# OPT101

# MONOLITHIC PHOTODIODE AND SINGLE-SUPPLY TRANSIMPEDANCE AMPLIFIER

## FEATURES

- SINGLE SUPPLY: +2.7 to +36V
- PHOTODIODE SIZE: 0.090 x 0.090 inch
- INTERNAL 1MΩ FEEDBACK RESISTOR
- HIGH RESPONSIVITY: 0.45A/W (650nm)
- BANDWIDTH: 14kHz at $R_F$ = 1MΩ
- LOW QUIESCENT CURRENT: 120µA
- AVAILABLE IN 8-PIN DIP, 5-PIN SIP, AND 8-LEAD SURFACE MOUNT PACKAGES

## APPLICATIONS

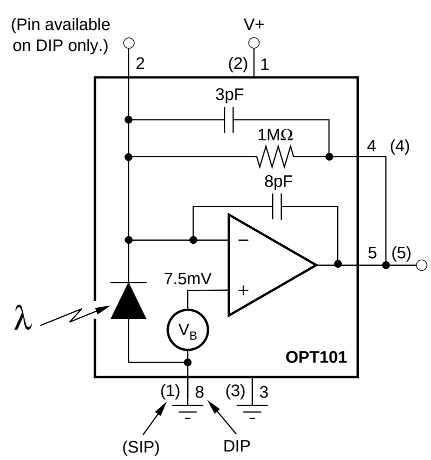
- MEDICAL INSTRUMENTATION
- LABORATORY INSTRUMENTATION
- POSITION AND PROXIMITY SENSORS
- PHOTOGRAPHIC ANALYZERS
- BARCODE SCANNERS
- SMOKE DETECTORS
- CURRENCY CHANGERS

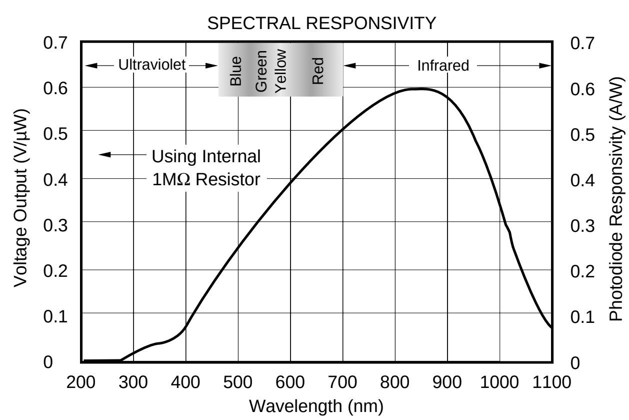
## DESCRIPTION

The OPT101 is a monolithic photodiode with on-chip transimpedance amplifier. Output voltage increases linearly with light intensity. The amplifier is designed for single or dual power supply operation, making it ideal for battery operated equipment.

The integrated combination of photodiode and transimpedance amplifier on a single chip eliminates the problems commonly encountered in discrete designs such as leakage current errors, noise pick-up and gain peaking due to stray capacitance. The 0.09 x 0.09 inch photodiode is operated in the photoconductive mode for excellent linearity and low dark current.

The OPT101 operates from +2.7V to +36V supplies and quiescent current is only 120µA. It is available in clear plastic 8-pin DIP, 5-pin SIP and J-formed DIP for surface mounting. Temperature range is 0°C to 70°C.





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# SPECIFICATIONS

At $T_A$ = +25°C, $V_S$ = +2.7V to +36V, λ = 650nm, internal 1MΩ feedback resistor, and $R_L$ = 10kΩ, unless otherwise noted.

| PARAMETER | CONDITIONS | OPT101P, W | | | UNITS |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| **RESPONSIVITY** | | | | | |
| Photodiode Current | 650nm | | 0.45 | | A/W |
| Voltage Output | 650nm | | 0.45 | | V/µW |
| vs Temperature | | | 100 | | ppm/°C |
| Unit to Unit Variation | 650nm | | ±5 | | % |
| Nonlinearity(1) | FS Output = 24V | | ±0.01 | | % of FS |
| Photodiode Area | (0.090 x 0.090in) | | 0.008 | | $in^2$ |
| | (2.29 x 2.29mm) | | 5.2 | | $mm^2$ |
| **DARK ERRORS, RTO(2)** | | | | | |
| Offset Voltage, Output | | +5 | +7.5 | +10 | mV |
| vs Temperature | | | ±2.5 | | µV/°C |
| vs Power Supply | $V_S$ = +2.7V to +36V | | 10 | 100 | µV/V |
| Voltage Noise, Dark, $f_B$ = 0.1Hz to 20kHz | $V_S$ = +15V, $V_{PIN3}$ = –15V | | 300 | | µVrms |
| **TRANSIMPEDANCE GAIN** | | | | | |
| Resistor | | | 1 | | MΩ |
| Tolerance, P | | | ±0.5 | ±2 | % |
| W | | | ±0.5 | | % |
| vs Temperature | | | ±50 | | ppm/°C |
| **FREQUENCY RESPONSE** | | | | | |
| Bandwidth | $V_{OUT}$ = 10Vp-p | | 14 | | kHz |
| Rise Fall Time, 10% to 90% | $V_{OUT}$ = 10V Step | | 28 | | µs |
| Settling Time, 0.05% | $V_{OUT}$ = 10V Step | | 160 | | µs |
| 0.1% | | | 80 | | µs |
| 1% | | | 70 | | µs |
| Overload Recovery | 100%, Return to Linear Operation | | 50 | | µs |
| **OUTPUT** | | | | | |
| Voltage Output, High | | ($V_S$) – 1.3 | ($V_S$) – 1.15 | | V |
| Capacitive Load, Stable Operation | | | 10 | | nF |
| Short-Circuit Current | $V_S$ = 36V | | 15 | | mA |
| **POWER SUPPLY** | | | | | |
| Operating Voltage Range | | +2.7 | | +36 | V |
| Quiescent Current | Dark, $V_{PIN3}$ = 0V | | 120 | 240 | µA |
| | $R_L$ = ∞, $V_{OUT}$ = 10V | | 220 | | µA |
| **TEMPERATURE RANGE** | | | | | |
| Specification | | 0 | | +70 | °C |
| Operating | | 0 | | +70 | °C |
| Storage | | –25 | | +85 | °C |
| Thermal Resistance, $\theta_{JA}$ | | | 100 | | °C/W |

NOTES: (1) Deviation in percent of full scale from best-fit straight line. (2) Referred to Output. Includes all error sources.

