19-1970; Rev 2; 1/02

# MAXIM

# 10Gbps, 3.3V Low-Power Transimpedance Amplifier with RSSI

*MAX3970*

## General Description

The MAX3970 is a compact, low-power transimpedance amplifier (TIA) optimized for use in 10Gbps optical receivers. The TIA provides transimpedance at 600V/A with 50Ω differential CML outputs. The MAX3970 has a typical input-referred noise of 1.1µA, and when coupled with a high-speed photodiode, achieves -18dBm sensitivity and +2mA input overload. A received-signal strength indicator (RSSI) simplifies optical assembly. The circuit operates from a single 3.3V supply over a junction temperature range from 0°C to +110°C.

## Features

♦ **150mW Power Dissipation at 3.3V Supply**

♦ **1.1µA$_{RMS}$ Noise (-18dBm Sensitivity)**

♦ **9GHz Bandwidth**

♦ **2mA$_{P-P}$ Input Overload**

♦ **Received-Signal Strength Indication**

♦ **8ps$_{P-P}$ Typical Jitter Generation at 1.3mA$_{P-P}$ Input Current**
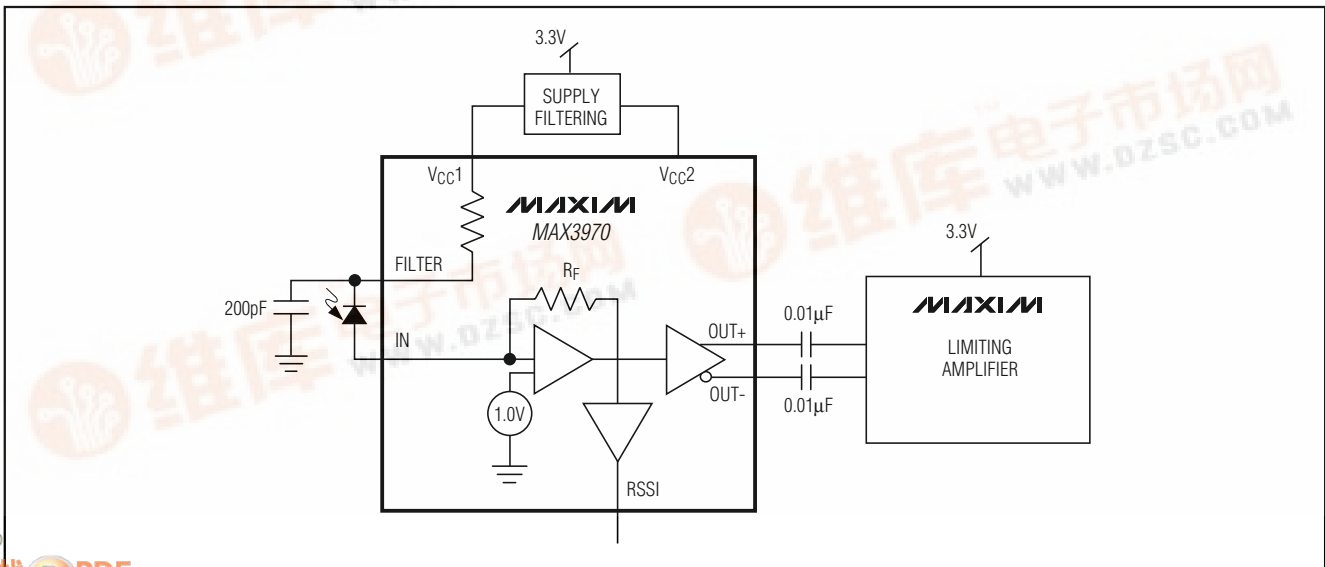
♦ **600V/A Transimpedance**

## Applications

10.3Gbps Ethernet Optical Receivers

OC-192 VSR Optical Receivers

Fibre-Channel Optical Receivers

## Ordering Information

| PART | TEMP RANGE | PIN-PACKAGE |
|---|---|---|
| MAX3970U/D | 0°C to +85°C | Dice |

***Note:*** *Dice are designed to operate over a 0°C to +110°C junction temperature (T$_J$) range, but are tested and guaranteed at T$_A$ = +25°C.*

## Typical Application Circuit

## MAXIM

*For pricing, delivery, and ordering information, please contact Maxim/Dallas Direct! at*

# 10Gbps, 3.3V Low-Power Transimpedance Amplifier with RSSI

## ABSOLUTE MAXIMUM RATINGS

Terminal Voltage
 Voltage $V_{CC}1$ and $V_{CC}2$ ...................................-0.3V to +5.0V
 Voltage at FILTER.................................-0.3V to ($V_{CC}1$ + 0.3V)
Voltage at OUT+, OUT-, RSSI ........................0V to ($V_{CC}$ + 0.5V)
Input Current
 IN, TEST ...........................................................-5mA to +5mA

Operating Junction Temperature Range...........-40°C to +125°C
Storage Temperature Range .............................-60°C to +150°C
Die Attach Process Temperature......................................+400°C

*Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

## ELECTRICAL CHARACTERISTICS

($V_{CC}$ = +3.0V to +3.6V, output loads = 50Ω to $V_{CC}$, $T_J$ = 0°C to +110°C. Typical values are at $V_{CC}$ = +3.3V, $C_{IN}$ = 0.25pF, $L_{IN}$ = 1.7nH, $T_A$ = +25°C, unless otherwise noted.) (Note 1)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| Supply Current | $I_{CC}$ | | | 46 | 62 | mA |
| Maximum DC Input Current | $I_{IN-MAX}$ | | 1.6 | | | mA |
| Input Linear Range | | 0.95 < linearity < 1.05 | 100 | 130 | | µA$_{P-P}$ |
| Input-Referred RMS Noise | $i_n$ | f = 7.5GHz (Note 2) | | 1.1 | 1.45 | µA |
| | | f = 10GHz (Note 2) | | 1.1 | 1.45 | |
| Input-Referred Noise Density | | f = 10GHz (Note 2) | | 11 | | pA/√Hz |
| Output Resistance (per side) | $R_{OUT}$ | | 43 | 50 | 58 | Ω |
| Small-Signal Transimpedance | $Z_{21}$ | Differential output 10µA$_{P-P}$ < Input < 100µA$_{P-P}$ | 450 | 600 | 875 | Ω |
| Small-Signal Bandwidth | BW | | 7.4 | 9 | 13.2 | GHz |
| Low-Frequency Cutoff | | | | 70 | 150 | kHz |
| Deterministic Jitter | DJ | $I_{IN}$ < 1.3mA | | 8 | | ps$_{P-P}$ |
| | | $I_{IN}$ = 2.0mA | | 16 | 22 | |
| Input Bias Voltage | $V_{IN}$ | | | 0.9 | 0.96 | V |
| RSSI Gain | | $I_{IN}$ = 100µA to 1mA | 900 | 1200 | 1500 | V/A |
| | | $I_{IN}$ = 10µA to 100µA | 1200 | 1800 | 3000 | |
| RSSI Bandwidth | | | 10 | 70 | | kHz |
| Photodiode Filter Resistance | $R_{FILTER}$ | | 330 | 410 | 500 | Ω |
| Maximum Differential Output Voltage | $V_{OD-MAX}$ | Input = 1mA$_{P-P}$ | 350 | 470 | 700 | mV$_{P-P}$ |

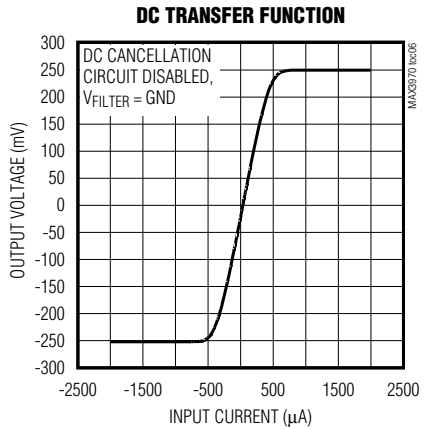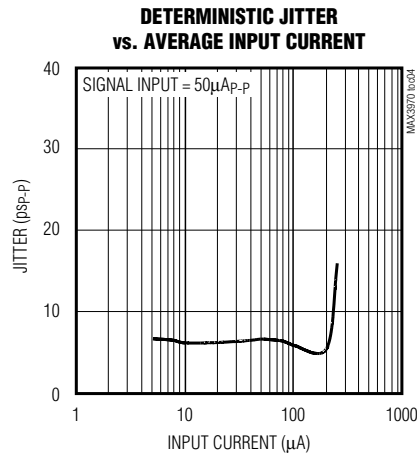**Note 1:** AC characteristics are guaranteed by design and characterization.
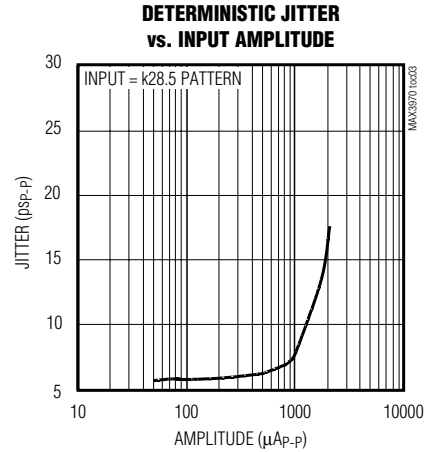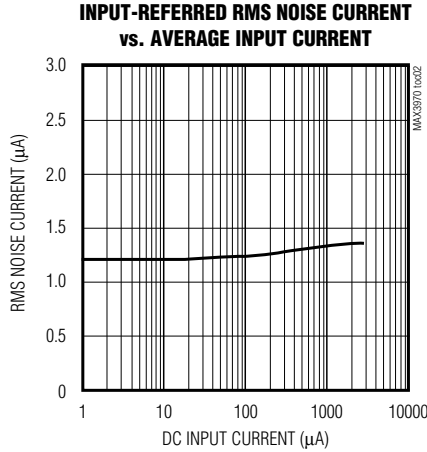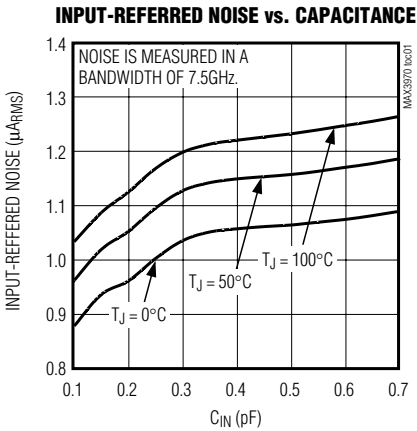**Note 2:** Input-referred noise is calculated as RMS output noise / (gain at f = 10MHz). Noise density is (input-referred noise) / √bandwidth. Noise measurements are made using 4-pole Bessel filters.

