19-1970; Rev 1; 10/01

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 590V/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**
- ♦ **2mAp-p Input Overload**
- ♦ **Received-Signal Strength Indication**
- ♦ **8psp-p Typical Jitter Generation at 1.3mAp-p Input Current**
- ♦ **590V/A Transimpedance**

Applications

10.3Gbps Ethernet Optical Receivers

OC-192 VSR Optical Receivers

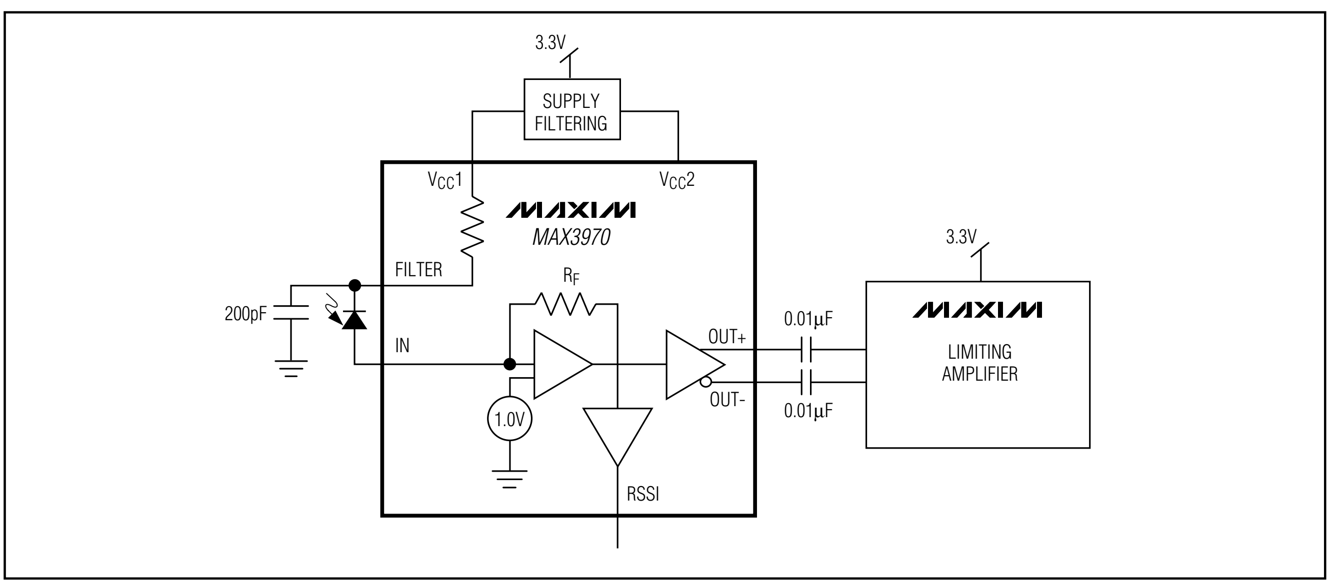
Fibre-Channel Optical Receivers

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



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)

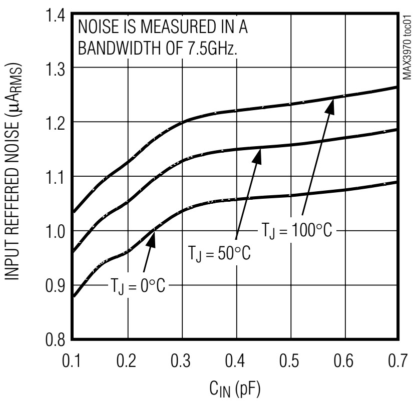
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Current	I_{CC}			46	62	mA
Maximum DC Input Current	$I_{IN\text{-}MAX}$		1.6			mA
Input Linear Range		0.95 < Linearity < 1.05	100	130		µAp-p
Input Referred RMS Noise	i_n	f = 7.5GHz (Note 2)		1.1	1.45	µA
		f = 10GHz (Note 2)		1.1	1.45	
Input Referred Noise Density		f = 10GHz (Note 2)		11		pA/(Hz)$^{1/2}$
Output Resistance (per side)	R_{OUT}		43	50	58	Ω
Small Signal Transimpedance	Z_{21}	Differential output 10µAp-p < Input < 100µAp-p	340	590	730	Ω
Small Signal Bandwidth	BW		7.4	9	13.2	GHz
Low Frequency Cut-Off				70	150	kHz
Deterministic Jitter	DJ	I_{IN} < 1.3mA		8		psp-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	$V_{OD\text{-}MAX}$	Input = 1mAp-p	350	470	700	mVp-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) / $\sqrt{\text{bandwidth}}$. Noise measurements are made using 4-pole Bessel filters.

