USER’S GUIDE

Quadcell Photoreceivers

Model 290X
Warranty

New Focus, Inc. guarantees its products to be free of defects for one year from the date of shipment. This warranty is in lieu of all other guarantees, expressed or implied, and does not cover incidental or consequential loss.

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Contents

Introduction  5
Overview  5
Tips for Best Operation  5

Operation  7
Setting up the Receiver  7
Checking and Replacing the Battery  8
Using an External Power Supply  9

General Features and Principles  11
Amplifier Circuitry  11
Gain and Bandwidth  13
Normalization of Outputs  14
Position Transfer Function  14
Selecting the Optimal Gain Setting  16
Frequency Response and Noise  16

Characteristics  23
Physical Specifications  23
Operating Specifications  24

Customer Service  25
Technical Support  25
Service  25
Introduction

Overview

The Model 290X family of photoreceivers use a combination of a quadrant cell photodiode and signal-processing amplifiers to generate position-sensitive signals from an incident light source.

Versions of the photoreceiver are available for visible (Model 2901) or infrared (Model 2903) beams. The photoreceiver can be operated from battery or a $\pm 15 \text{ V}$ DC power supply (we recommend the low-noise New Focus Model 0901 power supply for best performance).

Each model has a photodiode with a 3-mm diameter active region. Contact our technical support at the number listed on the front page of this manual to inquire about custom versions with different sizes or materials of photodiodes.

Tips for Best Operation

Avoid Room Lights

The 290X quadrant cell photoreceiver has a large active area. For a typically illuminated room of $1\text{–}10 \mu\text{W}/\text{mm}^2$, the SUM output can reach 1 V on the 30-\(\mu\text{W}\) saturation gain setting. The 120-Hz component of fluorescent room lights is extreme, and will almost certainly cause measurement difficulties.
The best solution is to shield the receiver as much as possible from room lights. A New Focus Model 1280 can be installed into the threads on the detector housing to hold filters or a light shield.

**Limiting Measurement Bandwidth**

As seen in the discussion “Impact of Noise on Position Measurement” on page 19, the measurement bandwidth plays an important role in the noise of your system. Select a measurement bandwidth consistent with your measurement goals. For instance, observation of thermal drifts in the sub-Hz range will benefit greatly from signal averaging or other bandwidth-limiting actions.

**Using Optical Filters**

Narrow-band optical filters, which transmit your laser’s wavelength while blocking other light sources, can be installed in a New Focus Model 1280 1” filter holder. Many filters are commercially available.

When using optical filters during position measurement, please consider the effects of multiple surface reflections. The ideal filter has a wedge shape, and good anti-reflection coating on one surface to ensure that the optical beam incident on the receiver does not contain interference fringes.
Operation

Setting up the Receiver

1. Supply power. The Model 290X is powered either by a single 9-V alkaline battery, or by a +/-15 V DC power supply. If both battery and external power are present, an internal relay connects the external power to the amplifier circuitry. To check the battery condition, push the red power switch to the BATT CHK position. If the green LED lights up, the battery is in good condition; if the LED does not light, the battery needs to be replaced (see page 8). Adjust the power switch to ON.

   **Note:** Remember to switch the power OFF when not in use to maximize battery life.

2. Mount the photoreceiver. Use the 8-32 thread (M4 for metric versions) on the bottom of the casing to mount the photoreceiver to a post or pedestal.

   Be careful not to over-tighten when attaching to a post or pedestal, or the threaded insert can strip out of the plastic pad.

3. Connect the receiver output. Connect your voltmeter, oscilloscope, or other instrument to the X, Y and SUM connectors on the back of the receiver.

   **Note:** The threading is seated in a non-conductive plastic pad to reduce the electrical noise associated with ground loops.
Electrical ground is only introduced to the housing through the BNC outer shells, and the power-supply ground pin. If you use a floating measurement instrument or a floating power supply, the photoreceiver may not be electrically grounded.