# PHOTODIODE SPECIFICATIONS

$T_A$ = +25°C, $V_S$ = +2.7V to +36V unless otherwise noted.

| PARAMETER | CONDITIONS | Photodiode of OPT101P | | | UNITS |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| Photodiode Area | (0.090 x 0.090in) | | 0.008 | | $in^2$ |
| | (2.29 x 2.29mm) | | 5.2 | | $mm^2$ |
| Current Responsivity | 650nm | | 0.45 | | A/W |
| | 650nm | | 865 | | $µA/W/cm^2$ |
| Dark Current | $V_{DIODE}$ = 7.5mV | | 2.5 | | pA |
| vs Temperature | | | doubles every 7°C | | |
| Capacitance | | | 1200 | | pF |

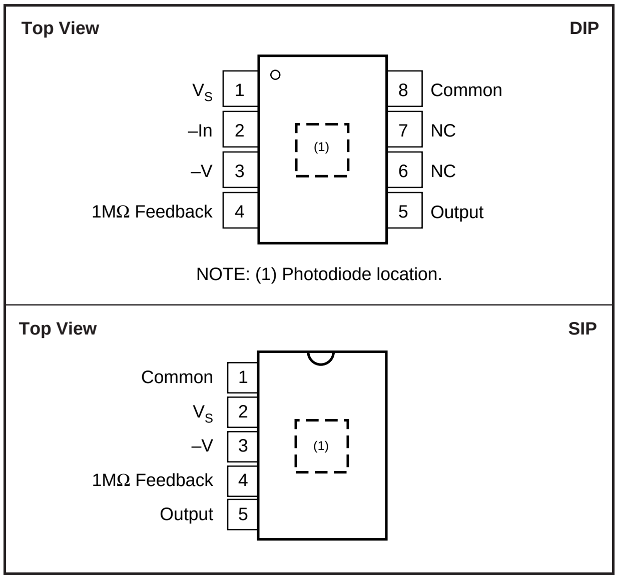
# OP AMP SPECIFICATIONS

At $T_A$ = +25°C, $V_S$ = +2.7V to +36V, λ = 650nm, internal 1MΩ feedback resistor, and $R_L$ = 10kΩ, unless otherwise noted.

| PARAMETER | CONDITIONS | OPT101 Op Amp(1) MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|
| **INPUT** | | | | | |
| Offset Voltage | | | ±0.5 | | mV |
| vs Temperature | | | ±2.5 | | μV/°C |
| vs Power Supply | | | 10 | | μV/V |
| Input Bias Current | (–) Input | | 165 | | pA |
| vs Temperature | (–) Input | | 1 | | pA/°C |
| Input Impedance | | | | | |
| Differential | | | 400 || 5 | | MΩ || pF |
| Common-Mode | | | 250 || 35 | | GΩ || pF |
| Common-Mode Input Voltage Range | Linear Operation | | 0 to [($V_S$) – 1] | | V |
| Common-Mode Rejection | | | 90 | | dB |
| **OPEN-LOOP GAIN** | | | | | |
| Open-loop Voltage Gain | | | 90 | | dB |
| **FREQUENCY RESPONSE** | | | | | |
| Gain-Bandwidth Product(2) | | | 2 | | MHz |
| Slew Rate | | | 1 | | V/μs |
| Settling Time 1% | | | 5.8 | | μs |
| 0.1% | | | 7.7 | | μs |
| 0.05% | | | 8.0 | | μs |
| **OUTPUT** | | | | | |
| Voltage Output, High | | ($V_S$) – 1.3 | ($V_S$) – 1.15 | | V |
| Short-Circuit Current | $V_S$ = +36V | | 15 | | mA |
| **POWER SUPPLY** | | | | | |
| Operating Voltage Range | | +2.7 | | +36 | V |
| Quiescent Current | Dark, $V_{PIN3}$ = 0V | | 120 | 240 | μA |
| | $R_L$ ∞, $V_{OUT}$ = 10V | | 220 | | μA |

NOTES: (1) Op amp specifications provided for information and comparison only. (2) Stable gains ≥ 10V/V.

## PIN CONFIGURATIONS




## ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| Supply Voltage ($V_S$ to *"Common"* or pin 3) | 0 to +36V |
| 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 | COLOR | PACKAGE | PACKAGE DRAWING NUMBER[1] |
|---|---|---|---|
| OPT101P | Clear | 8-Pin Plastic DIP | 006-1 |
| OPT101P-J | Clear | 8-Lead Surface Mount[2] | 006-4 |
| OPT101W | Clear | 5-Pin Plastic SIP | 321 |

NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book. (2) 8-pin DIP with J-formed leads for surface mounting.

## 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

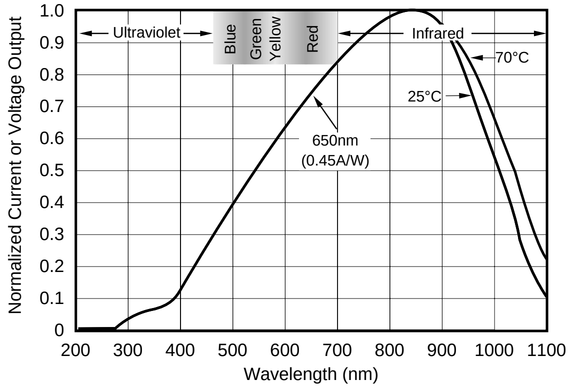
Clear plastic does not contain the structural-enhancing fillers used in black plastic molding compound. As a result, clear plastic is more sensitive to environmental stress than black plastic. This can cause difficulties if devices have been stored in high humidity prior to soldering. The rapid heating 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 OPT101 plastic packages cannot meet flammability test, UL-94.

