USER'S GUIDE

10-MHz Adjustable Balanced Photoreceivers

Models 2107 & 2117

CAUTION!

These photoreceivers are sensitive to electrostatic discharges and could be permanently damaged if subjected even to small discharges. Ground yourself adequately prior to handling these detectors or making connections. A ground strap provides the most effective grounding and minimizes the likelihood of electrostatic damage

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phone: (877) 835-9620
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Operation

Introduction

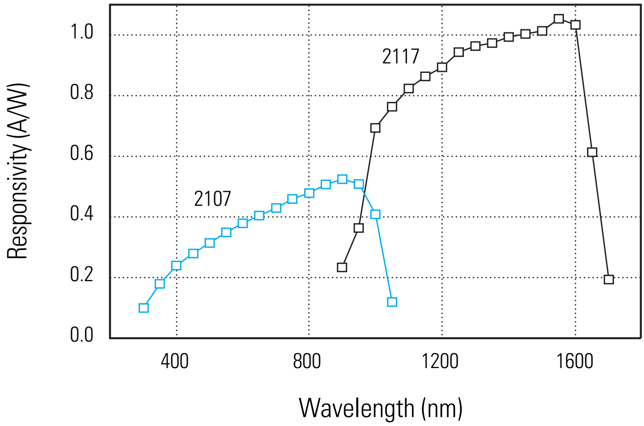
The Model 21X7 is a general-purpose balanced photoreceiver with adjustable gain and bandwidth. These receivers can be powered by batteries or by an external ±15-V power supply. There are two models available, each based on a different photodetector. Free-space (FS) and fiber-coupled (FC) versions are available for each model:

Model	Wavelength	Diode Type	Active Area
2107-FC	300–1070 nm	silicon	0.8 mm^2
2107-FS	300–1070 nm	silicon	0.8 mm^2
2117-FC	900–1700 nm	InGaAs	0.0078 mm^2
2117-FS	900–1700 nm	InGaAs	0.08 mm^2

Note: *Complete specifications begin on page 21.*

The 10-MHz three-stage transimpedance amplifier includes selectable gain and selectable low- or high-pass filters for easy signal optimization.

Figure 1: Typical responsivities of the Model 2107 & 2117 photodiodes



Note: *To obtain the value of the "response factor" in V/mW, divide the photodiode responsivity by 1.5. For more information on frequency response and noise, see page 13.*

Using the Photoreceiver

1. **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.
2. **Supply power.** Power the Model 21X7 using either two 9-volt alkaline batteries or a ±15-V low-noise linear power supply (such as the Newport Model 0901).
3. **Connect the receiver output.** Connect your voltmeter, oscilloscope, or other instrument to the Output SMA connector on the receiver.

   Note: *If you wish to connect to a BNC cable, you can purchase a BNC-to-SMA adapter such as the Newport Model 1225.*
4. **Turn on the photoreceiver power.** For external power, use ±15 VDC ON; for battery, use Batt Mode ON.
5. **Align optical beams onto the detectors.** The photodiodes are not very large, so take care when aligning each beam.
6. **Adjust the gain.** Use the knob and rocker switch on the receiver to set the gain. The bandwidths vary with the gain setting (see table on page 10).
7. **Adjust the filters.** Select low-pass and high-pass corner frequencies using the knobs on the receiver.
8. **Balance the optical input levels.** Alternately block each diode and observe the signal strength. When they are approximately equal and opposite, adjust their relative intensity until the balanced output is zero volts.
9. **Turn off the photoreceiver power.** When you are finished with the receiver, place the power switch in the ±15 VDC ON position and switch off or unplug the external power supply.

Checking the Batteries

The Model 21X7 can be powered by two standard 9-volt alkaline batteries. Under normal operating conditions with low light levels and a high impedance load attached to the BNC connector, the photoreceiver draws about 20 mA from the batteries, and the battery lifetime is approximately 24 hours.

