MONOLITHIC PHOTODIODE AND AMPLIFIER

FEATURES

- **WIDE BANDWIDTH, HIGH RESPONSIVITY:**
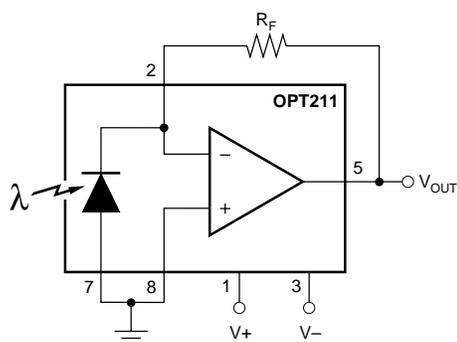
R_F	BANDWIDTH	
1MΩ	50kHz	*150kHz
100MΩ	5kHz	*13kHz

*with bootstrap buffer

- **PHOTODIODE SIZE: 0.090 x 0.090 inch (2.29 x 2.29mm)**
- **HIGH RESPONSIVITY: 0.45A/W (650nm)**
- **LOW DARK ERRORS: 2mV max**
- **EXCELLENT SPECTRAL RESPONSE**
- **LOW QUIESCENT CURRENT: 400μA**
- **TRANSPARENT 8-PIN DIP**

APPLICATIONS

- **MEDICAL INSTRUMENTATION**
- **LABORATORY INSTRUMENTATION**
- **POSITION AND PROXIMITY SENSORS**
- **PHOTOGRAPHIC ANALYZERS**
- **BARCODE SCANNERS**
- **SMOKE DETECTORS**

DESCRIPTION

The OPT211 is a monolithic photodiode with on-chip FET-input transpedance amplifier, that provides wide bandwidth at very high gains. Uncommitted input and feedback nodes allow a variety of feedback options for maximum versatility. Trade-offs in responsivity (gain), bandwidth and SNR can easily be made.

The monolithic combination of photodiode and transimpedance amplifier on a single chip eliminates the problems commonly encountered in discrete designs such as leakage current errors, noise pickup and gain peaking due to stray capacitance. The 0.09 x 0.09 inch photodiode is operated at zero bias for excellent linearity and low dark current. Direct access to the detector's anode allows photodiode bootstrapping, which increases speed performance.

The OPT211 operates over a wide supply range (±2.25V to ±18V) and supply current is only 400μA. It is packaged in a transparent plastic 8-pin DIP specified for the 0°C to 70°C temperature range.

SPECTRAL RESPONSIVITY
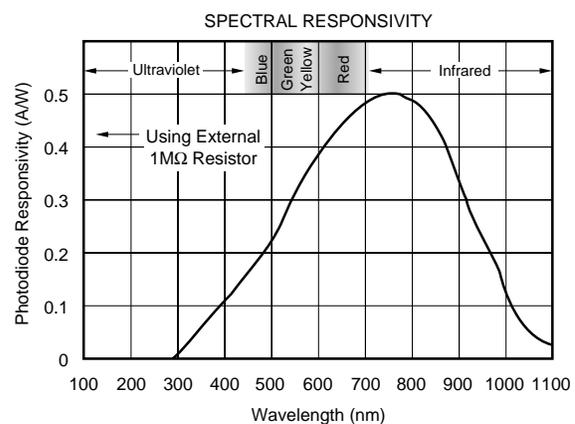
SPECIFICATIONS

At T_A = +25°C, V_S = ±15V, λ = 650nm, external 1MΩ feedback resistor, circuit shown in Figure 1, unless otherwise noted.