4. Align an optical beam onto the detector. Be careful to keep the optical power below the stated limits to avoid damage to the photoreceiver and amplifier circuitry.

5. Adjust the gain. Use the rotary switch on top of the receiver to set the gain. The table on page 13 gives a detailed description of the different channel gains and bandwidths associated with each switch setting.

Checking and Replacing the Battery

The Model 290X is powered by a single, standard 9-volt alkaline battery. Under normal operating conditions with low light levels and a high impedance load attached to the BNC connectors, the photoreceiver draws about 25 mA from the battery, and the battery lifetime will be approximately 40 hours.

To check the battery condition, push the power switch to the BATT CHK position. If the green LED lights up, the battery is in good condition.

When the battery voltage falls below about 6.5 volts, the green LED will not light, and the battery should be replaced.

1. Switch off the power and disconnect any external power supply.

2. Remove the screw in the back of the photoreceiver casing and remove the back cover.

3. Unplug the old battery by rotating it away from the circuit board about the snap-on terminal contacts.
4. Install a new 9-volt alkaline battery.

5. Reinstall the back cover and screw. Take care not to pinch the power wires from the external power connector.

6. Test the new battery by pushing the power switch to the BATT CHK position.

**Using an External Power Supply**

The Model 290X can be operated from any power supply which can supply 50 mA of ±15 V DC power. New Focus recommends use of the Model 0901 Power Supply, which features three pairs of low-noise linear ±15 V DC outputs.

If using the Model 0901 Power Supply, connect the Model 0923 M8B-to-M8B cable from the power supply to the jack on the back of the Model 290X.

If using a third-party power supply, connect the Model 9024 banana-plug-to-M8B cable from the power supply to the jack on the back of the Model 290X. The red jack should be connected to +15 V DC, the black to -15 V DC, both with respect to the green jack, which should be connected to the power supply COMMON terminal. It is recommended, but not required to use the green wire as an earth ground.

*Note: If you have an older version of the New Focus Model 0901 Power Supply, you can obtain Model 0925 Micro-connector-to-M8B cable to connect your power supply to the Model 290X, or you can use a Model 9024 banana-plug-to-M8B cable.*
General Features and Principles

Amplifier Circuitry

The circuitry inside of the Model 290X consists of a two-stage amplifier, with parallel gain paths for X, Y, and SUM outputs. Each stage has an adjustable gain and bandwidth. Figures 1 through 3 illustrate the basic circuit design, and the table on page 13 shows the gain and bandwidth of each amplifier stage for each possible setting of the rotary switch.

Each photocurrent from the quadrant photodiode is amplified at a first-stage amplifier. The value of $R_1$ depends on the gain setting, and can vary from 200 $\Omega$ to 200 $k\Omega$.

**Figure 1:** Each photocurrent is amplified at a first-stage amplifier.

The signals from each quadrant are differenced and amplified at a second-stage amplifier. The value of $G_2$...
depends on the setting of the gain switch, and can vary from 1 to 10. The bandwidth of this gain stage also varies, as indicated in the table on page 13.

Figure 2:
Signals from each quadrant are differenced and amplified at a second stage amplifier.

The signals from each quadrant are summed at a second-stage amplifier. The value of $G_3$ is fixed at unity. The bandwidth of this gain stage is fixed at 30 Hz.

Figure 3:
Signals from each quadrant are summed at a second-stage amplifier.
## Gain and Bandwidth

The following table shows the gain and bandwidth of each amplifier stage as a function of switch setting.