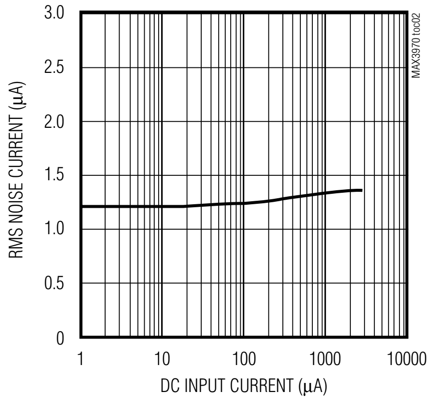
Typical Operating Characteristics

(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.)

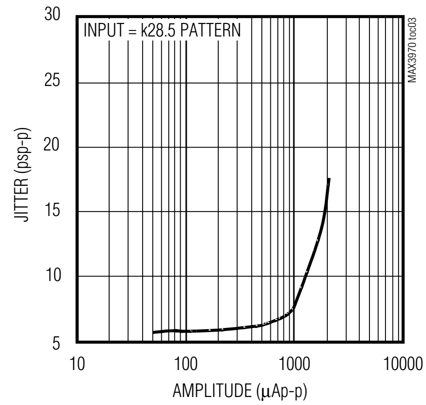
INPUT REFERRED NOISE vs. CAPACITANCE



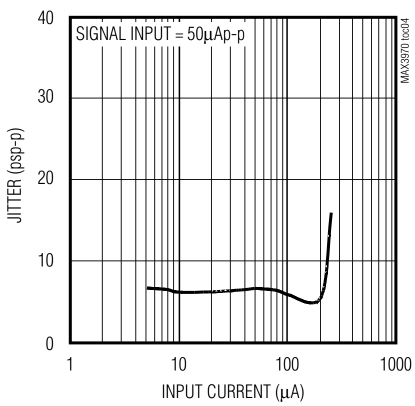
INPUT REFERRED RMS NOISE CURRENT vs. AVERAGE INPUT CURRENT



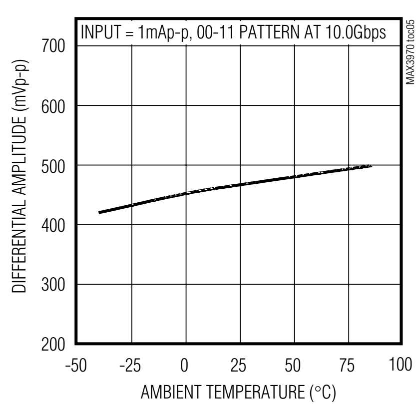
DETERMINISTIC JITTER vs. INPUT AMPLITUDE



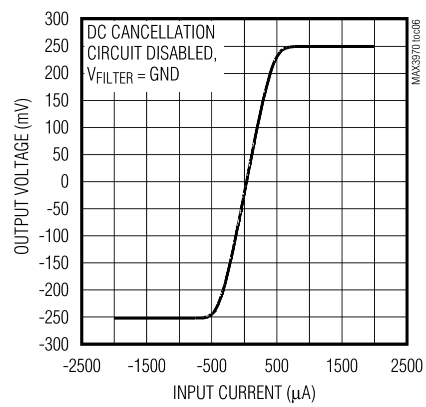
DETERMINISTIC JITTER vs. AVERAGE INPUT CURRENT