To check the condition of the battery:

1. Turn on the photoreceiver using the power switch.
2. Set the Low Frequency adjustment to DC.
3. Set the Gain to $3x10^4$.
4. Focus at least 1 μW of optical power on the detector (or place the detector in front of a desk lamp).

The output should be greater than 7 V. If it is not, replace the batteries with fresh ones.

Replacing the Batteries

The Model 21X7 is shipped with two fresh 9-V batteries installed. To avoid confusion due to low batteries, replace the batteries on a monthly basis when the receiver is in frequent use, or use an external linear power supply such as the Newport Model 0901.

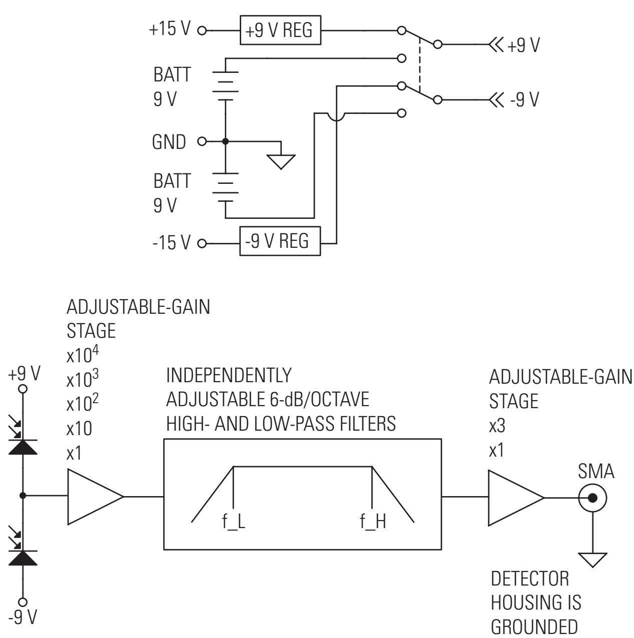
1. Turn off the receiver using the power switch.
2. Use a Phillips-head screwdriver to remove the two screws on the back panel of the photoreceiver.
3. Remove the back panel.
4. Replace the used 9-V batteries with fresh ones.
5. Replace the back panel and the two screws.
6. Recheck the battery level as described above.

General Features & Principles

Photoreceiver Circuitry

The circuitry inside the Model 21X7 consists of two photodiodes followed by a three-stage transimpedance amplifier. The gain can be adjusted from 626 V/A to 18.8×10^6 V/A in 5-dB steps. The low-noise amplifier design is optimized to maximize bandwidth at each gain setting. At the higher gain settings, the bandwidth is limited by amplifier gain-bandwidth product. The plots of Figure 3 show the typical frequency responses for the different gain settings.

Figure 2: Functional schematic of the Model 21X7 circuitry



The following table summarizes the bandwidth at each gain setting. The bandwidth on the 3x settings is somewhat lower than the 1x settings, and significantly decreases at the highest gain settings. There is little difference in frequency response between the visible (Model 2107) and IR (Model 2117) models. The plots of Figure 3 show the frequency-response details for each gain setting.

Gain Setting	Specification	Typical Performance
1x1	10 MHz	12 MHz
3x1	NA	6 MHz
1x10	NA	12 MHz
3x10	NA	6 MHz
$1x10^2$	NA	8 MHz
$3x10^2$	NA	6 MHz
$1x10^3$	NA	700 kHz
$3x10^3$	NA	700 kHz
$1x10^4$	NA	250 kHz
$3x10^4$	150 kHz	250 kHz

Optical Power and Output Voltage

The typical operating range for these receivers is from a few nanowatts up to 2 to 5 mW (depending on the model and gain setting). Be careful to keep the differential optical power below the maximum optical power difference of 10 mW to avoid damaging the photoreceiver.