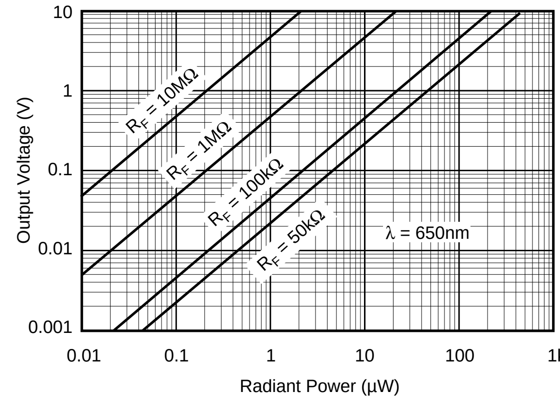
# TYPICAL PERFORMANCE CURVES

At $T_A$ = +25°C, $V_S$ = +2.7V to +36V, λ = 650nm, internal 1MΩ feedback resistor, and $R_L$ = 10kΩ, unless otherwise noted.

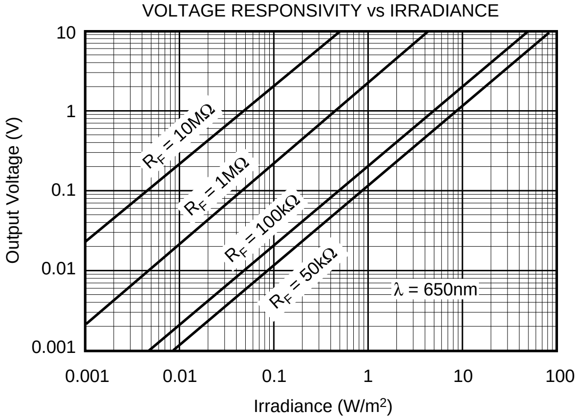
NORMALIZED SPECTRAL RESPONSIVITY



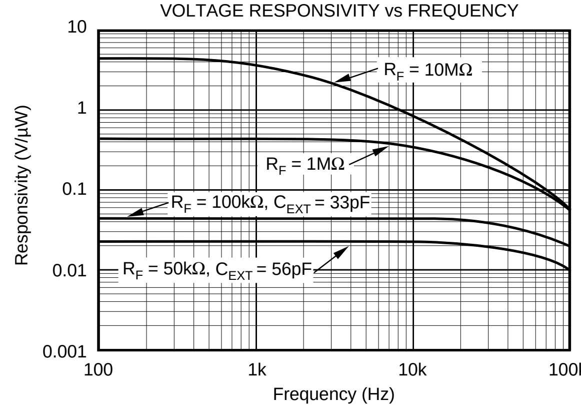

VOLTAGE RESPONSIVITY vs RADIANT POWER



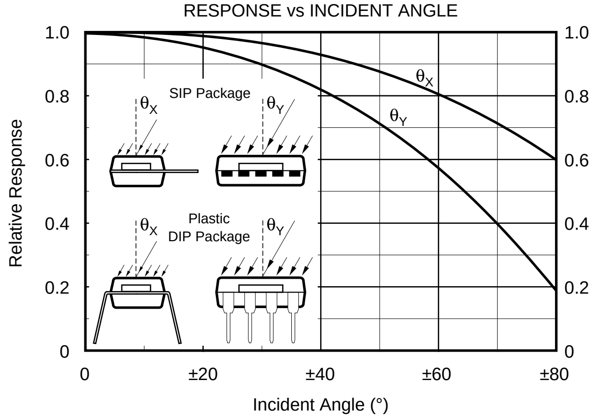

VOLTAGE RESPONSIVITY vs IRRADIANCE



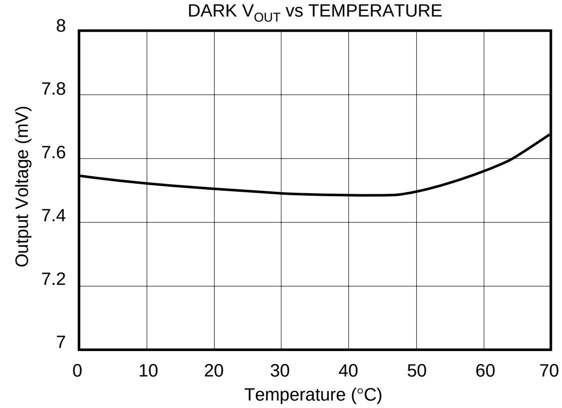

VOLTAGE RESPONSIVITY vs FREQUENCY




RESPONSE vs INCIDENT ANGLE



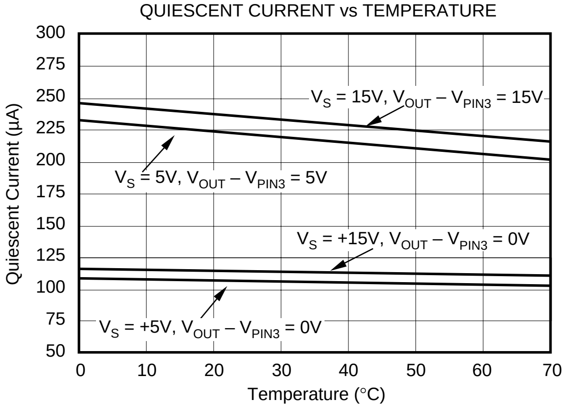

DARK $V_{OUT}$ vs TEMPERATURE



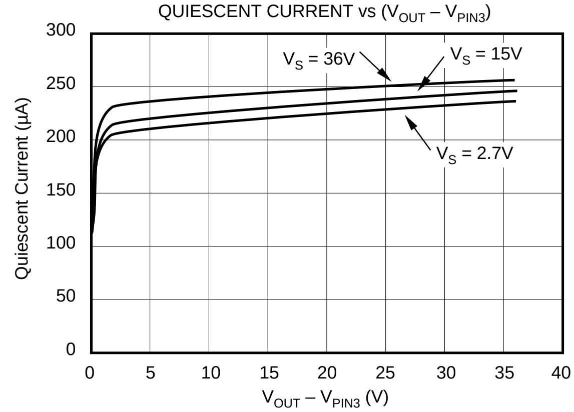
# TYPICAL PERFORMANCE CURVES (CONT)

At $T_A$ = +25°C, $V_S$ = +2.7V to +36V, λ = 650nm, internal 1MΩ feedback resistor, and $R_L$ = 10kΩ, unless otherwise noted.