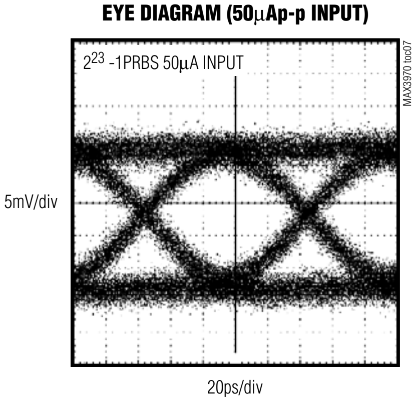
OUTPUT AMPLITUDE vs. TEMPERATURE



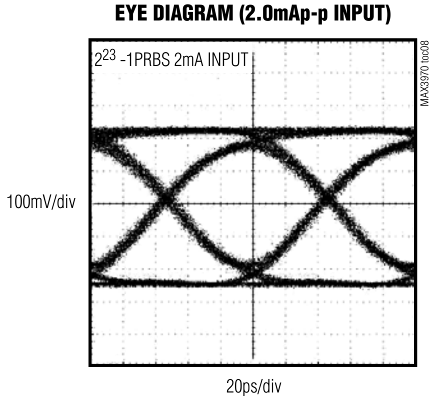
DC TRANSFER FUNCTION



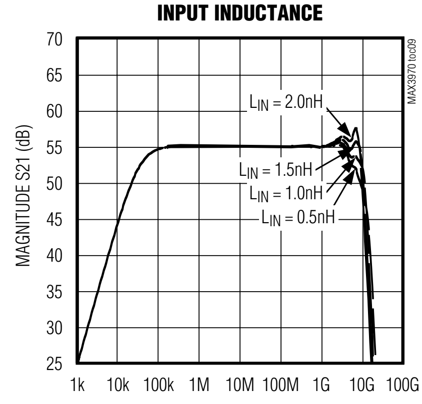
EYE DIAGRAM (50µAp-p INPUT)



EYE DIAGRAM (2.0mAp-p INPUT)



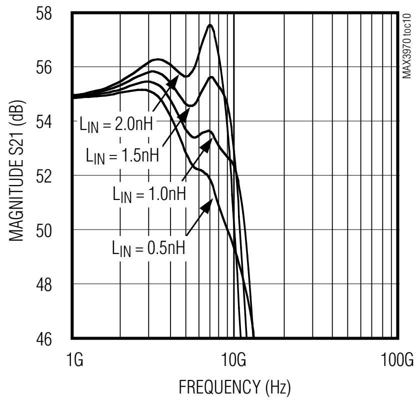
SIMULATED FREQUENCY RESPONSE vs. INPUT INDUCTANCE



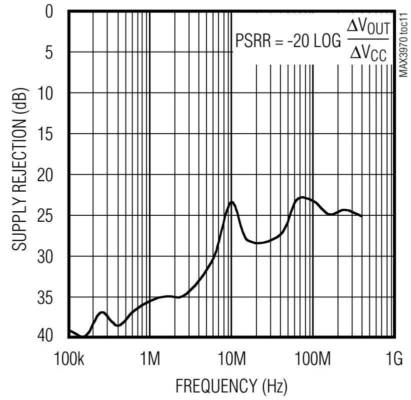
Typical Operating Characteristics (continued)

(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.)

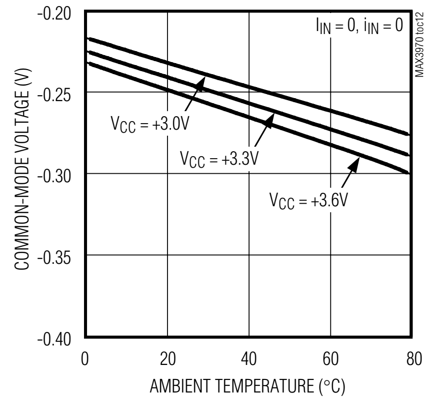
SIMULATED FREQUENCY RESPONSE vs. INPUT INDUCTANCE



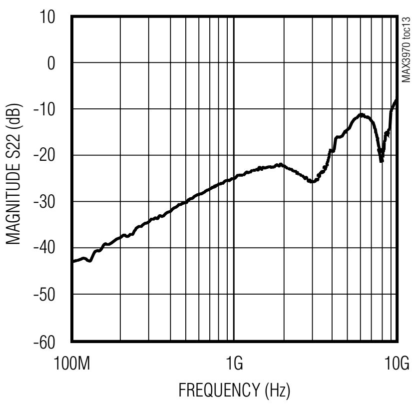
POWER SUPPLY REJECTION RATIO vs. FREQUENCY