PARAMETER	CONDITIONS	OPT211P			UNITS
		MIN	TYP	MAX	
RESPONSIVITY					
Photodiode Current	650nm		0.45		A/W
Unit-to-Unit Variation	650nm		±5		%
Voltage Output	λ = 650nm, R_F = 1MΩ		0.45		V/µW
Nonlinearity			0.01		% of FS
Photodiode Area	(0.090 x 0.090 inches)		0.008		in²
	(2.29 x 2.29mm)		5.2		mm²
DARK ERRORS, RTO[1]					
Offset Voltage, Output			±0.5	±2	mV
vs Temperature			±10		µV/°C
vs Power Supply	V_S = ±2.25V to ±18V		10	100	µV/V
Voltage Noise, Dark	Dark, f_B = 0.1Hz to 100kHz		1		mVrms
FREQUENCY RESPONSE					
Bandwidth	Anode Grounded[2]		50		kHz
	Anode Bootstrapped[3]		150		kHz
Rise Time, 10% to 90%, R_F = 1MΩ	Anode Grounded[2]		5		µs
	Anode Bootstrapped[3]		2		µs
Settling Time, FS to Dark	Anode Grounded[2]				
1%			10		µs
0.1%			25		µs
0.01%			30		µs
100% Overload Recovery Time	FS to Dark (to 1%)		44		µs
	V_S = ±5V		100		µs
	V_S = ±2.25V		240		µs
OUTPUT					
Voltage Output	R_L = 10kΩ	(V+) − 1.25	(V+) − 1		V
	R_L = 5kΩ	(V+) − 2	(V+) − 1.5		V
Capacitive Load, Stable Operation[4]			250		pF
Short-Circuit Current			±18		mA
POWER SUPPLY					
Operating Voltage Range		±2.25	±15	±18	V
Quiescent Current	V_{OUT} = 0V		±400	±500	µA
TEMPERATURE RANGE					
Specification		0		+70	°C
Operating		0		+70	°C
Storage		−25		+85	°C
Thermal Resistance, θ_{JA}			100		°C/W

NOTES: (1) Referred to Output. Includes all error sources. (2) See Figure 1. (3) See Figure 3. (4) See Figure 2.

PHOTODIODE SPECIFICATIONS

At T_A = +25°C, λ = 650nm, unless otherwise noted.

PARAMETER	CONDITIONS	Photodiode of OPT211			UNITS
		MIN	TYP	MAX	
Photodiode Area	(0.090 x 0.090 inches)		0.008		in²
	(2.29 x 2.29mm)		5.2		mm²
Current Responsivity	λ = 650nm		0.45		A/W
			865		µA/W/cm²
Dark Current	V_D = 0V		500		fA
vs Temperature			doubles every 10°C		
Capacitance	V_D = 0V		600		pF

OP AMP SPECIFICATIONS

T_A = +25°C, V_S = ±15V, R_L = 10kΩ, unless otherwise noted.

PARAMETER	CONDITIONS	OPT211 Op Amp[1]			UNITS
		MIN	TYP	MAX	
INPUT					
Offset Voltage			±0.5		mV
vs Temperature			±5		µV/°C
vs Power Supply	V_S = ±2.25V to ±18V		10		µV/V
Input Bias Current			±1		pA
vs Temperature			doubles every 10°C		
Input Impedance					
Differential			10^{12} || 3		Ω || pF
Common-Mode			10^{12} || 3		Ω || pF
Common-Mode Input Voltage Range	Linear Operation		±14.4		V
Common-Mode Rejection			106		dB
NOISE					
Voltage Noise Density	f = 10Hz		30		nV/√Hz
	f = 100Hz		25		nV/√Hz
	f = 1kHz		15		nV/√Hz
Current Noise Density	f = 1kHz		0.8		fA/√Hz
OPEN-LOOP GAIN					
Open-Loop Voltage Gain			120		dB
FREQUENCY RESPONSE					
Gain-Bandwidth Product[2]			16		MHz
Slew Rate			6		V/µs
Settling Time 0.1%			4		µs
0.01%			5		µs
OUTPUT					
Voltage Output	R_L = 10kΩ	(V+) − 1.25	(V+) − 1		V
	R_L = 5kΩ	(V+) − 2	(V+) − 1.5		V
Short-Circuit Current			±18		mA
POWER SUPPLY					
Operating Voltage Range		±2.25	±15	±18	V
Quiescent Current	I_O = 0mA		±400	±500	µA

NOTES: (1) Op amp specifications provided for information and comparison only. (2) Stable in gains ≥ 20V/V.