<table>
<thead>
<tr>
<th>Switch Position</th>
<th>$R_1$ Gain (V/A)</th>
<th>1st-Stage BW (kHz)</th>
<th>$G_2$ Gain (V/V)</th>
<th>$\Delta$-Stage BW (kHz) approx.</th>
<th>$G_3$ Gain (V/V)</th>
<th>Sum-Stage BW (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 mW (1)</td>
<td>200</td>
<td>100</td>
<td>1</td>
<td>100</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>30 mW (3)</td>
<td>200</td>
<td>100</td>
<td>3</td>
<td>100</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>30 mW (10)</td>
<td>200</td>
<td>100</td>
<td>10</td>
<td>100</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>3 mW (1)</td>
<td>2000</td>
<td>100</td>
<td>1</td>
<td>100</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>3 mW (3)</td>
<td>2000</td>
<td>100</td>
<td>3</td>
<td>100</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>3 mW (10)</td>
<td>2000</td>
<td>100</td>
<td>10</td>
<td>100</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>3 mW (10)</td>
<td>2000</td>
<td>100</td>
<td>10</td>
<td>0.03</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>0.3 mW (1)</td>
<td>20,000</td>
<td>100</td>
<td>1</td>
<td>100</td>
<td>1</td>
<td>0.03</td>
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<td>1</td>
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<td>1</td>
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<td>100</td>
<td>1</td>
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<td>3</td>
<td>100</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>30 µW (10)</td>
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<td>10</td>
<td>100</td>
<td>1</td>
<td>0.03</td>
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<tr>
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<td>100</td>
<td>10</td>
<td>0.03</td>
<td>1</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Normalization of Outputs

The signals X and Y vary in response to changes of the light position relative to the center of the quadrant photodiode. Because X and Y also vary in response to changes of the total light power, the SUM signal is provided as a means of normalization.

We have provided an example LabView™ VI on our website (www.newfocus.com) which demonstrates the use of this normalization in a data acquisition environment.

The bandwidth of the SUM signal is limited to 30 Hz. Therefore, the normalization cannot be performed for rapid power fluctuations characteristic of some laser beams. We will be happy to provide a customized version with the 30-Hz limit removed: just call our technical customer service line.

Position Transfer Function

When normalized, the signals X/SUM and Y/SUM can be used to measure position. For clarity, we will use the dimensionless units V/V for the normalized signals when describing the measured position transfer function. Because the signals are normalized, position output does not depend on $R_1$ gain setting, only on $G_2$.

Figures 4 and 5 illustrate the output response as a function of input position for an ideal Gaussian laser beam input. The nearly linear portion of the output response has a slope of 0.65 radii/V/V. For example, a normalized output of 0.5 V/V would occur for a Gaussian beam displaced $0.5 \text{ V/V} \times 0.65 \text{ radii/V/V} = 0.32 \text{ radii}$ from the center of the quadrant photodiode. If the beam radius in the above example were 1 mm, the normalized output of 0.5 V/V would occur at a displacement of 0.32 mm from the photodiode's center.
If the optical beam under measurement is not Gaussian, the above relationship will not hold. For example, if the beam is elliptical, the transfer function will be different along the major and minor axes. You can calibrate the position transfer function effectively by placing the photoreceiver on a two-axis translation stage and measuring output as a function of position.

**Figure 4:**
Normalized position output transfer function for $G_2=1$ settings assuming Gaussian beam input

**Figure 5:**
Normalized position output transfer function for $G_2=10$ settings assuming Gaussian beam input
Selecting the Optimal Gain Setting

In order to maximize signal fidelity, you should select the maximum gain setting possible, but not saturate the amplifier. The first and second stage gains can saturate independently, so you must take care to select an optimal value for each.

It is easy to identify if the first stage is saturated. The SUM output will reach its “rail” voltage of 2.5 V. Any time the SUM output exceeds 2 V, it is a good idea to reduce the gain setting by reducing $R_1$ by one decade.

Saturation of the second stage depends on the position of your optical beam relative to the photodiode center. X and Y can reach a maximum of $\pm 2.5$ V or $G_2 \times$ SUM, whichever is smaller. Test for saturation at your desired gain setting by creating the maximum expected beam displacement and observing the X and Y outputs. If the signal saturates, reduce the value of $G_2$ by selecting a different gain switch setting.

