19-1631; Rev 0; 1/00

MAXIM

# 2.5Gbps, Low-Power, +3.3V Clock Recovery and Data Retiming IC



## General Description

The MAX3876 is a compact, low-power clock recovery and data retiming IC for 2.488Gbps SDH/SONET applications. The fully integrated phase-locked loop (PLL) recovers a synchronous clock signal from the serial NRZ data input. The data is retimed by the recovered clock. Differential CML outputs are provided for both clock and data signals, and an additional 2.488Gbps serial input is available for system loopback diagnostic testing. The device also includes a TTL-compatible loss-of-lock ($\overline{LOL}$) monitor.

The MAX3876 is designed for both section-regenerator and terminal-receiver applications in OC-48/STM-16 transmission systems. Its jitter performance exceeds all of the SONET/SDH specifications.

This device operates from a +3.3V or +5.0V single supply over a -40°C to +85°C temperature range. Power consumption is typically only 445mW with a +3.3V supply. The MAX3876 is available in a 32-pin TQFP package as well as in die form.

## Applications

SDH/SONET Receivers and Regenerators

Add/Drop Multiplexers

Digital Cross-Connects

2.488Gbps ATM Receiver

Digital Video Transmission

SDH/SONET Test Equipment

Intrarack/Subrack Interconnects

## Features

- **Exceeds ANSI, ITU, and Bellcore SONET/SDH Regenerator Specifications**
- **440mW Power Dissipation (at +3.3V)**
- **Clock Jitter Generation: 3.7mUI$_{RMS}$**
- **+3.3V or +5V Single Power Supply**
- **Fully Integrated Clock Recovery and Data Retiming**
- **Additional High-Speed Input Facilitates System Loopback Diagnostic Testing**
- **Tolerates >2500 Consecutive Identical Digits**
- **Loss-of-Lock Indicator**
- **Differential CML Data and Clock Outputs**

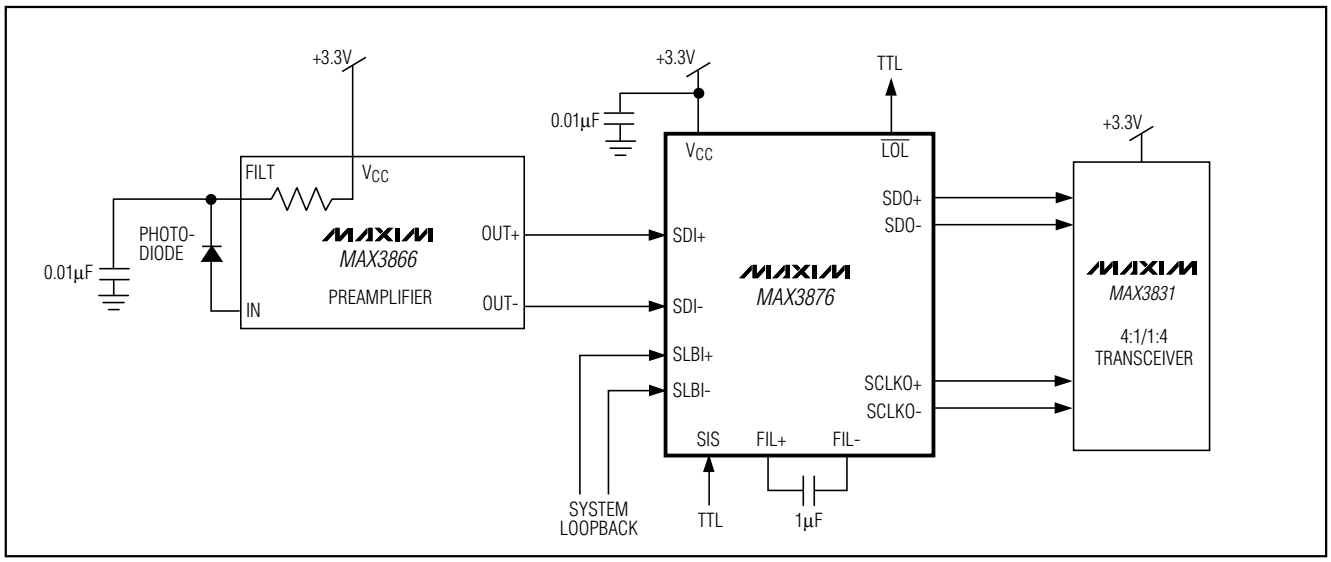
## Ordering Information

| PART | TEMP. RANGE | PIN-PACKAGE |
|---|---|---|
| MAX3876EHJ | -40°C to +85°C | 32 TQFP |
| MAX3876E/D | -40°C to +85°C | Dice* |

**Dice are designed to operate over this range, but are tested and guaranteed at $T_A$ = +25°C only. Contact factory for availability.*

***Pin Configuration appears at end of data sheet.***

## Typical Application Circuit






***For free samples and the latest literature: www.maxim-ic.com, or phone 1-800-998-8800. For small orders, phone 1-800-835-8769.***

# 2.5Gbps, Low-Power, +3.3V Clock Recovery and Data Retiming IC

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage, $V_{CC}$.....-0.5V to +7.0V
Input Voltage Levels
(SDI+, SDI-, SLBI+, SLBI-).....($V_{CC}$ - 0.5V) to ($V_{CC}$ + 0.5V)
Input Current Levels (SDI+, SDI-, SLBI+, SLBI-).....±11mA
CML Output Current Levels
(SDO+, $\overline{SDO}$-, SCLKO+, SCLKO-).....±22mA
Voltage at $\overline{LOL}$, SIS, FIL+, FIL-.....-0.5V to ($V_{CC}$ + 0.5V)