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PIN CONFIGURATIONS

Top View   **DIP**

V+	1	8 Common
−In	2	7 PD Anode
V−	3	6 NC
NC	4	5 V_{OUT}

(1)

NOTE: (1) Photodiode location.
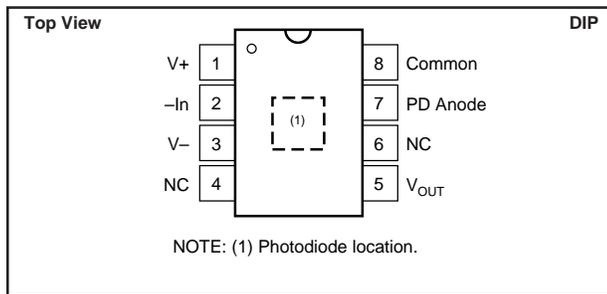
ABSOLUTE MAXIMUM RATINGS

Supply Voltage .... ±18V
Input Voltage Range .... ±V_S
Output Short-Circuit (to ground) .... Continuous
Operating Temperature .... −25°C to +85°C
Storage Temperature .... −25°C to +85°C
Junction Temperature .... +85°C
Lead Temperature (soldering, 10s) .... +300°C
  (Vapor-Phase Soldering Not Recommended)

PACKAGE INFORMATION

PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER[1]
OPT211P	8-Pin DIP	006-1

NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book.

ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.
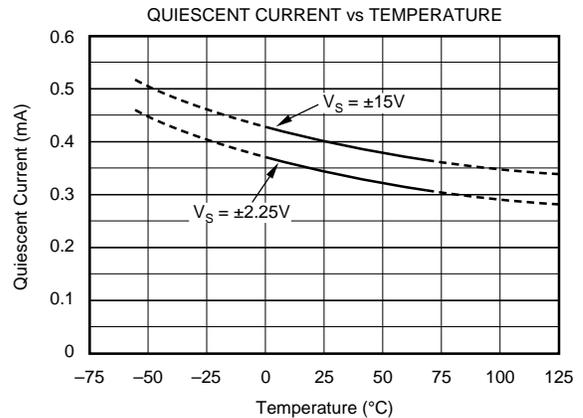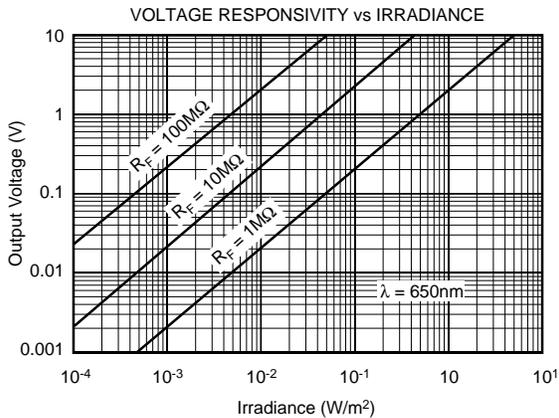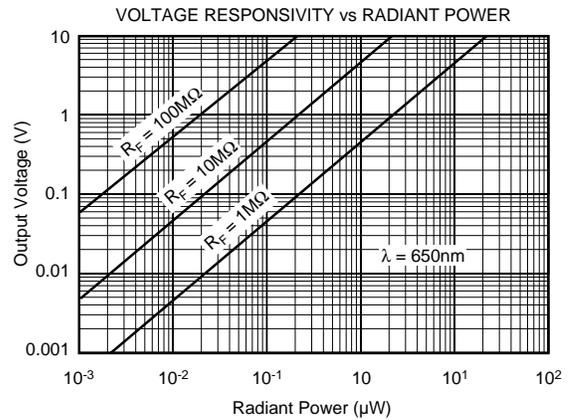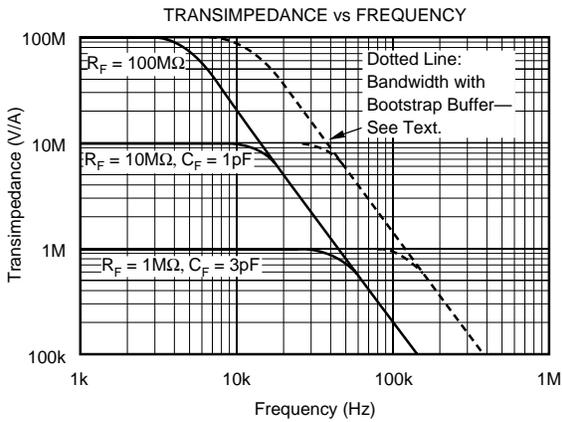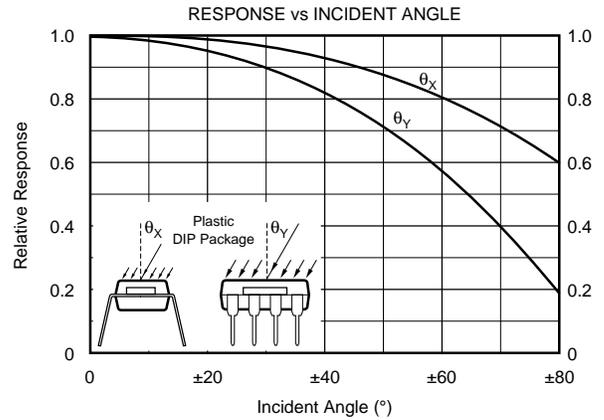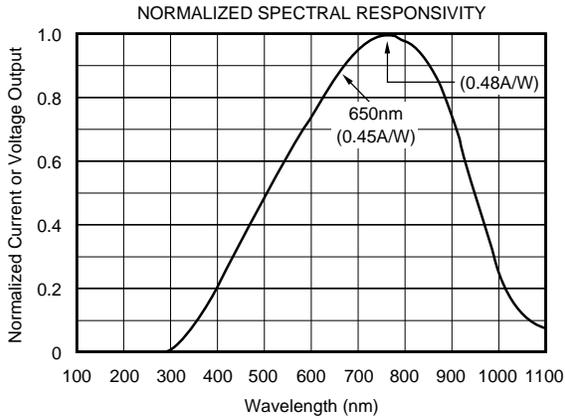
MOISTURE SENSITIVITY AND SOLDERING

