APPLICATION NOTE

Using a Philips Optical Receiver in CATV Applications

AN98060

Philips
Semiconductors

PHILIPS

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CONTENTS

1 MECHANICAL OUTLINES, PINNING AND GLASSFIBER OF THE MODULE

1.1 Mechanical Outlines

Unconnectorized optical CATV receivers are encapsulated in a SOT115U outline. For a detail specification see Chapter “Package outline”.

1.2 Pinning

The pinning of the BGE887BO is

PIN	DESCRIPTION
1	Voltage Monitor of the Photodiode Current (typ. 0.8 V/mW)
2	Common
3	Common
5	$+V_B$
7	Common
8	Common
9	75 Ω electrical output

1.3 Glassfiber

1.3.1 DIMENSIONS OF THE NKF GLASSFIBER

The optical input of the BGY887BO is a single mode glassfiber of NKF. This glassfiber is double coated.

The dimensions of this glassfiber are:

Nominal mode field diameter	9 – 10 µm ± 10%
Cladding diameter	125 µm ± 3 µm
Primary coating diameter	250 µm ± 15 µm
Secondary coating diameter	950 µm + 0 mm/–0.1 mm

The mechanical characteristics are:

Bending radius	min. 30 mm
Pulling force	max. 6 Newton

1.3.2 DIMENSIONS OF THE SIECOR GLASSFIBER

The optical input of the BGE887BO is a single mode glassfiber of Siecor (Corning SMF-28, type 1R41-31131-24). This glassfiber is double coated.

The dimension of this glassfiber are:

Nominal mode field diameter	9.3 μm ± 0.5 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. 30 mm
Pulling force	max. 6 Newton

1.3.3 STRIPPING OF GLASSFIBER

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

1. Strip the secondary coating with a mechanical stripper. The diameter of this stripper (closed) must be 0.40 mm (Parts of ±1.5 cm length 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 glassfiber can also be removed by dissolving the coating with di-chlorine-methylene (CH2CL2).

Two mechanical strippers that can be used are:

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

These strippers can be ordered at:

Radikor Electronics B.V.
PO-box 50006
1305 AA Almere
The Netherlands
tel. +31 365 312 554
fax +31 365 312 465

2 SPECIFICATION:

In the specification of optical receivers, a table with characteristics is included where the main parameters of the device are mentioned. In this chapter, these characteristics are explained.

2.1 Responsivity

The responsivity of an optical receiver is defined as: $\text{responsivity} = \dfrac{\text{output voltage [V]}}{\text{input power of modulated light [W]}}$

The responsivity is given in voltage per Watt and can be calculated to Amperes/Watt and Watt/Watt as follows:

Responsivity [A/W] = Responsivity [V/W]/load impedance [Ω]

Responsivity [W/W] = Responsivity $[V/W]^2$/load impedance [Ω].

Measuring 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 function of frequency, the DC output has a responsivity of 2 V/W of the un-modulated 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 75 Ω. 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:

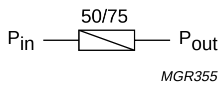


Fig.1 Minimum loss pad.

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

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

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

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

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

The current attenuation of a minimum loss pad from 50 to 75 Ω is 20.Log(0.4236) = –7.46 dB.

The current attenuation of a minimum loss pad from 75 to 50 Ω is 20.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 responsivity cal.ref.rec. = 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 corrected for this 'thru-line':

Responsitivity DUT	= measured resp	+	current att	+	responsivity cal.ref.rec.
	= 36 dB	+	–7.46 dB	+	–7.00 dB
	= 21.54 dB				
	= 11.93 A/W				
	= 895.5 V/W (in 75 Ω)				

2.2 Flatness Of The Frequency Response

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 = constant
C = cable constant
f_x = desired frequency
f_1 = start frequency

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:

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

where
R_n = the measured response at the stop frequency
R_1 = the measured response at the start frequency
f_n = stop frequency.

The value of R is chosen so 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.

2.3 In- And Output Return Losses

The output return loss of an optical receiver is the measured S22 of the output of this module in dB. This S22 is the $-20 \log_{10}$ of the reflection coefficient, which indicates the matching between the output impedance and the characteristic impedance of 75 Ω.

The input return loss of an optical receiver is the optical back reflection of the photodiode, measured at the fiber. At a level of –45 dB input reflection, 0.56% of the total light is reflected back into the fiber.

2.4 Second Order Distortion

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

Example:

$P_{optical}$	= 0.5 mW per laser
$m_{odulation\ index}$	= 40%
f_1	= 135 MHz
f_2	= 189.25 MHz
$f_{measurement}$	= 324.25 MHz

- Two lasers are set at an (DC) optical output power level of 0.5 mW each
- One laser is modulated for 40% with 324.25 MHz
- The output power measured at 324.25 MHz is set as 0 dB level.

After this calibration:

- Two lasers are modulated for 40% with 135 and 186.25 MHz respectively
- The distortion power is measured at the frequency $f_1 + f_2$ = 324.25 MHz compared to the 0 dB level. This distance is the second order distortion.

2.5 Third Order Distortion

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

Example:

$P_{optical}$	= 0.33 mW per laser
$m_{odulation\ index}$	= 40 %
f_1	= 326.25 MHz
f_2	= 333.25 MHz
f_3	= 335.25 MHz
$f_{measurement}$	= 324.25 MHz

- Three lasers are set at a (DC) optical output power level of 0.33 mW each respectively
- One laser is modulated for 40% with 324.25 MHz
- The output power measured at 324.25 MHz is set as 0 dB level.

After this calibration:

- Three lasers are modulated for 40% with 326.25, 333.25 and 335.25 MHz
- The distortion power is measured at the frequency $f_1 + f_2 - f_3$ = 324.25 MHz compared to the 0 dB level. This distance is the third order distortion.

2.6 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.

