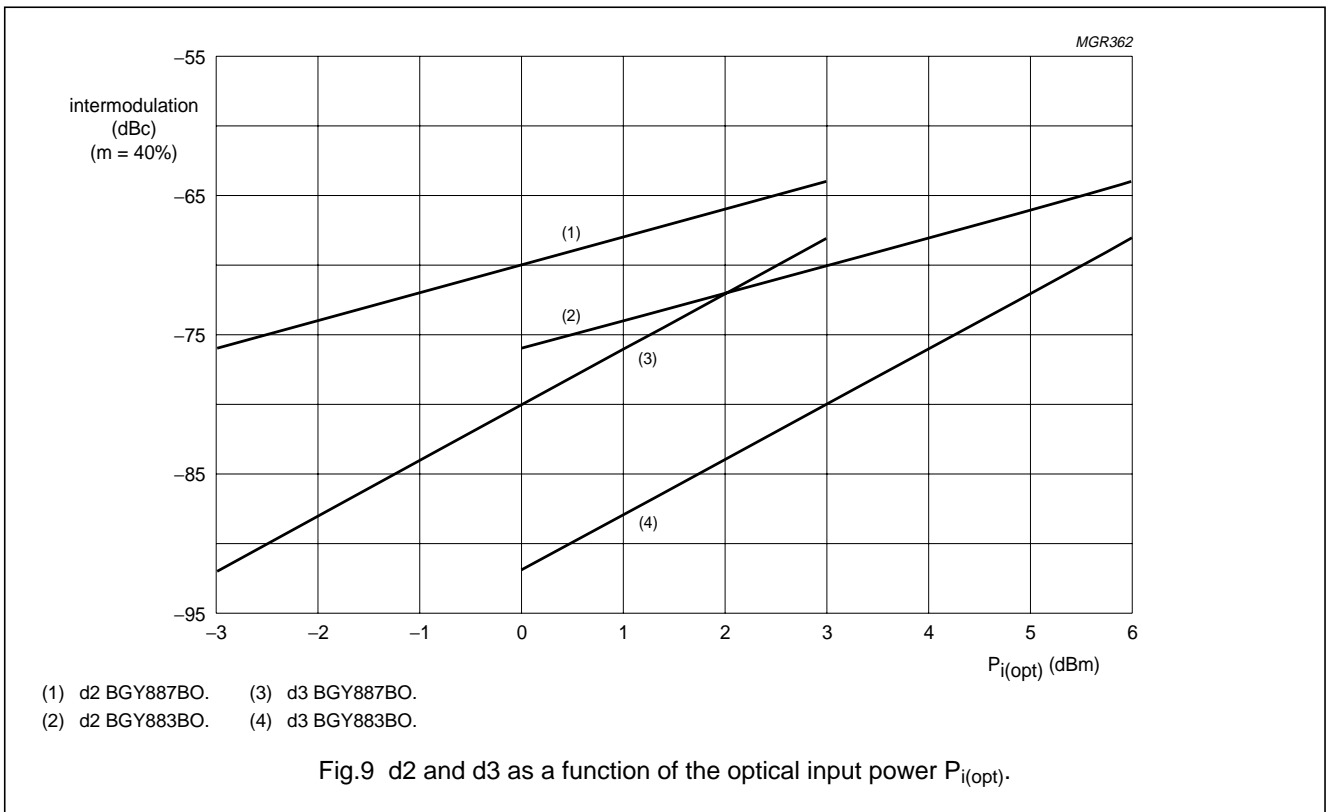
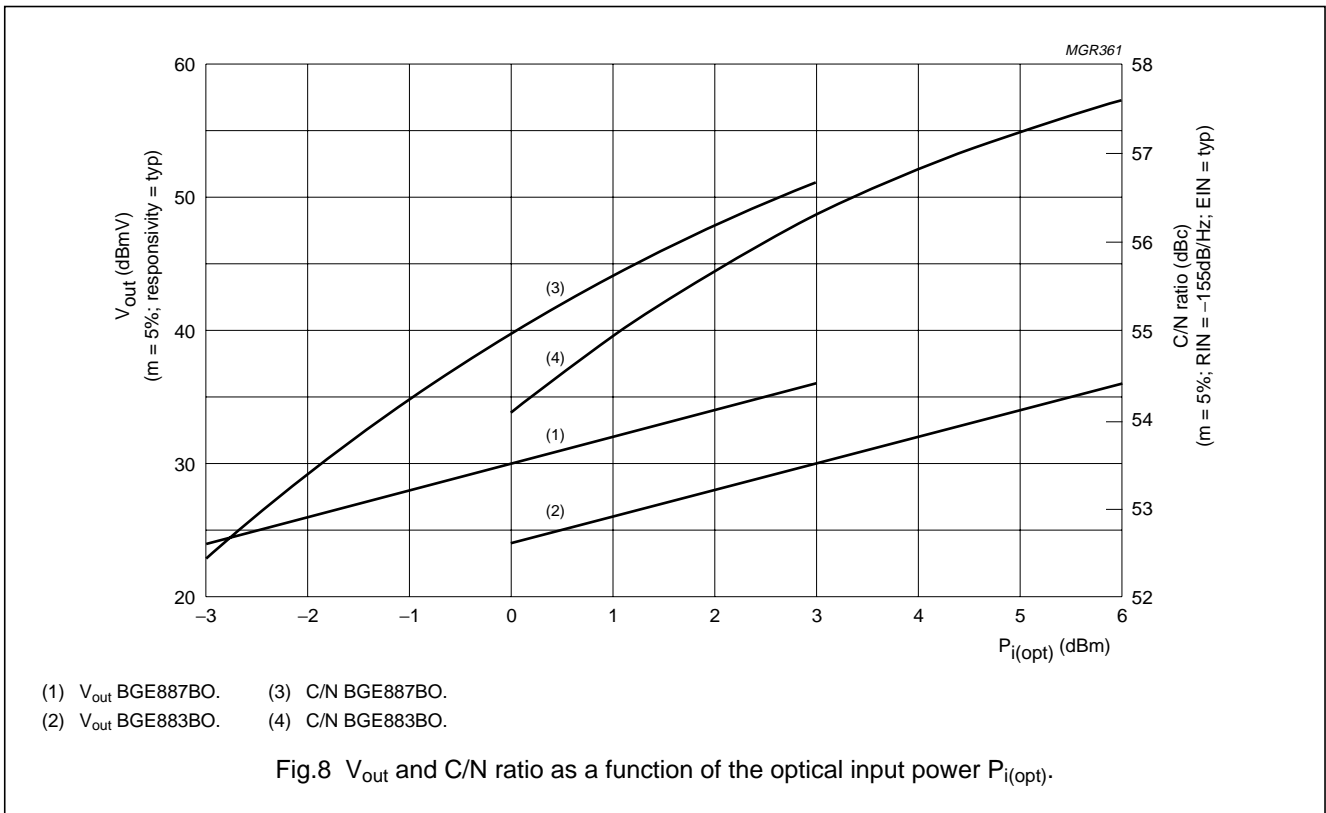
The equivalent input noise of this module is higher, but at these levels not limiting. The BGE883BO has 6 dB less responsivity, 400 V/W instead of 800 V/W. The output return-loss of this module has been improved significantly. For the optical input range between 0 and 3 dBm both modules can be used. It depends on the application, which one is preferred.

Fig.8 shows the output voltage of the module versus the optical input power and also the carrier to noise ratio versus the optical input power. The output voltage of the two different modules differ with 3 dB of input power. The C/N ratios of the two different modules also differ and have another shape in addition.

Fig.9 shows the d2 and d3 intermodulation versus the optical input power. The d2 and d3 curves of the two different modules differ with 3 dB of input power.

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9.2 BGE847BO and BGO847

The BGE847BO has been used mainly in 750 MHz systems. Since bandwidth of present CATV systems has been increasing up to 870 MHz bandwidth, the need for an improved optical receiver appeared. This improved optical receiver is the BGO847. The improvement has been achieved at second order distortion (d_2) and equivalent input noise, especially between 750 and 870 MHz.

In the graph, shown in Fig.10, the second order distortion d_2 as a function of the frequency of the BGE847BO and the BGO847 is given. The BGO847 gives an improvement through the whole frequency range, especially above 650 MHz.

