iC212

HIGHSPEED PHOTORECEIVER

preliminary

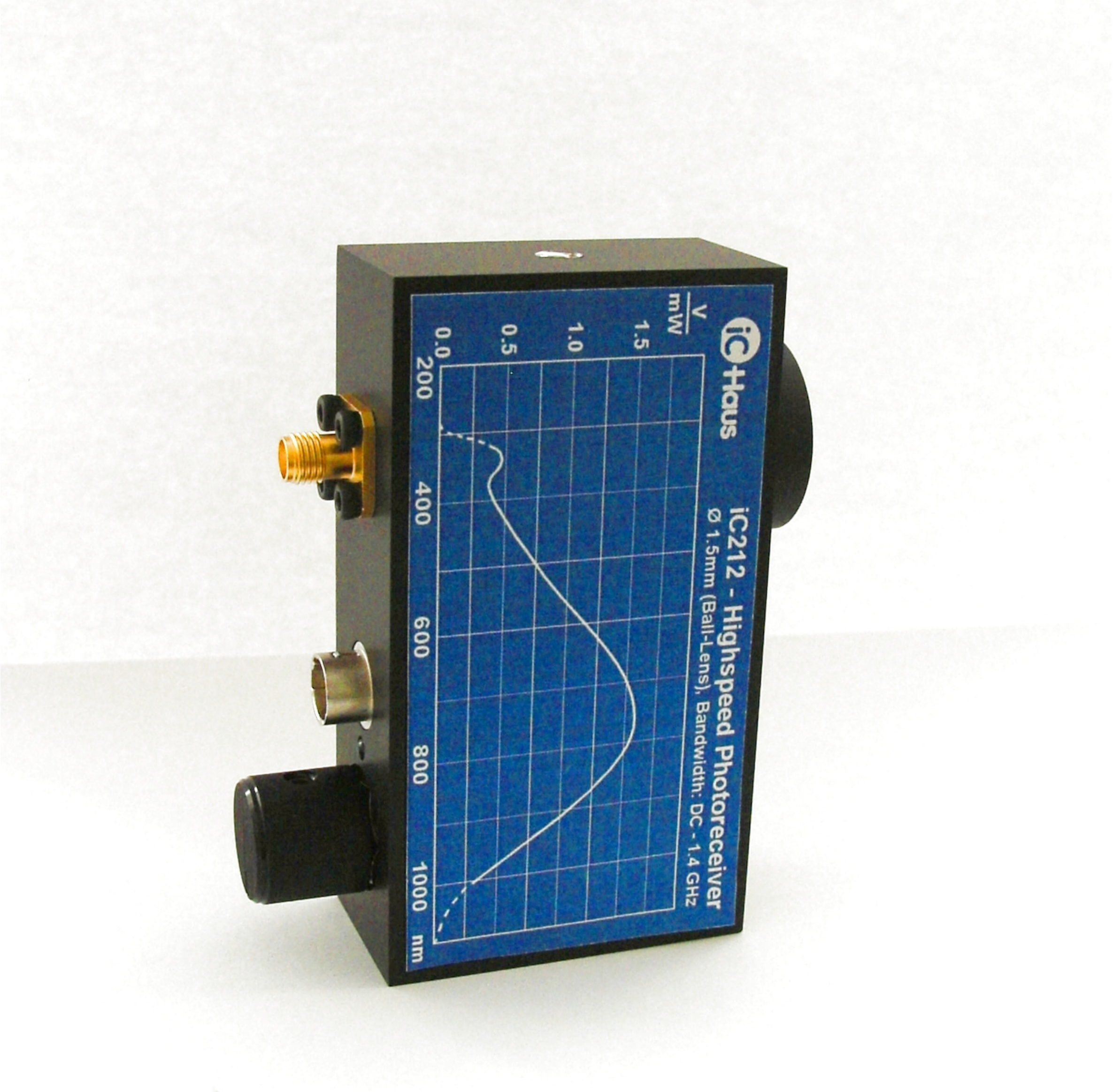
FEATURES

Bandwidth DC to 1.4 GHz
Si PIN photodiode, Ø 0.4 mm active area diameter
Spectral response range λ = 320 to 1000 nm
Amplifier transimpedance (gain) 3.125 V/mA
Max. conversion gain 1.625 V/mW @ 760 nm

APPLICATIONS

Fast pulse and transient measurement
Optical triggering
Optical front-end for oscilloscopes

BLOCK DIAGRAM



DESCRIPTION

The iC-Haus Highspeed Photoreceiver iC212 has been developed for optical high speed measurement. With its bandwidth ranging from DC up to 1.4 GHz it detects photo signals from constant light to high speed with rise times down to 280 ps. The iC212 Highspeed Photoreceiver also features offset adjustment to compensate DC levels of the input signal.

The photodiode used offers a spectral range from 320 to 1000 nm with an active area diameter of about Ø 0.4 mm, which is increased by an Ø 1.5 mm ball lens, resulting in an effective usable area of typical 0.75 mm². The Highspeed Photoreceiver is able to detect optical power levels in the sub mW range at GHz speed.

The iC212 Highspeed Photoreceiver comes with M6 mounting holes for integration in optical bench systems and an optional fiber-optic input adapter for optical fiber coupling.

ABSOLUTE MAXIMUM RATINGS

Beyond these values damage may occur; device operation is not guaranteed.

Item No.	Symbol	Parameter	Conditions	Min.	Max.	Unit
G001	Pmax	Optical Input Power			10	mW
G002	Vs	Power Supply Voltage			±20	V

ELECTRICAL CHARACTERISTICS

Test Conditions: Vs = ±15 V, Ta = 25 °C, System Impedace 50 Ω

Item No.	Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
Gain							
101	A	Amplifier Transimpedance Conversion Gain	50 Ω load λ = 760 nm		3.125 1.625		V/mA V/mW
Frequency Response							
201	fmax	Upper Cut-Off Frequency	-3 dB		1.4		Ghz
202	ΔA	Gain Flatness			±1		dB
203	tr	Rise Time	10 to 90%		280		ps
204	tpd	Propagation Delay	optical in => electrical out, 50% to 50%		750		ps
Detector (Si PIN photodiode)							
301	d	Active Area Diameter	ball lens Ø 1.5 mm		0.4		mm
302	Aeff	Effective Active Area	ball lens Ø 1.5 mm, note tolerances from Fig. 3		0.75		mm²
303	λ	Spectral Range		320		1000	nm
304	Pmax	Max. Optical Input Power	average linear amplification @ 760 nm		10 615		mW µW
305	NEP	Noise equivalent power	including amplifier noise, at λ=760nm and f = 1 GHz; (for frequency dependence see Fig. **??**)		115		pW/$\sqrt{\text{Hz}}$
Output							
401	Rout	Output Impedance			50		Ω
402	Vout	Output Voltage Swing	50 Ω load, for linear amplification	-0.3		1.0	V
403	Vos	Offset Voltage (adjustable)*	DC offset cancellation	-1.25		0.15	V
404	Pos	Offset (adjustable)*	equivalent optical power	-92		750	µW
405	twu	Warm-Up Time	stable offset voltage		30		min
Power Supply							
501	Vs	Supply Voltage				±15	V
502	Is	Supply Current		±150			mA

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* The output is clipped to -0.5 V, if the offset voltage is less than 0.5 V and no DC light is present.