Clear plastic does not contain the structural-enhancing fillers used in black plastic molding compound. As a result, clear plastic is more sensitive to environmental stress than black plastic. This can cause difficulties if devices have been stored in high humidity prior to soldering. The rapid heating during soldering can stress wire bonds and cause failures. Prior to soldering, it is recommended that plastic devices be baked-out at +85°C for 24 hours.

The fire-retardant fillers used in black plastic are not compatible with clear molding compound. The OPT211 plastic packages cannot meet flammability test, UL-94.
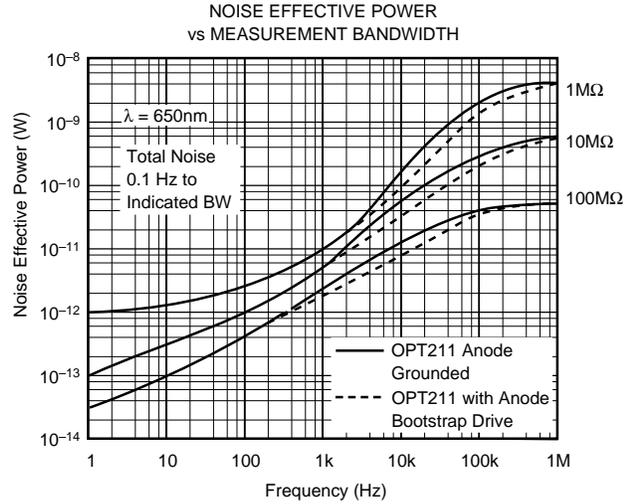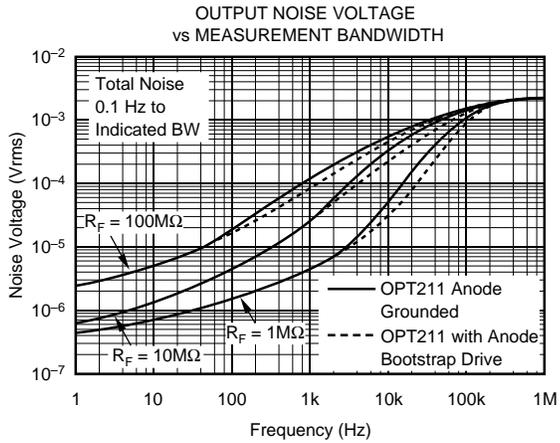
TYPICAL PERFORMANCE CURVES

At T_A = +25°C, V_S = ±15V, λ = 650nm, external 1MΩ feedback resistor, circuit shown in Figure 1, unless otherwise noted.

NORMALIZED SPECTRAL RESPONSIVITY

RESPONSE vs INCIDENT ANGLE

TRANSIMPEDANCE vs FREQUENCY

VOLTAGE RESPONSIVITY vs RADIANT POWER

VOLTAGE RESPONSIVITY vs IRRADIANCE

QUIESCENT CURRENT vs TEMPERATURE

OPT211

TYPICAL PERFORMANCE CURVES (CONT)

At T_A = +25°C, V_S = ±15V, λ = 650nm, external 1MΩ feedback resistor, circuit shown in Figure 1, unless otherwise noted.