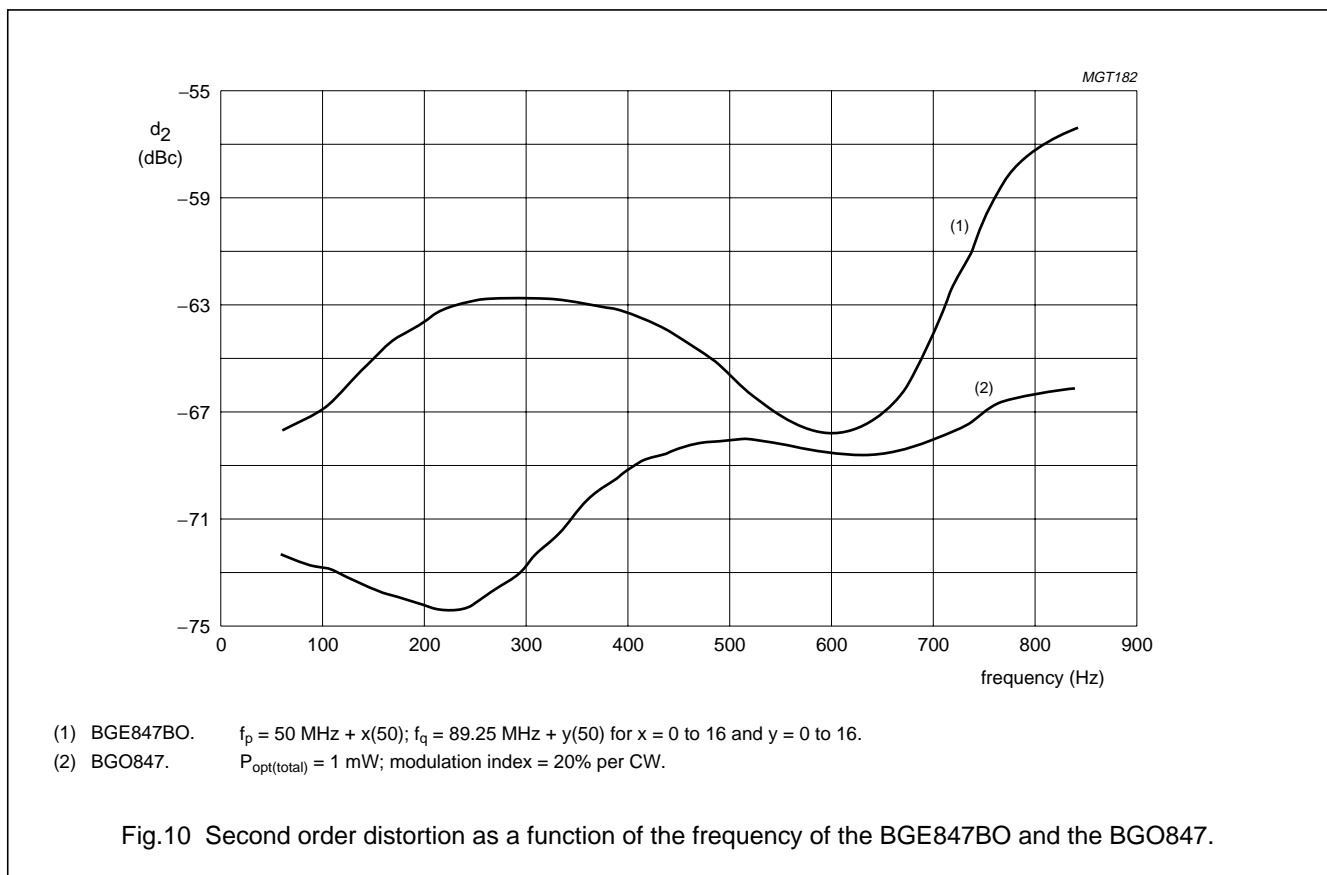
The equivalent input noise as a function of the frequency of the BGE847BO and the BGO847 is shown in Fig.11. The BGO847 gives an improvement above 400 MHz.

Compared to the BGE847BO specification, the specification of the BGO847 has been extended on three parameters:

First one is the addition of d_2 and d_3 distortion measurements

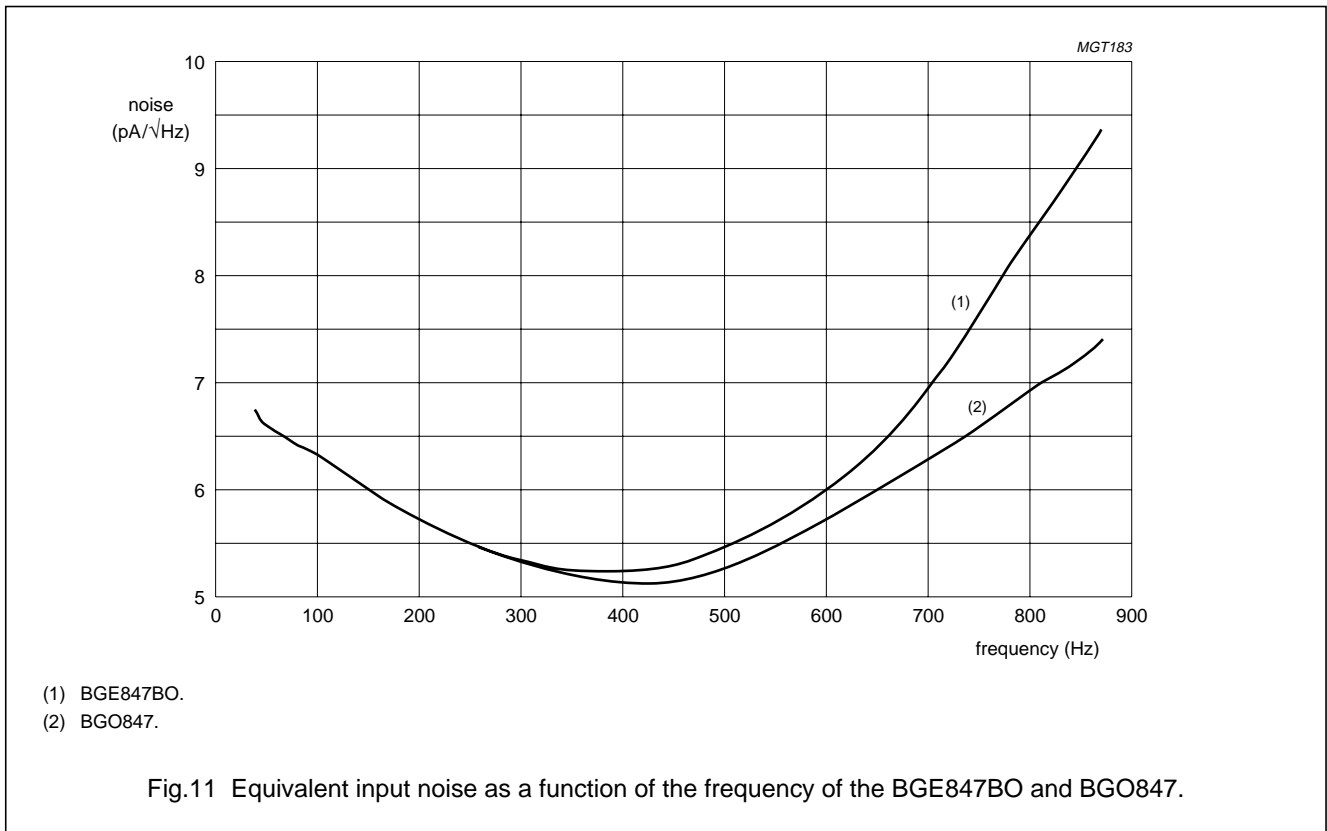
Second, the equivalent input noise specification has been extended, specified through the whole frequency range from 40 up to and including 870 MHz

Third, a slope specification has been added for the BGO847.



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10 MULTI CHANNEL DISTORTION MEASUREMENTS

CATV amplifiers are specified on multichannel behaviour. The number of channels used for the measurements depends on the application. Measurements are done with multichannel equipment which has a generator for each channel. Doing multichannel measurements on optical receivers requires a big number of lasers. One laser for each channel is needed to prevent from distortion of the laser being added to the measurement results. This is a very expensive measurement method. Another option is using one linear laser and doing two multi channel measurements with one setting of the laser by using an optical attenuator. After these two measurements, the total voltage of the measured multichannel measurement can be split up in the distortion voltage of the laser and the distortion voltage of the optical receiver. With this type of measurement, it is important that the distortion of the laser is low compared to the distortion of the optical receiver. An example of this measurement method and calculation of distortion is given in Section 10.1.

10.1 Calculation of the CTB Figure of optical receivers

The Composite Triple Beat (CTB) is the distance, expressed in dB or dBc, between the carrier and the CTB distortion voltage. Since the CTB is a third order distortion product, the relation between the output voltage V_o and the CTB voltage V_{CTB} is 1 to 3. This means, that the relation between output voltage and CTB, which is always expressed relative to the carrier, is 1 to 2 and V_{CTB} increases three times faster than the output power. So, an increase of 1 dB optical input power leads to an increase of 2 dB electrical output voltage, which leads to an increase of 6 dB of V_{CTB} . This is illustrated in Fig.12.

As shown on the left side of Fig.12, the output voltage V_o is 35 dBmV, and the CTB voltage V_{CTB} is -35 dBmV, resulting in a CTB of -70 dBc. On the right side of the figure, an output voltage increase of 5 dB is shown. Increasing the output voltage V_o with 5 dB to 40 dBmV results in a CTB voltage V_{CTB} increase of 15 dB to -20 dBmV. This results in a CTB of -60 dBc. In the following discussion, CTB is the relative difference between carrier signal and distortion, and is expressed in dB or dBc. The absolute CTB distortion voltage is denoted by V_{CTB} and is expressed in dBmV or mV.