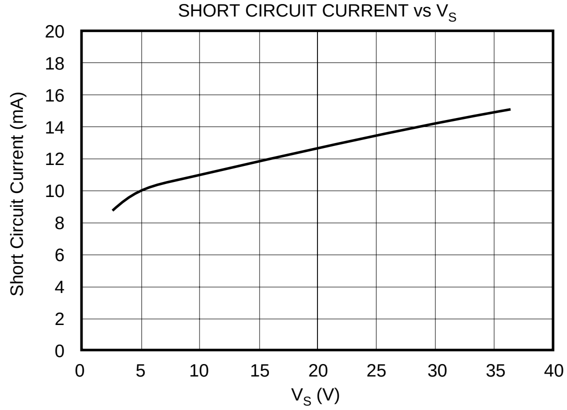
QUIESCENT CURRENT vs TEMPERATURE



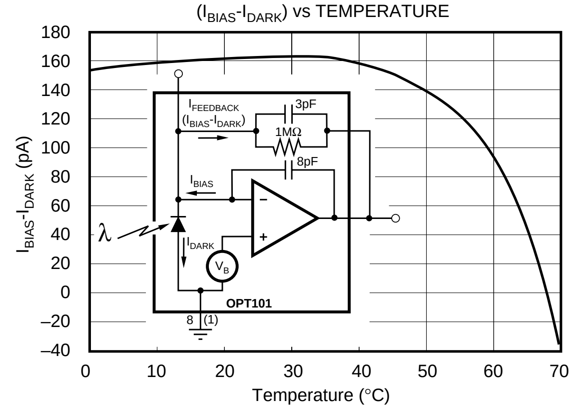

QUIESCENT CURRENT vs ($V_{OUT}$ – $V_{PIN3}$)



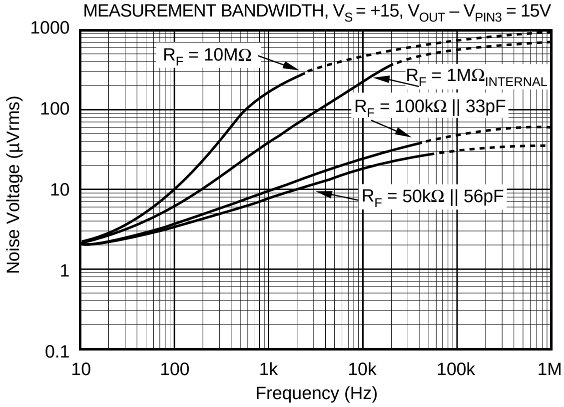

SHORT CIRCUIT CURRENT vs $V_S$



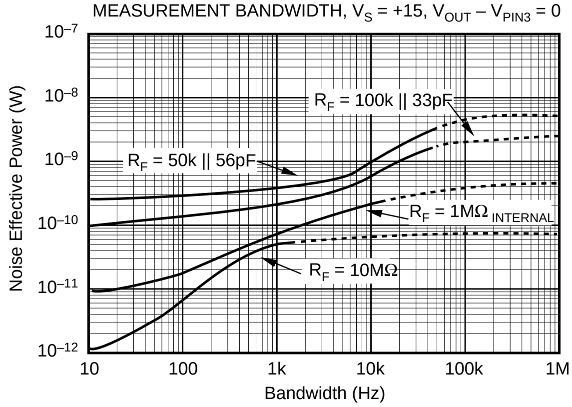

($I_{BIAS}$-$I_{DARK}$) vs TEMPERATURE




OUTPUT NOISE VOLTAGE vs MEASUREMENT BANDWIDTH, $V_S$ = +15, $V_{OUT}$ – $V_{PIN3}$ = 15V



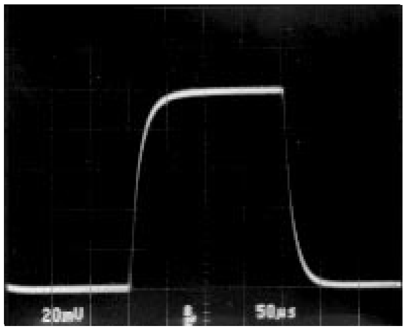

NOISE EFFECTIVE POWER vs MEASUREMENT BANDWIDTH, $V_S$ = +15, $V_{OUT}$ – $V_{PIN3}$ = 0



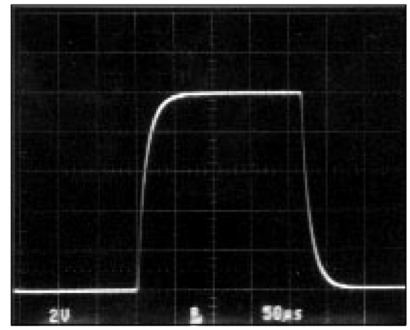
## TYPICAL PERFORMANCE CURVES (CONT)

At $T_A$ = +25°C, $V_S$ = +2.7V to +36V, λ = 650nm, internal 1MΩ feedback resistor, and $R_L$ = 10kΩ, unless otherwise noted.