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# 10Gbps, 3.3V Low-Power Transimpedance Amplifier with RSSI

## Typical Operating Characteristics

(V_CC = +3.3V, T_A = +25°C, input bondwire inductance = 1.0nH, unless otherwise noted. $C_{IN}$ is total source capacitance to die. All measurements made on MAX3970 EV Kit.)

**INPUT-REFERRED NOISE vs. CAPACITANCE**

NOISE IS MEASURED IN A BANDWIDTH OF 7.5GHz.

$T_J = 100°C$
$T_J = 50°C$
$T_J = 0°C$

**INPUT-REFERRED RMS NOISE CURRENT vs. AVERAGE INPUT CURRENT**

**DETERMINISTIC JITTER vs. INPUT AMPLITUDE**

INPUT = k28.5 PATTERN

**DETERMINISTIC JITTER vs. AVERAGE INPUT CURRENT**

SIGNAL INPUT = 50µA_P-P

**OUTPUT AMPLITUDE vs. TEMPERATURE**

INPUT = 1mA_P-P, 00–11 PATTERN AT 10.0Gbps

**DC TRANSFER FUNCTION**

DC CANCELLATION CIRCUIT DISABLED, V_FILTER = GND

**EYE DIAGRAM (50µA_P-P INPUT)**

2^23 - 1PRBS 50µA INPUT

5mV/div

20ps/div

**EYE DIAGRAM (2.0mA_P-P INPUT)**

2^23 - 1PRBS 2mA INPUT

100mV/div

20ps/div

**SIMULATED FREQUENCY RESPONSE vs. INPUT INDUCTANCE**

$L_{IN} = 2.0nH$
$L_{IN} = 1.5nH$
$L_{IN} = 1.0nH$
$L_{IN} = 0.5nH$

# 10Gbps, 3.3V Low-Power Transimpedance Amplifier with RSSI

## Typical Operating Characteristics (continued)

($V_{CC}$ = +3.3V, $T_A$ = +25°C, input bondwire inductance = 1.0nH, unless otherwise noted. $C_{IN}$ is total source capacitance to die. All measurements made on MAX3970 EV Kit.)
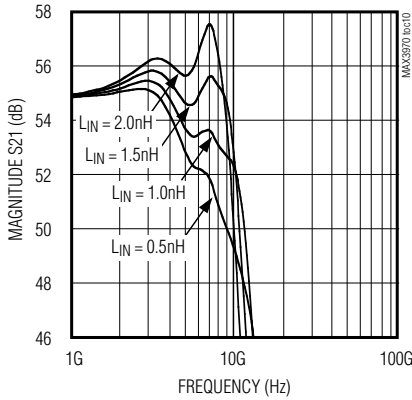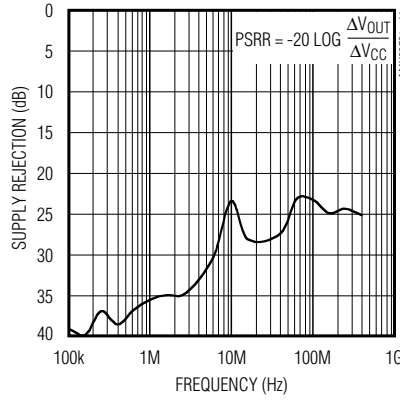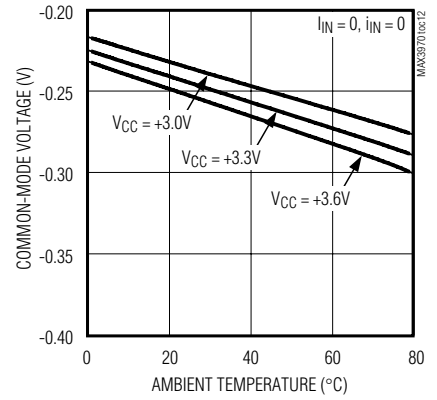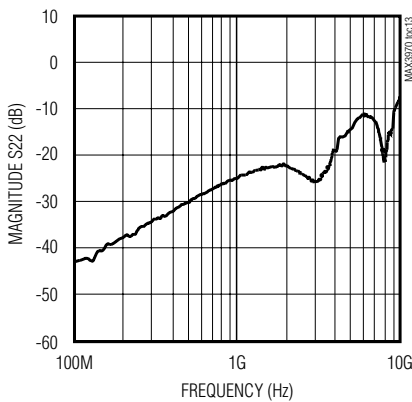
### SIMULATED FREQUENCY RESPONSE vs. INPUT INDUCTANCE
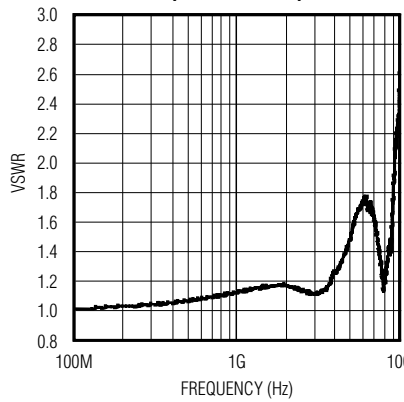