CONTENTS

The purchased parts package includes

- Highspeed Photoreceiver iC212
- Power adapter (230 VAC)
- Coaxial cable with SMA plugs
- SMA to BNC adapter
- Fiber adapter

Figure 1: Box contents

DIMENSIONS

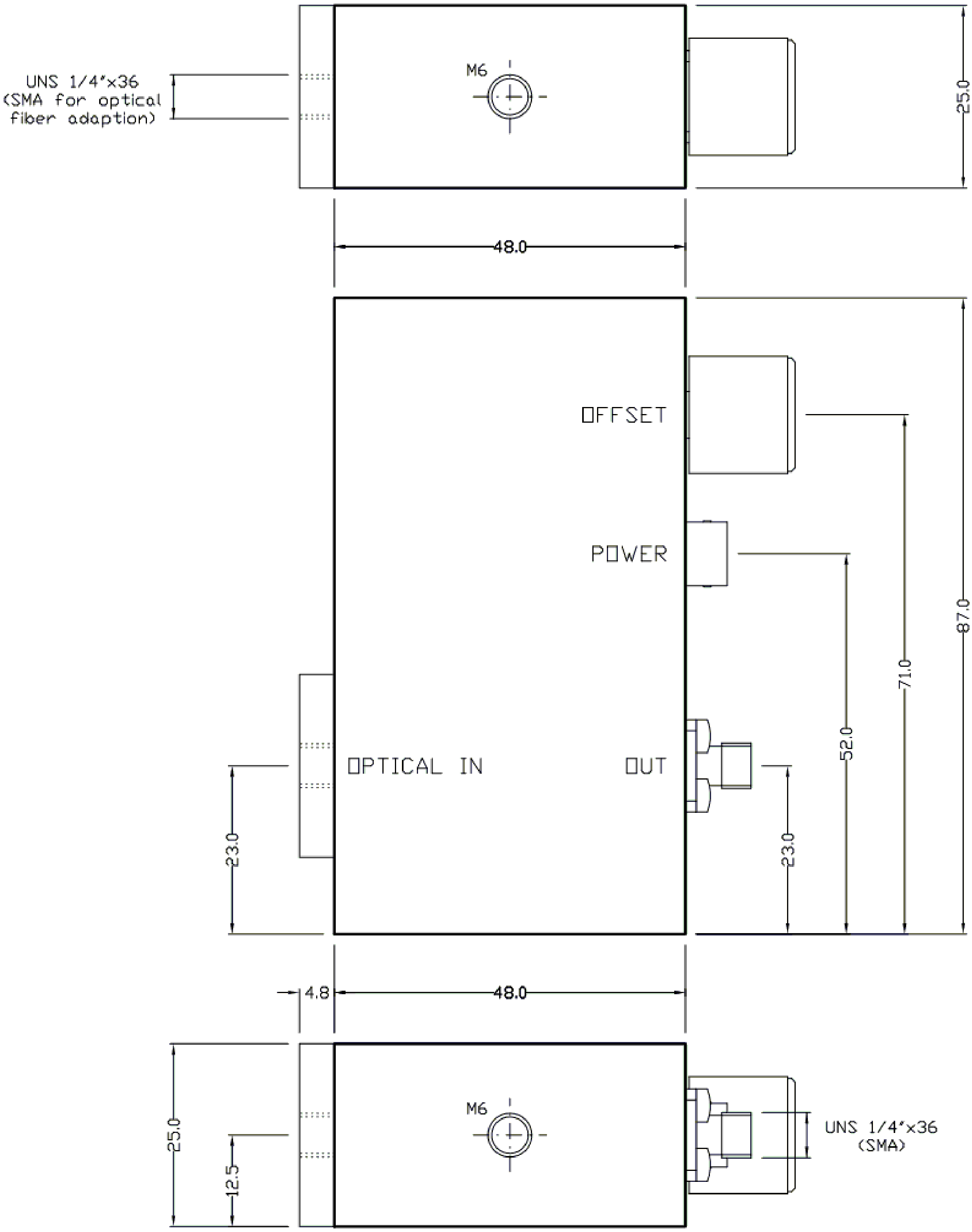


Figure 2: Case dimensions (all units in mm)

CONNECTORS

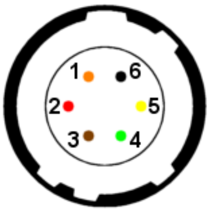
Input	Optical, with microbench adapter (Ø 25 mm) and SMA fiber adaption
Output	SMA Connector
Power Supply	Hirose series HR10-7R-6P, 6-Pin Pin 1, 2: +Vs Pin 3, 6: GND Pin 4, 5: -Vs 

Table 1: Connectors

PHOTODIODE WITH BALL LENS

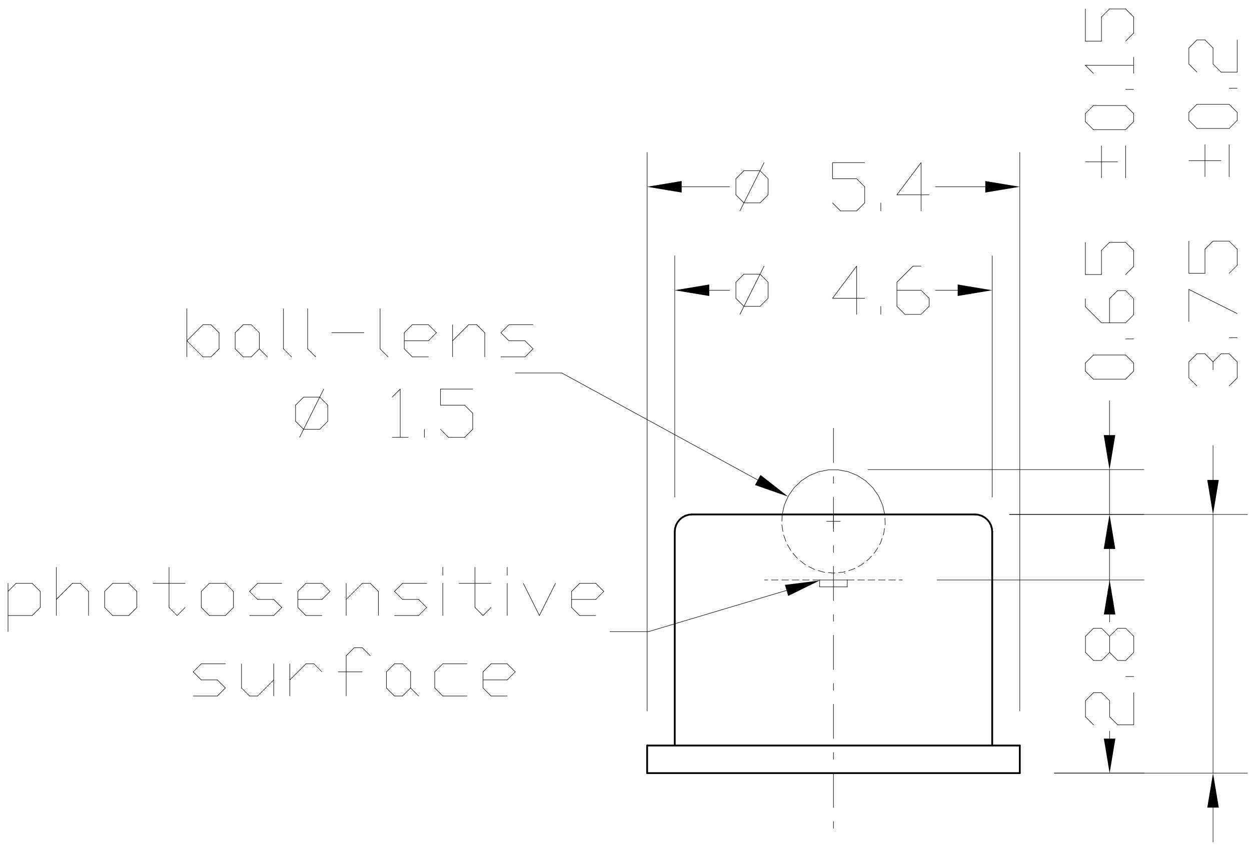


Figure 3: Photodiode with ball lens (lens type borosilicate glass)