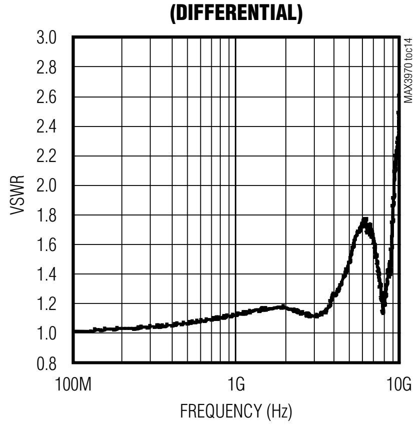
OUTPUT COMMON-MODE VOLTAGE (REFERENCED TO V_{CC}) vs. TEMPERATURE



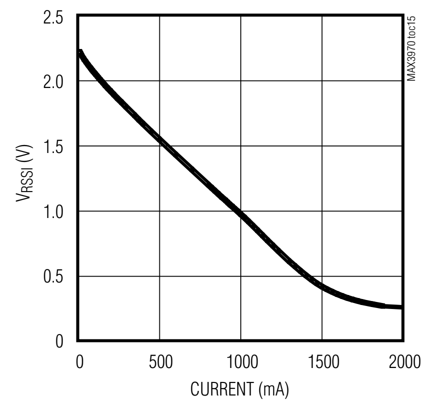
S22 vs. FREQUENCY



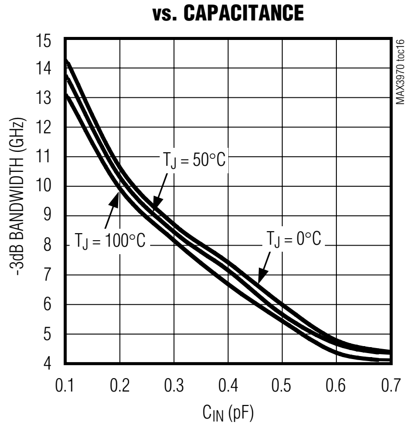
OUTPUT VSWR (DIFFERENTIAL)



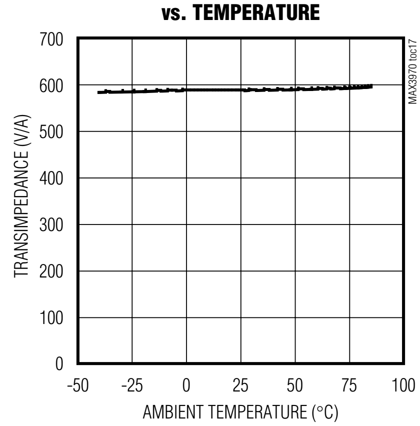
RSSI OUTPUT VOLTAGE vs. AVERAGE INPUT CURRENT



SIMULATED SMALL SIGNAL BANDWIDTH vs. CAPACITANCE



SMALL SIGNAL TRANSIMPEDANCE vs. TEMPERATURE



Pad Description

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, 500mVp-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