OUTPUT NOISE VOLTAGE
vs MEASUREMENT BANDWIDTH

NOISE EFFECTIVE POWER
vs MEASUREMENT BANDWIDTH

STEP RESPONSE
R_F = 1MΩ, Anode Grounded
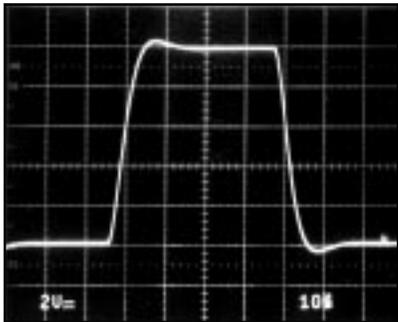
STEP RESPONSE
R_F = 1MΩ, Bootstrap Buffer
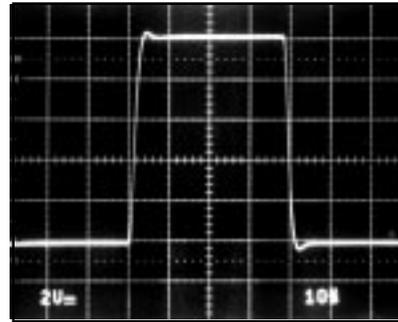
APPLICATIONS INFORMATION

Figure 1 shows the basic connections required to operate the OPT211. Applications with high impedance power supplies may require decoupling capacitors located close to the device pins as shown in Figure 1.
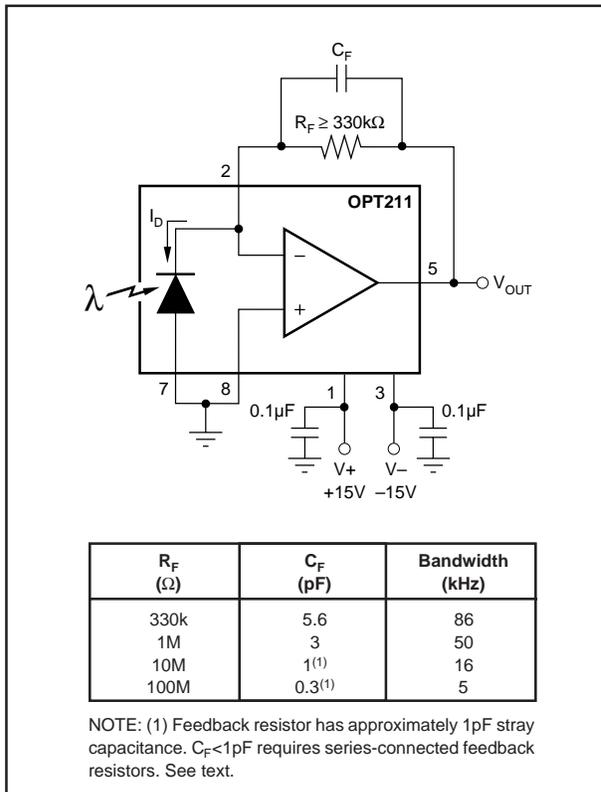

FIGURE 1. Basic Circuit Connections.

R_F (Ω)	C_F (pF)	Bandwidth (kHz)
330k	5.6	86
1M	3	50
10M	1[1]	16
100M	0.3[1]	5

NOTE: (1) Feedback resistor has approximately 1pF stray capacitance. C_F<1pF requires series-connected feedback resistors. See text.

Output is zero volts with no light and increases with increasing illumination. Photodiode current is proportional to the radiant power (watts) falling in the photodiode. At 650nm wavelength (visible red) the photodiode *responsivity* is approximately 0.45A/W. Responsivity at other wavelengths is shown in the typical performance curve "Responsivity vs Wavelength."

The OPT211's output voltage is the product of the photodiode current and feedback resistor, ($I_D R_F$). The feedback resistor must be greater than 330kΩ for proper stability. A feedback capacitor, C_F, must be connected as shown. Recommended values are shown in Figure 1. Capacitor values for other feedback resistances can be interpolated.