2.7 Equivalent Input Noise

The schematic of the measurement set-up to measure the equivalent input noise of the optical receiver is given in Fig.2:

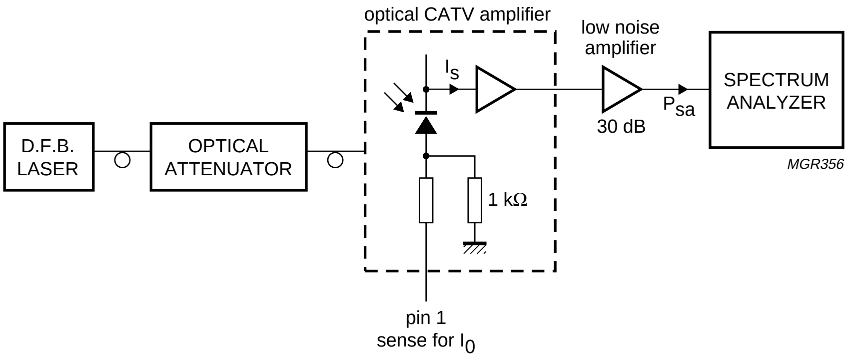


Fig.2 Equivalent input noise measurement set-up.

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

P_{sa} = Laser noise + Photodiode shot noise + Optical receiver noise (thermal).

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

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

Where:

P_{sa}	= noise power measured at the spectrum analyzer	[W]
RIN	= relative intensity noise of the laser source	[dB/Hz]
I_0	= DC detector current (= $V_{pin\ 1}$/1 kΩ)	[A]
e	= 1.6E-19	[Coulomb = A/Hz]
I_n	= receiver equivalent input noise current	[A/√Hz]
B	= resolution bandwidth of spectrum analyzer	[Hz]
Rd	= responsivity of the opt. CATV ampl. = $\frac{P_{sa}}{I_s^2}$	[Ω]

Out of this noise power measurement, the receiver equivalent input noise can be calculated, which is also frequency dependent. For this calculation, a few assumptions are made:

- RIN of the used laser > 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 dB)
- The noise floor of the used spectrum analyzer is much lower than the receiver noise (use a good pre-amplifier if necessary, as given in the schematic of the measurement equipment).

2.7.1 MEASUREMENT

1. Measure the P_{sa} with no optical input signal (I_0 = 0 mA, $V_{pin\ 1}$ = 0 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 minimally 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 by measuring the $V_{pin\ 1}$/1 kΩ. 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 function of I_0.

2.7.2 CALCULATION

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

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

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

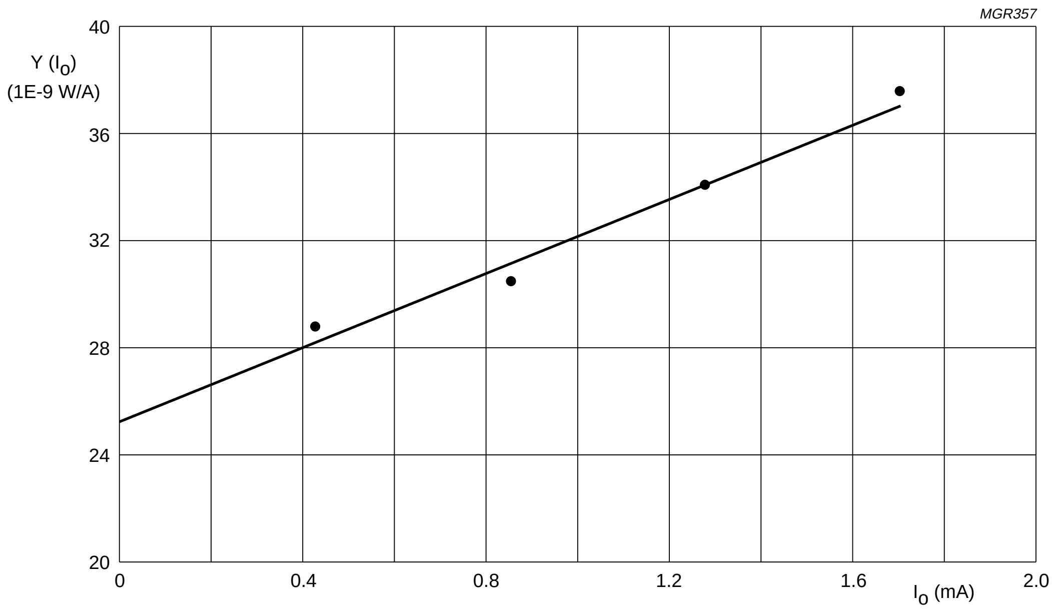


Fig.3 $Y(I_0)$ versus I_0.

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

For I_0 = 0 (no optical input signal):

$P_{sa}(0) = I_n^2 \cdot B \cdot Rd$ (see (1)) and $Y(0) = 2 \cdot e \cdot Rd \cdot B$ (see (2)).

These two formulas combined give the formula to calculate the receiver equivalent input noise (EIN):

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

where:

P_{sa} = the measured noise power at the spectrum analyzer without an optical input signal

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

I_n = the receiver equivalent noise current.

3 MONITOR CURRENT 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 current out of the photodiode is the responsivity of a photodiode. This responsivity depends on the used wavelength, the so called spectral sensitivity. The photodiodes used in 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 current out 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 (> 10 MΩ, low ohmic will influence the voltage drop). Because of the use of a 1 kΩ transfer resistor, the monitor current pin will have a typical output voltage of 0.85 V/mW.

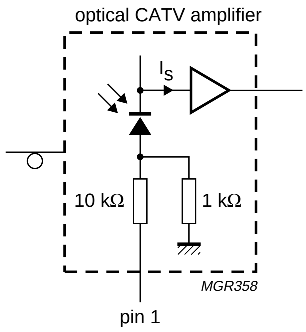


Fig.4 The monitor current pin.

The pin 1 output voltage is dependent on several items:

P_{opt} = Optical input power at the receiver

Resp = Responsivity of the used photodiode

$R_{transfer}$ = 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 maximally 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 ±1%. After the assembly of the total receiver, this accuracy is decreased to 1000 Ω ±10% due to different temperature steps.

The pin 1 accuracy is:

$V_{pin\ 1}$ = (P_{opt} – Connector loss) × Resp × $R_{transfer}$

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

$V_{pin1\ max}$ = P_{opt} × 1 × 0.95 × 1100 = 1.05 V/mW (0.93 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.

4 OPTICAL CATV RECEIVER TEST SETUP

The schematic diagram of the optical CATV receiver test set-up, which is used by Philips, is given at the next page. At the left side of this diagram, three lasers are placed, biased via three laser power supplies. The three lasers can be modulated by three RF-generators which is needed to measure **d2 and d3**. 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 measuring 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 splitted 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 **d2 and d3** 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. With a multimeter, the pin 1 voltage of the DUT can be measured, needed for the **EIN** measurement. The output of the DUT can be switched to port 2 of the S-parameter test-set to measure the **responsivity and S22**. The output of the DUT can also be connected to the input of a spectrum analyzer to measure **d2 and d3**. 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 which is used is:

- 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 (50/50%, 30/70% and 5/95% ratio)
- 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.