To compute the approximate output voltage for a given input optical power use the relationship

$$V_{out} = (P_+ - P_-) \cdot R \cdot G,$$

where P_+ and P_- are the input optical powers in Watts on the right and left photodiodes respectively, R is the photodetector's response factor in V/mW, and G is the amplifier's gain setting.

Note: *Estimate the value of the response factor by dividing the responsivity shown in Figure 1 by 1.5.*

For example, the Model 2107 on the $1x10^3$ gain setting and with 10 µW of optical power at 900 nm on one photodiode will have an output voltage of approximately

$$(0.01\ \text{mW})\cdot(0.35\ \text{V/mW})\cdot(1x10^3) = 3.5\ \text{V}.$$

The maximum differential optical power that can be detected by the photoreceiver is determined by the input optical power at which either stage of the transimpedance gain saturates. We can calculate the saturation power at 900 nm for the Model 2107 at its maximum output voltage of ±7 V with fresh batteries or operating from an external ±15 VDC power supply.

Using the expression $7\ \text{V} = P_{sat}\cdot R\cdot G$, the Model 2107 has a differential saturation power of 20 mW for the lowest gain setting up to 0.7 µW for the highest gain setting. At other wavelengths where the responsivity is lower, the saturation power increases inversely with response factor.

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Frequency Response and Noise

Measuring Bandwidth

The frequency response and noise characteristics of the photoreceiver depend on the selected gain. The figures beginning on page 16 give the typical frequency response and noise behavior for the photoreceivers at each of the gain settings. The frequency response of the transimpedance gain is plotted using the expression

$$20 \cdot \log[\mathrm{Gain}(f)/\mathrm{Gain}(0)],$$

where f is the frequency and Gain(0) is the gain at DC. The photoreceiver's bandwidth is defined as the frequency where the gain has decreased by 3 dB, or a factor of $\sqrt{2}$.

Measuring Noise

The photoreceiver noise is characterized using the noise equivalent power (NEP), which is a measure of the weakest optical signal that the photoreceiver can detect. The NEP is the optical power which will produce a signal-to-noise ratio of 1 in a 1-Hz bandwidth. The minimum detectable optical power can be found using the relationship

$$\text{Minimum Optical Power} = NEP \cdot \sqrt{\mathrm{BW}},$$

where BW is the bandwidth. Note that NEP is a wavelength-dependent quantity that changes with the photodetector's responsivity.

Another way to characterize the noise is with the photocurrent noise (I_n), which is related to NEP by

$$I_n = R \cdot NEP,$$

where R is the photodetector's responsivity (in A/W). The photocurrent noise is independent of wavelength because it gives the noise of the photoreceiver with the photodetector's responsivity factored out.

To characterize the noise of the photoreceiver, the output electrical noise spectrum is measured with a spectrum analyzer. This voltage noise spectrum is converted to an equivalent optical photocurrent noise by dividing the voltage noise by the transimpedance gain (V/A). The photocurrent noise, $I_n(f)$, has units of pA/$\sqrt{\text{Hz}}$ and is plotted in Figure 3 and Figure 4 using the expression $20 \cdot \log[In(f)/1\ \text{A}]$.

Calculating NEP

The noise equivalent power (NEP) can be calculated by dividing the photocurrent noise by R, the detector's responsivity (see page 6).

From DC to 150 kHz the average photocurrent noise for the Model 2107 on the high gain setting is about 0.4 pA/$\sqrt{\text{Hz}}$, corresponding to an average NEP at 900 nm of 0.8 pW/$\sqrt{\text{Hz}}$. The integrated noise equivalent power from DC to 150 kHz is then obtained by multiplying the average NEP by $\sqrt{\text{BW}}$, the square root of the bandwidth.

The expression $BW = 2\pi f_{3\text{-dB}}/4$ for a one-pole low-pass filter is useful for calculating the equivalent noise bandwidth. Using the high-pass filter set 1 decade below the low-pass cutoff reduces noise-equivalent bandwidth by approximately 10 %. For the Model 2107 with a 3-dB bandwidth of 150 kHz, the equivalent noise bandwidth is 235 kHz. This gives an optical noise equivalent power of about 390 pW, so the minimum detectable optical signal at 900 nm (with a signal-to-noise ratio of 1) for the Model 2107 on the highest gain setting is 390 pW when operating at full detector bandwidth.