Continuous Power Dissipation ($T_A$ = +85°C)
32-Pin TQFP (derate 16.1mW/°C above +85°C).....1.0W
Operating Temperature Range
MAX3876EHJ.....-40°C to +85°C
Operating Junction Temperature Range (die) ..-55°C to +150°C
Storage Temperature Range .....-60°C to +160°C
Processing Temperature (die) .....+400°C
Lead Temperature (soldering, 10s) .....+300°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.*

## DC ELECTRICAL CHARACTERISTICS

($V_{CC}$ = +3.0V to +5.5V, $T_A$ = -40°C to +85°C, unless otherwise noted. Typical values are at +3.3V and $T_A$ = +25°C.) (Note 1)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| Supply Current | $I_{CC}$ | Excluding CML output termination | | | 135 | 167 | mA |
| Input Common-Mode Voltage | $V_{CM}$ | DC-coupled | | $V_{CC}$ - 0.25 | | | V |
| Differential Input Voltage (SDI±, SLBI±) | $V_{ID}$ | Figure 1, DC-coupled | | 50 | | 1000 | mVp-p |
| | | Figure 1, AC-coupled | | 50 | | 1600 | |
| Single-Ended Input Voltage (SDI±, SLBI±) | $V_{IS}$ | | | $V_{CC}$ - 0.4 | | $V_{CC}$ + 0.4 | V |
| Input Termination to $V_{CC}$ (SDI±, SLBI±) | $R_{IN}$ | | | | 48 | | Ω |
| CML Differential Output Voltage Swing | | $R_L$ = 50Ω to $V_{CC}$ | $T_A$ = 0°C to +85°C | 640 | 800 | 1000 | mVp-p |
| | | | $T_A$ = -40°C | 580 | 800 | 1000 | |
| Differential Output Impedance | | | | 85 | 100 | 115 | Ω |
| CML Output Common-Mode Voltage | | $R_L$ = 50Ω to $V_{CC}$ | | | $V_{CC}$ - 0.2 | | V |
| TTL Input High Voltage (SIS) | $V_{IH}$ | | | 2.0 | | | V |
| TTL Input Low Voltage (SIS) | $V_{IL}$ | | | | | 0.8 | V |
| TTL Input Current (SIS) | | | | -10 | | +10 | µA |
| TTL Output High Voltage ($\overline{LOL}$) | $V_{OH}$ | | | 2.4 | | $V_{CC}$ | V |
| TTL Output Low Voltage ($\overline{LOL}$) | $V_{OL}$ | | | | | 0.4 | V |

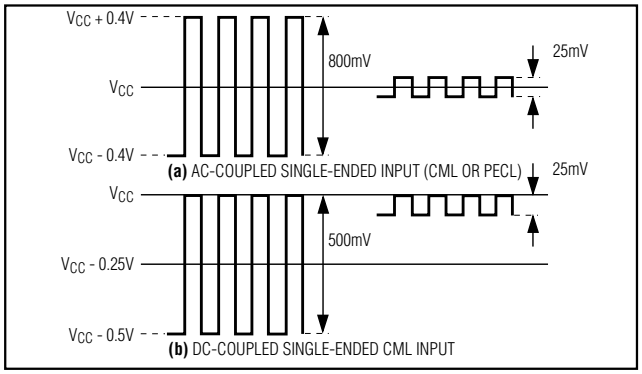



*Figure 1. Input Amplitude*

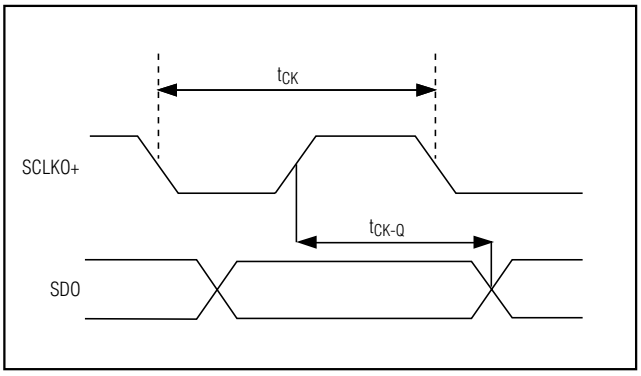



*Figure 2. Output Clock-to-Q Delay*

## AC ELECTRICAL CHARACTERISTICS

($V_{CC}$ = +3.0V to +5.5V, $T_A$ = -40°C to +85°C, unless otherwise noted. Typical values are at +3.3V and $T_A$ = +25°C.) (Note 2)