MAGNITUDE S21 (dB) vs. FREQUENCY (Hz)

$L_{IN}$ = 2.0nH
$L_{IN}$ = 1.5nH
$L_{IN}$ = 1.0nH
$L_{IN}$ = 0.5nH

MAX3970 toc10

### POWER-SUPPLY REJECTION RATIO vs. FREQUENCY



SUPPLY REJECTION (dB) vs. FREQUENCY (Hz)

$PSRR = -20 \, LOG \, \dfrac{\Delta V_{OUT}}{\Delta V_{CC}}$

MAX3970 toc11

### OUTPUT COMMON-MODE VOLTAGE (REFERENCED TO $V_{CC}$) vs. TEMPERATURE



COMMON-MODE VOLTAGE (V) vs. AMBIENT TEMPERATURE (°C)

$I_{IN}$ = 0, $i_{IN}$ = 0
$V_{CC}$ = +3.0V
$V_{CC}$ = +3.3V
$V_{CC}$ = +3.6V

MAX3970 toc12

### S22 vs. FREQUENCY



MAGNITUDE S22 (dB) vs. FREQUENCY (Hz)

MAX3970 toc13

### OUTPUT VSWR (DIFFERENTIAL)



VSWR vs. FREQUENCY (Hz)

MAX3970 toc14

### RSSI OUTPUT VOLTAGE vs. AVERAGE INPUT CURRENT



$V_{RSSI}$ (V) vs. CURRENT (mA)

MAX3970 toc15
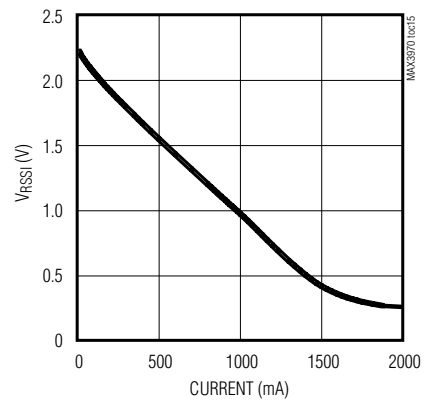
### SIMULATED SMALL-SIGNAL BANDWIDTH vs. CAPACITANCE



-3dB BANDWIDTH (GHz) vs. $C_{IN}$ (pF)

$T_J$ = 50°C
$T_J$ = 100°C
$T_J$ = 0°C

MAX3970 toc16
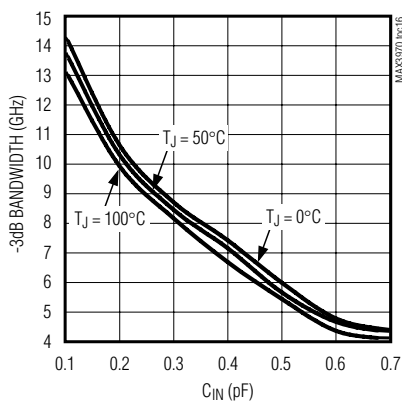
### SMALL-SIGNAL TRANSIMPEDANCE vs. TEMPERATURE
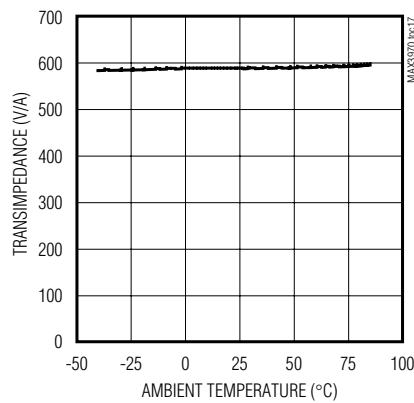


TRANSIMPEDANCE (V/A) vs. AMBIENT TEMPERATURE (°C)

MAX3970 toc17

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| PAD | NAME | FUNCTION |
|---|---|---|
| BP1, BP2, BP18 | $V_{CC}1$ | Power Supply. Provides supply voltage to input circuitry and bias to the photodiode via an internal 410Ω resistor. |
| BP3 | FILTER | Provides bias voltage for the photodiode through a 410Ω resistor to $V_{CC}1$. When grounded, this pin disables the DC cancellation circuit to allow a DC path from IN to OUT+ and OUT- for testing. |
| BP4 | TEST | Test Pad. This pad is connected to IN via a 1kΩ resistor. |
| BP5 | IN | Amplifier Input. Accepts photodiode input current. |
| BP6, BP7 | GND1 | Ground |
| BP8, BP9 | GND2 | Ground |
| BP10, BP13 | GND3 | Ground |
| BP11 | OUT- | Negative CML Output. Current flowing into IN causes OUT- to decrease. |
| BP12 | OUT+ | Positive CML Output. Current flowing into IN causes OUT+ to increase. |
| BP14, BP15 BP16 | $V_{CC}2$ | Power Supply. Provides supply voltage to the output buffers. |
| BP17 | RSSI | Received-Signal Strength Indicator. This pin provides a voltage proportional to the DC input current. Monitor this output during assembly to optimally align the photodiode to the optics. |

## Detailed Description

The MAX3970 transimpedance amplifier is optimized for 10Gbps fiber optic receivers. Figure 1 is a functional diagram of the MAX3970, which comprises a transimpedance amplifier, a voltage amplifier, an output buffer, a received-signal strength indicator, and a DC-cancellation circuit.