You can further improve your signal-to-noise ratio by using optical modulators or choppers with lock-in amplifiers to limit the detection bandwidth. Using such techniques you can reduce equivalent bandwidth to 1 Hz or less.

Calculating Output-Voltage Noise

The output-voltage noise can be calculated from

$$G \cdot R \cdot NEP \cdot \sqrt{\mathrm{BW}}\,,$$

where *G* is the gain (V/V), *R* is the photodiode response factor (V/mW), *NEP* is the average noise equivalent power, and *BW* is the bandwidth. This gives an output noise voltage for the Model 2107 on the high gain setting of

$$(3\mathrm{x}10^{4}\ \mathrm{V/V}) \cdot (0.35\ \mathrm{V/mW}) \cdot (0.8\mathrm{x}10^{-9}\ \mathrm{mW}/\sqrt{\mathrm{Hz}}) \cdot \sqrt{\frac{2\pi}{4} \cdot 150 \times 10^{3}\,\mathrm{Hz}} = 4\ \mathrm{mV_{rms}}.$$

CAUTION!

The Johnson noise at the input of a 100-MHz bandwidth oscilloscope with 1-MΩ input impedance is 1.6 mV_{rms}. This is often the limiting factor in broadband measurements.

Summary

With the Model 2107 on the highest gain setting the minimum NEP is 0.8 pW/$\sqrt{\mathrm{Hz}}$, and this yields an output noise voltage of 4 $\mathrm{mV_{rms}}$. Viewed another way, for operation at the peak responsivity wavelength of 900 nm and for the high gain setting, you will achieve a signal-to-noise ratio of unity if the input power is 390 pW.

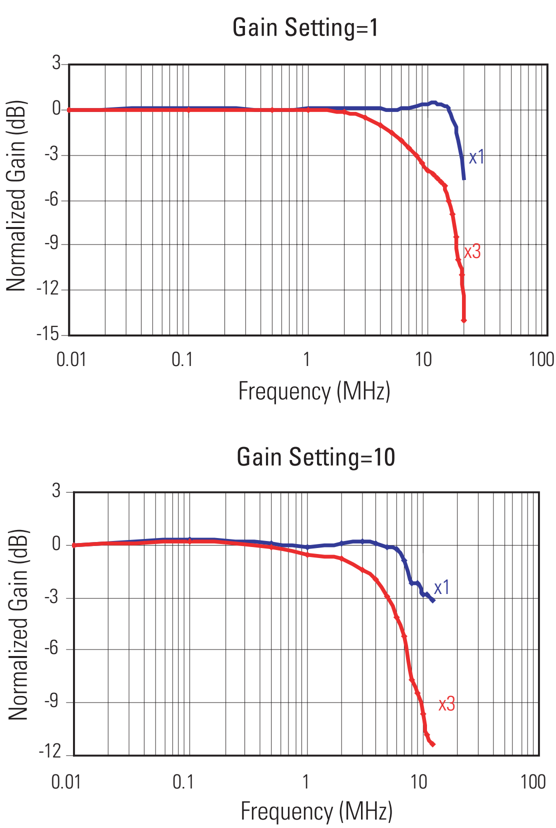
For the Model 2117 with an InGaAs photodiode, the NEP at peak response wavelength of 1500 nm is 0.4 pW/$\sqrt{\mathrm{Hz}}$ over the 150-kHz bandwidth. The full bandwidth signal-to-noise ratio of 1 is achieved around 200 pW.