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

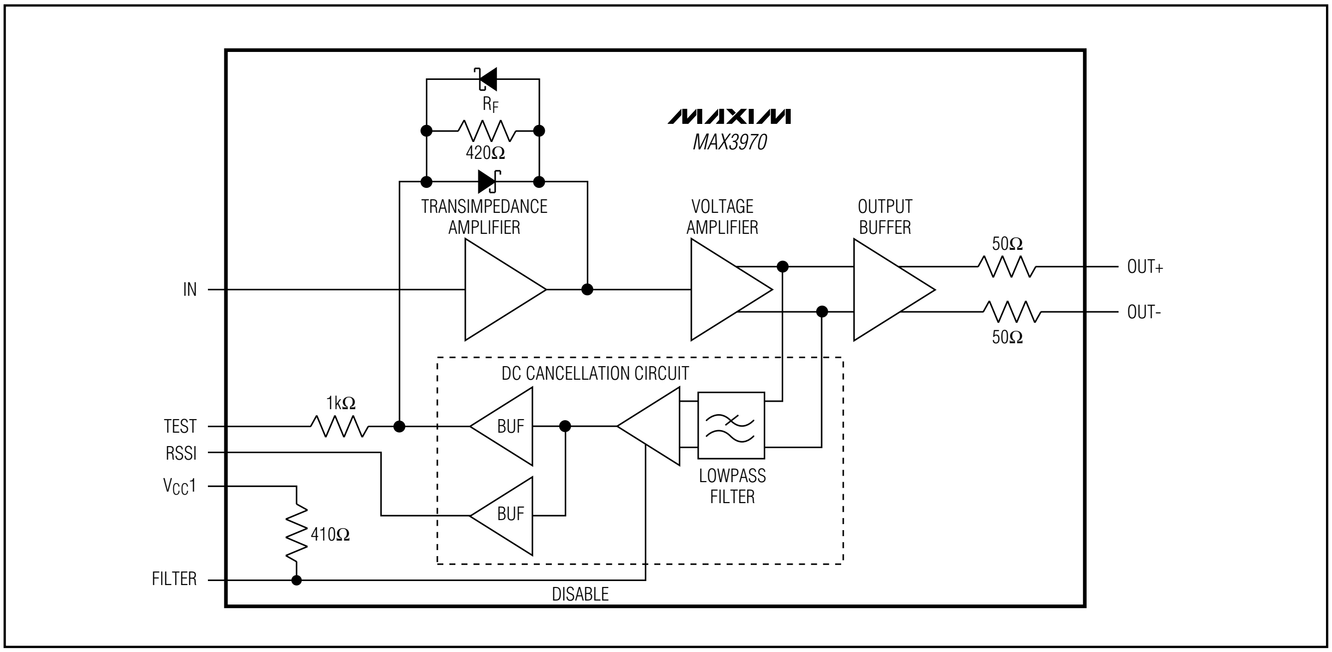


Figure 1. Functional Diagram

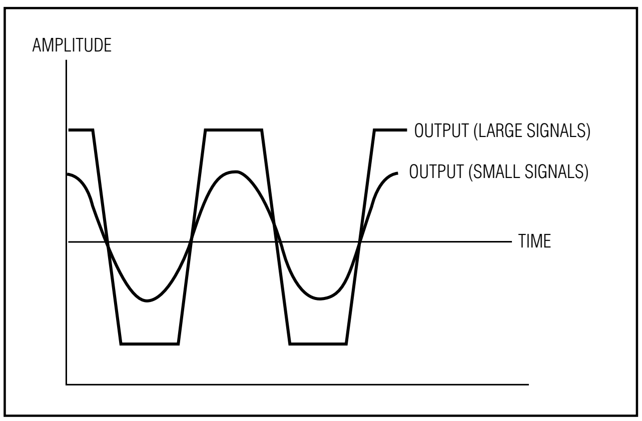


Figure 2. MAX3970 Limited Output

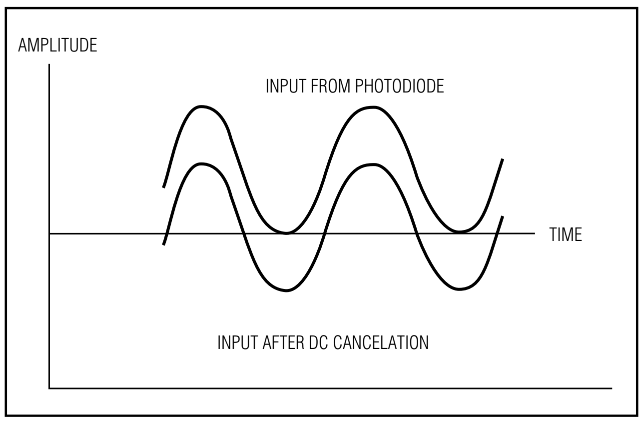


Figure 3. Effects of DC Cancellation on Input Signal

main supply terminal and decoupling capacitors as close to the die as possible.

Photodiode Filter

Supply-voltage noise at the cathode of the photodiode produces a current I = C_{PD} ΔV/Δt, 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 (refer to 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 = 100mVp-p, C_{PD} = 0.25pF, R_{FILTER} = 410Ω, 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.

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 (<30mils) to optimize performance.

The MAX3970 has two power-supply connections ($V_{CC}1$ and $V_{CC}2$) 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 V_{CC}, 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 web page 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 pull-up 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