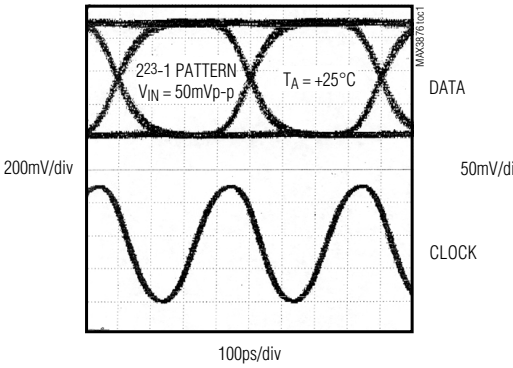
| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| Serial Output Clock Rate | | | | 2.488 | | GHz |
| Clock-to-Q Delay | | Figure 2 | 110 | | 290 | ps |
| Jitter Peaking | $J_P$ | f ≤ 2MHz | | 0.03 | 0.1 | dB |
| Jitter Transfer Bandwidth | $J_{BW}$ | | | 1.4 | 2.0 | MHz |
| Jitter Tolerance | | f = 70kHz (Note 3) | 2.1 | 4.4 | | UIp-p |
| | | f = 100kHz | 1.76 | 3.32 | | |
| | | f = 1MHz | 0.41 | 0.74 | | |
| | | f = 10MHz | 0.32 | 0.51 | | |
| Jitter Generation | $J_{GEN}$ | Jitter BW = 12kHz to 20MHz | | 3.7 | 6.2 | $mUI_{RMS}$ |
| | | | | 19.2 | 61.0 | mUIp-p |
| Clock Output Edge Speed | | 20% to 80% | | 75 | | ps |
| Data Output Edge Speed | | 20% to 80% | | 95 | | ps |
| Tolerated Consecutive Identical Digits | | | | 2500 | | Bits |
| Input Return Loss (SDI±, SLBI±) | | 100kHz to 2.5GHz | | 17 | | dB |
| | | 2.5GHz to 4.0GHz | | 15 | | |

**Note 1:** Dice are tested at $T_A$ = +25°C only.
**Note 2:** AC characteristics are guaranteed by design and characterization.
**Note 3:** At jitter frequencies < 70kHz, the jitter tolerance characteristics exceed the ITU/Bellcore specifications.

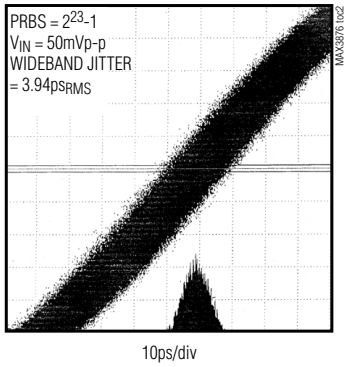
## Typical Operating Characteristics

($V_{CC}$ = +3.3V, $T_A$ = +25°C, unless otherwise noted.)

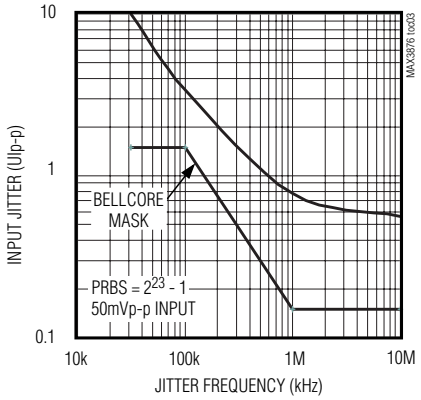
**RECOVERED DATA AND CLOCK (DIFFERENTIAL OUTPUT)**




**RECOVERED CLOCK JITTER**




**JITTER TOLERANCE**

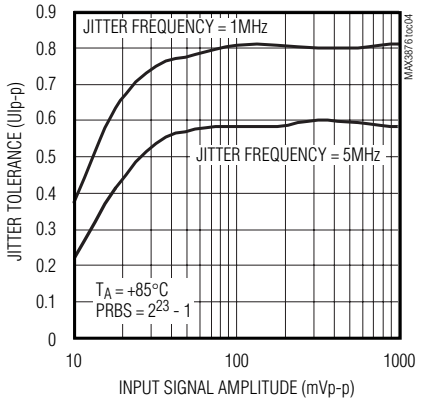


# 2.5Gbps, Low-Power, +3.3V Clock Recovery and Data Retiming IC

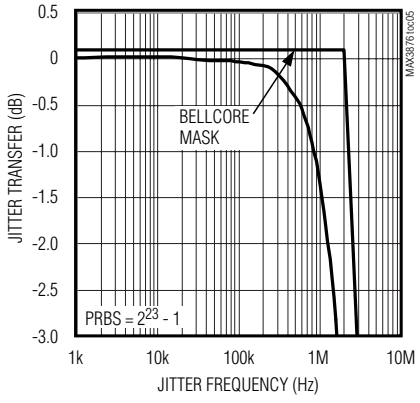
## Typical Operating Characteristics (continued)

($V_{CC}$ = +3.3V, $T_A$ = +25°C, unless otherwise noted.)

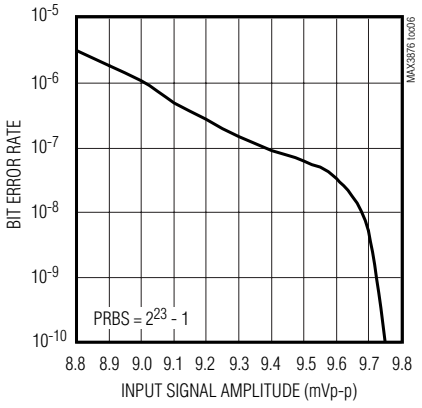
**JITTER TOLERANCE vs. INPUT AMPLITUDE**