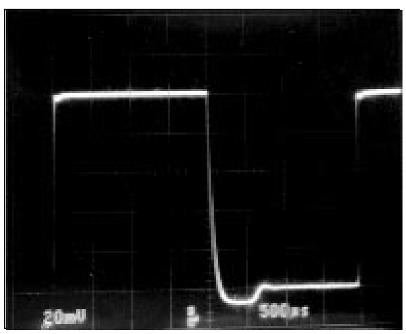
SMALL SIGNAL RESPONSE



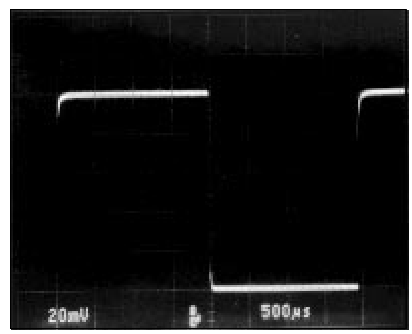

LARGE SIGNAL RESPONSE




SMALL SIGNAL RESPONSE ($C_{LOAD}$ = 10,000 pF)
(Pin 3 = 0V)




SMALL SIGNAL RESPONSE ($C_{LOAD}$ = 10,000 pF)
(Pin 3 = –15V)



## APPLICATIONS INFORMATION

Figure 1 shows the basic connections required to operate the OPT101. Applications with high-impedance power supplies may require decoupling capacitors located close to the device pins as shown. Output is 7.5mV dc with no light and increases with increasing illumination.

Photodiode current, $I_D$, is proportional to the radiant power, or flux, (in watts) falling on the photodiode. At a wavelength of 650nm (visible red) the photodiode Responsivity, $R_I$, is approximately 0.45A/W. Responsivity at other wavelengths is shown in the typical performance curve "Responsivity vs Wavelength."

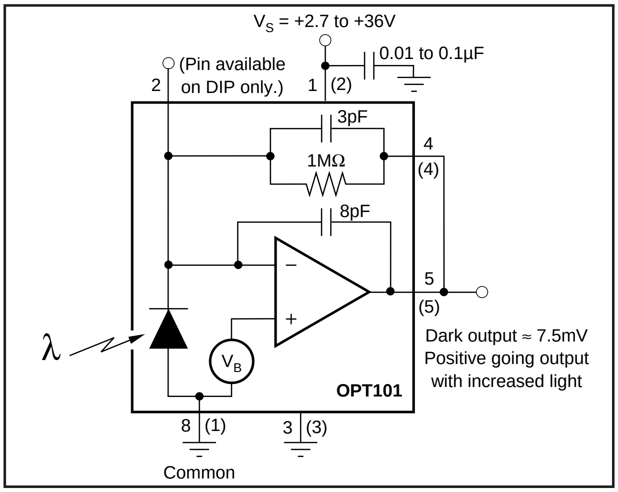



FIGURE 1. Basic Circuit Connections.

The typical performance curve "Output Voltage vs Radiant Power" shows the response throughout a wide range of radiant power. The response curve "Output Voltage vs Irradiance" is based on the photodiode area of 5.2mm$^2$.

The OPT101's voltage output is the product of the photodiode current times the feedback resistor, ($I_DR_F$), plus a pedestal voltage, $V_B$, of approximately 7.5mV introduced for single supply operation. The internal feedback resistor is laser trimmed to 1MΩ. Using this resistor, the output voltage responsivity, $R_V$, is approximately 0.45V/µW at 650nm wavelength. Figure 1 shows the basic circuit connections for the OPT101 operating with a single power supply and using the internal 1MΩ feedback resistor for a response of 0.45V/µW at 650nm. Pin 3 is connected to common in this configuration.

### CAPACITIVE LOADING

The OPT101 is capable of driving load capacitances of 10nF without instability. However, dynamic performance with capacitive loads can be improved by applying a negative bias voltage to Pin 3 (shown in Figure 2). This negative power supply voltage allows the output to go negative in response to the reactive effect of a capacitive load. An internal JFET connected between pin 5 (output) and pin 3 allows the output to sink current. This current sink capability can also be useful when driving the capacitive inputs of some analog-to-digital converters which require the signal source to sink currents up to approximately 100µA. The benefits of this current sink are shown in the typical performance curves "Small Signal Response ($C_{LOAD}$ = 10,000pF)" which compare operation with pin 3 grounded and connected to –15V.

Due to the architecture of this output stage current sink, there is a slight increase in operating current when there is a voltage between pin 3 and the output. Depending on the magnitude of this voltage, the quiescent current will increase by approximately 100µA as shown in the typical performance curve "Quiescent Current vs ($V_{OUT} - V_{PIN3}$)".

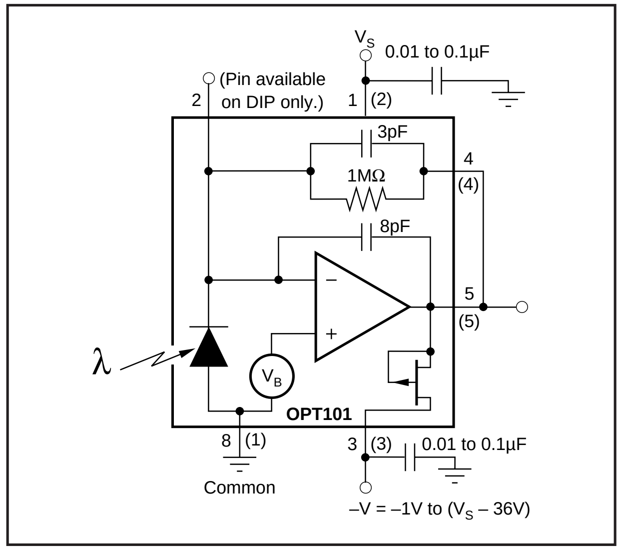



FIGURE 2. Bipolar Power Supply Circuit Connections.

### NOISE PERFORMANCE

Noise performance of the OPT101 is determined by the op amp characteristics, feedback components and photodiode capacitance. The typical performance curve "Output Noise Voltage vs Measurement Bandwidth" shows how the noise varies with $R_F$ and measured bandwidth (0.1Hz to the indicated frequency), when the output voltage minus the voltage on pin 3 is greater than approximately 50mV. Below this level, the output stage is powered down, and the effective bandwidth is decreased. This reduces the noise to approximately 1/3 the nominal noise value of 300µVrms, or 100µVrms. This enables a low level signal to be resolved.

Noise can be reduced by filtering the output with a cutoff frequency equal to the signal bandwidth. This will improve signal-to-noise ratio. Also, output noise increases in proportion to the square root of the feedback resistance, while responsivity increases linearly with feedback resistance. Best signal-to-noise ratio is achieved with large feedback resistance. This comes with the trade-off of decreased bandwidth.