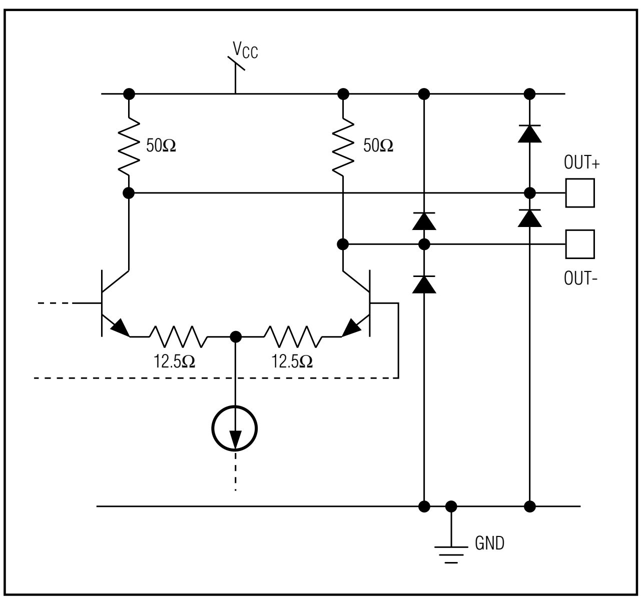


Figure 4. OUT Pads

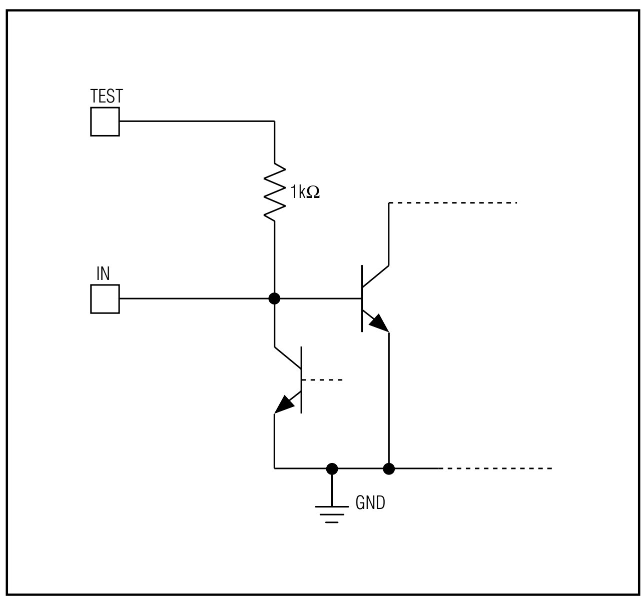


Figure 5. IN and TEST Pads

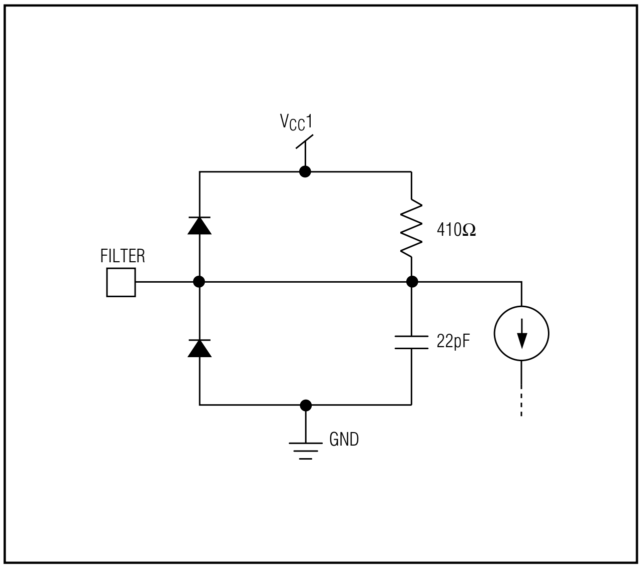


Figure 6. FILTER Pad

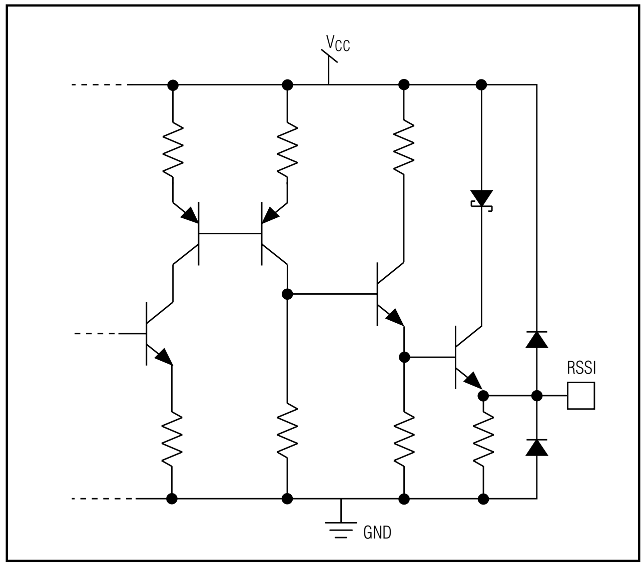


Figure 7. RSSI Pad

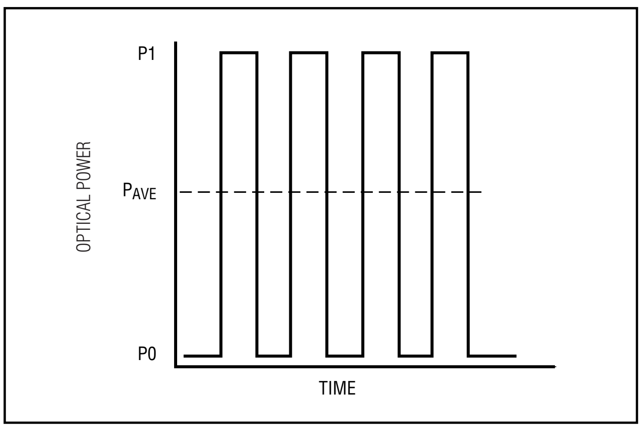


Figure 8. Optical Power Relations

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%.

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 x 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 ρ 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:

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

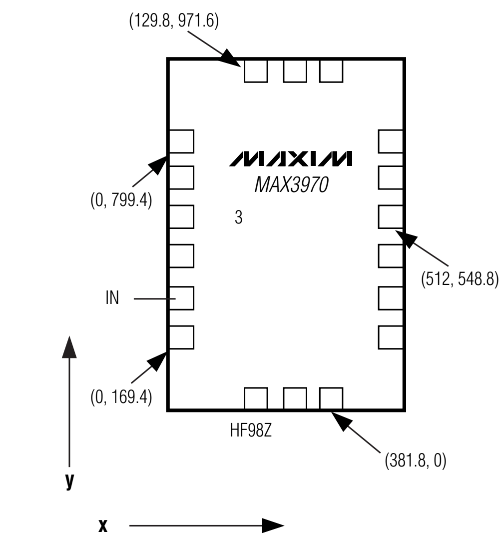
Table 1. Optical Power Relations*