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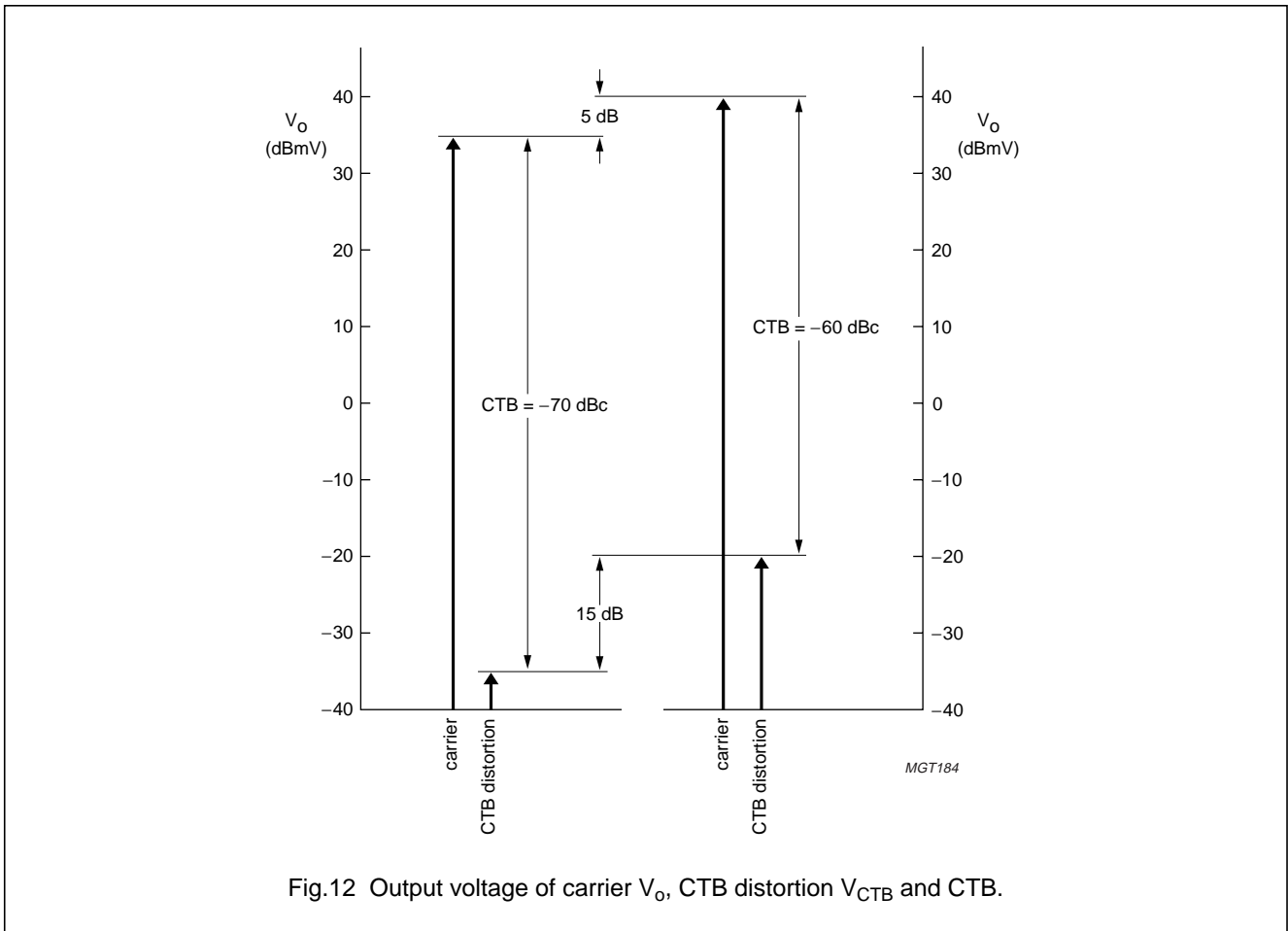


Fig.12 Output voltage of carrier V_o , CTB distortion V_{CTB} and CTB.

For the calculation of the CTB of the optical receiver, we also make use of the 1:2 relationship between optical in and electrical out, as already discussed in Chapter 7, "Output Voltage Calculation". With these relations in mind, we can now focus on the measurement and calculation of the CTB itself.

The method of calculating the CTB figure of an optical receiver is explained with the help of an example. The CTB of the total optical system, is measured twice: test 1 and test 2, each test at a different optical input power by means of an optical attenuator. Because the CTB of the laser is kept constant, we have two equations with two unknowns, which can be solved with linear algebra.

If the optical input power, the responsivity of the optical receiver and the CTB of the total optical system are known, the total CTB voltage V_{CTB} at the output can be calculated:

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Overview of the test values of the CTB measuring

SYMBOL	CONDITION	TEST 1	TEST 2
Optical Input Power: • P _{optical} • modulation index • P _{optical(average)}	one carrier	6 dBm 4 mW 3.7% $4.0 \times 10^{-3} \times 0.037 \times (1/\sqrt{2}) =$ $104.6 \times 10^{-6} \text{ W} =$ 104.6 μW	3 dBm 2 mW 3.7% $2.0 \times 10^{-3} \times 0.037 \times (1/\sqrt{2}) =$ $52.3 \times 10^{-6} \text{ W} =$ 52.3 μW
Output Voltage: responsivity = 900 V/W V _{out}	one carrier	$104.6 \times 10^{-6} \times 900 =$ 94.2 mV = 39.5 dBmV	$52.3 \times 10^{-6} \times 900 =$ 47.1 mV = 33.5 dBmV
CTB Voltage CTB _{total} [dBc] V _{CTB(total)}		-63.15 dBc $39.5 - 63.15 \text{ dBmV} =$ -23.65 dBmV = 0.0655 mV	-66.52 dBc $33.5 - 66.52 \text{ dBmV} =$ -33.0 dBmV = 0.0222 mV

The CTB voltage V_{CTB(total)} at the output of the receiver is the addition of the amplified input V_{CTB(tx)resp} and the V_{CTB(rx)opt} of the optical receiver. At test 1, the total CTB voltage at the output of the optical receiver is:

$$V_{CTB(total1)} = V_{CTB(tx)resp} + V_{CTB(rx)opt} \tag{3}$$

When the input signal is attenuated optically, the CTB distance of the optical input signal stays the same. The amplified input CTB will also be the same in distance but the absolute voltage of this signal is lower; -6 dB at test 2 compared to test 1. The added CTB of the optical receiver is 12 dB lower in distance. The added V_{CTB(rx)opt} is 18 dB lower in absolute output voltage (when an output signal is attenuated with x dB, the third order distortion level is 3 x dB lower).

Using the numbers and voltages of the formulas of test 1, the total output CTB voltage of test 2 is:

$$V_{CTB(total2)} = (V_{CTB(tx)resp} - 6\text{dB}) + (V_{CTB(rx)opt} - 18\text{dB}) \tag{4}$$

$$V_{CTB(total2)} = (V_{CTB(tx)resp} \times 0.5012) + (V_{CTB(rx)opt} \times 0.1259) \tag{5}$$

Equations (3) and (5) form two equations with two unknowns, and can be solved with linear algebra:

$$\begin{bmatrix} V_{CTB(total1)} \\ V_{CTB(total2)} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0.5012 & 0.1259 \end{bmatrix} \times \begin{bmatrix} V_{CTB(tx)resp} \\ V_{CTB(rx)opt} \end{bmatrix}$$

in which:

- V_{CTB(total1)} measured CTB voltage at high optical input power
- V_{CTB(total2)} measured CTB voltage at low optical input power
- V_{CTB(tx)resp} amplified CTB voltage of laser
- V_{CTB(rx)opt} CTB voltage of optical receiver

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In numbers, this is as follows:

$$\begin{bmatrix} 0.0655 \\ 0.0222 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0.5012 & 0.1259 \end{bmatrix} \times \begin{bmatrix} V_{CTB(tx)resp} \\ V_{CTB(rx)opt} \end{bmatrix}$$

With deriving the inverse of the 2×2 matrix, we get the following result, expressed in mV:

$$\begin{bmatrix} V_{CTB(tx)resp} \\ V_{CTB(rx)opt} \end{bmatrix} = \frac{1}{0.1259 - 0.5012} \times \begin{bmatrix} 0.1259 & -1 \\ -0.5012 & 1 \end{bmatrix} \times \begin{bmatrix} 0.0655 \\ 0.0222 \end{bmatrix} = \begin{bmatrix} 0.037 \\ 0.028 \end{bmatrix}$$

which can also be expressed in dBmV's:

$$\begin{bmatrix} V_{CTB(tx)resp} \\ V_{CTB(rx)opt} \end{bmatrix} = \begin{bmatrix} -28.5 \\ -31 \end{bmatrix}$$

Since the 0 dB level is at 39.5 dBmV, the CTB values (in dBc) are as follows:

$$\begin{bmatrix} CTB_{(tx)resp} \\ CTB_{(rx)opt} \end{bmatrix} = \begin{bmatrix} -28.5 \\ -31 \end{bmatrix} - \begin{bmatrix} 39.5 \\ 39.5 \end{bmatrix} = \begin{bmatrix} -68 \\ -70.5 \end{bmatrix}$$

This procedure leads to the CTB of both the laser and the optical receiver. As shown, the input CTB (CTB of the laser) is relatively high compared to the CTB of the optical receiver. Nevertheless, the optical receiver also has a contribution in the CTB. Especially in the case when $CTB_{(tx)resp} \approx CTB_{(rx)opt}$, it can be valuable to perform some extra calculations, considering measurement accuracy of the measured CTB values, and the consequences on the resulting calculated values of $CTB_{(tx)resp}$ and $CTB_{(rx)opt}$. If the measurement accuracy causes significant differences in the results, more measurements have to be done in order to achieve higher accuracy.

Another way to reduce the distortion of the laser can be done by:

- Decreasing the number of channels
- Using a more linear laser
- Using a laser with an optical isolator
- Using a laser with pre-distortion.

Remark: take care that the optical connections don't have a bad optical back reflection (reflections into the laser!).