The OPT211 provides excellent performance with very high feedback resistor values. To achieve maximum bandwidth with $R_F \geq 10M\Omega$, good circuit layout is required. With careful circuit board layout and a 10MΩ feedback resistor, stray capacitance will provide approximately the correct parallel capacitance for stable operation and widest bandwidth. For larger feedback resistor values, two resistors connected in series and laid-out end-to-end will reduce the stray capacitance to a few tenths of a picofarad. With experimentation, circuit board traces can be used to produce the necessary stray capacitance for proper compensation and widest possible bandwidth.

The circuit in Figure 1 can drive capacitive loads up to 250pF. To drive load capacitance up to 1nF, connect R_1 and the feedback components as shown in Figure 2.

DARK ERRORS

Dark error specifications include all error sources and are tested with the circuit shown in Figure 1 using R_F=1MΩ. The dominate dark error source is the input offset voltage of the internal op amp. The combination of photodiode dark current and op amp input bias current is approximately 1.5pA at 25°C. Even with very large feedback resistors, this contributes virtually no offset error. Dark current and input bias current increase with temperature, doubling (approximately) for each 10°C increase. At 70°C, dark current is approximately 35pA. This would produce 3.5mV offset with a 100MΩ feedback resistor.

Circuit board leakage currents can increase dark error. Use clean assembly procedures to avoid contamination, particularly around the sensitive inverting input node (pin 2). Errors due to leakage current from the V+ supply (pin 1) can be eliminated by encircling the trace connecting to pin 2 with a guard trace connected to ground.

IMPROVING BANDWIDTH

Bandwidth of the OPT211 can be increased with the feedback buffer circuits shown in Figure 3. Driving the anode of the photodiode (pin 7) in this manner reduces the effect of the photodiode's capacitance on signal bandwidth. This "bootstrap drive" circuit boosts bandwidth by approximately 3x. Bandwidth achieved with various R_F values is shown in Figure 2. When using a bootstrap buffer, R_F must be greater or equal to 1MΩ for stable operation.
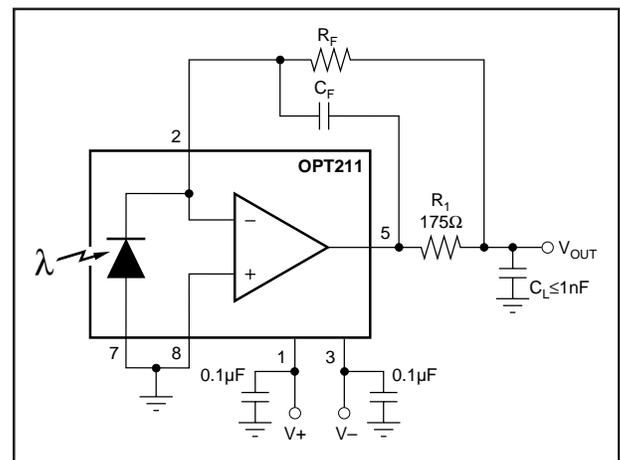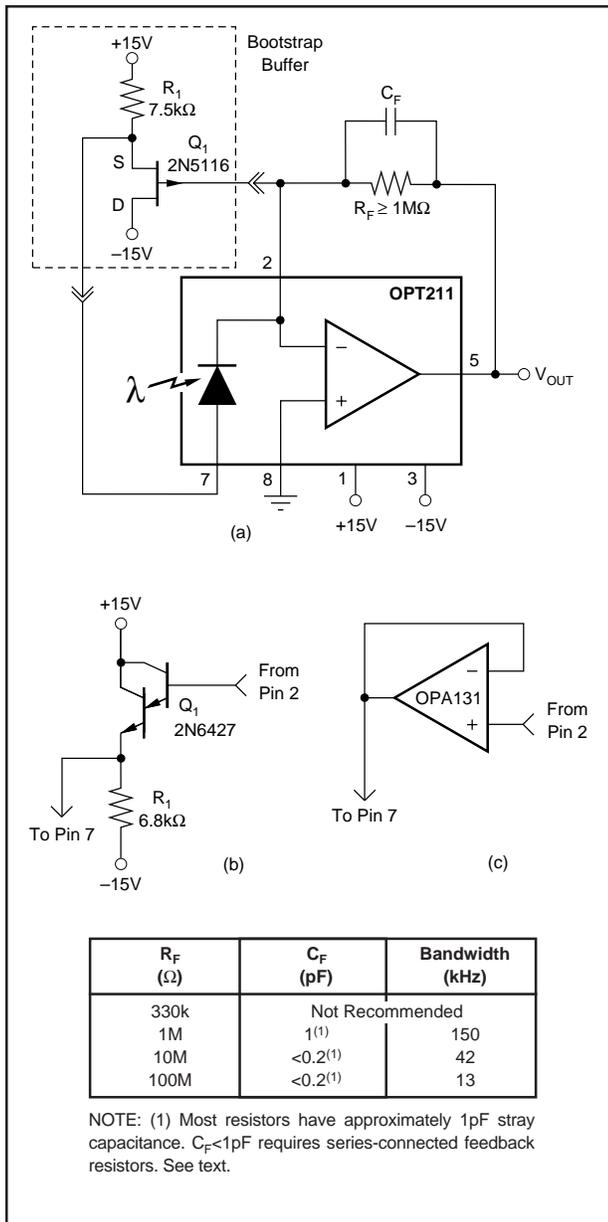