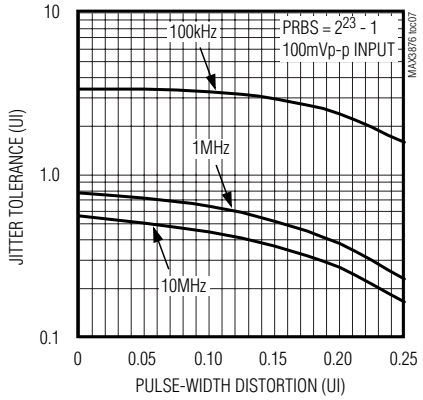

**JITTER TRANSFER**



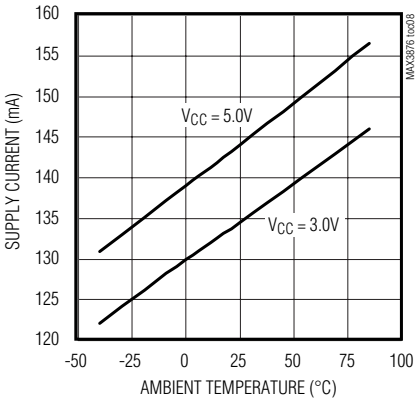

**BIT ERROR RATE vs. INPUT AMPLITUDE**




**JITTER TOLERANCE vs. PULSE-WIDTH DISTORTION**




**SUPPLY CURRENT vs. TEMPERATURE**




## Pin Description

| PIN | NAME | FUNCTION |
|---|---|---|
| 1, 2, 8, 9, 10, 16, 26, 29, 32 | GND | Supply Ground |
| 3, 6, 11, 14, 15, 17, 20, 21, 24, 27, 28 | $V_{CC}$ | Positive Supply Voltage |
| 4 | SDI+ | Positive Data Input. 2.488Gbps serial-data stream. |
| 5 | SDI- | Negative Data Input. 2.488Gbps serial-data stream. |
| 7 | SIS | Signal Input Selection, TTL. Low for normal data input. High for system loopback input. |
| 12 | SLBI+ | Positive System Loopback Input. 2.488Gbps serial-data stream. |
| 13 | SLBI- | Negative System Loopback Input. 2.488Gbps serial-data stream. |
| 18 | SCLKO- | Negative Serial Clock Output, CML, 2.488GHz. SDO- is clocked out on the falling edge of SCLKO-. |

## Pin Description (continued)

| PIN | NAME | FUNCTION |
|---|---|---|
| 19 | SCLKO+ | Positive Serial Clock Output, CML, 2.488GHz. SDO+ is clocked out on the rising edge of SCLKO+. |
| 22 | SDO- | Negative Data Output, CML, 2.488Gbps |
| 23 | SDO+ | Positive Data Output, CML, 2.488Gbps |
| 25 | $\overline{LOL}$ | Loss-of-Lock Output, TTL, PLL loss-of-lock monitor, active low (internal 10kΩ pull-up resistor) |
| 30 | FIL- | Negative Filter Input. PLL loop filter connection. Connect a 1.0µF capacitor between FIL+ and FIL-. |
| 31 | FIL+ | Positive Filter Input. PLL loop filter connection. Connect a 1.0µF capacitor between FIL+ and FIL-. |

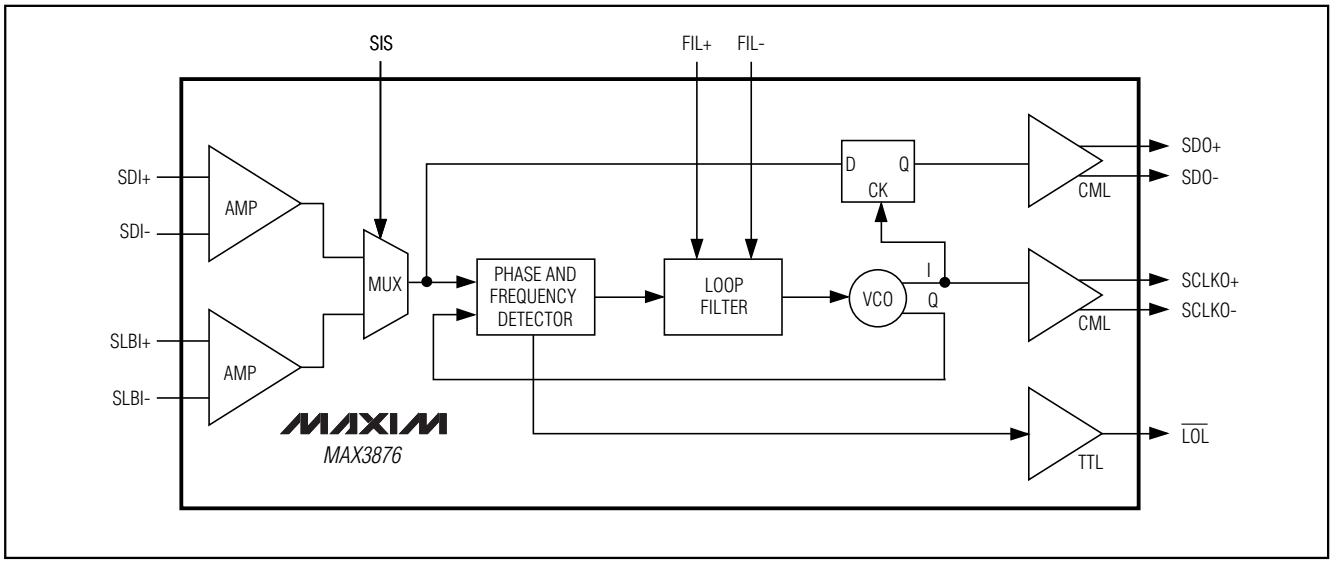



*Figure 3. Functional Diagram*

## Detailed Description

The MAX3876 consists of a fully integrated phase-locked loop (PLL), input amplifier, data retiming block, and CML output buffer (Figure 3). The PLL consists of a phase/frequency detector (PFD), a loop filter, and a voltage-controlled oscillator (VCO).

This device is designed to deliver the best combination of jitter performance and power dissipation by using a fully differential signal architecture and low-noise design techniques.