To consider measurements at other optical input power levels as well, the general form of the matrix equation is shown below:

$$\begin{bmatrix} V_{CTB(total1)} \\ V_{CTB(total2)} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 10^{\left(\frac{-2 \times (P_{opt(high)} - P_{opt(low)})}{20}\right)} & 10^{\left(\frac{-6 \times (P_{opt(high)} - P_{opt(low)})}{20}\right)} \end{bmatrix} \times \begin{bmatrix} V_{CTB(tx)resp} \\ V_{CTB(rx)opt} \end{bmatrix}$$

in which:

- $P_{opt(high)}$ the optical input power without attenuation expressed in dBm
- $P_{opt(low)}$ the optical input power with attenuation expressed in dBm

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This can be rewritten into the following form by using the inverse matrix:

$$\begin{bmatrix} V_{CTB(tx)resp} \\ V_{CTB(rx)opt} \end{bmatrix} = \text{InverseMatrix} \times \begin{bmatrix} V_{CTB(total1)} \\ V_{CTB(total2)} \end{bmatrix} \text{ in which:}$$

$$\text{InverseMatrix} = \frac{1}{10^{\left(\frac{-6 \times (P_{opt(high)} - P_{opt(low)})}{20}\right)} - 10^{\left(\frac{-2 \times (P_{opt(high)} - P_{opt(low)})}{20}\right)}} \times \begin{bmatrix} 10^{\left(\frac{-6 \times (P_{opt(high)} - P_{opt(low)})}{20}\right)} - 1 \\ -10^{\left(\frac{-2 \times (P_{opt(high)} - P_{opt(low)})}{20}\right)} + 1 \end{bmatrix}$$

10.2 Calculation of the CSO figure of optical receivers

The Composite Second Order (CSO) is the difference in dB or dBc between the carrier signal and the CSO distortion voltage. Since the CSO is a second order distortion product, the relation between the output voltage V_o and the CSO voltage V_{CSO} is 1 to 2, so the V_{CSO} increases two times faster than the output power. This means, that the relation between output voltage and CSO, which is always expressed as a distance, relative to the carrier, is 1 to 1. see Fig.13. So, an increase of 1 dB optical input power leads to an increase of 2 dB electrical output voltage, which leads to an increase of 4 dB of V_{CSO} .

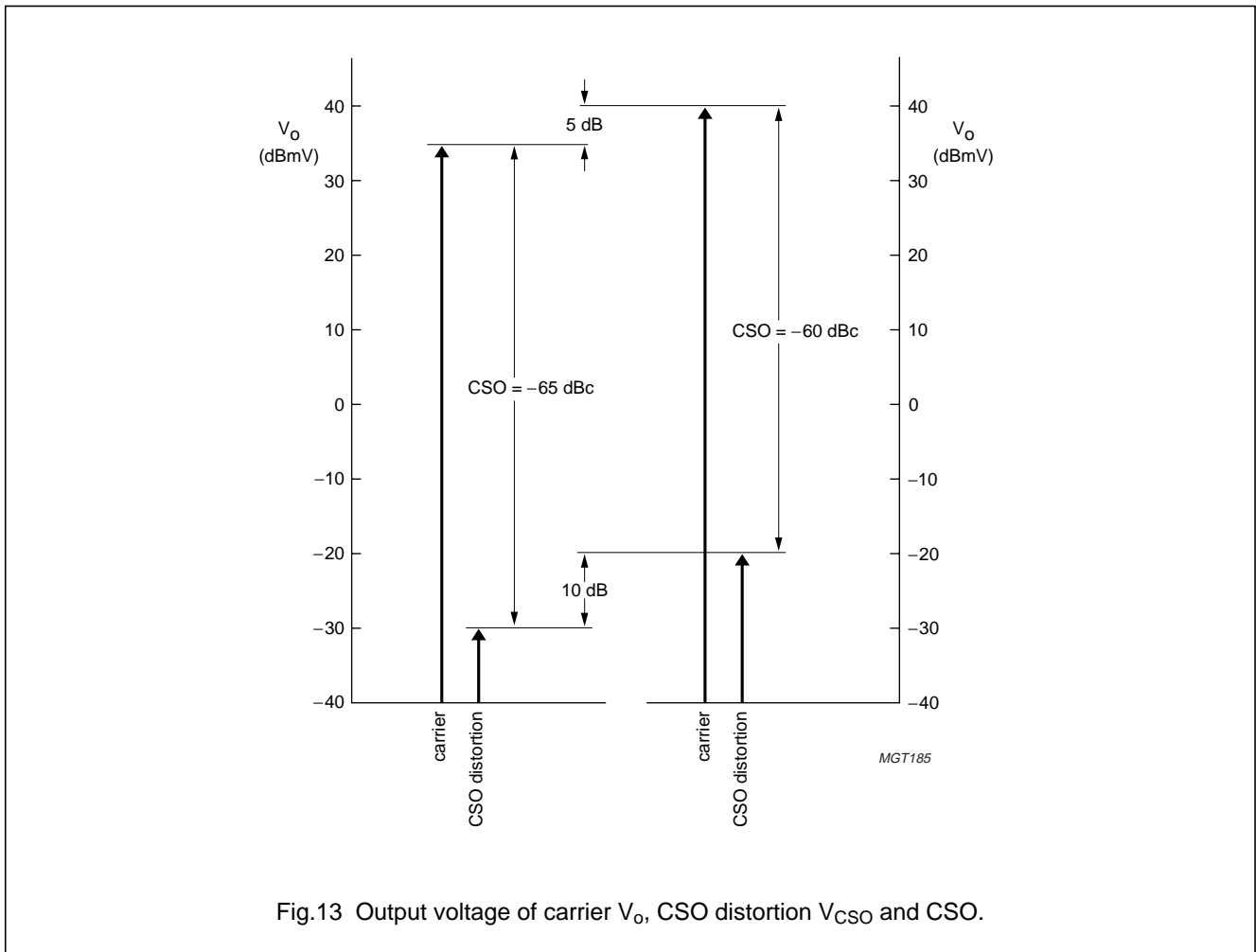


Fig.13 Output voltage of carrier V_o , CSO distortion V_{CSO} and CSO.

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As shown on the left side of Fig. 13, the output voltage V_o is 35 dBmV, and the CSO voltage V_{CSO} is -30 dBmV, resulting in a CSO of -65 dBc. On the right side of the figure, an output voltage increase of 5 dB is shown. Increasing the output voltage V_o with 5 dB to 40 dBmV results in a CSO voltage V_{CSO} increase of 10 dB to -20 dBmV. This results in a CSO of -60 dBc. In the following discussion, CSO is the relative difference between carrier signal and distortion, and is expressed in dB or dBc. The absolute CSO distortion voltage is denoted by V_{CSO} and is expressed in dBmV or mV.

For the calculation of the CSO of the optical receiver, we also make use of the 1:2 relationship between optical in and electrical out, as already discussed in Chapter 7, "Output Voltage Calculation". With these relations in mind, we can now focus on the measurement and calculation of the CSO itself.

The method of calculating the CSO figure of an optical receiver is explained with the help of the same example as is used for the calculation of CTB. The CSO of the total optical system, is measured twice: test 1 and test 2, each test at a different optical input power by means of an optical attenuator. Because the CSO of the laser is kept constant, we have two equations with two unknowns, which can be solved with linear algebra.

When the optical input power, the responsivity of the optical receiver and the CSO of the total optical system are known, the total CSO voltage V_{CSO} at the output can be calculated:

Overview of the test values of the CSO measuring

	CONDITIONS	TEST 1	TEST 2
Optical Input Power: <ul style="list-style-type: none"> • $P_{optical}$ • Modulation index 		6 dBm 4 mW 3.7%	3 dBm 2 mW 3.7%
• $P_{optical}$ (average)	one carrier	$4.0 \times 10^{-3} \times 0.037 \times (1/\sqrt{2}) =$ $104.6 \times 10^{-6} W =$ 104.6 μW	$2.0 \times 10^{-3} \times 0.037 \times (1/\sqrt{2}) =$ $52.3 \times 10^{-6} W =$ 52.3 μW
Output Voltage: responsivity = 900 V/W V_{out}	one carrier	$104.6 \times 10^{-6} \times 900 =$ 94.2 mV = 39.5 dBmV	$52.3 \times 10^{-6} \times 900 =$ 47.1 mV = 33.5 dBmV
CSO Voltage: CSO_{total} [dBc]		-64.8 dBc	-65.5 dBc
$V_{CSOtotal}$		$39.5 - 64.8 \text{ dBmV} =$ $-25.3 \text{ dBmV} =$ 0.0543 mV	$33.5 - 65.5 \text{ dBmV} =$ $-32.0 \text{ dBmV} =$ 0.0251 mV

The CSO voltage $V_{CSO(total)}$ at the output of the receiver is the addition of the amplified input $V_{CSO(tx)resp}$ and the $V_{CSO(rx)opt}$ of the optical receiver. At test 1, the total CSO voltage at the output of the optical receiver is:

$$V_{CSO(total1)} = (V_{CSO(tx)resp}) + (V_{CSO(rx)opt}) \tag{6}$$

When the input signal is attenuated optically, the CSO distance of the optical input signal stays the same. The amplified input CSO will also be the same in distance but the absolute voltage of this signal is lower; -6 dB at test 2 compared to test 1. The added CSO of the optical receiver is 6 dB lower in distance. The added $V_{CSO(rx)opt}$ is 12 dB lower in absolute output voltage. When an output signal is attenuated with x dB, the second order distortion level is $2 \times x$ dB lower.

