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USER'S GUIDE

Large-Area Balanced Photoreceivers

Models 2307 & 2317



2584 Junction Ave. • San Jose, CA 95134-1902 • USA
phone: (408) 919–1500 • e-mail: contact@newfocus.com • www.newfocus.com

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Operation

Introduction

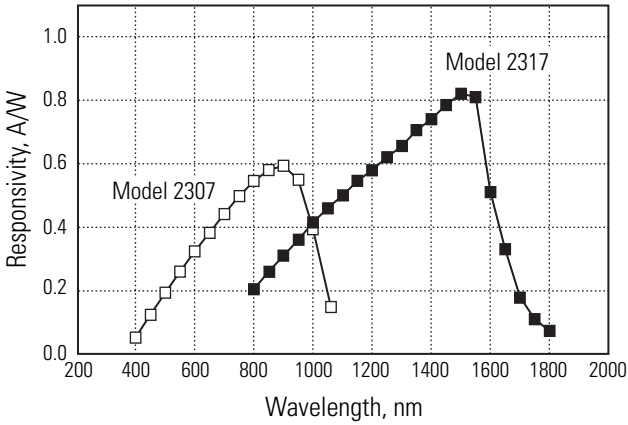
The Model 23X7 is a general-purpose balanced photoreceiver with a large-area photodetector. These receivers can be powered by battery or by an external ±15-V power supply. There are two versions of the Model 23X7 receiver, each based on a different photodetector:

Model	Wavelength	Type	Diam.
2307	400–1070 nm	silicon	8 mm
2317	800–1750 nm	germanium	5 mm

Note: *Complete specifications begin on page 21.*

The large area of the photodetector makes it easy to couple light from a variety of sources (including diode lasers, broadband sources, and light from optical fibers) onto the detector without requiring precise optical alignment or focusing. Figures 1 and 2 on the following page show the typical responsivity curves for the different detectors.

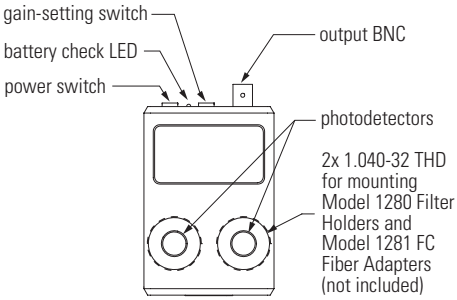
Figure 1: Typical responsivities of the Model 2307 & 2317 photodiodes



Note: *For more information on frequency response and noise, see page 11.*

The photoreceiver's slim casing, shown on the next page, makes it easy to position it in a set-up between closely spaced optics. The switches and BNC output connector are located on top of the receiver for easy access.

Figure 2: The Model 23X7 casing



Note: *A full mechanical diagram of the Model 23X7 casing is available on page 21.*

Using the Photoreceiver

1. **Check the battery voltage.** The Model 23X7 can be powered by a single 9-volt alkaline battery or an external power supply. If you are using a battery, check the battery condition by pushing 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).
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.



The threading is seated in a non-conductive plastic pad to reduce the electrical noise associated with ground loops. Be careful not to over-tighten when attaching the casing 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 **Output** BNC connector on top of the receiver.
4. **Turn the power switch to "on."** The output voltage should register on your scope or other instrument.
5. **Align optical beams onto the detectors.** Be careful to keep the optical intensity for each detector under the damage threshold (6 mW/mm^2 for Model 2317, 10 mW/mm^2 for the Model 2307).
6. **Adjust the gain.** Use the black switch on top of the receiver to set the gain to low, medium, or high. The bandwidths vary with the gain setting (the label on the front of the photoreceiver indicates the gain and bandwidth values).
7. **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.

8. **Turn the receiver off.** When you are finished with the receiver, return the power switch to the "off" position.

Checking the Battery

The Model 23X7 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 connector, the photoreceiver draws about 1 mA from the battery, and the battery lifetime is approximately 500 hours.

To check the condition of the battery, push the red 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 up, and the battery should be replaced.

Replacing the Battery

1. Turn the red power switch to "off" to prevent damage to the receiver.
2. Remove the screw on 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.
6. Check the battery level as described above.