RESPONSE

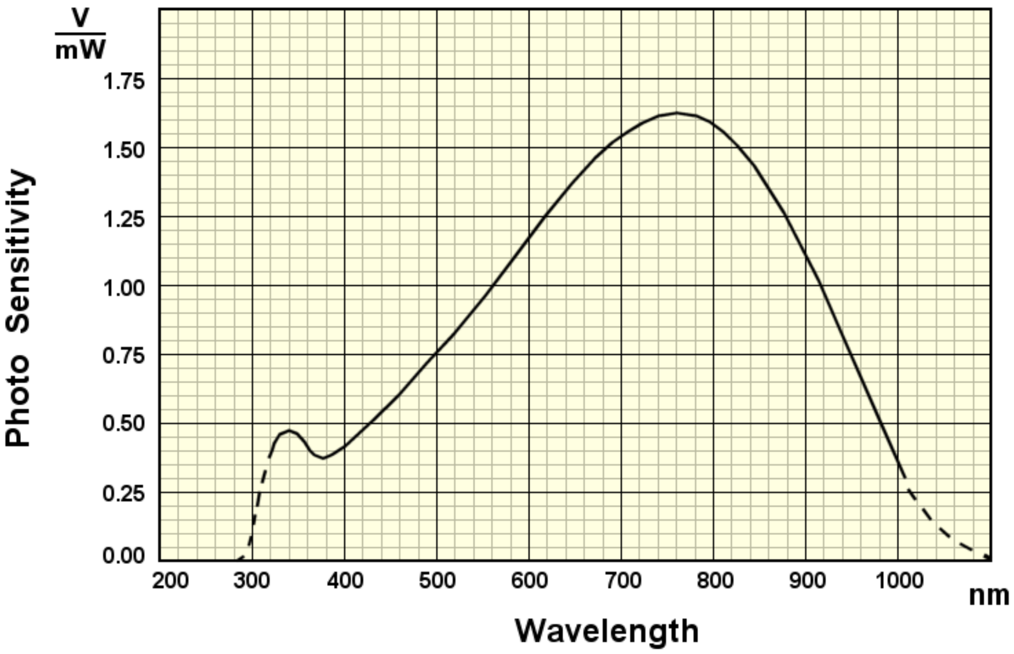
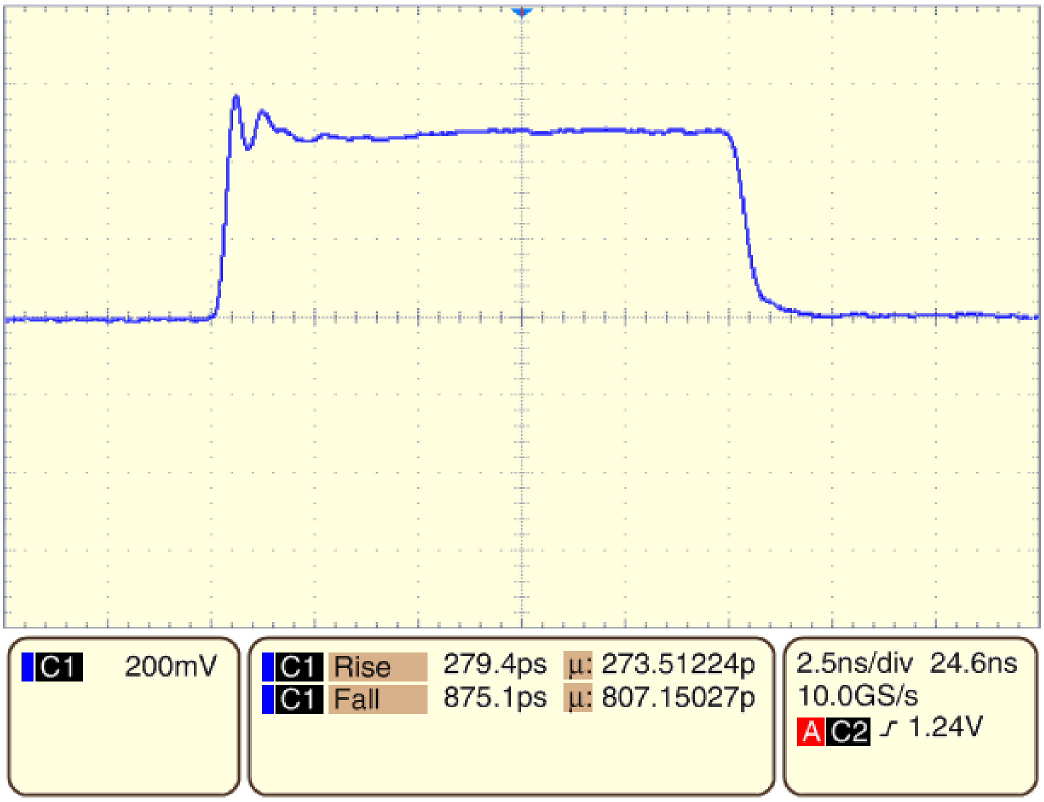


Figure 4: Spectral response



```
C1   200mV     C1 Rise   279.4ps  µ: 273.51224p    2.5ns/div  24.6ns
               C1 Fall   875.1ps  µ: 807.15027p    10.0GS/s
                                                   A C2 ƒ 1.24V
```

Figure 5: Pulse response

APPLICATION NOTES

These application notes are meant to demonstrate some typical measurement tasks, carried out with the iC212 and verified with a standard optical power meter.

Mesurement of total optical output power P_{opt}

1. Put laser in pulse mode
2. Adjust lens, for maximum amplitude at the output of iC212 (Fig. 6)
3. Read amplitude: U = 0.803 V (Fig. 7)
   Calculation: $\lambda = 635$ nm, spectral response taken from Figure 4: S(@635 nm) = 1.34 V/mW

$$P_{opt}(iC212) = \frac{U}{S} = \frac{0.803\,V}{1.34\,\frac{V}{mW}} = 0.60\,mW$$

4. Put laser in CW mode
5. Put Newport sensor into laser beam and read the power: P_{opt}(Newport) = 0.641 mW (Fig. 8)

The results match within 7%.