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Using the numbers and voltages of the formulas of test 1, the total output CSO voltage $V_{\text{CSO}(\text{total}2)}$ of test 2 is:

$$V_{\text{CSO}(\text{total}2)} = (V_{\text{CSO}(\text{tx})\text{resp}} - 6 \text{ dB}) + (V_{\text{CSO}(\text{rx})\text{opt}} - 12 \text{ dB}) \quad (7)$$

$$V_{\text{CSO}(\text{total}2)} = (V_{\text{CSO}(\text{tx})\text{resp}} \times 0.5012) + (V_{\text{CSO}(\text{rx})\text{opt}} \times 0.2519) \quad (8)$$

Equations (6) and (8) form two equations with two unknowns, and can be solved with linear algebra:

$$\begin{bmatrix} V_{\text{CSO}(\text{total}1)} \\ V_{\text{CSO}(\text{total}2)} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0.5012 & 0.2519 \end{bmatrix} \times \begin{bmatrix} V_{\text{CSO}(\text{tx})\text{resp}} \\ V_{\text{CSO}(\text{rx})\text{opt}} \end{bmatrix}$$

in which

$V_{\text{CSO}(\text{total}1)}$	measured CSO voltage at high optical input power
$V_{\text{CSO}(\text{total}2)}$	measured CSO voltage at low optical input power
$V_{\text{CSO}(\text{tx})\text{resp}}$	amplified CSO voltage of laser
$V_{\text{CSO}(\text{rx})\text{opt}}$	CSO voltage of optical receiver

In numbers, this is as follows:

$$\begin{bmatrix} 0.0543 \\ 0.0251 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0.5012 & 0.2519 \end{bmatrix} \times \begin{bmatrix} V_{\text{CSO}(\text{tx})\text{resp}} \\ V_{\text{CSO}(\text{rx})\text{opt}} \end{bmatrix}$$

With deriving the inverse of the 2 x 2 matrix, we get the following result, expressed in mV:

$$\begin{bmatrix} V_{\text{CSO}(\text{tx})\text{resp}} \\ V_{\text{CSO}(\text{rx})\text{opt}} \end{bmatrix} = \frac{1}{0.2519 - 0.5012} \times \begin{bmatrix} 0.2519 & -1 \\ -0.5012 & 1 \end{bmatrix} \times \begin{bmatrix} 0.0543 \\ 0.0251 \end{bmatrix} = \begin{bmatrix} 0.0459 \\ 0.0084 \end{bmatrix}$$

which can also be expressed in dBmV's:

$$\begin{bmatrix} V_{\text{CSO}(\text{tx})\text{resp}} \\ V_{\text{CSO}(\text{rx})\text{opt}} \end{bmatrix} = \begin{bmatrix} -26.8 \\ -41.5 \end{bmatrix}$$

Since the 0 dB level is at 39.5 dBmV, the CSO values (in dBc) are as follows:

$$\begin{bmatrix} \text{CSO}_{(\text{tx})\text{resp}} \\ \text{CSO}_{(\text{rx})\text{opt}} \end{bmatrix} = \begin{bmatrix} -26.8 \\ -41.5 \end{bmatrix} - \begin{bmatrix} 39.5 \\ 39.5 \end{bmatrix} = \begin{bmatrix} -66.3 \\ -81 \end{bmatrix}$$

This procedure leads to the CSO of both the laser and the optical receiver. As shown, the input CSO (CSO of the laser) is high compared to the CSO of the optical receiver. Especially in this case, when $\text{CSO}_{(\text{tx})\text{resp}} \gg \text{CSO}_{(\text{rx})\text{opt}}$, it is essential to perform some extra calculations, considering measurement accuracy of the measured CSO values, and the consequences on the resulting calculated values of $\text{CSO}_{(\text{tx})\text{resp}}$ and $\text{CSO}_{(\text{rx})\text{opt}}$. It shows, that a measurement accuracy of ± 0.1 dB of the two CSO measurements, results in a -78.8 to -83.9 dB window for the $\text{CSO}_{(\text{rx})\text{opt}}$, and a -65.9 to -66.6 dB window for $\text{CSO}_{(\text{tx})\text{resp}}$. If the measurement accuracy causes significant differences in the results, more measurements have to be done in order to achieve higher accuracy.

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Another way to reduce the distortion of the laser can be done by:

- Decreasing the number of channels
- Using a more linear laser
- Using a laser with an optical isolator
- Using a laser with pre-distortion.

Remark: take care that the optical connections don't have a bad optical back reflection (reflections into the laser!).

To consider measurements at other optical input power levels as well, the general form of the matrix equation is shown below:

$$\begin{bmatrix} V_{\text{CSO(total1)}} \\ V_{\text{CSO(total2)}} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 10^{\left(\frac{-2 \times (P_{\text{opt(high)}} - P_{\text{opt(low)}})}{20}\right)} & 10^{\left(\frac{-4 \times (P_{\text{opt(high)}} - P_{\text{opt(low)}})}{20}\right)} \end{bmatrix} \times \begin{bmatrix} V_{\text{CSO(tx)resp}} \\ V_{\text{CSO(rx)opt}} \end{bmatrix}$$

In which:

$P_{\text{opt(high)}}$ the optical input power without attenuation; in dBm

$P_{\text{opt(low)}}$ the optical input power with attenuation; in dBm

This can be rewritten into the following form by using the inverse matrix:

$$\begin{bmatrix} V_{\text{CSO(tx)resp}} \\ V_{\text{CSO(rx)opt}} \end{bmatrix} = \text{InverseMatrix} \times \begin{bmatrix} V_{\text{CSO(total1)}} \\ V_{\text{CSO(total2)}} \end{bmatrix}$$

in which:

$$\text{InverseMatrix} = \frac{1}{10^{\left(\frac{-4 \times (P_{\text{opt(high)}} - P_{\text{opt(low)}})}{20}\right)} - 10^{\left(\frac{-2 \times (P_{\text{opt(high)}} - P_{\text{opt(low)}})}{20}\right)}} \times \begin{bmatrix} 10^{\left(\frac{-4 \times (P_{\text{opt(high)}} - P_{\text{opt(low)}})}{20}\right)} & -1 \\ -10^{\left(\frac{-2 \times (P_{\text{opt(high)}} - P_{\text{opt(low)}})}{20}\right)} & 1 \end{bmatrix}$$

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11 INPUT DYNAMIC RANGE

The photodiodes used in the Philips optical receivers can handle a maximum input power of 5 mW = 7 dBm, without any damage or degradation of the photodiode.

11.1 $V_{\text{pin 1}}$ versus input power

In Fig.14, the current monitor voltage at pin 1 is given as a function of the optical input power. Note, that the optical input power is expressed in mW.

This voltage at pin 1, expressed in Volts, is linear related to the optical input power, expressed in mW, when ranging between 1 and 5 mW.

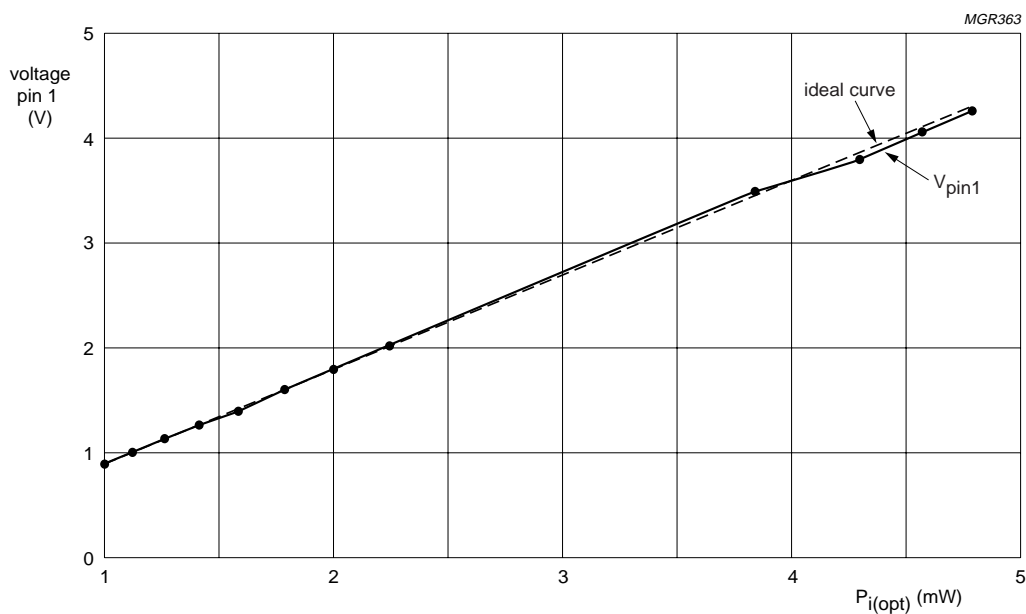


Fig.14 The current monitor voltage at pin1 as a function of the optical input power $P_{i(\text{opt})}$.

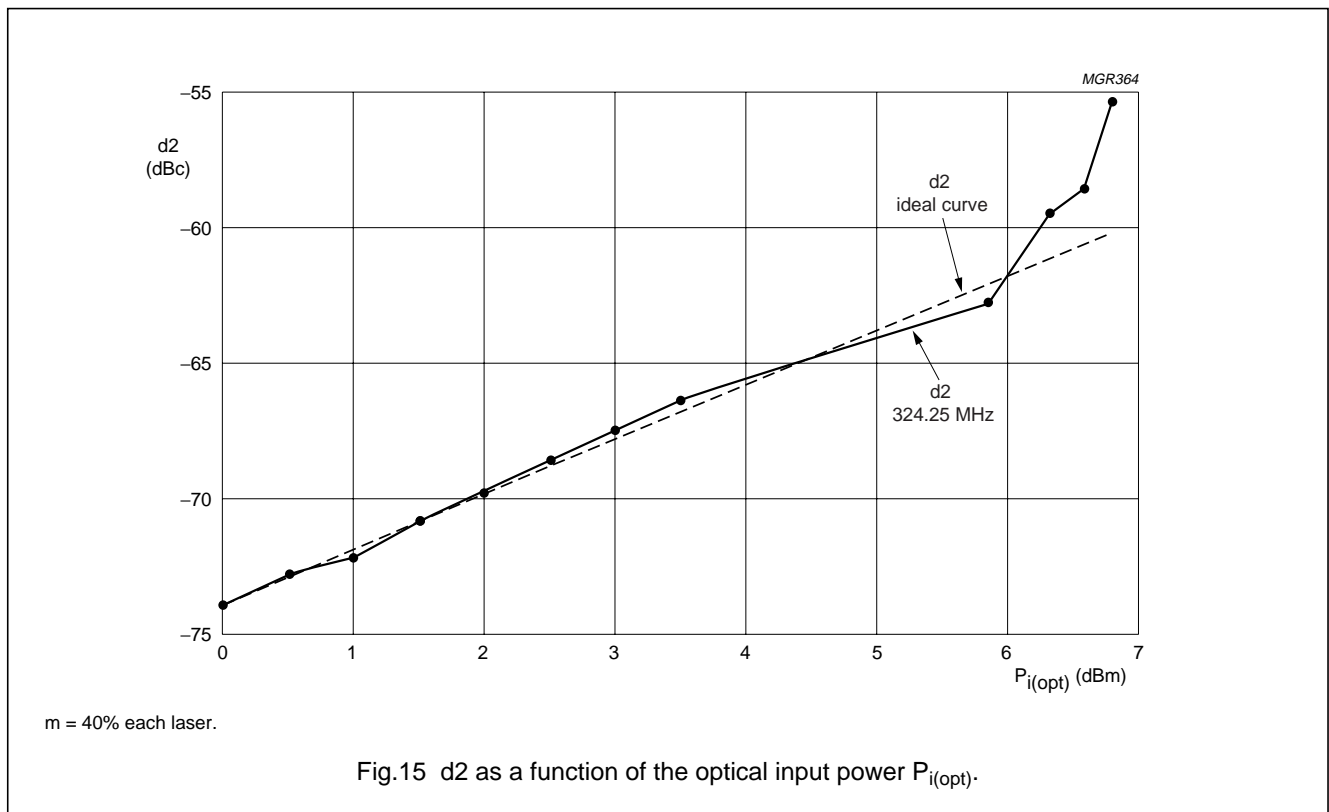
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11.2 d2 versus input power