General Features & Principles

Photoreceiver Circuitry

The circuitry inside the Model 23X7 consists of two photodiodes followed by an electronic gain stage. The black switch on top of the casing allows you to select one of three gain settings: low ($2x10^3$ V/A), medium (10^5 V/A), and high ($2x10^6$ V/A). The label on the front of the casing lists the gain and bandwidth values for each of these three gain settings. The amplifier design is optimized so it consumes a minimum of power and generates a minimum of noise at each of the gain settings. A simplified schematic of the Model 23X7 circuitry is shown in Figure 3.

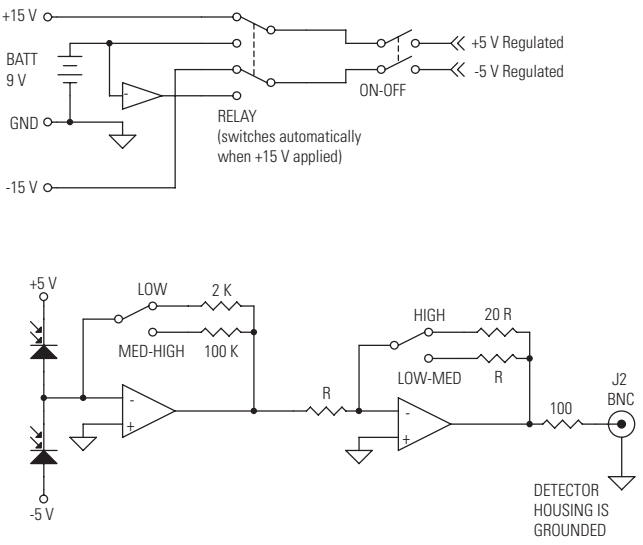


Figure 3: Functional schematic of the Model 23X7 circuitry

Optical Power and Output Voltage

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

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

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

where P_{in} and P_{out} are the input optical powers in Watts on the right and left photodiodes respectively, R is the photodetector's responsivity in A/W (see page 6 for typical responsivities), and G is the amplifier's trans-impedance gain in V/A.

For example, the Model 2307 on the medium gain setting and with 10 µW of optical power at 900 nm on one photodiode will have an output voltage of approximately (10 µW)·(0.6 A/W)·(10^5 V/A) = 0.6 V.

The maximum differential optical power that can be detected by the photoreceiver is determined by the input optical power at which the transimpedance gain stage saturates. We can calculate the saturation power at 900 nm for the Model 2307 at its maximum output voltage of ± 4 volts.

Using the expression 4 V = $P_{sat}\cdot R\cdot G$, the Model 2307 has a differential saturation power of 3.3 mW for the low gain setting, 67 µW for the medium gain setting, and 3.3 µW for the high gain setting. At other wavelengths where the responsivity is lower, the saturation power increases inversely with responsivity.

Frequency Response and Noise

Measuring Bandwidth

The frequency response and noise characteristics of the large-area photoreceiver depend on the selected gain. The figures beginning on page 15 give the typical frequency response and noise behavior for the photoreceivers at each of the three gain settings—low, medium, and high. The frequency response of the transimpedance gain is plotted using the expression

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

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

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

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. The photocurrent noise is independent of wavelength because it gives the photoreceiver's noise with the photodetector's responsivity factored out.

To characterize the noise of the large-area 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/$\sqrt{Hz}$ and is plotted in Figure 4 and Figure 5 using the expression $20 \cdot \log[I_n(f)/1\ A]$.

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 2307 on the high gain setting is about 2 pA/$\sqrt{Hz}$, corresponding to an average NEP at 900 nm of 3.3 pW/$\sqrt{Hz}$. The integrated noise equivalent power from DC to 150 kHz is then obtained by multiplying the average NEP by $\sqrt{BW}$, 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. For the Model 2307 with a 3-dB bandwidth of 150 kHz, the equivalent noise bandwidth is 235 kHz. This gives an optical noise equivalent power of about 1.6 nW, so the minimum detectable optical signal at 900 nm (with a signal-to-noise ratio of 1) for the Model 2307 on the high gain setting is 1.6 nW.

You can further improve your signal-to-noise ratio by using electrical filters or optical modulators or choppers with lock-in amplifiers to limit the detection bandwidth.

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 transimpedance gain (V/A), *R* is the photodiode responsivity (A/W), *NEP* is the average noise equivalent power, and *BW* is the bandwidth. This gives an output noise voltage for the Model 2307 on the high gain setting of $(2\text{x}10^6\ \text{V/A}) \cdot (0.6\ \text{A/W}) \cdot (3.3\ \text{pW}/\sqrt{Hz}) \cdot \sqrt{235kHz} = 1.9\ \text{mV}_{\text{rms}}$.