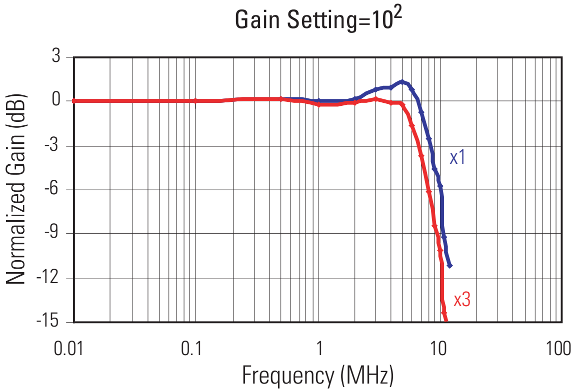
Note that this assumes operation without any post-photoreceiver filtering and with the full photoreceiver bandwidth. By using the built-in electronic band-pass filter or an optical chopper and a lock-in amplifier, the receiver can detect significantly weaker optical signals.

Performance Data for Frequency Response

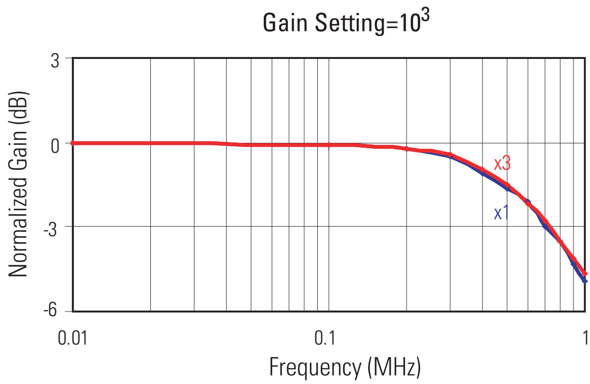
The 3-dB frequency bandwidth is defined as the frequency where the photoreceiver's transimpedance gain has decreased by a factor of $\sqrt{2}$. The typical frequency responses for the Model 2107 and Model 2117 are shown in the following figures.

Figure 3: Typical frequency response for Model 21X7 at each gain setting

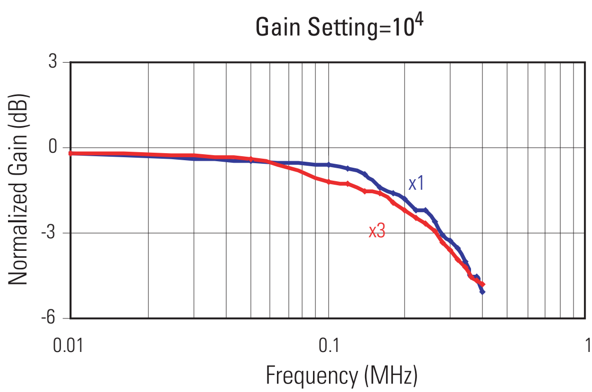




Gain Setting=10^2
3
0
-3
-6
-9
-12
-15
Normalized Gain (dB)
0.01
0.1
1
10
100
Frequency (MHz)
x1
x3



Gain Setting=10^3
3
0
-3
-6
Normalized Gain (dB)
0.01
0.1
1
Frequency (MHz)
x3
x1



Gain Setting=10^4
3
0
-3
-6
Normalized Gain (dB)
0.01
0.1
1
Frequency (MHz)
x1
x3

Performance Data for Noise

Figure 4 shows the typical noise spectrum expressed as photocurrent noise for Model 21X7 photoreceivers on the highest gain setting.

To derive the receiver's Noise Equivalent Power (NEP), divide the photocurrent noise by the photodiode responsivity. To convert to output voltage noise (RMS), multiply the photocurrent noise by the gain setting from the 21X7 front label, then by 630 V/A (the scaling factor between the gain setting labels and the actual amplifier transimpedance gain).