In Fig.15, the second order distortion is given as function of optical input power. Note, that the optical input power is expressed in dBm.

The second order distortion, expressed in dBc, is linear related to the optical input power, expressed in dBm, when ranging between 0 and 6. Above 6 dBm, the optical receiver becomes non-linear because the reverse voltage decreases too much. The reverse biasing of the photodiode is done via two 1 kΩ resistors. 6 dBm optical input power gives a voltage decrease of 8 V (6 dBm = 4 mW, causing a pin-diode current ≈ 4 mA), which brings the photodiode in the non-linear region.



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12 OPTICAL CONNECTORS

Optical connectors are used to couple the light from one glass fibre into another glass fibre. For CATV applications, single mode glass fibre is used. The nominal mode field diameter of these fibres (that part of the glass fibre which is used to transport the light) is 9 to 10 μm . Because of this small diameter, a precise mating of the two glass fibre end faces is needed to couple all the light from one glass fibre into the other glass fibre.

Another problem with glass fibre is reflection of light when the transport medium changes, e.g. from glass into air. Reflection means losses and also a chance exists that light gets back into the laser. The last effect influence the proper functioning of the laser. To solve these problems as much as possible, specific high quality connectors are used. Philips supplies FC0/APC and SC0/APC connectors.

12.1 APC-Ferrules

In an optical connector, the end of the glass fibre is placed in a ferrule, a ceramic or glass bush to fix the glass fibre within the mechanical outline. The last three characters of the optical connector names are used to specify the end face of this ferrule of the connector. The characters APC stand for Angled Physical Contact. The end of the ferrule used in the FC0/APC and SC0/APC connectors is angled; $8^\circ \pm 0.5^\circ$. Because of this angle, less light is reflected into the glass fibre when the glass fibre is open-ended (optical return loss is minimally 60 dB).

By using a physical contact between the end of two ferrules, the light goes directly from glass fibre into glass fibre. This means less reflections and also less losses (optical insertion loss maximal 0.5 dB). When light goes from one glass fibre via air into another glass fibre, the optical losses are 8% (an interface between glass fibre and air gives 4% loss). The end faces of APC ferrules are also polished to get a very flat plane which makes a better physical contact. The repeatability of APC connectors is 0.2 dB. Two mated APC ferrules are drawn in Fig.16.

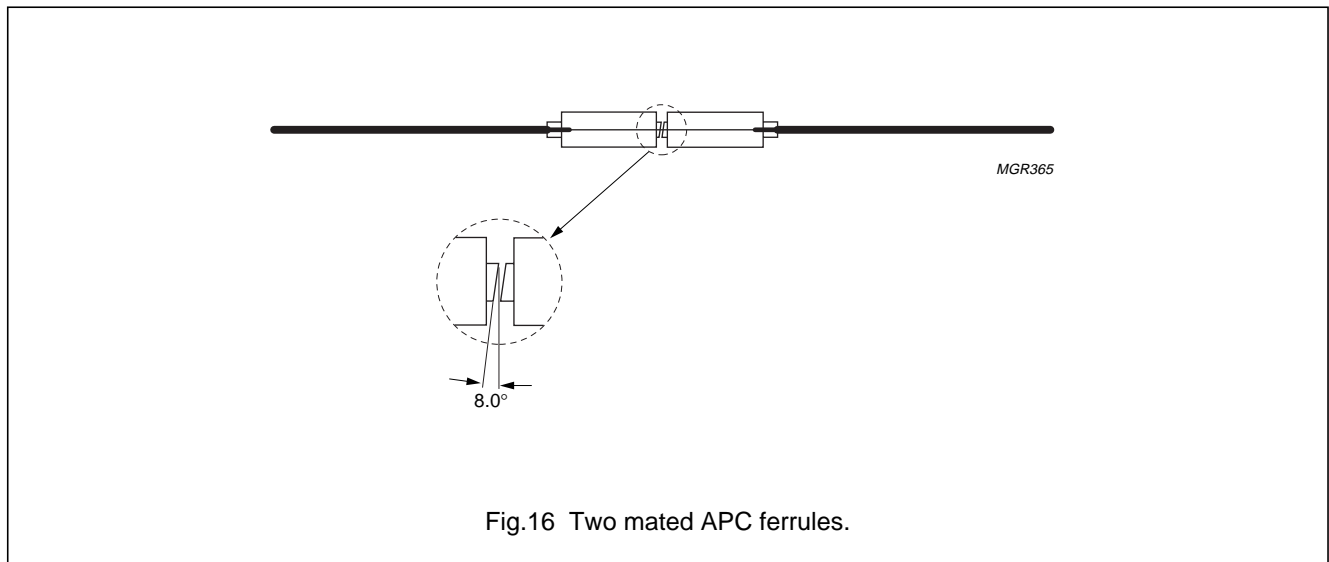


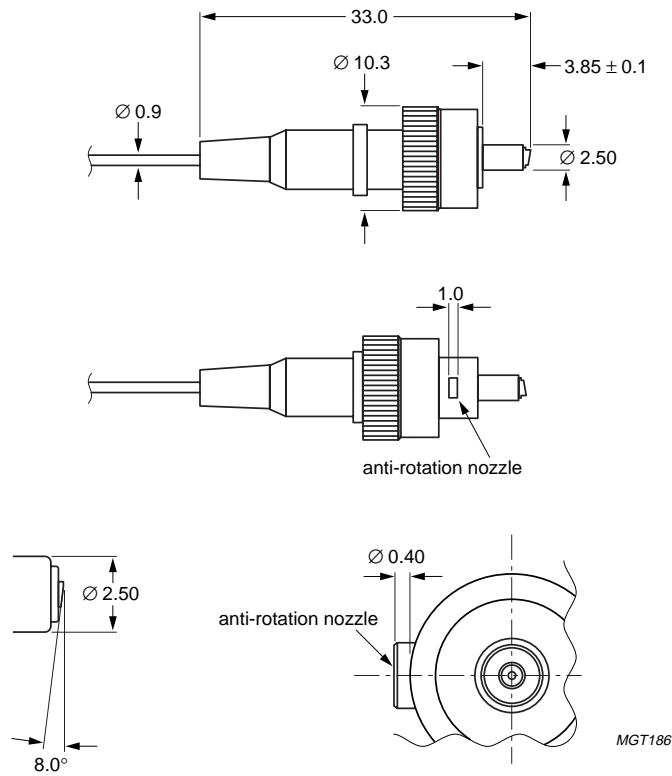
Fig.16 Two mated APC ferrules.

12.2 FC and SC Connectors

The first two characters of the connector names are used to specify the mechanical outline of the connector. The outlines FC and SC have a very tight mechanical specification to get the ferrules exactly in front of each other and with a specified pressure pushed to each other by a spring (7.85 to 11.8 Newton). The outlines of the FC0/APC and SC0/APC connectorized are shown in Figs 17 and 18.

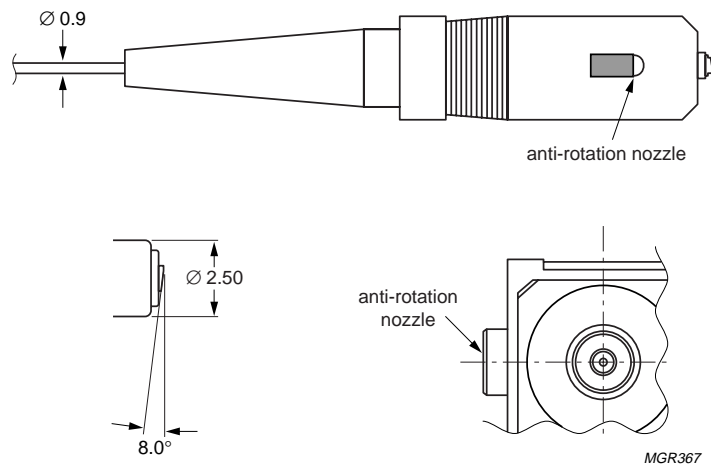
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Dimensions in millimetre.

Fig.17 FC0/APC connector.



Dimensions in millimetre.

Fig.18 SC0/APC connector.