### Transimpedance Amplifier

Photodiode signal current flows into the summing node of a high-gain amplifier. Shunt feedback through $R_F$ converts this current into a voltage with a gain of approximately 400Ω. Schottky diodes clamp the output voltage for large input currents, as shown in Figure 2.

### Voltage Amplifier

The voltage amplifier converts single-ended signals to differential signals and introduces approximately 4dB of gain.

### Output Buffer

The output buffer is optimized to drive a 100Ω differential load between OUT+ and OUT-. Although short-circuit protection is provided, this stage will not drive a 50Ω load to ground. For proper operation, the load must be AC-coupled. For large signals, the output buffer produces a limited, 500mV$_{P-P}$ differential output voltage.

Terminate the MAX3970 outputs differentially for optimum supply-noise rejection. If a single-ended output is required, terminate the used and unused outputs similarly.

### DC Cancellation Circuit

The DC cancellation circuit centers the input signal within the transimpedance amplifier's linear range (Figure 3). Low-frequency feedback is employed to remove the input signal's DC component.

The DC cancellation circuit is internally compensated and therefore does not require external capacitors. This circuit minimizes pulse-width distortion for data sequences that exhibit a 50% mark density. A mark density significantly different from 50% will cause the MAX3970 to generate pulse-width distortion.

### Received-Signal Strength Indicator

The received-signal strength indicator (RSSI) provides a voltage proportional to the DC input current. The RSSI circuitry is designed to drive a 10kΩ load and is used during the assembly process to optimally align the photodiode. The lowpass filter in the DC cancellation circuit determines the response time of the RSSI circuit.

## Design Procedure

### Power Supply

The MAX3970 requires wide-band power-supply decoupling. Power-supply bypassing should provide low impedance between $V_{CC}$ and ground for frequencies between 50kHz and 10GHz. Use LC filtering at the main supply terminal and decoupling capacitors as close to the die as possible.
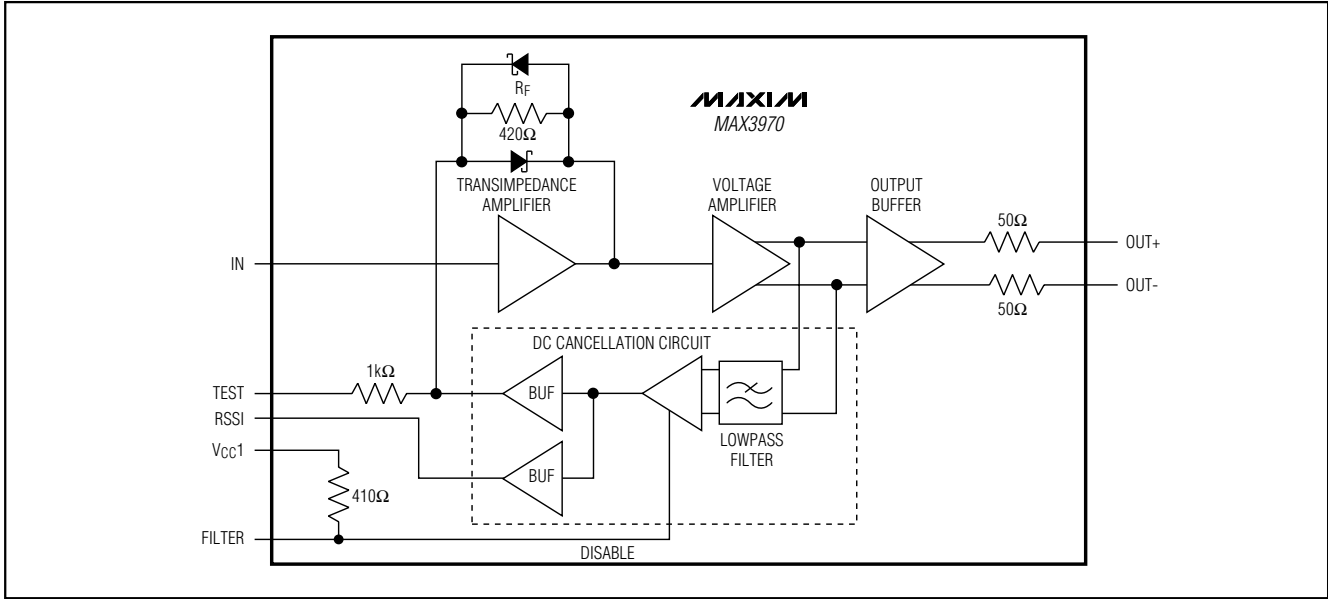
**MAX3970**