FIGURE 2. Increasing C-Load Drive.

OPT211

FIGURE 3. Increasing Bandwidth with Bootstrap Buffer.

R_F (Ω)	C_F (pF)	Bandwidth (kHz)
330k	Not Recommended	
1M	1[1]	150
10M	<0.2[1]	42
100M	<0.2[1]	13

NOTE: (1) Most resistors have approximately 1pF stray capacitance. C_F<1pF requires series-connected feedback resistors. See text.

Gate or base current of the buffer transistor flows through the feedback resistor, increasing the dark offset voltage. If dark errors are important, use a FET transistor with picoamp gate current. A P-channel FET is used to assure that the anode is at ground potential or slightly negative.

If dark errors are not critical, an NPN Darlington transistor can be used for a buffer as shown in Figure 3b. A FET-input op amp connected as a buffer can be used as shown in Figure 3c, but its noise may degrade circuit performance slightly. Bandwidth of the buffer should be 4MHz, minimum.

AC COUPLING

Some applications are concerned only with sensing variation in light intensity. Simple capacitive coupling at the OPT211's output may be adequate. With large feedback resistors or bright ambient light, however, the OPT211's output may saturate. The circuit in Figure 4 can reject very bright ambient light, yet provide high AC gain for best signal-to-noise ratio. The output voltage is integrated and fed back to the inverting input through R_3. This drives the average (dc) voltage at the output to zero. Application Bulletin AB-061 provides more details on this technique.
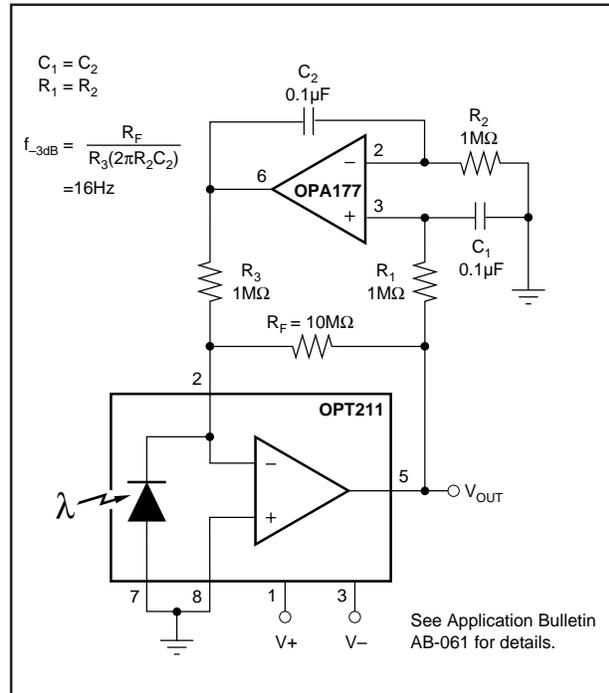

FIGURE 4. Rejecting Ambient Light.

This circuit also corrects output offset produced by input bias current of a buffer used to extend bandwidth. A Darlington transistor can be used for a bandwidth-enhancing bootstrap buffer in this circuit without creating offset error.

NOISE PERFORMANCE

Noise performance of the OPT211 is shown in typical curves for various feedback resistor values. This curve specifies the total noise measured from 0.1Hz to the indicated bandwidth. High frequency noise is reduced with the bootstrap transistor buffer circuits shown in Figure 1. This effect is shown on the typical curve.