### Input Amplifier

Input amplifiers are implemented for both the main data and system loopback inputs. These amplifiers accept DC-coupled differential input amplitudes from 50mVp-p up to 1000mVp-p. With AC-coupling, differential input signal amplitudes can be increased to a maximum of 1600mVp-p. The bit error rate is better than $1 \cdot 10^{-10}$ for input signals as small as 10mVp-p, though the jitter tolerance performance will be degraded. For interfacing with PECL signal levels, see *Applications Information*.

### Phase Detector

The phase detector incorporated in the MAX3876 produces a voltage proportional to the phase difference between the incoming data and the internal clock. Because of its feedback nature, the PLL drives the error voltage to zero, aligning the recovered clock to the center of the incoming data eye for retiming.

# 2.5Gbps, Low-Power, +3.3V Clock Recovery and Data Retiming IC

### Frequency Detector

The digital frequency detector (FD) aids frequency acquisition during start-up conditions. The frequency difference between the received data and the VCO clock is derived by sampling the in-phase and quadrature VCO outputs on the rising edge of the data input signal. Depending on the polarity of the frequency difference, the FD drives the VCO until the frequency difference is reduced to zero. Once frequency acquisition is complete, the FD returns to a neutral state. False locking is completely eliminated by this digital frequency detector.

### Loop Filter and VCO

The phase detector and frequency detector outputs are summed into the loop filter. An external capacitor, $C_F$, is required to set the PLL damping ratio. See *Design Procedure* for guidelines on selecting this capacitor.

The loop filter output controls the on-chip LC VCO running at 2.488GHz. The VCO provides low-phase noise and is trimmed to the correct frequency. Clock jitter generation is typically $1.5ps_{RMS}$ within a jitter bandwidth of 12kHz to 20MHz.

### Loss-of-Lock Monitor

A loss-of-lock ($\overline{LOL}$) monitor is incorporated in the MAX3876 frequency detector. A loss-of-lock condition is signaled immediately with a TTL low. When the PLL is frequency locked, $\overline{LOL}$ switches to TTL high in approximately 800ns.

**Note:** The $\overline{LOL}$ monitor is valid only when a data stream is present on the inputs to the MAX3876. As a result, $\overline{LOL}$ does not detect a loss-of-power condition due to loss of the incoming signal.

## Design Procedure

### Setting the Loop Filter

The MAX3876 is designed for both regenerator and receiver applications. Its fully integrated PLL is a classic second-order feedback system, with a loop bandwidth ($f_L$) fixed at 1.5MHz. The external capacitor, $C_F$, can be adjusted to set the loop damping. Figures 4 and 5 show the open-loop and closed-loop transfer functions.

The PLL zero frequency, $f_Z$, is a function of external capacitor $C_F$, and can be approximated according to:

$$f_Z = \frac{1}{2\pi(60)\,C_F}$$

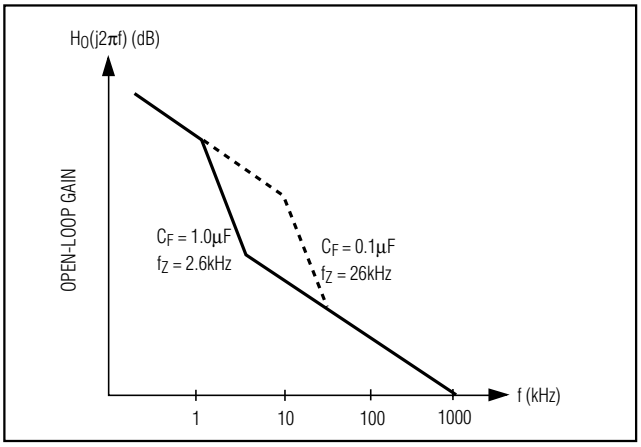



*Figure 4. Open-Loop Transfer Function*

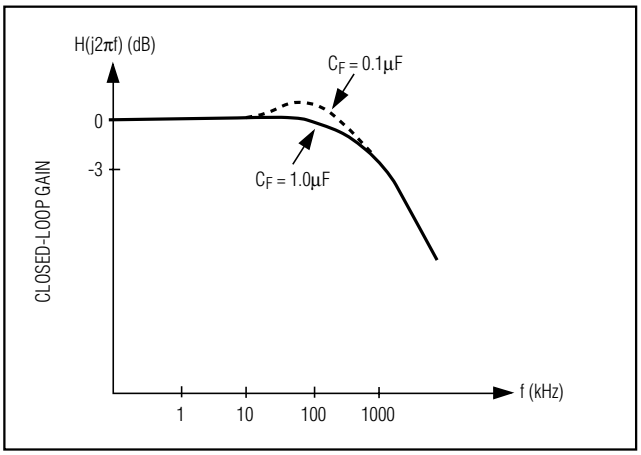



*Figure 5. Closed-Loop Transfer Function*

For an overdamped system ($f_Z/f_L$) < 0.25, the jitter peaking ($M_P$) of a second-order system can be approximated by:

$$M_P = 20\log\left(1+\frac{f_Z}{f_L}\right)$$

For example, using $C_F$ = 0.1µF results in a jitter peaking of 0.2dB. Reducing $C_F$ below 0.01µF may result in PLL instability. The recommended value for $C_F$ is 1.0µF to guarantee a maximum jitter peaking of less than 0.1dB. $C_F$ must be a low TC, high-quality capacitor of type X7R or better.