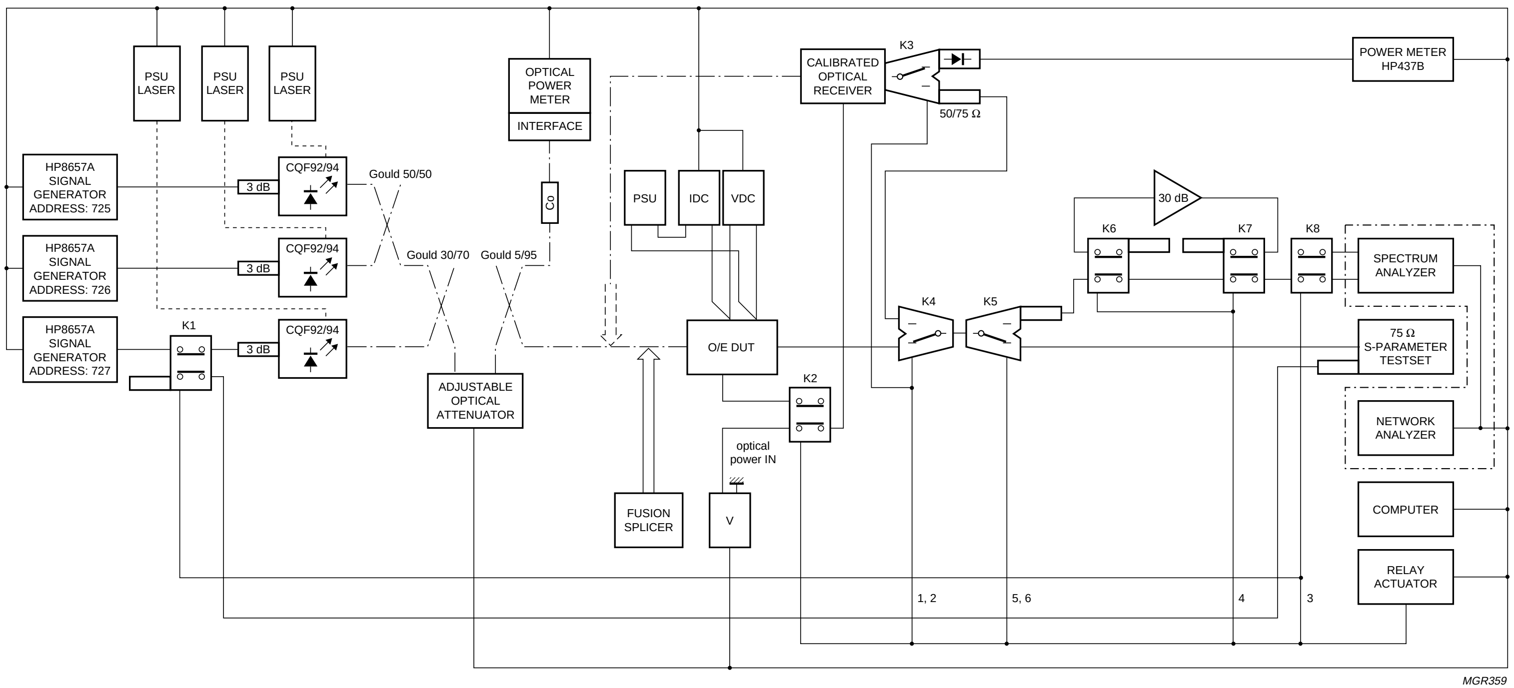


Fig.5 Optical Receiver Test Setup.

5 BGE887BO CIRCUIT DIAGRAM

The BGE887BO circuit diagram is given in Fig.6.

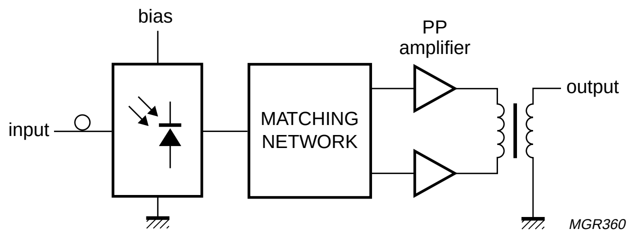


Fig.6 Circuit diagram of the BGE887BO.

The photo-diode at the input of a BGE887BO transducers the light into electrical current. The matching networks matches the photo-diode to the push-pull amplifiers. The transformers used in this matching network amplify the photo-diode 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.

6 OUTPUT VOLTAGE CALCULATION

An optical CATV receiver converts amplitude modulated optical light into an electrical RF signal. This chapter describes how to calculate this conversion.The output voltage of an optical CATV receiver can be calculated with the formula:

Output Voltage (peak) = Responsivity × Optical Input Power × m

Where:

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

Example:

A practical situation is:
Optical input power is 1 mW (0 dBm).
Modulation index m = 5%.
Responsivity = 900 V/W (the typical responsivity of the BGE887BO).

Output Voltage (peak) = Responsivity × Optical Input Power × m

$Vout(peak) = R \times P_{optical} \times m$

$Vout(peak) = 900 \times 1E\text{-}3 \times 0.05$

Vout(peak) = 45 mV

$Vout(average) = Vout(peak)/\sqrt{2}$

$Vout(average) = 45/\sqrt{2} = 31.8$ mV

Vout(dBmV) = 20log(31.8) = 30 dBmV.

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:

Responsivity [A/W] = Responsivity [V/W]/Load impedance (75 Ω)

Responsivity [W/W] = Responsivity $[V/W]^2$/Load Impedance (75 Ω).