Frequency Response and Noise

Measuring Bandwidth

The frequency response and noise characteristics of the quadrant cell photoreceiver depend on the selected gain. Figures 6–10 on the following pages give the typical frequency response and noise behavior for the photoreceivers at each of the 16 possible gain settings. The frequency response of the receiver in Figure 6 is plotted using the expression

$$20 \times \log \left( \frac{V_{out}(f)}{V_{out}(DC)} \right)$$

where $V_{out}(f)$ is the output from the X, Y, or SUM output of the receiver. New Focus uses the -3 dB electrical definition for bandwidth.
**Figure 6:** Frequency response for X, Y and SUM outputs with 30-µW saturation setting ($R_1 = 200 \, \text{ohm}$)

![Graph showing frequency response](image)

**Figure 7:** Output voltage noise spectral density for X, Y outputs with 30-µW saturation setting ($R_1 = 200 \, \text{k}\Omega$)

![Graph showing noise](image)

**Figure 8:** Output voltage noise spectral density for X, Y outputs with 0.3-mW saturation setting ($R_1 = 20 \, \text{k}\Omega$)

![Graph showing noise](image)
Figure 9:
Output voltage noise spectral density for X, Y outputs with 3-mW saturation setting ($R_1 = 2 \, k\Omega$)

Figure 10:
Output voltage noise spectral density for X, Y outputs with 30-mW saturation setting ($R_1 = 200 \, \text{ohm}$)

Measuring Noise
The photoreceiver noise ($V_n$) is measured as a noise spectral density [$V_{\text{rms}}/\sqrt{\text{Hz}}$]. The noise spectral density at each of the gain settings is provided in Figures 7–10 on the previous pages. Depending on your measurement system, you may utilize only a fraction of the receiver's available bandwidth. The noise in your measurement will be the integral of the receiver's noise.
spectral density over the frequency range \((f_{\text{min}} \text{ to } f_{\text{max}})\) observed by your measurement system:

\[
\int_{f_{\text{min}}}^{f_{\text{max}}} V_n^2 \, df
\]

For a flat noise spectrum in a DC-coupled measurement system with a 3-dB bandwidth of \(f_{3\text{dB}}\), the measured rms noise will be .

\[
V_n \cdot \frac{2\pi}{\sqrt{3\text{dB}}} \cdot \frac{2\pi}{4}
\]

**Impact of Noise on Position Measurement**

Unlike photoreceivers which are often used to measure optical power, the quadrant cell photoreceiver is a position transducer. Therefore, the receiver's output noise is observed as position measurement noise. Although a real measurement system may also have noise due to laser power instability, or undesired mechanical vibrations, the receiver's output noise sets a lower limit on position sensitivity.

Recall that the position transfer function for a Gaussian beam is 0.65 radii/V/V of normalized output. For other beam shapes, the position transfer function will differ. Considering that the electrical noise of the receiver effects both numerator and denominator of the normalized output, you can approximate the expected noise in the normalized output signal as
The bandwidth of the SUM output is intentionally limited to 30 Hz, which reduces the contribution of $V_{n_{SUM}}$ to negligible in most cases. Therefore, the position uncertainty is simply equal to the output voltage noise divided by the normalized SUM output, multiplied by the position transfer function.

If you take the worst case, which shows up for the 30-µW settings (200 kΩ $R_1$) and 10 voltage gain second stage, the Y output noise level peaks at about 2 µV(rms)/√Hz. All other gain settings have lower noise.

Over the 100 kHz bandwidth of the receiver, this noise integrates to about 0.5 mV(rms). If your voltage converter, such as an oscilloscope has wider bandwidth, you may observe somewhat more voltage noise. If you reduce the second stage gain to 1, the integrated noise in 100 kHz drops to about 0.1 mV(rms).