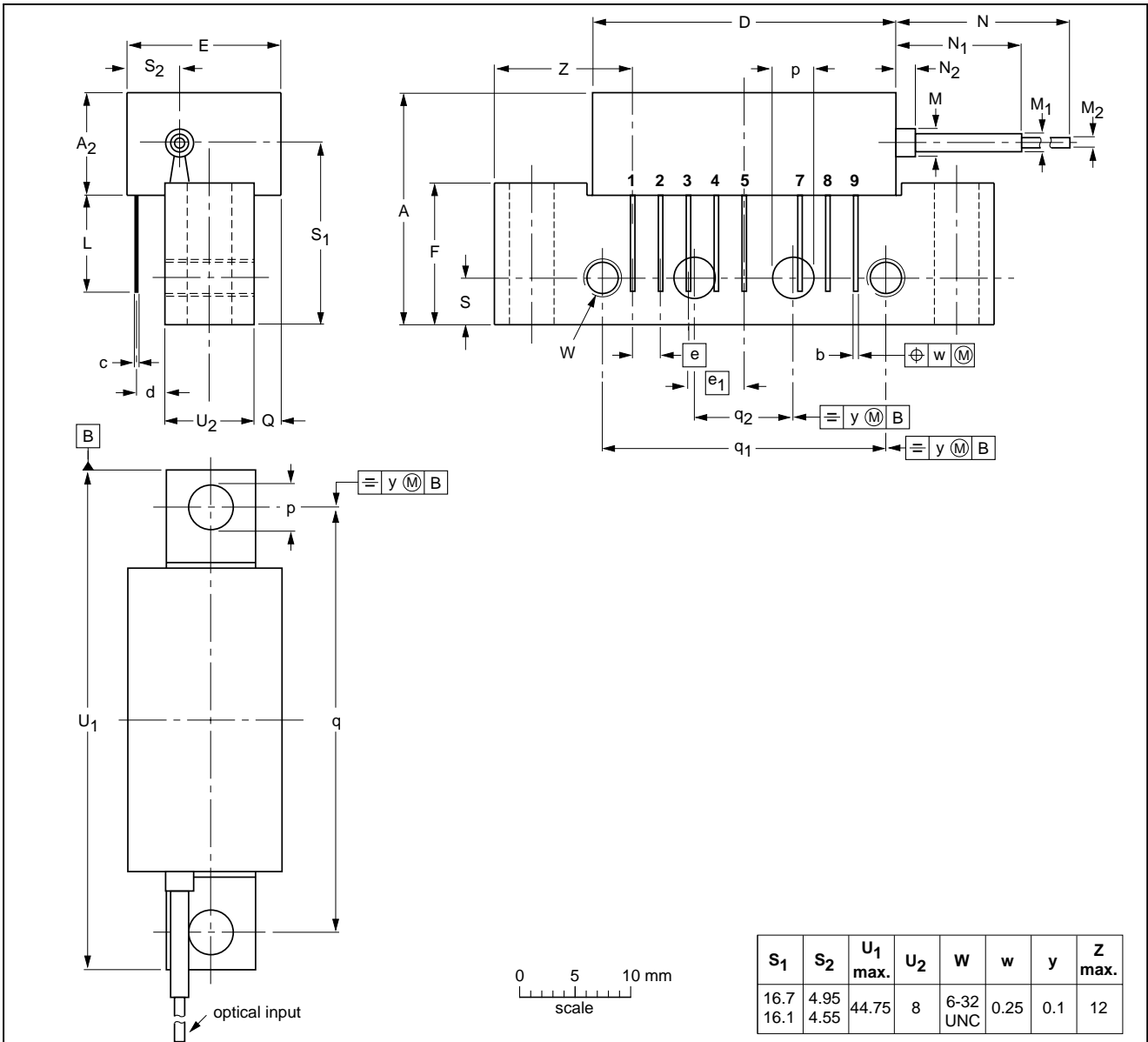
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13 PACKAGE OUTLINES

Rectangular single-ended package; aluminium flange; 2 vertical mounting holes;
2 x 6-32 UNC and 2 extra horizontal mounting holes; optical input; 8 gold-plated in-line leads

SOT115T



S ₁	S ₂	U ₁ max.	U ₂	W	w	y	Z max.
16.7	4.95	44.75	8	6-32 UNC	0.25	0.1	12
16.1	4.55						

DIMENSIONS (mm are the original dimensions)

UNIT	A max.	A ₂ max.	b	c	D max.	d max.	E max.	e	e ₁	F	L min.	M	M ₁	M ₂	N min.	N ₁ max.	N ₂ max.	p	Q max.	q	q ₁	q ₂	S
mm	20.8	9.1	0.51 0.38	0.25	27.2	2.54	13.75	2.54	5.08	12.7	8.8	2.5	1.6	0.9	1000	10.7	5	4.15 3.85	2.4	38.1	25.4	10.2	4.2

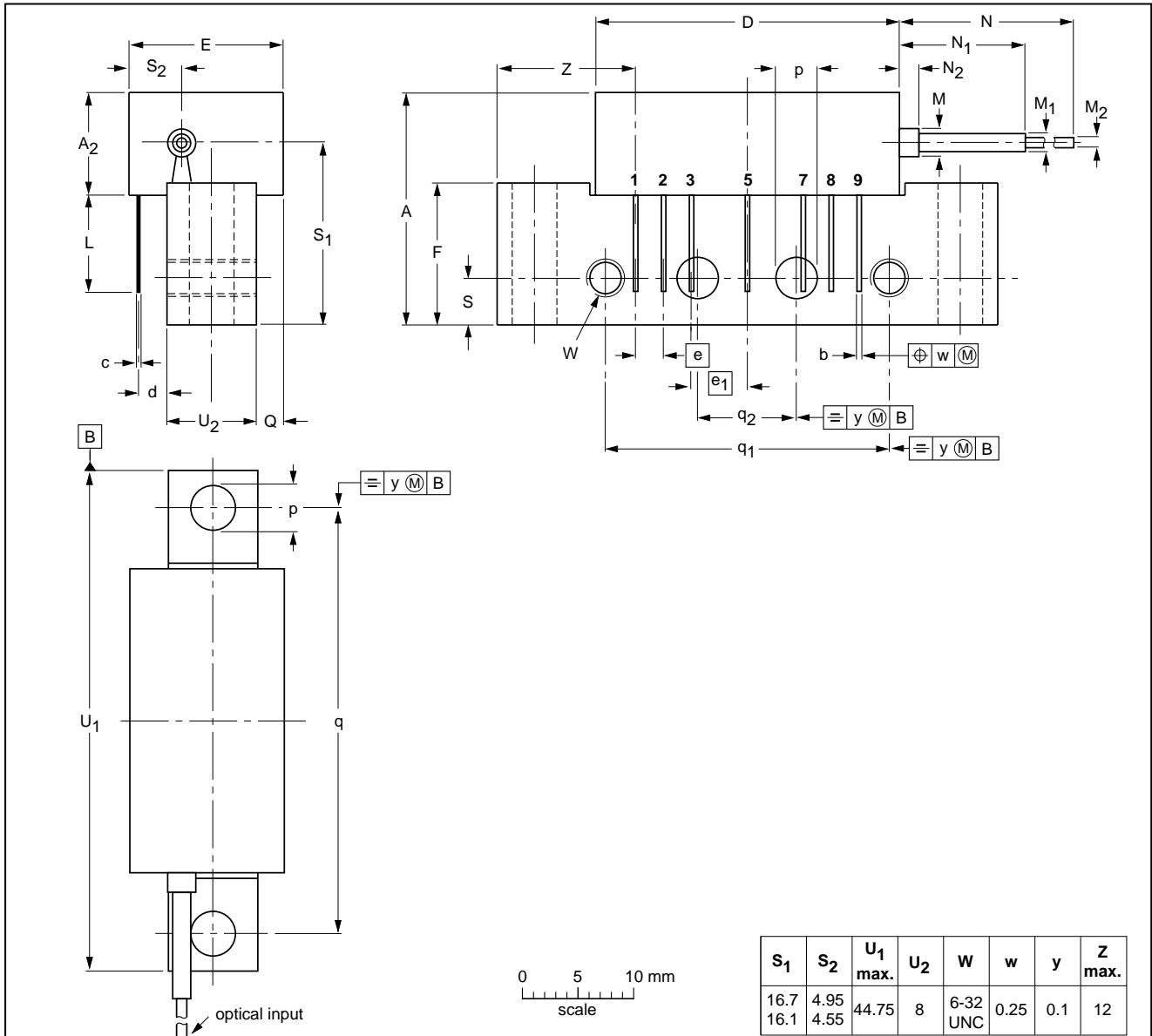
OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT115T						-99-04-13 01-08-10

Using a Philips Optical Receiver in CATV Applications

Application note AN98060

**Rectangular single-ended package; aluminium flange; 2 vertical mounting holes;
2 x 6-32 UNC and 2 extra horizontal mounting holes; optical input; 7 gold-plated in-line leads**

SOT115U



DIMENSIONS (mm are the original dimensions)

UNIT	A max.	A ₂ max.	b	c	D max.	d max.	E max.	e	e ₁	F	L min.	M	M ₁	M ₂	N min.	N ₁ max.	N ₂ max.	p	Q max.	q	q ₁	q ₂	S
mm	20.8	9.1	0.51 0.38	0.25	27.2	2.54	13.75	2.54	5.08	12.7	8.8	2.5	1.6	0.9	1000	10.7	5	4.15 3.85	2.4	38.1	25.4	10.2	4.2