The noise performance of the photodetector is sometimes characterized by *Noise Effective Power* (NEP). This is the radiant power that would produce an output signal equal to the noise level. NEP has the units of radiant power (watts), or Watts/$\sqrt{Hz}$ to convey spectral information about the noise. The typical performance curve "Noise Effective Power" vs Measurement Bandwidth" illustrates the NEP for the OPT101.

## DARK ERRORS

The dark errors in the specification table include all sources. The dominant source of dark output voltage is the “pedestal” voltage applied to the non-inverting input of the op amp. This voltage is introduced to provide linear operation in the absence of light falling on the photodiode. Photodiode dark current is approximately 2.5pA and contributes virtually no offset error at room temperature. The bias current of the op amp's summing junction (– input) is approximately 165pA. The dark current will be subtracted from the amplifier's bias current, and this residual current will flow through the feedback resistor creating an offset. The effects of temperature on this difference current can be seen in the typical performance curve “($I_{BIAS} – I_{DARK}$) vs Temperature.” The dark output voltage can be trimmed to zero with the optional circuit shown in Figure 3. A low impedance offset driver (op amp) should be used to drive pin 8 (DIP) because this node has signal-dependent currents.

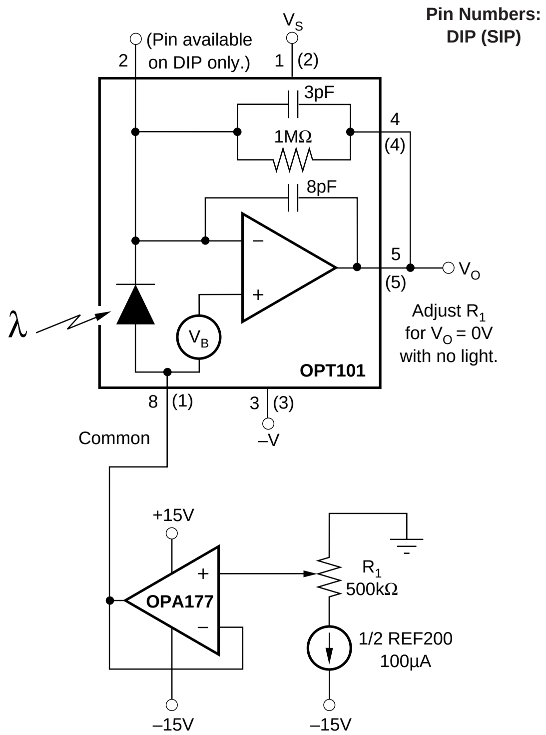
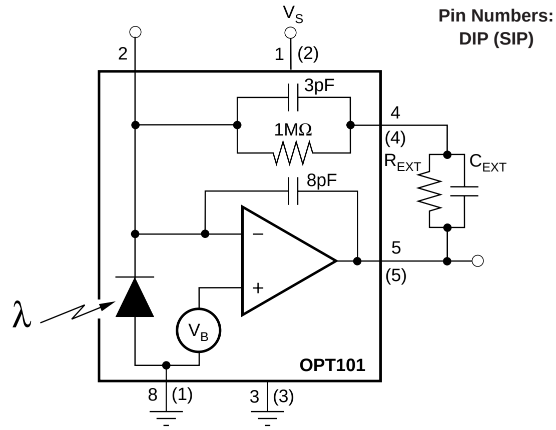



FIGURE 3. Dark Error (Offset) Adjustment Circuit.

## CHANGING RESPONSIVITY

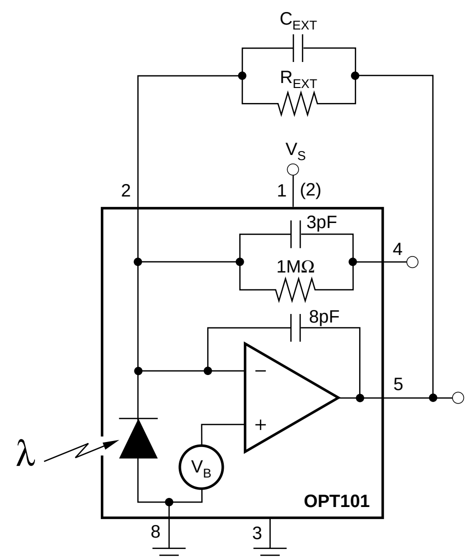
An external resistor, $R_{EXT}$, can be connected to set a different voltage responsivity. To increase the responsivity, this resistor can be placed in series with the internal 1MΩ (Figure 4a), or with the DIP package, the external resistor can replace the internal resistor by not connecting pin 4 (Figure 4b). The second configuration also allows the circuit gain to be reduced below $10^6$V/A by using external resistors of less than 1MΩ.

Figure 4 includes tables showing the responsivity and bandwidth. For values of $R_F$ less than 1MΩ, an external capacitor, $C_{EXT}$ should be connected in parallel with $R_F$. This capacitor eliminates gain peaking and prevents instability. The value of $C_{EXT}$ can be determined from the table in Figure 4. Values of $R_F$, other than shown in the table, can be interpolated.




*(a)*-Series $R_{EXT}$ (for SIP package).

| $R_{EXT}$ (MΩ) | $C_{EXT}$ (pF) | DC Gain ($\times 10^6$V/A) | Bandwidth (kHz) |
|---|---|---|---|
| 1 | 50 | 2 | 8 |
| 2 | 25 | 3 | 6 |
| 5 | 10 | 6 | 2.5 |
| 10 | 5 | 11 | 1.3 |
| 50 | — | 51 | 0.33 |




*(b)*-External Feedback (for DIP package).

| $R_{EXT}$ (MΩ) | $C_{EXT}$ (pF) | DC Gain ($\times 10^6$V/A) | Bandwidth (kHz) |
|---|---|---|---|
| 0.05(1) | 56 | 0.05 | 58 |
| 0.1(1) | 33 | 0.1 | 44 |
| 1 | — | 1 | 23 |
| 2 | — | 2 | 9.4 |
| 5 | — | 5 | 3.6 |
| 10 | — | 10 | 1.8 |
| 50 | — | 50 | 0.34 |

Note: (1) May require 1kΩ in series with pin 5 when driving large capacitances.