As an example we can approximate the position measurement noise you might observe in a typical application. If you have about 1 mW of HeNe power, you will use the 3 mW setting (2 kΩ $R_1$). If you are trying to observe small, high frequency position changes, the 10 setting for $G_2$ will give you a voltage swing in the X/SUM or Y/SUM calculated output from -1.56 to +1.56 when the beam travels over the range of -0.1*radius to +0.1*radius. The position transfer function is therefore given by $X/SUM/1.56 = x/0.1*radius$, or $x = 6.5*radius*X/SUM$. The SUM output

\[
\text{SIGNAL}_{\text{actual}} + \Delta\text{SIGNAL} = \frac{X_{\text{actual}} + V_{n_x}}{\text{SUM}_{\text{actual}} + V_{n_{SUM}}} 
\]

\[
\approx \frac{X_{\text{actual}}}{\text{SUM}_{\text{actual}}} + \frac{V_{n_x}}{\text{SUM}_{\text{actual}}}
\]
will be 1 mW * 0.5 A/W (responsivity at 633 nm) * 2 kΩ = 1 V. The integrated voltage noise in 100 kHz bandwidth on this setting (Figure 9) is 0.1 mV rms. Putting it all together, the observed position noise due to electronics will be 0.00065*radius (rms). If the beam radius is 300 microns, the position noise due to electronics is 0.2 microns (rms).

In practice, laser power fluctuation, air turbulence, table vibrations, and other factors may give you larger noise. You should also take care to acquire the data and normalize X/SUM and Y/SUM or else power fluctuations will map into perceived position changes.
Characteristics

Physical Specifications

- output BNC (X)
- output BNC (Y)
- output BNC (SUM)
- power switch
- battery check LED
- external input power (±15VDC)
- 1.00" (25.4)
- 1.25" (31.7)
- 4.17" (105.9)
- 1.79" (45.5)
- 1.16" (29.5)
- 2x 1.040-32 THD for mounting Model 1280 Filter Holders (not included)
- quad cell 3mm × 3mm active area
- 8-32 (M4) THD
### Operating Specifications

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Model 2901</th>
<th>Model 2903</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-dB Bandwidth (typical)</td>
<td>100 kHz</td>
<td>100 kHz</td>
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<tr>
<td>Conversion Gain</td>
<td>$10^2$ to $10^6$ V/W</td>
<td>$2 \times 10^2$ to $2 \times 10^6$ V/W</td>
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<tr>
<td>Maximum Responsivity</td>
<td>0.5 A/W</td>
<td>1 A/W</td>
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<tr>
<td>Transimpedance Gain</td>
<td>$2 \times 10^2$ to $2 \times 10^6$ V/A</td>
<td>$2 \times 10^2$ to $2 \times 10^6$ V/A</td>
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<td>Outputs</td>
<td>X, Y, SUM</td>
<td>X, Y, SUM</td>
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<tr>
<td>Output Impedance</td>
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<td>1 kΩ</td>
</tr>
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<td>cw Saturation Power (per channel)</td>
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<td>15 mW</td>
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<td>Output Voltage Range</td>
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<td>-2.5 to +2.5 V</td>
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<td>BNC</td>
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<tr>
<td>Power Requirements</td>
<td>±15 V or 9-V Battery</td>
<td>±15 V or 9-V Battery</td>
</tr>
</tbody>
</table>
Customer Service

Technical Support

Information and advice about the operation of any New Focus product is available from our technical support engineers.

Engineers are on duty from 8:00–5:00 PST, Monday through Friday (excluding holidays). For quickest response, ask for "Technical Support" and know the model number and serial number for your laser (these numbers are located on the label on the back of the laser.

Phone: (408) 919-1500
Fax: (408) 980-8883

Support is also available by email:
technicalsupport@newfocus.com

We typically respond to email within one business day.

Service

In the event that your device malfunctions or becomes damaged, please contact New Focus for a return authorization number and instructions on shipping the unit back for evaluation and repair.