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	$P1 = 2P_{AVG} \frac{r_e}{r_e + 1}$
Optical Power of a "0"	P0	$P0 = 2P_{AVG} / (r_e + 1)$
Optical Modulation Amplitude	P_{IN}	$P_{IN} = P1 - P0 = 2P_{AVG} \frac{r_e - 1}{r_e + 1}$

*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



- All dimensions are in microns.
- Pad dimensions:

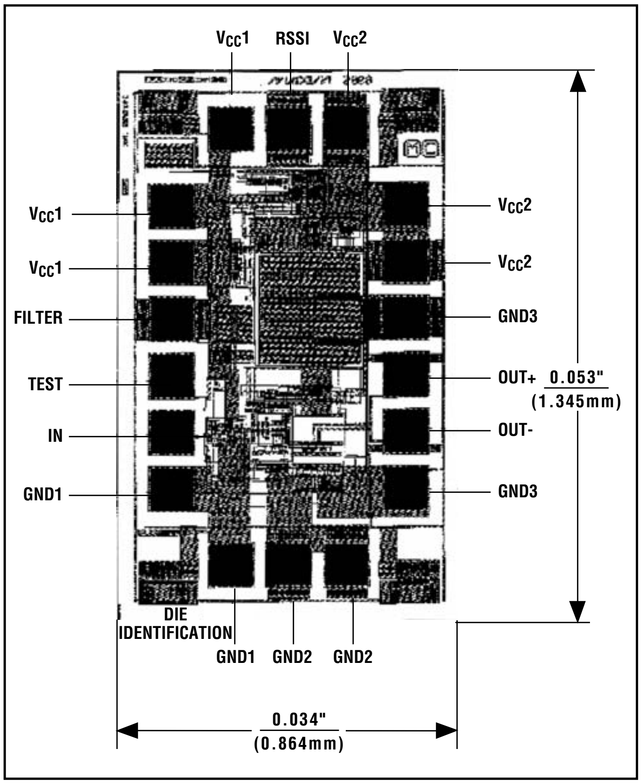
METAL	PASSIVATION OPENING
H=102.4 microns	94.4 microns
W=102.4microns	94.4microns

- Coordinates specify lower left corner of the pad.

Figure 9. Bondpad Diagram

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

Chip Topography



Chip Information

TRANSISTOR COUNT: 125

PROCESS: SILICON GERMANIUM BIPOLAR