Output noise of the OPT211 extends beyond the signal bandwidth, especially for high feedback resistor values. Signal-to-noise ratio can be improved by filtering the OPT211's output to a bandwidth equal to the signal bandwidth—see Figure 5.

Best signal-to-noise ratio is achieved by using the highest practical feedback resistor. This comes with the trade-off of decreased bandwidth.

The noise performance of a photodetector is sometimes characterized by its *noise effective power* (NEP). This is the radiant power which would produce an output signal equal to the output noise level. NEP has the units of radiant power (W). A NEP curve is provided.

LIGHT SOURCE POSITIONING

The OPT211 is 100% tested with a light source that uniformly illuminates the full area of the integrated circuit, including the op amp. Although all IC amplifiers are light-sensitive to some degree, the OPT211 op amp circuitry is designed to minimize this effect. Sensitive junctions are shielded with metal, and differential stages are cross-coupled. Furthermore, the photodiode area is very large relative to the op amp input circuitry making these effects negligible.

If your light source is focused to a small area, be sure that it is properly aimed to fall on the photodiode. If a narrowly focused light source were to miss the photodiode area and fall only on the op amp circuitry, the OPT211 would not perform properly. The large (0.090 inch x 0.090 inch)

photodiode area allows easy positioning of narrowly focused light sources. The photodiode area is easily visible as it appears very dark compared to the surrounding active circuitry.

The incident angle of the light source also affects the apparent sensitivity in uniform irradiance. For small incident angles, the loss in sensitivity is simply due to the smaller effective light gathering area of the photodiode (proportional to the cosine of the angle). At a greater incident angle, light is diffracted and scattered by the side of the package. These effects are shown in the typical performance curve "Responsivity vs Incident Angle."

LINEARITY PERFORMANCE

The photodiode inside the OPT211 is designed to be operated in the photoconductive mode ($V_{DIODE} = 0V$) for very linear operation with radiant power throughout a wide range. Nonlinearity remains below approximately 0.05% up to $100\mu A$ photodiode current.

This very linear performance at high radiant power assumes that the full photodiode area is uniformly illuminated. If the light source is focused to a small area of the photodiode, nonlinearity will occur at lower radiant power.
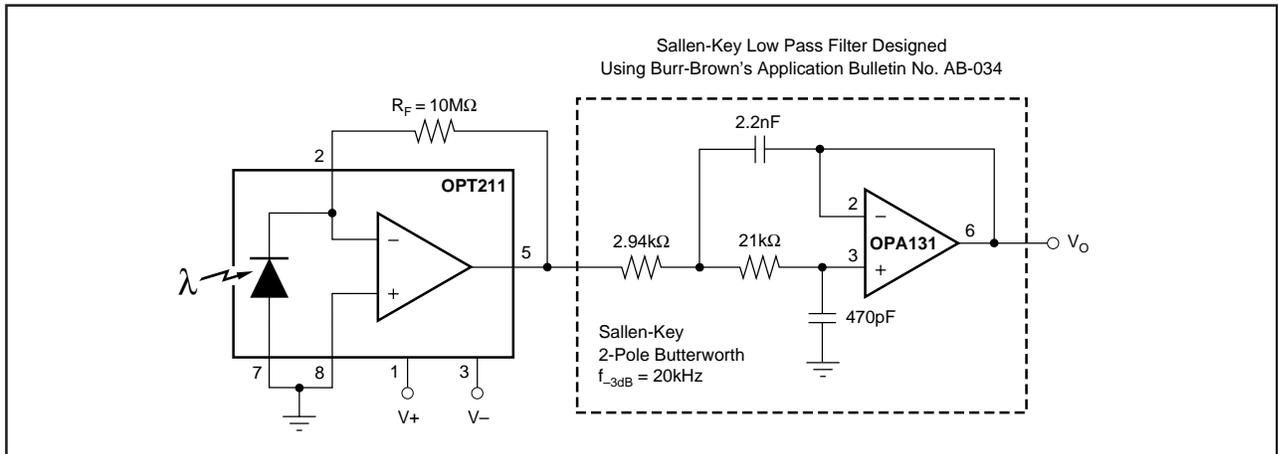

FIGURE 5. Low Pass Filter for Improved Signal-to-Noise Ratio.

OPT211