The Johnson noise at the input of a 100 MHz bandwidth oscilloscope with 1 M-ohm input impedance is 1.6 mV rms. This is often the limiting factor in broad-band measurements.

Summary

The Model 2307 on the high gain setting the average NEP is 3.3 $\text{pW}/\sqrt{Hz}$, and this yields an output noise voltage of 1.9 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 1.6 nW.

For the Model 2317 with large-area Germanium photodiodes, the NEP at peak response wavelength of 1500 nm is 25 $\text{pW}/\sqrt{Hz}$. Over the 30-kHz bandwidth, the output noise voltage is 9 mV_{rms}. The full bandwidth signal-to-noise ratio of 1 is achieved around 5 nW.

Note that this assumes operation without any post-photoreceiver filtering and with the full photoreceiver

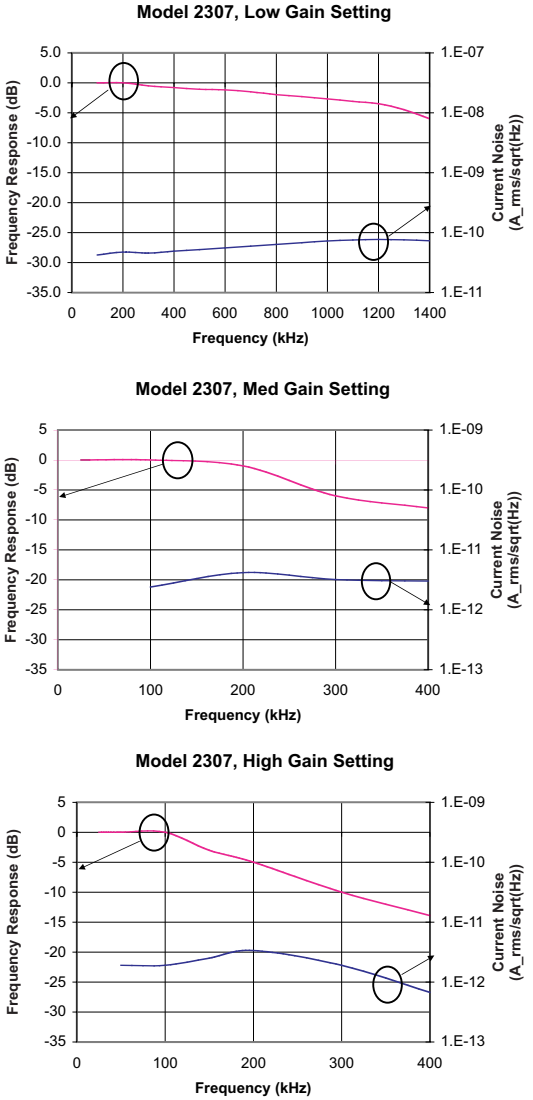
bandwidth. By using an electronic band-pass filter or an optical chopper and a lock-in amplifier, the receiver can detect significantly weaker optical signals.

Typical Frequency Response and Noise Spectra

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 and noise spectra for the Model 2307 and Model 2317 are shown in the figures on the following pages.

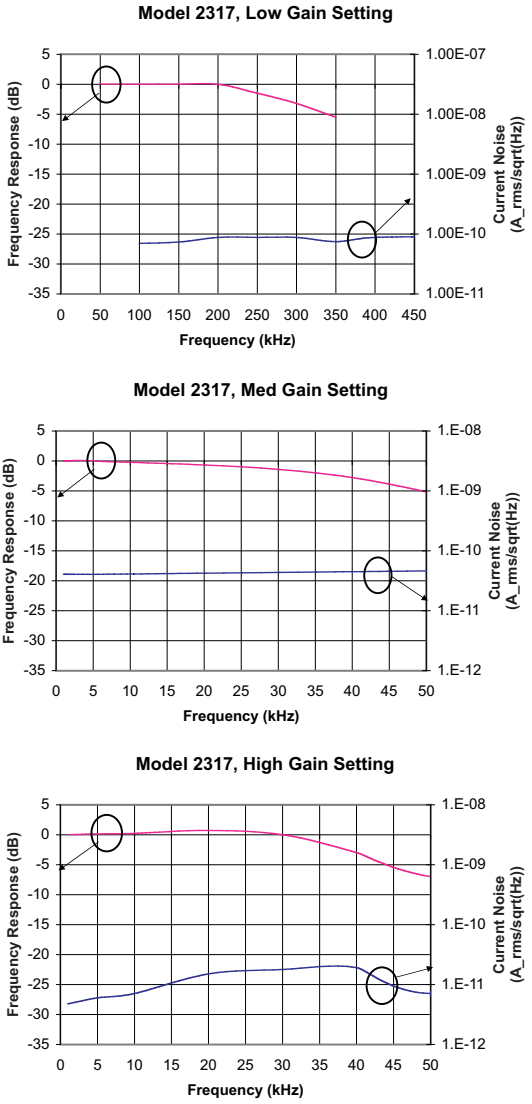
For the Model 2307 on the low setting the gain is $2x10^3$ V/A and the bandwidth is 1 MHz. The gain on the medium setting is 10^5 V/A, and the bandwidth is 200 kHz. The gain on the high setting is $2x10^6$ V/A, and the bandwidth is 150 kHz. The noise spectrum is plotted in units of photocurrent noise, $pA/\sqrt{Hz}$.