7 CARRIER TO NOISE RATIO CALCULATION

The carrier to noise ratio of an optical link (from laser to the output of the receiver) can be determined by the following equation: $\frac{C}{N} = \frac{0.5 \cdot m^2 \cdot I_{pd}^2}{2 \cdot e \cdot I_{pd} \cdot B + RIN \cdot I_{pd}^2 \cdot B + I_n^2 \cdot B}$

Where:

m = modulation index optical input signal

I_{pd} = photodiode current (= V_{pin1}/1 k)

e = 1.6×10^{-19} (C = A/Hz)

B = bandwidth (= 5 MHz)

RIN = relative intensity noise of the laser (dB/Hz)

I_n = equivalent input noise optical receiver (pA/Hz)

Example:

m = 5%

I_{pd} = 1 mA ($V_{pin\ 1}$ = 1 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/√Hz

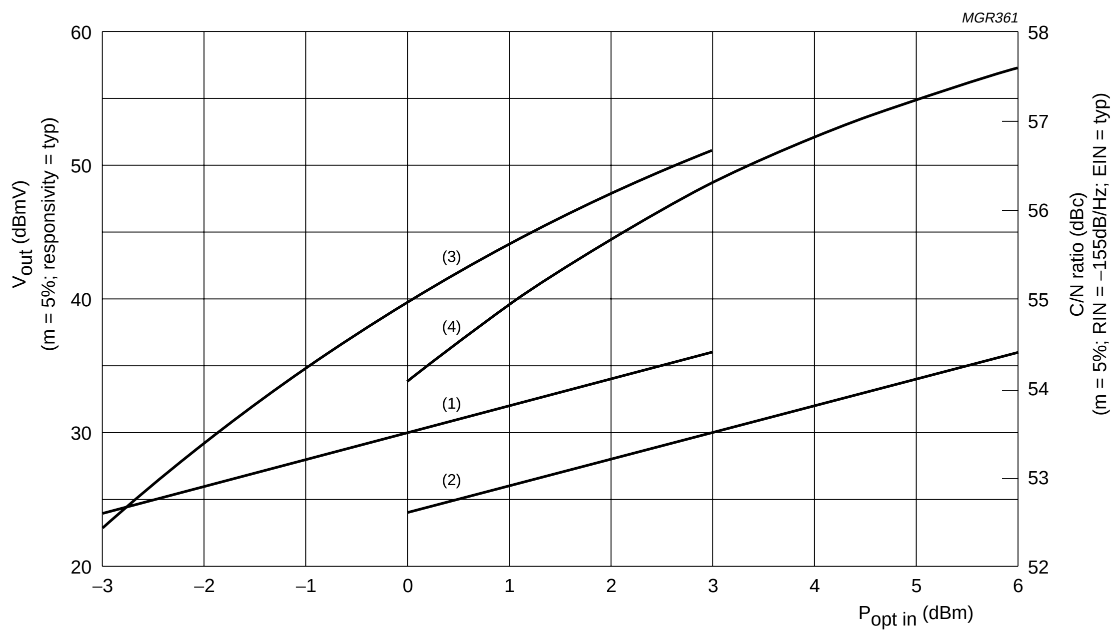
$$\frac{C}{N} = \frac{0.5 \cdot (0.05)^2 \cdot \left(1 \cdot 10^{-3}\right)^2}{2\left(1.6 \cdot 10^{-19}\right) \cdot \left(1 \cdot 10^{-3}\right) \cdot \left(5 \cdot 10^{6}\right) + \left(3.2 \cdot 10^{-16}\right) \cdot \left(1 \cdot 10^{-3}\right)^2 \cdot \left(5 \cdot 10^{6}\right) + \left(7 \cdot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

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

8 BGE887BO AND BGE883BO APPLICATION CONSIDERATIONS

The BGE887BO has been designed for an optical input power of around 0 dBm. Because higher optical input powers are getting more important, Philips designed the BGE883BO. In this chapter the differences between the BGE883BO and BGE887BO are explained. The BGE887BO has been designed for the 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 noise of the BGE887BO is not important at those levels.The BGE883BO has been designed for an optical input power range between 0 and 6 dBm (3 dB higher than the BGE887BO). The intermodulation behaviour of this module is improved. The noise of this module is higher, but at these levels not limiting. The BGE883BO has 6 dB less responsivity, >400 V/W in stead 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 is dependent of the application, which one is preferred.

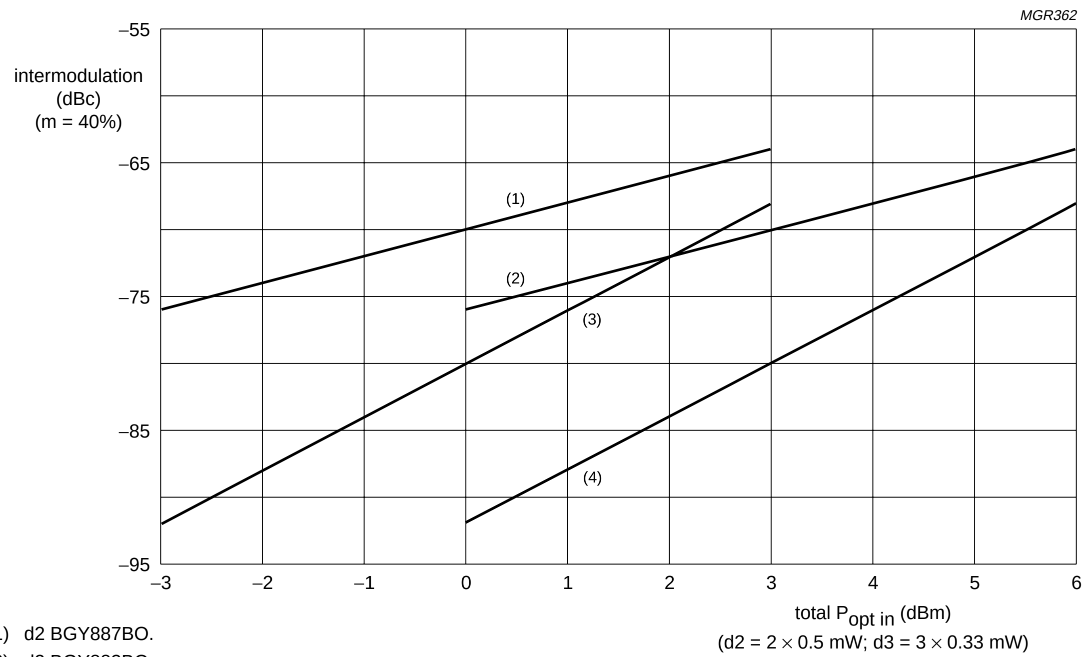
In Fig.7, a graph is given of the output voltage of the module versus the optical input power and also the carrier to noise ratio versus the optical input power. The output voltage of the two modules is just shifted with 3 dB of input power. The C/N ratio is also shifted but has also an other shape.