FIGURE 4. Changing Responsivity with External Resistor.

## LIGHT SOURCE POSITIONING

The OPT101 is tested with a light source that uniformly illuminates the full area of the integrated circuit, including the op amp. Although IC amplifiers are light-sensitive to some degree, the OPT101 op amp circuitry is designed to minimize this effect. Sensitive junctions are shielded with metal, and the photodiode area is very large relative to the op amp input circuitry.

If your light source is focused to a small area, be sure that it is properly aimed to fall on the photodiode. A narrowly focused beam falling on only the photodiode will provide improved settling times compared to a source that uniformly illuminates the full area of the die. If a narrowly focused light source were to miss the photodiode area and fall only on the op amp circuitry, the OPT101 would not perform properly. The large 0.09" x 0.09" (2.29mm x 2.29mm) 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 effects 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 package. These effects are shown in the typical performance curve "Responsivity vs Incident Angle."

## DYNAMIC RESPONSE

Using the internal 1MΩ resistor, the dynamic response of the photodiode/op amp combination can be modeled as a simple R • C circuit with a –3dB cutoff frequency of approximately 14kHz. The R and C values are 1MΩ and 11pF respectively. By using external resistors, with less than 3pF parasitic capacitance, the frequency response can be improved. An external 1MΩ resistor used in the configuration shown in Figure 4b will create a 23kHz bandwidth with the same $10^6$V/A dc transimpedance gain. This yields a rise time of approximately 15µs (10% to 90%). Dynamic response is not limited by op amp slew rate. This is demonstrated by the dynamic response oscilloscope photographs showing virtually identical large-signal and small-signal response.

Dynamic response will vary with feedback resistor value as shown in the typical performance curve "Responsivity vs Frequency." Rise time (10% to 90%) will vary according to the –3dB bandwidth produced by a given feedback resistor value:

$$t_r = \frac{0.35}{f_C}$$

where:

$t_r$ is the rise time (10% to 90%)

$f_C$ is the –3dB bandwidth

## LINEARITY PERFORMANCE

The photodiode is operated in the photoconductive mode so the current output of the photodiode is very linear with radiant power throughout a wide range. Nonlinearity remains below approximately 0.05% up to 100µA photodiode current. The photodiode can produce output currents of 1mA or greater with high radiant power, but nonlinearity increases to several percent in this region.

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.

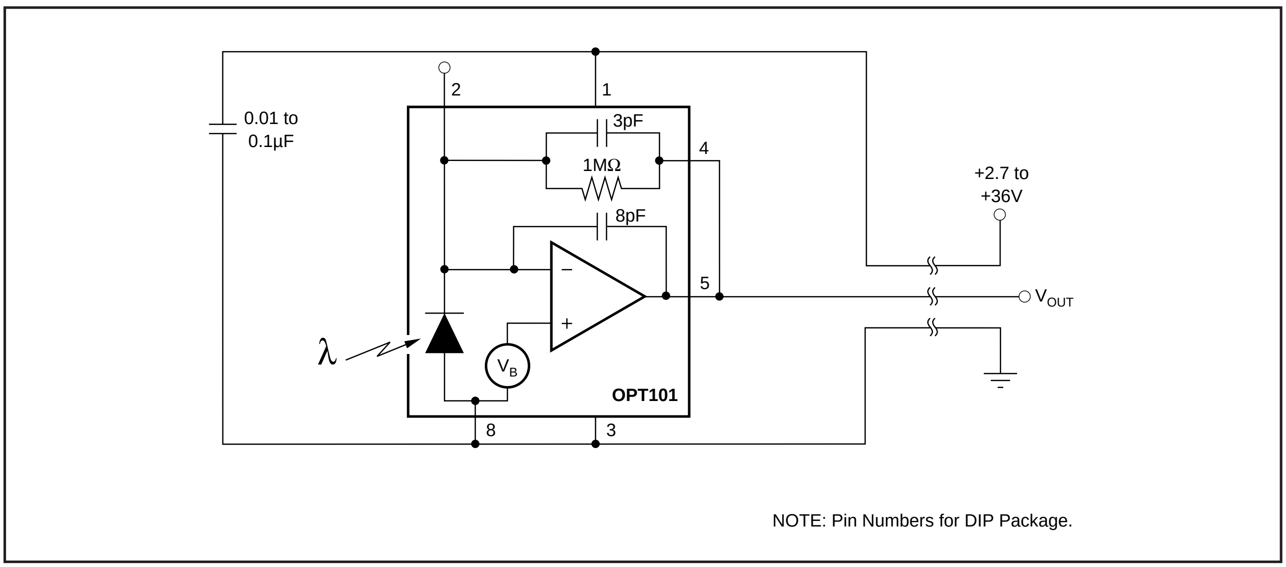



FIGURE 5. Three-Wire Remote Light Measurement.