For example, the output voltage noise (RMS) for Model 2117 in the $3x10^3$ setting is approximately:

$$0.4\ \mathrm{pA}/\sqrt{\mathrm{Hz}} \times 3 \times 10^3 \times 630\ \mathrm{V/A} = 0.75\ \mu V_{rms}/\sqrt{\mathrm{Hz}}.$$

For the 700 kHz of amplifier bandwidth in the $3x10^3$ gain setting, the equivalent noise bandwidth is:

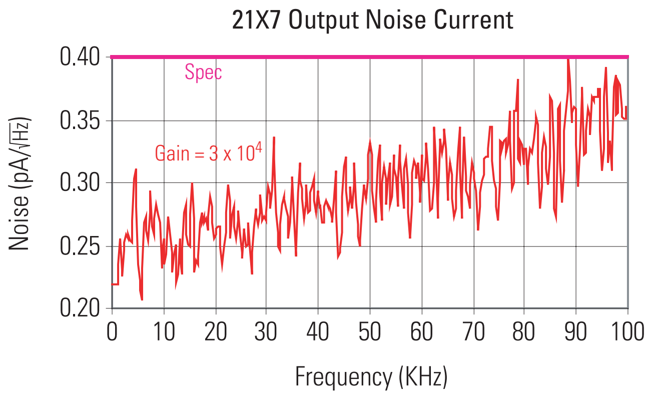
$$(2 \times \pi/4) \times 700 \times 10^3\ \mathrm{Hz} = 1.1\ \mathrm{MHz},$$

so the predicted output noise voltage is approximately

$$0.75\ \mu V_{rms}/\sqrt{\mathrm{Hz}} \times \sqrt{1.1 \times 10^6 \mathrm{Hz}} = 0.8\ mV_{rms}.$$

Because the NEP is listed at the highest gain setting, some additional considerations add to the NEP at lower gain settings. First, the noise spectrum (Figure 4) is not flat, rising at frequencies above 100 kHz. This contributes an extra 20% to the output noise voltage in the 3×10^3 setting compared to 3×10^4. Also, as the output noise voltage approaches 1 mV_{rms}, the Johnson noise limit of your measurement instrument will become important. Note that the Johnson noise for an oscilloscope with 100-MHz bandwidth (assuming perfect roll off) and 1-MΩ input impedance is 1.2 mV_{rms}.

Figure 4:
Typical noise spectrum for Model 21X7



Common Mode Rejection

Using the Model 21X7 balanced photoreceivers with equal signal powers on each photodiode results in an output with reduced common mode signal. The common-mode rejection ratio, or CMRR, is a measurement of the effectiveness of the balanced subtraction.

Figure 5 shows the CMRR of each model using the following definition:

$$CMRR = -20 \cdot \log((V_{out1} - V_{out2})/V_{out1}).$$

Because the common mode subtraction occurs before the first amplifier stage, the only practical bandwidth limitation on common mode rejection is the photodiode bandwidth. Thus, as seen in the following figures, the CMRR for higher gain settings is relatively flat to frequencies well beyond the useful frequency response of the gain setting.

Figure 5: Typical CMRR for Model 2107 in each gain setting

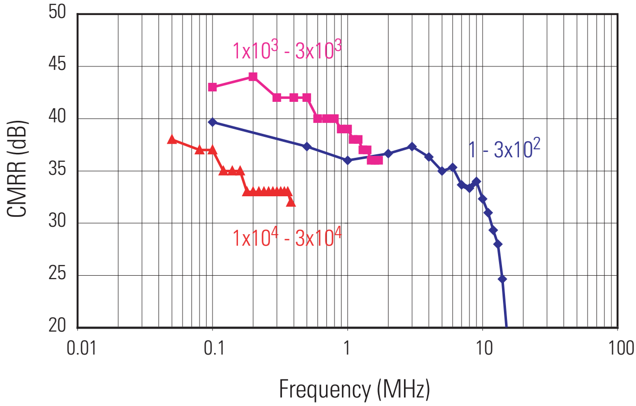
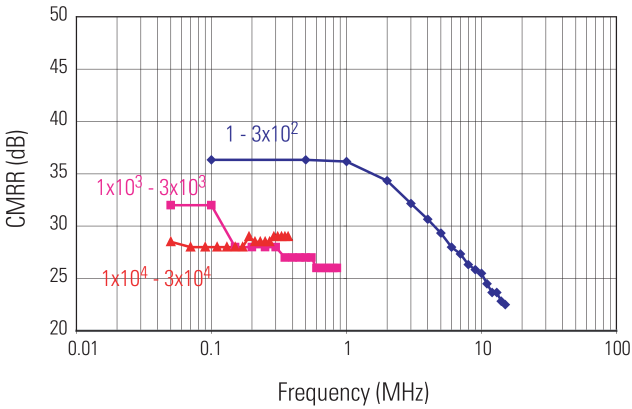