(1) V(out)BGE887BO.
(2) V(out)BGE883BO.
(3) C/N BGE887BO.
(4) C/N BGE883BO.

Fig.7 V(out) and C/N ratio versus P(optical in).

In Fig.8, a graph is given of the d2 and d3 intermodulation versus the optical input power. These d2 and d3 of the two modules are just shifted with 3 dB of input power.



(1) d2 BGY887BO.
(2) d2 BGY883BO.
(3) d3 BGY887BO.
(4) d3 BGY883BO.

Fig.8 d2 and d3 versus P (optical input).

9 MULTI CHANNEL MEASUREMENTS

CATV amplifiers are specified on multichannel behaviour. The number of channels used for measurements is dependent on the application. Measurements are done with multichannel equipment which has a generator for each channel. Doing multichannel measurements on optical CATV receivers requires a big number of lasers. One laser for each channel is needed to prevent that distortion of the laser is added to the measurement results. This is a very expensive way of measuring. 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 power of the measured multichannel measurement can be divided in the distortion power of the laser and the distortion power of the optical CATV receiver. An example of this way of measurement and calculation of distortion is given in Section 9.1.

9.1 Calculation of the BGE887BO CTB Figure

The method of calculating the CTB figure of an optical CATV receiver is explained with the help of an example. The CTB, of the total measurement system, is measured twice; test 1 and test 2.

When the input power and the responsivity of the optical CATV receiver are known, the total CTB power at the output can be calculated:

Table 1

	TEST 1	TEST 2
Input Power:	1.8 dBm	–3 dBm
• Poptical	1.5 mW	0.5 mW
• Modulation index	3.5%	3.5%
• Poptical (average) 1 carrier	1.5E-3 × 0.035 × (1/√2) = 37.1E-6 W = 37.1 μW	0.5E-3 × 0.035 × (1/√2) = 12.4E-6 W = 12.4 μW
Output Power:		
BGE887BO: responsivity = 900 V/W		
	= 37.1E-6 × 900	= 12.4E-6 × 900
Vout 1 carrier:	= 33.4 mV	= 11.1 mV
	= 30.5 dBmV	= 20.9 dBmV
	= –18.3 dBm	= –27.8 dBm
CTB Power		
(319.25 MHz)		
CTB	= –63.5 dBc	= –66.0 dBc
Pout	= –18.3 – 63.5	= –27.8 – 66
	= –81.8 dBm	= –93.8 dBm
	= 6.607E-9 mW	= 0.417E-9 mW

The CTB product at the output of the receiver is the product of the amplified input CTB and the CTB distortion of the receiver BGE887BO. At test 1, the total CTB power at the output of the BGE887BO is:

$$CTB_{total(1)} = (CTB_{transmitter} \times responsivity) + (CTB_{module}) \quad (3)$$

When the input signal is attenuated optically, the CTB distance of the input CTB stays the same. The amplified input CTB will also be the same in distance but the absolute power of this signal is lower; –9.6 dB at test 2 compared to test 1. The added CTB of the receiver BGE887BO is 19.2 dB lower in distance and 28.8 dB lower in absolute output power (when an output signal is attenuated with x dB, the third order distortion product is 3× dB lower). At test 2 the total output CTB power is: (compared with test 1, in terms of the used powers at that formula).(1)

$$CTB_{total(2)} = ((CTB_{transmitter} \times responsivity) - 9.6\ dB) + (CTB_{module} - 28.8\ dB) \quad (4)$$

$$= ((CTB_{transmitter} \times responsivity) \times 0.11) + (CTB_{module} \times 0.0013)$$

In numbers that is:

$CTB_{total(1)} = 6.607E\text{-}9\ mW = (CTB_{transmitter} \times responsivity) + (CTB_{module})$

$CTB_{total(2)} = 0.417E\text{-}9\ mW = 0.11(CTB_{transmitter} \times responsivity) + 0.0013\ (CTB_{module})$

Or:

$$CTB_{total(1)} = 6.607E\text{-}9\ mW = (CTB_{transmitter} \times responsivity) + (CTB_{module}) \quad (5)$$

$$9.09 \times CTB_{total(2)} = 3.791E\text{-}9 = 1\ (CTB_{transmitter} \times responsivity) + 0.0118\ (CTB_{module}) \quad (6)$$

Subtracting equation (5) from (6) leads to:

$CTB_{total(1)} - \{9.09 \times CTB_{total(2)}\} = 2.816E\text{-}9\ mW = 0.9882\ (CTB_{module})$

$CTB_{module} = 2.850E\text{-}9\ mW$

Substitution in equation (5) yields:

$CTB_{transmitter} \times responsivity = 3.757E\text{-}9\ mW$ (@ test 1)

All these powers in mW, are given in Table 2 in dBm. The input signal of 1 carrier is also given in dBm, so the several CTB figures can be calculated in dBc. The different CTB products are:

(1) CTB is a third order distortion product, so CTB decreases three times faster than the input power.

Table 2

	TEST 1	TEST 2
Pout carrier	–18.3 dBm	–27.8 dBm
Pout (CTB trans. × resp.)	3.757E-9 mW –84.3 dBm	0.413E-9 mW –93.8 dBm
Pout (CTB module)	2.85OE-9 mW –85.5 dBm	3.7E-12 mW –114.3 dBm
Pout (CTB total)	6.607E-9 mW –81.8 dBm	0.417E-9 mW –93.8 dBm
Input CTB	–66.0 dBc	–66.0 dBc
Module CTB	–67.2 dBc	–86.5 dBc
Total CTB	–63.5 dBc	–66.0 dBc

As shown in the table above, the input CTB (CTB of the transmitter) is already high. The BGE887BO also has a contribution in the CTB. To measure the CTB of the receiver accurately, the input CTB must be more than 10 dB better than the CTB of the receiver. This can be done by:

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

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

9.2 Calculation of the BGE887BO CSO Figure

The CSO can be calculated in the same way as done with the CTB calculation. The method of calculating the CSO figure of an optical CATV receiver is also explained with the help of the same example. The CSO, of the total measurement system, is measured twice; test 1 and test 2.