Figure 4: Typical frequency response and noise spectra for the Model 2307



For the Model 2317 the bandwidth exceeds 150 kHz (250 kHz for the unit pictured in Figure 5) for the low gain setting, 30 kHz for the medium gain setting, and 30 kHz for the high gain setting.

Figure 5: Typical frequency response and noise spectra for the Model 2317



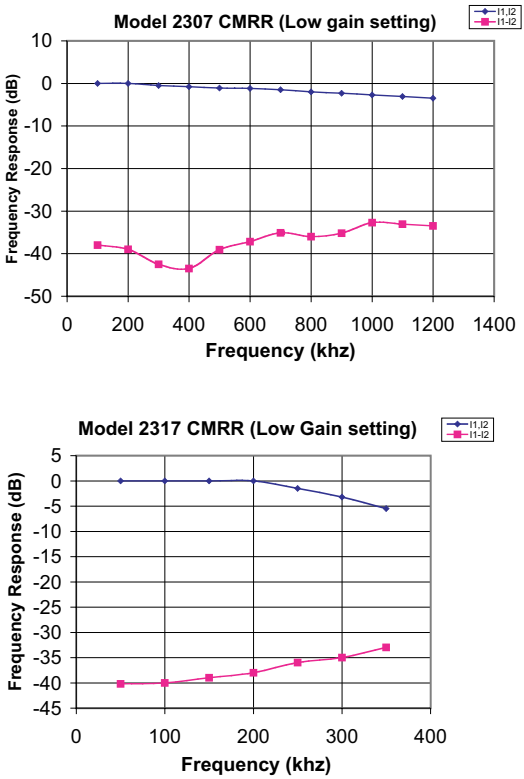
Common Mode Rejection

Using the Model 23X7 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 6 shows the CMRR of each model using the following definition:

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

Figure 6: Typical CMRR for the Model 2307 and Model 2317 at the low gain settings



Using Filters and Optical Fiber

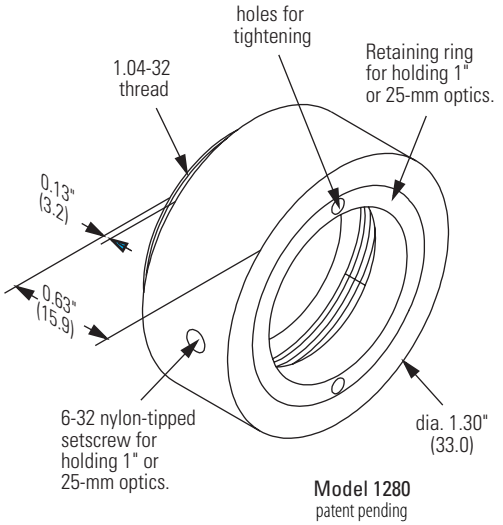
New Focus offers accessories to attach a 1"-diameter filter or an optical fiber to the Model 23X7 large-area photoreceiver. These accessories are sold separately, and they are not supplied with the photoreceiver. Both accessories attach to the photoreceiver using the 1.04-32 threads located in the casing around the photodetector. Note that the accessories are also compatible with two other New Focus products, the Model 215X femtowatt photoreceiver and the Model 162X nanosecond photodetector.