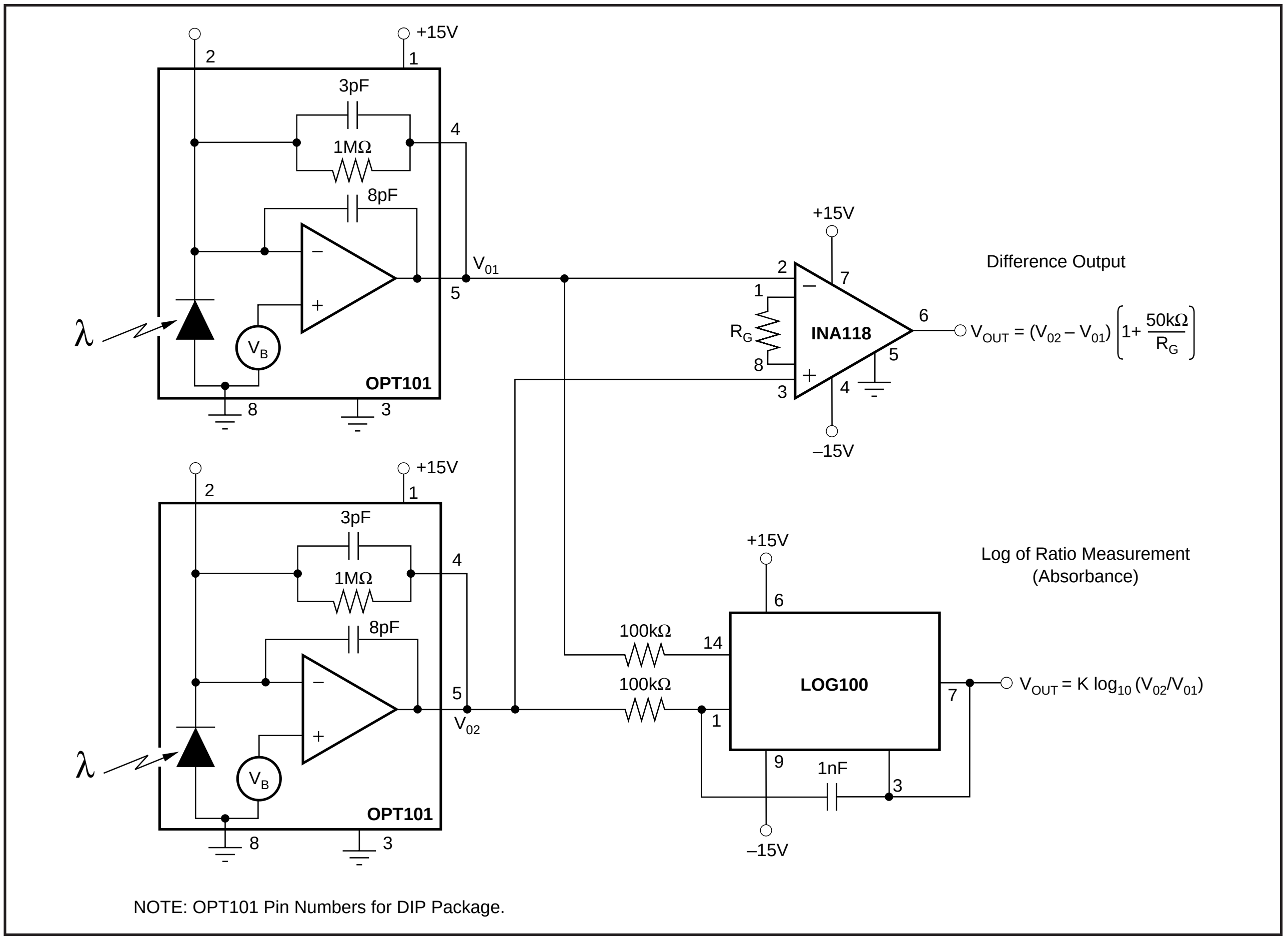



FIGURE 6. Differential Light Measurement.

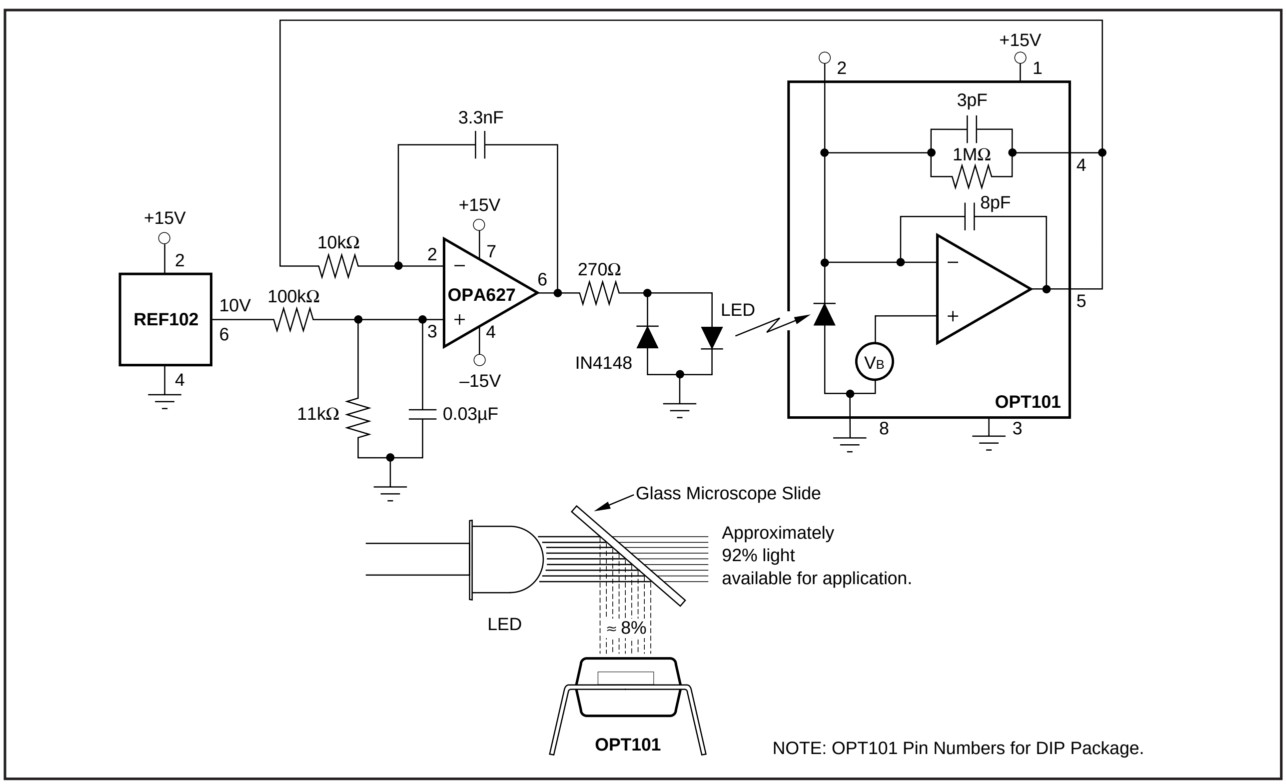



FIGURE 7. LED Output Regulation Circuit.