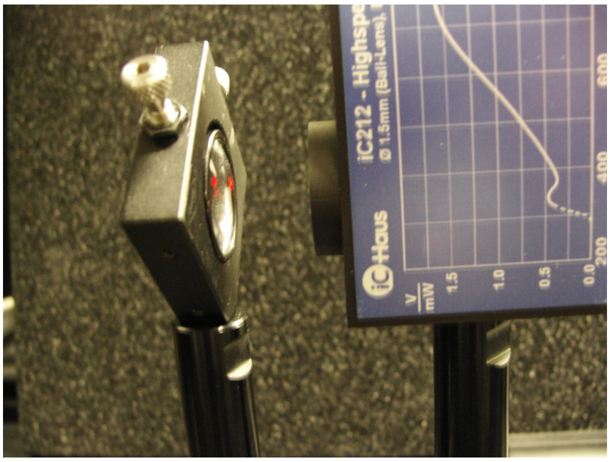
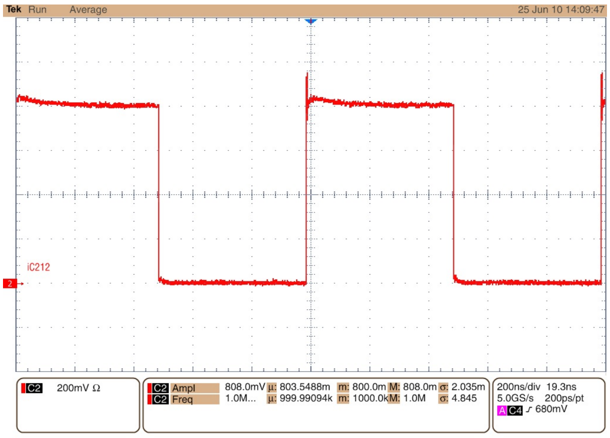


Figure 6: The laser light focused with a collecting lens onto the sensor



C2 200mV Ω

C2 Ampl 808.0mV µ: 803.5488m m: 800.0m M: 808.0m σ: 2.035m
C2 Freq 1.0M... µ: 999.99094k m: 1000.0k M: 1.0M σ: 4.845

200ns/div 19.3ns
5.0GS/s 200ps/pt
A C4 ƒ 680mV

Figure 7: Oscilloscope reading

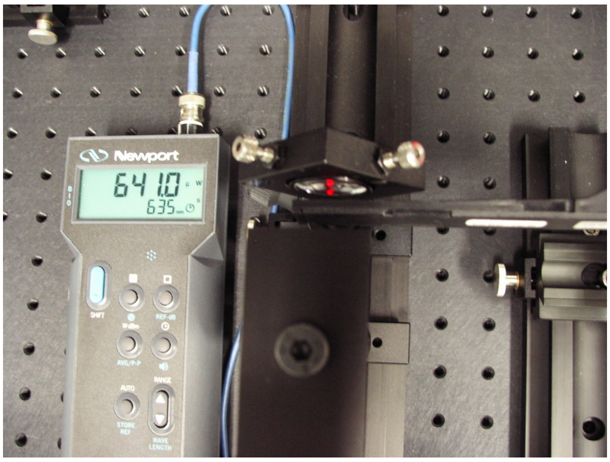


Figure 8: Total optical output power with 1 cm² sensor (Newport)

Measurment of Irradiance E

1. Put laser in CW mode
2. Homogenisation of laser light with microlens arrays (Fig. 10)
3. Put iC212 into the center of the homogenised laser light (Fig. 11)
4. Read oscilloscope: U = 76 mV (Fig. 12)
   Calculation: λ = 659 nm, spectral response taken from Figure 4: S(@659 nm) = 1.42 V/mW, effective area (Item No. 302: Aeff = 0.75 mm²)

$$\begin{aligned} E(iC212) &= \frac{U}{S * A_{eff}} \\ &= \frac{0.076\,V}{1.42\frac{V}{mW} * 0.75\,mm^2} = 0.071\frac{mW}{mm^2} \end{aligned}$$

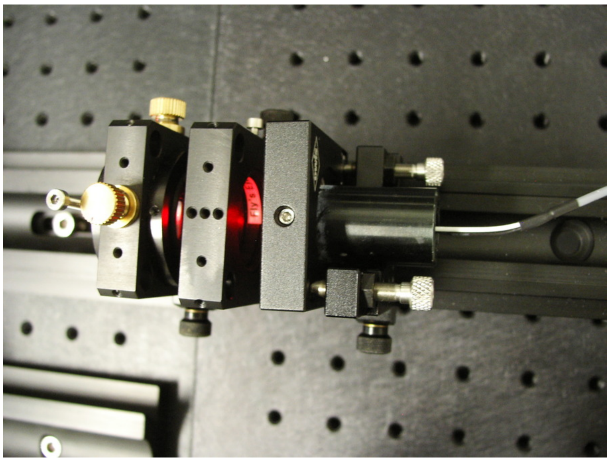


Figure 9: Laser 659 nm, 150 mW with two microlens arrays for homogenisation

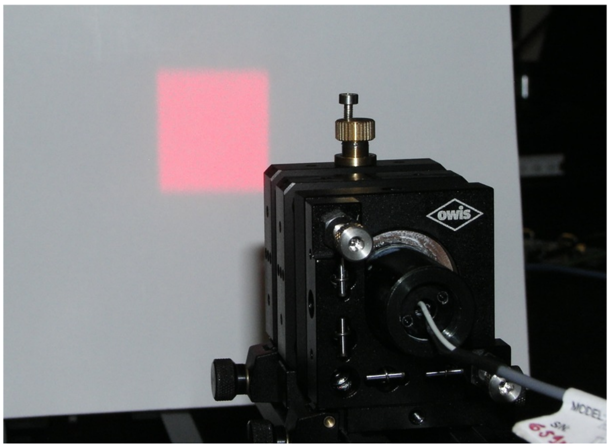


Figure 10: Homogeneously illuminated area of ca. 4 cm x 4 cm

5. Put Newport sensor into laser beam and read the power: P_{opt}(Newport) = 6.441 mW (Fig. 13)
6. With a sensor area of 100 mm² this results in E(Newport) = 0.0644 mW/mm²

The results match within 10%.