The Model 1280 1" filter holder allows you to mount a 1"-diameter optic in front of the photodetector. For instance, you can mount a colored glass filter to remove unwanted wavelengths or mount a neutral-density filter to attenuate the optical power incident on the photodetector. The Model 1280 has a plastic ring for mounting a filter that is up to about 0.25" (6.4-mm) thick. A thicker optic can be held in place using the 6-32 nylon-tipped set screw. Use a 1/16" or 1.5-mm Allen key or ball-driver to adjust the set screw.

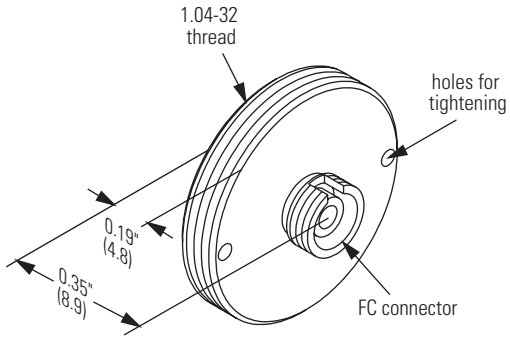
The Model 1281 FC fiber adapter allows you to connect an FC-connectorized fiber to the front of the photodetector.

See Figure 7 on the next page for drawings of these two accessories.

Figure 7: Model 1280 filter holder and Model 1281 FC-fiber adapter



Model 1280
patent pending

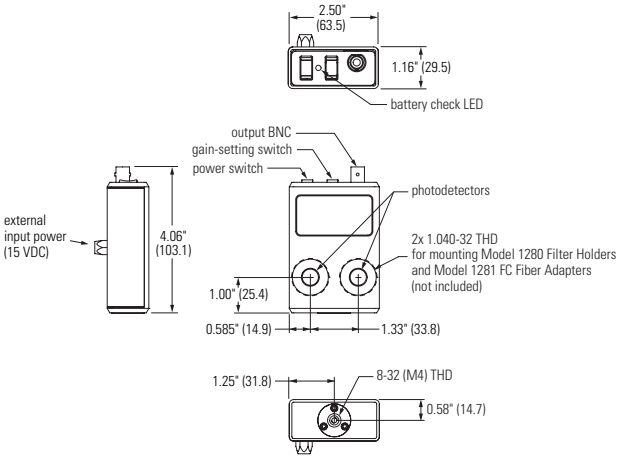


Model 1281

Characteristics

Physical Specifications

Figure 8: Mechanical drawing of the Model 23X7 casing



Model 2307 Specifications

	Model 2307
Wavelength Range	400–1070 nm
3-dB Bandwidth	1 MHz, 200 kHz, 150 kHz
Typical Common-Mode Rejection	40 dB
Rise Time	500 ns
Peak Conversion Gain	1.2×10^6 V/W
Typical Max. Responsivity	0.6 A/W
Max. Transimpedance Gain	2×10^3, 10^5, 2×10^6 V/A
Output Impedance	100 Ω
Minimum NEP	3.3 pW/ $\sqrt{\text{Hz}}$
CW Saturation Power	4 mW
Max. Differential Power	4 mW
Max. Power per Photodiode (damage threshold)	10 mW/mm^2
Detector Material	Si/PIN
Detector Diameter	8 mm
Optical Input	Free Space
Electrical Output	BNC
Package Dimensions	2.5" x 1.16" x 4.18"
Power Requirements	±15 VDC External Power Supply or 9-V Battery

Model 2317 Specifications

	Model 2317
Wavelength Range	800–1750 nm
3-dB Bandwidth	150 kHz, 30 kHz, 30 kHz
Typical Common-Mode Rejection	40 dB
Rise Time	3.3 µs
Peak Conversion Gain	1.6×10^6 V/W
Typical Max. Responsivity	0.8 A/W
Max. Transimpedance Gain	2×10^3, 10^5, 2×10^6 V/A
Output Impedance	100 Ω
Minimum NEP	25 pW/$\sqrt{\text{Hz}}$
CW Saturation Power	3 mW
Max. Differential Power	3 mW
Max. Power per Photodiode (damage threshold)	6 mW/mm^2
Detector Material	Ge/PN
Detector Diameter	5 mm
Optical Input	Free Space
Electrical Output	BNC
Package Dimensions	2.5" x 1.16" x 4.18"
Power Requirements	±15 VDC External Power Supply or 9-V Battery

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