### Input and Output Terminations

The MAX3876's digital outputs (SDO+, SDO-, SCLKO+, SCLKO-) are internally terminated with 50Ω to $V_{CC}$ (Figure 6). See the *DC Electrical Characteristics* for signal swing and common-mode voltage levels. To ensure best performance, the differential outputs must have balanced loads. The input termination can be driven differentially or can be driven single-ended by externally biasing SDI- or SLBI- to the center of the voltage swing.

### Jitter Tolerance and Input Sensitivity Trade-Offs

When the received data amplitude is higher than 50mVp-p, the MAX3876 provides a typical jitter tolerance of 0.51UI at jitter frequencies greater than 10MHz. The SDH/SONET jitter tolerance specification is 0.15UI, leaving a jitter allowance of 0.36UI for receiver preamplifier and postamplifier design.

The BER is better than $1 \cdot 10^{-10}$ for input signals greater than 10mVp-p. At this input level, jitter tolerance will be degraded but will still be above the SDH/SONET requirement. The user can make a trade-off between jitter tolerance and input sensitivity according to the specific application. See the *Typical Operating Characteristics* for Jitter Tolerance and BER vs. Input Amplitude graphs.

### Jitter Tolerance vs. Pulse-Width Distortion

The MAX3876 can typically tolerate up to 0.20UI of pulse-width distortion (PWD) and still exceed ITU and Bellcore specifications for sinusoidal jitter tolerance. Refer to the *Typical Operating Characteristics* for Jitter Tolerance and PWD vs. Jitter Frequency graphs.

## Applications Information

### Consecutive Identical Digits (CIDs)

The MAX3876 has a low phase and frequency drift in the absence of data transitions. As a result, long runs of consecutive zeros and ones can be tolerated while maintaining a BER of $1 \cdot 10^{-10}$. The CID tolerance is tested using a $2^{13} - 1$ PRBS, substituting a long run of zeros to simulate the worst case. A CID tolerance of 2500 bits is typical.

### System Loopback

The MAX3876 is designed to allow system loopback testing. The user can connect a serializer output in a transceiver directly to the SLBI+ and SLBI- inputs of the MAX3876 for system diagnostics. To select the SLBI± inputs, apply a TTL logic high to the SIS pin.

### PECL Input Levels

When interfacing with differential PECL input levels, it is important to attenuate the signal while still maintaining 50Ω termination (Figure 7). AC-coupling is also required to maintain the input common-mode level.

### Layout

The MAX3876's performance can be significantly affected by circuit board layout and design. Use good high-frequency design techniques, including minimizing ground inductance and using fixed-impedance transmission lines on the data and clock signals. Power-supply decoupling should be placed as close to $V_{CC}$ as possible. Take care to isolate the input from the output signals to reduce feedthrough.