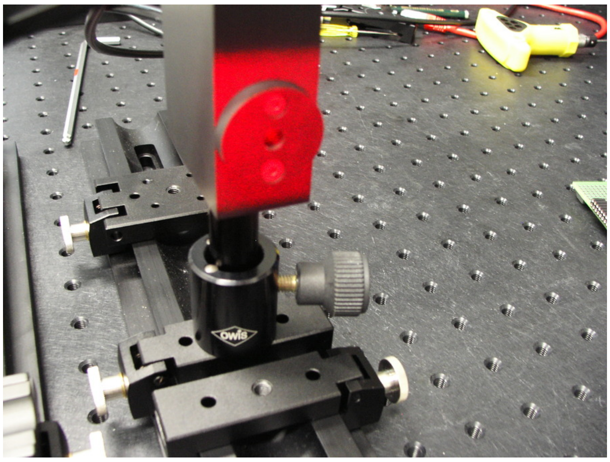


Figure 11: iC212 in the center of the homogenised laser light

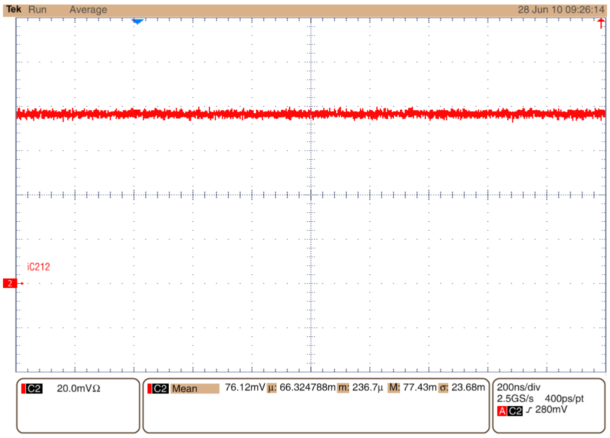


Figure 12: Oscilloscope reading

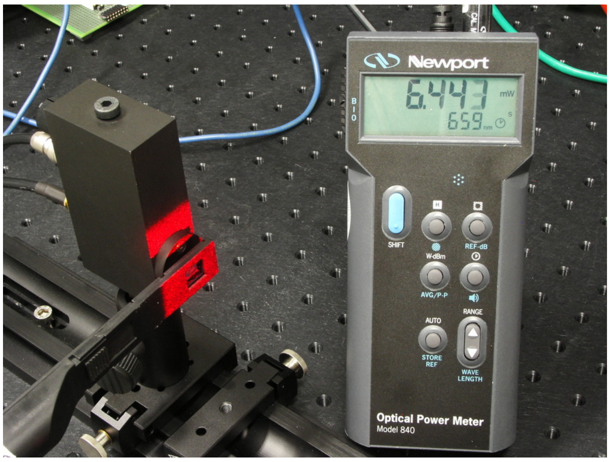


Figure 13: Newport sensor in the center of the homogenised laser light

Measuring time of flight

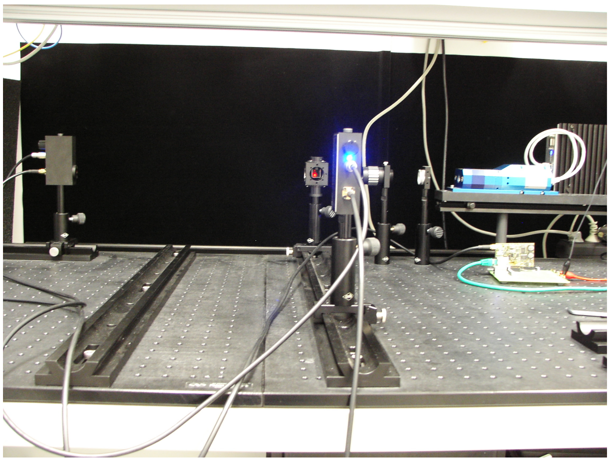
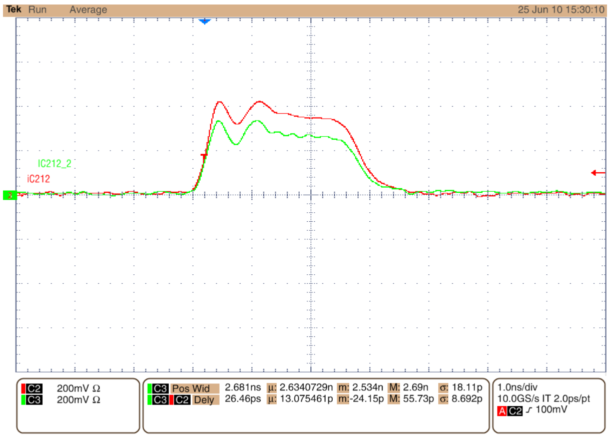


Figure 14: Laser, pole filter, beam expander, beam splitter and two iC212



```
C2   200mV Ω     C3 Pos Wid     2.681ns  µ: 2.6340729n  m: 2.534n   M: 2.69n   σ: 18.11p   1.0ns/div
C3   200mV Ω     C3 C2 Dely     26.46ps  µ: 13.075461p  m:-24.15p   M: 55.73p  σ: 8.692p   10.0GS/s IT 2.0ps/pt
                                                                                          A C2 ⎍ 100mV
```

Figure 15: No propagation time difference at same distance from beam splitter

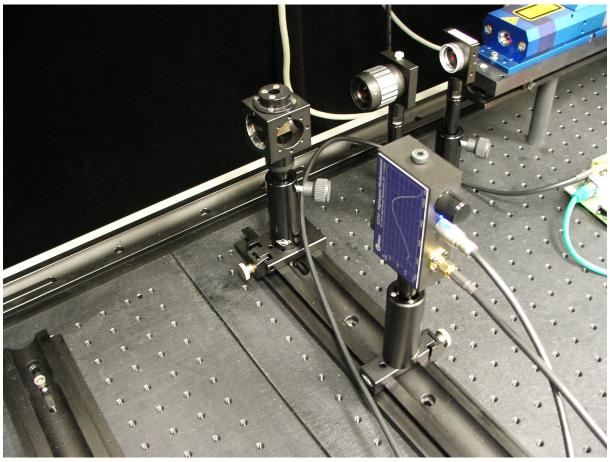
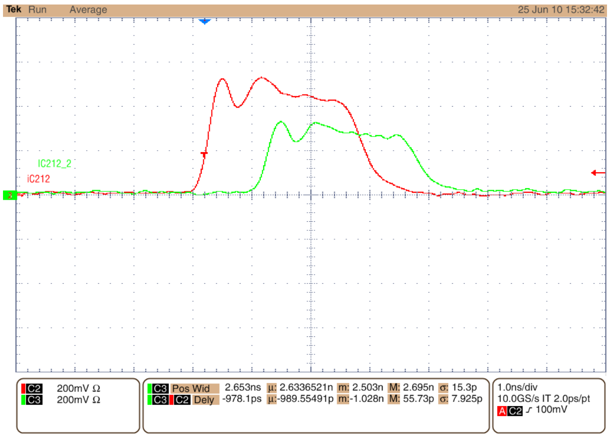


Figure 16: One iC212 positioned 30 cm closer to the beam splitter



```
C2   200mV Ω     C3 Pos Wid     2.653ns  µ: 2.6336521n  m: 2.503n   M: 2.695n  σ: 15.3p    1.0ns/div
C3   200mV Ω     C3 C2 Dely    -978.1ps  µ:-989.55491p  m:-1.028n   M: 55.73p  σ: 7.925p   10.0GS/s IT 2.0ps/pt
                                                                                          A C2 ⎍ 100mV
```