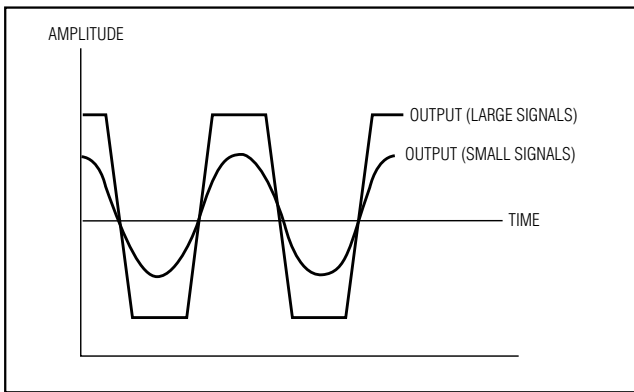Figure 1. Functional Diagram



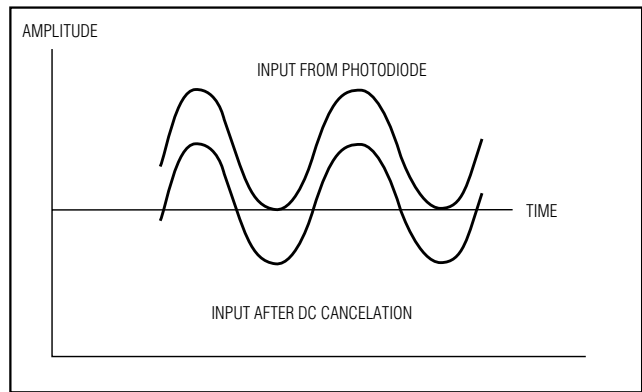Figure 2. MAX3970 Limited Output



Figure 3. Effects of DC Cancellation on Input Signal

### Photodiode Filter

Supply-voltage noise at the cathode of the photodiode produces a current $I = C_{PD}\,\Delta V / \Delta t$, which reduces the receiver sensitivity ($C_{PD}$ is the photodiode capacitance). The MAX3970 contains an internal lowpass filter to reduce photodiode noise current and improve receiver sensitivity. An external capacitor connected between the FILTER pad and ground can further reduce this noise (see the *Typical Application Circuit*). Current generated by supply-noise voltage is divided between the filter capacitance and photodiode capacitance. Assuming the filter capacitance is much larger than the photodiode capacitance, the input noise current due to supply noise is:

$$I_{NOISE} = (V_{NOISE})(C_{PD}) / (R_{FILTER})(C_{FILTER})$$

where $C_{FILTER}$ is the external capacitance plus the internal 22pF capacitor. If the amount of tolerable noise is known, the filter capacitance can be easily selected:

$$C_{FILTER} = (V_{NOISE})(C_{PD}) / (R_{FILTER})(I_{NOISE})$$

For example, with maximum noise voltage = 100mV$_{P-P}$, $C_{PD}$ = 0.25pF, $R_{FILTER}$ = 410$\Omega$, and $I_{NOISE}$ selected to be 300nA (1/4 of the MAX3970's input noise):

$$C_{FILTER} = (100mV)(0.25pF) / (410\Omega)(300nA) \approx 200pF$$

Thus, the required external filter capacitance is 200pF -22pF = 178pF.

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## Wire Bonding

For high current density and reliable operation, the MAX3970 uses gold metalization. Connections to the die should be made with gold wire only. Aluminum bonding is not recommended. Die thickness is typically 8mils (0.203mm). Bondwire inductance between the photodiode and the IN pad can be optimized to obtain best performance. Higher inductance improves bandwidth while lower bondwire inductance reduces time domain ringing. See the Frequency Response vs. Input Inductance plot in the *Typical Operating Characteristics*. Bondwires on all other pads should be kept as short as possible (<30mil) to optimize performance.

The MAX3970 has two power-supply connections (VCC1 and VCC2) and three ground connections (GND1, GND2, and GND3). Maxim recommends connecting all power supply and ground pads. At a minimum, connect at least one pad from each section. The backside of the MAX3970 die is fully insulated and can be connected to VCC, ground, or left floating.

## Input Capacitance

Noise and bandwidth are adversely affected by capacitance on the MAX3970's input node as shown in Input Referred Noise vs. Capacitance and Small Signal Bandwidth vs. Capacitance in the *Typical Operating Characteristics*. Use any technique available to minimize input capacitance.

## Output Coupling Capacitors

The output coupling capacitors should be low impedance over a frequency range from 50kHz to 10GHz. For more information on selecting coupling capacitors, visit Maxim's website and follow the links to HFAN1.1, *Choosing AC-Coupling Capacitors.*

## _____ Applications Information

### Interface Schematics

Figures 4 through 7 show interface pads for the MAX3970. Back termination is provided by integrated 50Ω pullup resistors.

### Optical Power Relations

Many MAX3970 specifications relate to the input signal amplitude. When working with fiber optic receivers, the input is sometimes expressed in terms of average optical power and extinction ratio. Figure 8 shows the relations that are helpful for converting optical power to optical modulation amplitude when designing with the MAX3970.