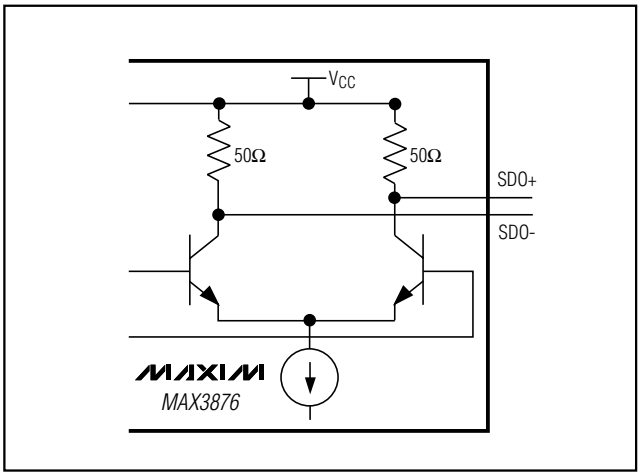



*Figure 6. CML Outputs*

# 2.5Gbps, Low-Power, +3.3V Clock Recovery and Data Retiming IC

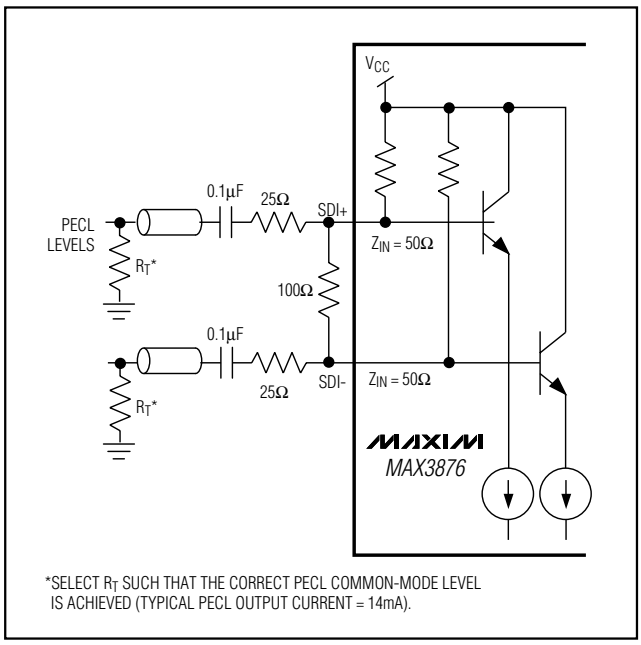



*Figure 7. PECL-to-CML Interface*

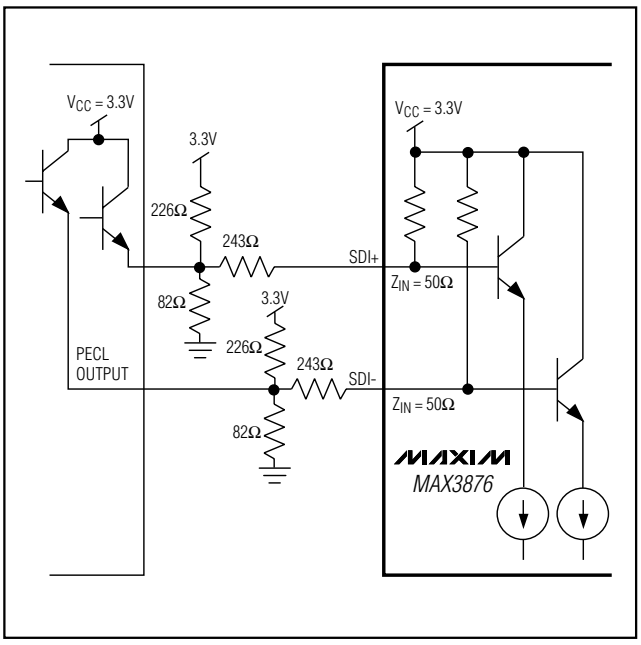
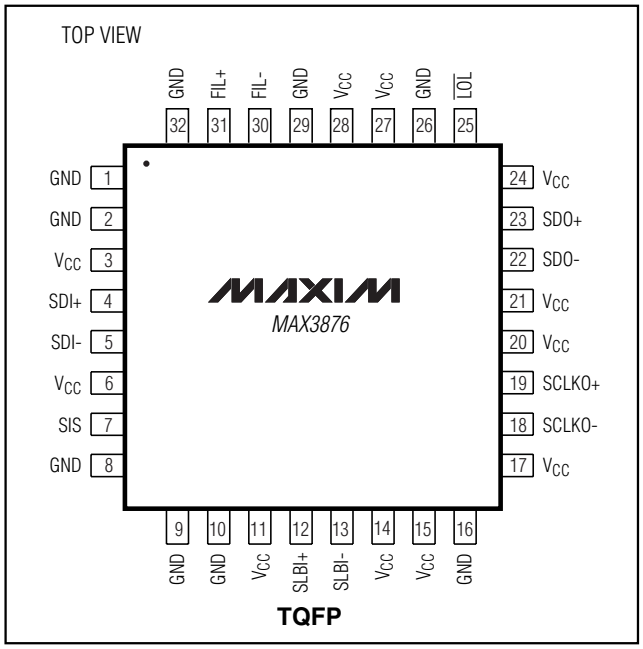