Figure 17: 30 cm distance difference means 1 ns propagation time difference

Fiber-optic input

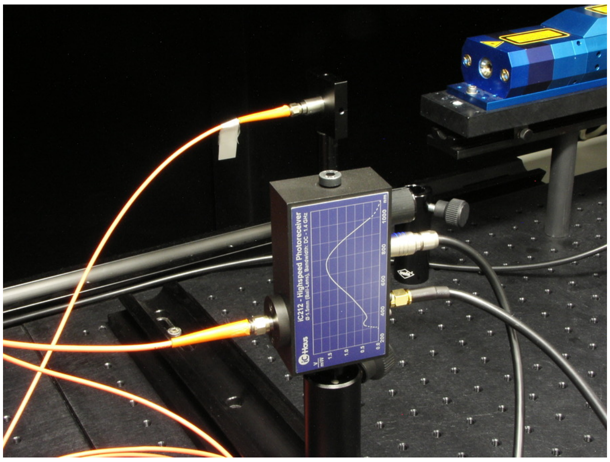


Figure 18: Laser, SMA fiber collimator, fiber, iC212 fiber adapter, iC212

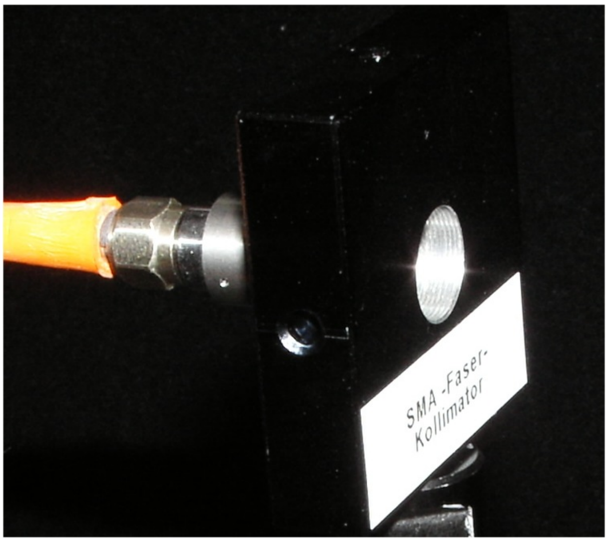


Figure 20: SMA fiber collimator

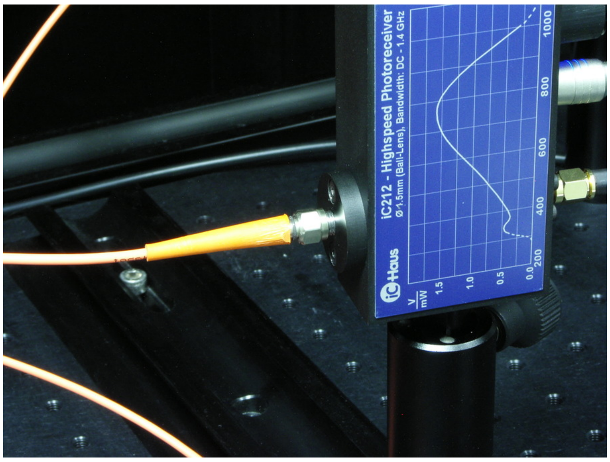
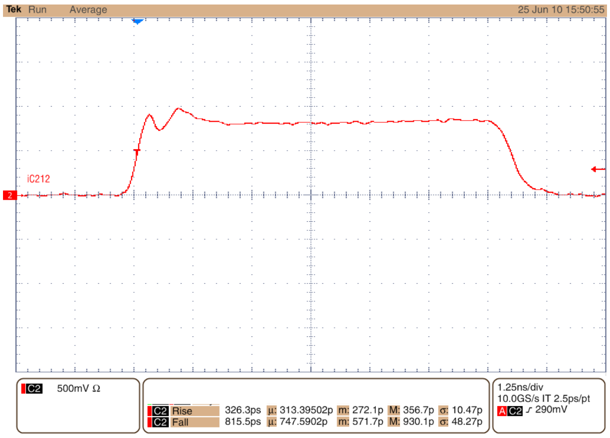


Figure 19: iC212 fiber adapter



```
C2    500mV Ω

C2 Rise   326.3ps  µ: 313.39502p  m: 272.1p  M: 356.7p  σ: 10.47p
C2 Fall   815.5ps  µ: 747.5902p   m: 571.7p  M: 930.1p  σ: 48.27p

1.25ns/div
10.0GS/s IT 2.5ps/pt
A C2 ⎍ 290mV
```

Figure 21: Fiber transmitted light pulse

Noise Equivalent Power (NEP)

NEP specifies the lowest light power (Pmin) that can be detected by the sensor. In that case the signal to noise ratio (S/N) would be 1, which means the signal to be measured is of the same magnitude as the noise.

$$P_{min}(\lambda) = \frac{S_{max}}{S(\lambda)} * NEP * \sqrt{BW}$$

$P_{min}(\lambda)$ - minimum detectable power, which can be distinguished from noise (only white noise, 1/f-noise ignored)
$S(\lambda)$ - photo sensitivity at wavelength λ
S_{max} - maximum photo sensitivity
NEP - NEP at maximum photo sensitivity
BW - bandwidth

Example

Blue LED with λ = 473 nm, square wave modulated f = 1 MHz (T = 1 µs), bandwidth of measuring circuit BW = 93 MHz.

S_{max} = 1.625 V/mW (Figure 4)
NEP = 115 pW/$\sqrt{\text{Hz}}$ (Item No. 305)
$S(\lambda = 473\,\text{nm})$ = 0.67 V/mW (Figure 4)

$$\begin{aligned} P_{min}(\lambda = 473\,nm) &= \frac{1.625}{0.67} * 115 \frac{pW}{\sqrt{Hz}} * \sqrt{93\,MHz} \\ &= 2.7\,\mu W_{RMS} \end{aligned}$$

This calculation is only valid, if the input noise is frequency independent. Figure 22 shows the input noise (INV = Input Noise Voltage) of the photo amplifier.

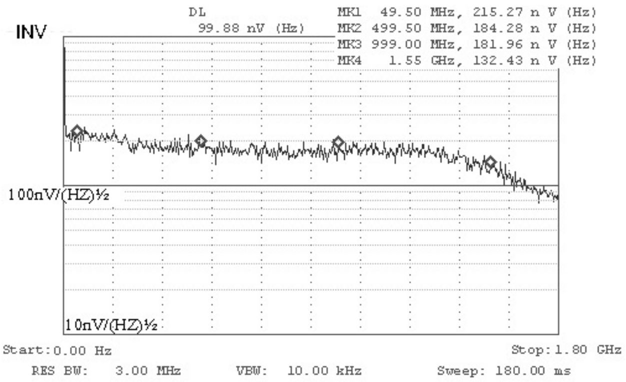


Figure 22: Input Noise Voltage as a function of the frequency - with lower frequencies there is higher noise

For frequencies around 93 MHz an input noise of 215 nV/$\sqrt{\text{Hz}}$ can be estimated.

$$\begin{aligned} NEP(\lambda) &= INV(f) * 1/S(\lambda) \\ NEP(\lambda = 473\,\text{nm}) &= INV(93\,\text{MHz}) / S(\lambda = 473\,\text{nm}) \\ NEP(\lambda = 473\,\text{nm}) &= 215\,\text{nV}/\sqrt{\text{Hz}} * 1\,\text{mW} / 0.67\,\text{V} \\ &= 320\,\text{pW}/\sqrt{\text{Hz}} \\ Noise(BW) &= NEP(\lambda = 473\,\text{nm}) * \sqrt{BW} \\ Noise(93\,\text{MHz}) &= 320\,\text{pW}/\sqrt{\text{Hz}} * \sqrt{93\,\text{MHz}} \\ &= 3.09\,\mu W_{RMS} \end{aligned}$$

As to be expected this value is slightly higher than in the first estimation.

Mesurement of minimum optical power $P_{min}(\lambda)$

1. Homogenisation of the blue LED light with microlens arrays (Figure 23)
2. LED modulation with 1 MHz
3. Change distance between iC212 and LED until signal is barely distinguishable from noise (method imprecise but rather simple to get a basic estimation)
4. Put Newport sensor at same distance as iC212 into the LED beam and read the power: PM = 126 µW (Figure 25)

Because of the duty cycle (50%), the measured power has to be multiplied by 2. The Newport sensor is completely illuminated (100 mm²). Hence the irradiance can be calculated to

$$E(Newport) = 2 * \frac{126\,\mu W}{100\,mm^2} = 2.52 \frac{\mu W}{mm^2}$$

With the effective area of the iC212 sensor (Item No. 302, A_{eff} = 0.75 mm²) this yield a total power of

$$\begin{aligned} P_{min}(\lambda = 473, measured) &= 2.52 \frac{\mu W}{mm^2} * 0.75\,mm^2 \\ &= 1.9\,\mu W \end{aligned}$$

This matches the calculated value reasonably well.

Output noise without signal:

$$\begin{aligned} Noise(BW) &= INV(f) * \sqrt{BW} \\ Noise(93\,MHz) &= 215 \frac{nV}{\sqrt{Hz}} * \sqrt{93\,MHz} \\ &= 2.07\,mV_{RMS} \end{aligned}$$

A slightly higher value of µ = 3 mV_{RMS} has been measured though.