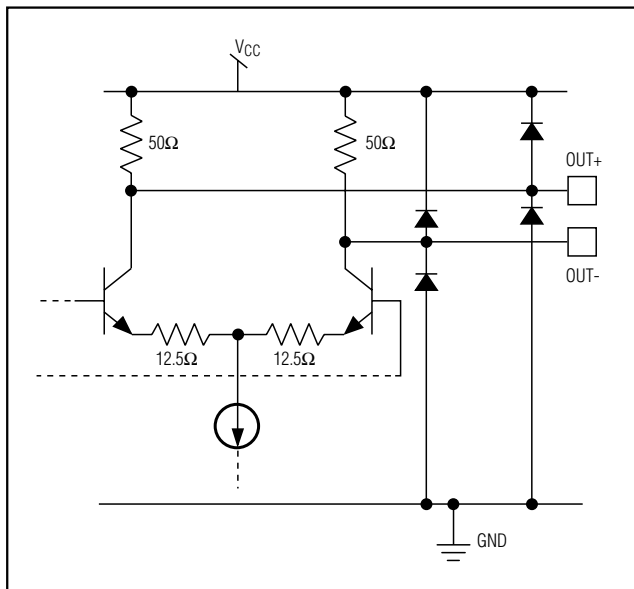Optical power relations are shown in Table 1 for an average mark density of 50% and an average duty cyle of 50%.
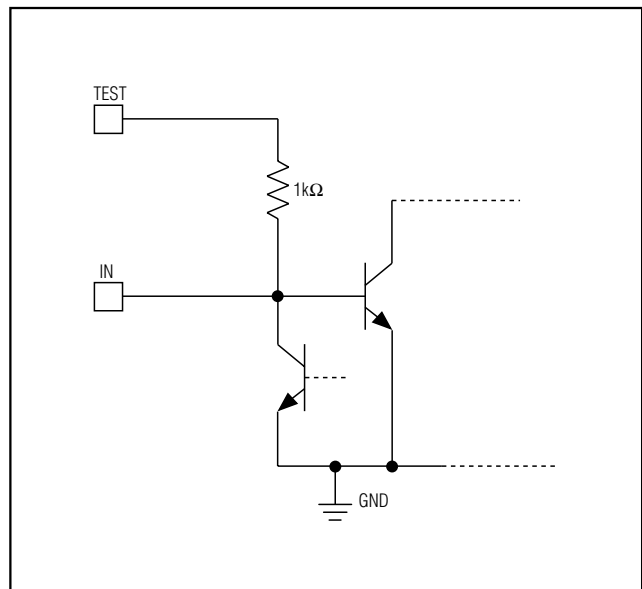


Figure 4. OUT Pads
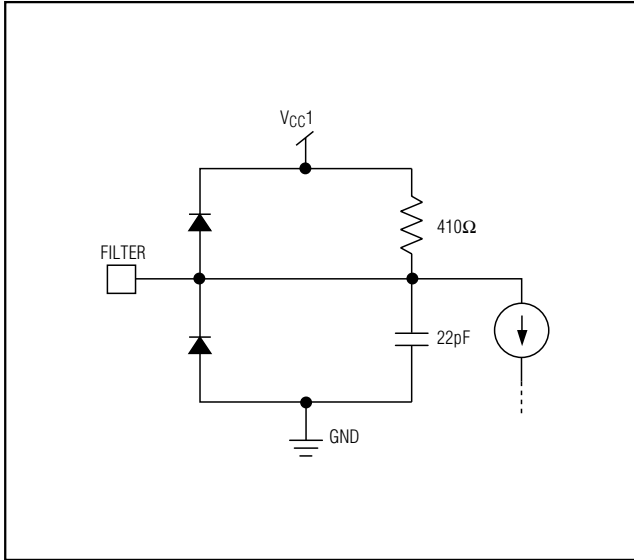


Figure 5. IN and TEST Pads
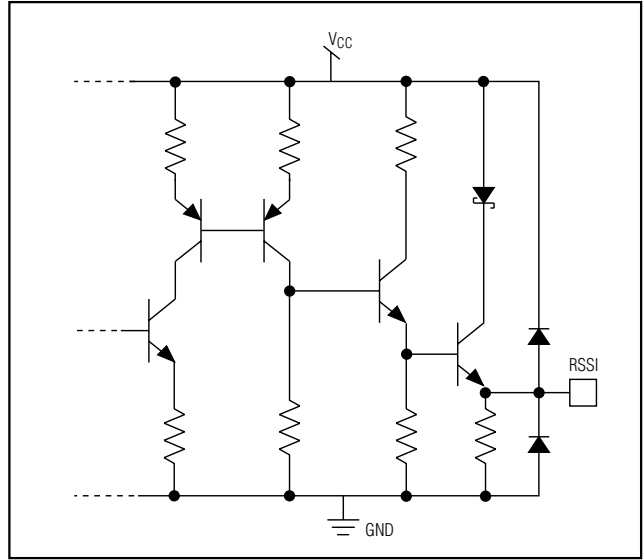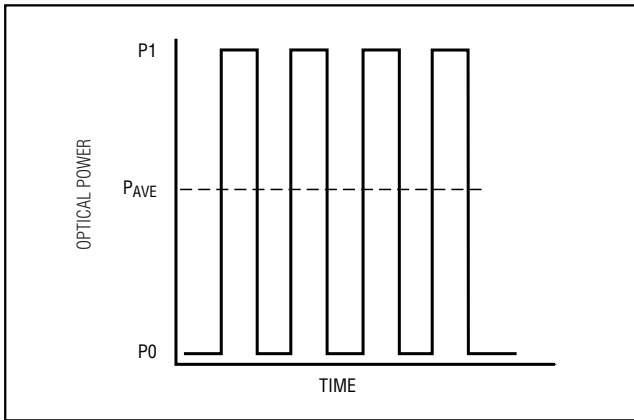
Figure 6. FILTER Pad



Figure 7. RSSI Pad



Figure 8. Optical Power Relations

### Optical Sensitivity Calculation

The MAX3970 input-referred RMS noise current $i_n$ generally determines the receiver sensitivity. To obtain a system bit error rate (BER) of $1 \times 10^{-12}$, the signal-to-noise ratio must always exceed 14.1. The input sensitivity, expressed in average power, can be estimated as:

$$\text{Sensitivity} = 10\log\left(\frac{14.1 \times i_n \times (r_e + 1)}{2 \times \rho \times (r_e - 1)} \times 1000\right)\text{dBm}$$

where $\rho$ is the photodiode responsivity in A/W.