When the input power and the responsivity of the optical CATV receiver are known, the total CSO power at the output can be calculated:

Table 3

	TEST 1	TEST 2
Input Power: • Poptical • Modulation index • Poptical (average) 1 carrier	1.8 dBm 1.5 mW 3.5% 1.5E-3 × 0.035 × (1/√2) = 37.1E-6 W = 37.1 µW	–3 dBm 0.5 mW 3.5% 0.5E-3 × 0.035 × (1/√2) = 12.4E-6 W = 12.4 µW
Output Power: BGE887BO: responsivity = 900 V/W Vout 1 carrier:	 = 37.1E-6 × 900 = 33.4 mV = 30.5 dBmV = –18.3 dBm	 = 12.4E-6 × 900 = 11.1 mV = 20.9 dBmV = –27.8 dBm
CSO Power (319.25 MHz) CSO Pout	 = –64.8 dBc = –18.3 – 64.8 = –83.1 dBm = 4.898E-9 mW	 = –65.5 dBc = –27.8 – 65.5 = –93.3 dBm = 0.468E-9 mW

The CSO product at the output of the receiver is the product of the amplified input CSO and the CSO distortion of the receiver BGE887BO. At test 1, the total CSO power at the output of the BGE887BO is:

$$CSO_{total(1)} = (CSO_{transmitter} \times responsivity) \times (CSO_{module}) \quad (7)$$

When the input signal is attenuated optically, the CSO distance of the input CSO stays the same. The amplified input CSO will be the same in distance but the absolute power of this signal is lower; –9.6 dB at test 2 compared with test 1. The added CSO of the receiver BGE887BO is 9.6 dB lower in distance and 19.2 dB lower in absolute output power (when an output signal is attenuated with x dB, the second order distortion product is 2× dB lower).

At test 2 the total output CSO power is: (compared with test 1, in terms of the used powers at that formula)(1)

$$CSO_{total(2)}$$

$$= ((CSO_{transmitter} \times responsivity) - 9.6\ dB) + (CSO_{module} - 19.2\ dB) \quad (8)$$

$$= ((CSO_{transmitter} \times responsivity) \times 0.11) + (CSO_{module} \times 0.012)$$

In numbers that is:

$CSO_{total(1)}$ = 4.898E-9 mW = $(CSO_{transmitter} \times responsivity) + (CSO_{module})$

$CSO_{total(2)}$ = 0.468E-9 mW = 0.11 $(CTB_{transmitter} \times responsivity)$ + 0.012(CTB_{module})

(1) CSO is a second order distortion product, so CSO decreases twice times faster than the input power.

Or:

$$CSO_{total(1)} = 4.898E\text{-}9\ mW = (CSO_{transmitter} \times responsivity) + (CSO_{module}) \quad (9)$$

$$9.09 \times CSO_{total(2)} = 4.255E\text{-}9\ mW = 1\,(CSO_{transmitter} \times responsivity) + 0.109\,(CSO_{module}) \quad (10)$$

$CSO_{total(1)} - \{9.09 \times CSO_{total(2)}\} = 0.643E\text{-}9\ mW = 0.891(CSO_{module})$

$CSO_{module} = 0.722E\text{-}9\ mW$

Substitution in equation (9) yields:

$CSO_{transmitter} \times responsivity = 4.179E\text{-}9\ mW$ (@ test 1)

All these powers in mW, are given below in dBm. The input signal of 1 carrier is also given in dBm, so the several CSO figures can be calculated in dBc. The different CSO products are:

Table 4

	TEST 1	**TEST 2**
Pout carrier	–18.3 dBm	–27.8 dBm
Pout (CSO trans. × resp.)	4.179E-9 mW –83.8 dBm	0.459E-9 mW –93.4 dBm
Pout (CSO module)	0.722E-9 mW –91.4 dBm	8.66E-12 mW –110.6 dBm
Pout (CSO total)	4.898E-9 mW –83.1 dBm	0.468E-9 mW –93.3 dBm
Input CSO	–65.5 dBc	65.6 dBc
Module CSO	–73.1 dBc	82.8 dBc
Total CSO	–64.8 dBc	65.5 dBc

As shown in Table 4, the input CSO (CSO of the transmitter) is already high. The BGE887BO also has a contribution in the CSO. To measure the CSO of the receiver accurately, the input CSO must be more than 10 dB better than the CSO of the receiver. This can be done by:

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

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

10 INPUT DYNAMIC RANGE

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

10.1 $V_{pin\ 1}$ versus Input Power

In Fig.9, the pin 1 monitor voltage is given as function of the optical input power.