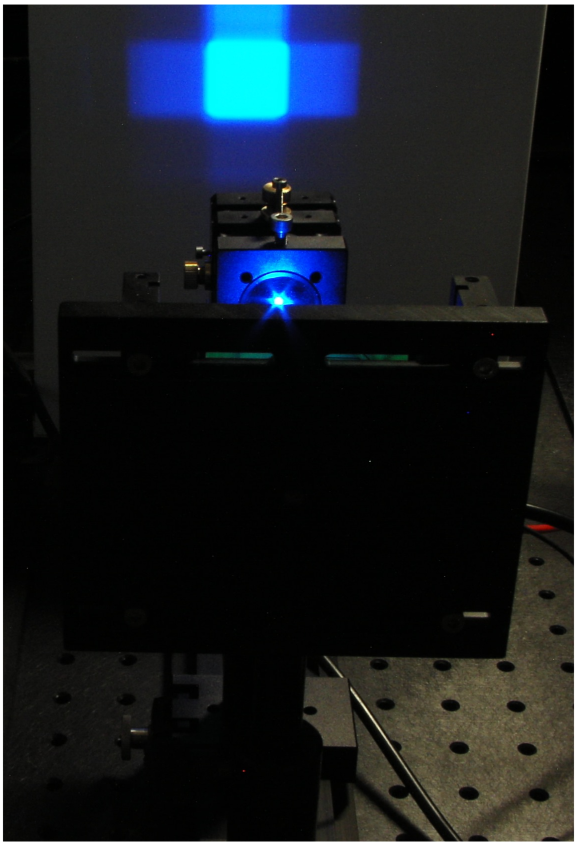


Figure 23: Homogenised blue LED light

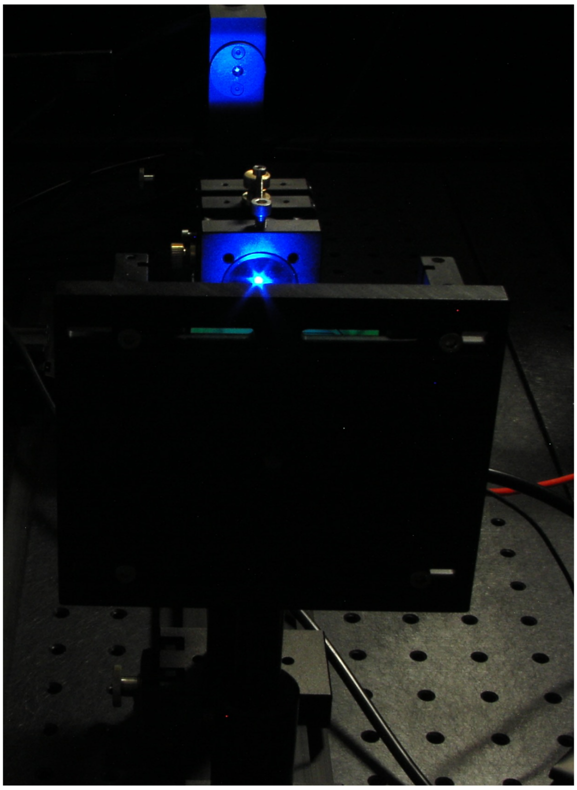


Figure 24: Homogeniously illuminated iC212

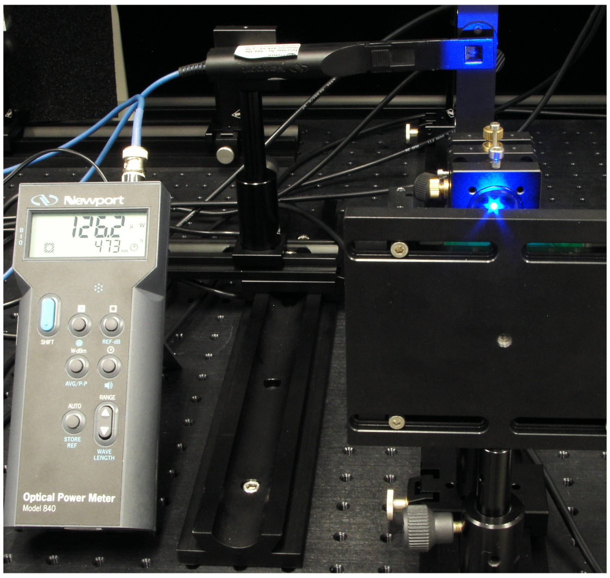
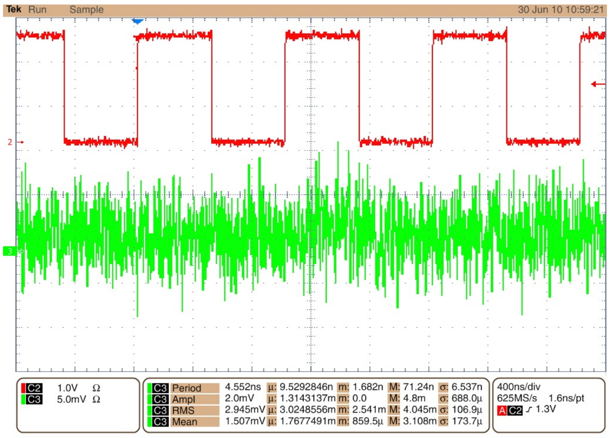


Figure 25: Homogeniously illuminated Newport sensor

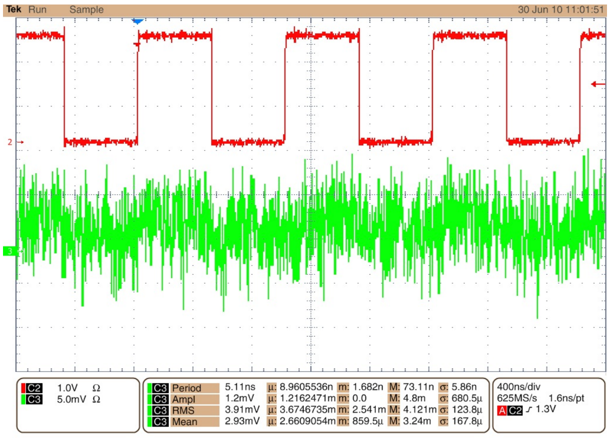


```
C2  1.0V   Ω
C3  5.0mV  Ω

C3 Period  4.552ns  µ: 9.5292846n  m: 1.682n  M: 71.24n  σ: 6.537n
C3 Ampl    2.0mV    µ: 1.3143137m  m: 0.0     M: 4.8m    σ: 688.0µ
C3 RMS     2.945mV  µ: 3.0248556m  m: 2.541m  M: 4.045m  σ: 106.9µ
C3 Mean    1.507mV  µ: 1.7677491m  m: 859.5µ  M: 3.108m  σ: 173.7µ

400ns/div
625MS/s   1.6ns/pt
A C2 ƒ 1.3V
```

Figure 26: Noise



```
C2  1.0V   Ω
C3  5.0mV  Ω

C3 Period  5.11ns   µ: 8.9605536n  m: 1.682n  M: 73.11n  σ: 5.86n
C3 Ampl    1.2mV    µ: 1.2162471m  m: 0.0     M: 4.8m    σ: 680.5µ
C3 RMS     3.91mV   µ: 3.6746735m  m: 2.541m  M: 4.121m  σ: 123.8µ
C3 Mean    2.93mV   µ: 2.6609054m  m: 859.5µ  M: 3.24m   σ: 167.8µ

400ns/div
625MS/s   1.6ns/pt
A C2 ƒ 1.3V
```