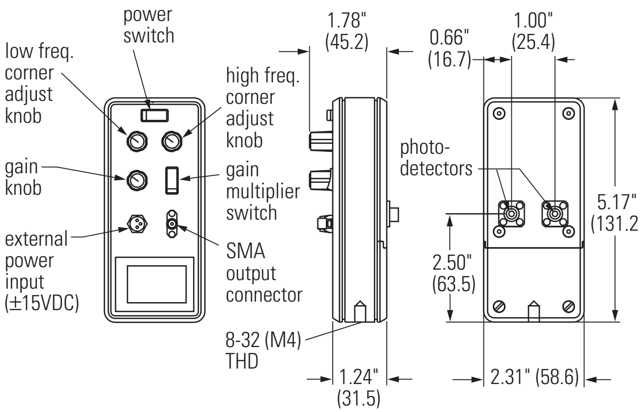
Figure 6: Typical CMRR for Model 2117 in each gain setting



Characteristics

Physical Specifications

Figure 7: Mechanical drawing of the Model 21X7 casing



Model 2107 Specifications

	Model 2107
Wavelength Range	300–1070 nm
3-dB Bandwidth	10 MHz, 5 MHz, 150 kHz
Typical Common-Mode Rejection	25 dB
Rise Time	80 ns
Peak Conversion Gain	9.4×10^6 V/W
Typical Max. Responsivity	0.5 A/W
Max. Transimpedance Gain	18.8×10^6 V/A
Output Impedance	16 Ω
Minimum NEP	0.8 pW/$\sqrt{Hz}$
CW Saturation Power	20 mW @ 850 nm
Max. Differential Power	20 mW @ 850 nm
Max. Power per Photodiode if balanced (damage threshold)	20 mW @ 850 nm
Detector Material/Type	Si/PIN
Detector Active Area	1.0 mm x 0.8 mm
Optical Input	FC or Free Space
Electrical Output	SMA
Power Requirements	±15 VDC <150 mA External Power Supply or Two 9-V Batteries

Model 2117 Specifications

	Model 2117
Wavelength Range	900–1700 nm
3-dB Bandwidth	10 MHz, 5 MHz, 150 kHz
Typical Common-Mode Rejection	25 dB
Rise Time	80 ns
Peak Conversion Gain	18.8 x 10^6 V/W
Typical Max. Responsivity	1 A/W
Max. Transimpedance Gain	18.8 x 10^6 V/A
Output Impedance	16 Ω
Minimum NEP	0.4 pW/ $\sqrt{Hz}$
CW Saturation Power	10 mW @ 1600 nm
Max. Differential Power	10 mW @ 1600 nm
Max. Power per Photodiode (damage threshold)	10 mW @ 1600 nm
Detector Material/Type	InGaAs/PIN
Detector Active Area	0.3-mm diam. (FS) 0.1-mm diam. (FC)
Optical Input	FC or Free Space
Electrical Output	SMA
Power Requirements	±15 VDC <150 mA External Power Supply or Two 9-V Batteries

Customer Service

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Information and advice about the operation of any Newport product is available from our applications engineers. For quickest response, ask for "Technical Support" and know the model number and serial number for your product.

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