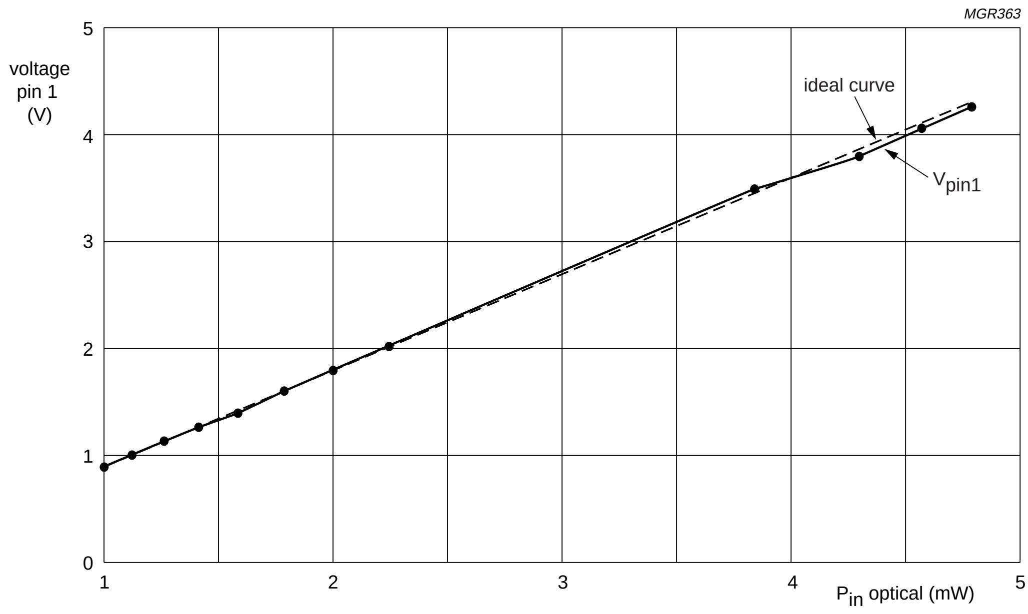
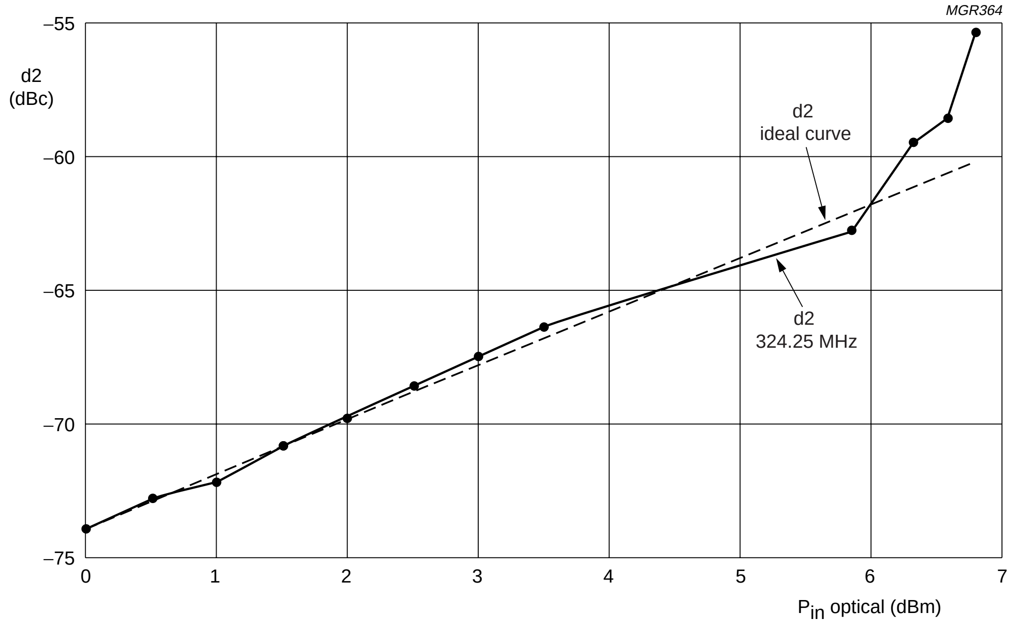


Fig.9 BGE887BO $V_{pin\ 1}$ versus Pin.

The pin 1 voltage is linear with the optical input power between 1 and 5 mW.

10.2 D2 versus Input Power

In Fig.10, the second order distortion is given as function of optical input power.



m = 40% each laser.

Fig.10 BGE887BO d2 versus Pin.

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

11 OPTICAL CONNECTORS

Optical connectors are used to get the light out of one glassfiber into an other glassfiber. For CATV applications, single mode glassfiber is used. The nominal mode field diameter of these fibers (that part of the glassfiber which is used to transport the light) is 9 – 10 µm. Because of this small diameter, a precise mating of the two glassfiber end faces is needed to get all the light from one glassfiber into the other glassfiber. Another problem with glassfiber is reflection of light when the transport medium changes, e.g. from glass into air. Reflection means losses and there is also a chance that light gets back into the laser which influence the proper functioning of the laser. To solve these problems as much as possible, specific high quality connectors are used. Philips supplies FC/APC and SC/APC connectors.

11.1 APC-Ferrules

In an optical connector, the end of the glassfiber is placed in a ferrule, a ceramic or glass bush to fix the glassfiber 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 FC/APC and SC/APC connectors is angled; 8° ± 0.5°. Because of this angle, less light is reflected into the glassfiber when the glassfiber 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 glassfiber into glassfiber. This means less reflections and also less losses (optical insertion loss maximally 0.5 dB). When light goes from one glassfiber via air into an other glassfiber, the optical losses are 8% (an interface between glassfiber 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.11.

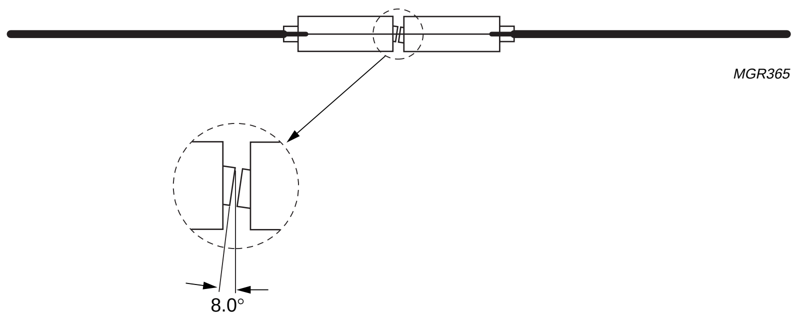
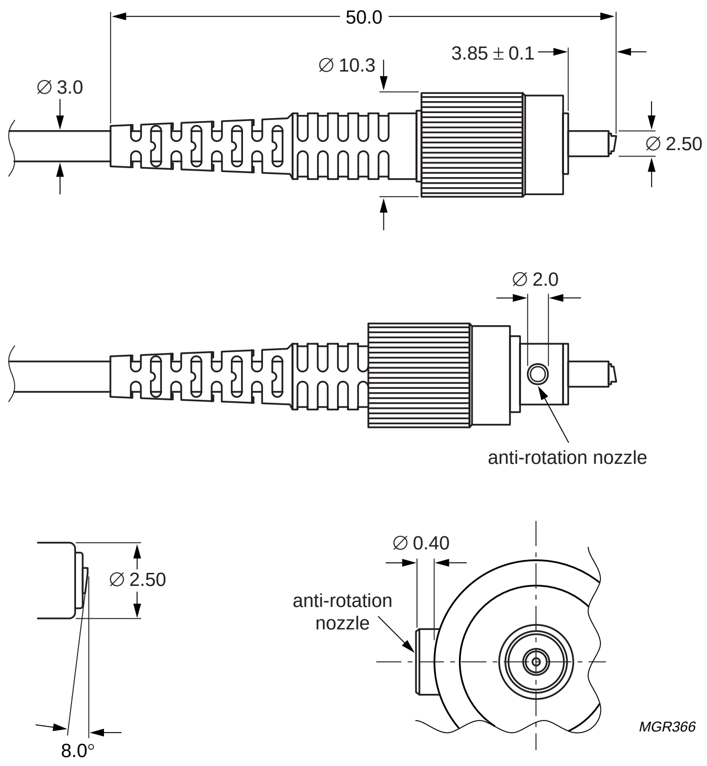


Fig.11 Two mated APC ferrules.