### Input Optical Overload

The overload is the largest input that the MAX3970 accepts while meeting specifications. Optical overload can be estimated in terms of average power with the following equation:

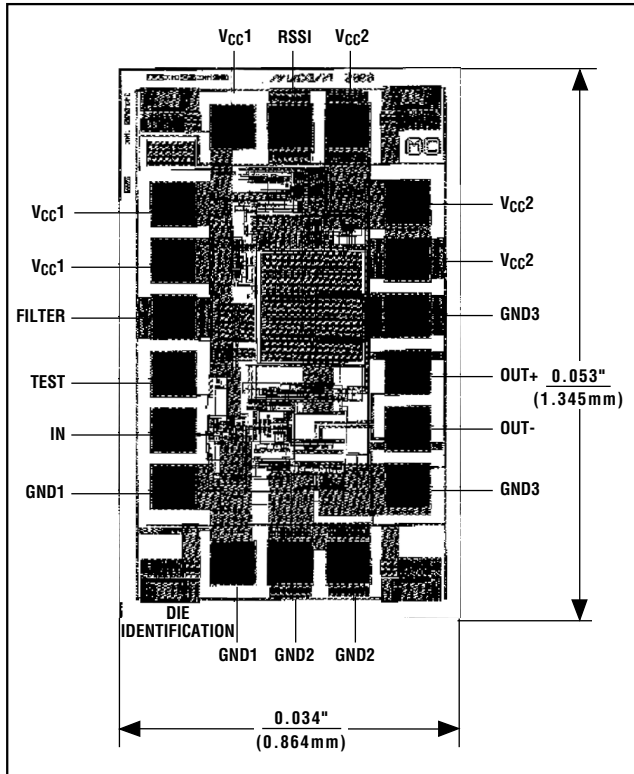$$\text{Overload} = 10\log\left(\frac{2\text{mA}}{2 \times \rho} \times 1000\right)\text{dBm}$$

### Optical Linear Range

The MAX3970 has high gain, and operates in a linear range for inputs not exceeding:

$$\text{Linear Range} = 10\log\left(\frac{60\mu\text{A}(r_e + 1)}{2 \times \rho \times (r_e - 1)} \times 1000\right)\text{dBm}$$

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## Table 1. Optical Power Relations*

| PARAMETER | SYMBOL | RELATION |
|---|---|---|
| Average Power | $P_{AVG}$ | $P_{AVG} = (P0 + P1) / 2$ |
| Extinction Ratio | $r_e$ | $r_e = P1 / P0$ |
| Optical Power of a "1" | P1 | $P1 = 2P_{AVG}\dfrac{r_e}{r_e + 1}$ |
| Optical Power of a "0" | P0 | $P0 = 2P_{AVG} / (r_e+1)$ |
| Optical Modulation Amplitude | $P_{IN}$ | $P_{IN} = P1 - P0 = 2P_{AVG}\dfrac{r_e - 1}{r_e + 1}$ |

*Assuming a 50% average mark density.*

## Table 2. MAX3970 Bondpad Information

| PAD | NAME | COORDINATES | |
|---|---|---|---|
| | | X | Y |
| BP1 | $V_{CC}1$ | 0 | 799.4 |
| BP2 | $V_{CC}1$ | 0 | 673.4 |
| BP3 | FILTER | 0 | 547.4 |
| BP4 | TEST | 0 | 421.4 |
| BP5 | IN | 0 | 295.4 |
| BP6 | GND1 | 0 | 169.4 |
| BP7 | GND1 | 129.8 | 0 |
| BP8 | GND2 | 255.8 | 0 |
| BP9 | GND2 | 381.8 | 0 |
| BP10 | GND3 | 512 | 170.8 |
| BP11 | OUT- | 512 | 296.8 |
| BP12 | OUT+ | 512 | 422.8 |
| BP13 | GND3 | 512 | 548.8 |
| BP14 | $V_{CC}2$ | 512 | 674.8 |
| BP15 | $V_{CC}2$ | 512 | 800.8 |
| BP16 | $V_{CC}2$ | 381.8 | 971.6 |
| BP17 | RSSI | 255.8 | 971.6 |
| BP18 | $V_{CC}1$ | 129.8 | 971.6 |



Figure 9. Bondpad Diagram

# 10Gbps, 3.3V Low-Power Transimpedance Amplifier with RSSI

## Chip Topography



Chip topography diagram showing pad labels: V_CC1, RSSI, V_CC2 (top); V_CC1, V_CC1, FILTER, TEST, IN, GND1 (left); V_CC2, V_CC2, GND3, OUT+, OUT-, GND3 (right); DIE IDENTIFICATION, GND1, GND2, GND2 (bottom). Dimensions: 0.053" (1.345mm) vertical, 0.034" (0.864mm) horizontal.

## Chip Information

TRANSISTOR COUNT: 125
PROCESS: SILICON GERMANIUM BIPOLAR