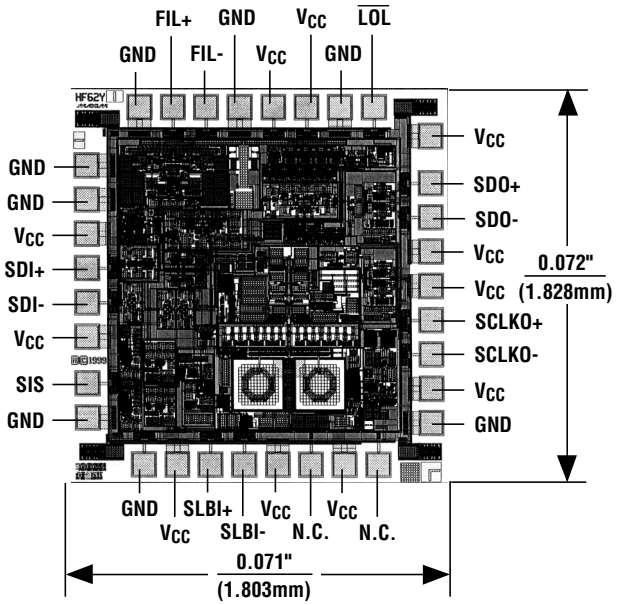

*Figure 8. Direct Coupling of a PECL Output into the MAX3876*

# 2.5Gbps, Low-Power, +3.3V Clock Recovery and Data Retiming IC

## Pin Configuration




## Chip Topography

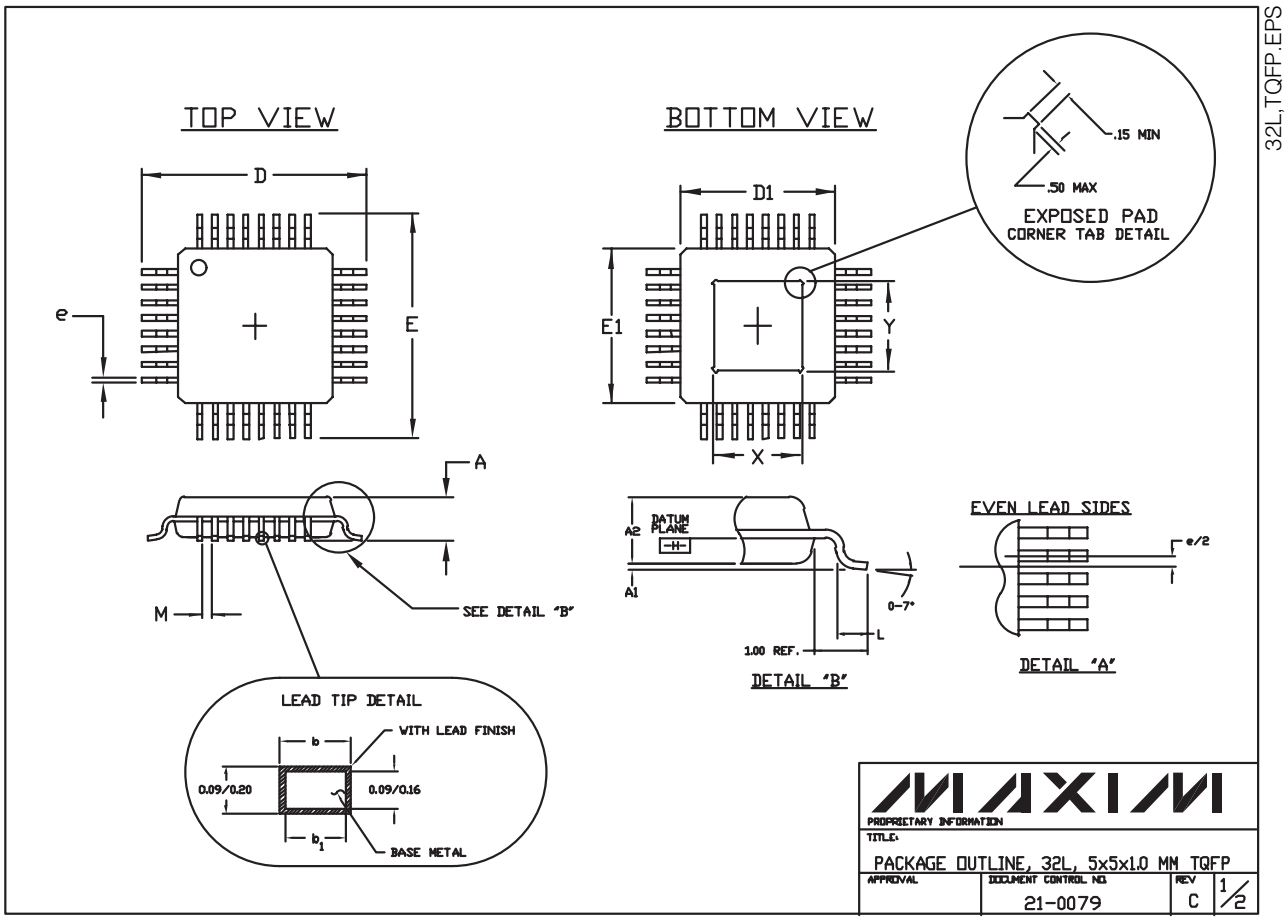



TRANSISTOR COUNT: 1334

SUBSTRATE CONNECTED TO GROUND

# 2.5Gbps, Low-Power, +3.3V Clock Recovery and Data Retiming IC

## Package Information



## Package Information (continued)

NOTES:
1. ALL DIMENSIONING AND TOLERANCING CONFORM TO ANSI Y14.5-1982.
2. DATUM PLANE -H- IS LOCATED AT MOLD PARTING LINE AND COINCIDENT WITH LEAD, WHERE LEAD EXITS PLASTIC BODY AT BOTTOM OF PARTING LINE.
3. DIMENSIONS D1 AND E1 DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE MOLD PROTRUSION IS 0.254 MM ON D1 AND E1 DIMENSIONS.
4. THE TOP OF PACKAGE IS SMALLER THAN THE BOTTOM OF PACKAGE BY 0.15 MILLIMETERS.
5. DIMENSION b DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.08 MM TOTAL IN EXCESS OF THE b DIMENSION AT MAXIMUM MATERIAL CONDITION.
6. CONTROLLING DIMENSION: MILLIMETER.
7. THIS OUTLINE CONFORMS TO JEDEC PUBLICATION 95, REGISTRATION MO-136.
8. EXPOSED DIE PAD SHALL BE COPLANAR WITH BOTTOM OF PACKAGE WITHIN 2 MILS (.05 MM).
9. LEADS SHALL BE COPLANAR WITHIN .004 INCH.
10. DIMENSIONS X AND Y APPLY TO EXPOSED PAD VERSIONS ONLY.

| | JEDEC VARIATIONS<br>DIMENSIONS IN MILLIMETERS | | | |
|---|---|---|---|---|
| | AA | | AA-EP* | |
| | 5x5x1.0 MM | | 5x5x1.0 MM | |
| | MIN. | MAX. | MIN. | MAX. |
| A | ~~ | 1.20 | ~~ | 1.20 |
| $A_1$ | 0.05 | 0.15 | 0.05 | 0.15 |
| $A_2$ | 0.95 | 1.05 | 0.95 | 1.05 |
| D | 7.00 BSC. | | 7.00 BSC. | |
| $D_1$ | 5.00 BSC. | | 5.00 BSC. | |
| E | 7.00 BSC. | | 7.00 BSC. | |
| $E_1$ | 5.00 BSC. | | 5.00 BSC. | |
| L | 0.45 | 0.75 | 0.45 | 0.75 |
| M | 0.15 | ~~ | 0.15 | ~~ |
| N | 32 | | 32 | |
| e | 0.50 BSC. | | 0.50 BSC. | |
| b | 0.17 | 0.27 | 0.17 | 0.27 |
| b1 | 0.17 | 0.23 | 0.17 | 0.23 |
| X | N/A | N/A | 2.70 | 3.30 |
| Y | N/A | N/A | 2.70 | 3.30 |

* EXPOSED PAD

MAXIM

PROPRIETARY INFORMATION

TITLE:

PACKAGE OUTLINE, 32L, 5x5x1.0 MM TQFP

| APPROVAL | DOCUMENT CONTROL NO. | REV | |
|---|---|---|---|
| | 21-0079 | C | 2/2 |

# 2.5Gbps, Low-Power, +3.3V Clock Recovery and Data Retiming IC

**NOTES**

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