Figure 27: Noise with signal barely detectable

Ulbricht sphere

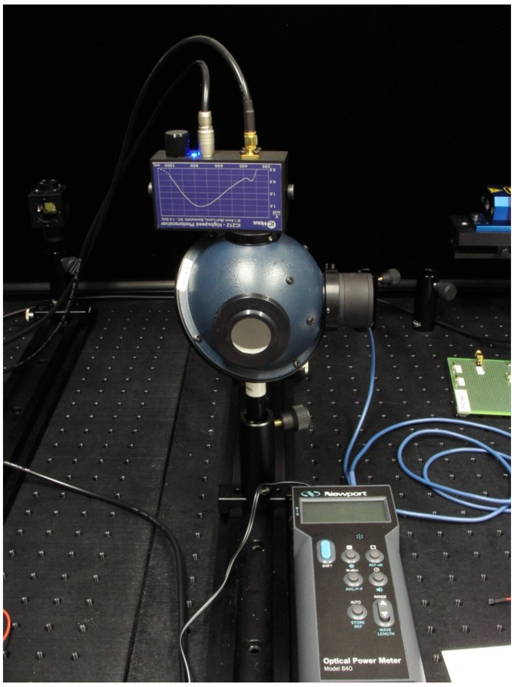


Figure 28: 3-port Ulbricht sphere with iC212 and Newport power meter

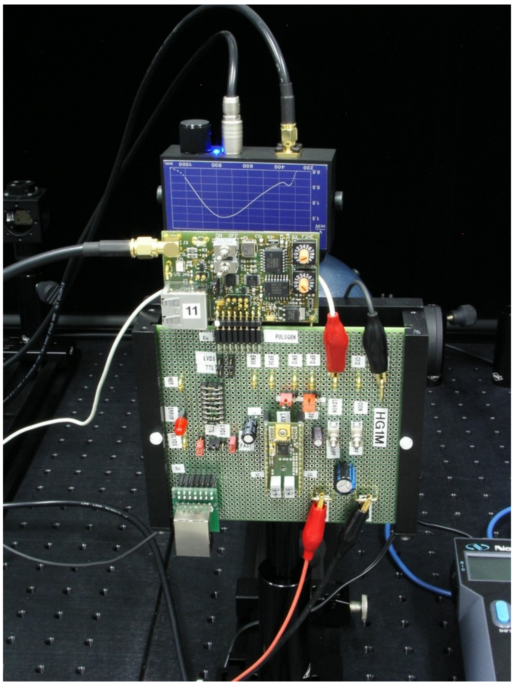


Figure 29: HG1M laser controller with 2 W CW laser diode

On the ideal size of an Ulbricht sphere see also "How to select an integrating sphere for your application" by Valerie C. Coffey at www.optoiq.com.

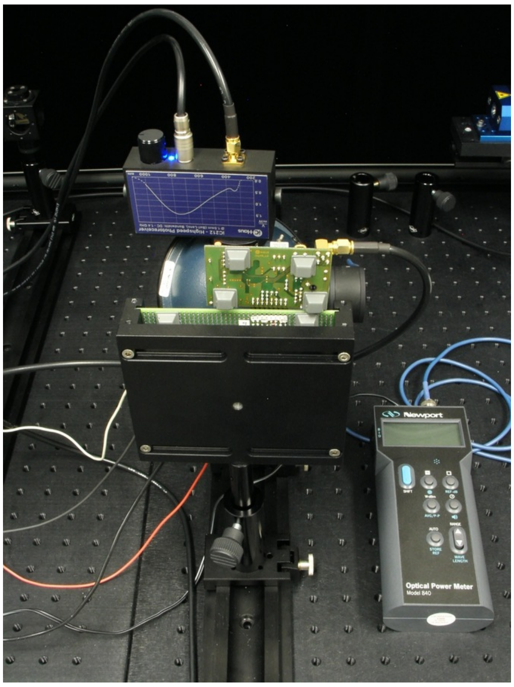


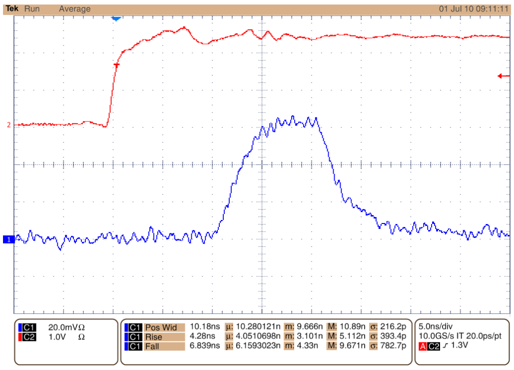
Figure 30: Laser light coupled into the Ulbricht sphere

```
C2  1.0V   Ω
C3  500mV  Ω

C3 Pos Wid  10.1ns    µ: 10.035051n  m: 9.917n  M: 10.12n  σ: 49.44p
C3 Rise     259.6ps   µ: 287.94752p  m: 241.6p  M: 335.9p  σ: 20.47p
C3 Fall     965.6ps   µ: 1.8723374n  m: 871.7p  M: 5.497n  σ: 1.286n

5.0ns/div
10.0GS/s IT 20.0ps/pt
A C2 ↗ 1.3V
```

Figure 31: Laser pulse with 260 ps rise time (channel 1)



```
C1  20.0mVΩ
C2  1.0V   Ω

C1 Pos Wid  10.18ns   µ: 10.280121n  m: 9.666n  M: 10.89n  σ: 216.2p
C1 Rise     4.28ns    µ: 4.0510698n  m: 3.101n  M: 5.112n  σ: 393.4p
C1 Fall     6.839ns   µ: 6.1593023n  m: 4.33n   M: 9.671n  σ: 782.7p

5.0ns/div
10.0GS/s IT 20.0ps/pt
A C2 ↗ 1.3V
```

Figure 32: Due to size of Ulbricht sphere the pulse gets distorted (ca. 4 ns rise time)

Equipment used

Mesuring instruments

Tektronix:	TDS7404B, 4 GHz, 20 GS/s, 4-Channel Digital Phosphor Oscilloscope
Newport:	Optical Power Meter Model 840
Newport:	Sensor 818-ST, Sensor 818-UV, Sensor 818-ST/CM
Newport:	819D-SL-3.3, 3-Port 3.3" Spectralon Ulbricht Sphere
Ocean Optics:	USB2000 Fiber-optic Spectrometer 320 - 1100 nm
Omicron:	LDM639.40.500, 40 mW Laser, f_{MOD} > 500 MHz
Femto:	HSA-X-S-1G4-SI, Ultra High Speed Photoreceiver
iC-Haus:	iC212 Highspeed Photoreceiver, DC to 1.4 GHz
HP:	8590L, Spectrum Analyzer

Accessories

iC-Haus:	iC149, 8-Bit pulse generator ,1 to 64 ns, compatibel to LDMxxx series lasers by Omicron
iC-Haus:	iC213, 12-Bit Oszillator, 40 kHz to 500 MHz, compatibel to LDMxxx series lasers by Omicron
iC-Haus:	iC215_6, pulse width modulator, 640 ps to 10.23 ns, compatibel to LDMxxx series lasers by Omicron and iC213
iC-Haus:	HG1M, control module for high speed, high power laser diodes

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We understand suitable application of our published designs to be state-of-the-art technology which can no longer be classed as inventive under the stipulations of patent law. Our explicit application notes are to be treated only as mere examples of the many possible and extremely advantageous uses our products can be put to.

ORDERING INFORMATION

Type	Package	Order Designation
iC212		iC212

For technical support, information about prices and terms of delivery please contact:

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