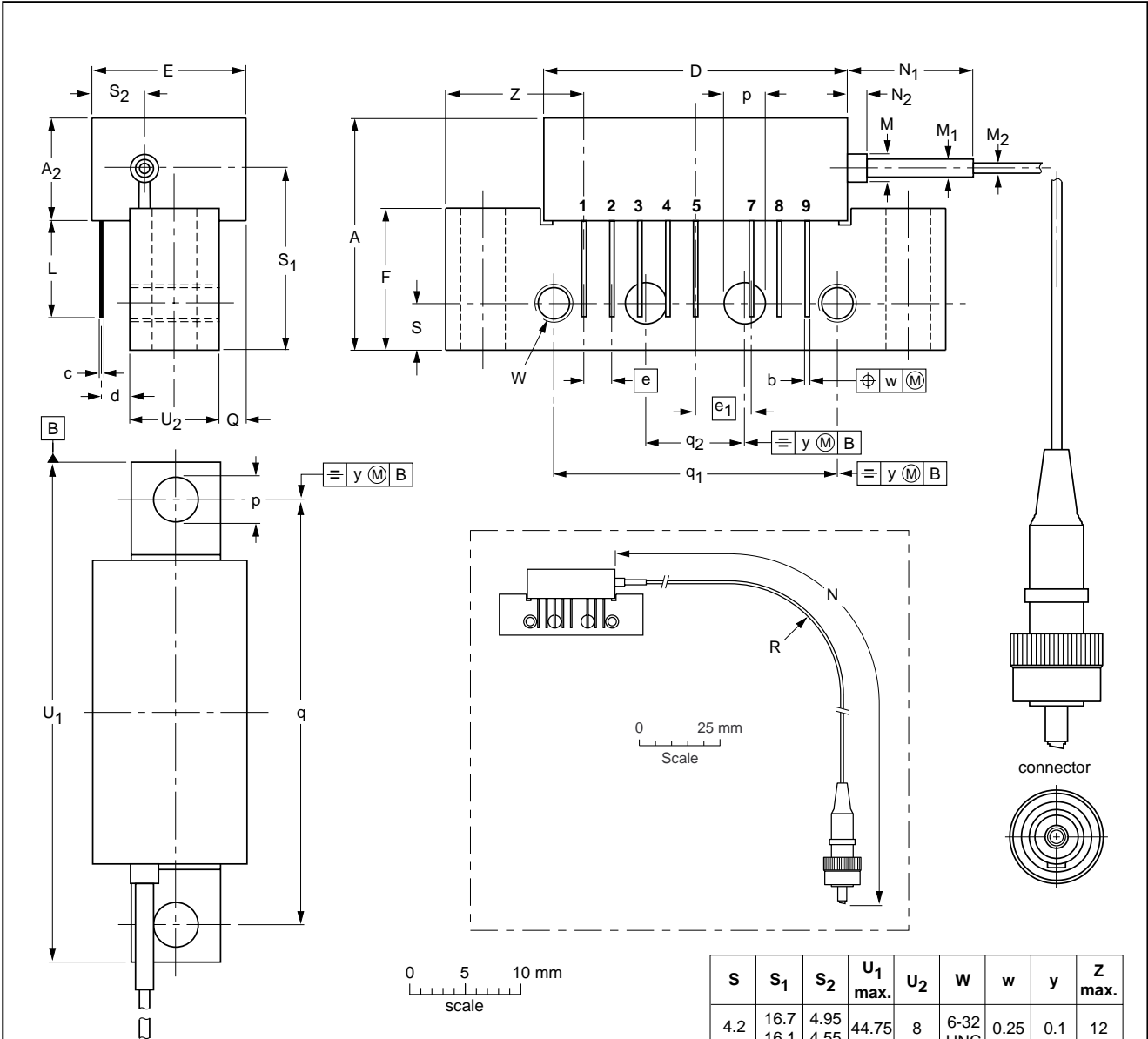
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	IEC	JEDEC	EIAJ		
SOT115U					99-04-13 01-08-10

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**Rectangular single-ended package; aluminium flange;
2 vertical mounting holes; 2 x 6-32 UNC and 2 extra horizontal mounting holes;
optical input with connector; 8 gold-plated in-line leads**

SOT115X



S	S ₁	S ₂	U ₁ max.	U ₂	W	w	y	Z max.
4.2	16.7 16.1	4.95 4.55	44.75	8	6-32 UNC	0.25	0.1	12

DIMENSIONS (mm are the original dimensions)

UNIT	A max.	A ₂ max.	b	c	D max.	d max.	E max.	e	e ₁	F	L min.	M	M ₁	M ₂	N	N ₁ max.	N ₂ max.	p	Q max.	q	q ₁	q ₂	R min.
mm	20.8	9.1	0.51 0.38	0.25	27.2	2.54	13.75	2.54	5.08	12.7	8.8	2.5	1.6	0.9	861 746	10.7	5	4.15 3.85	2.4	38.1	25.4	10.2	35

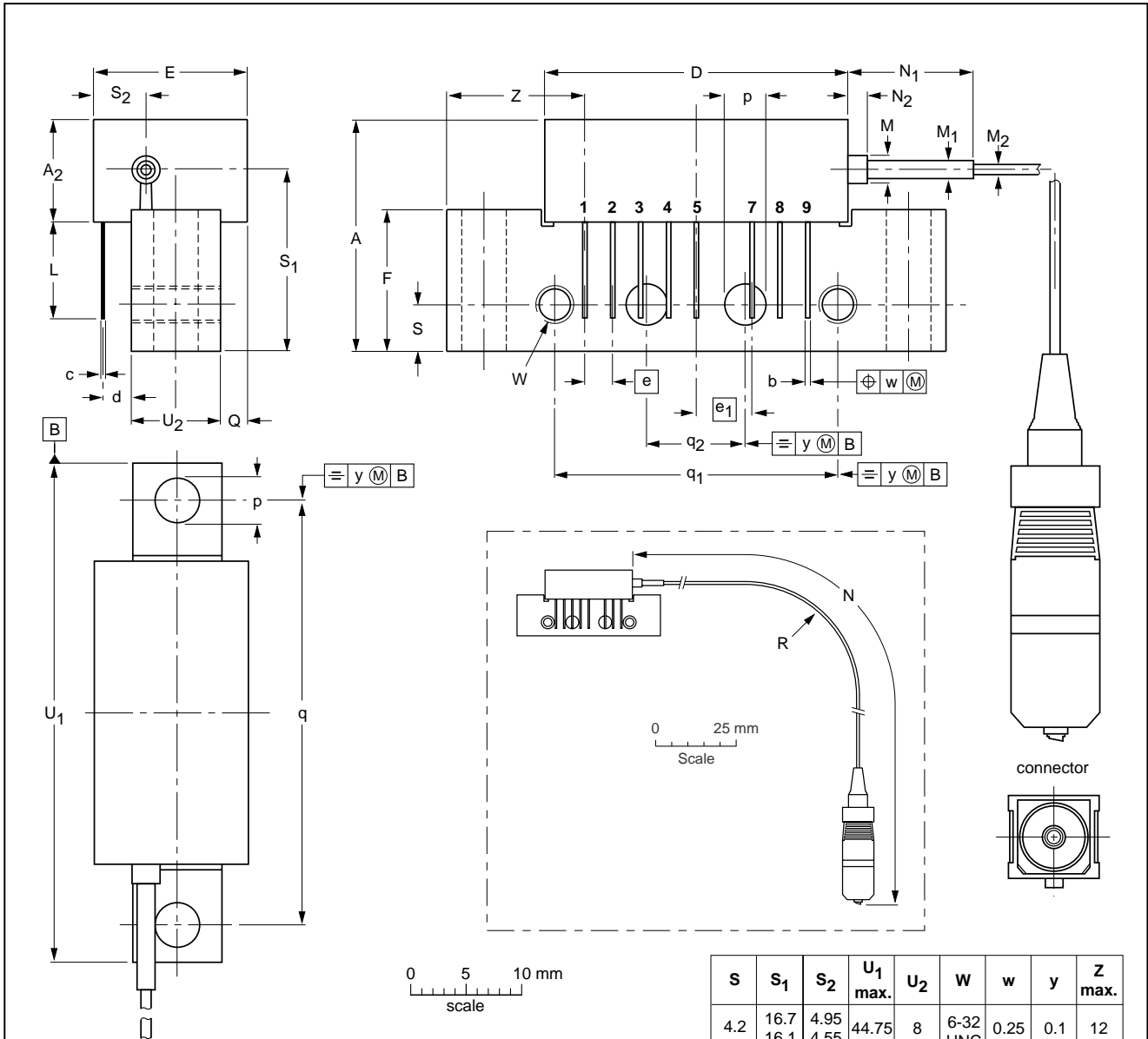
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	IEC	JEDEC	EIAJ			
SOT115X						00-01-06- 01-08-10

Using a Philips Optical Receiver in CATV Applications

Application note AN98060

**Rectangular single-ended package; aluminium flange;
2 vertical mounting holes; 2 x 6-32 UNC and 2 extra horizontal mounting holes;
optical input with connector; 8 gold-plated in-line leads**

SOT115Y



S	S ₁	S ₂	U ₁ max.	U ₂	W	w	y	Z max.
4.2	16.7 16.1	4.95 4.55	44.75	8	6-32 UNC	0.25	0.1	12

DIMENSIONS (mm are the original dimensions)

UNIT	A max.	A ₂ max.	b	c	D max.	d max.	E max.	e	e ₁	F	L min.	M	M ₁	M ₂	N	N ₁ max.	N ₂ max.	p	Q max.	q	q ₁	q ₂	R min.
mm	20.8	9.1	0.51 0.38	0.25	27.2	2.54	13.75	2.54	5.08	12.7	8.8	2.5	1.6	0.9	861 746	10.7	5	4.15 3.85	2.4	38.1	25.4	10.2	35

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT115Y						00-01-06 01-08-10

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