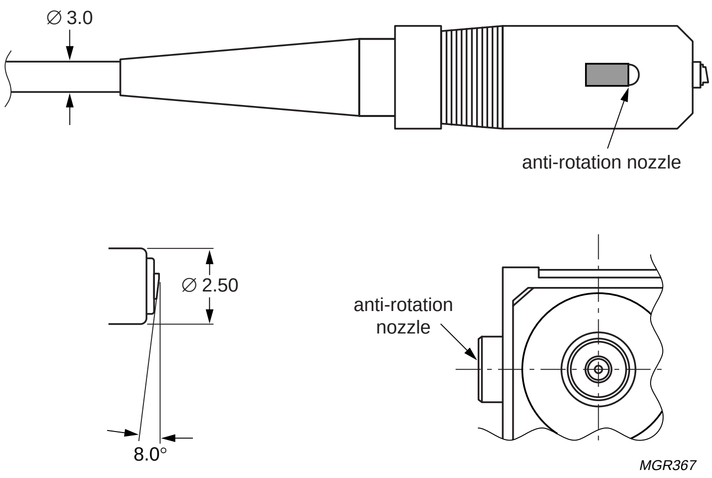
11.2 FC and SC Connectors

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 (0.80 to 1.20 kgf spring force).The FC/APC and SC/APC connectorized optical CATV receivers of Philips also have a buffered glassfiber. Over the glassfiber a thermoplastic yellow 3 mm tube is placed. In between this tube and the glassfiber a Kevlar aramid fiber is placed. This Kevlar fiber is connected to the connector and can be used as strain relief by fixing the kevlar at the end tube end, near by the receiver. The outlines of the FC/APC and SC/APC connectors are given in Figs 12 and 13.



Dimensions in millimetre.

Fig.12 FC/APC connector.

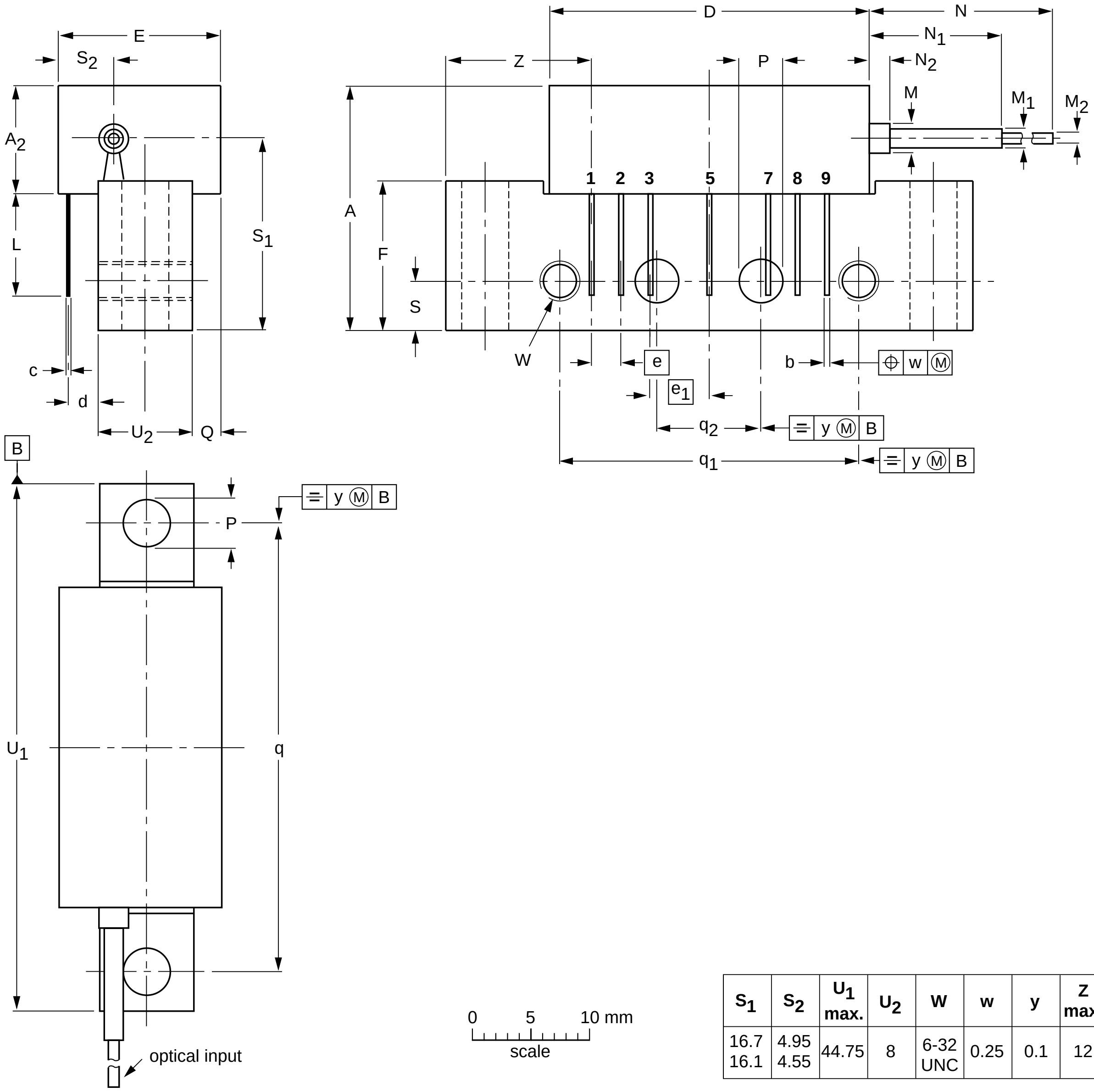


Dimensions in millimetre.

Fig.13 SC/APC connector.

12 PACKAGE OUTLINE

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**



S_1	S_2	U_1 max.	U_2	W	w	y	Z max.
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 min.	N_1	N_2	∅ 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 8.7	5 1	4.15 3.85	2.4	38.1	25.4	10.2	4.2

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
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SOT115U						97-08-24

NOTES

NOTES

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